Regional Evaluation of the Coalbed Methane Potential in the Plains and Foothills of Alberta, Stratigraphy and Rank Study

Alberta Energy and Utilities Board
Alberta Geological Survey

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In a project of this scale, many people play a part in the development and accomplishment of the task. Those who were responsible for the many aspects of this project are listed in the next section.

Many who helped with this project are not part of the Alberta Research Council, but nevertheless played a key role in the completion of the project. The original concept of a regional, industry funded assessment of the deep coal in Alberta, and its potential for coalbed methane was developed in conjunction with Les Smith of LAS Energy Associates, Ltd.

Dennis Nikols took the concept of a regional coalbed methane evaluation, developed it with Les Smith, polished the idea, presented it internally, and with some limited support, took it forth to industry. He spearheaded and coordinated the initial presentations to industry and signed up many of the participants. It was through his vision and foresight that the highly successful seminars on "Coalbed Methane - What's It All About?" were organized, providing much of the publicity and background information upon which companies began to appreciate the potential of coalbed methane in Alberta.

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Project Personnel

Michel Brulotte	Technologist. Wrote the database queries to permit Genmap to draw information from the Ingres database.
Roy Eccles	Contract Autocad specialist. Operated the Autocad system to enhance the cross-sections which had been produced by Terrastation.
Curtis Evans	Contract stratigrapher. Produced the plains cross-sections through Terrastation. Picked the plains coals for much of the province.
Barry Fildes	Technologist. Computing support. Produced maps, checked data, ran the plotters.

Dr. Thomas Gentzis	Coal petrologist. Did the vitrinite relectance analyses.
Dr. Willem Langenberg	Structural geologist. Prepared the structural cross-sections and supervised the foothills aspects of the project.
Gregory Mandryk	Computing geologist. Ingres database administrator. Coordinated collection of pre-existing vitrinite reflectance data.
Dennis Nikols	Section manager. Originated the project, then got out of the way and let us do it.
Joe Olic	Technologist. General computing and well log support. Checked data and produced maps.
Rick Richardson	Geologist. Plains stratigraphy and coal geology.
Brian Rottenfusser	Project Manager. Geologist. Assisted with plains stratigraphy, mapping and coordinated report preparation.
Murray Spelrem	Contract stratigrapher. Produced plains cross-sections and picked coals for much of the north half of the province.
Brent Sprecher	Contract structural geologist. Produced foothills cross-sections and maps, picked foothills coal.
Sheila Stewart	Technologist. General computing and well log support. Checked data and produced maps.
Desmond Wynne	Computing geologist. Built the Genmap automated mapping procedures.
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Executive Summary

The coal resource in place in Alberta is tremendous by whichever estimate is used. One such zone, the Paleocene Ardley coal zone, has calculated resources in the order of 425 gigatonnes along a 250 mile (400 kilometre) subcrop and dipping, to more than 2950 feet (900 m) depth, 90 miles (150 km) southwest into the Alberta Syncline. The geologic model developed for the Ardley Coal zone involves a continental setting in an alluvial plain environment characterized by widespread peat swamps that were far removed from marine conditions. Due to extremely low relief, relatively rapid subsidence and sediment starvation, thick and extensive peats developed. In general the seams thicken and more seams are present with increasing depth. These deeper coal resources may contain large volumes of gas.

1 Introduction/Previous Work

1.1 Ardley/Coalspur Coal Zones

Research on the Ardley coal zone dates back to the 1920's (Allan, 1924). A more recent evaluation of the coal resources by Richardson et. al. (1988) reviews previous work and describes the geology of the coal zone. That study although focussed on the coals to a depth of 400 m was based on the examination of 1408 oil and gas wells to depths of more than 900 m and 98 Alberta Research Council coal exploration drill holes in the shallow sub-crop area.

The Coalspur coal zone of the foothills is equivalent to the Ardley. Some aspects of this coal zone have been discussed in Macdonald et al. (1989).

1.2 Horseshoe Canyon Formation

Research on the stratigraphy and coal resources of the Horseshoe Canyon Formation dates back to the early 1920's. J.A. Allen (1921) described an important coal mining area, the Drumheller Coal Field, in one of the Alberta Research Council's earliest publications. More recent contributions by the Alberta Research Council include reports by Campbell and Almadi (1964), Campbell (1974), Campbell (1975), Holter, Chu and Yurko (1976) and Holter and Chu (1977). Reports on lower Horseshoe Canyon equivalent coals in the Wapiti Formation include those by Allan and Carr (1946), Campbell (1972), and Chu (1978). These reports are based largely on outcrop examination and results from coal exploration drilling.

An examination of the geology and coal resources of the upper part of the Horseshoe Canyon Formation in the Red Deer area was produced in 1980 by Nurkowski. A number of coal resource evaluation studies undertaken by the Alberta Research Council (most recently McCabe, et al., 1989) have helped to further refine the stratigraphic understanding. The latter study had the largest scope in terms of geography and data point density.

1.3 Wapiti Group

The term Wapiti was first applied by Dawson (1881) in the Peace River area to a 90 m thick succession of sandstones, shales, and coal beds overlying a series of dark shales he named the Smoky River Shales. McLearn (1919) assigned 275 m of strata on the Smoky River south of Bezanson to the Wapiti Formation, and he stated that the top of the formation was not observable. Rutherford (1930) provided a more detailed description of the Wapiti Formation and felt that in the Grande Prairie area the formation was equivalent in age to the Belly River Formation.

Allen and Rutherford (1934) suggested that the beds defined by Dawson and McLearn are probably equivalent to those beds designated as Edmonton Formation by Selwyn (1874): "The Edmonton is extended west across the Smoky through the Grande Prairie district where the upper part of the Wapiti is correlated with the Edmonton on a lithological basis." North of the Edmonton region, Green (1972) mapped the entire succession overlying the Lea Park Formation (including the Belly River and Edmonton strata) as the Wapiti Formation.

1.4 Belly River Formation

Stratigraphic relationships within the Belly River Group were established from surface outcrops in southern Alberta during the early half of the century. More recently, McLean (1971) provided a regional synthesis of the subsurface stratigraphy of the Belly River in the southern Plains region. A number of coal resource evaluation studies undertaken by the Alberta Research Council (most recently Macdonald, et al., 1987) have helped to further refine the stratigraphic understanding. The latter study has had the largest scope in terms of geography and data point density.

1.5 Brazeau Formation

The Brazeau Formation of the foothills contains coals that are equivalent to coals from the Belly River and Horseshoe Canyon formations. Jerzykiewicz (1985) redefined the usage of the term Brazeau for this specific stratigraphic interval.

1.6 Mannville Group

A great volume of stratigraphic related literature has been published on the Mannville Group because of its importance in being the main reservoir rock for the oil sands deposits in northern Alberta and as a conventional reservoir in the Lloydminster and southern Alberta regions. No attempt will be made here to review that body of work. However, two coal reports that involve Mannville coal resources deserve mention are Yurko's (1976) and Williams and Murphy's (1981) studies on the deep coal resources of the Alberta plains.

1.7 Gates/Spirit River Formation

The Gates Formation of the foothills and Spirit River Formation of the plains region are important coal bearing units. The Gates Formation is the main source for Alberta's metallurgical export coal. The regional coal quality of its coals have been described by Macdonald et al. (1989). The Spirit River Formation is an important gas reservoir in the Deep Basin.

1.8 Gething/Gladstone Formation

The Gething Formation (type section along the Peace River) is mainly restricted to British Columbia, but extends into the northern Alberta foothills and northern plains. South of the Kakwa River this stratigraphic interval only has minor coal seams and the interval is called the Gladstone Formation. The type section of the Gladstone Formation is in southern Alberta. Coals of the Gething Formation have been described by Kalkreuth (1982) and Kalkreuth and McMechan (1984 and 1988).

1.9 Kootenay Group

Alberta's oldest coal-bearing strata belong to the Kootenay Group, found in the southern foothills and mountains. The Kootenay was extensively described by Gibson (1985). Macdonald et al. (1989) describe some coal quality aspects of the Kootenay.

1.10 Petrographic Coal Rank Studies

Hacquebard and Donaldson (1974) published the first extensive rank study of coals in the foothills. The first sub-surface rank study in the plains area was by Hacquebard (1977). In the 1980's the database grew rapidly and a better understanding of rank and geothermal history was developed from studies such as Kalkreuth and McMechan (1984 and 1988), Langenberg et al. (1987), Langenberg et al. (1989), Macdonald et al. (1989), Nurkowski (1985), Radke et al. (1982), Bustin (1983), England (1984), England and Bustin (1986), Weiss (1985), and Wyman (1984). These papers produced the bulk of the presently existing data on rank. In the late 1980's and early 1990's papers by Law et al. (1989), Connolly (1989), Tilley et al. (1989), Cao (1990) and Osadetz et al. (1990) have produced data on paleo-geothermal gradients and geothermal history of the basin.

2 Stratigraphy

Before any stratigraphic correlations could be made the stratigraphy to be used by the Coalbed Methane project had to be determined; therefore, the stratigraphic chart (figure 1) was generated prior to cross-sectioning. A simplified version of the stratigraphic chart focusing on the coal zones is shown in figure 2. The chart was derived from a variety of stratigraphic charts, with a major part coming from the ERCB chart in ST 90-31 1989.

In generating the chart an unknown coal zone in the middle of the Horseshoe Canyon Formation was recognized. This coal zone is, except in northwestern Alberta, considered to be distinct from the other coal zones in the formation. A reference to coals in the middle of the Horseshoe Canyon formation is contained in Steiner et al, (1972) who considered the Daly to be equivalent to the Weaver. Gibson (1977) described various coal seams with a variety of names from the walls of the Red Deer river valley; the most common name was the “Daly coal seam”. The term Daly was used by the CBM project. The Alberta Plains Coal Evaluation by McCabe et al. (1989); mentions the presence of a Weaver Coal zone in the middle of the formation but the coal seams were not documented in the electronic database that accompanied the project, nor were they mapped as a separate unit.

Coal zones within the Lower Cretaceous strata in the Plains have never been defined, and no coal seams have been recognized and named. Almost all coal zone and seam names for this interval are derived from outcrops in the foothills. The one exception is the Medicine River Coal from the area of central-western Alberta. Since “Medicine River” applies only to the very thick coal seam within that specific area, and the correlation to the coal zones in the foothills is not formally defined, all of the coals in the Upper Mannville Group have been grouped into the “Upper Mannville Coal Zone”. Due to the the lack of previous research on the continuity of the coal seams, it is thought best to avoid splitting the very large Upper Mannville Coal Zone.

One area that presented difficulties in formation correlation was the top of the Mannville and the Blairmore in south western Alberta because the formation boundaries are indistinct and difficult to determine. It was assumed that the stated equivalence of the tops for the Mannville and Blairmore Groups is correct and that they merge in areas closer to the foothills.

The formation boundaries above the Milk River formation and its equivalents were generally picked based on the records of the Geologic Atlas of the Western Canada Sedimentary Basin (in prep.). In the CBM and Atlas study it was considered feasible to correlate a marker sequence considered equivalent to the Bearpaw Formation in areas where the formation is not present. This pick was instrumental in distinguishing between the Lethbridge and the Drumheller coal zones. A similar distinction is made between the Carbon-Thompson and the Ardley coal zones. They are usually separated by a large fluvial sandstone (Whitemud Formation) and/or shale (Battle Fm.).

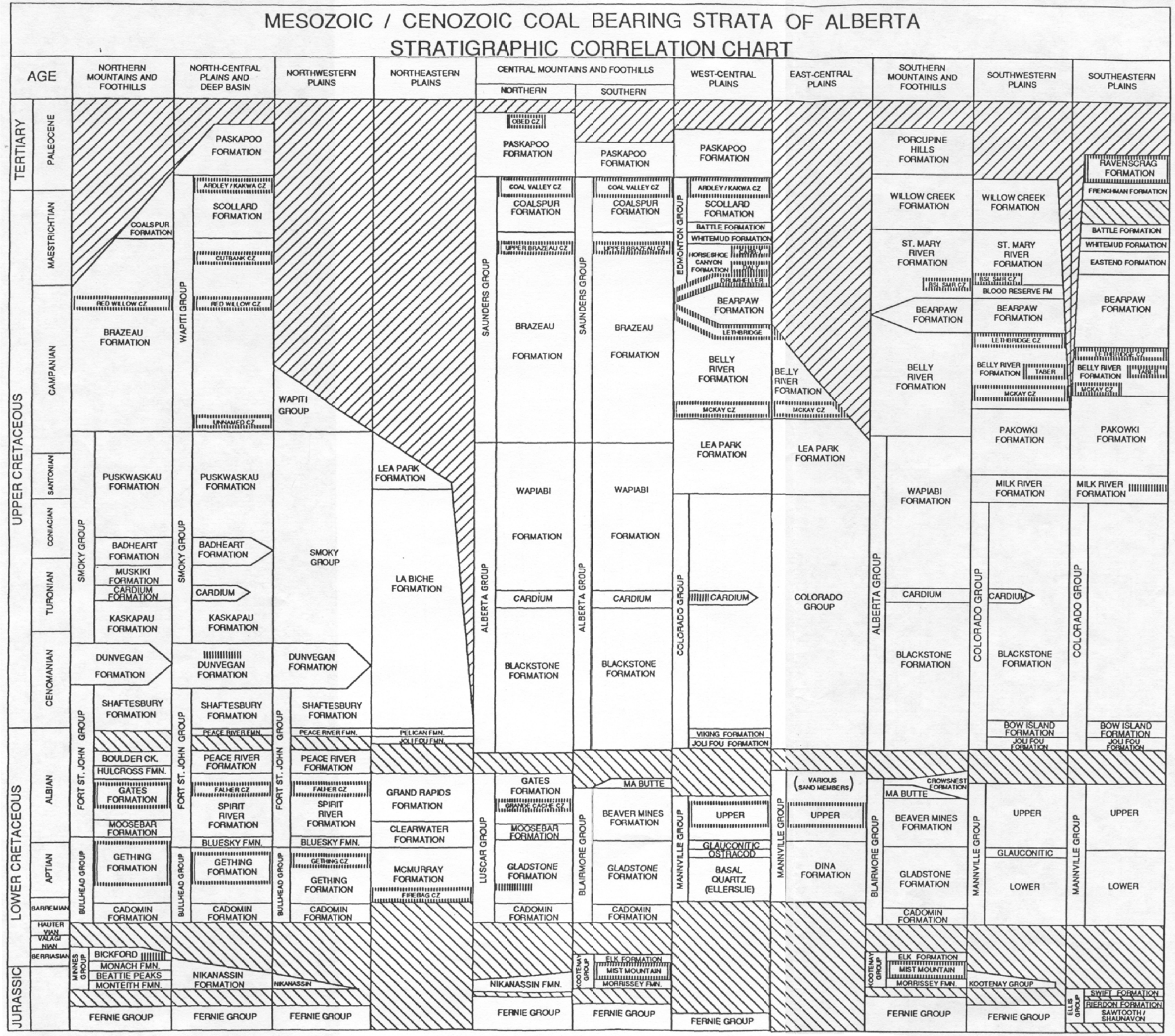


Figure 1. Mesozoic/Cenozoic coal bearing strata of Alberta stratigraphic correlation chart.

MESOZOIC / CENOZOIC COAL BEARING STRATA OF ALBERTA
STRATIGRAPHIC CORRELATION CHART SUMMARY

AGE		NORTHERN	NORTHERN MOUNTAINS AND FOOTHILLS	SOUTHERN MOUNTAINS AND FOOTHILLS	WEST-CENTRAL PLAINS	SOUTHERN
TERTIARY	PALEOCENE		OBED COAL ZONE			RAVENSCRAG FORMATION
UPPER CRETACEOUS	MAESTRICHTIAN	ARDLEY / KAKWA COAL ZONE CUTBANK COAL ZONE	COALSPUR COAL ZONE UPPER BRAZEAU COAL ZONE		ARDLEY / KAKWA COAL ZONE CARBON / THOMPSON COAL ZONE DALY COAL ZONE DRUMHELLER COAL ZONE	
	CAMPANIAN	RED WILLOW COAL ZONE UNNAMED COAL ZONE		BASAL ST. MARY RIVER COAL ZONE BELLY RIVER COAL ZONE	LETHBRIDGE COAL ZONE MCKAY COAL ZONE	BASAL ST. MARY RIVER COAL ZONE LETHBRIDGE COAL ZONE TABER COAL ZONE MCKAY COAL ZONE
	SANTONIAN					MILK RIVER FORMATION
	CONIACIAN					
	TURONIAN					
	CENOMANIAN					
LOWER CRETACEOUS	ALBIAN	FALHER COAL ZONE	GATES COAL ZONE	BLAIRMORE GROUP	MANNVILLE GROUP UPPER	
	APTIAN	GETHING FORMATION FIREBAG COAL ZONE	GLADSTONE FORMATION			
	BARREMIAN					
	HAUTERIVIAN					
	VALAGINIAN					
	BERRIASIAN	BICKFORD				
JURASSIC				KOOTENAY COAL ZONE		KOOTENAY COAL ZONE

Figure 2. Mesozoic/Cenozoic coal bearing strata of Alberta stratigraphic correlation chart summary.

3 Coal Geology of the Alberta Basin Plains Area

Since the first recorded discovery of coal in Alberta; on February 12, 1793 along Kneehills Creek near Drumheller, by Peter Fidler, a Hudson's Bay surveyor; much has been written about Alberta coal. This section begins with a primer and review of coal depositional models with particular emphasis on their relevance to the Alberta Basin. Next an overview of coal within the Basin is presented.

3.1 Coal Geology Models

Coal seams can be viewed as deposits for mining or as reservoirs for coalbed methane. In both cases, close attention must be paid to measuring the lateral continuity of seams, thickness variation, and aspects of coal quality (including gas content). Understanding the depositional controls on peat formation and the associated clastic successions is a fundamental first step in the exploration process. Coal deposits can be found in a wide variety of depositional settings, most coals in the Alberta basin are associated with alluvial plain and coastal plain settings. Regional exploration models for these two depositional settings are outlined in this paper. Concepts of sequence stratigraphy provides an additional exploration tool. For coal bearing successions associated with coastal plain deposits, periods of coal accumulation may linked to low-stand systems tracts. These aspects of exploration strategies will be expanded upon after a brief introduction to coal facies and conditions necessary for peat (coal) development.

3.2 Relationship Between Coal and Clastic Sediments

Most facies models for coal-bearing strata show peat accumulating close to active clastic depositional environments such as on the floodplain of meandering rivers, coastal mires immediately behind beach barrier systems or in interdistributary bays of deltas. Detailed examination of some of these settings, however, suggests that relatively thick clastic sediment accumulations (primarily muds and silts) are introduced during frequent floods, storm surges or exceptionally high tides. Mires located close to active clastic environments are more likely to produce carbonaceous shales rather than coals (McCabe, 1988).

Thick, low ash peat accumulations are most commonly formed in areas that were removed from active clastic deposition for extended periods of time. As one example, in the Okefenokee Swamp in Georgia, 4 metres of peat required more than 5,000 years to accumulate. Assuming a compaction ratio of 10:1 for the peat to transform to coal, a 1 m thick coal seam will require uninterrupted peat deposition for tens of thousands of years.

Coal seams have complex internal stratigraphies leading to considerable variation in coal quality both laterally and vertically. Variation in plant types, early alteration of organic material and climate changes are important controlling factors during peat accumulation. Charcoal zones, which develop into fusain layers in coal, indicate that major drought periods also occurred, lowering regional water tables and allowing major fires to sweep across the mire. Similar variations in the vertical profile of coal seams is observed based on maceral distributions and palynological studies (Hacquebard and Donaldson, 1969; Demchuk and Strobl, 1989). These types of studies suggest that ignoring the coal facies and interpreting the coal simply as "a swamp" may be equivalent to interpreting any carbonate reservoir as "warm shallow marine" (McCabe, 1988). Coal studies, especially coal quality studies, warrant more detailed investigations of the coal facies.

Mires can be classified into three types: raised, low-lying and floating. Low-lying mires form in areas of poor drainage. Floating mires develop over lakes until the lake infills with sediment or peat and can later develop into larger low-lying mires. If climatic conditions are favourable, a raised mire can develop. Raised mires occur in areas where annual precipitation is greater that annual evaporation, typically in maritime (ever-wet) environments. Examples of modern raised mires can be found in southeast Asia, northwest Europe and the Fraser River delta in British Columbia. Today, most of the world's mires are low-lying, accumulating in cool climates between 50 and 70 degrees north latitude. Interestingly, most tropical rainforests are not sites of peat accumulation because the organic matter rapidly deteriorates.

3.3 Alluvial Plain Settings

Coal zones in Alberta which are associated with alluvial plain/fluvial sediments include the Ardley at the top of the Scollard Formation (Richardson et al., 1988); the Coalspur in the Saunders Group; Carbon-Thompson in the uppermost Horseshoe Canyon Formation (Nurkowski, 1980; Nurkowski and Rahmani, 1984); the Kakwa, Cutbank and Red Willow Coal Measures of the Wapiti Group (Dawson et al., 1989); and the Obed coal zone in the uppermost Paskapoo Formation (Macdonald et al., 1989).

The alluvial plain environment is characterized by widespread mires and very low gradients. For the Carbon-Thompson coal zone, and portions of the Ardley/Kakwa coal zones, these coals are commonly associated with lacustrine deposits (Nurkowski and Rahmani, 1984; Baofang and Dawson, 1988). For the other study areas, associated sediments appear to be predominantly fluvial in origin. The moderately low ash content, and laterally persistent and relatively thick nature of many of these coal seams suggests the development of widespread mires isolated from clastic deposition for long periods of time.

3.4 Coastal Plain Settings

Coal zones in Alberta associated with coastal plain settings include the Upper Mannville coals (Medicine River seam) (Williams and Murphy, 1981); Cadomin-Luscar coals (Jewel Seam) (Langenberg et al, 1989); lower Horseshoe Canyon Formation coals (Drumheller coal zone) (McCabe et al., 1989); Belly River Formation coals (Lethbridge, Taber and McKay coal zones) (Macdonald et al., 1987) and the St. Mary River Formation coals (Latour, 1961). In virtually all of these coal zones, some of the thickest and most economic coal seams occur as elongate pods, parallel to paleoshorelines. These coals commonly overlie regressive shoreface sandstones, pinching out in a landward direction.

The model presented in by Ryer (1981) for the Cretaceous Ferron coals, show how coal seams extend up to 24 km perpendicular to paleoshorelines and up to 58 km parallel to paleoshoreline trends. The Ferron coals reach their maximum thickness, up to 10 m, about 10 km landward of the landward pinchout of each regressive sequence. Thickness trends observed on isopach maps of individual seams are parallel to paleoshorelines which is consistent with the model proposed. Isopachs can be pod-like due to the effects of fluvial and/or estuarine channel systems flowing perpendicular to the coast. As this example points out, the methods of mapping coals associated with shoreline sequences contrast sharply with those used for alluvial plain coals because of pronounced differences in geometries and depositional controls.

Alberta examples include the coals of the Drumheller coal zone, in the lower Horseshoe Canyon Formation. Spectacular outcrop exposures in the Drumheller and East Coulee areas allows us to model these coals in considerable detail. As predicted by Ryer's model, some of the thickest coals of the Drumheller zone overlie regressive shoreface sandstones. Tying in subsurface drillhole information with the outcrop data, Rahmani (1988), shows the seaward limit of coal deposition and the effects of estuarine channels on coal development.

In a more regional subsurface study of the lower Horseshoe Canyon coals, similar trends are found to those observed in outcrop (McCabe et al., 1989). Moderately thick coal seams directly overlie shoreface sandstones and pinch out landward. Regional coal seam isopach maps for the lower Horseshoe Canyon Formation show well defined eastern and western limits reflecting controls on mire formation by shoreline position. Coal seams in the lower Horseshoe Formation are commonly less than 2 m thick, but locally can be 4 m or more in thickness. Local thickening can often be tied to the underlying topography at the time of mire development. Thicker coals should be expected, for example, between beach ridges.

The Jewel seam in the Cadomin-Luscar area shows similar trends to those of the Horseshoe Canyon Formation. The Jewel seam is up to 10 m thick and directly overlies the Torrens Sandstone. As mentioned in the introduction, peats accumulating in the Okefenokee Swamp overlie much older Pleistocene beach ridges and shoreface sandstones. Using concepts of sequence stratigraphy, we have an additional exploration tool to complement the coal facies model. We recognize that in many sedimentary basins, siliciclastic sequences occur with a 100,000 to 200,000 year frequency and that the lowstand tract is the dominant systems tract preserved (Van Wagoner et al., 1990). Deeply incised valleys extend over the shelf during the lowstands, suggesting that shoreline positions can move seaward considerable distances. This may help explain why anomalously thick and laterally extensive coal seams, such as the Jewel seam of the Cadomin-Luscar area and the Medicine River seam of the central plains area, are developed.

3.5 Coal Distribution (Overview)

The coal-bearing strata of Alberta were deposited in a sedimentary basin along the eastern edge of the evolving Rocky Mountains. They form part of a clastic wedge ranging in age from late Jurassic to mid-Tertiary. In general, the source area of the sediments was from the emerging mountains to the west. The coals of this succession occur mainly in nine coal zones, which are from oldest to youngest the Kootenay, Gething/Firebag, Gates/Mannville, McKay, Taber, Lethbridge, Drumheller/Red Willow/St. Mary River, Carbon/Thompson, and Ardley/Coalspur coal zones. Other, smaller and less continuous coal bearing intervals are contained within the Dunvegan, Cardium, Milk River and upper Paskapoo (Obed) formations. In the plains the coal bearing strata are gently dipping, while in the mountains and foothills these strata have been deformed and dip at varying angles.

The oldest coal-bearing rocks belong to the Jurassic-Cretaceous Kootenay Group of the mountains and foothills. Thick coals are present in the Lower Cretaceous Mannville Group of the plains. They are generally at great depth. Equivalent coal-bearing strata are exposed in the mountains and foothills where they form part of the Luscar Group. Late Cretaceous coal-bearing strata are found in the plains. Coal zones are present in the Belly River Group at the base (McKay), middle (Taber) and top (Lethbridge). Equivalent strata occur in the mountains and foothills but the coal is not as well developed. The Belly River Group is a thick, continental, clastic sequence that was sourced from the west. Marine sediments are known to underlie, overlie and interfinger with the group, becoming more dominant to the east in Saskatchewan.

Two major coal zones are found within the Upper Cretaceous Horseshoe Canyon Formation of the plains; the Drumheller/Red Willow zone and the Carbon-Thompson zone. There is a local, discontinuous coal zone in the middle of the formation which we have called the Daly (has been referred to as the Weaver coal zone in some studies). It was not mapped. The upper Brazeau coal zone is roughly equivalent in the foothills. The Horseshoe Canyon/Bearpaw series is similar to the Belly River Group, being a clastic wedge sequence of continental sediments interfingering with marine and near-shore marine sediments.

The Tertiary Paskapoo Formation contains the locally restricted Obed zone near the top of the formation. There are two coal zones within the Cretaceous-Tertiary Scollard Formation of the plains; the thick and extensive Ardley/Kakwa coal zones at the top of the formation; and the equivalent coal-bearing strata of the Coalspur Formation in the foothills.

Economically, the Ardley is one of the most important coal producing zones in Alberta where near-surface deposits are mined to supply mine-mouth power stations. More than 15 million tonnes annually are mined west of Edmonton along the subcrop.

4 Methods

4.1 Decision to Work Plains and Foothills Separately

The cross-sections for this project appear in two formats - the foothills are structural cross-sections and the plains/foothills are stratigraphic cross-sections. The reason for the distinction is that the foothills structural sections need to be without vertical exaggeration while the plains stratigraphic sections need to have extreme vertical exaggeration to show the entirety of the plains strata in a coherent manner. Thus the foothills sections are of two types: the structural sections showing how the coal bearing formations are affected by the folding and thrusting of the foothills and the front ranges, and an exaggerated stratigraphic section which shows how the coal bearing strata of the foothills fit in relation to the plains cross-sections. We consider the latter to be important in that it is an attempt to show physical correlations between the greatly differing stratigraphic and coal zone nomenclature of the plains and the foothills zones.

5 Data Handling (Geological Picks and Database)

This section describes how the geological data was assimilated, reconciled, and then mapped in the Plains portion of the Coalbed Methane study.

5.1 Database Design

A relational database management system (Ingres) was used to manage most of the data used in the study. This approach was chosen over just using a series ASCII computer files for storage and mapping for several reasons.

i) Use of a relational database management system enforces consistency on the data. Consistency was very important in this project because data was being merged from many different sources; almost each source used a distinct data format.
ii) In addition, it was realized that multiple iterative plots would be needed after the many data sources were merged during the course of data refinement and reconciliation. The iterations were required because the standards used to recognize coal using geophysical logs has improved with time and the stratigraphic relationships and nomenclature of the coal zones has also changed with time. A relational database management system would thereby serve as the one and only version of the data and any changes would only be made to data in the database, and not to the ASCII files derived from the database. This ensured that no mix-ups could occur where older versions of the data where mapped instead of the revised data.

iii) The database system would serve as the source of the raw data (i.e. coal tops, coal zone names) upon which all derived products would be based. Therefore, all procedures used to produce information on cumulative coal in any coal zone, thickest coal seam and so on would be based on one information source, the database.
iv) Use of a relational database to manage the data meant that once the data was reconciled (tops, zone names) it was a simple job to query the database for information needed by the Plains cross-sections, such as cumulative coal in a zone and vitrinite reflectance along a cross-section.

5.1.1 Location of Database Tables

The Alberta Geological Survey has numerous databases created in Ingres. The tables used by the Coalbed Methane project were created in the Coal database, a major database of coal and coal-related information.

5.1.2 CBM Table Design

The tables needed by the CBM project were designed along the same general methodology used in table design throughout the coal database. Design entailed creating tables that contained similar information about something. This resulted in four main tables, a table of location information, coal tops (coal picks) information, a table of formation names, and a table relating the coal picks to coal zone mapping units. (A table containing vitrinite information was also created and is discussed in a different section of this report.) The four main tables had ancillary tables related to them containing reference information.

The tables are all related to each other using relational numbers. These numbers serve to relate the tables together and allow both querying and data independence (data independence: design independent from applications). The relational nature of the database allowed many different types of queries to be run without having to redesign the tables to suit the queries. Proper initial design meant that all queries were made on one set of tables containing the only set of project data.

5.1.3 Location Data

The location database table stores information about the surface location of a data source, such as an outcrop or drillhole. The same location table was used for both reflectance and coal pick locations. The mapping coordinates, latitude and longitude, of all sources are also stored in the location table.

5.1.4 Pick Data

The pick database table stores information on formation pick and coal picks used by the study. The pick table is related to the location table, i.e. at a location where picks exist. The depth to formation tops and the depth to coal seam tops and bases are stored in the pick table. This table is also related to a table of formation and coal zone names, where each pick has a coal zone name. Each coal seam pick also has attributes which serves as a toggle to allow the seam to be either used or not used in mapping and another attribute which indicates the study which produced each pick. A study code allowed data produced by different studies to be compared during reconciliation.

5.1.5 Formation Name Data

The Energy Resources Conservation Board's (ERCB) table of formation codes forms the basis of this database table. This table also includes coal zones, which are not a part of the original ERCB table of formation codes. Every coal pick and formation pick in the pick table has a coal zone code or formation code attached to it, therefore, the table of formation names is related to the pick data table.

5.1.6 Map Code and CBM_ Corr table

A database table containing synonymous names allowed synonymous coal zone names to be grouped into mapping units for the purpose of mapping and determining the cumulative coal for the coal zones on the cross-sections. This table allowed the actual, local coal zone name to be assigned to coal picks in the pick database table; during mapping, synonymous names could be grouped into map units. For example, in the central Alberta Plains the Ardley coal zone was divided into an upper and lower coal zone, together these comprise the Ardley coal zone for mapping purposes. The Ardley coal zone is equivalent to the Kakwa coal zone in the Grande Prairie region and for mapping purposes the upper Ardley, lower Ardley, Ardley, and Kakwa coal zones all comprised one mappable coal zone.

5.1.7 Table Structures for Optimization of Queries

The design of the the CBM project database strove to use as few tables as possible in order to simply operations and speed queries. Once database design and data loading had concluded the tables were modified to btree structures with secondary indices on some columns. Statistics were also collected on the relational columns to speed the run time of database queries

5.1.8 Relational Design - Constant Uptime

The database design and the nature of a relational database meant that constant uptime was possible. The phased nature of the project called for data to be mapped and reconciled as soon as it was loaded into the database. The database allowed datasets to be mapped, viewed, and edited as other, distinct datasets were copied into the same database tables. While mapping and verification of one set took place another data set was being prepared and loaded. This included the loading and verification of the pre-existing vitrinite data and the newly acquired vitrinite data.

5.2 Data Sources

The Coalbed Methane study attempted to include as much pre-existing coal geology data into the study as was possible. In addition, coal picks were made on a series of infill wells and along the project's cross-section wells. This array of information had to be combined into one, consistent set of data. This section describes the coal stratigraphy data sources.

5.2.1 Plains Evaluation Data

The Plains Evaluation study was a multi year study that determined the location, depth, and thicknesses of the coal in the Ardley coal zone (Scollard Fm.), Horseshoe Canyon Fm, and Belly River Gp. to a depth of approximately 400 m in the Plains region of Alberta. The Plains Evaluation study provides good regional coverage of the shallower coal under the Alberta Plains (Macdonald et al. 1987, McCabe et al. 1989, Richardson et al. 1988).

5.2.2 Data Entry of Plains Evaluation Data

The Plains Evaluation data is available on a diskette (Mandryk and Richardson 1988) in the form of ASCII files. The coal stratigraphy information was copied into the CBM project tables.

5.2.3 Infill Data

The Coalbed Methane study made formation and coal picks across the coal-bearing portion of Alberta underlain by undeformed strata. The wells chosen were between the CBM cross-section lines. Coals were studied from surface to the deepest coal bearing formations.

5.2.4 Data Entry of Infill Data

Coal tops, bases, and the coal zone name were marked on the paper printouts of the geophysical logs along with a few marker horizons wherever present (Base of Fish Scales, Chungo, Milk River). Data entry was facilitated with the creation of an electronic, data entry form. A person typed the well identifier, coal tops and bases along with any marker formations as read off the paper geophysical log directly into the database entry form. The data entry form was linked to database tables. The Alberta Geological Survey's oil and gas (AGSWDB) database was automatically queried for the well's kelly bushing and well name when the well's identifier was entered. The data entry operator would verify that the paper log's wellid matched the wellid the computer would use by visual comparison of well name between the paper log and the computer screen. The retrieved kelly bushing would be automatically stored in the coal picks database table.

The electronic data entry form had many data verification features built in to it to trap data entry errors. The entry form checked that all depths were in allowable depth ranges based on the particular coal zone being entered. Reversal of tops with bases was checked for. The coal zone name assigned to any picks had to be from a list of valid zone names. The form also recorded the units of depth and converted all depths to metres where necessary.

5.2.5 Cross-Section Data

Nine cross-sections that spanned the non-deformed, coal-bearing strata of the Alberta basin were assembled by the CBM study. Digitized geophysical logs were digitally processed to produce a series of coal seam tops and bases at each well. The coal zone name of each pick was assigned by a geologist.

5.2.6 Data Entry of Cross-Section Data

The ASCII computer files listing the well identifier, top depth of coal seam, bottom depth of coal seam, and coal zone name were copied into the project database tables. This was done for the cross-sections in the Alberta Plains. The cross-sections in the foothills/mountains had their picks entered into Tripod.

5.2.7 Other Sources

The project also had access to a set of coal seam picks made by a GSC study of the deep coal resources of western Canada (Williams and Murphy 1981). The GSC study made picks of the depth to the top and bottom of coal seams across the undeformed portion of the Alberta basin with a focus on the Mannville Group coal seams.

5.2.8 Data Entry of Other Sources

The ASCII files of the above study were copied into tables of the Alberta Geological Survey's coal database and related to the CBM project tables.

5.3 Merging of Data Into the Database

Using stratigraphic data from numerous sources meant that the original data files had to be converted into one common format. The common target format was the format and data types of the Coalbed Methane database tables.

5.3.1 Locations

Most of the data had geographic coordinates (latitude, longitude, or UTM) or a well location (Dominion Land Survey). The surface location of each data point was stored in the location database table. Each unique location was assigned a unique internal Alberta Geological Survey database number called sitid. As data was added to the database the locational information was added to the location table. Only unique locations were added, if a dataset had picks (or if vitrinite data was present at the location) at a location already in the location table then the location was not added again.

The latitude and longitude of the oil and gas and coal holes from the plains in the database are the surface locations of the holes. The wellid (srcid) is the bottom hole location of the oil and gas well except where the well extension is unknown. The srcid represents the surface location where the well extension is unknown.

All new data generated by the CBM study attempted to record the actual wellid where it was known, thereby positively and uniquely identifying the well where data was collected and ensuring the true Kelly bushing elevation was known. All of the pre-existing data did not come with the well extension attached to the location of the well. This meant that the actual location of the well within a LSD and the KB was unknown. The KB is needed to derive the elevation of the pick or the sample.

The location of outcrops and coal drill holes given only in DLS coordinates were converted to the latitude and longitude at the centroid of the LSD because all mapping was done by latitude and longitude. Outcrops expressed in UTM coordinates were also converted to latitude and longitude. The United States Geological Survey's projection conversion software was used.

5.3.2 Finding Unique Well ID

The unique well id could be found in about 80% of the wells which originally lacked well extensions. The procedure of finding the well id involved using the Alberta Geological Survey oil and gas database and the data set lacking well ids. In the case where a well's location was in a LSD where only one well had ever been drilled then an exact match existed and the well id was assigned.

The case where a well was situated in a LSD where more than one well had been previously drilled was handled in the following manner. The deepest pick or sample depth of the well where well id was being found represented the minimum drilled depth of that particular well. All wells situated in the LSD whose total depth was shallower than this point were eliminated. If only one well remained then a match existed and the well id was assigned. If more than one well remained then a well id could not be assigned with certainty and the first drilled well that remained had its well id assigned. The well was given the negative sitid of the first drilled well that remained to indicate the uncertainty of exact location and KB.

5.3.3 Assigning Formation Codes

The formation names or coal zones names used within the data set were assigned the equivalent formation code used by the coal database. All picks, regardless of the origin, had a consistent naming scheme. Some of the original names may have required re-assignment, this was handled in the data reconciliation phase.

5.4 Use of Database, Mapping Interface

The Coalbed Methane project's database tables served as a major information hub for the project. This section will describe how various groups of people had access to the data and how data was selected from the database for mapping. The data flow during mapping will also be described. This section will conclude by describing how revisions were made to the data.

5.4.1 Database Administrator (DBA) Account

The database tables used by the CBM project were created in the Alberta Geological Survey's coal database using the database administrator's computer account. This meant that only one person had the ability to create and destroy database tables and add, update, or delete data. Allowing only one person to change the data meant that changes could be tracked and the likelihood of project members reversing each others modifications was eliminated. Project members used the project account.

5.4.2 Project Account

A CBM project computer account was used by all project members involved in the generation of maps. The account had a subdirectory created for each user, this allowed each user to keep their work in their own subdirectory. Using one project account also allowed the team members to access a common set of tools for mapping. When a change was made to a base map or when a subcrop boundary was added, all team members producing maps had immediate access to the information through GENMAP (GENMAP is discussed in a later section and in the Appendix).

5.4.3 Data Flow During Mapping

5.4.3.1 Map Production

The production of maps was a multistage process which was designed to be entirely automated once the user entered the required parameters. The automated process is called Genmap. (The automated map making process is also summarized in the Appendix).

Genmap is a set of Digital Command Language (DCL) computer commands that run the map making operation. Once genmap is started the user answers a series of computer prompted questions with brief replies. The results of these replies guide genmap's operations. The result is a small draft map on letter-sized paper or a large plot. Genmap allowed the map making portion of the CBM project to consume as little as 5 minutes of the team members time in setting up a map production run for each map.

Genmap queries the user for the type of map to be produced (structure, isopach, depth to coal, etc.), the coal zone to map (Ardley, Drumheller, etc.), whether contouring parameters were to be revised, whether the database is to be queried or if a pre-existing file is to be re-contoured, the various kinds of overlay information needed (Alberta border, various coal subcrops), for blanking polygons to be used in contouring, and finally where the map is to be sent, a page printer or a large plotter.
Genmap queries the Coalbed Methane database tables through Ingres reports.

A series of Ingres reports were written to query the Coalbed Methane database tables. These reports were designed to retrieve the information needed to make maps.

The Ingres report serves as the link between the user's request for particular data and the entire collection of raw data in the coal database. An Ingres report is basically a computer program that accepts parameters which specify what is needed from the database, queries the database based on the selection parameters, and finally the report writes the results of the query into a file. The format of the output file was set to match the input format needed by the mapping package.

One report was written for the following four map types,

1) Structure of the top of the coal zone,
2) Depth to coal zone,
3) Thickest seam in a coal zone,
4) Cumulative coal in a coal zone.

The two parameters, or restrictions, passed to the reports from Genmap are the coal zone to be mapped and the dataset to use in mapping. The user let Genmap know what coal zone to map and which dataset to use. Genmap passed these parameters to the Ingres report. The Ingres report then queried the database returning the mapping file required.

The data file that was produced by the Ingres report became the input file to the Alberta Geological Survey's cartographic utility called AGSSYS. AGSSYS handled most of the coordination of the mapping operations. AGSSYS would read the data file produced by the Ingres report and, (i) do all cartographic processing needed to plot a map. This includes producing line work of the Alberta boundary, a township/range grid, the cities, and subcrop maps of the coal zones, and (ii) post the data locations on a map if only a posting map is required, or (iii) pass the processed data file to surface II for grid interpolation and contouring.

Surface II was the interpolation and contouring package used by the project in the Plains region of Alberta. The interpolation parameters used by Surface II to determine grid spacing, data point search radius, number of points to use in interpolation, and contouring interval were all specifiable through Genmap and passed to Surface II during interpolation. The resulting Surface II map will be passed back to AGSSYS for plotting.

If data was to be contoured then AGSSYS would accept the contour map from Surface II. This contour map would be overlaid in AGSSYS with other pre-existing plot files, such as the outline of Alberta, the township/range grid, and subcrops. The combined set of plot files would be sent to large format plotters or a page size laser printer for quick previews.

5.4.3.2 Pick_Look

All maps were reviewed for accuracy. An electronic Ingres form was designed to allow the mapping team to look at the raw data in the database used to produce the map. Being able to examine the raw data showed the actual information that produced a contour trend. For example, whether coal picks had a coal zone name differing from the project's accepted stratigraphy.

The electronic form (called pick_look) was a database form that allowed the location, pick, and coal zone name information to be seen together in one screen form. All fields in the form were queryable. To examine the picks at a location the user would enter the well's id and the form would fill with the well's information and picks. The mapper compared the information displayed with the project's stratigraphy and decided whether the coal pick needed to be revised.

5.4.3.3 Revisions to Database Data

All changes to the database data were made by one person based on requests from the CBM project team. This approach was taken to keep all changes in a systematic and controlled fashion. Changes were made through default Ingres database forms. Revisions were made to the data in the project database tables as a result of the data reconciliation phase.

5.5 Reconciling Data in the Database

Consistency in the mappable information was ensured before the final set of maps and cross-sections were produced. Information within a mappable coal zone had to be consistent in terms of depth, thickness, and naming of coal seams. Reconciliation was required for a number of reasons, (i) coal seam mapping is challenging, (ii) data from numerous studies was being combined, and (iii) the mapped data and cross-section information must be consistent.

5.5.1. Assigning Coal Zone Names

Maps were produced by coal zone. Every coal seam occurring within a mappable coal zone had a coal zone name assigned. Seams picked by the CBM study had coal zone names assigned at the time the coal was picked. Most of the coal seams from the Plains Evaluation study already had seam or zone names, except for the Horseshoe Canyon coals which lacked coal zone names. Coal picks from the Geological Survey of Canada paper 81-13 had a seam naming convention which was used with modification by the CBM study.

5.5.2 Finding Anomalies (by using PV-Wave)

The consistency and accuracy of data sets in the project database were determined by producing a series of draft maps and map data displays in PV-Wave designed to highlight errors in the data. PV-Wave (Precision Visual's Workstation Analysis and Visualization Environment) is computer visualization software. Since regional contour maps can mask errors at an individual well the software product PV-Wave was used to display the values at each individual well contributing to the regional coal zone map. The input file to PV-Wave was the Ingres report produced by Genmap. The PV-Wave display appeared on a computer workstation monitor where data values at each mappable well were color coded; potential anomalies appeared as out-of-sequence colors. Anomalies were selected with a pointing device (mouse) and the unique well id was displayed and recorded. The team member used pick_look to examine the data at the well used to produce the potential anomaly.

5.5.3 Changing Coal Seam Data

When the potential anomaly seen using PV-Wave or by mapping was actually a real anomaly then any data associated with the seam could be changed. Changes were instigated using a hard copy change form. Frequently, the coal zone name and depth to the top or bottom of the seam was modified. As soon as the change was made to the database the data could be re-extracted from the database. If necessary, data revisions to the database and the onset of another map production run could be done in less than 5 minutes. What became very time consuming in the reconciliation phase was examining the geophysical log microfiche of the surrounding wells in order to construct the local coal stratigraphy around the anomalous data. Coal seam picks could be switched off (made non-mappable) when the geophysical logs did not confidently support the presence of coal. Coal picks made by studies done prior to the CBM study had to be switched off in some cases.

Data reconciliation by individual data sets proceeded in an iterative fashion until full confidence in the data set was reached. All data sets from a coal zone were thus reconciled separately. Once each individual set was “correct”, all data sets from a coal zone were mapped together.

Mapping all data sets for a coal zone together triggered another phase of data reconciliation. In this phase the integratibility of the mapped data sets were checked. The process of reconciliation was similar to that for single data sets.

5.5.4 Assigning Names to Horseshoe Canyon Coals

Coal zone names were assigned to coal seam picks made by the Horseshoe Canyon study of the Plains Evaluation study (McCabe et al. 1989). Zone assignment was made by comparing the coal seam’s depth to the relative depth and absolute position of adjacent marker horizons. Seams that could not be resolved by this process were not used by the CBM project. All seams that were assigned zone names by this method went through the data reconciliation process for the Carbon-Thompson and Drumheller coal zones.

5.6 Multiple Studies at a Location

Using data sets that were produced by previous studies (Plains Evaluation study and its substudies, and the Geological Survey of Canada data from GSC paper 81-13) resulted in having coal seams in the project database with two or more sets of tops and bases.

5.6.1 Multiple Picks for the Same Coal Seam

If mapped, multiple picks of one coal seam would produce cumulative coal maps that were too thick. In addition, the question arose of which study to use when multiple picks were found for a coal.

5.6.2 Turning Duplicates Off

Duplicate picks were listed. This was possible because each pick was tagged with the originating study name. The list was reviewed by a geologist and the duplicate picks which would not be used were turned off in the database. The data for the duplicate picks was not deleted, only set to be not mappable. In general the duplicate picks from the most recent study was used in mapping.

5.6.3 Ensuring Picks Used on Maps Were on Cross-Sections

It was important that the cross-section data and the mapped data were in phase. Changes to coal seam depth or naming on cross-section wells was kept synchronous between the mapping and cross-section data sets.

During the data reconciliation phase it was found that other previous studies had in some cases recognized and picked coal seams on the CBM project cross-section wells. These picks were added to the cross-sections wherever valid.

5.6.4 Grid Intersect

Data reconciliation between coal zones followed the process of reconciling the data within coal zones. This was necessary to ensure that none of the mapped coal zones intersected one another. Intersection was conceivable since coal zones do “merge”, for example the Drumheller and Lethbridge coal zones in areas where the Bearpaw shale is not present.

Searching for coal zone intersections was accomplished by calculating the grid difference of the coal zone top and base structures for adjacent coal zones. Most intersections were in regions beyond the data distribution of a zone. A few intersections based on real data were located and corrected.

5.7 Final Comments on use of the Database

5.7.1 Client-Server Computer Architecture

The computer system which housed the project database used by genmap was a local area VAX cluster (LAVC). Ingres, the relational database used by the project, was configured in a client-server mode on the LAVC. That is, the database server ran on a Vax Server 3400 and the database client ran on a VAX 3300. Genmap and Surface II ran on the VAX 3300. This resulted in a separation of processing, with database queries running on one computer while mapping ran on another computer. The computers used common disks, and therefore data.

5.7.2 Cumulative Coal on Section Wells

The cumulative coal in each coal zone on the cross-section wells was derived from the project database. A database query summed the coal in each coal zone, for every well on the cross-sections. A listing was produced and used to place the values on the cross-sections. This list was produced after the data reconciliation was completed.

5.8 Foothills Data Handling

This section describes how the foothills data for this study was handled, put in a database and prepared for cross-section construction and mapping.

5.8.1 Database Design

Because a lot of the existing vitrinite reflectance data in the foothills was our own data and was already available in ASCII files, it was decided to use these files directly. Consequently, the foothills database is a non-relational database, consisting of a collection of ASCII files. Also the fact that the foothills coal picks were done manually and entered in TRIPOD data bases, which can produce ASCII files, convinced us to use a collection of ASCII files as foothills database.

5.8.2 Data Sources

The ASCII files containing coal picks (produced by TRIPOD) were entered into Terrastation for stratigraphic section construction.

Pre existing vitrinite reflectance data from different sources (see section on Petrographic Rank Studies) were added to our ASCII files of new vitrinite data. Ten different files were made, an outcrop and well file for each coal zone (Coalspur, Brazeau, Gates, Gething and Kootenay coal zones). These files were used for mapping.

5.8.2.1 Outcrop Data

In the Grande Cache and Cadomin areas a combined total of about 400 vitrinite reflectance measurements were done for previous ARC projects (Langenberg et al., 1987 and 1989), most on Gates coals. This large number of data in relatively small areas will clutter regional maps. Because there is quite a bit of variation, depending on where in the area the coal was sampled and from which stratigraphic position in the coal zone, an experience based selection process was used to select 19 locations in the Grande Cache area and 17 locations in the Cadomin area for the Gates (see ASCII file GATESO.REFL). Preference was given to coals near the middle of the coal zone, because there might be quite a difference between the upper and lower coals in a 200 m thick coal zone, such as the Gates coal zone (Langenberg et al., 1987). In the Grande Cache area the largest number of samples is from the #4 seam, which is upper lower Gates coal zone. However, in the Cadomin area all samples are from the Jewel seam near the base of the zone, because the 10 m thick Jewel seam is the only thick coal seam in the area (Langenberg et al., 1989).

Of the other coal zones only the Coalspur and Kootenay coal zones needed data selection. In the Coal Valley Mine many analyses of Coalspur coals were done by Cameron (pers. comm., 1991) and one representative analyses was selected (see ASCII file COALSPO.REFL). For the Kootenay coal zone many analyses came from measured sections by Gibson (1985), who showed that the coal zone can be up to 450 m thick in Alberta. Analyses are available for coals of most coals in the sections. Coals from the middle of the coal seam were selected for our study (see ASCII file KOOTO.REFL).

It should be noted that some of these analyses also form part of the general (mainly plains) relational Ingres database. **Users of the two data bases: be aware that the same reflectance data may be in both data bases!**

Some of the outcrop reflectance values were plotted on the structural cross-sections.

5.8.2.2 Well Data

ASCII files with a similar format as the outcrop files were built for the reflectance data from wells. These files include existing published data, donations and new data. From the new data 75 samples were from coal zones in the foothills. All these analyses are also in the general (mainly plains) relational Ingres database.

Existing data and donations were added to these files. Where several analyses of the same coal zone are available, the ones from the top of the coal zone were selected. This selection was done to make this data compatible with the new data, where LAS generally sampled the first cuttings present in the well cuttings vials. Consequently, they were largely from the top of the coal zones.
Where analyses from several fault repeats of the same coal zone were available, only an analyses from the upper fault slice was entered in our ASCII files.

Some of the existing vitrinite data and donations may also form part of the general (mainly plains) relational Ingres database. **Users of the two data bases: be aware that the same reflectance data may be in both data bases!**

5.9 Plains Coal Seam Picking - Well Logs

Hand picking of the coal seams in the infill wells was done utilizing the gamma log as one of the main logs for recognizing coal and as the only log used to determine the seam thickness. The bulk density log was the second defining log, resistivity was the third defining log, and the caliper log was the fourth defining log. The sonic (interval transit time) log was used when no moderate to good quality bulk density log was available. For the average log used in this study, coals were defined when the gamma value was less than 70 GAPI, the neutron value was less than 2000 kg/m^3, the resistivity was greater than 80 ohm-m, the sonic was 400 or greater, and where the caving was negligible.

The module PETRA of the Terrastation software package was used to make the coal picks along the cross-section wells in the Plains region. (All coal were hand picked in the Foothills/Mountains). The digitized logs that were used were the gamma, medium resistivity, and either bulk density or sonic logs. The use of three logs allowed the determination of four lithologies: coal, sand, shale, and limestone. It was not possible to delineate caved intervals due to the fact that there was no digitized caliper log. This meant that many caved intervals usually were analyzed as coals. It was found that the standard algorithm used by PETRA usually over-rode the low resistivity response when the hole was caved. Normally the best definition between a cave and a coal when there is no caliper log is the resistivity response - if it is low then the interval can be considered a cave, if it is high (greater than 50) then the interval is considered a coal. Due to the limitations in number of lithologies, PETRA concluded that any low-gamma, low density, (or high sonic) intervals were coals, irrespective of the resistivity log.

A generalized set of parameters were set for all well analyses with the intention that all log responses were similar for all the wells in the project. The CROSSPLOT and PETRA analysis programs were run in detail on certain representative cross-section wells to determine primary lithologic coefficients for initial coal analysis and background for editing. A 60 to 80 percent accuracy on the number and thickness of the coals was found with each well averaging 15 to 30 minutes in processing time.

The coefficients used for the majority of the wells to determine primary lithologies for initial coal analysis are shown in table 1.

Table 1. Log parameters used by Terrastation for litholog analysis.

	Sandstone	Shale	Coal	Limestone
3=GR	65	110	45	25
4=DENS	2300	2450	1600	2650
5=SONIC	320	350	500	200
70=RES	12	7	80	400

All coal picks done by Terrastation were verified against the original paper copies of the logs. After the coal picks were made and verified they were uploaded into the Ingres database system.

5.10 Plains Cross-Sections

5.10.1 Selection of Well Logs

The working cross-sections from the post-Wapiabi and Mannville chapters from "The Geologic Atlas of the Western Canada Sedimentary Basin" (Mossop, in prep.) were used to better correlate the stratigraphy and determine the locations for the CBM cross-sections. The general stratigraphic correlations on the working cross-sections for this study were partly based on the Atlas cross-sections and ERCB picks on the logs.

The Geologic Atlas of the Western Canada Sedimentary Basin project has built a large database of oil and gas well statistics for Alberta. Software has been written to select the "most representative" in each township of Alberta. For the CBM project, the Atlas software was used to select candidate oil and gas wells using the criteria indicated in table 2.

Table 2. Criteria for selection of cross-section wells.

Primary Criteria	
Year of drilling	0 (first run for stratigraphy) 1978 (second run for vitrinite samples)
Stratigraphy	down to 4140 (Fernie Group)
Deviated wells	less than 2% TD/TVD
Secondary Criteria	
Sample size	up to 100 wells "most representative" is the well with the highest score based on the following relative weighting
Minimum depth to SP/Res.	0.75 (approx csg)
Log coverage 0.90	
Stratigraphic depth	1.00
Pick abundance	0.80
ARC coal data	0.60
Elevation consistancy	0.60

5.10.2 Use of Terrastation

The electronic picking of formation tops for stratigraphic definition of the cross-section wells was started on Terrastation. All formation tops on the paper cross-sections were color-coded, and re-checked with revisions to the electronic cross-sections to ensure that all picks were consistant. Originally, all major formational picks in the Cretaceous and Jurassic were made; later, the picks were revised to include only the coalbearing formations (kb, cs, hc, bp, br, lp, uman, lman, nord, nik, fernie) and one marker horizon (Base of Fish Scales).

The cross-section configuration was determined to be structurally hung for both the plains and the foothills (datum is mean sea level); with the rough scaling factors as 1:5000 vertical and 1:200 000 horizontal. All well logs were cut off at or just below the Nordegg/Paleozoic pick.

5.11 Foothills Cross-Sections

5.11.1 Selection of Foothills Cross-Section Lines

The cross-section lines in the foothills were selected based on location of the plains cross-sections and the existance of previously constructed foothills cross-sections of the 7 areas. The exact location of the structural cross-sections is indicated on all sections by the UTM coordinates (Zone 11) of the end points of the sections. Because the previous sections were generally constructed with older wells, the cross-sections were modified using the information from new wells. The stratigraphic Foothills sections follow the structural Foothills section and are based on the same wells.

5.11.2 Pincher Creek Area

A structural cross-section was obtained from P.R. Fermor (pers.comm., 1991), which has been published previously in Hacquebard and Cameron (1989). Use was also made of cross-sections by Hiebert and Spratt (1990), and Hage (1940).

5.11.3 Highwood River Area

The structural cross-section is along the same line as a section published in a guidebook by Gordy, Frey and Ollerenshaw (1975), which was originally published by Bally, Gordy and Stewart (1966). Use was also made of cross-sections through the Mount Head area by Douglas (1958).

5.11.4 Canmore Area

The structural cross-section of the Canmore area is along the line of the well known Foothills section by Price and Fermor (1985).

5.11.5 Nordegg Area

No readily available cross-section existed for the Nordegg area. A section line trough the Nordegg town site was selected, which is close to a section published in a guide book by Jones and Workum (1978). Use was also made of a cross-section by Douglas (1956), which is mainly based on surface information, and a seismic line published in a guidebook by Perkins et al. (1984).

5.11.6 Cadomin Area

The cross-section line and interpretation for the Cadomin area was taken from a structural cross-section constructed by Langenberg (in prep.), with an extension through the Mountain Park area based on Mountjoy and Lebel (in press).

5.11.7 Grande Cache Area

The cross-section through the Grande Cache area is based on a section by Mountjoy (1978).

5.11.8 Narraway River Area

The structural cross-section of the Narraway River area is based on a recent cross-section by McMechan (in press).

5.12 Selection of Wells

Two categories of wells were used in the foothills portion of the coalbed methane project. The decision of which wells to use for the final product depended on which of the two catagories they represent. The first category consisted of wells in close proximity to the seven structural cross-sections, but with limited value for making precise coal picks. These wells usually had an incomplete log suite, were too old, or had severe hole problems making the logs unrelaiable for coal picking. The second category consisted of wells which were considered to be more reliable for picking coal zone and coal seam thicknesses. These wells had a more complete log suite and were generally in close proximity to the seven structural cross-sections. A representative number of these wells were selected and used to make the stratigraphic cross-sections. Wells were projected in from greater distances where representative wells could not be found in the immediate vicinity of the structural sections. An additional well was added to the end of each of the foothills stratigraphic sections to provide a tie with the plains stratigraphic sections.

5.13 Selection of Sample Intervals

Selection of the intervals to be sampled for coal cuttings followed a similar procedure. Wells in the vicinity of the seven structural cross-sections were divided into two groups, those drilled pre-1977 and those drilled post-1977. Wells drilled pre-1977 were immediately eliminated because of the tendancy to coke the samples during the drying process prior to this date. Of those wells remaining, sampling intervals were generally only selected for those wells to be used in the construction of the final structural or statigraphic cross-sections. Where possible, an attempt was made to sample successive fault repeats of the same coal zone. Some exceptions were made with wells considered to be of particular importance either for their structural positioning or their stratigraphic signifigance. These wells were sampled regardless of their age but seldom gave any reliable results.

5.14 Coal Picks

Generally three logs were used for picking coals, i.e. Gamma, Sonic and Resistivity. Density was also used (if available), but considered unreliable because the coals have often caved out in the foothills. The coal tends to fracture, get sheared and preferentially cave out while drilling. This makes the density logs not very reliable. Sonic logs are better because of their deeper penetration.

Seam thicknesses were measured from the inflection point (1/3 way up the curve) on the Gamma log (Sonic is not as reliable for estimating thickness). An attempt was made to match the gamma log picks with stratigraphic logs, where available. Mud logs were also useful in some cases to pick coal gas kicks, although very few were available through coal.

Many of the older logs result in less reliable coal picks. However, these picks had to be used when no nearby recent wells are present.

5.15 Use of TRIPOD

The TRIPOD software (Charlesworth et al., 1989) was used to construct databases of stratigraphic and coal picks for the different cross-section areas and to draw frame-works for the structural cross-sections.

TRIPOD is the only commercially available software which can produce down plunge cross-sections. In this mode cylindrically folded areas are determined and outcrop and drill hole data are projected parallel to the fold axis onto the plane of cross-section. This allows geological information that is situated off the line of section to be used in the interpretation of the geology. The most weight can be given to information that was projected the shortest distance.

TRIPOD databases were built of locations of the Kelly Bushings of the wells (using top hole UTM coordinates), the depth to the tops and bottoms of coal seams and other stratigraphic horizons in the wells, and deviation data where available. These TRIPOD data bases can produce ASCII files of the coal picks, which are part of the electronic database provided with this report. The locations of the wells are measured from the corner of the section, not just at the centre of the LSD.

All 7 structural cross-sections presented in this report are based on down plunge cross-sections produced by TRIPOD.

5.16 Use of Deviation Data

Only limited deviation logs are available from the ERCB fiche. Deviation data from 8 wells were entered in the TRIPOD databases. The deviation data of 17 additional wells portrayed as their projections on a plane perpendicular to the deformation front (in general parallel to our section planes) was obtained through the cooperation of Peter Fermor of Shell Canada Resources Ltd. For the remaining wells the deviation path was estimated from the top and bottom hole coordinates.

5.17 Use of Terrastation

Use of the Terrastation log analysis package was minimal in the foothills portion of the coalbed methane study. The log analysis package was considered too simplistic to make accurate coal picks. The log suite available for analysis was too incomplete and hole caving problems were too great to trust any picks made by the computer. Consequently, it was nesessary to make all coal picks by hand and to enter these picks into the Terrastation module manually. These coal picks could then be plotted on the final Terrastation output prior to their transfer into the AutoCad system for final drafting of the cross-sections. The Terrastation module was used in no other way in the foothills portion of the CBM project.

6 Plains Mapping

6.1 Plains Infill Wells

Knowledge of the coal seam thickness and coal zone occurrences between the cross-sections was deemed necessary, and a separate realm of wells were analysed as infill wells. The first task in the infill analysis was to generate a list of wells suitable for the purpose; the Atlas well selection program previously used for the definition of the cross-section wells was utilized. The next step was to pick the top and bottom depths of coal seams on the printed paper copies of the well logs. Data entry was directly from the logs into the project database. The coals were picked in the same manner as the original cross-section wells.

There were three phases of infill well analysis for the areas between cross-sections, with the first phase having a low density of wells and covering the entire province and each subsequent phase having greater well densities and concentrating on better coal bearing locations. The last phase of infill wells were in areas with the inferred best coal occurrences. This allowed creation of an infill well location map with designated coal zone zero edges (approximate) also plotted.

Infill wells were selected between the cross-sections in the plains and then the top and base of all coal seams thicker than 0.5 m were picked in each well. The infill wells were selected in several stages, with each successive stage of infill focussing on the areas which looked most interesting at the previous level of data control. Acquisition of several other data sets has greatly enhanced the well data available to the project. A great deal of effort was dedicated to entering, organizing, and combining these data sets for use in the project. Later, a posting map of cross-section and infill well locations was plotted. The infill well density was checked and additional areas with sparse data were examined.

The shallow coals on many of the infill wells were not entered into the Ingres database for mapping because they already exist in the Plains Evaluation Coal Study database. The stratigraphic picks on the cross-sections were reconciled with the picks on the infill wells, and all coal zone names were checked for stratigraphic consistancy.

7 Foothills Mapping

In the foothills the thickness of coal seams is highly variable because of local tectonic thickening or thinning. In addition, many wells may show several thrust repeats of the same coal zone. Also, the foothills have a lower density of drilling than the plains. Wells are generally deeper and more expensive to drill. As discussed earlier the older wells are not very reliable for picking coals. Consequently, the number of wells available for mapping is relatively small. Another consideration is that the foothills are generally about 50 to 60 km wide, which results in long narrow strips of areas of interest.

For these reasons it was felt that mapping the thicknesses of coal seams would not be very meaningful. A good impression of seam thicknesses can be obtained from the 7 stratigraphic foothills cross-sections and in the description and discussion of the cross-sections. In addition, all coal picks are in our foothills database (ASCII files); accurate thicknesses of all coal picks can be obtained from these files.

Consequently, the only parameter mapped in the foothills is vitrinite reflectance.

7.1 Vitrinite Reflectance Mapping

Foothills vitrinite reflectance data were mapped using the in-house AGSSYS mapping system using our ASCII files described in the data handling section. Some editing of these ASCII files had to be done, for example where sample locations where so close that the postings were overprinted. Maximum vitrinite reflectance was posted at each outcrop and well location for the different coal zones. These postings were hand contoured, digitized, and added to the maps of equivalent coal zones of the plains region.

8 Vitrinite Reflectance

To assess the coalbed methane potential of Alberta's coal-bearing rocks, it is necessary to determine the rank of the coals in the various coal zones. Large amounts of methane is generated during the coalification process of transformation of peats to coal. The degree of progressive transformation of peat is defined as the rank of coal, which is expressed in the natural series from lignite to anthracite. The rank classes can be determined by measuring the reflectance of the maceral called vitrinite. A good correlation between the rank determined from vitrinite reflectance and rank determined according to standard chemical methods (ASTM standard D-388) is generally accepted (Bustin et al., 1985). Chemical methods use fixed carbon contents (dry, mineral matter free) for higher ranks and calorific value (moist, mineral matter free) for lower rank coals. The vitrinite reflectance rank parameter has the advantage that it can be used on small samples, such as cuttings from oil and gas wells. In addition, it can be used over the whole range of coalification. For this reason vitrinite reflectance has been used as the rank and maturity parameter (and consequently coalbed methane potential indicator) for this study.

8.1 Measurement of Vitrinite Reflectance

Pellets were made of the coal cuttings, which were ground, polished, and the vitrinite reflectance measured according to standard procedures (ASTM standard D 2798-79). Vitrinite reflectance can be measured as mean random vitrinite reflectance (using non-polarized light and calculating the mean of about 50 measurements), or as mean maximum vitrinite reflectance (using polarized light, rotating the microscope stage, measuring the maximum reflectance of about 50 individual vitrinite grains and calculating the mean). The mean random measurements are easier and quicker. However, the mean maximum method is preferred by many petrographers for higher rank coals, because the standard deviation is smaller and different populations (if they are present, for example from cavings) are easier to differentiate. For the new data collected for the present study, reflectances over 1.3 percent are maximum vitrinite reflectance and below 1.3 percent are random vitrinite reflectance in oil.

Most of the existing vitrinite reflectance data in the Plains is random, while in the Foothills the preferred method has traditionally been maximum (the Foothills coals generally have a higher rank). For this reason all data in the Foothills is reported as maximum vitrinite reflectance, while all data in the Plains is reported as random vitrinite reflectance. The maximum reflectance can be determined from random reflectance (and vice-versa) by the formula (Bustin et al., 1985 and Ting, 1978):

$$R_{max} = 1.06 \times R_m$$

where R_{max} = maximum vitrinite reflectance and R_m = random vitrinite reflectance.

8.2 Rank Classes

ASTM rank classes can be estimated from vitrinite reflectance, as discussed earlier. Recent work by Cameron (1989) allows a more precise estimation for western Canadian coals. These rank classes, which are based on random reflectance, are shown in table 3. The maximum reflectance rank classes are modified from Davis (1978). These modifications had to be made, because Davis's classes are based on Carboniferous eastern U.S. coals and not Mesozoic western Canadian coals. Cameron (1989) has shown that the rank classes are slightly different because of higher inertinite contents of the western coals. These rank classes were used as contour intervals on the maps for the maximum vitrinite reflectance data in the foothills and for the random vitrinite reflectance data in the plains.

8.3 Pre-Existing Vitrinite Data

Vitrinite reflectance data from completed studies were entered in our database. These studies are listed in Appendix D.

Table 3. ASTM rank classes in term of vitrinite reflectance. Based on Cameron (1989) and Davis (1978).

Rank	Rmax	Rrandom
Lignite		< 0.40
Subbit. B	0.45-0.53	0.40-0.50
High-vol. C Bit.	0.53-0.70	0.50-0.65
High-vol B Bit.	0.70-0.80	0.65-0.75
High-vol. A Bit.	0.80-1.00	0.75-0.95
Medium-vol. Bit.	1.00-1.50	0.95-1.45
Low-vol. Bit.	1.50-2.00	1.45-1.90
Semi-anthracite	> 2.00	> 1.90

8.4 New Vitrinite Reflectance Data

Maturity data, based on pre-existing vitrinite reflectance samples, are not evenly distributed across the basin. This necessitated collecting additional samples (564 samples). New, unpublished, vitrinite reflectance data was also donated to this study by various scientists. New coal samples for vitrinite reflectance analysis were collected to fill gaps in the data distribution of the pre-existing (approximately 1100 samples) vitrinite reflectance data.

8.4.1 Selection of Wells

The first step in collecting new cutting samples for vitrinite reflectance measurement was to develop a data set of selected well intervals to be sampled for coal chips. Initially, this was a list of depth to the top and bottom of the coal zones within the cross-section and infill wells. Approximately 1000 sample locations (well and depth) were provided to LAS Energy Associates for sampling. The wells were those from the regional cross-sections and had been selected for logs through the coal zones and a recent completion date. Sample duplication was minimized by plotting the pre-existing vitrinite reflectance sample locations by formation. Sample collection locations for new samples were thus based on the data distribution of the pre-existing vitrinite reflectance data.

Once we were able to assure the GSC that we had checked thoroughly against previous work (including much unpublished material which they made available to us), and would not resample any wells which had been previously sampled, we were permitted to begin sampling. Based on this list about 220 samples were taken. Because of the screening procedure to select the wells, we had expected a larger number of cuttings samples to be available. In many parts of the province, cuttings are not collected until the well is below the coal zones in which we were interested.

Time was spent working with the ERCB Core Research Centre to identify wells in which they had obtained shallow cuttings, which could then be sampled at the GSC. This was very useful and helped greatly in identifying wells with cuttings in the Ardley, Horseshoe Canyon and Belly River Formations. Information on coal occurrences in core was obtained from a variety of sources, including ERCB records, industry personnel and Alberta Geological Survey reports. All coals in cores for which we could find no previous vitrinite reflectance data, were sampled.

8.4.2 Handling of Samples

The samples picked from the cuttings at the GSC, as well as samples collected from cores and mine sites, and samples submitted by participating companies, were submitted to T. Gentzis at the Coal Research Centre in Devon. He prepared the samples and took the vitrinite reflectance measurements. A scattering of duplicate samples were submitted as per the request of the participant group.

8.5 Entry of Vitrinite Reflectance Data in Database

All vitrinite reflectance data was collected with the intention of placing the information about the samples in a relational database for the purpose of data preservation and processing. This imposes higher standards on what is known and recorded about a sample, in turn, the sample's data has more value and can eventually be more useful. The most critical information recorded about a sample is discussed in this section.

8.5.1 Pre-existing Vitrinite Reflectance Data

Data from the published literature is an essentially free source of information. The cost of this data increases when authors are not extremely specific about what they are actually publishing. Information gathered when examining pre-existing vitrinite reflectance data are discussed below along with some of the problems encountered.

The type of location where a sample was collected was recorded. For example, whether sample location is a drillhole, outcrop, mine, adit. Most samples originated from oil and gas drillholes.

Location refers to the geographic location of a sample on the Earth's surface. Most authors described their samples as being from drillholes located by Dominion Land Survey (DLS) coordinates. Knowledge of a sample's DLS coordinates are useful, although more information is often required such as the Kelly Bushing (KB) elevation of the well. If only the DLS location of a well is listed in a report and the KB of the well needs to be found, complications arise when multiple events have happened at the DLS location or when more than one drillhole is situated in the legal subdivison. The problem requiring resolution is which well is the data really from?

The kelly bushing elevation was recorded or looked up whenever samples originated in a drillhole. Finding the KB elevation became very important when the report did not provide the formation name where the sample was collected from. In instances where sample depths without formation names were listed it became necessary to use the sample depths to determine the formation name.

The sample depth was recorded in order to determine the formation name in cases where the formation name was not provided. The formation name was needed for mapping. Sample depth was also needed to plot the location of any samples on the cross-sections.

The formation where the sample was collected from was recorded so samples could be mapped by coal zone. In some cases the formation designation of a sample was too general to allow assignment of the sample to a particular coal zone, an example would be a Horseshoe Canyon sample, this sample can be assigned to one of two coal zones.

The type of sample was recorded, such as whether core, cutting, channel sample. The host media was also recorded where known. This information was not used in mapping or in cross-section plotting.

Vitrinite reflectance data can be measured and reported in various ways (i.e. mean random reflectance, mean maximum reflectance, etc.). This information was recorded where listed. In some cases the measurement basis was not given and the author of the report had to be contacted.

8.5.2 New Vitrinite Reflectance Data

Coal samples were collected by this project to make vitrinite reflectance measurements on. This section discusses what information was recorded for mapping and cross-section display purposes.

The location of the oil and gas well where samples were collected was recorded by DLS coordinates. The well extension was usually known beforehand and recorded. The KB of the well was determined based on the DLS location of the well and the well extension code. The sample depth was recorded based on the cored depth or cuttings depth. The formation and coal zone of a sample were determined by selecting samples from coal zones seen on geophysical well logs and the cross-sections. The type of sample was recorded. In most cases the samples are cuttings.

8.6 Preparation of Vitrinite Reflectance Data for Mapping

In preparation for mapping and cross-section posting some final work was done on the vitrinite reflectance data gathered from the literature, donations, and from this project. The additions and improvements to the data were made in the project database table containing vitrinite reflectance data.

Some coal samples were received with only locations and depths and no formations or coal zones attached. The sample locations and depths were compared to the geophysical logs for the particular well and the coal zone was assigned.

The location of vitrinite reflectance samples needs to be expressed in latitude and longitude for mapping. The top hole, surface latitude and longitude coordinates of data collected from oil and gas wells was selected from the Alberta Geological Survey's Oil and Gas Database (AGSWDB). Where data came referenced by only DLS coordinates, for example outcrops, the centroid of the LSD was converted to latitude and longitude.

The Kelly bushing elevation was needed for all wells where the coal zone of the sample is unknown. The sample depth was subtracted from the KB elevation to give the sample elevation relative to sea level. The sample elevation is used in the grid intersect process of assigning formation names.

In some cases the vitrinite reflectance data as listed in scientific papers was in a form that did not indicate the particular coal zone a vitrinite reflectance sample came from. The two possibilities found are, sample depth and vitrinite reflectance value were given with no formation name, and secondly, when the formation or group contains more than one coal zone. Computer processing, followed by manual assignment where necessary was used to determine the coal zone in the case of samples lacking coal zone names. Computer processing was used since the number of samples with indeterminant coal zone numbered in the hundreds.

To assign the coal zone name to vitrinite reflectance samples lacking coal zone names involved extracting the location of the sample (as latitude, longitude and depth). This information about each sample was intersected with computer grid files of each coal zone mapped by this project. Samples that occur within a coal zone, as defined by the top and bottom structure map of the zone were assigned that particular coal zone's name. The project database table of vitrinite reflectance data was updated with the output of this procedure.

A visual check was made of the vitrinite reflectance data where more than one sample occurs at or below a land location. This was done to spot vitrinite reflectance values that were anomalous. Locations with only one sample at or below a land location were checked during the mapping stage.

Mapping of the vitrinite reflectance data by coal zone revealed some anomalous data. A computer form which was a database view allowed project staff to view the raw data being mapped and note any necessary changes.

Vitrinite reflectance data from cross-section wells was selected from the database and posted on the cross-sections. This selection retrieved vitrinite reflectance data generated by this study, also found and posted was data from the pre-existing data sets.

The vitrinite reflectance data in the Plains region (undeformed strata) was mapped and also plotted on the cross-sections on a mean random reflectance basis. This entailed converting any data originally reported as mean maximum reflectance to mean random reflectance using the formula:

mean random reflectance = (mean maximum reflectance)/1.06.

9 Gas Content Predictions

Large amounts of methane may be generated during coalification. Total amounts of gas present depend of rank, volume of coal and methane retention. In addition, the gas must be able to migrate through the bed at an acceptable rate to be able to be produced. The volumes of coal can be calculated from thickness and aerial extent of the coal zones.

No specific study of gas retention was made in this study, although it is known that methane is retained in pores in the coal. Methane molecules are adsorbed on the organic surfaces in micropores. Consequently, pore volume data should not be used for retention calculations. The primary controlling factor for the amount of gas stored in coal is the surface area contained within the coal micropore system.

Spacing of cleats (which are fractures perpendicular to the coalbed) and their orientation, influences the reservoir flow. This determines if the gas can be produced. Therefore, the fractures determine permeability. No study of coal permeability was made in the present study.

9.1 Gas Content Predictions from Rank

Throughout the whole period of geochemical history, from peat to graphitization, organic matter undergoes a continuous loss of mass accompanied by the evolution of volatile products. Estimates of total amounts of gas generated during coalification vary greatly. It depends on the rank attained and on the proportion of macerals present in the coal. Rightmire (1984) provides a table of approximate gas generation by rank. No thermogenic methane is generated in subbituminous coal. About 20cc/gram (640cf/ton) is generated in high-volatile bituminous coals, 104cc/gram (3328cf/ton) when the coal is through the medium volatile bituminous stage, 172cc/gram (5504cf/ton) after the high volatile bituminous stage, 196cc/gram (6272cf/ton) after semi anthracite and 224cc/gram (7168cf/ton) after anthracite, when the coalification is essentially complete. Not all gas generated will be retained in the coalbed. The gas may migrate elsewhere and be trapped in conventional reservoirs. Most of Alberta's Deep Basin gas was probably sourced by coal.

Measured gas contents in coal generally range from 0 to 25cc/gram (0 to 800cf/ton), see Rightmire (1984, figure 9). The gas contents are dependant on rank and depth. After 300m depth the gas contents do not increase much more with depth. High volatile bituminous has between 2 and 9cc/gram, medium volatile bituminous to anthracite has between 5 and 20cc/gram. These figures are from U.S. coals. Little is known about Canadian coals. However, the few published analyses fall in the same range.

These figures indicate that coals with ranks of at least medium volatile bituminous rank will contain about twice as much methane as high volatile bituminous coals. Consequently, these higher rank coals are the main sources for coalbed methane potential. However, the high volatile bituminous coals should not be excluded because volumes could make up for lower gas contents. Also, high volatile A and B bituminous are more prospective than high volatile C bituminous coals. These considerations were guidelines in the discussion of coalbed methane potential based on thicknesses and rank distribution (presented in our maps and cross-sections).

10 Limitations of Regional Coal Resource Maps and Cross-Sections Produced

The localized nature of coal seam development and variable thickness of seams within deposits and the orientation of deposits can all affect the reliability of coal mapping. The data set used to generate these maps commonly consists of only 1 to 4 wells per township where data are available and limitations are imposed by casing in petroleum wells and shallow drilling depths in coal exploration holes. Some locally anomalous areas (consisting of thick and economic seams), are likely to be missed in this evaluation. Detailed geology and exploration drilling will undoubtedly find many more coal deposits at depth. The well distribution along the cross-sections (about 1 well per township) is also considered very coarse for coal seam correlations. In some coal basins a cross-section used for seam correlation might be no more than a township long. The maps and cross-sections in this report are regional and were produced to illustrate trends, rather than detailed evaluations on a seam by seam basis. That level of detail would be needed in any CBM development program.

11 Cross-Sections

One of the most fundamental problems in the early stages of assessing an area for its coal potential is to establish where the coals are within a succession of strata and how they are spatially connected. Stratigraphy becomes a very important tool in establishing a framework whereby the geologist can make reasonable correlations of coal and rock units. The recognition of marker horizons, such as bentonites, tonsteins, coquina beds, or continuous sand beds is a necessary first step in establishing this stratigraphic framework in both surface and subsurface mapping. A stratigraphic framework is necessary at all levels of exploration, from reconnaissance to mine site planning. Once this stratigraphic framework is established, individual coal seams can be correlated and their lateral extent determined.

11.1 Plains Region East-West Cross-Sections

11.1.1 Crowsnest to Cypress Hills (R’-R”)

Stratigraphic cross-section R’ - R” runs in an east-west direction across the southern part of the province from the Crowsnest area, Tp 6 R 28 W4M on the west, to the Cypress Hills, Tp 7 R 2 W4M on the east.

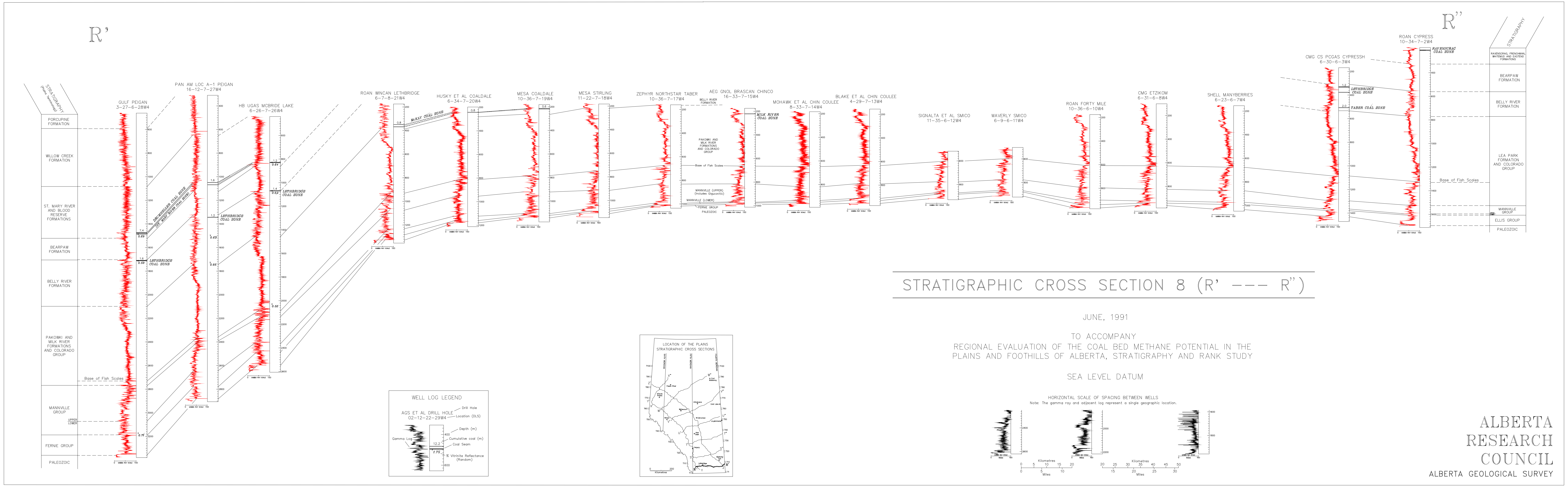
In the west, the section runs from the Fernie Group at the base up to the Mannville and Milk River Formations, Belly River, Bearpaw, St. Mary River and Blood Reserve Formations to the Willow Creek and Porcupine Formations at the top over a thickness of approximately 2700 m. In the east, the section is in the Cypress Hills and is approximately 1400 m thick with a thin Mannville section at the bottom overlain by thick Lea Park and Colorado Group shales and thinner Belly River Formation, Bearpaw Formation and capped by an assortment of thin units called the Ravenscrag, Frenchmen’s, Whitemud, and Eastend Formations. Very little coal is shown in this section. The stratigraphically oldest coal in the section is a single occurrence of the Milk River coal zone in the middle of the section at a depth of about 200 m in Tp 7 R 15 W4M. More widespread, at the base of the Belly River Formation, in the western part of the cross-section is the McKay coal zone which occurs in three wells before it disappears behind casing at shallower depths. The McKay coal zone is quite shallow in this area ranging in depth from 350 up to 200 m. It contains only one or two coal seams with less than a metre of cumulative coal. The Taber coal zone in the middle of the Belly River Formation occurs in only a single well in the Cypress Hills area towards the east end of the cross-section with a coal seam 2 m thick. At the top of the Belly River Formation is the Lethbridge coal zone, which occurs in the three westernmost wells on the cross-section at depth ranging from 1700 m up to 1016 m and seam thicknessess up to 1.6 m. It also occurs in one well in the Cypress Hills area at the east end of the cross-section with cumulative coal there of about 1.2 m. The Lethbridge coal zone vitrinite reflectance rank in the wells at the western end of the section runs around 0.6 at depths ranging from 1060 m down to 1700 m.

The Drumheller coal zone in this area occurs also in the three western-most wells on the cross-section. At the base of the St. Mary River Formation at depths of 1470 m up to about 820 m the Drumheller coal zone contains up to 7.4 m of cumulative coal and ranges in rank from 0.64 to 0.69 at depths of 1500 m. At the easternmost end of this cross-section at a depth of about 200 m, occurs the only occurrence of the Ravenscrag coal zone which was seen in this study. This occurs within the Cypress Hills and is not widespread. An interesting feature of this cross-section is that both wells which have vitrinite reflectance measurements for both the Drumheller and Lethbridge coal zones have the higher values in the Drumheller coal zone which is shallower than the Lethbridge, although the differences are not very large and may not be significant.

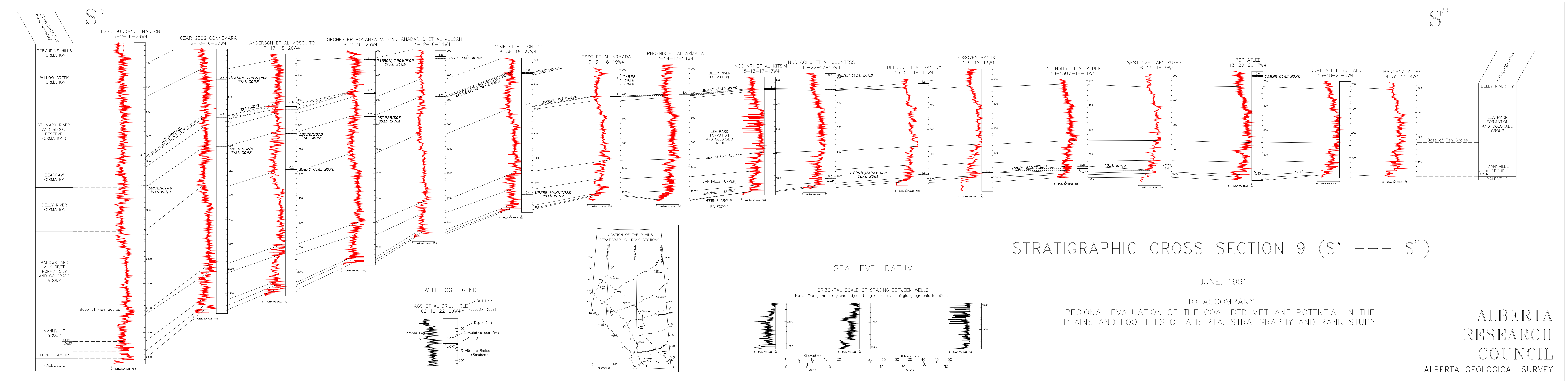
11.1.2 Nanton to Sand Hills (S’-S”)

Stratigraphic cross-section 9, S’ - S” runs across the southern part of province from Tp 6, R 29 W4M to Tp 21, R 4 W4M

At the west end the section is approximately 2500 m thick and runs from the Jurassic Fernie Group at the base to the Porcupine Hills Formation at the top. In the east the section is about 700 m thick and has the Mannville Group sitting directly on Paleozoic rocks at the base and the Belly River Formation at the top of the section. Only occasional scattered occurrences of the Upper Mannville coal zone occur near the base of this section at depths ranging from 900 to 1300 m. The Upper Mannville coal zone contains three coal seams or less in this area with aggregate thickness of no more than 2.8 m. Higher in the



R'
R''
STRATIGRAPHIC CROSS SECTION 8 (R' --- R'')
JUNE, 1991
TO ACCOMPANY
REGIONAL EVALUATION OF THE COAL BED METHANE POTENTIAL IN THE
PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY
SEA LEVEL DATUM
HORIZONTAL SCALE OF SPACING BETWEEN WELLS
ALBERTA
RESEARCH
COUNCIL
ALBERTA GEOLOGICAL SURVEY
WELL LOG LEGEND
LOCATION OF THE PLAINS STRATIGRAPHIC CROSS SECTIONS
GULF PEIGAN 3-27-6-28W4
PAN AM LOC A-1 PEIGAN 16-12-7-27W4
HB UGAS MCBRIDE LAKE 6-26-7-26W4
ROAN WINCAN LETHBRIDGE 6-7-8-21W4
HUSKY ET AL COALDALE 6-34-7-20W4
MESA COALDALE 10-36-7-19W4
MESA STIRLING 11-22-7-18W4
ZEPHYR NORTHSTAR TABER 10-36-7-17W4
AEG GNOL BRASCAN CHINCO 16-33-7-15W4
MOHAWK ET AL CHIN COULEE 8-33-7-14W4
BLAKE ET AL CHIN COULEE 4-29-7-13W4
SIGNALTA ET AL SMICO 11-35-6-12W4
WAVERLY SMICO 6-9-6-11W4
ROAN FORTY MILE 10-36-6-10W4
CMG ETZIKOM 6-31-6-8W4
SHELL MANYBERRIES 6-23-6-7W4
CMG CS PCGAS CYPRESSH 6-30-6-3W4
ROAN CYPRESS 10-34-7-2W4
PORCUPINE FORMATION
WILLOW CREEK FORMATION
ST. MARY RIVER AND BLOOD RESERVE FORMATIONS
BEARPAW FORMATION
BELLY RIVER FORMATION
PAKOWKI AND MILK RIVER FORMATIONS AND COLORADO GROUP
Base of Fish Scales
MANNVILLE GROUP
FERNIE GROUP
PALEOZOIC
LETHBRIDGE COAL ZONE
McKAY COAL ZONE
MILK RIVER COAL ZONE
TABER COAL ZONE
RAVENSCRAG COAL ZONE
LEA PARK FORMATION AND COLORADO GROUP
ELLIS GROUP


S'
S''
STRATIGRAPHY
PORCUPINE HILLS FORMATION
WILLOW CREEK FORMATION
ST. MARY RIVER AND BLOOD RESERVE FORMATIONS
BEARPAW FORMATION
BELLY RIVER FORMATION
PAKOWKI AND MILK RIVER FORMATIONS AND COLORADO GROUP
Base of Fish Scales
MANNVILLE GROUP
FERNIE GROUP
PALEOZOIC
ESSO SUNDANCE NANTON 6-2-16-29W4
CZAR GEOG CONNEMARA 6-10-16-27W4
ANDERSON ET AL MOSQUITO 7-17-15-26W4
DORCHESTER BONANZA VULCAN 6-2-16-25W4
ANADARKO ET AL VULCAN 14-12-16-24W4
DOME ET AL LONGCO 6-36-16-22W4
ESSO ET AL ARMADA 6-31-16-19W4
PHOENIX ET AL ARMADA 2-24-17-19W4
NCO MRI ET AL KITSIM 15-13-17-17W4
NCO COHO ET AL COUNTESS 11-22-17-16W4
DELCON ET AL BANTRY 15-23-18-14W4
ESSOVEN BANTRY 7-9-18-13W4
INTENSITY ET AL ALDER 16-13UM-18-11W4
WESTCOAST AEC SUFFIELD 6-25-18-9W4
PCP ATLEE 13-20-20-7W4
DOME ATLEE BUFFALO 16-18-21-5W4
PANCANA ATLEE 4-31-21-4W4
LETHBRIDGE COAL ZONE
CARBON-THOMPSON COAL ZONE
McKAY COAL ZONE
DALY COAL ZONE
TABER COAL ZONE
UPPER MANNVILLE COAL ZONE
BELLY RIVER FORMATION
LEA PARK FORMATION AND COLORADO GROUP
MANNVILLE (UPPER)
MANNVILLE (LOWER)
LEA PARK FORMATION AND COLORADO GROUP
MANNVILLE GROUP
WELL LOG LEGEND
AGS ET AL DRILL HOLE 02-12-22-29W4
Drill Hole
Location (DLS)
Gamma Log
Depth (m)
Cumulative coal (m)
Coal Seam
% Vitrinite Reflectance (Random)
LOCATION OF THE PLAINS STRATIGRAPHIC CROSS SECTIONS
SEA LEVEL DATUM
HORIZONTAL SCALE OF SPACING BETWEEN WELLS
Note: The gamma ray and adjacent log represent a single geographic location.
Kilometres
Miles
STRATIGRAPHIC CROSS SECTION 9 (S' --- S'')
JUNE, 1991
TO ACCOMPANY
REGIONAL EVALUATION OF THE COAL BED METHANE POTENTIAL IN THE PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY
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section, at the base of the Belly River Formation a thin McKay coal zone occurs throughout the middle part of this cross-section at depths of 220 to 580 m. It contains one or two seams with an aggregate thickness of no more than 2.7 m. There is no vitrinite reflectance data on the McKay zone in this cross-section. There are three scattered occurrences of the Taber coal zone within the middle part of the Belly River Formation about 100 or 120 m above the McKay. The Taber attains a maximum thickness of 2.6 m within this cross-section. The top of the Belly River Formation on the western side of the cross-section contains widespread but very thin occurrences of the Lethbridge coal zone which, throughout the middle and eastern part of the section, is lost behind surface casing. This zone contains up to three coal seams with a cumulative coal thickness of up to 3.8 m. There is no vitrinite reflectance data for either the Taber or Lethbridge coal zones. The Drumheller coal zone occurs in the four westernmost wells of the cross-section at about 200 m above the Lethbridge coal zone. It ranges in depth from 540 m down to 1160 m. It contains up to about four or five seams and attains a maximum thickness of 8.6 m. There is no vitrinite reflectance data for the Drumheller coal zone in this area. Above the Drumheller occur scattered occurrences of the Daly and the Carbon-Thompson coal zones. They are thin, irregularly distributed and not mapped in this area.

11.1.3 Dogpound to Provost (T’-T”)

Cross-section T’ - T’’ runs from the Dog Pound area, northwest of Calgary, in a east northeasterly direction to near the town of Provost on the Saskatchewan border.

Along the western end near the Foothills, the cross-section shows sediments ranging in age from the Mannville Group at the base at depths of 2700 m to 2900 m, up to the Paskapoo Formation at the top. On the eastern end, near the Saskatchewan border, the section shows only about 800 m of sediment with the Mannville Group at the base and the Belly River Formation at the top. Six different coal zones are shown on this section with the Upper Mannville coal zone near the base having the widest extent and appearing continuously across the width of the section. The Upper Mannvile coal zone ranges in depth from 2800 m at the western end, up to depths of 800 m in the east. It contains up to six coal seams spread over about 60 m of section with cumulative thicknessess up to 8.2 m. The thickest coal accumulations are through the central part of the cross-section. Vitrinite reflectance measurements are about 0.4 near the eastern end of the section, at depths of about 950 m. The values gradually increase below 1200 m to 0.6 and range up to 0.64 at depths of 2100 m. Then, in the most westerly well, values are as high as 0.88 at depths of about 2750 m. There is a very anomalous value of 1.18 in one of the most easterly wells at a depth of about 860 m. This value is questionable for sediments at that depth, but checking failed to reveal any reason for the anomalous value.

At much shallower depths than the Upper Mannville coal zone, through the central part of the cross-section occurs the McKay coal zone near the base of the Belly River Formation. It ranges in depth from approximately 600 m up to about 350 m with one seam occurrence far to the west at 1640 m. Through the central part of the cross-section, the McKay contains two to three coal seams with cumulative thicknessess up to 2.6 m. There are no vitrinite reflectance measurements for the McKay coal zone in this cross-section nor are there for the Taber which occurs about 100 m above the McKay through the same central part of the cross-section. The Taber occurs at depths ranging from 500 m up to about 260 m in this cross-section with a couple of sporadic occurrences at greater depths to the west. The Taber coal zone is only about 20 m thick and contains approximately 1 m of coal. At the top of the Belly River Formation, the Lethbridge coal zone is widespread across the western half of this cross-section. It ranges in depth from 1100 m up to about 200 m where is disappears behind surface casing. The zone is thickest and most continuous at the shallow depth. At the shallower depths, the Lethbridge coal zone contains up

STRATIGRAPHIC CROSS SECTION 10 (T' --- T'')

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to five coal seams, spread out over as much as 100 m of the Belly River Formation. Cumulative thicknesses of coal range up to 5 m. There is no vitrinite reflectance data for the Lethbridge coal zone in this cross-section.

Overlying the Lethbridge with only the very thin extension of the Bearpaw Formation to separate them, lies the Drumheller coal zone at the base of the Horseshoe Canyon Formation. The Drumheller coal zone ranges in depth in this section from 1360 m in the west up to less than 200 m in the centre of the cross-section where it disappears behind surface casing. It is continuous across the western half of the cross-section. The zone ranges in thickness up to 140 m. It contains four to seven coal seams with cumulative coal thicknesses up to 9 m. There is vitrinite reflectance data only in the westernmost well, where the vitrinite ranges from 0.68 at the top of the Drumheller coal zone down to 0.74 at the base at about 1500 m. The central part of the Horseshoe Canyon Formation contains scattered occurrences of the Daly coal zone which was not mapped by this study. A few of the westernmost wells in this cross-section contain occurrences of the Carbon-Thompson coal zone near the top of the Horseshoe Canyon Formation. It ranges in depth from 1060 m up to about 260 m and has a sporadic occurrence. The maximum cumulative coal within the Carbon-Thompson coal zone is 2.2 m and the vitrinite reflectance rank is 0.58 at a depth of 1060 m in the westernmost well.

11.1.4 Ram River to Lloydminster (U'-U")

Cross-section U' - U" runs from the Ram River area in an east-northeast direction to near the town of Lloydminster.

At the western end, the section shows a fairly complete sequence from the Mannville Group at the bottom through the Lea Park Formation and the Colorado Group to the Belly River Formation and Horseshoe Canyon Formations and is capped by the Scollard and Paskapoo Formations at the top. Whereas, at the eastern end, the section is very much condensed to only about 500 m in thickness and contains only the Mannville Group overlaid by the Lea Park and Colorado Groups. In the west, the section shown is about 2800 m thick. This cross-section shows several different coal zones with the lowermost being the Upper Mannville coal zone which appears virtually all of the way across this section with the exclusion of a couple of shallow wells near the eastern end. Towards the western end, the Upper Mannville coal zone lies at depths of about 3200 m, rising gradually as you move towards the east to depths of about 500 m near the eastern end of the section. The coal zone is thickest through the middle part of the section between Red Deer and Edmonton where it contains six to eight coal seams with a cumulative thickness of over 10 m spread over 80 - 100 m of Mannville Formation. In several different wells the Upper Mannville coal zone thins to a single seam of about 1.8 m at the western end of the section and a single seam of less than 1 m at the eastern end. Virtrinite reflectance values are around 0.6 in several wells through the middle of the section and gradually increase to 0.8 towards the western end and then very abruptly to 1.3 in the westernmost well.

Through the central part of the cross-section, near the base of the Belly River Formation, are scattered occurrences of the McKay coal zone, which ranges in depth from 800 m up to about 300 m and is behind surface casing farther to the east. It usually contains two to four coal seams in this cross-section with an aggregate coal thickness of up to 2.8 m. About 100 m above the McKay and even more restricted in occurrence is the Taber coal zone in a few wells in the middle of the section. It ranges in depth from about 500 m up to about 200 m, but has cumulative coal thickness of less than 2 m spread over two to four seams. There are only two widely scattered occurrences of the Lethbridge coal zone near the top of the Belly River Formation on this section. The single seam in each well is a maximum of

STRATIGRAPHIC CROSS SECTION 11 (U' --- U")
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SEA LEVEL DATUM
HORIZONTAL SCALE OF SPACING BETWEEN WELLS
Note: The gamma ray and adjacent log represent a single geographic location.
Kilometres
Miles
WELL LOG LEGEND
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0.6 m thick. There is no vitrinite reflectance data available for any of the coals in the Belly River Formation on this cross-section. About two thirds of the way across the section towards the east, the Belly River becomes too shallow and disappears behind surface casing or is eroded away.

Above the Bearpaw marker, at the base of the Horseshoe Canyon Formation, is the Drumheller coal zone which occurs widely in the west central part of the cross-section at depths ranging from 900 up to 200 m. The zone ranges up to 140 m in thickness and contains up to ten or twelve coal seams with the greatest number of coal seams and up to 13.8 m of cumulative coal occurring in the shallower wells. Downdip to the west, the number of coal seams decreases and the aggregate thickness of coal diminishes until the coal zone disappears. Near the top of the Horseshoe Canyon Formation is the Carbon-Thompson coal zone, which is thin, but fairly widespread along the western end of this cross-section. It contains two or three coal seams with aggregate thickness of up to 2.2 m spread out over about 30 m of Horseshoe Canyon Formation. There is no rank information available for either the Drumheller or the Carbon-Thompson coal zones on this cross-section. The western half of the cross-section contains the Ardley coal zone of the Scollard Formation. It ranges in depth from 1000 m in the west up to about 200 m half way across the cross-section where it disappears behind surface casing. The Ardley contains up to six seams spread over an 80 m interval with cumulative thicknessess up to 8 m. In the westernmost well the vitrinite reflectance rank in the Ardley coal zone is about 0.6. There are no measurements at shallower depths. This is an interesting cross-section as it shows seven of the eight coal zones which are mapped within this project indicating their relative thickness, distribution and postion in the stratigraphic section. It is also interesting that coals at around 900 m depth, whether they are from the Ardley or the Upper Mannville have essentially the same vitrinite reflectance rank.

11.1.5 Coalspur to Winefred Lake (V'-V")

Stratigraphic cross-section 12, V' - V" runs in a southwest, northeasterly direction from near Hinton to north of Cold Lake.

In the west, the section at the base has Mannville Group sediments overlying thin Nikanassin and Fernie going up through the usual Cretaceous sequence to Scollard and Paskapoo Formations at the top over a section of approximately 3000 m. In the east, near the Saskatchewan border, the section is condensed to less than 400 m as McMurray Formation lies directly on the Paleozoic with Grand Rapids and Clearwater above and capped by LaBiche, Pelican and Joli Fou. There is no coal in the easternmost quarter of this cross-section. The oldest and deepest coal zone shown is the Upper Mannville coal zone, which ranges in depths from about 3040 m at the western edge up to about 560 m at its easternmost occurrence. The Upper Mannville coal zone is quite continuous across about two thirds of the cross-section and ranges in thickness up to about 100 m. It contains up to six individual coal seams with cumulative coal thicknesses of as much as 9 m. The greateast cumulative coal thicknessess being towards the western end of the cross-section. Vitrinite reflectance ranks vary from as low as 0.40 at a depth of about 670 m, gradually increasing as the depths increase down to 1.38 at a depth of 3060 m. As in most of the other cross-sections there is a fairly dramatic increase in rank between depths of about 2200 m and 3000 m where the rank increases from 0.75 up to 1.38.

The only Belly River Formation coals showing on this section are scattered occurrences of the McKay coal zone near the centre of the cross-section which contains one or two seams with cumulative thicknesses of less than a metre. The Horseshoe Canyon Formation contains three coal zones in this area. The Drumheller coal zone near the base occurs in several wells in the west central part of the cross-section at depths ranging from 200 m down to 600 m. The Drumheller coal zone contains either


STRATIGRAPHIC CROSS SECTION 12 (V' --- V'')
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SEA LEVEL DATUM
HORIZONTAL SCALE OF SPACING BETWEEN WELLS
Note: The gamma ray and adjacent log represent a single geographic location.
Kilometres
Miles
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one or two coal seams and cumulative coal thicknessess up to 2.2 m. Overlying and farther to the west downdip from the occurrences of the Drumheller are occurrences of the Daly coal zone which was not mapped in this project. It lies in the middle of the Horseshoe Canyon Formation at depths of 720 to 250 m. The Daly coal zone contains up to three or four coal seams with cumulative thicknesses of up to 2.2 m. There is no vitrinite reflectance data available for either the Daly or the Drumheller coal zones on this cross-section. The westernmost third of this cross-section contains thin, but very continuous occurrences of the Carbon-Thompson coal zone, which ranges in depth from 350 m down to 1060 m. It contains up to three or four coal seams and cumulative thicknesses of up to 4.2 m. Near the western edge there is a vitrinite reflectance rank of 0.66 at a depth of about 1000 m within the Carbon-Thompson coal zone. One hundred to three hundred metres above the Carbon-Thompson coal zone and in the same area are widespread occurrences of the Ardley coal zone which occurs at depths of 200 m down to 600 m within this cross-section. The Ardley coal zone ranges up to 200 m in thickness and contains as many as six or seven coal seams with cumulative thicknesses as much as 20.6 m. Rank of the Ardley coal zone is about 0.62 to 0.77 between 5 and 600 m in depth near the western edge of the cross-section.

11.1.6 Grande Cache to Ft. McMurray (W'-W")

Stratigraphic cross-section W' - W" runs from the area of Grande Cache in a northeasterly direction to near the city of Fort McMurray.

In the west, the cross-section is dominated by the Bluesky and Gething Formations at the base with overlying Spirit River Formation and then very thick Smoky Group, Wapiti Group and capped by thinner Scollard Formation and Paskapoo at the top over an interval of approximately 3100 m. In the east, the section is condensed to about 150 m on the cross-section, made up almost entirely of Grand Rapids and Clearwater Formations with a thin McMurray Formation at the base and some LaBiche, Pelican and Joli Fou Formations at the top. The cross-section shows coals only in the western half of the section, since the rare occurrences of coal in the McMurray Formation in the Firebag and McMurray areas do not show up on this cross-section. The oldest and deepest coal zone is the Gething which occurs in the westernmost wells in this cross-section at depths ranging from 1770 m down to 3420 m. The Gething coal zone is very thin in this area with only one or two seams and cumulative thicknessess of up to 1.6 m. Vitrinite reflectance rank is in the range of 0.75 to 0.85 at depths between 2600 and 2900 m in the two wells where such data is available. About 100 m above the Gething, but much wider in extent and thicker, is the Upper Mannville coal zone, which ranges in depth from about 1000 m down to greater than 3000 m over the western half of this cross-section. The Upper Mannville coal zone contains as many as 10 coal seams and cumulative thicknesses of up to 13.8 m. The ranks range from 0.61 at depths of about 1000 m down to 1.32 at 3200 m. This cross-section also contains two thin occurrences of the McKay coal zone at the bottom of the Belly River Formation.

There are a few scattered occurrences of the Drumheller/Red Willow coal zone in the western part of this cross-section at depths between 400 and 1200 m. The occurrences are scattered, the coal zone is less than 100 m thick and the cumulative coal thicknessess range up to 3.4 m. Also in this western part of the cross-section, but at shallower depths, ranging between 400 and 800 m are occurrences of the Cutbank coal zone which contains two to three seams and cumulative thicknesses up to 1.4 m. The youngest and shallowest coal zone present is the Kakwa, which occurs in the three westernmost wells at depths of 400 to 550 m. The Kakwa contains up to six coal seams and cumulative thicknessess of up to 4.6 m. There is no vitrinite reflectance rank information for the Drumheller, Red Willow, Cutbank or Kakwa coal zones in this area. An interesting feature of this cross-section is the very rapid increase in vitrinite reflectance


W'
W''
STRATIGRAPHIC CROSS SECTION 13 (W' --- W'')
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PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY
SEA LEVEL DATUM
HORIZONTAL SCALE OF SPACING BETWEEN WELLS
Note: The gamma ray and adjacent log represent a single geographic location.
Kilometres
Miles
WELL LOG LEGEND
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rank within the Upper Mannville coal zone as it drops from 2760 m down to 3200 m. There is an increase in rank from 0.81, all the way to 1.32 over a distance of only about 37 km.

11.1.7 Narraway to Manning (X'-X")

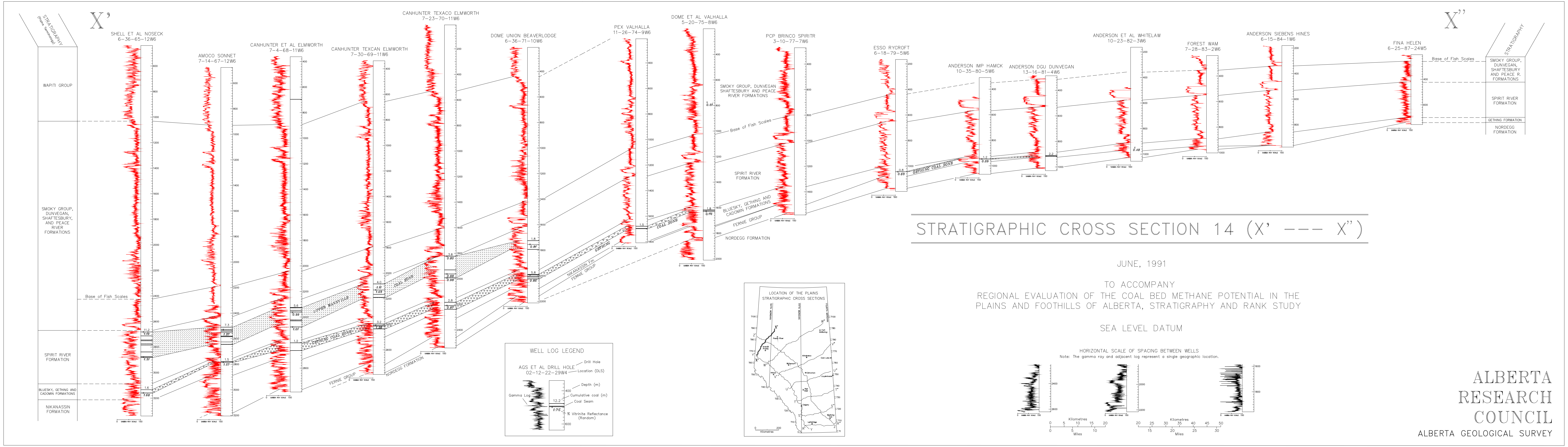
Stratigraphic Cross-Section X' - X" runs in a north easterly direction from Tp 65, R 12, W6 M to Tp 87, R 24, W5M.

The section begins near the disturbed belt and at that southwestern end contains sediments from the Nikanassin Formation at the base through to the Wapiti Group at the top with a thickness of approximately 2600 m. At the northeastern end the section is only approximately 600 m thick and has Gething Formation at the bottom through to Smoky Group at the top. The Gething coal zone is the deepest coal zone present. It can be traced about two thirds of the way across the section. The coal zone is relatively compact and consists of two to five coal seams over a 20-60 m interval. Cumulative coal ranges up to 5.8 m. The vitrinite reflectance rank in the Gething coal zone ranges from 0.48 towards the northeastern end of the section, gradually, but very regularly increasing down to 1.68 at the deepest occurrence in the well closest to the foothills. In the southwestern part of the section, about 200 m above the Gething coal zone lies the Upper Mannville Coal Zone within the Spirit River Formation. This coal zone is much thicker than the Gething, ranging up to about 200 m. The zone contains 3 to 8 seams and cumulative coal ranges up to 11.2 m with the thickest and greatest number of seams occurring downdip to the southwest. The top of this zone runs from about 2700 m depth up to about 1720 m. Vitrinite reflectance rank within this zone ranges from 0.81 at 1760 m at the shallowest occurrences to 1.31 at 2880 m near the disturbed belt. Within that deep occurrence the zone is about 200 m thick and the rank decreases to 1.19 at the top of the zone. An interesting feature on this cross-section is the change in vitrinite reflectance rank between T69 and 70, R 11 W6 where the vitrinite reflectance rank changes from 0.87 to 1.28 over a very short distance. This may reflect depression of the true reflectance values for these coals. Please see section on vitrinite reflectance.

12 North-South Cross-Sections

12.1 Alberta Syncline (Y-Y')

Cross-section Y - Y' runs from south to north along the depth of the Alberta syncline from Tp 5 R 25 W4M, northerly along the 5th meridian to about the area of Calgary and then angles to the northwest along the edge of the deformed belt and through the Deep Basin to near the Alberta/B.C. border in the area of Tp 65 R 12 W6M. For ease of handling, the cross-section is split into two halves, called 15A and 15B, which join between Tp 42 R 15 W5M and Tp 44 R 11 W5M. This cross-section runs through the deepest part of the Foreland Basin and shows the various plains coal zones at their deepest depths. Because of the length of this section there are several nomenclature changes in the stratigraphy along the length of the section. In the south, the zone of interest has the Mannville Group at the base with occasional thin slivers of the Kootenay Group showing below that. Overlying the Mannville are thick Lea Park and Milk River Formations and Colorado Group with Belly River Formation above that and marine Bearpaw Formation and St. Mary River at the top. As the cross-section jogs out from the mountain front beneath the Porcupine Hills we get a section of Willow Creek Formation and Porcupine Hills Formation lying at the top of the section. The Kootenay Group occurs only in a few wells at the base of the section near the south end and does not contain coal. To the north, the St. Mary River Formation becomes the Horseshoe Canyon Formation and the Willow Creek Formation is roughly equivalent to the Scollard. This stratigraphy of Mannville Group at the base with thick Lea Park


STRATIGRAPHIC CROSS SECTION 14 (X' --- X")
JUNE, 1991
TO ACCOMPANY
REGIONAL EVALUATION OF THE COAL BED METHANE POTENTIAL IN THE PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY
SEA LEVEL DATUM
HORIZONTAL SCALE OF SPACING BETWEEN WELLS
Note: The gamma ray and adjacent log represent a single geographic location.
Kilometres
Miles
ALBERTA RESEARCH COUNCIL
ALBERTA GEOLOGICAL SURVEY
X'
X"
STRATIGRAPHY
WAPITI GROUP
SMOKY GROUP, DUNVEGAN, SHAFTESBURY, AND PEACE RIVER FORMATIONS
SPIRIT RIVER FORMATION
BLUESKY, GETHING AND CADOMIN FORMATIONS
NIKANASSIN FORMATION
SHELL ET AL NOSECK 6-36-65-12W6
AMOCO SONNET 7-14-67-12W6
CANHUNTER ET AL ELMWORTH 7-4-68-11W6
CANHUNTER TEXCAN ELMWORTH 7-30-69-11W6
CANHUNTER TEXACO ELMWORTH 7-23-70-11W6
DOME UNION BEAVERLODGE 6-36-71-10W6
PEX VALHALLA 11-26-74-9W6
DOME ET AL VALHALLA 5-20-75-8W6
PCP BRINCO SPIRITR 3-10-77-7W6
ESSO RYCROFT 6-18-79-5W6
ANDERSON IMP HAMCK 10-35-80-5W6
ANDERSON DGU DUNVEGAN 13-16-81-4W6
ANDERSON ET AL WHITELAW 10-23-82-3W6
FOREST WAM 7-28-83-2W6
ANDERSON SIEBENS HINES 6-15-84-1W6
FINA HELEN 6-25-87-24W5
Base of Fish Scales
UPPER MANNVILLE
GETHING COAL ZONE
FERNIE GROUP
NORDEGG FORMATION
NIKANASSIN Fm.
SMOKY GROUP, DUNVEGAN, SHAFTESBURY AND PEACE RIVER FORMATIONS
SPIRIT RIVER FORMATION
BLUESKY, GETHING AND CADOMIN FORMATIONS
SMOKY GROUP, DUNVEGAN, SHAFTESBURY AND PEACE R. FORMATIONS
GETHING FORMATION
NORDEGG FORMATION
WELL LOG LEGEND
AGS ET AL DRILL HOLE 02-12-22-29W4
Drill Hole
Location (DLS)
Depth (m)
Cumulative coal (m)
Coal Seam
% Vitrinite Reflectance (Random)
Gamma Log
LOCATION OF THE PLAINS STRATIGRAPHIC CROSS SECTIONS
Kilometres
GAMMA RAY SCALE

STRATIGRAPHIC CROSS SECTION 15A (Y --- Y')

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STRATIGRAPHIC CROSS SECTION 15B (Y --- Y')

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Formation in Colorado Group above, overlain by Belly River Formation and Horseshoe Canyon Formation, Scollard Formation and capped by Paskapoo at the top continues far to the north until the lower part of the Mannville Group becomes the Bluesky/Gething and Cadomin Formations and the Upper Mannville becomes the Spirit River Formation. At this northern end of the cross-section the thick interval which farther south had been called Lea Park and Colorado is called Smoky Group, Dunvegan, Jasper and Peace River Formations and overlain by the Wapiti Group which is equivalent to the Belly River and part of the Horseshoe Canyon Formations.

The oldest coal-bearing strata on this cross-section is the Gething Formation near the northern end of the cross-section since the thin sliver of Kootenay far to the south did not contain coal within the cross-section. On this cross-section the Gething coal zone occurs at depths of 3000 m to 3720 m. This zone ranges up to 60 m in thickness and contains as much as 2.2 m of cumulative coal spread across one to three coal seams. Rank of the Gething coal zone ranges between 1.17 and 1.68. The most widespread coal zone shown on this cross-section is the Upper Mannville coal zone which occurs continuously across the northern two thirds of the cross-section, all the way from Tp 17 R 4 W5M to the north end of the cross-section in Tp 65 R 12 W6M. The Upper Mannville coal zone ranges in depth from 2180 m at its most southernly occurrence down to 3400 m depth near the north end of the cross-section. The zone contains up to eight coal seams with cumulative thicknessess of coal as much as 11.2 m. With the greatest thicknesses also occurring at the greatest depths near the north end of the section. Rank of the coals along the Upper Mannville coal zone ranges from 0.61 at 2180 m in the most southerly occurrence seam up to a maximum of 1.44 in the north end of the cross-section. The rank generally varies in accordance with the depth of the coal. The rank of the Gething coals varies from 1.17 at 3040 m to 1.68 at 3160 m depth. The cross-section is far enough to the west that it lies outside the main areas of development of coals within the Belly River Formation and contains only sporadic, scattered occurrences of the McKay and Lethbridge coal zones at the base and top of the Belly River Formation respectively. Throughout the southern half of the cross-section, the McKay coal zone attains thicknessess of only 0.8 m within this cross-section while the Lethbridge coal zone has some thicker occurrences and has as much as 2 m of coal. Rank of the Lethbridge coal zone ranges between 0.71 and 0.79 along this cross-section at depths varying from 1230 m down to 2300 m.

The Drumheller coal zone overlies the Lethbridge coal zone with the Bearpaw Formation in between. The Drumheller coal zone lies at the base of the Horseshoe Canyon or St. Mary River Formations. It is much more widespead in the south half of the cross-section and has been correlated as equivalent to the Red Willow coal zone near the north end of the cross-section. The Drumheller ranges in depth from 630 m to 1920 m and attains zone thickness of up to 170 m. There are as many as eleven coal seams within that interval, with cumulative thicknessess of as much as 9.4 m. Farther to the north the Red Willow coal zone attains thicknessess of much as 340 m, but contains only a maximum of 4.4 m of coal within that interval. The Red Willow has very sporadic coal seam occurrences and the zone varies dramatically in thickness, whereas the Drumheller to the south is much more predictable and regular. Rank within the Drumheller coal zone varies from 0.59 at a depth of 1200 m to 0.80 at 1500 m, while rank within the Red Willow coal zone is unknown within this cross-section. Within the middle of the Horseshore Canyon Formation there are sporadic occurrences of the Daly coal zone which was not mapped within this study, coal thicknessess of up to 1.0 m are attained. Widely spread near the top of the Horseshoe Canyon Formation through the central part of this cross-section are the thin, but relatively continuous Carbon-Thompson coal zones which have been correlated far to the north and considered equivalent to the Cutbank coal zone near the north end of the cross-section. Along the line of this section the Carbon-Thompson varies in depth from as little as 400 m to as much as 1120 m. It rarely attains thicknessess of more than 60 m and has cumulative coal of up to a maximum of 4.6 m. The equivalent Cutbank coal zone to the north can be as much as 160 m in thickness, but contains only up to 3.2 m of coal. The Cutbank lies at depths of 600 - 900 m within this cross-section. The rank of the Cutbank is 0.62 at a depth of 850 m, while farther to the south the Carbon-Thompson has a rank of 0.58 at 1050 m depth.

Through the central to northern parts of this cross-section are widespread and relatively continuous occurrences of the Ardley coal zone which far to the north is correlated to the Kakwa coal zone. The Ardley Kakwa coal zone ranges in depth from 320 m to 780 m. The zone ranges in thickness up to 170 m and contains as many as eight seams with cumulative coal thicknessess up over 17 m. Very little rank information is available, but runs at about 0.63 or 0.64 at depths of 500 - 600 m. It is interesting on this section that Upper Mannville coals at depth of almost 2200 m have a very similar rank to Ardley coals at a depth of 500 or 600 m. This may be an example of suppression of the vitrinite reflectance which is discussed in the Appendix.

12.2 Cypress Hills to Peace River (Z-Z')

Cross-section 16, Z - Z', runs from the area of the Cypress Hills, Tp 7 R 2 W4M in a northerly and then northwesterly direction to near the Alberta/B.C. border in the Boundary Lake area, Tp 83 R 12 W6M.

For ease of handling this cross-section has been split into two halves, section 16A is the southernly section and 16B is the north half. This cross-section runs much farther out on the plains than cross-section 15 and therefore the stratigraphic section is much thinner. At the south end of the section the stratigraphic succession of interest has thin Mannville Group at the base overlain by thick Lea Park Formation and Colorado Group. That is most of the sequence for most of the cross-section. In places there is some overlying Belly River Formation and in places like the Cypress Hills at the end of the section that is overlain by Bearpaw Formation and several thinner units at the crest of the Cypress Hills. The Mannville Group thickens gradually northward until at the north of the section, about half of the stratigraphic succession shown is equivalent to the lower and Upper Mannville, although by that time they are called Gething and Spirit River Formations. The thick Lea Park Formation and Colorado Group form the middle of the cross-section throughout its length, but by the north end have become the Smoky Group, Dunvegan, Jasper and Peace River Formations. The presence or absence of overlying Belly River and Horseshoe Canyon sediments is largely dependent upon the location of the cross-section as it wanders back and forth near the erosional edges of these formations. The stratigraphically oldest coals on this cross-section are a few occurrences of the Gething coal zone near the north end of the cross-section. On this section the Gething coal zone ranges in depth from about 980 m down to 1180 m. It contains only one to three coal seams with maximum cumulative coal thicknesses up to 2.8 m. The rank of the Gething coals range from 0.50 to 0.80. Widespread through the middle part of the cross-section are Upper Mannville zone coals which extend for about half the length of the cross-section. They range in depth on this cross-section from about 900 m to about 1500 m. The cross-section shows up to nine coal seams within the Upper Mannville coal zone and cumulative thicknessess of as much as 11.6 m over a 60 - 80 m thick zone. Rank varies from 0.51 at a 1000 m depth to 0.65 at 1300 m depth.

Within the Belly River Formation, both the McKay coal zone at the base and the Taber coal zone in the middle of the formation have very sporadic occurrence on this cross-section due to the skirting of the cross-section around the edge of the main depositional area for those two coal zones. Where they do occur is primarily in the southern half of the cross-section with the McKay occurring anywhere between 200 and 700 m depth and the Taber occurring from 150 m down to over 500 m depth. Neither zone is more than 30 – 40 m thick, with the McKay containing up to three coal seams and cumulative thickness of as much as 5 m of coal, while the Taber contains one to three seams with cumulative thicknesses of


Z
Z'
STRATIGRAPHIC CROSS SECTION 16A (Z ---- Z')
JUNE, 1991
TO ACCOMPANY
REGIONAL EVALUATION OF THE COAL BED METHANE POTENTIAL IN THE
PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY
SEA LEVEL DATUM
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STRATIGRAPHIC CROSS SECTION 16B (Z ---- Z')
JUNE, 1991
TO ACCOMPANY
REGIONAL EVALUATION OF THE COAL BED METHANE POTENTIAL IN THE
PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY
SEA LEVEL DATUM
ALBERTA
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COUNCIL
ALBERTA GEOLOGICAL SURVEY

up to 2.7 m of coal. There is no rank information on either of these coal zones within this cross-section. The Lethbridge coal zone at the top of the Belly River Formation is quite continuous and widespread where it occurs near the south end of this cross-section. The zone ranges up to 60 m in thickness and contains as many as three or four coal seams, with cumulative coal up to 5.8 m. Again, there is no vitrinite reflectance data for this coal zone.

Overlying the Lethbridge coal zone, through the south-central part of the cross-section is the Drumheller coal zone which is quite continuous and widespread where it has not been removed by erosion. It occurs at the top of the wells in this cross-section, usually between depths of 200 and 300 m. Often seen on the Drumheller wells is at least part of the coal behind surface casing. The Drumheller coal zone contains up to ten coal seams with cumulative thicknesses of as much as 13.8 m. There is no vitrinite reflectance data available for the Drumheller wells on this cross-section.

There is a single occurrence of the Ravenscrag coal zone at the top of the southernmost well in the cross-section. This zone is very limited in occurrence and was not mapped during this study.

13 Foothills Cross-Sections

13.1 Stratigraphic Cross-Section 1 (R-R') Pincher Creek

The major coal bearing units present in the Pincher Creek area are the St. Mary River and Belly River formations, and the Kootenay Group.

13.1.1 St. Mary River Formation

Coals of the St. Mary River formation are found only in the easternmost portion of the disturbed belt, in the east dipping strata of the Triangle zone. No coals have been mapped at the surface in the immediate vicinity of the section line. However, in the plains tie-in well on the stratigraphic section R-R', 7.4 metres of St. Mary River coals have been identified. The nearest outcrop of St. Mary River coals in the southern foothills, which was sampled for vitrinite reflectance, is in Tp 4 R 27 W4M (near Hill Spring), approximately 34 km from the cross-section line.

13.1.2 Belly River Formation

Only Lethbridge equivalent coals have been identified within the Belly River Formation in the Pincher Creek area. These coals are again restricted to the east dipping strata of the triangle zone in the disturbed belt. No outcrop samples have been sampled in the immediate area, but some subsurface coals have been identified in the plains tie in well. These coals were mined in the Triangle Zone near Lundbreck and below the Lewis Trust near Sentinel. Their vitrinite reflectance forms part of our database.

13.1.3 Kootenay Group

The major coal bearing unit of the Kootenay group is the Mist Mountain Formation. Minor coals are present in the Elk Formation but are considered insignificant. Mist Mountain coals have been identified in most of the drill holes in the area as can be seen on the stratigraphic cross-section R-R'. Coal zone and seam thicknesses vary throughout the area but some general trends can be seen. Coal zone thicknesses as well as cumulative coal thicknesses decrease eastwards towards the erosional subcrop edge of the Kootenay Group. In general, the Kootenay coals are seen to directly underlie the Cadomin

STRATIGRAPHIC CROSS SECTION 1 (R --- R')

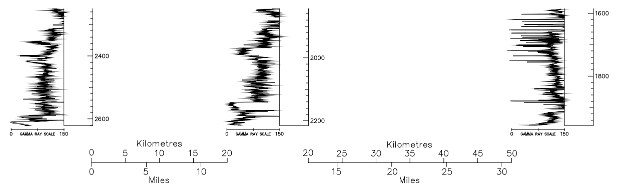
TO ACCOMPANY
REGIONAL EVALUATION OF THE COAL BED METHANE POTENTIAL IN THE PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY

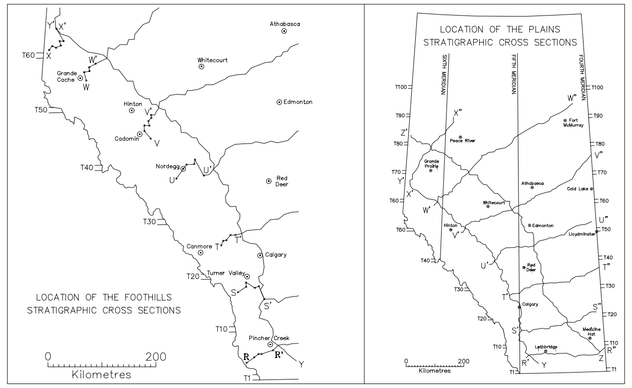
JUNE, 1991

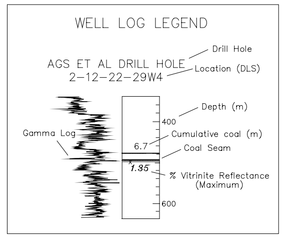
SEA LEVEL DATUM

HORIZONTAL SCALE OF SPACING BETWEEN WELLS

Note: The gamma ray and adjacent log represent a single geographic location.







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conglomerate or its equivalent. A maximum cumulative thickness of 12.9 metres of Mist Mountain coal has been identified in the area from wells. Some fault repeats in certain wells did not show any coal. Outcrops of the Kootenay Group were sampled for vitrinite reflectance near the old mines of Beaver Mines and along the Mill Creek.

13.1.4 Structural Cross-Section 1 (FR-FR') Pincher Creek Area

The structural interpretation for the Pincher Creek area is modified from an unpublished cross-section by P. Fermor (pers. comm., 1991). Modifications to the cross-section are largely due to recent drilling in the area, in particular Shell Waterton 2-16-5-2W5M and Shell Waterton 11-4-6-1W5M. The former of the wells causes a major elevation shift upwards in the culmination of the Waterton duplex structure (approximately 600m uplift). The latter introduces another Paleozoic thrust sheet into the lower part of the section. Each change causes uplift of the Kootenay coal zone in the area by a corresponding amount. Balancing problems were encountered subsequent to these two changes particularly with the addition of the thrust sheet in Shell Waterton 11-4. Fermor accounted for much of his thrust displacement by inclusion of major detachments in the Blairmore and Fernie Groups. Introduction of this new thrust sheet means that much of the displacement must actually cut farther up section. This lead to some balancing problems, which were not totally resolved.

Recent work by Hiebert and Spratt (1990) was also used to modify the interpretation, but only in the triangle zone part of the section. Modifications to the triangle zone were minor and did not greatly affect the positioning of the coal zones within the section. Mapping by Hage (1940) was used to locate the coal zones more accurately.

13.2 Stratigraphic Cross-Section 2 (S-S') Highwood River

The major coal-bearing units are the St. Mary River and Belly River formations and the Kootenay Group.

13.2.1 St. Mary River Formation

The St. Mary River coal zone can be mapped into the Triangle Zone from the plains. It has a cumulative thickness of 13.1 m in well 11-32-18-1W5M. Some St. Mary River coals are exposed underneath the Longview bridge. Some of the coals in Kananaskis Country sampled as Belly River coals may be St. Mary River coals. In the foothills the Bearpaw Formation can generally not be mapped and the whole Belly River to St. Mary River interval is mapped as Brazeau Formation. No significant coals were seen in the Brazeau interval west of the Triangle Zone.

13.2.2 Belly River Formation

Some Lethbridge equivalent coals are present, but they do not show any significant thicknesses (only up to 1.5 m).

13.2.3 Kootenay Group

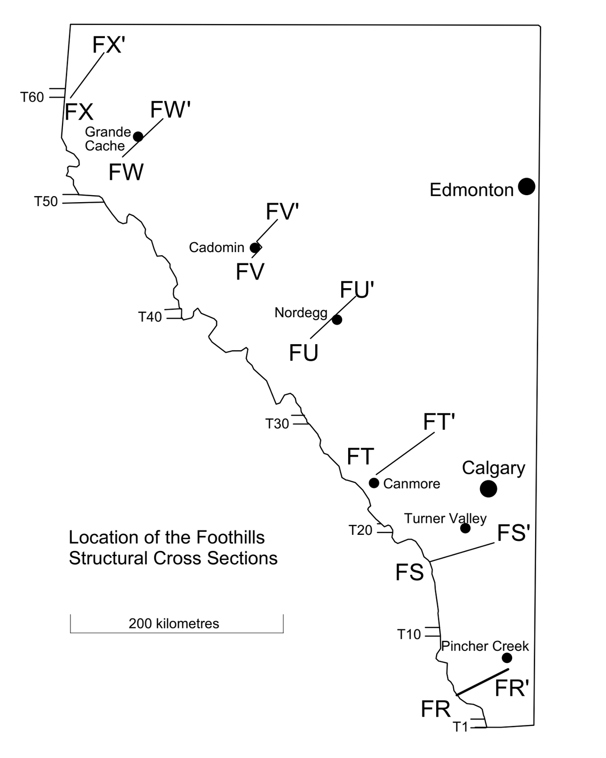
The Kootenay Group thickens westwards from the erosional edge. The most significant thicknesses are west of the drilling control in the Highwood Ford coal field and further west. Maximum cumulative thickness of the wells is 6 m.

- Coal Zones
- KTsw St. Mary and Willow Creek Formations
- KBP Bearpaw Formation
- KBR Belly River Formation
- KBCW Blackstone, Cardium and Wapiabi Formations
- Bl Top of Blairmore Formation
- KBL Blairmore Formation
- Kt Top of Kootenay Group
- JKFK Fernie and Kootenay Groups
- Pal Paleozoics
- PC Pre Cambrian
- 1.09 Percent vitrinite reflectance (maximum)
- Thrust fault with sense of displacement

Geology modified from Fermor (unpublished)
Hiebert & Spratt (1990) and Hage (1940)

To Accompany:
Regional Evaluation of the
Coal Bed Methane Potential in the
Plains and Foothills of Alberta,
Stratigraphy and Rank Study

Structural Cross Section 1: Pincher Creek Area



Location of the Foothills Structural Cross Sections

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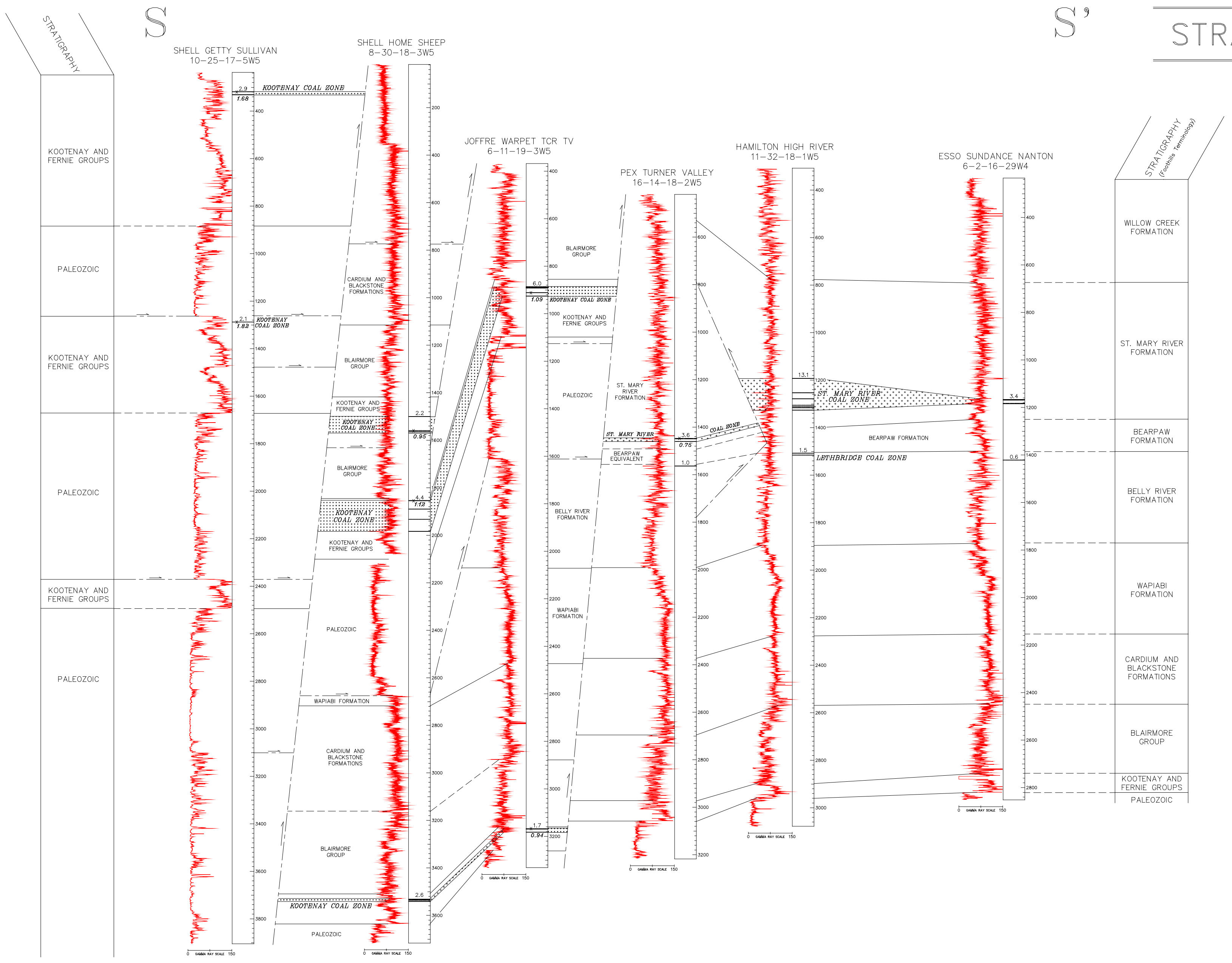


STRATIGRAPHIC CROSS SECTION 2 (S --- S')

TO ACCOMPANY

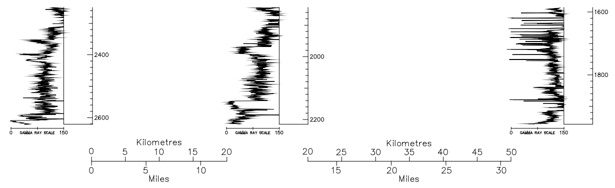
REGIONAL EVALUATION OF THE COAL BED METHANE POTENTIAL IN THE PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY

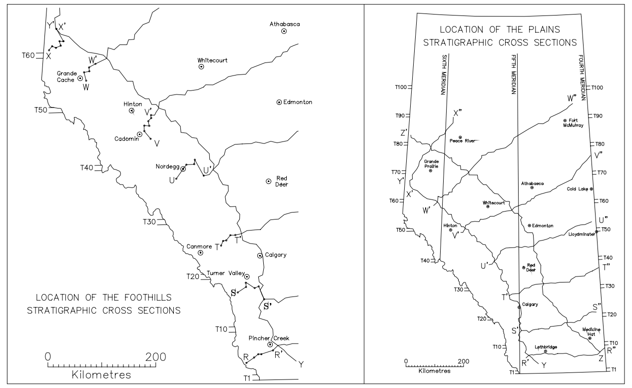
JUNE, 1991

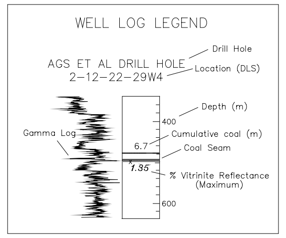
SEA LEVEL DATUM

HORIZONTAL SCALE OF SPACING BETWEEN WELLS

Note: The gamma ray and adjacent log represent a single geographic location.







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13.2.4 Structural Section 2 (FS-FS') Highwood River

Cross-section FS-FS' shows the structural interpretation of the Highwood River area. The interpretation is based on the cross-section, published in a guidebook by Gordy, Frey and Ollerenshaw (1975), which was previously published by Bally, Gordy and Stewart (1966). Information from recent drilling form the basis for some modifications. Well 10-25-17-5W5M was drilled on the Sullivan Anticline, which is an anticlinal stack of duplexes. This well clearly defines the stacked duplexes. Further east, a well in 6-24-18-3W5M brings Paleozoics closer to the surface than previously thought (in the so-called Highwood Structure). In addition, minor changes had to be made to the Turner Valley Anticline to take new information into consideration.

The largest changes were necessary in the area between the Sullivan Creek anticline and Atkinson Thrust. On the original section too much room exists between Cardium and Paleozoic. To solve this problem, some of the faults are suggested to cut up-section more quickly. This solution enabled us to draw in several imbricates of the Kootenay Coal zone. The west side of the cross-section from the Highwood Ford Coal field to the Alberta-B.C. border is based on mapping by Allan and Carr (1947).

13.3 Stratigraphic Section 3 (T-T') Canmore

The major coal zones are in the Brazeau Formation and Kootenay Group. Minor coal is present in the Blairmore Group.

13.3.1 Brazeau Formation

The Upper Brazeau Coal zone may be equivalent to the Carbon/Thompson Coal zone. Coal lower down in the succession may be equivalent to the Lethbridge Coal zone. However, accurate correlations are difficult because the Bearpaw Formation can not be mapped.

13.3.2 Blairmore Group

Minor coal was found in some wells in this succession. Major coal develops in this interval 50 km further north, where this interval is known as the Luscar Group.

13.3.3 Kootenay Group

The Kootenay Coal zone can be mapped in all wells west of the erosional edge. The coal tends to be relatively thin (maximum cumulative thickness 4.2 m), sheared, and often caved.

13.3.4 Structural Cross-Section 3 (FT-FT') Canmore Area

The structural interpretation is based on Price and Fermor (1985), who used only pre-1975 drilling. Post 1975 drilling indicates that some changes have to be made to this interpretation, especially between the Burnt Timber and McConnell thrusts. The well in 2-18-27-7W5M indicates that the Kootenay Coal zone underneath the Burnt Timber Trust does not extend all the way to underneath the McConnell Trust as previously thought. This also indicates that the Burnt Timber Trust does not bring up any Paleozoics and that this thrust is rooted in the Fernie Group. The thrust bringing up the Paleozoics (and Kootenay) in this area is mapped as the West Keystone Thrust and its splays. Further south these thrusts bring Paleozoics to the surface in the Moose Mountain Dome.

SW
NE
metres
Lewis Thrust
Coleman Thrust
Highwood Ford Coal Field
McConnell Thrust
Sullivan Creek Anticline
Dyson Mt. Thrust
Barwell Mt. Thrust
Atkinson Creek Thrust
Longview Thrust
Turner Valley Anticline
Kootenay Coal Zone
St Mary River Coals
Lethbridge Coals
FS
FS'
UTM start coordinates
650000m E
5584050m N
Kilometres
UTM end coordinates
712121m E
5609149m N
Coal Zones
TKPP Porcupine Hills, Willow Creek Formations
KBBR Belly River, Bearpaw and St. Mary River Formations
KBZ Brazeau Formation
KW Wapiabi Formation
Cr Top of Cardium Formation
KBC Blackstone and Cardium Formations
Bl Top of Blairmore Group
KBL Blairmore Group
Kt Top of Kootenay Formation
JKKF Kootenay and Fernie Groups
JF Fernie Group
Tr Triassic
Rd Top of Rundle Group
Pal Paleozoics
Percent vitrinite reflectance (maximum)
Thrust fault with sense of displacement
Geology modified from Gordy, Frey and Ollerenshaw (1975) and Douglas (1958)
To Accompany:
Regional Evaluation of the Coal Bed Methane Potential in the Plains and Foothills of Alberta, Stratigraphy and Rank Study
Structural Cross Section 2:
Highwood River Area
Edmonton
Calgary
Location of the Foothills Structural Cross Sections
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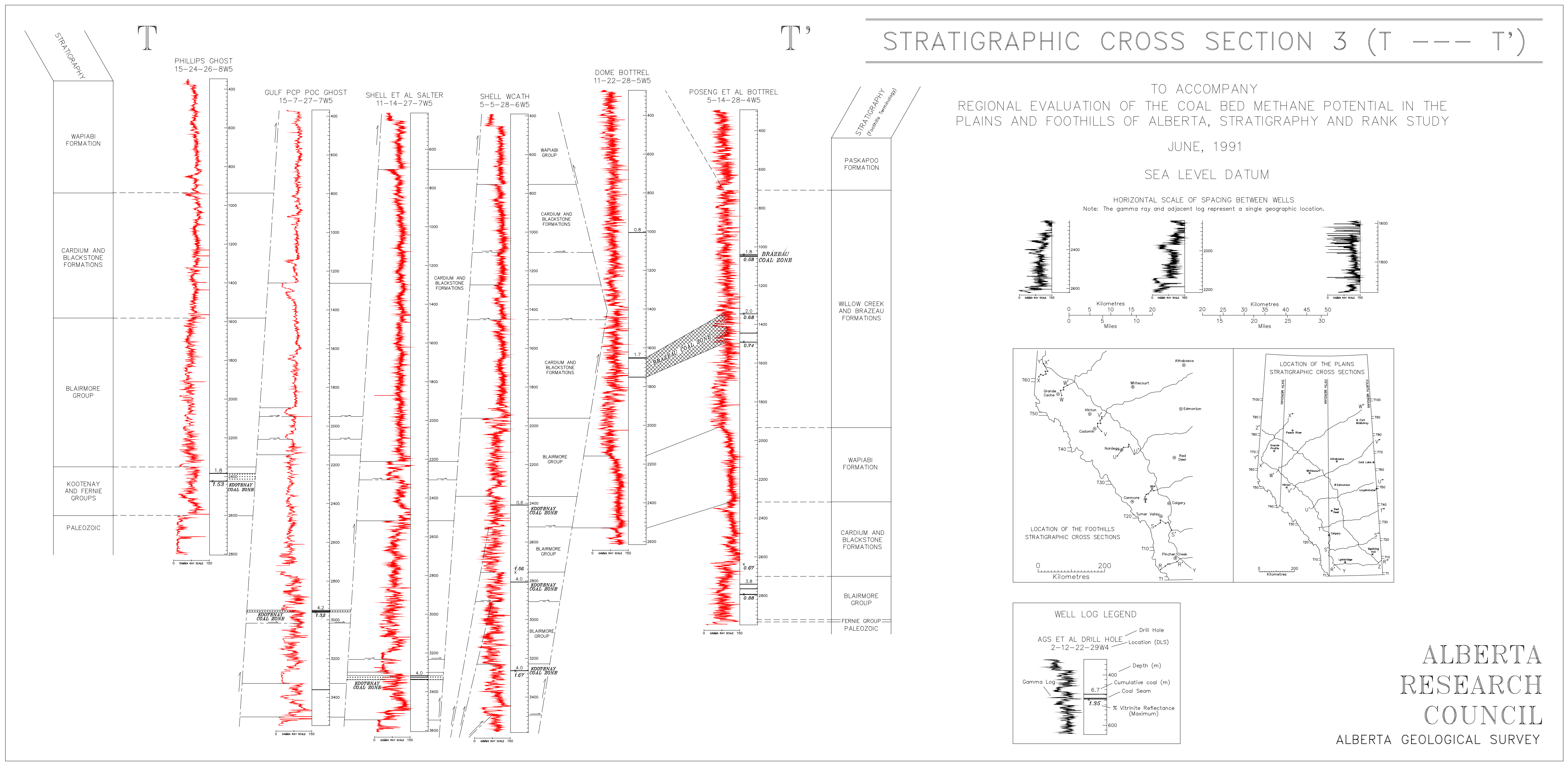

STRATIGRAPHIC CROSS SECTION 3 (T --- T')
TO ACCOMPANY
REGIONAL EVALUATION OF THE COAL BED METHANE POTENTIAL IN THE PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY
JUNE, 1991
SEA LEVEL DATUM
HORIZONTAL SCALE OF SPACING BETWEEN WELLS
Note: The gamma ray and adjacent log represent a single geographic location.
Kilometres
Miles
T
T'
STRATIGRAPHY
WAPIABI FORMATION
CARDIUM AND BLACKSTONE FORMATIONS
BLAIRMORE GROUP
KOOTENAY AND FERNIE GROUPS
PALEOZOIC
PHILLIPS GHOST 15-24-26-8W5
GULF PCP POC GHOST 15-7-27-7W5
SHELL ET AL SALTER 11-14-27-7W5
SHELL WCATH 5-5-28-6W5
DOME BOTTREL 11-22-28-5W5
POSENG ET AL BOTTREL 5-14-28-4W5
KOOTENAY COAL ZONE
BRAZEAU COAL ZONE
PASKAPOO FORMATION
WILLOW CREEK AND BRAZEAU FORMATIONS
FERNIE GROUP
LOCATION OF THE FOOTHILLS STRATIGRAPHIC CROSS SECTIONS
LOCATION OF THE PLAINS STRATIGRAPHIC CROSS SECTIONS
Edmonton
Calgary
WELL LOG LEGEND
AGS ET AL DRILL HOLE 2-12-22-29W4
Drill Hole
Location (DLS)
Depth (m)
Cumulative coal (m)
Coal Seam
% Vitrinite Reflectance (Maximum)
Gamma Log
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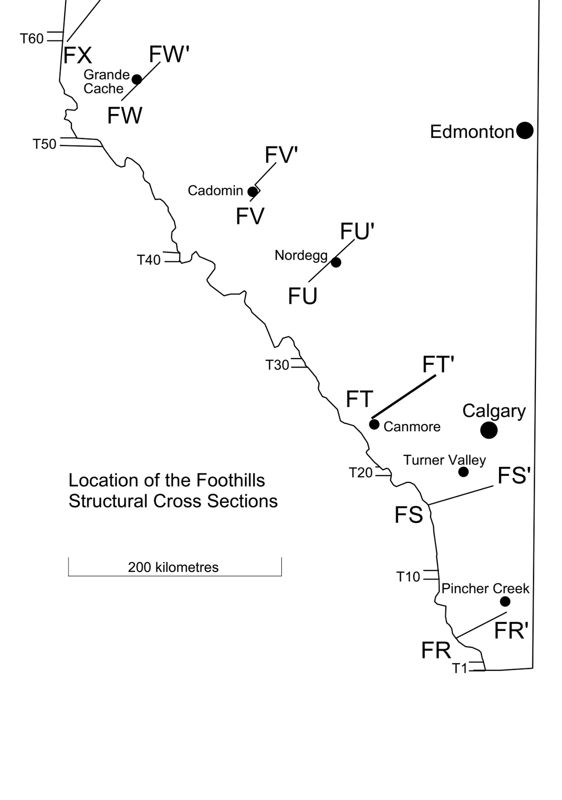
■	Coal Zones
T_P	Paskapoo Formation
K_{BZ}	Brazeau Formation
K_W	Wapiabi Formation
K_{BC}	Blackstone, Cardium Formations
K_{BI}	Blairmore Group
JK_{KF}	Kootenay group and Fernie Group
JK_F	Fernie Formation
K_t	Top of Kootenay Group
JK_K	Kootenay group
Mt	Top of Mount Head Formation
Pal	Paleozoics
● 0.71	Percent vitrinite reflectance (maximum)
	Thrust fault with sense of displacement

Geology modified from Price and Fermor (1985)

To Accompany:
Regional Evaluation of the
Coal Bed Methane Potential in the
Plains and Foothills of Alberta,
Stratigraphy and Rank Study

Structural Cross Section 3: Canmore Area



Location of the Foothills Structural Cross Sections

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A well in 16-30-28-5W5M eliminates the need for a splay of the Brazeau Thrust and simplifies the Triangle Zone in this area. The upper and lower detachments of the Triangle zone come together in the interval that is equivalent to the Bearpaw shales in the Brazeau Formation.

13.4 Stratigraphic Cross-Section 4 (U-U') Nordegg Area

The major coal bearing units are the Coalspur, Brazeau, and Gates formations.

13.4.1 Coalspur Formation

The Coalspur Coal zone was encountered in several wells with a maximum cumulative thickness of 7.8 m. It crops out along the North Saskatchewan River, where it used to be mined near Saunders. However, no vitrinite reflectance measurements from this site are in our database.

13.4.2 Brazeau Formation

Some coal is present in the upper part of the Brazeau Formation. However, the coal seems to be discontinuous and the coal zone is not well developed. The coal zone might outcrop along the North Saskatchewan River (Erdman, 1946).

13.4.3 Gates Formation

The Gates Formation of the Luscar Group (equivalent to the Upper Manville) is the main coal-bearing unit of the Nordegg area. It used to be mined in this area and the old mine workings are one of the main tourist attractions for this area at the present time. It can be easily recognized in all wells, having a maximum cumulative thickness of 11.1 m.

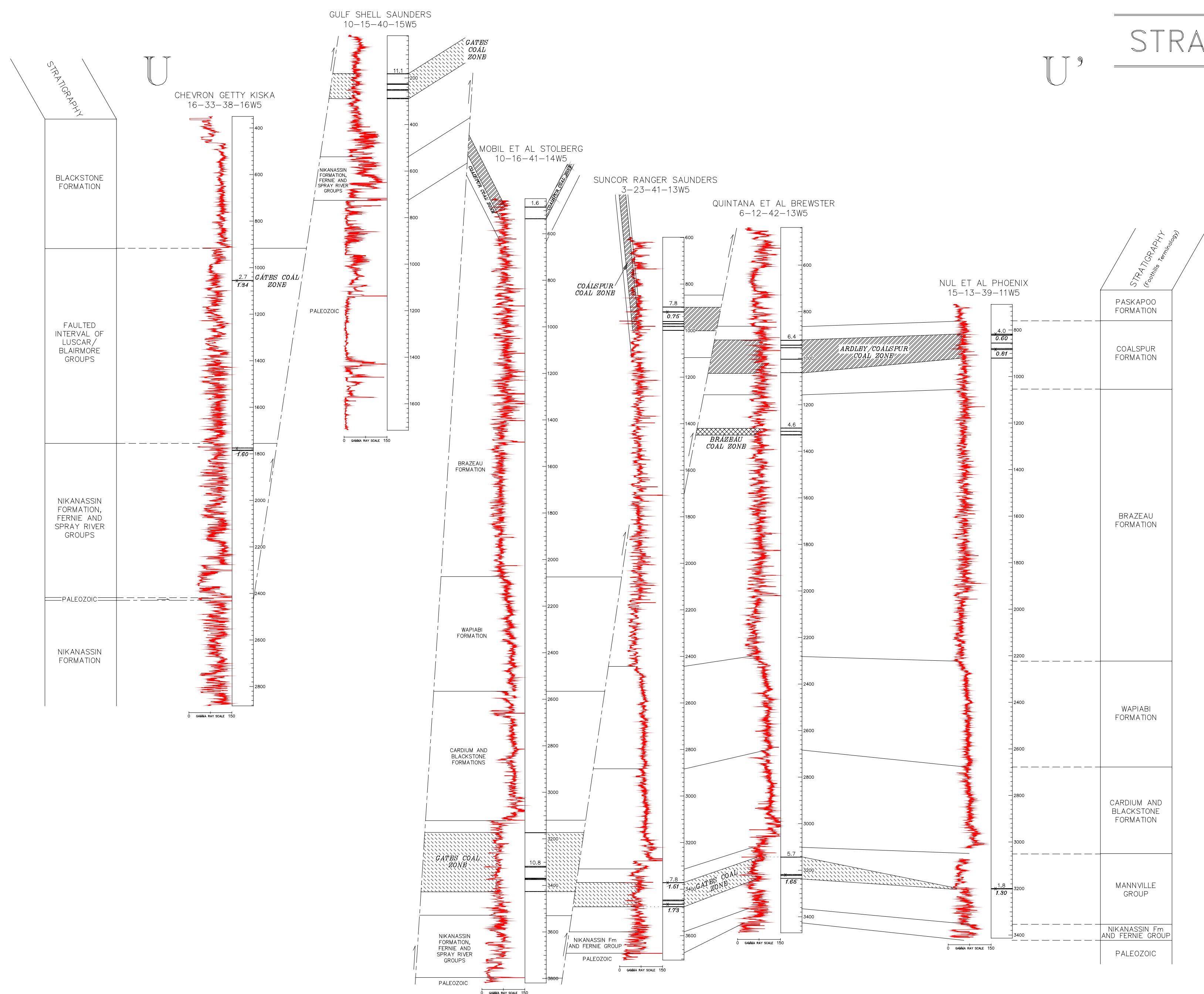
13.4.4 Structural Cross-Section 4 (FU-FU') Nordegg Area

The structure between the Bighorn Thrust and the Stolberg Gas field on the Ancona Anticline can be tied in closely with the seismic line through the Nordegg townsite, published by Perkins et al. (1984). The main structure is the Brazeau Thrust and its splay, the Brazeau Range Thrust. This structure is clearly outlined by by wells 10-15-40-15W5M and 15-36-40-15W5M.

Repeats of the Cardium Formation and faulting in the Luscar Group are indicative in the east verging structure below the Stolberg Gas field. The Ancona Thrust is shown as a folded thrust over the Ancona Anticline, following Jones and Workum (1978). They exclude the Stolberg structure from being a Triangle Zone, because of the folded fault theory for the Ancona Thrust. However, we believe that west verging faults may be present on the east limb of the Ancona Anticline, making it a typical Triangle Zone. The Ancona Thrust could connect with the east verging faults in the core of the Ancona Anticline.

Drawing the western part of the cross-section is somewhat problematic, because the section crosses the Bighorn lateral ramp and tear faults (Douglas, 1956). The cross-section will not balance in this area, because some of the displacement is out of the section on this lateral ramp. The cross-section, as drawn, is a cartoon of how the subsurface could look like based on the two wells (9-17-38-17W5M and 16-33-38-16W5M). The Luscar Group interval in well 16-33-38-16W5M is heavily faulted, but the orientation of these faults is not known and they are not shown on the cross-section.

STRATIGRAPHIC CROSS SECTION 4 (U --- U')

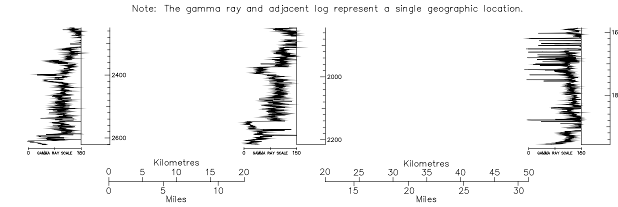


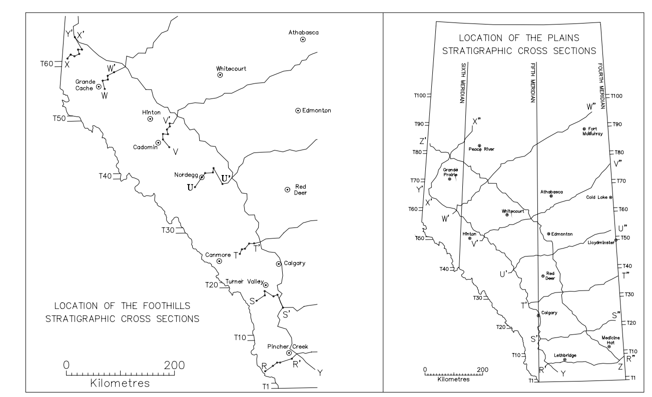
TO ACCOMPANY
REGIONAL EVALUATION OF THE COAL BED METHANE POTENTIAL IN THE PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY

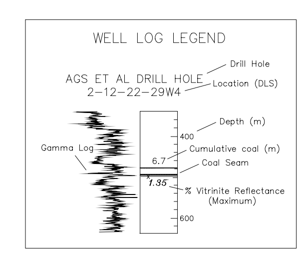
JUNE, 1991

SEA LEVEL DATUM

HORIZONTAL SCALE OF SPACING BETWEEN WELLS
Note: The gamma ray and adjacent log represent a single geographic location.







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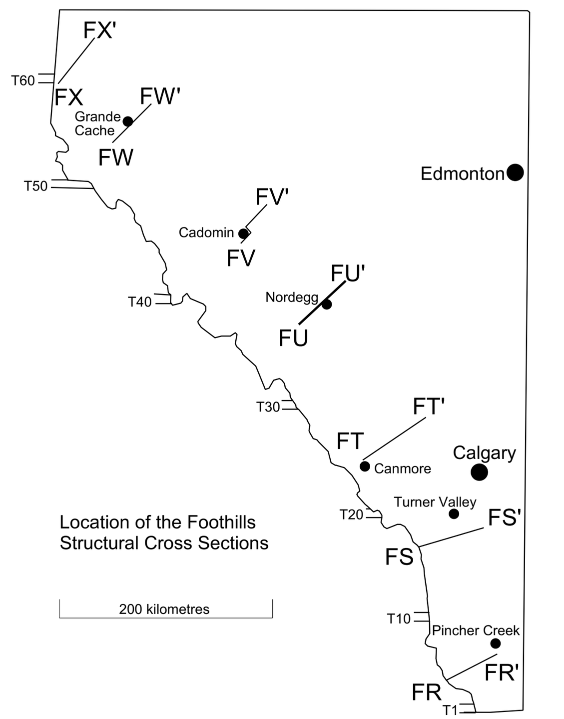
Structural Cross Section 4: Nordegg Area

(red)	Coal Zones
TP	PPaskapoo Formation
KBZ	Brazeau Formation
W	Top of Wapiabi Formation
KW	Wapiabi Formation
CR	Top of Cardium Formation
KBC	Blackstone and Cardium Formations
MP,BI	Top of Mountain Park Member, Top of Blairmore Group
GA	Top of Gates Coal Zone
KL	Luscar Group
Cd	Cadomin Formation
JKFN	Fernie and Nikanassin Groups
Rd	Top of Rundle Group
Pal	Paleozoics
● 1.65	Percent vitrinite reflectance (maximum)
	Thrust fault with sense of displacement

Geology modified from Douglas (1956), Jones and Workum (1978), and Perkins et al (1984)

To Accompany:
Regional Evaluation of the
Coal Bed Methane Potential in the
Plains and Foothills of Alberta,
Stratigraphy and Rank Study



Location of the Foothills Structural Cross Sections

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13.5 Stratigraphic Cross-Section 5 (V-V') Cadomin Area

The major coal zones are in the Coalspur, Brazeau, and Gates formations. The Gladstone Formation has additional minor coal.

13.5.1 Coalspur Formation

The Coalspur Coal zone comes close to the surface and outcrops in the Triangle Zone near the Pedley Thrust and in the Entrance syncline. It has been extensively mined in the past and is presently mined at Coal Valley (Luscar-Sterco Mine). Its cumulative thickness is up to 26 m.

13.5.2 Brazeau Formation

The main coal zone in the Brazeau Formation is near the top of the formation. It has a maximum cumulative thickness of 3.8 m. Thin coals are occasionally found in other parts of the formation.

13.5.3 Gates Formation

The Gates Coal zone is well developed in all the wells and has a maximum cumulative thickness of 8.7 m. These coals are being mined by the Cardinal River and Gregg River mines near Cadomin townsite.

13.5.4 Gladstone Formation

Gladstone coals get to be only about 1 m thick.

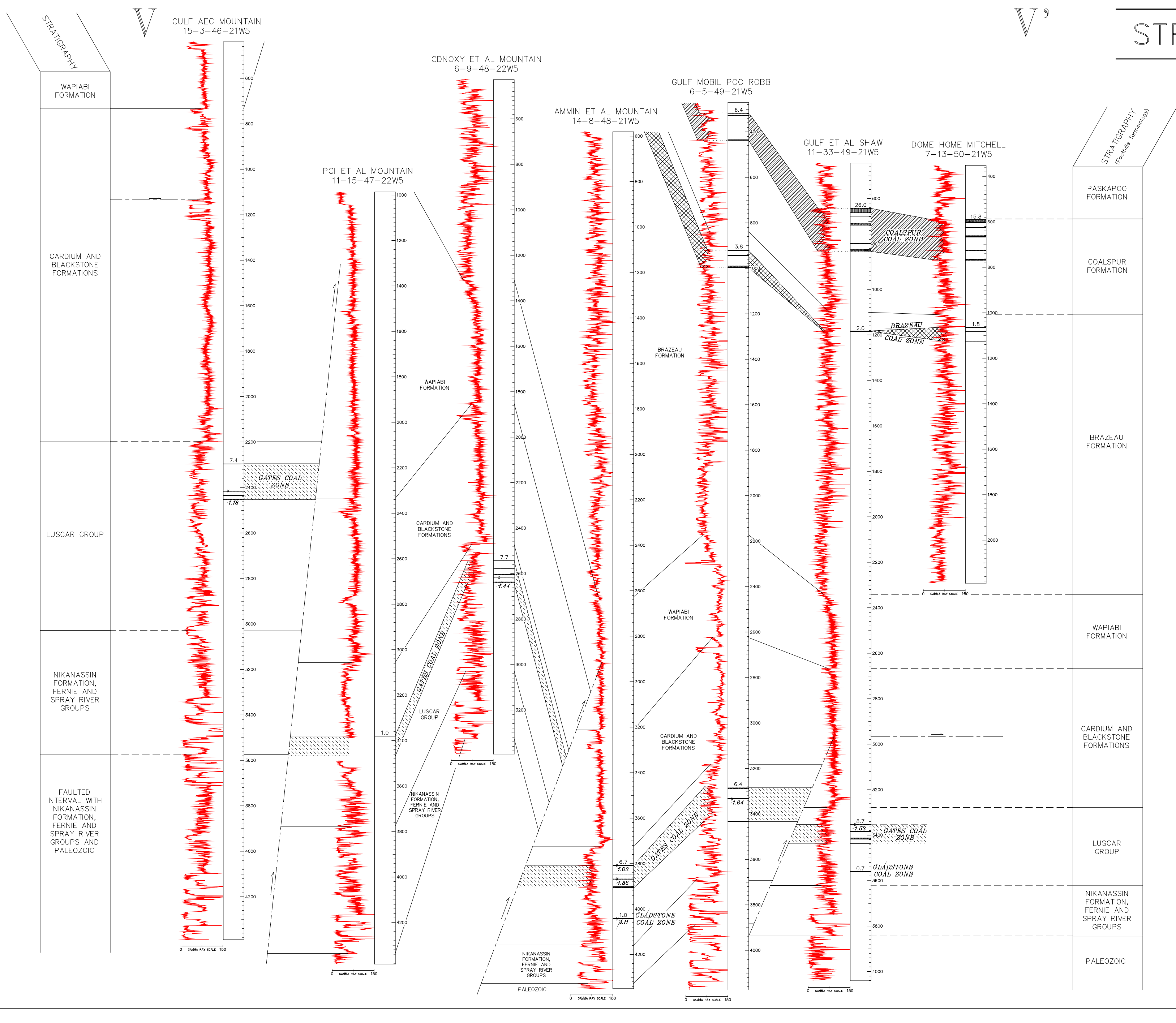
13.5.5 Structural Cross-Section 5 (FV-FV') Cadomin Area

This structural cross-section is based on mapping by Langenberg (1990) for the eastern part between Alberta Syncline and Grave Flats Thrust, and for the western part on work by Mountjoy and Lebel (in press). The eastern part is well constrained by a seismic line from Mercoal to Pedley thrusts. The western part is mainly based on surface information and well 15-3-46-21W5M, which was projected 16.5 km NW. Consequently, it is not very reliable for the structure on the section line. The duplexes in the Brazeau Thrust zone are inferred from faulting in this well and are similarly a cartoon of possible geometry.

Well 11-15-47-22W5M was projected 5.1 km and shows possibly more faulting than along the section line.

This cross-section clearly shows the interaction between east verging structures in the west and west verging structures (Mercoal and Pedley thrusts) in the east. The Brazeau Syncline and syncline in the Cadomin East Coal field show some of the overturned structures, that are charcteristic for this part of the foothills.

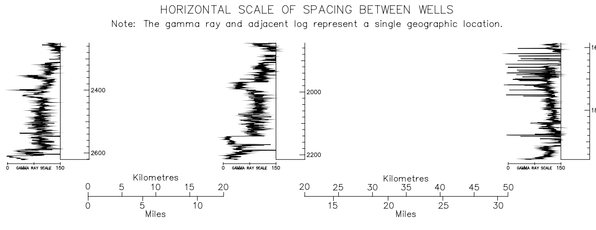
STRATIGRAPHIC CROSS SECTION 5 (V --- V')

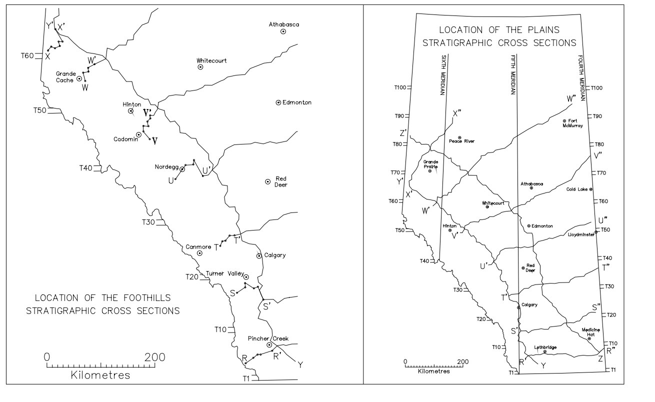


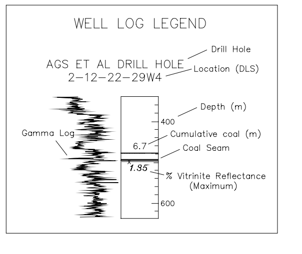
TO ACCOMPANY
REGIONAL EVALUATION OF THE COAL BED METHANE POTENTIAL IN THE PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY

JUNE, 1991

SEA LEVEL DATUM







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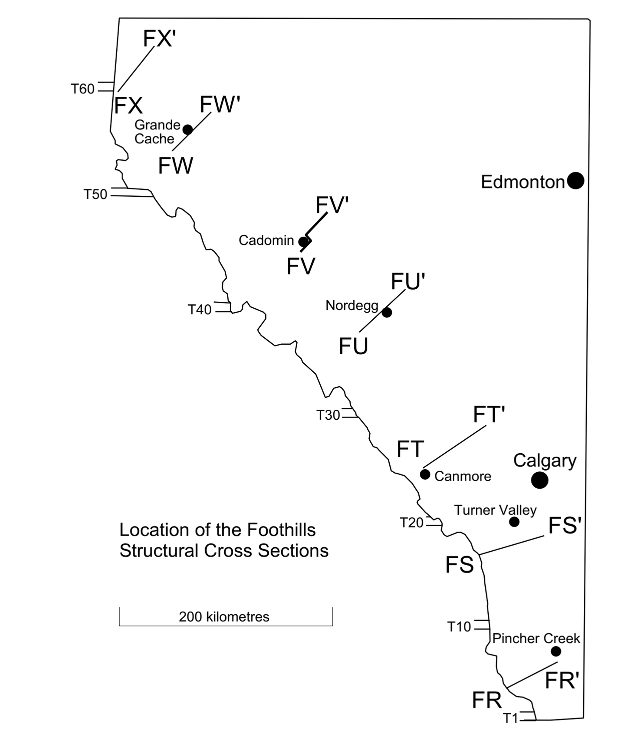
- Coal Zones
- T_P Paskapoo Formation
- K_{BZ} Brazeau Formation
- K_W Wapiabi Formation
- K_{BC} Blackstone and Cardium Formations
- MP Top of Mountain Park Member
- TFN Triassic, Fernie and Nikanassin Formations
- Rd Top of Rundle Group
- Pal Paleozoics
- ● 0.97 Percent vitrinite reflectance (maximum)
- Thrust fault with sense of displacement

Geology modified from Langenberg (in preparation) and Mountjoy and Lebel (in press)

To Accompany:
Regional Evaluation of the
Coal Bed Methane Potential in the
Plains and Foothills of Alberta,
Stratigraphy and Rank Study

Structural Cross Section 5: Cadomin Area



Location of the Foothills Structural Cross Sections

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13.6 Stratigraphic Cross-Section 6 (W-W') Grande Cache

The major coal zones are present in the Coalspur and Gates formations. The Brazeau and Gladstone formations contain minor coals.

13.6.1 Coalspur Formation

The Coalspur Coal zone is well developed on the east limb of the Findley Triangle Zone and has a maximum cumulative thickness of 4.2 m.

13.6.2 Gates Formation

The Gates Coal zone can be easily mapped and is well known from mining in the Smoky River Mine. Its maximum cumulative thickness is 10.9 m.

13.6.3 Brazeau and Gladstone Formations

Only thin coals (up to 0.6 m) have been found in these rock units.

13.6.4 Structural Cross-Section 6 (FW-FW') Grande Cache Area

The cross-section is after Mountjoy (1978). The only post 1978 drilling is on the east flank of the Findley Triangle Zone. No drilling for oil and gas has happened west of the Mason Thrust and the interpretation is based on outcrops only. Isolated outcrops of lower Gates coals allow us to draw the Gates Coal zone on the section in this area. The depth to the Paleozoic can be inferred from stratigraphic thicknesses. The Findley Triangle Zone is underlain by an anticlinal stack of duplexes involving Paleozoic to Lower Cretaceous rocks. The upper and lower detachment surfaces come together in the Shaftesbury Formation.

Thrusts appear to have more displacement in the Paleozoic than in the Mesozoic part of the stratigraphic succession. However, the Mesozoic shows more folding than the Paleozoic. A lot of the shortening by thrusting of the Paleozoic is balanced by shortening by folding in the Mesozoic. Most of the folds in the Mesozoic are detachment folds and the folds in front of the thrusts are fault-propagation folds.

13.7 Stratigraphic Cross-Section 7 (X-X') Narraway River Area

The major coal zones are in the Brazeau/Wapiti, Gates, and Gething formations.

13.7.1 Brazeau/Wapiti

Coals in this succession are exposed on Nose Mountain. They are fairly close to the surface and were not logged in the wells (the interval is cased). From mapping, two coal zones can be distinguished in the upper Brazeau, i.e. the Cutbank and Red Willow coal zones.

13.7.2 Gates Formation

The Gates Coal zone can be easily mapped in all wells. It has a maximum cumulative thickness of 15.5 m. They have been targets for coal exploration in the western part of the cross-section.

STRATIGRAPHIC CROSS SECTION 6 (W --- W')

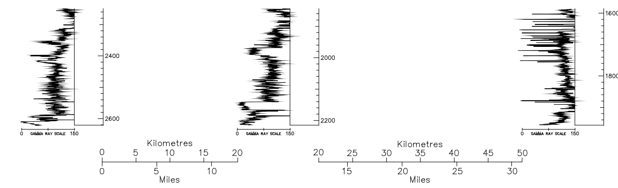
TO ACCOMPANY
REGIONAL EVALUATION OF THE COAL BED METHANE POTENTIAL IN THE PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY

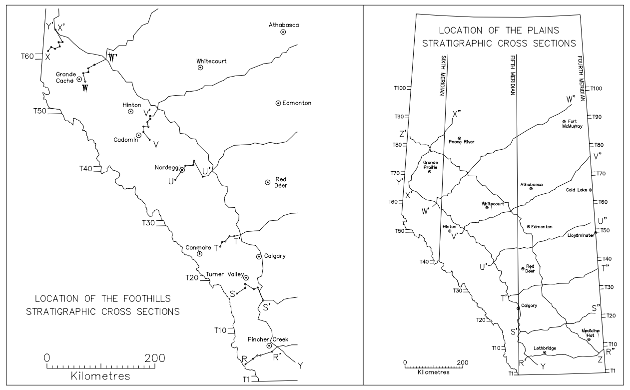
JUNE, 1991

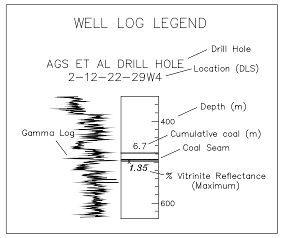
SEA LEVEL DATUM

HORIZONTAL SCALE OF SPACING BETWEEN WELLS

Note: The gamma ray and adjacent log represent a single geographic location.







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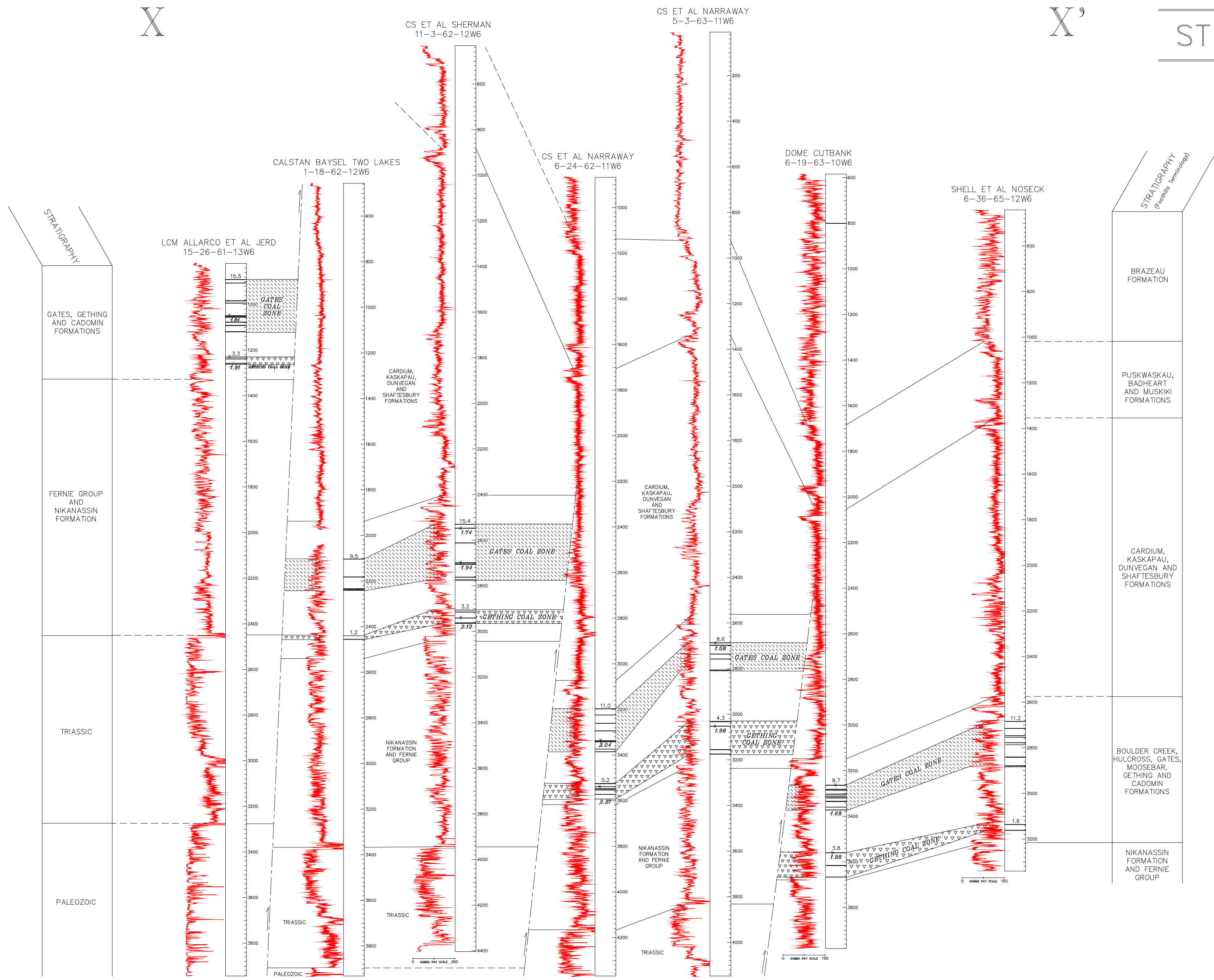
SW
NE
metres
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
Mt. Russell Thrust
Tip Top Thrust
Cowlick Thrust
Sterne Thrust
Mason Thrust
Findley Gas Field
Shell Mahon Creek 6-25-56-6W6 (proj. 7.5km NW)
PCP et al Findley 10-32-57-6W6 (proj. 4.6km SE)
PCP et al Findley 16-23-57-6W6 (proj. 1.6km NW)
Ammin Findley 10-7-58-5W6 (proj. 0.1km)
Ammin et al Smoky 15-11-58-5W6 (proj. 4.5km NW)
Ammin Findley 10-29-58-5W6 (proj. 2.0km SE)
Gates Coal Zone
Gladstone Coal Zone
Gladstone/Gething Coal Zone
TJ
Pal
KSDKC
KBZ
KW
TP
FW
FW'
0
5
10
15
20
25
30
35
40
45
Kilometres
UTM start coordinates
362500m E
5956600m N
UTM end coordinates
392023m E
5990562m N
Coal Zones
TP Paskapoo Formation
KBZ Brazeau Formation
Pu Top of Wapiabi Formation
KW Wapiabi Formation
Cr Top of Cardium Formation
KSDKC Shaftebury, Dunvegan, Kaspakau, Cardium Formations
Ga Top of Gates Formation
GA Top of Gates Coal Zone
EA Top of Gladstone Coal Zone
TJ Triassic and Jurassic Formations
Rd Top of Rundle Group
Pal Paleozoics
1.49 Percent vitrinite reflectance (maximum)
Thrust fault with sense of displacement
Geology modified from Mountjoy (1978)
To Accompany:
Regional Evaluation of the Coal Bed Methane Potential in the Plains and Foothills of Alberta, Stratigraphy and Rank Study
Structural Cross Section 6: Grande Cache Area
Edmonton
Calgary
Location of the Foothills Structural Cross Sections
200 kilometres
ALBERTA RESEARCH COUNCIL
Alberta Geological Survey



STRATIGRAPHIC CROSS SECTION 7 (X --- X')

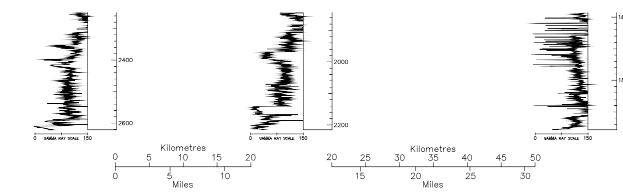
TO ACCOMPANY
REGIONAL EVALUATION OF THE COAL BED METHANE POTENTIAL IN THE PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY

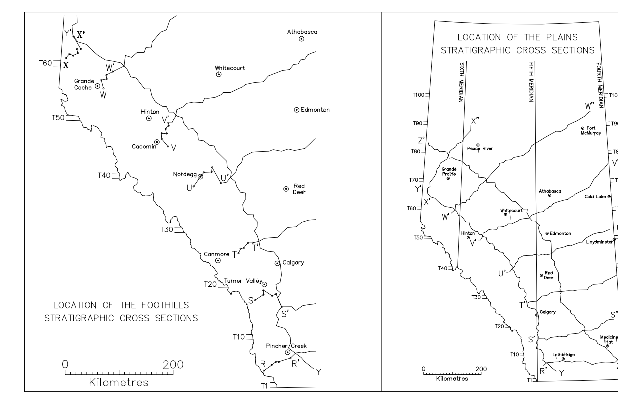
JUNE, 1991

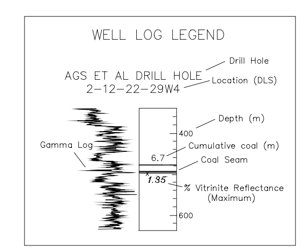
SEA LEVEL DATUM

HORIZONTAL SCALE OF SPACING BETWEEN WELLS

Note: The gamma ray and adjacent log represent a single geographic location.







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13.7.3 Gething Formation

This is the only area in the Foothills where this stratigraphic interval shows coals of significant thickness. Elsewhere this interval is known as the Gladstone formation, which has only minor coal. The maximum cumulative thickness of the Gething Coal zone in this area is 5.2 m.

13.7.4 Structural Cross-Section 7 (FX-FX') Narraway River

The cross-section is based on a recent cross-section by McMechan (in press). No additional drilling occurred since this cross-section was drawn and no changes had to be made to the interpretation. The only task required was drawing the coal zones based on the coal picks. The Cutbank and Red Willow coal zones were drawn based on outcrop and coal drilling information (M. Dawson, pers.comm., 1990). The Triangle Zone has a low angle taper and is similar to structures found further northwest (McMechan, 1985).

14 Maps

14.1 Problems of Marrying Different Data Sets

The contents of the map package was determined by data availability and the distribution of coal zones. The smaller, and less continuous coal zones were not mapped due to the limited availability of data, small aerial coverage, and uncertain correlations. Thus there were eight mappable coal zones with one coal zone lumped with a larger neighbour (the Daly was mapped as part of the Drumheller)

15 Descriptions of maps

15.1 Ardley/Kakwa/Coal Zones

The data distribution for the coal zone is excellent (1739 sites in data set) in all areas except in the far north-eastern area between Twps. 59-69, Ranges 8-18 W5M. The coal zone is present west of the subcrop edge between Twps. 30 and 69, Ranges 23 W4M to 5 W6M.

15.1.1 Depth to Top of Coal Zone

On this map the coal zone is shown to dip from the subcrop edge (1.5 m) to more than 800 metres along the disturbed belt (maximum 914.2 m). Contour interval is 100 metres and reflects not only the basin structure but also the present day erosional (surface) topography.

15.1.2 Isopach of Coal Zone

On this map the coal zone is shown to thicken from 0.5 m near the subcrop edge to more than 265 metres along the disturbed belt. Contour interval is 30 metres. The thickening of the coal zone is related to increased deposition and subsidence in the west during the coal forming period.

15.1.3 Total Cumulative Coal

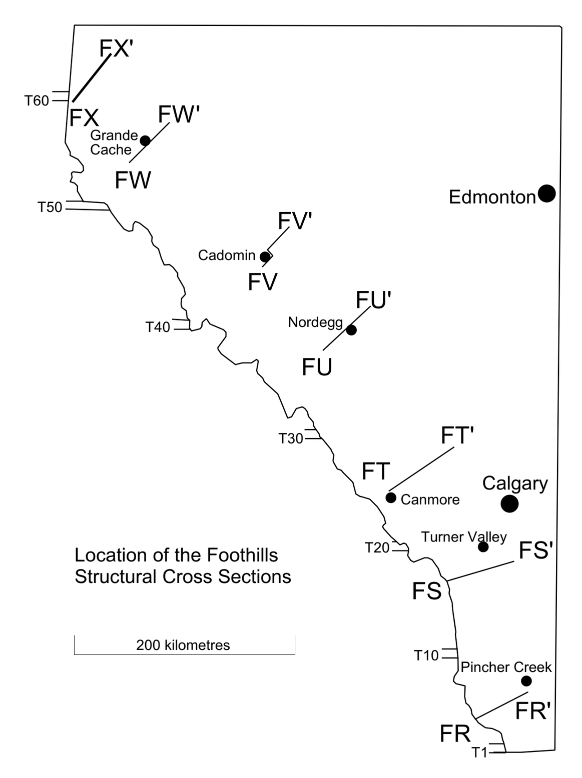
Two arms with total cumulative coal (TCC) in excess of 12 metres can be seen on this map. The contour interval is 3 metres and the majority of the area has TCC values greater than 6 metres (minimum 0.5 to

Structural Cross Section 7:
Narraway River Area

- Coal Zones
- KBW — Brazeau/Wapiti Formation
- KMBP — Muskiki, Badheart, Puskwaskau Formation
- Pu — Top of Puskwaskau Formation
- CR — Top of Cardium Sandstone
- KSDKC — Shaftebury, Dunvegan, Kaspakau, Cardium Formations
- Mp — Top of Mountain Park Member
- Pd — Top of Paddy Member
- FA — Top of Gates/Falher Coal Zone
- EA — Top of Gething Coal Zone
- JKFM — Fernie, Minnes Formation
- Tr — Triassic
- Pal — Paleozoics
- Be — Top of Belloy Formation
- 0.65 — Percent vitrinite reflectance (maximum)
- Thrust fault with sense of displacement

Geology modified from McMechan (in press)

To Accompany:
Regional Evaluation of the
Coal Bed Methane Potential in the
Plains and Foothills of Alberta,
Stratigraphy and Rank Study



Location of the Foothills Structural Cross Sections

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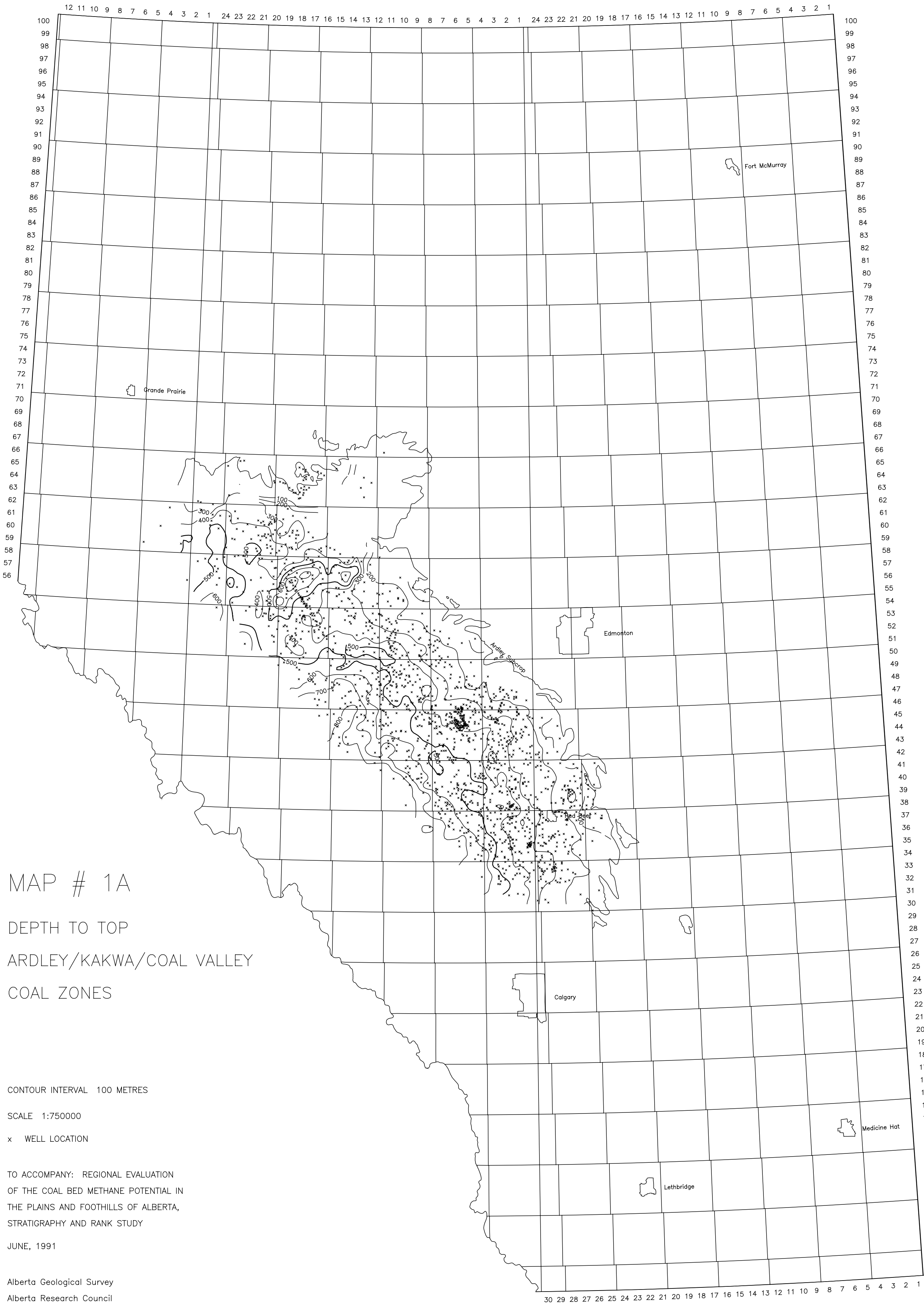

MAP # 1A

DEPTH TO TOP

ARDLEY/KAKWA/COAL VALLEY

COAL ZONES

CONTOUR INTERVAL 100 METRES

SCALE 1:750000

x WELL LOCATION

TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
STRATIGRAPHY AND RANK STUDY

JUNE, 1991

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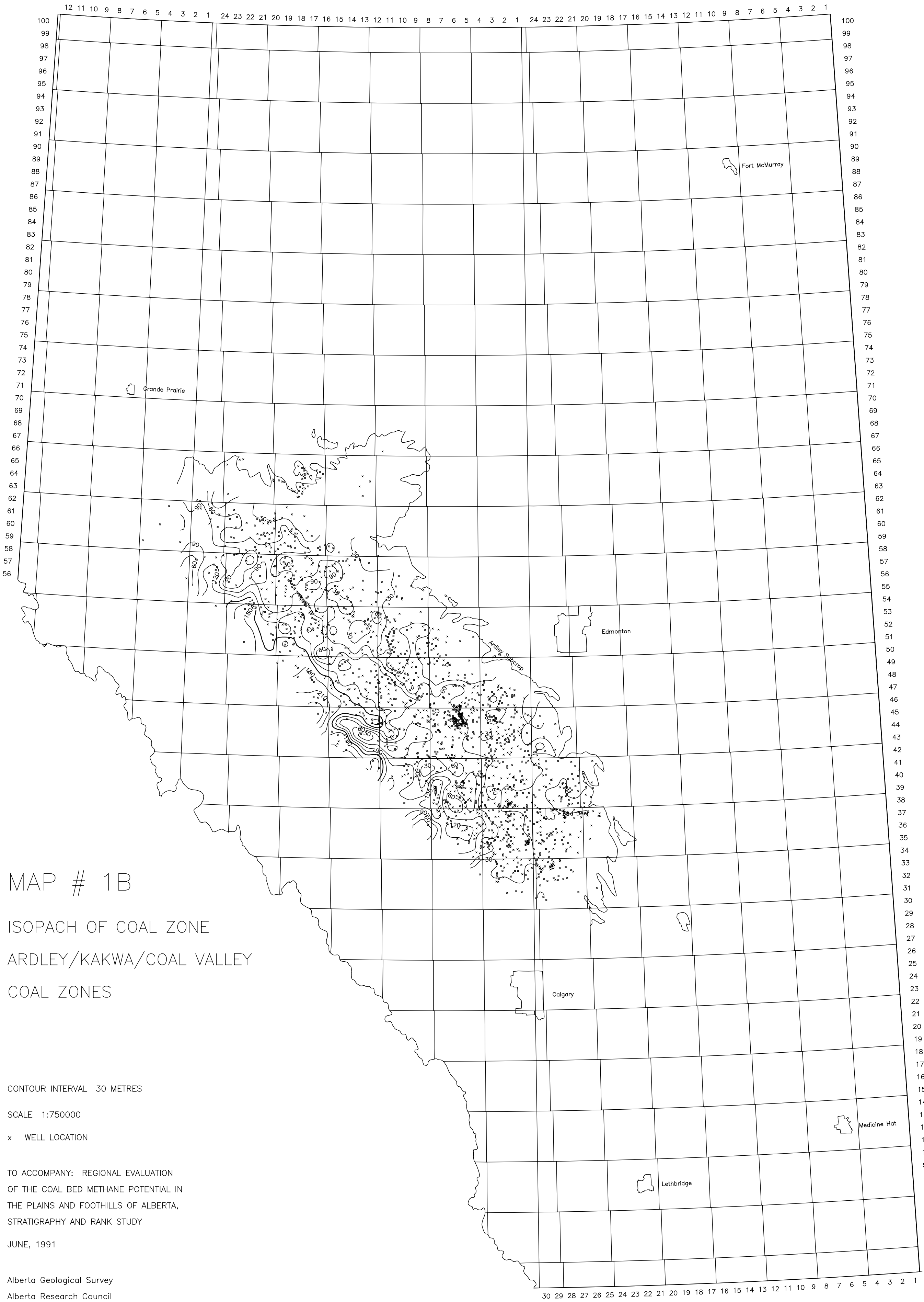

MAP # 1B

ISOPACH OF COAL ZONE
ARDLEY/KAKWA/COAL VALLEY
COAL ZONES

CONTOUR INTERVAL 30 METRES

SCALE 1:750000

x WELL LOCATION

TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
STRATIGRAPHY AND RANK STUDY

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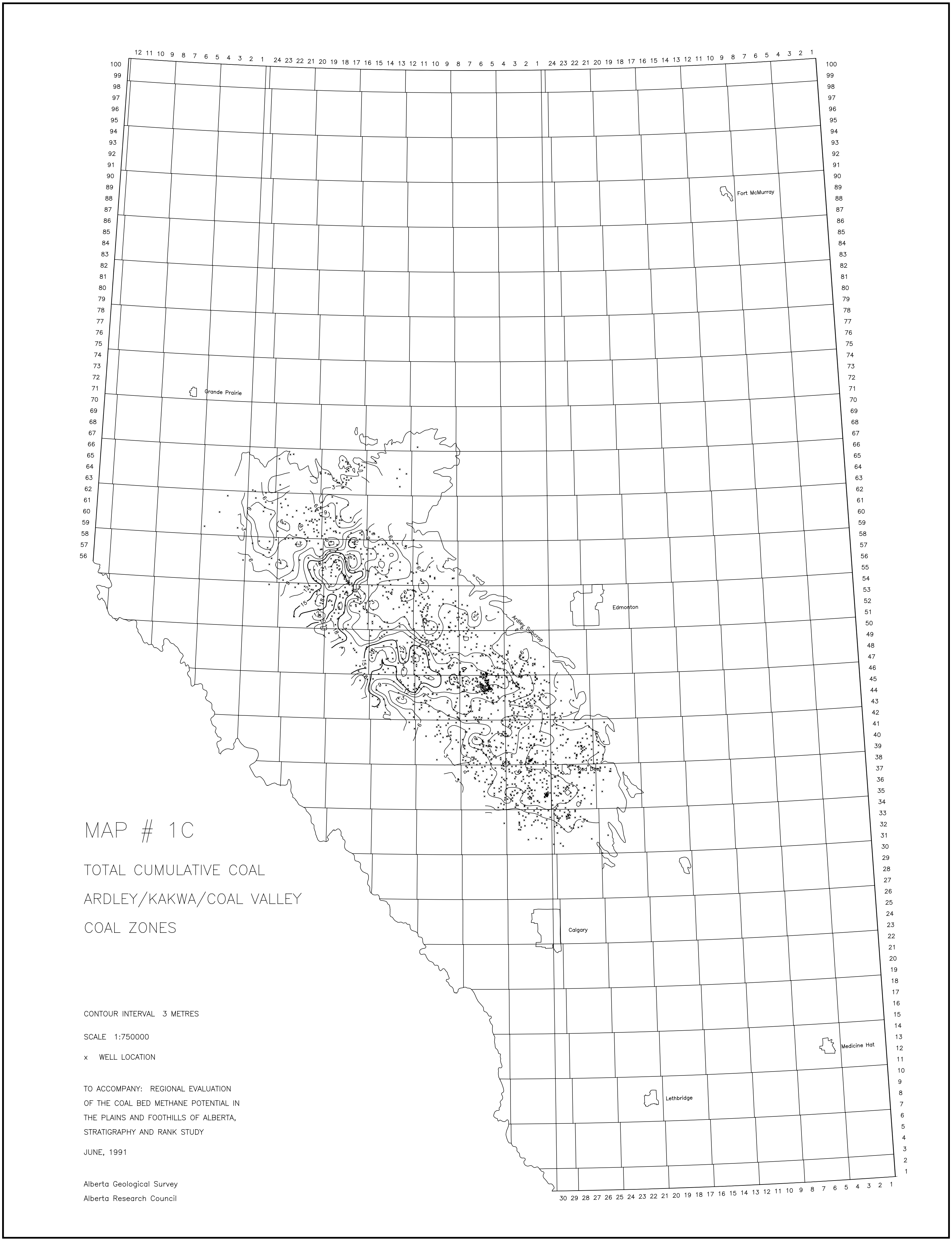
Fort McMurray
Grande Prairie
Edmonton
Ardley Subcrop
Red Deer
Calgary
Medicine Hat
Lethbridge
MAP # 1C
TOTAL CUMULATIVE COAL
ARDLEY/KAKWA/COAL VALLEY
COAL ZONES
CONTOUR INTERVAL 3 METRES
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
STRATIGRAPHY AND RANK STUDY
JUNE, 1991
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maximum 25 m). The Ardley in general has the greatest and most areally extensive TCC of any Alberta coal zone. The areas of greatest TCC area at depth towards the disturbed belt.

15.1.4 Isopach of Thickest Seam

The thickest seams shown on this map range between 3 and 4 metres (contour interval 1 m) with few scattered areas having seam thicker than 4 metres (minimum 0.25 to maximum 11 metres). The Drumheller and upper Mannville have seams as thick as the upper Ardley but only the upper Mannville seams are as extensive.

15.1.5 Iso-Reflectance map

Reflectance data was difficult to gather in the shallow Ardley/Kakwa coal zones and data distribution is poor with only 47 sites available (99 samples). The data does support the findings of Nurkowski (1985) in that the deeper Ardley coals have ranks in 0.6 to 0.7% range and generally fall in the High-vol. C bituminous in rank (minimum R_{mean} 0.39%, subbituminous C., maximum R_{mean} 0.72%, high-volatile B bit.).

15.2 Carbon Thompson/Cutbanck Coal Zones

The data availability for the coal zone is lean in all areas (168 data points), however the areal distribution is good and the characteristics of the coals should be accurately displayed. The coal zone is present west and north of the subcrop edge with coal identified between Twps. 16 and 64, Ranges 22 W4M to 6 W6M.

15.2.1 Depth to Top of Coal Zone

On this map the coal zone is shown to dip from the subcrop edge (min. 182.3 m) to more than 1100 metres (max. 1300 m) along the disturbed belt. Contour interval is 100 metres and reflects mainly the basin structure but also some overprint of the present day erosional (surface) topography.

15.2.2 Isopach of Coal Zone

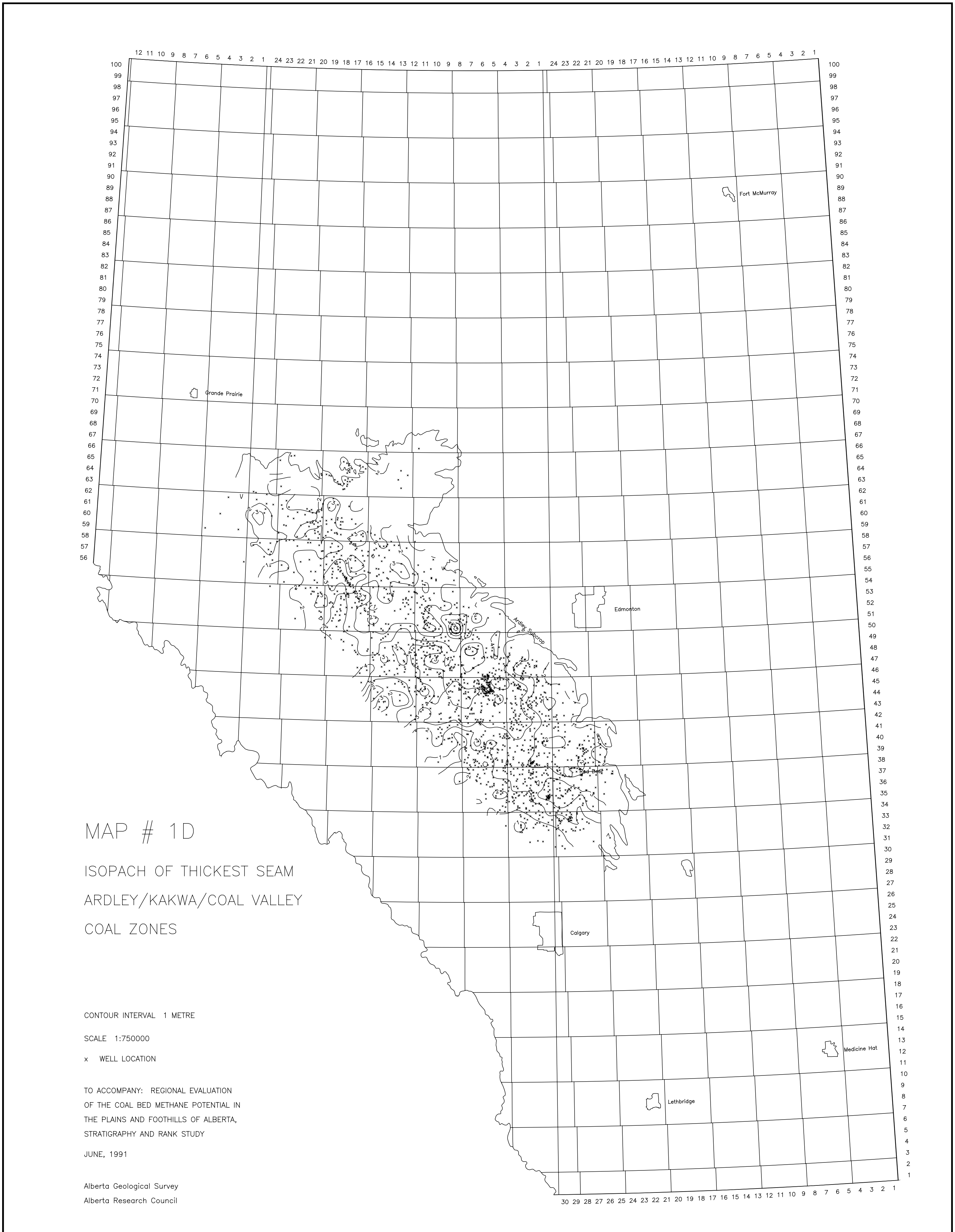
On this map the coal zone is shown to range from 10 to 20 metres for most of the area east of R. 10 W5M (Minimum 0.2 m - single seam). Along the disturbed belt the coal zone thickens to more than 50 metres (maximum 79.86 m). Contour interval is 10 metres. The thickening of the coal zone is thought to relate to increase deposition and subsidence in the west during the coal forming period and/or the presence of additional coal seams.

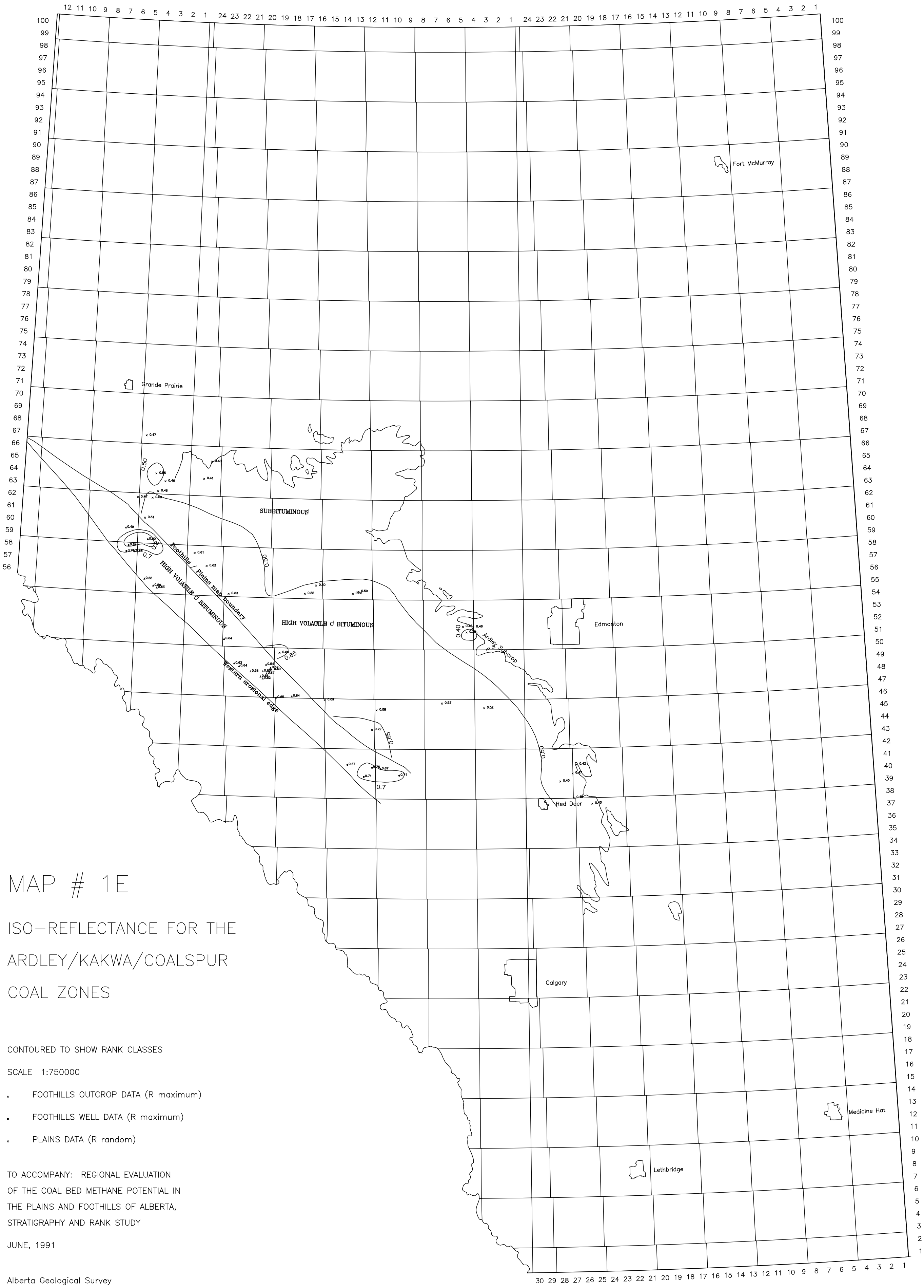
15.2.3 Total Cumulative Coal

The coal zone has total cumulative coal in excess of 2 to 3 metres in only a few isolated spots. TCC of 1 to 2 metres are common. Minimum TCC was 0.2 metres and maximum was 5.5 metres. The contour interval is 1 metre.

15.2.4 Isopach of Thickest Seam

The thickest seams map shows a high correlation with the TCC map indicating only a couple of seams


MAP # 1D
ISOPACH OF THICKEST SEAM
ARDLEY/KAKWA/COAL VALLEY
COAL ZONES
CONTOUR INTERVAL 1 METRE
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
STRATIGRAPHY AND RANK STUDY
JUNE, 1991
Alberta Geological Survey
Alberta Research Council
Fort McMurray
Grande Prairie
Edmonton
Ardley Subcrop
Red Deer
Calgary
Medicine Hat
Lethbridge



MAP # 1E

ISO–REFLECTANCE FOR THE ARDLEY/KAKWA/COALSPUR COAL ZONES

CONTOURED TO SHOW RANK CLASSES

SCALE 1:750000

- FOOTHILLS OUTCROP DATA (R maximum)
- FOOTHILLS WELL DATA (R maximum)
- PLAINS DATA (R random)

TO ACCOMPANY: REGIONAL EVALUATION OF THE COAL BED METHANE POTENTIAL IN THE PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY

JUNE, 1991

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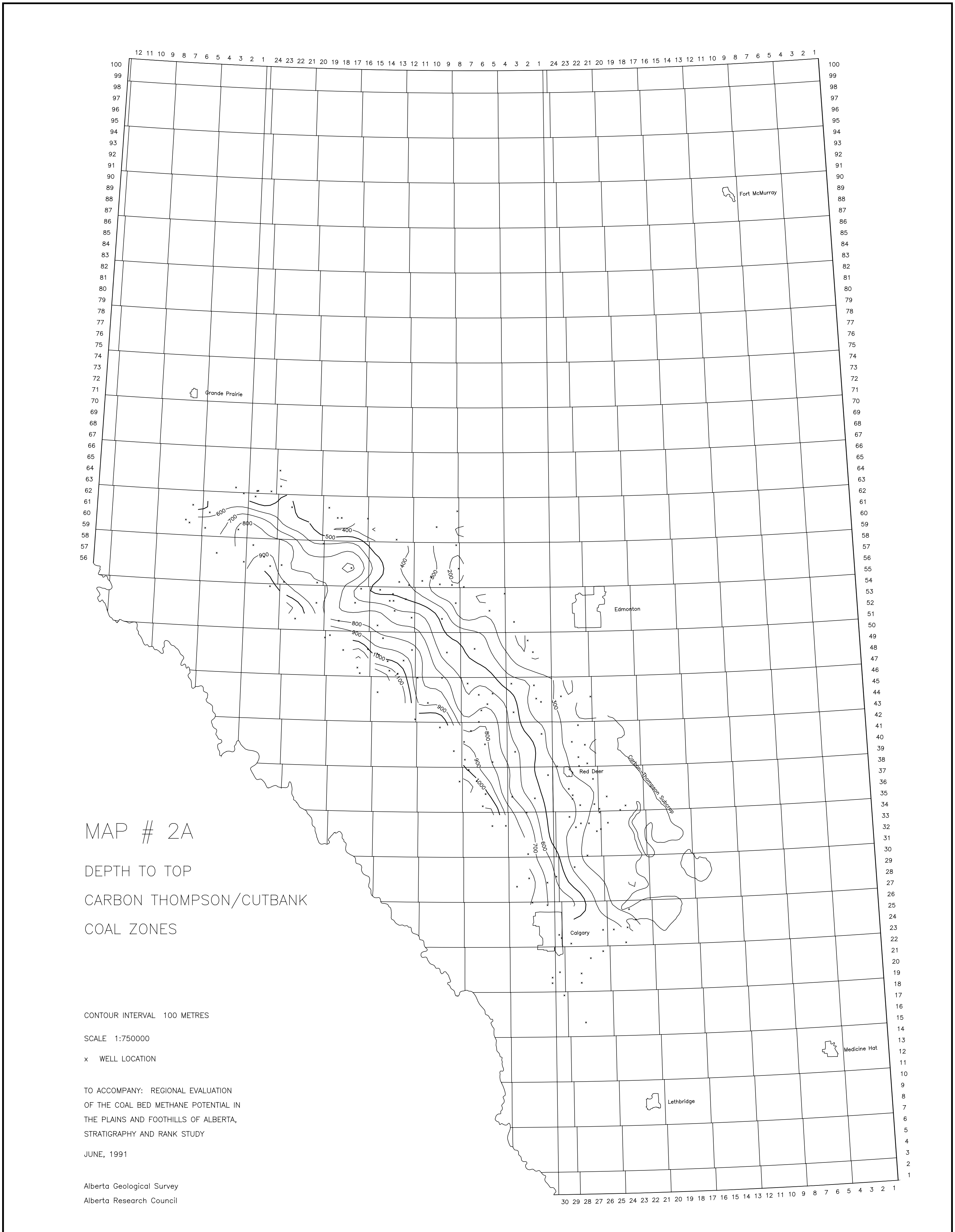
MAP # 2A
DEPTH TO TOP
CARBON THOMPSON/CUTBANK
COAL ZONES
CONTOUR INTERVAL 100 METRES
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
STRATIGRAPHY AND RANK STUDY
JUNE, 1991
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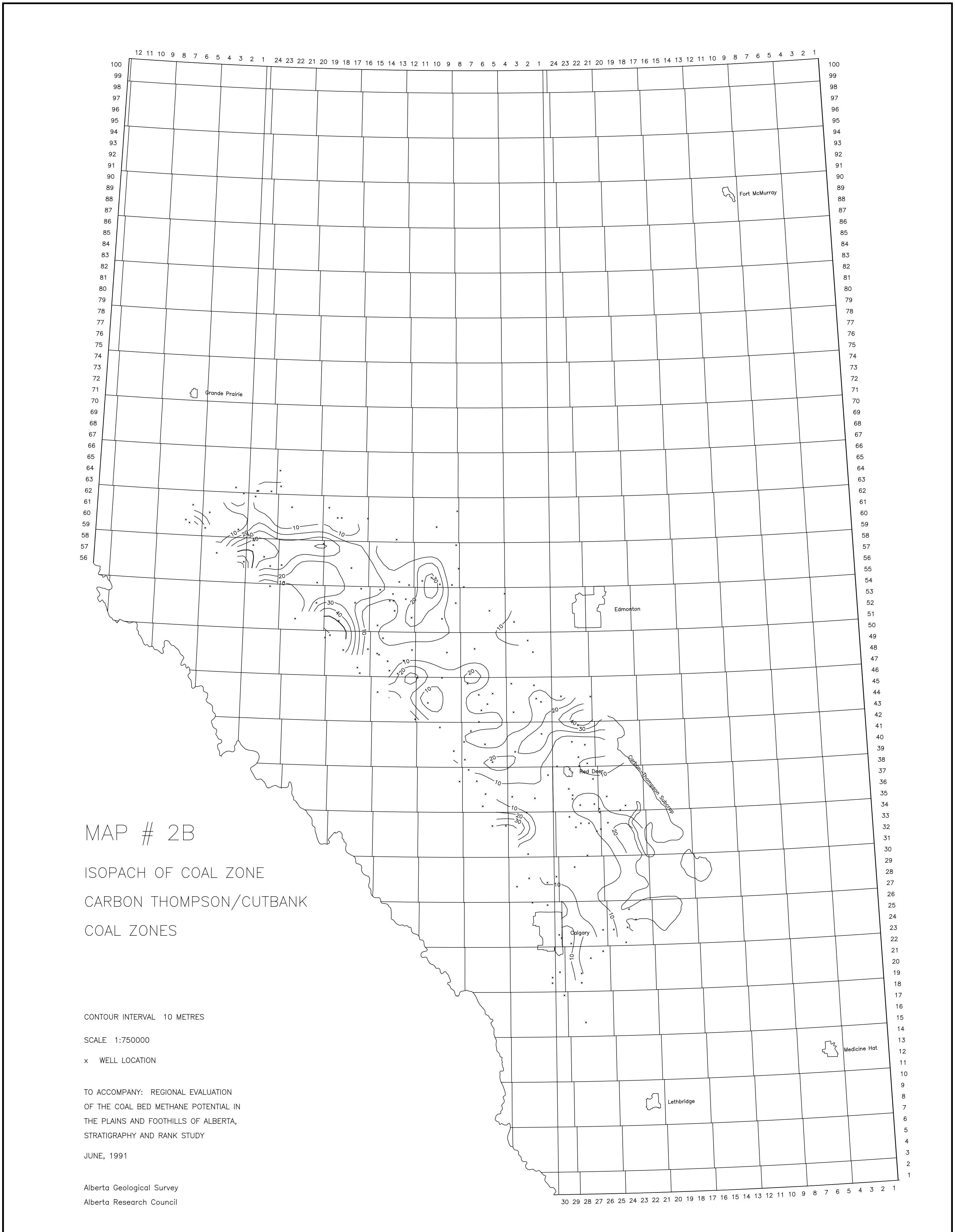
Alberta Research Council
Fort McMurray
Grande Prairie
Edmonton
Red Deer
Calgary
Medicine Hat
Lethbridge
Carbon Thompson Subcrop


MAP # 2B
ISOPACH OF COAL ZONE
CARBON THOMPSON/CUTBANK
COAL ZONES
CONTOUR INTERVAL 10 METRES
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
STRATIGRAPHY AND RANK STUDY
JUNE, 1991
Alberta Geological Survey
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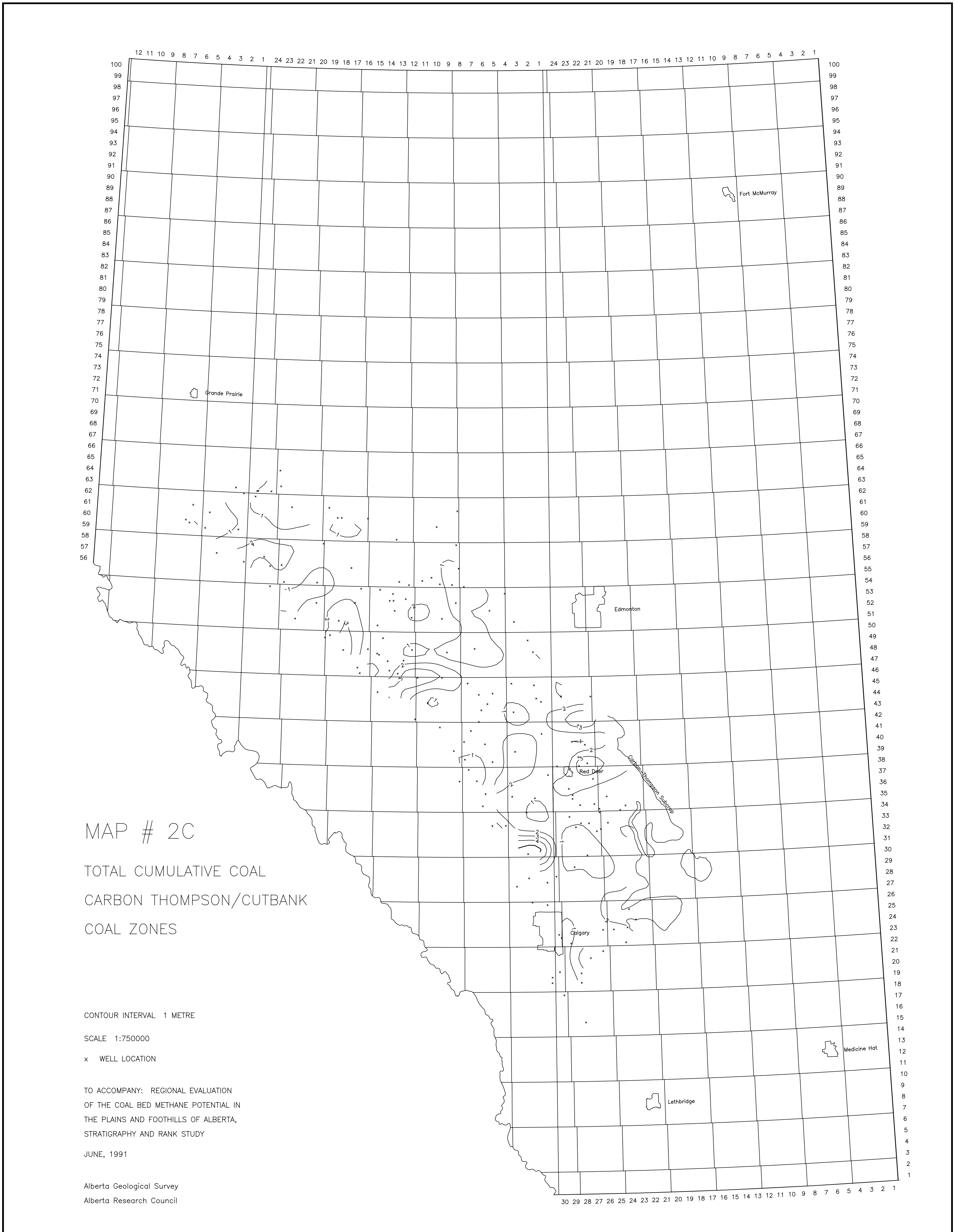
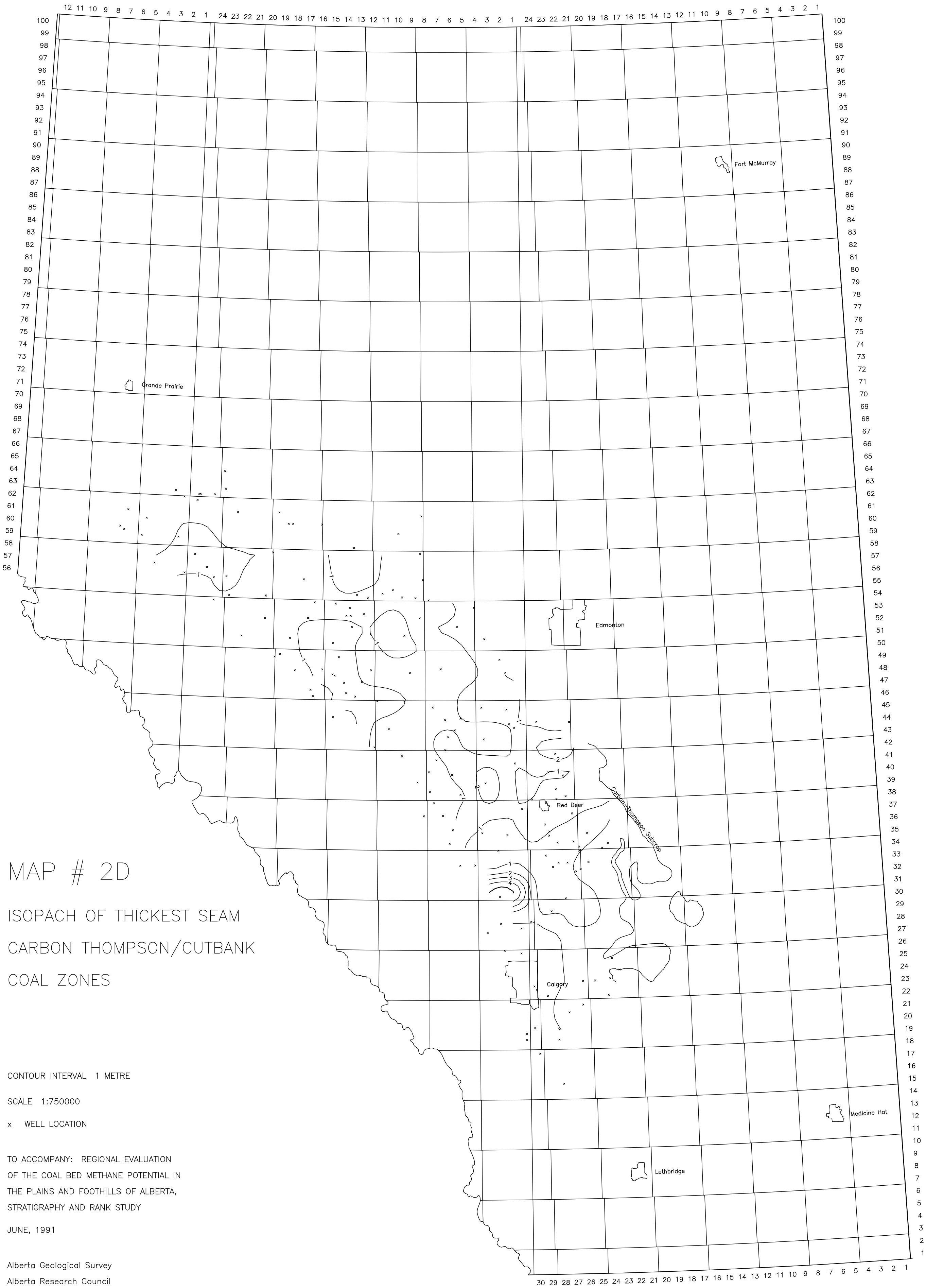
Edmonton
Red Deer
Carbon–Thompson Subcrop
Calgary
Medicine Hat
Lethbridge


MAP # 2C
TOTAL CUMULATIVE COAL
CARBON THOMPSON/CUTBANK
COAL ZONES
CONTOUR INTERVAL 1 METRE
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
STRATIGRAPHY AND RANK STUDY
JUNE, 1991
Alberta Geological Survey
Alberta Research Council
Fort McMurray
Grande Prairie
Edmonton
Red Deer
Carbon - Thompson Subcrop
Calgary
Medicine Hat
Lethbridge


Fort McMurray
Grande Prairie
Edmonton
Red Deer
Carbon Thompson Subcrop
Calgary
Medicine Hat
Lethbridge
MAP # 2D
ISOPACH OF THICKEST SEAM
CARBON THOMPSON/CUTBANK
COAL ZONES
CONTOUR INTERVAL 1 METRE
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
STRATIGRAPHY AND RANK STUDY
JUNE, 1991
Alberta Geological Survey
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are present. Some areas with 2 metre thick seams are present but much of the area has seams near 1 metre in thickness. Minimum seam thickness was 0.2 metres and maximum was 5.5 metres (identical to the TCC min. and max.).

15.2.5 Iso-Reflectance map

Reflectance data was difficult to gather in the Carbon Thompson/Cutbank coal zones and data distribution is very poor with only 19 sites available (38 samples). The data does support those values in the overlying Ardley coals. The reflectance data has ranks in the 0.52 to 0.7% range (maximum R_{mean} 0.76%, high-volatile A bit.). The majority of these coal are also likely High-volatile C bituminous in rank.

15.3 Drumheller/Red Willow Coal Zones

A total of 761 data points were used in generating these maps. The data distribution for the coal zone is excellent in the south but is poor north and west of Edmonton and towards the disturbed belt. The coal zone is present west of the subcrop edge between Twps. 2 and 67, Ranges 14 W4M to 7 W6M.

15.3.1 Depth to Top of Coal Zone

On this map the coal zone is shown to dip from near the subcrop edge to more than 1300 metres along the disturbed belt north and south of Calgary. The range within the data set was a minimum of 103 metres to 1923.8 metres. Contour interval is 100 metres and reflects mainly basin structure.

15.3.2 Isopach of Coal Zone

On this map the coal zone is shown to thicken to more than 240 metres between Calgary and Drumheller (minimum 0.2 to 288.4 metres). This thickening is related to a larger number of seams and seam separation in this area. Contour interval is 20 metres.

15.3.3 Total Cumulative Coal

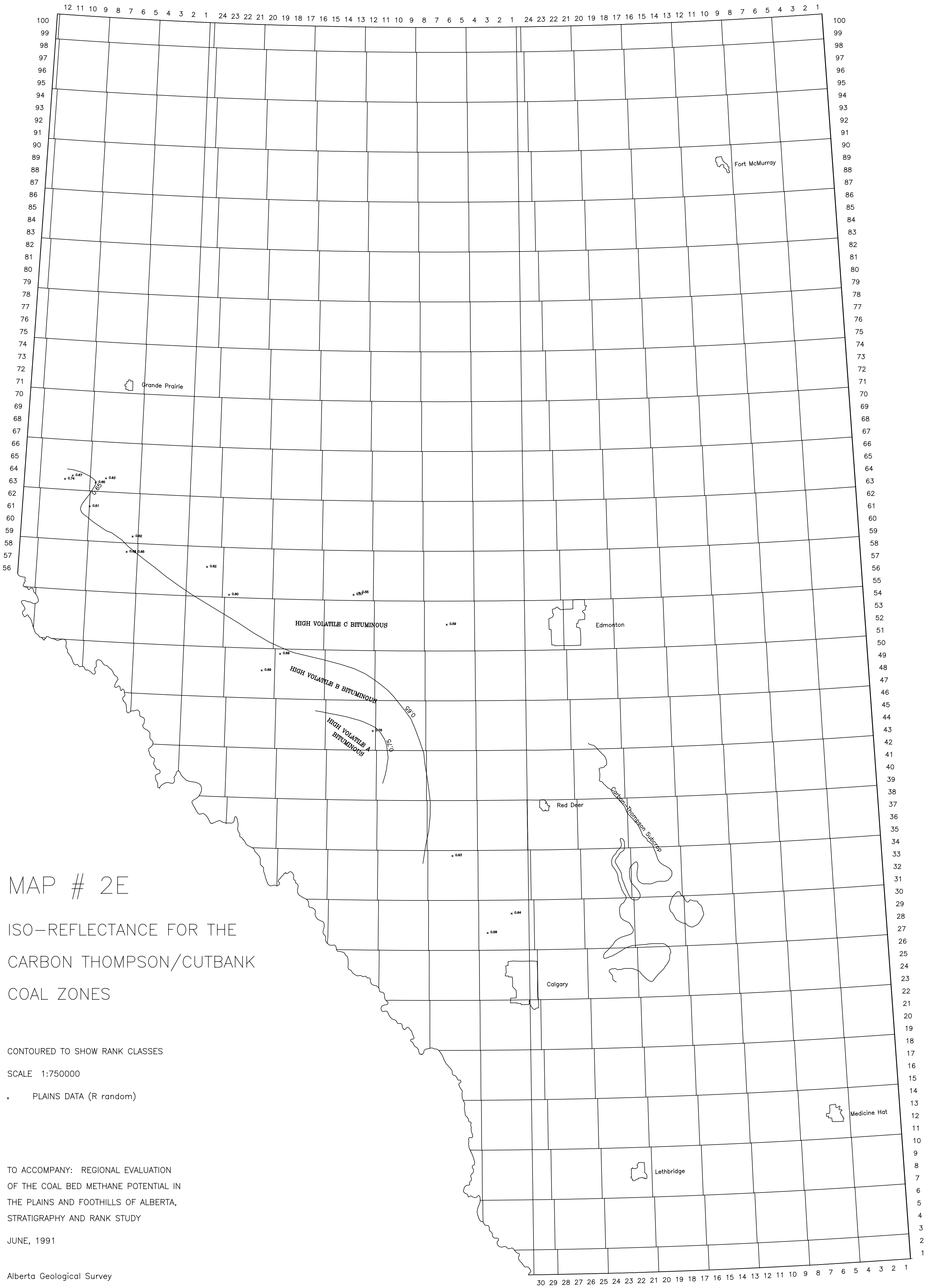
The area with the greatest total cumulative coal, in excess of 18 metres, is located just west of Drumheller (minimum 0.2 to 35.1 metres). The Drumheller contains the largest amount of TCC of any Alberta coal zone (largest TCC at 11 28 28 23 W4M), however, these thick packages of coal are not as extensive as the thick Ardley and upper Mannville coals. A large north-south belt of TCC greater than 8 metres can be seen on the map. The contour interval is 2 metres.

15.3.4 Isopach of Thickest Seam

The thickest seams over much of the area range between 1 and 2 metres. Thicker seams (3 to 4 m) are found in the same area of great TCC. Many seams are however present in those areas. Further south are local areas with seams up to 5 metres thick which account for the bulk of the TCC in those pods. The thinnest seam in the dataset was 0.2 m while the thickest seam was a substantial 10.5 metres.

15.3.5 Iso-Reflectance map

The scattering of reflectance data provides a fair representation even though only 41 sites (54 samples)



MAP # 2E

ISO-REFLECTANCE FOR THE CARBON THOMPSON/CUTBANK COAL ZONES

CONTOURED TO SHOW RANK CLASSES

SCALE 1:750000

× PLAINS DATA (R random)

TO ACCOMPANY: REGIONAL EVALUATION OF THE COAL BED METHANE POTENTIAL IN THE PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY

JUNE, 1991

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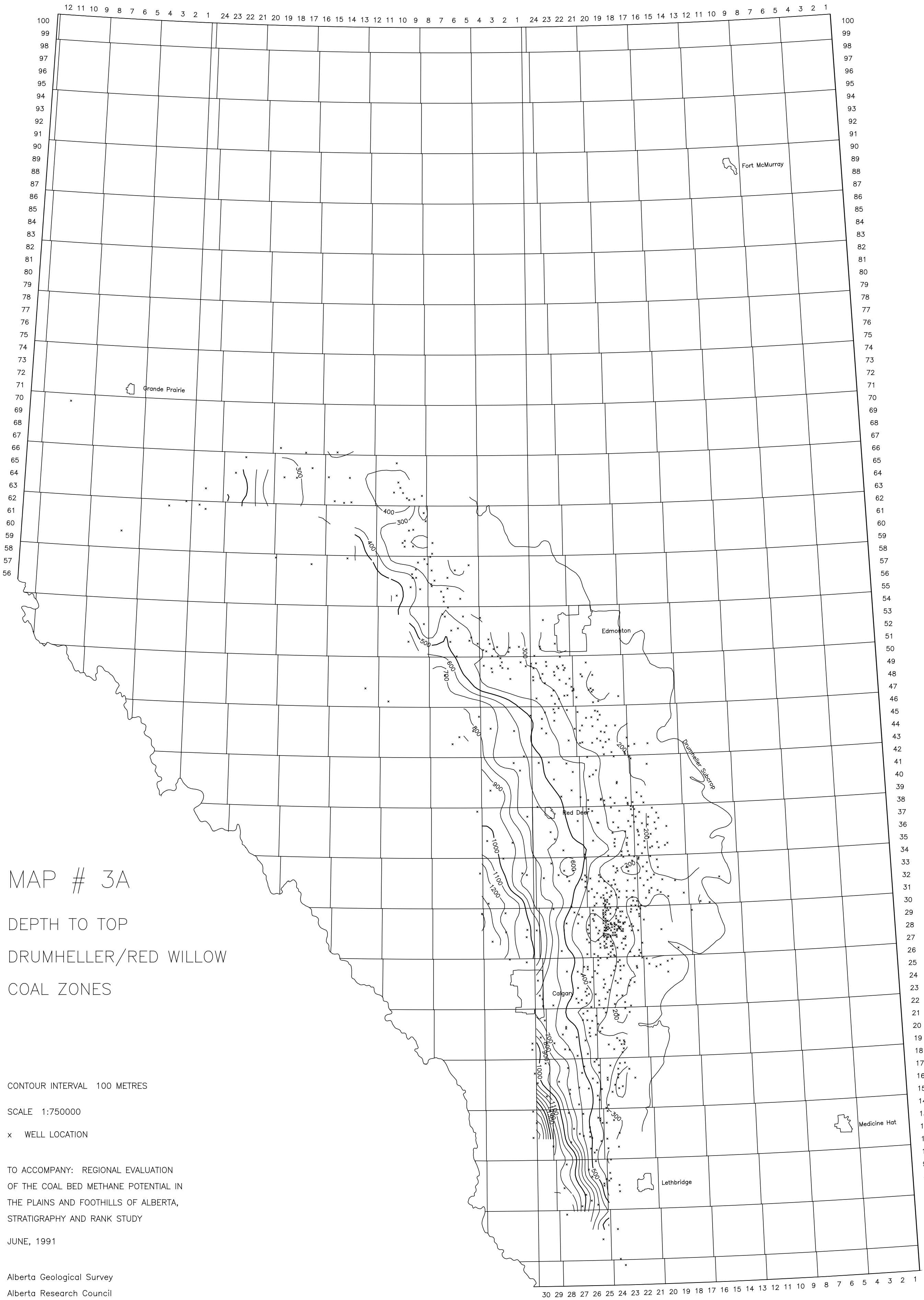
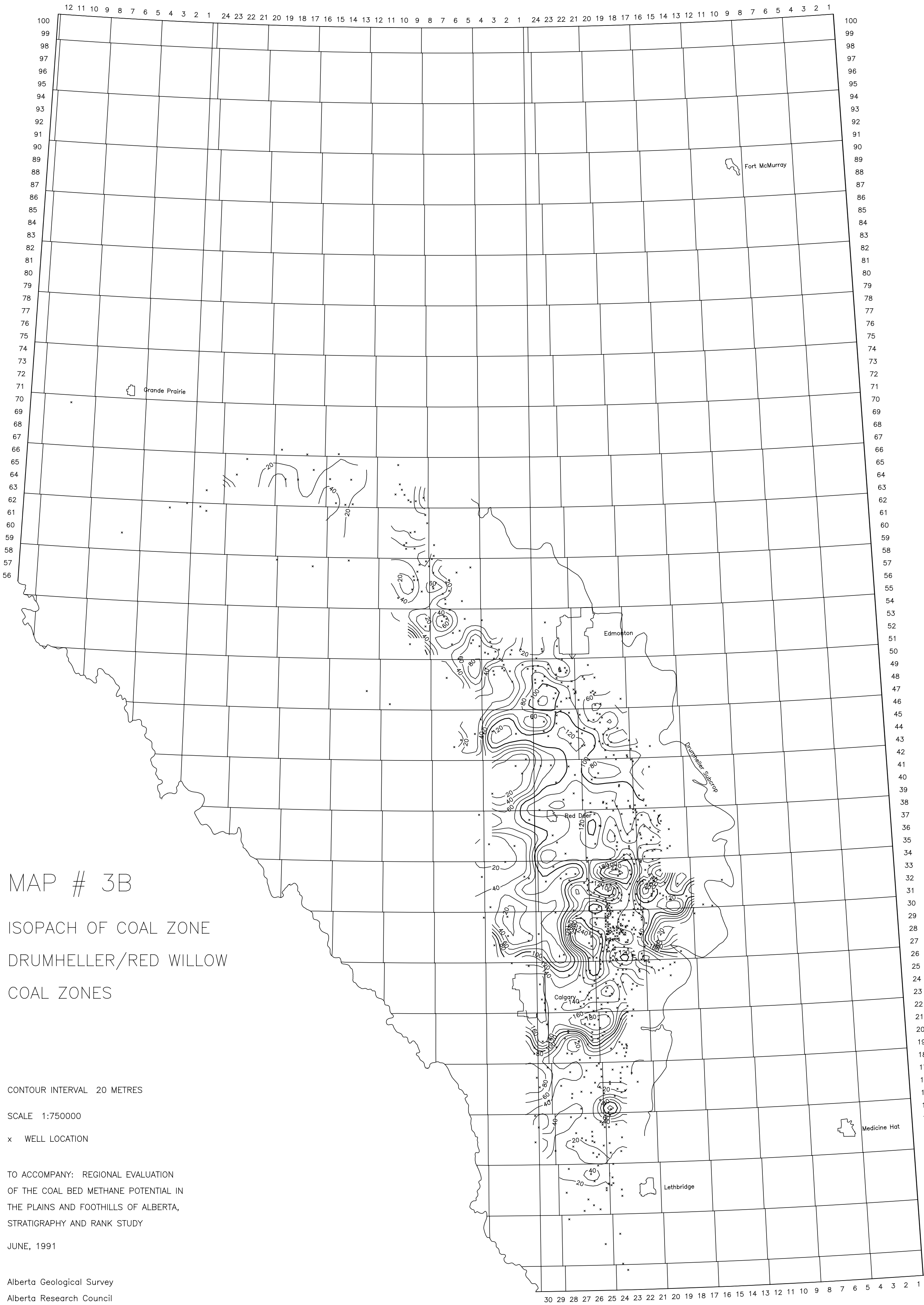
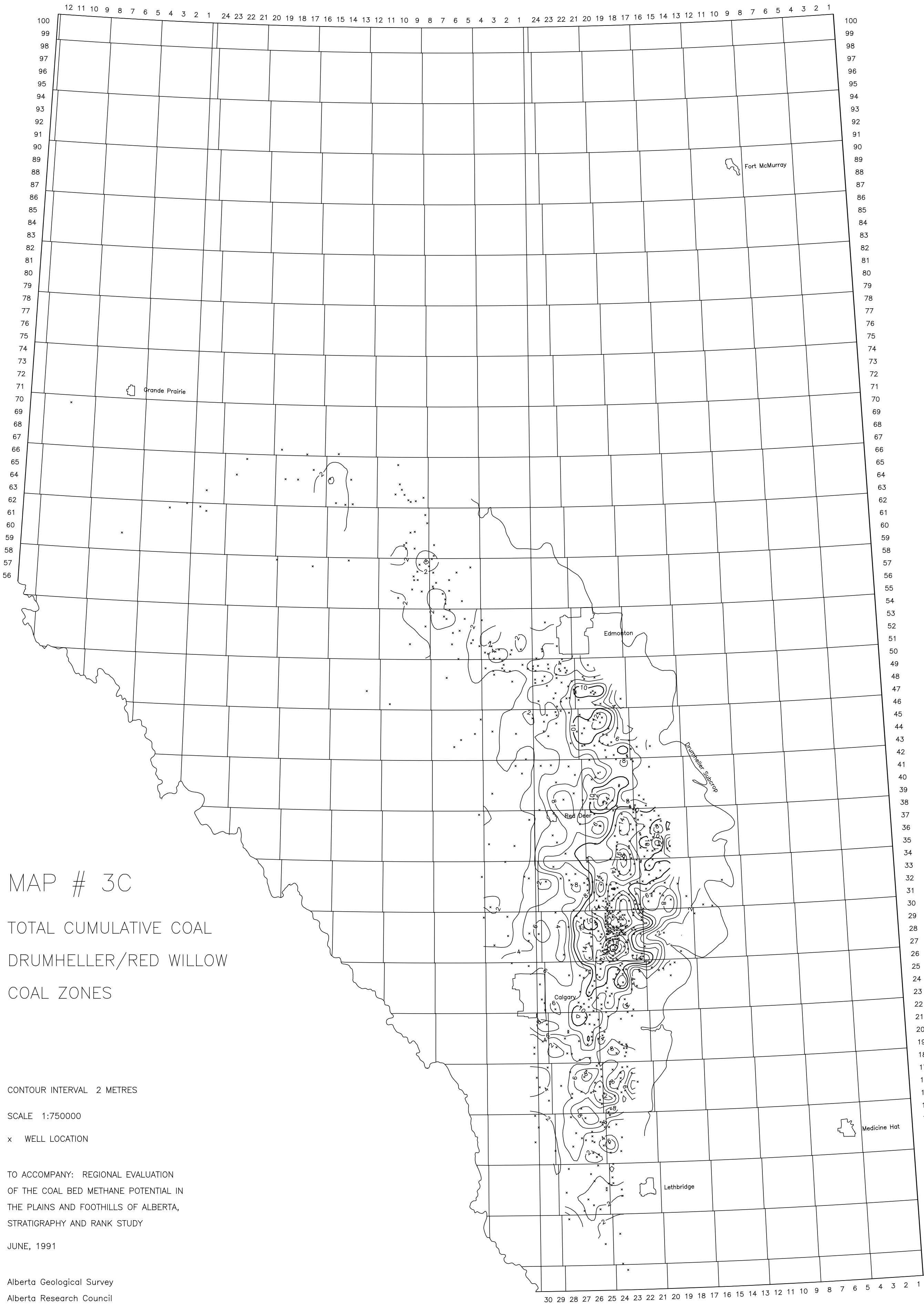

MAP # 3A
DEPTH TO TOP
DRUMHELLER/RED WILLOW
COAL ZONES
CONTOUR INTERVAL 100 METRES
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
STRATIGRAPHY AND RANK STUDY
JUNE, 1991
Alberta Geological Survey
Alberta Research Council
Fort McMurray
Grande Prairie
Edmonton
Drumheller Subcrop
Red Deer
Calgary
Medicine Hat
Lethbridge


MAP # 3B
ISOPACH OF COAL ZONE
DRUMHELLER/RED WILLOW
COAL ZONES
CONTOUR INTERVAL 20 METRES
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
STRATIGRAPHY AND RANK STUDY
JUNE, 1991
Alberta Geological Survey
Alberta Research Council
Fort McMurray
Grande Prairie
Edmonton
Red Deer
Calgary
Medicine Hat
Lethbridge
Drumheller Subcrop



MAP # 3C

TOTAL CUMULATIVE COAL DRUMHELLER/RED WILLOW COAL ZONES

CONTOUR INTERVAL 2 METRES

SCALE 1:750000

x WELL LOCATION

TO ACCOMPANY: REGIONAL EVALUATION OF THE COAL BED METHANE POTENTIAL IN THE PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY

JUNE, 1991

Alberta Geological Survey
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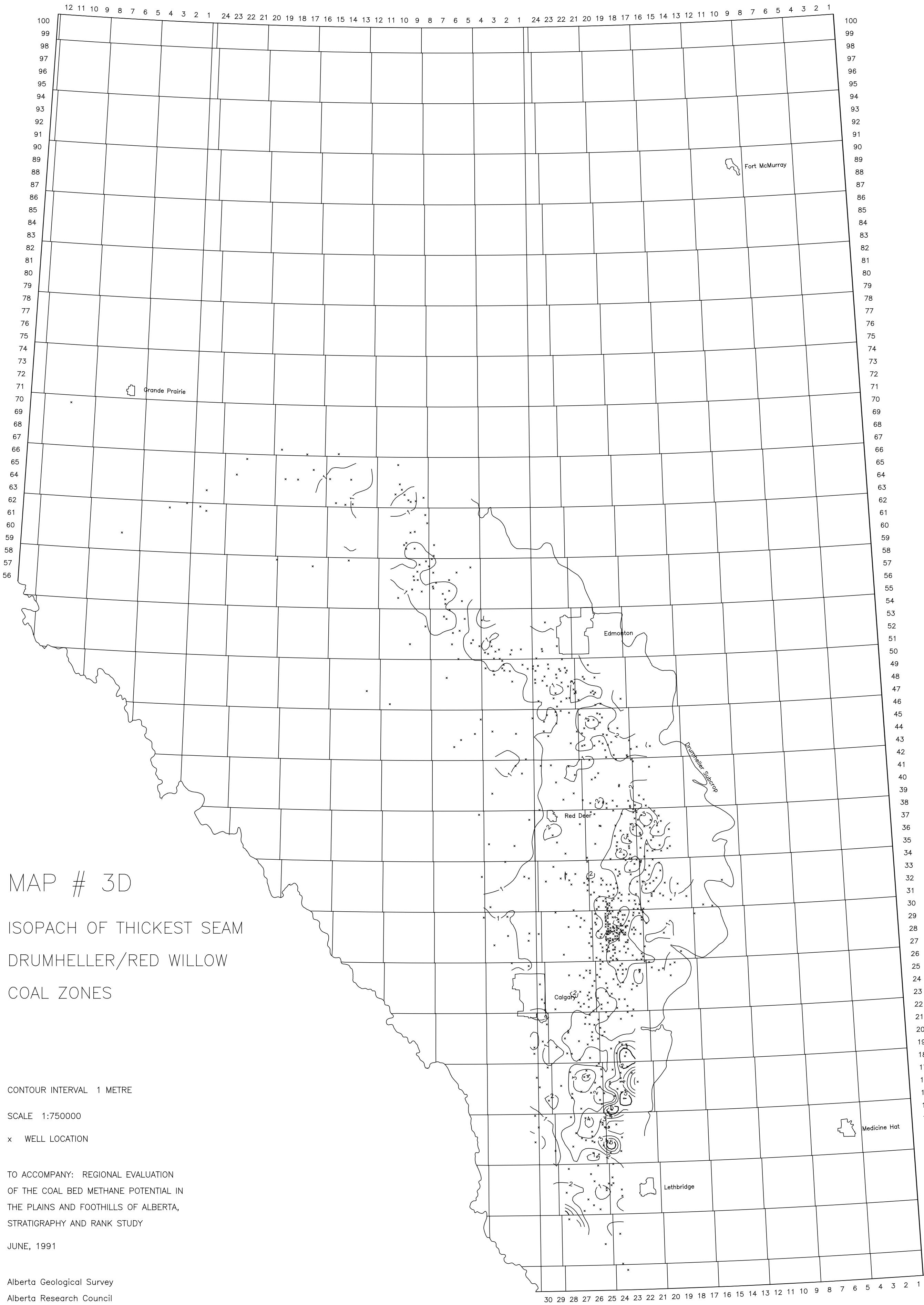
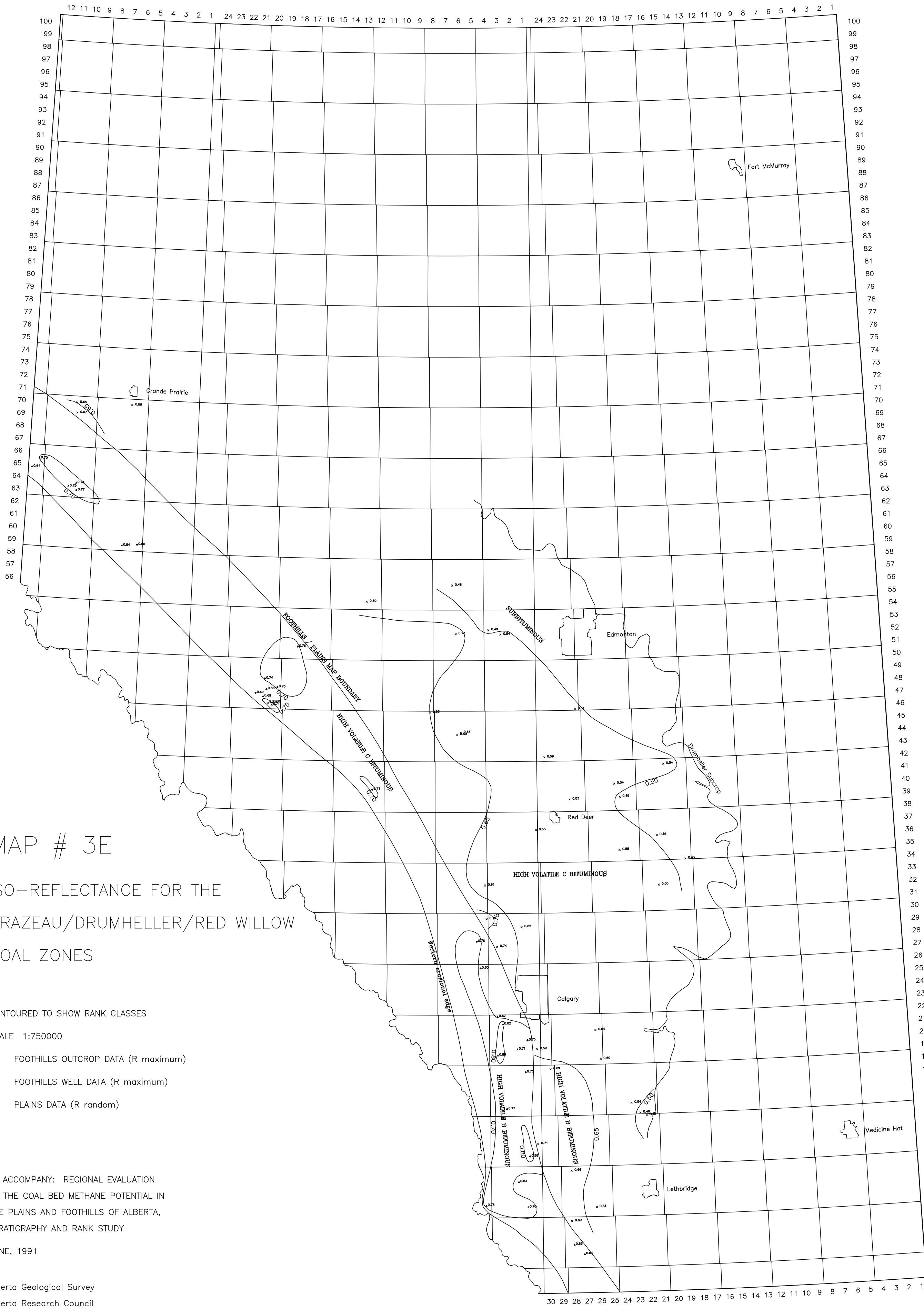


MAP # 3D
ISOPACH OF THICKEST SEAM
DRUMHELLER/RED WILLOW
COAL ZONES
CONTOUR INTERVAL 1 METRE
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
STRATIGRAPHY AND RANK STUDY
JUNE, 1991
Alberta Geological Survey
Alberta Research Council
Fort McMurray
Grande Prairie
Edmonton
Drumheller Subcrop
Red Deer
Calgary
Medicine Hat
Lethbridge



MAP # 3E

ISO—REFLECTANCE FOR THE BRAZEAU/DRUMHELLER/RED WILLOW COAL ZONES

CONTOURED TO SHOW RANK CLASSES

SCALE 1:750000

- FOOTHILLS OUTCROP DATA (R maximum)
- FOOTHILLS WELL DATA (R maximum)
- PLAINS DATA (R random)

TO ACCOMPANY: REGIONAL EVALUATION OF THE COAL BED METHANE POTENTIAL IN THE PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY

JUNE, 1991

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were available in the data set. The of the range of values are from subbituminous B at 0.43% to high-vol A at 0.80% R_{mean}. Most of the coals fall in the High-volatile C bituminous rank.

15.4 Lethbridge Coal Zone

The data distribution for the coal zone is excellent in the south but is poor north and west of Red Deer and towards the disturbed belt (769 data sites in data set). The coal zone is present west of the subcrop edge between Twps. 1 and 67, Ranges 1 W4M to 18 W5M. The coal zone is particularly hard to trace north west of Edmonton and is present in widely scattered seams (see cross-sections). The coal zone has been removed by erosion over the Sweetgrass Arch. It is present along the eastern flank in the area of the Cypress Hills.

15.4.1 Depth to Top of Coal Zone

On this map the coal zone is shown to dip from the subcrop edge (5.3 m) to more than 2000 metres (maximun 2284 m) along the disturbed belt south of Calgary. Most of the coal falls between 300 and 600 metres in depth. Contour interval is 100 metres and reflects basin structure, in particular the Cypress Hills and the deep basin to the west. It should be noted that towards the north the Drumheller/Cutbank and the Lethbridge coal zones converge.

15.4.2 Isopach of Coal Zone

Over most of the map area the coal zone is shown to be less than 10 metres thick (minimum 0.2 m, maximum 83.8 m). This thin coal zone embodies only one or two adjacent seams at most sites. Contour interval is 10 metres.

15.4.3 Total Cumulative Coal

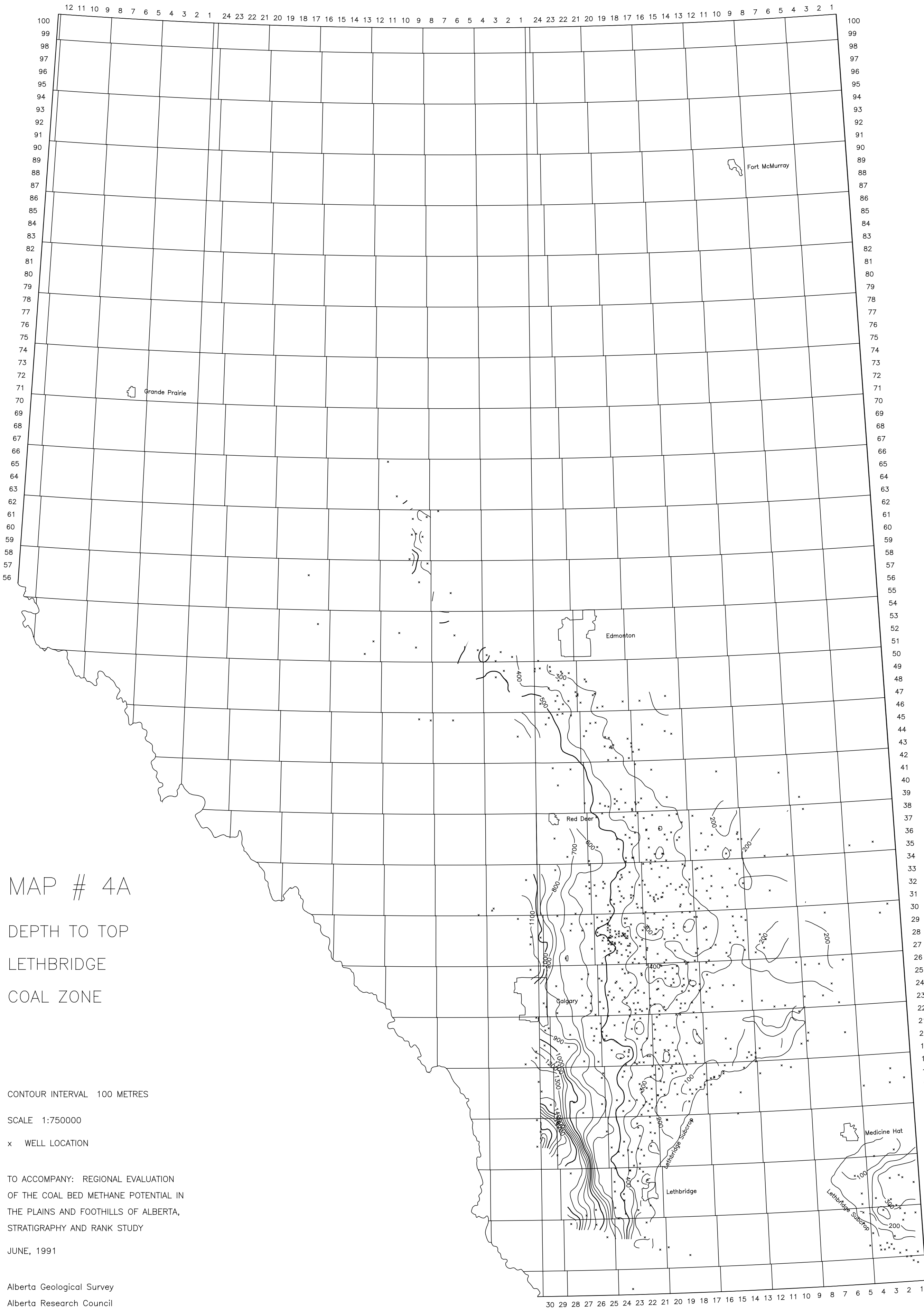
Total cumulative coal varies from 1 to 3 metres in the coal zone. This coal zone TCC is generally small but (very) local thickening of seams is known to occur (minimum 0.2 m, maximum 6.1 m). The contour interval is 1 metre.

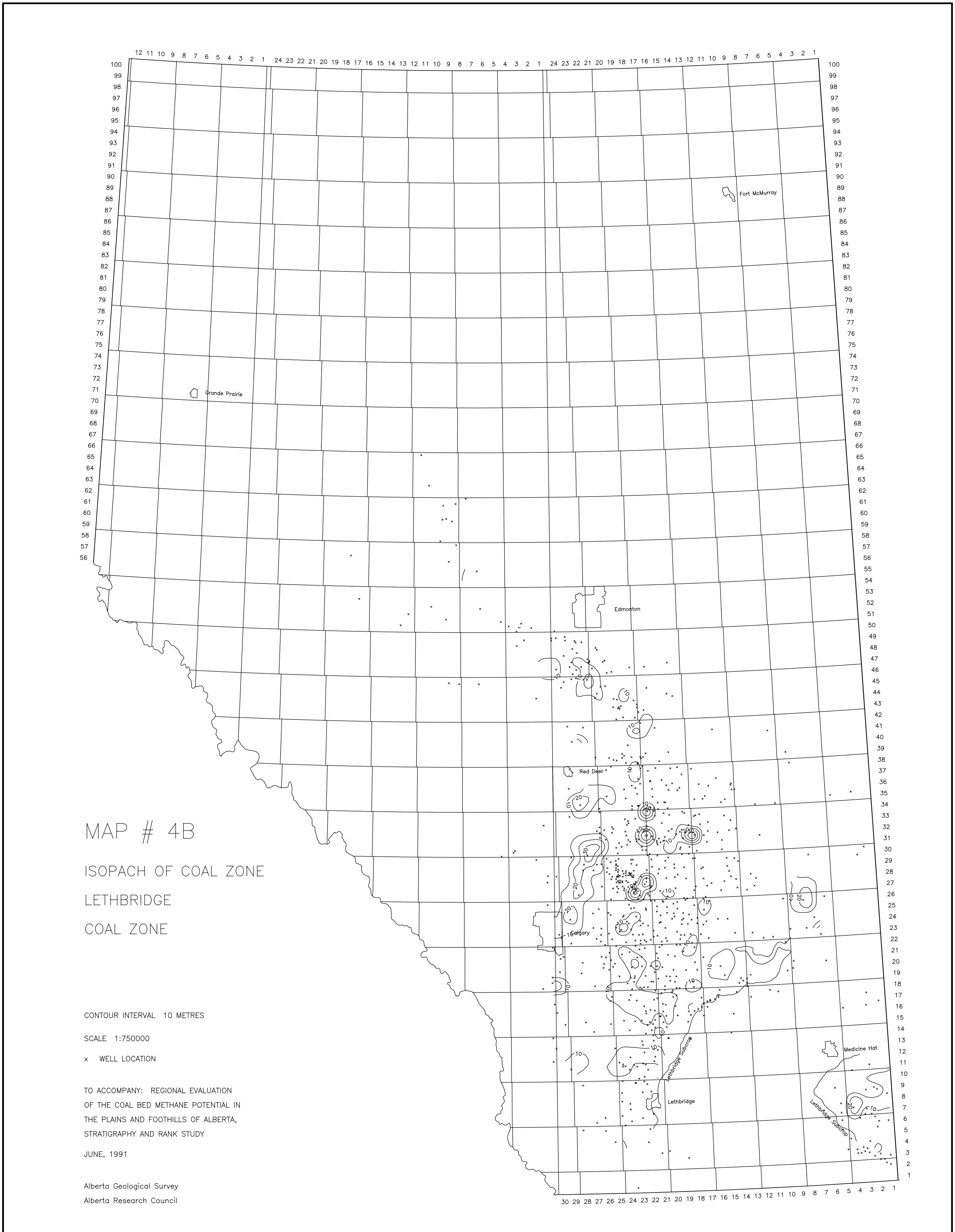
15.4.4 Isopach of Thickest Seam

The thickest seams over much of the area range between over 1 and less than 2 metres. Large areas have thickest seams of less than 1 metre (minimum 0.2 m, maximum 3 m). The contour interval is 1 metre.

15.4.5 Iso-Reflectance map (Lethbridge, Taber McKay)

Since the data distribution for each of the Belly River coal zones is sparse and the range of reflectance values is narrow; the data has been combined into one map. The number of combined sites was 112 with124 samples from the Lethbridge, 19 from the Taber, and 94 from the McKay. Data from the Taber and McKay can be found in the east and in the area of the Cypress Hills where the Lethbridge coalk zone is missing. In that area the coals are subituminous C in rank (minimum R_{mean} 0.37%, lignite) Towards the west, near the disturbed belt, data from the McKay coal zone range within High-Vol. B Bituminous in rank (maximum R_{mean} 0.77%, high-vol. A bit.). Even with the the combined coal zone data the distribution is uneven and clustered. Some of the tortuous contour pattern may be related to the use of three coal zones or poor data distribution or different geo-thermal gradients in some areas.


MAP # 4A
DEPTH TO TOP
LETHBRIDGE
COAL ZONE
CONTOUR INTERVAL 100 METRES
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
STRATIGRAPHY AND RANK STUDY
JUNE, 1991
Alberta Geological Survey
Alberta Research Council
Fort McMurray
Grande Prairie
Edmonton
Red Deer
Calgary
Medicine Hat
Lethbridge
Lethbridge Subcrop
Lethbridge Subcrop


Fort McMurray
Grande Prairie
Edmonton
Red Deer
Calgary
Lethbridge Subcrop
Lethbridge
Medicine Hat
MAP # 4B
ISOPACH OF COAL ZONE
LETHBRIDGE
COAL ZONE
CONTOUR INTERVAL 10 METRES
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
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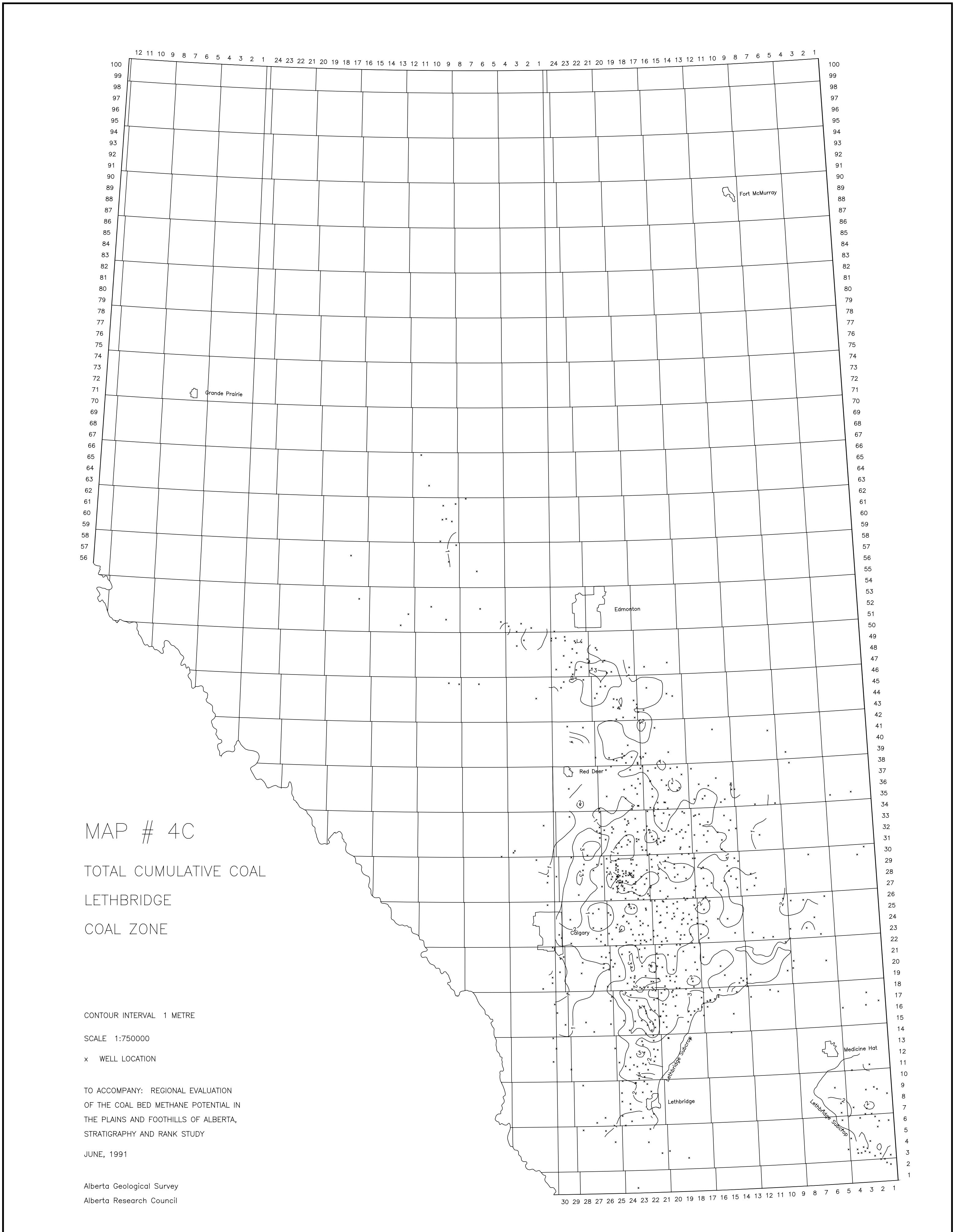
MAP # 4C
TOTAL CUMULATIVE COAL
LETHBRIDGE
COAL ZONE
CONTOUR INTERVAL 1 METRE
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
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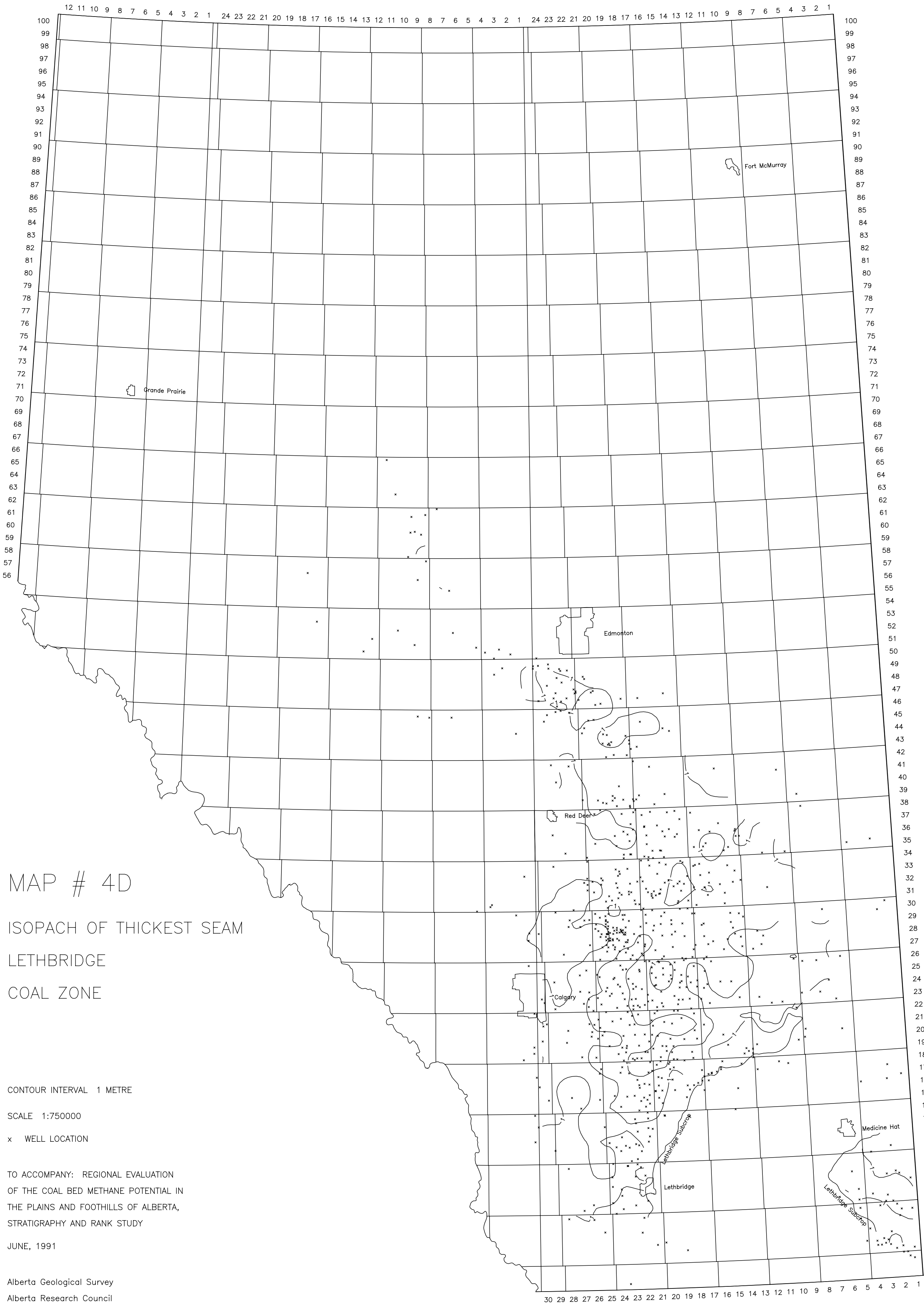
Alberta Geological Survey
Alberta Research Council
Fort McMurray
Grande Prairie
Edmonton
Red Deer
Calgary
Lethbridge
Medicine Hat
Lethbridge Subcrop


MAP # 4D
ISOPACH OF THICKEST SEAM
LETHBRIDGE
COAL ZONE
CONTOUR INTERVAL 1 METRE
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
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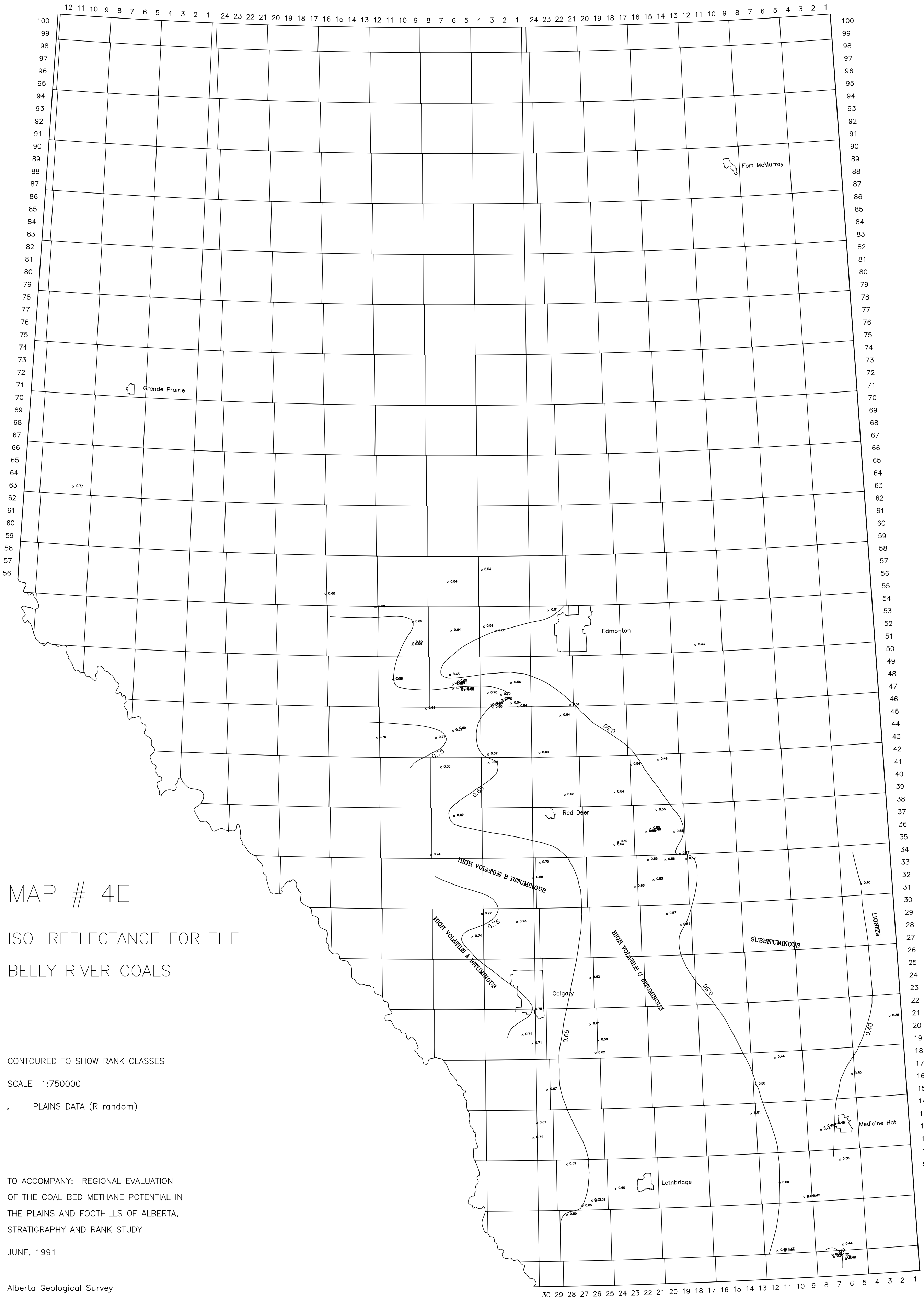
Alberta Geological Survey
Alberta Research Council
Fort McMurray
Grande Prairie
Edmonton
Red Deer
Calgary
Lethbridge
Lethbridge Subcrop
Medicine Hat


MAP # 4E
ISO-REFLECTANCE FOR THE
BELLY RIVER COALS
CONTOURED TO SHOW RANK CLASSES
SCALE 1:750000
x PLAINS DATA (R random)
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
STRATIGRAPHY AND RANK STUDY
JUNE, 1991
Alberta Geological Survey
Alberta Research Counci
Fort McMurray
Grande Prairie
Edmonton
Red Deer
Calgary
Lethbridge
Medicine Hat
HIGH VOLATILE B BITUMINOUS
HIGH VOLATILE A BITUMINOUS
HIGH VOLATILE C BITUMINOUS
SUBBITUMINOUS
LIGNITE
0.75
0.65
0.50
0.40

Support for the later suggestion is supported in that some of the deepest coals are in the southwestern part of the map area where reflectance levels are no greater than reflectance levels west of Edmonton where the coals are very shallow.

15.5 Taber Coal Zone

The coal zone is present west of the subcrop edge between Twps. 1 and 64, Ranges 1 W4M to 11 W5M. The data distribution for the coal zone is excellent in the southeastern part of the province and extending in a 10 township wide band northwest of Edmonton to about Twp. 64. Very little data is available in the west toward the disturbed belt as the coal zone thins and only scattered thin seams are present. The coal zone has been removed by erosion over the Sweetgrass Arch near the U.S. border. It is present along the eastern flank in the area of the Cypress Hills.

15.5.1 Depth to Top of Coal Zone

On this map the coal zone is shown to dip from the subcrop edge (2.7 m) to more than 600 metres east of Calgary (one site north of Calgary at 1335.4 m depth may be anomalous). Most of the coal is less than 500 metres in depth. Contour interval is 100 metres and reflects basin structure particularly the Sweetgrass Arch. Surface topography of the Cypress Hills is well displayed on this map.

15.5.2 Isopach of Coal Zone

On this map the coal zone is shown to range from 10 to 40 metres with large areas greater than 10 and less than 30 metres (minimum 0.1 m, maximum 71.9 m). North of Edmonton the zone is thinner. Contour interval is 10 metres.

15.5.3 Total Cumulative Coal

Total cumulative coal varies from 1 to 3 metres over most of the area with some areas near Medicine Hat having more than 6 metres TCC (minimum 0.1 m, maximum 7.4 m). The contour interval is 1 metre.

15.5.4 Isopach of Thickest Seam

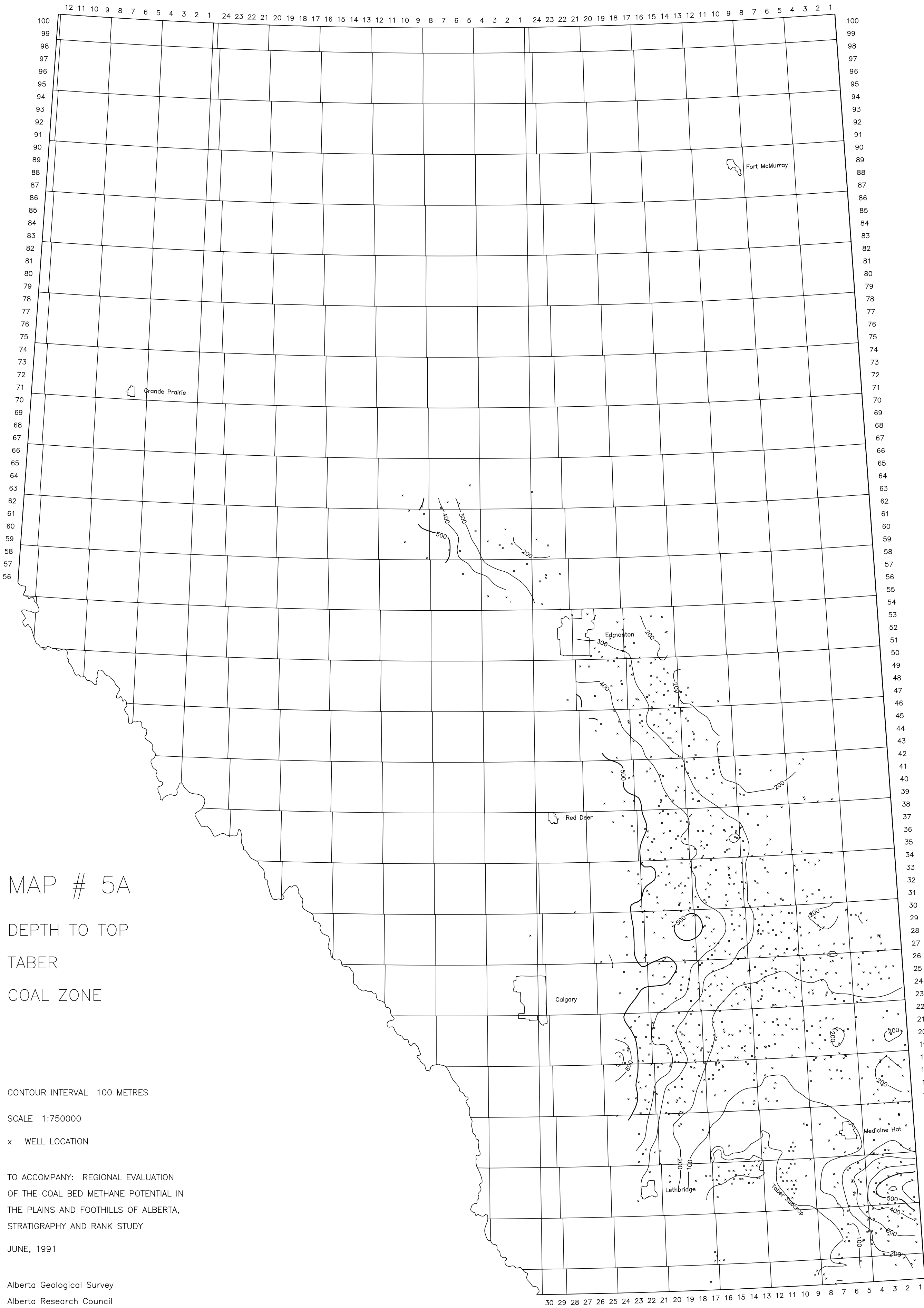
The thickest seams over much of the area range between over 1 and less than 2 metres (minimum 0.1 m, maximum 3 m). Large areas have thickest seams of less than 1 metre.

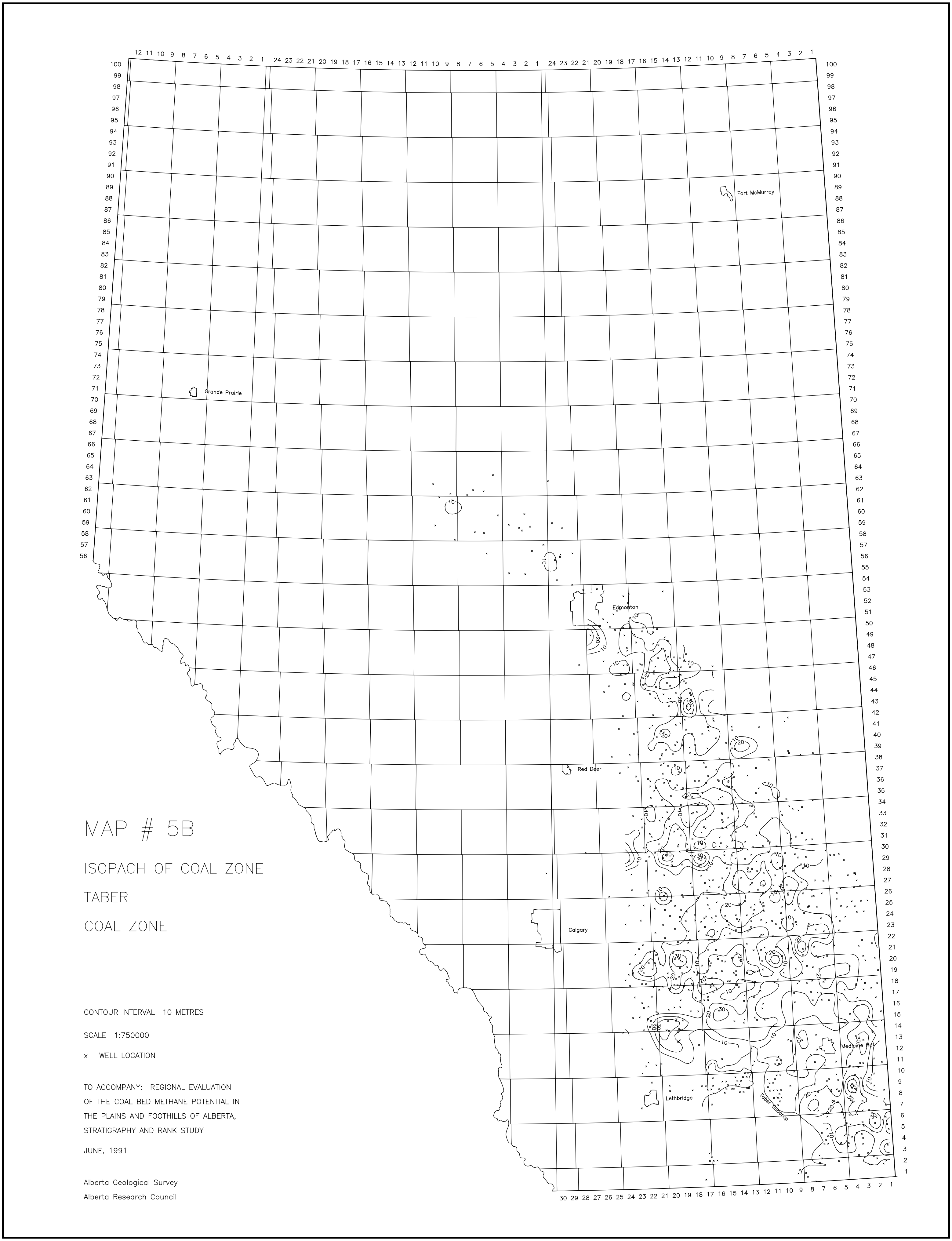
15.6 McKay Coal Zone

The coal zone is present between Twps. 1 and 69, Ranges 1 W4M to 12 W5M. A total of 1402 data points were used in generating these maps. The data distribution for the coal zone is excellent over much of the province but very little data is available in the west toward the disturbed belt as the coal zone thins and only scattered thin seams are present. Fewer data sites are available over the Sweetgrass Arch.

15.6.1 Depth to Top of Coal Zone

On this map the coal zone is shown to dip (subcrop edge, 1.8 m) to more than 2300 metres (maximum 2369.8 m) south of Calgary. Contour interval is 100 metres and reflects basin structure; particularly the


MAP # 5A
DEPTH TO TOP
TABER
COAL ZONE
CONTOUR INTERVAL 100 METRES
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
STRATIGRAPHY AND RANK STUDY
JUNE, 1991
Alberta Geological Survey
Alberta Research Council
Fort McMurray
Grande Prairie
Edmonton
Red Deer
Calgary
Lethbridge
Medicine Hat
Taber Subcrop



MAP # 5B
ISOPACH OF COAL ZONE
TABER
COAL ZONE
CONTOUR INTERVAL 10 METRES
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
STRATIGRAPHY AND RANK STUDY
JUNE, 1991
Alberta Geological Survey
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Edmonton
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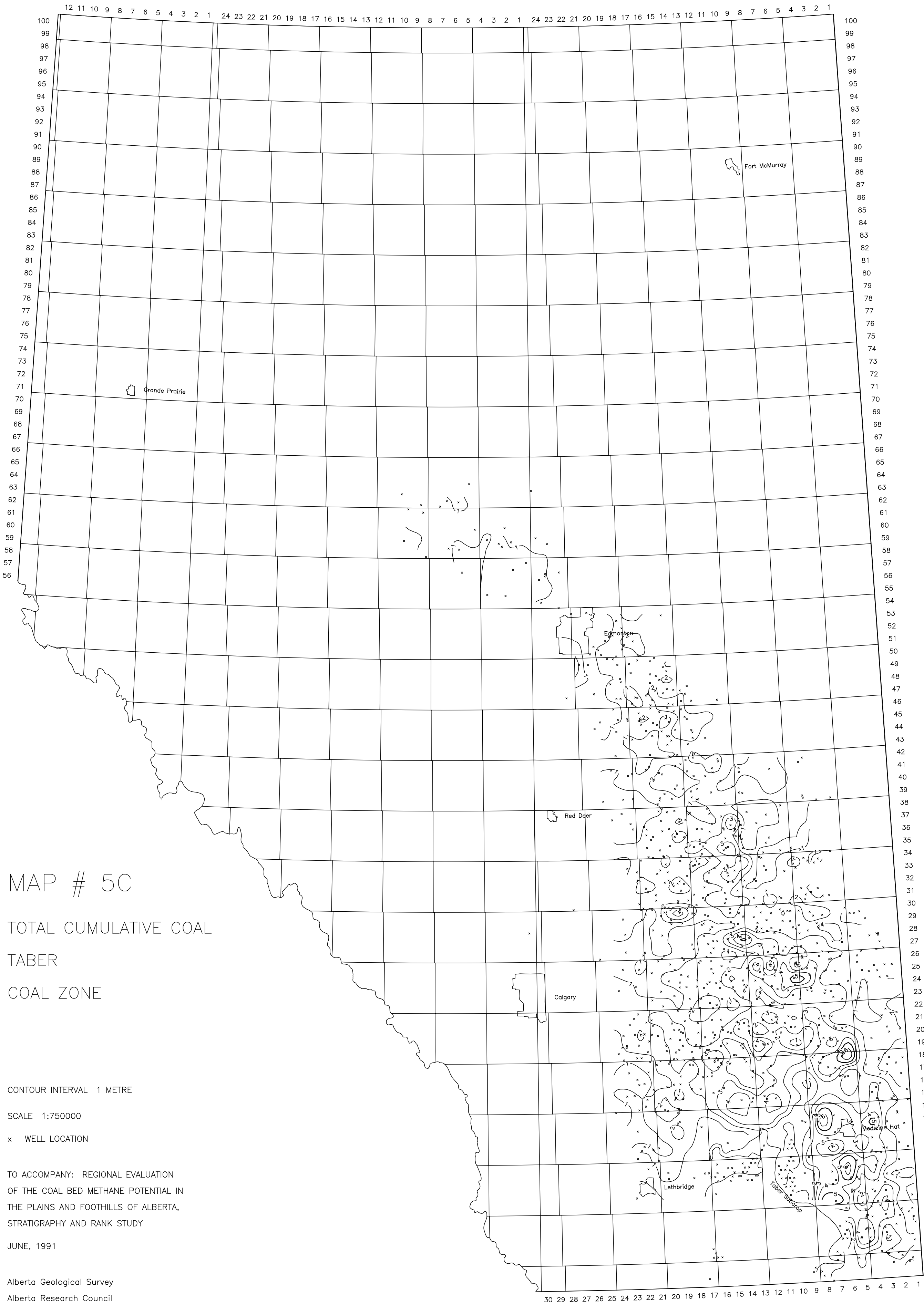
Calgary
Lethbridge
Medicine Hat
Taber Subcrop



MAP # 5C

TOTAL CUMULATIVE COAL

TABER

COAL ZONE

CONTOUR INTERVAL 1 METRE

SCALE 1:750000

x WELL LOCATION

TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
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JUNE, 1991

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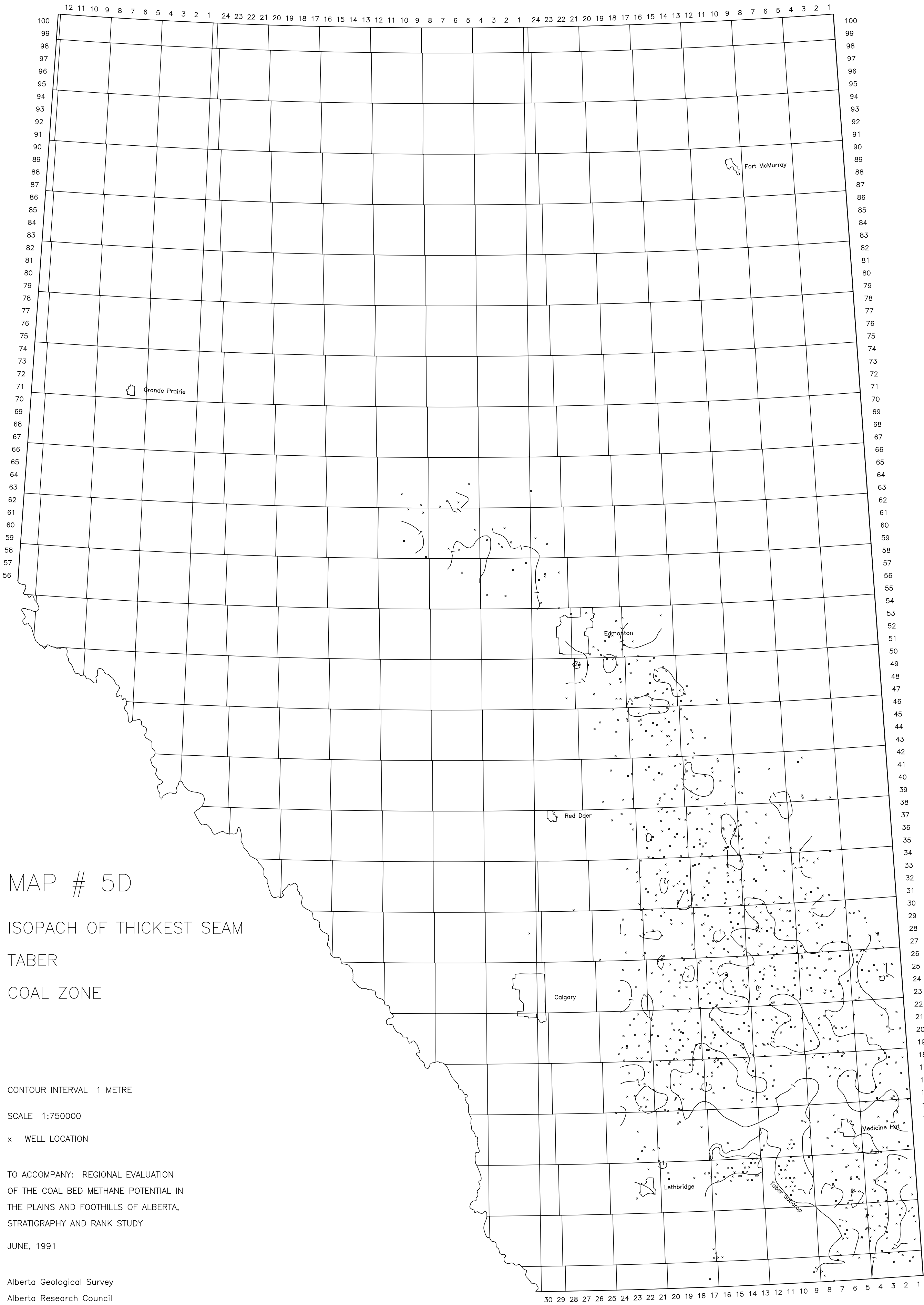

MAP # 5D

ISOPACH OF THICKEST SEAM

TABER

COAL ZONE

CONTOUR INTERVAL 1 METRE

SCALE 1:750000

x WELL LOCATION

TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
STRATIGRAPHY AND RANK STUDY

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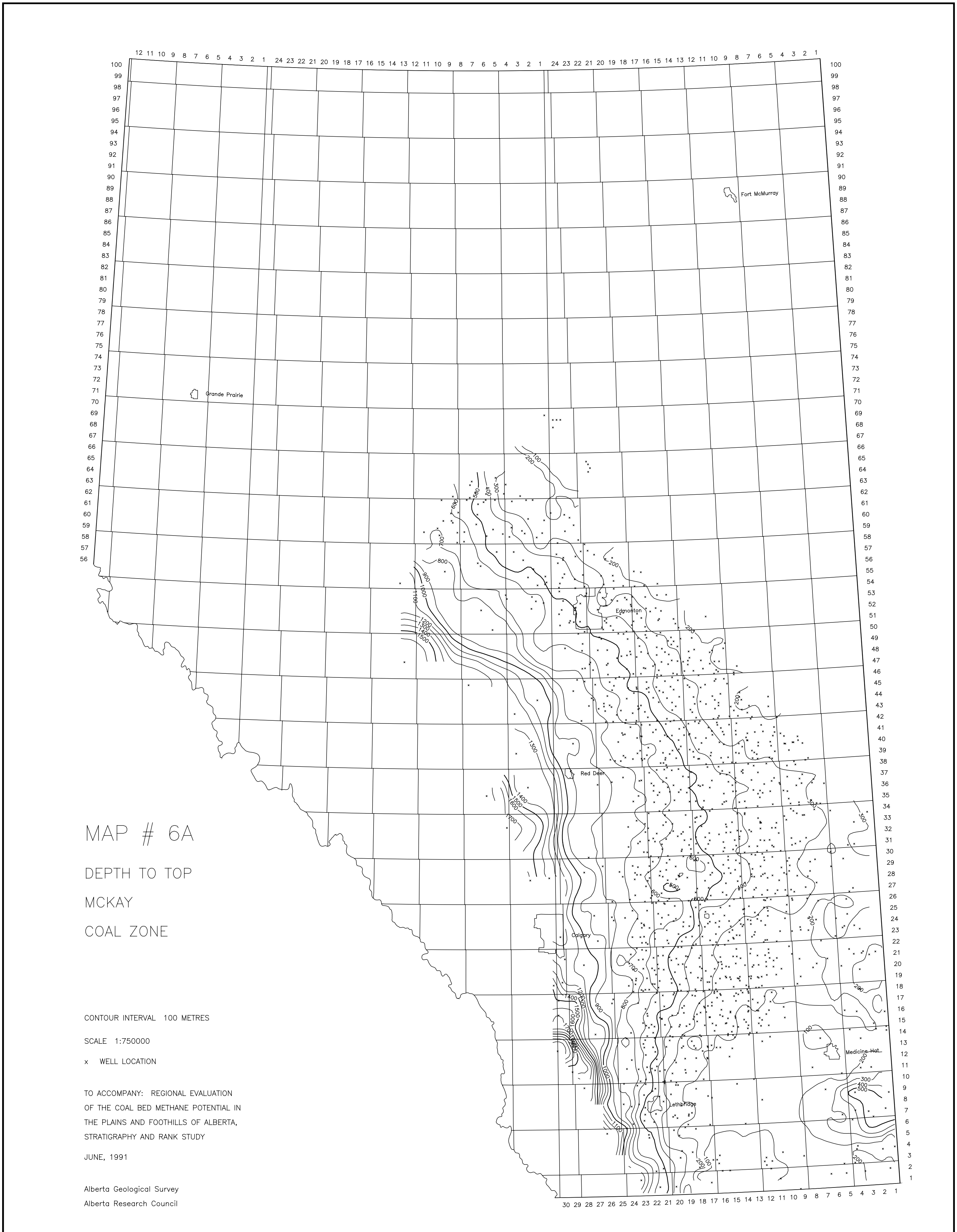

MAP # 6A
DEPTH TO TOP
MCKAY
COAL ZONE
CONTOUR INTERVAL 100 METRES
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
STRATIGRAPHY AND RANK STUDY
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Alberta Geological Survey
Alberta Research Council
Fort McMurray
Grande Prairie
Edmonton
Red Deer
Calgary
Medicine Hat
Lethbridge

Sweetgrass Arch. Surface topography of the Cypress Hills is also well displayed on this map.

15.6.2 Isopach of Coal Zone

On this map the coal zone is shown to range from 10 to 40 metres with large areas greater than 10 and less than 20 metres (minimum 0.13 m, maximum 72.8 m). West of Twp. 24 W4M the coal zone thins. Contour interval is 10 metres.

15.6.3 Total Cumulative Coal

Total cumulative coal varies from 1 to 3 metres over most of the area with some areas near Medicine Hat having more than 4 metres TCC (maximum 6.6 m). The contour interval is 1 metre.

15.6.4 Isopach of Thickest Seam

The thickest seams over much of the area range between over 1 and less than 2 metres (maximum 3.0 m). The majority of the area have thickest seams of less than 1 metre (minimum 0.13 m.).

15.7 Upper Mannville/Falher Coal Zones

A total of 1673 data points were used in generating these maps. The data distribution for the coal zone is excellent, even towards the disturbed belt. The coal zone is present from the Saskatchewan border between Twps. 14 and 76, Ranges 1 W4M to 13 W6M. Areally this is the most extensive coal zone in Alberta and large by world standards.

15.7.1 Depth to Top of Coal Zone

On this map the coal zone is shown to dip from 264 metres in the northeast to more than 2900 metres (maximum 3590 m.) along the disturbed belt. Contour interval is 100 metres and reflects mainly basin structure (the Swan Hills can be detected on the map).

15.7.2 Isopach of Coal Zone

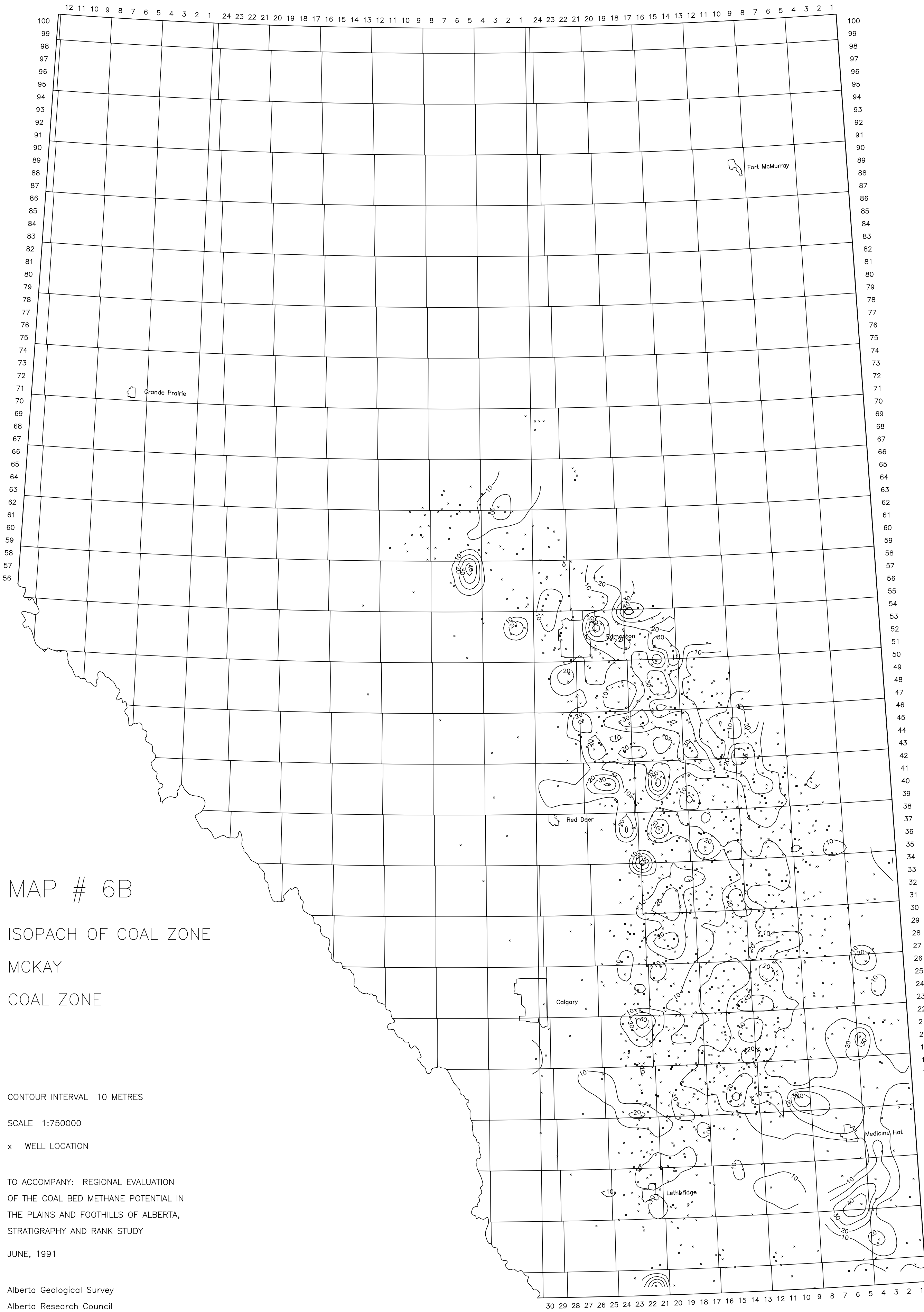
On this map the coal zone is shown to thicken to more than 180 metres in the deep basin in the northwest (minimum 0.2 to 200.5 metres). This thickening is related to a larger number of seam and seam separation in this area. Contour interval is 20 metres.

15.7.3 Total Cumulative Coal

The area with the greatest total cumulative coal, between 6 and 12 metres, is located in the Red Deer area. Other areas with large TCC can be found near the edge of the deformed belt and in the deep basin in the northwest. TCC ranges from 0.2 to 16.5 metres; however over most of this extensive area TCC is between 2 and 6 metres and the total volume of coal is enormous. The contour interval on the map is 2 metres.

15.7.4 Isopach of Thickest Seam

Over the map area seams range from 0.2 to 12.2 metres in thickness. The thickest seams range between


MAP # 6B
ISOPACH OF COAL ZONE
MCKAY
COAL ZONE
CONTOUR INTERVAL 10 METRES
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
THE PLAINS AND FOOTHILLS OF ALBERTA,
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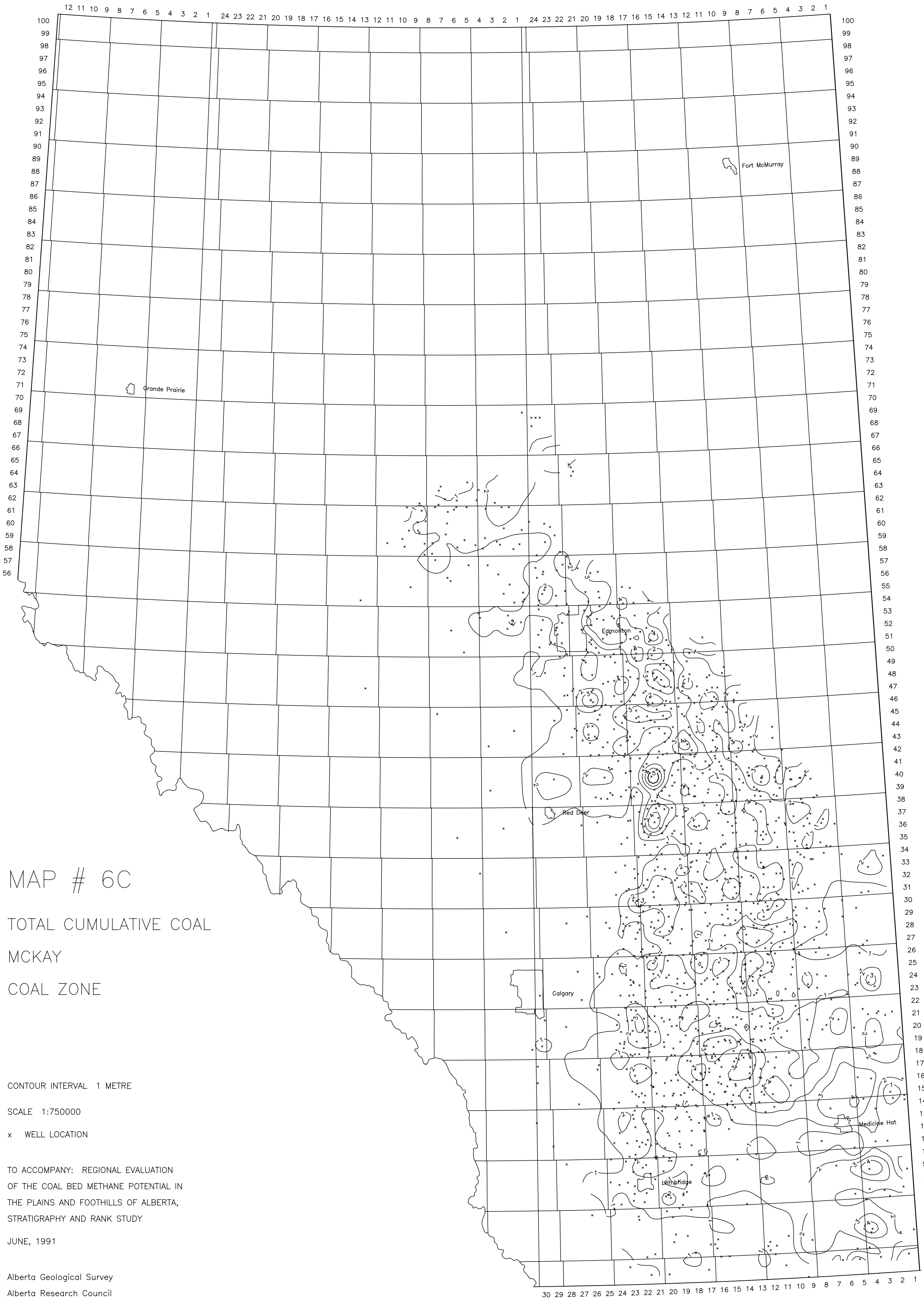
Calgary
Medicine Hat
Lethbridge



MAP # 6C

TOTAL CUMULATIVE COAL

MCKAY

COAL ZONE

CONTOUR INTERVAL 1 METRE

SCALE 1:750000

x WELL LOCATION

TO ACCOMPANY: REGIONAL EVALUATION
OF THE COAL BED METHANE POTENTIAL IN
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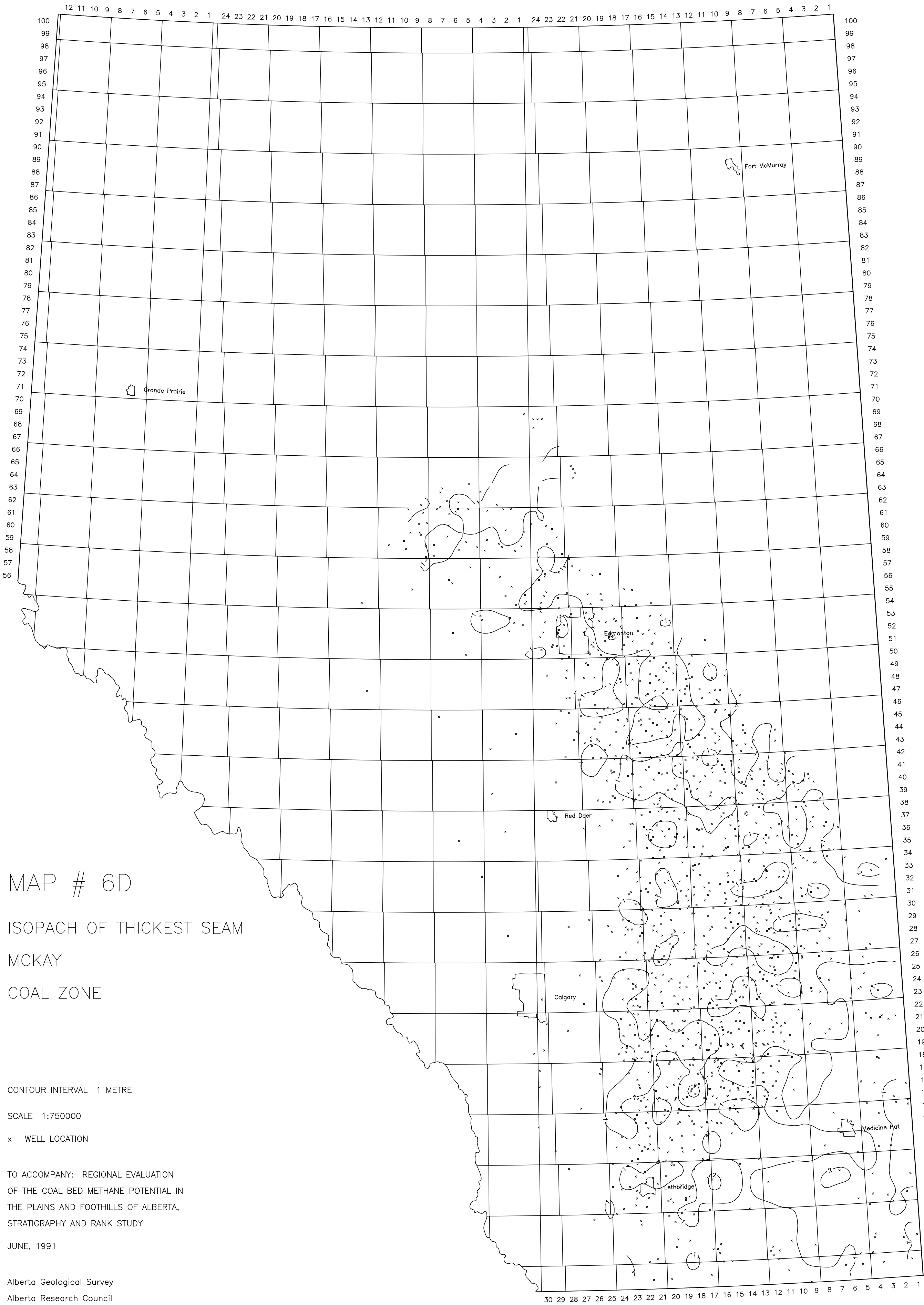

MAP # 6D

ISOPACH OF THICKEST SEAM

MCKAY

COAL ZONE

CONTOUR INTERVAL 1 METRE

SCALE 1:750000

x WELL LOCATION

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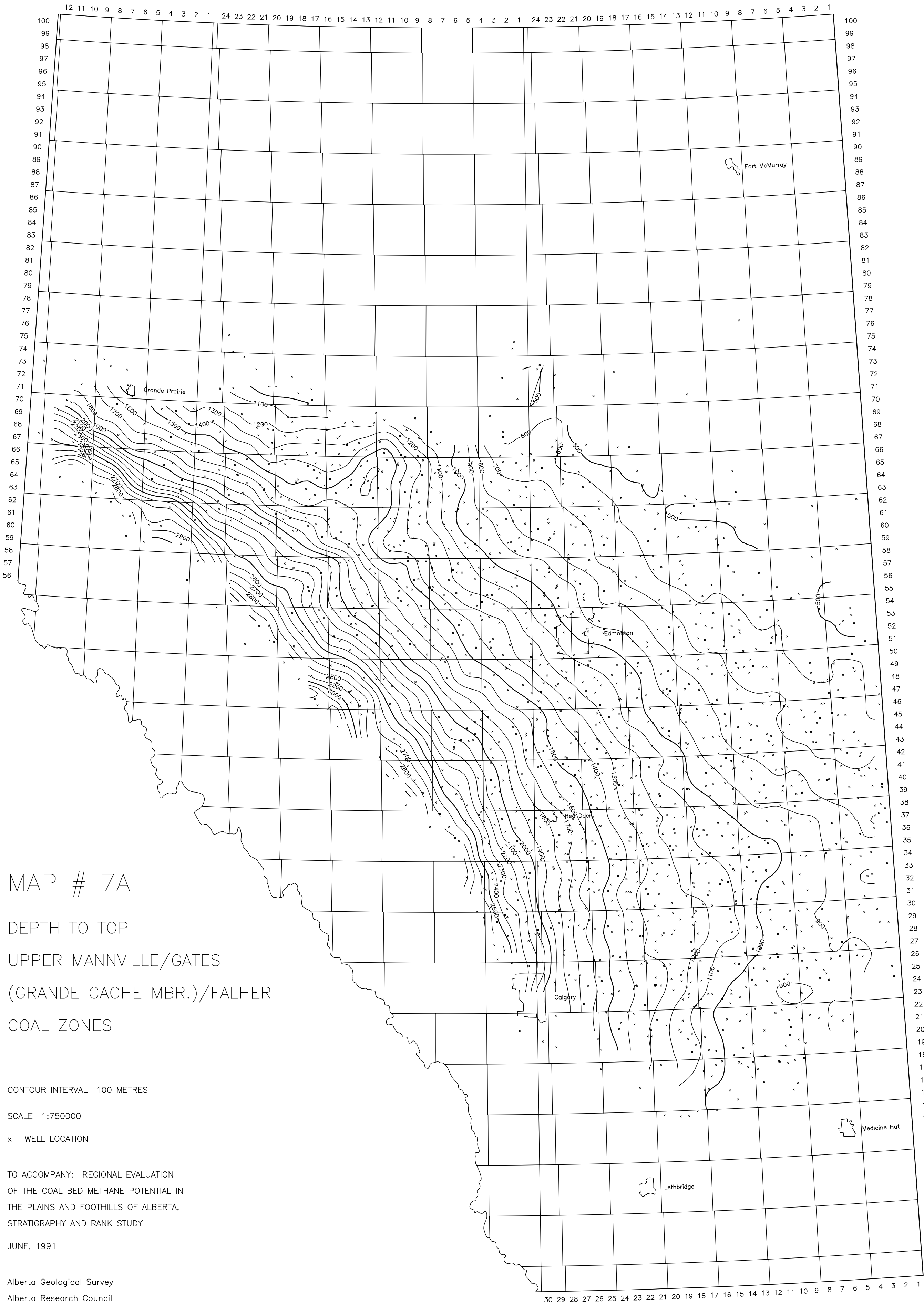

MAP # 7A
DEPTH TO TOP
UPPER MANNVILLE/GATES
(GRANDE CACHE MBR.)/FALHER
COAL ZONES
CONTOUR INTERVAL 100 METRES
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
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Grande Prairie
Edmonton
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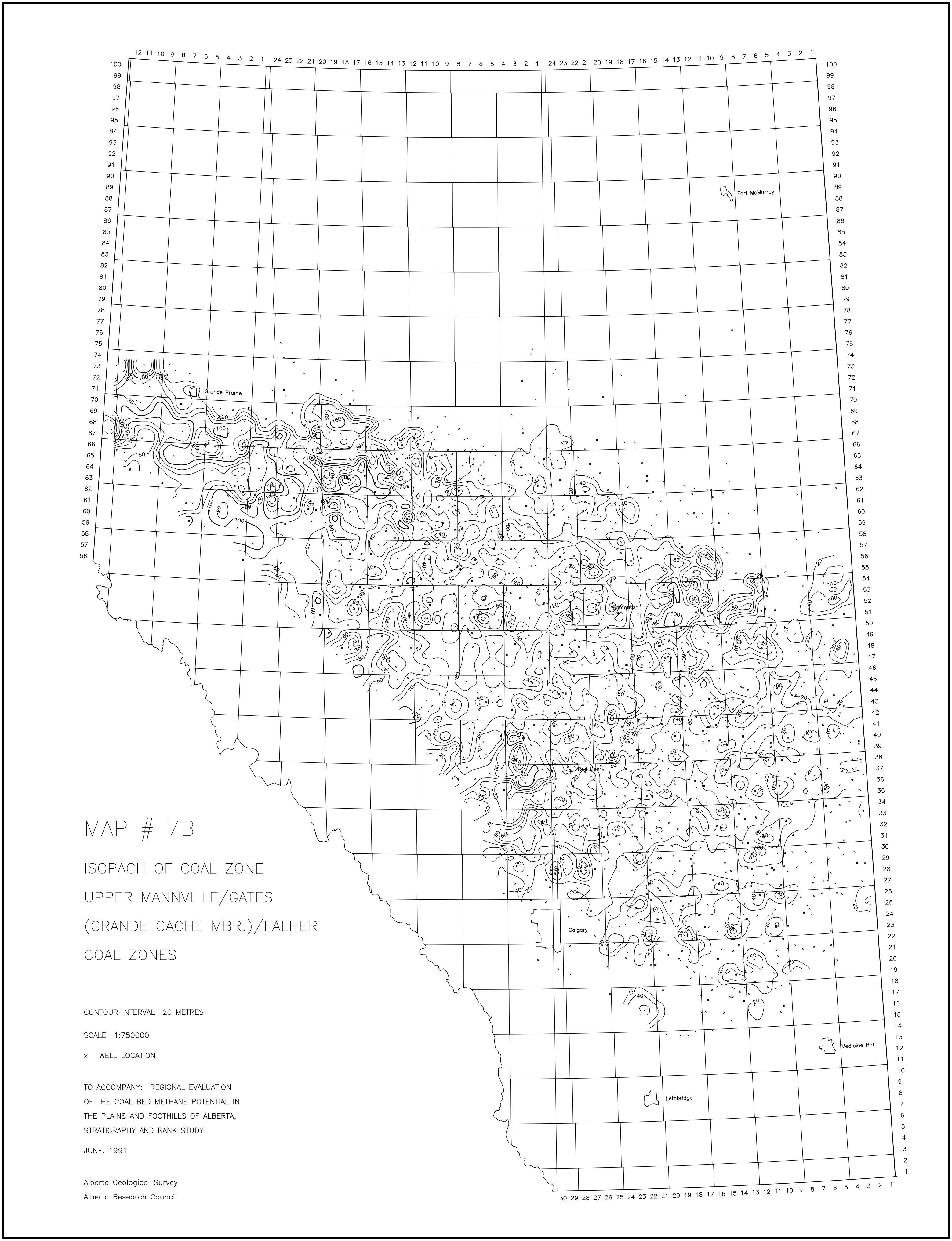
Medicine Hat
Lethbridge



Fort McMurray
Grande Prairie
Edmonton
Red Deer
Calgary
Medicine Hat
Lethbridge
MAP # 7B
ISOPACH OF COAL ZONE
UPPER MANNVILLE/GATES
(GRANDE CACHE MBR.)/FALHER
COAL ZONES
CONTOUR INTERVAL 20 METRES
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
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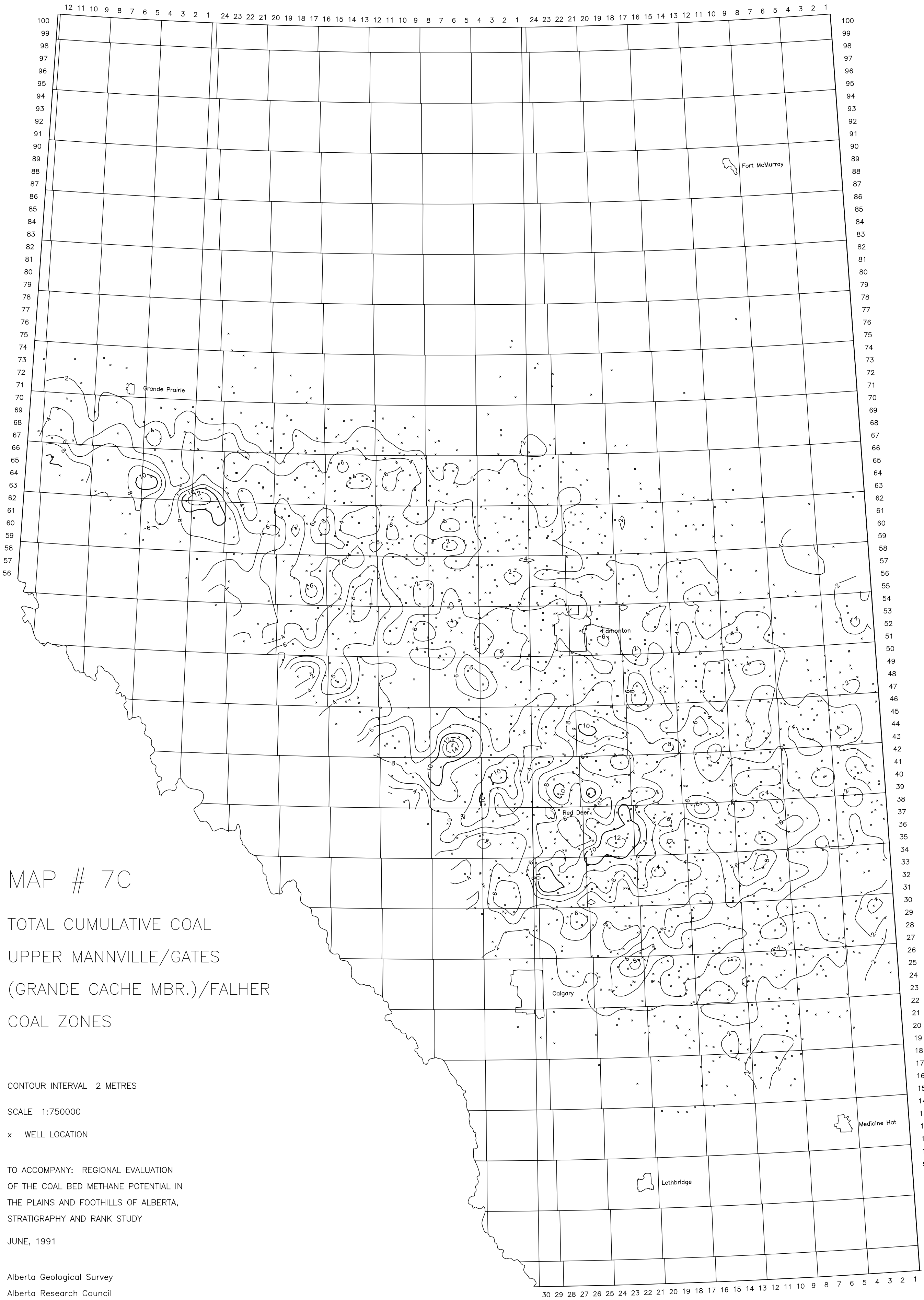

MAP # 7C
TOTAL CUMULATIVE COAL
UPPER MANNVILLE/GATES
(GRANDE CACHE MBR.)/FALHER
COAL ZONES
CONTOUR INTERVAL 2 METRES
SCALE 1:750000
x WELL LOCATION
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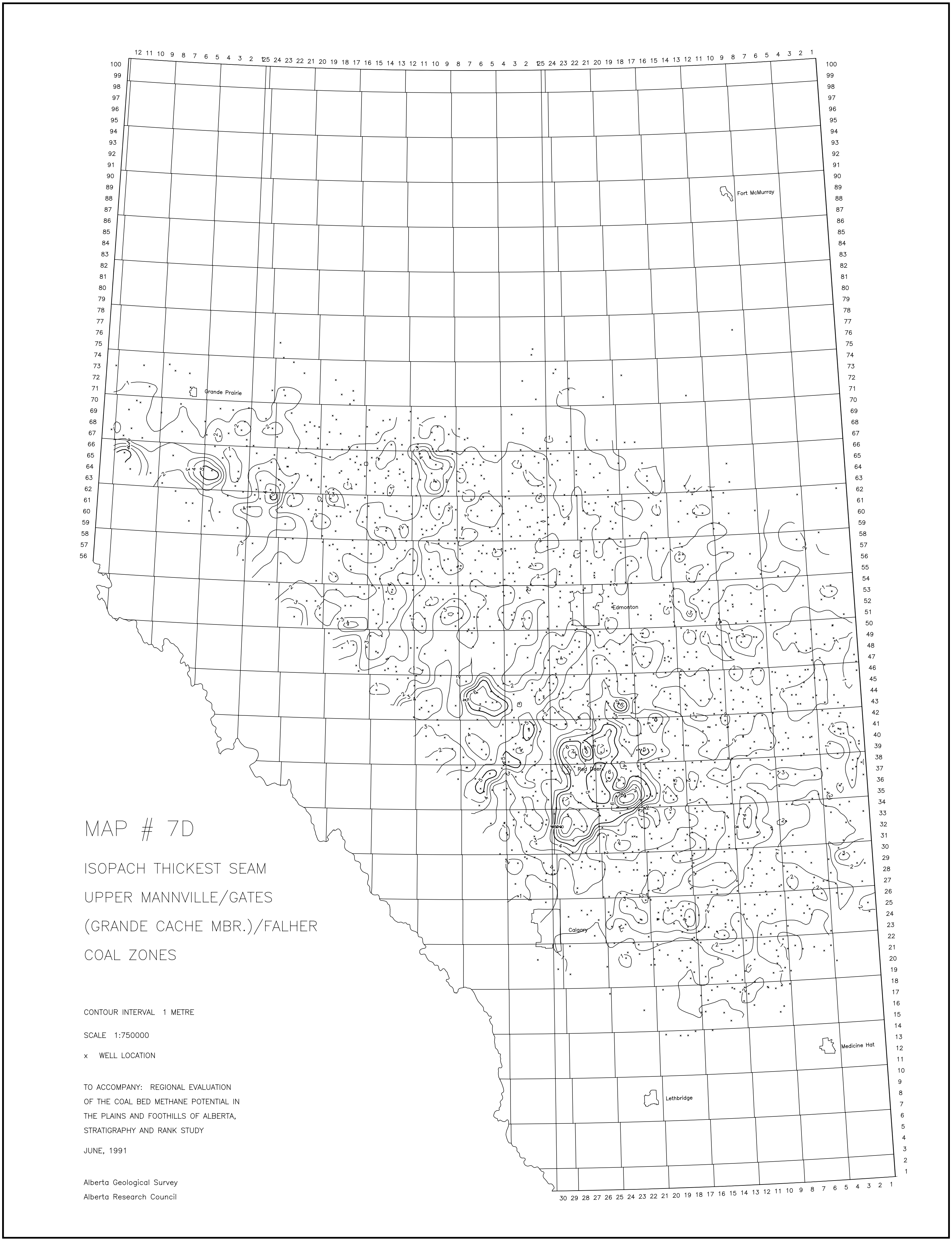

MAP # 7D
ISOPACH THICKEST SEAM
UPPER MANNVILLE/GATES
(GRANDE CACHE MBR.)/FALHER
COAL ZONES
CONTOUR INTERVAL 1 METRE
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
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2 and 4 metres. The area with the greatest seam thickness values is centered on the Red Deer area. In general areas with the greatest TCC had also the greatest thickest seam values. Contour interval is 1 metre.

15.7.5 Iso-Reflectance Map

The upper Mannville/Falher coal zone provides the best reflectance data for coals in the Alberta basin (total of 498 sites, 755 samples). In the east and northeast the coal ranges in rank from lignite to subbituminous C and B rank (minimum R_{mean} 0.28%). In the deep basin, to the north west and along the disturbed belt, medium-volatile to low-volatile bituminous coals are found (some as high rank as semi anthracite; (maximum R_{mean} 2.13%). A broad band of coals with reflectance values between 0.50 and 0.80% can be seen in the central part of the map area. This band may contain values that have been depressed from 0.1 to 0.4% (see discussion on factors influencing reflectance values in appendix). Differences in geothermal gradient may have also affected the reflectance values. The area south of Twp. 25 appears depressed and may be related to a lower geothermal gradient. An anomalous data point, (R_{mean} 1.18%), in Tp. 35 R. 4 W4 was remeasured and gave a substantially lower value of R_{mean} 0.75%. It appears the coals have been badly oxidized and this data point should be regarded as unreliable.

15.8 Gething/Firebag Coal Zones

A total of 125 data points were used in generating these maps. The data distribution for the coal zone is good since the area of the two coal zones is restricted. The Gething coal zone is present between Twps. 59 and 82, Ranges 15 W5M to 13 W6M. and is centred on Grande Prairie. The Firebag coal zone is present between Twps. 93 and 100, Ranges 4 W4M to 8 W4M. at scattered sites north of Fort McMurray.

15.8.1 Depth to Top of Coal Zone

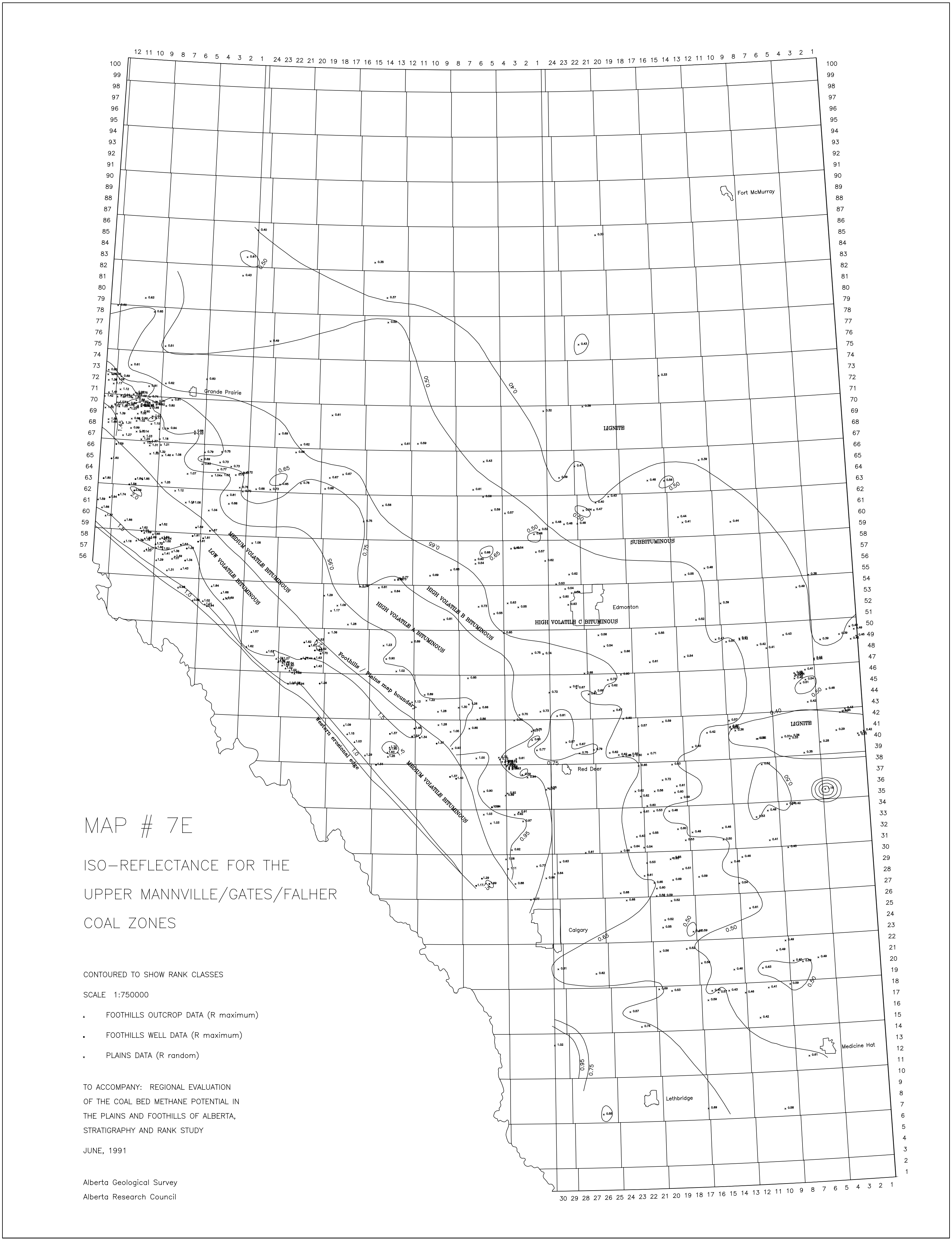
On this map the the shallowest Firebag coal zone data is found at 9.94 metres. The gething coals dip from about 900 metres in the northeast to more than 3500 metres (maximum 3728.4 m.) along the disturbed belt. Contour interval is 100 metres.

15.8.2 Isopach of Coal Zone

On this map the Gething coal zone is shown to thicken to more than 50 metres in the deep basin in the northwest (minimum 0.2 to 194.4 metres). The Firebag coal zone is also highly variable in thickness (minimum 0.31 to 22.86 metres). In the case of the Firebag coal zone this variability is thought to be related to the formation of the thicker coals in salt solution collapse basins. The Gething coal zone varibility is related to increased deposition and subsidence in the deep basin during the coal forming period. Contour interval is 10 metres.

15.8.3 Total Cumulative Coal

The greatest total cumulative coal in the Gething coal zone ranges between 2 and 4 metres (west and north of Grande Prairie), however large areas have TCC values less than 2 metres (minimum 0.2 m to maximum 6.3 m). The Firebag coal zone is highly variable and TCC ranges from 0.31 to 11.28 metres. The contour interval on the map is 2 metres.


MAP # 7E
ISO-REFLECTANCE FOR THE
UPPER MANNVILLE/GATES/FALHER
COAL ZONES
CONTOURED TO SHOW RANK CLASSES
SCALE 1:750000
FOOTHILLS OUTCROP DATA (R maximum)
FOOTHILLS WELL DATA (R maximum)
PLAINS DATA (R random)
TO ACCOMPANY: REGIONAL EVALUATION
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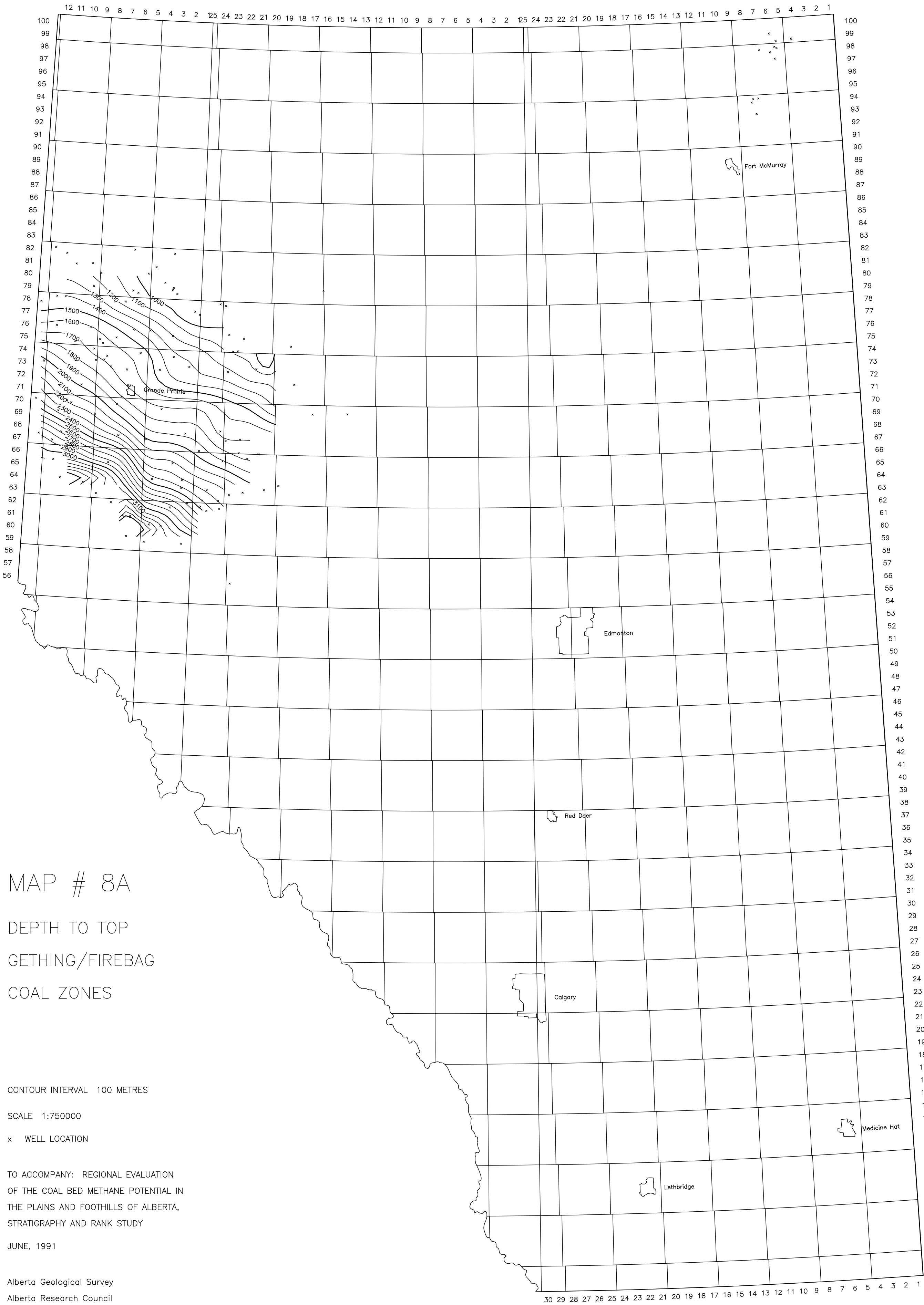
Medicine Hat
Lethbridge
LIGNITE
SUBBITUMINOUS
HIGH VOLATILE C BITUMINOUS
HIGH VOLATILE B BITUMINOUS
HIGH VOLATILE A BITUMINOUS
MEDIUM VOLATILE BITUMINOUS
LOW VOLATILE BITUMINOUS
Foothills / Plains map boundary
Western erosional edge



MAP # 8A

DEPTH TO TOP

GETHING/FIREBAG

COAL ZONES

CONTOUR INTERVAL 100 METRES

SCALE 1:750000

x WELL LOCATION

TO ACCOMPANY: REGIONAL EVALUATION
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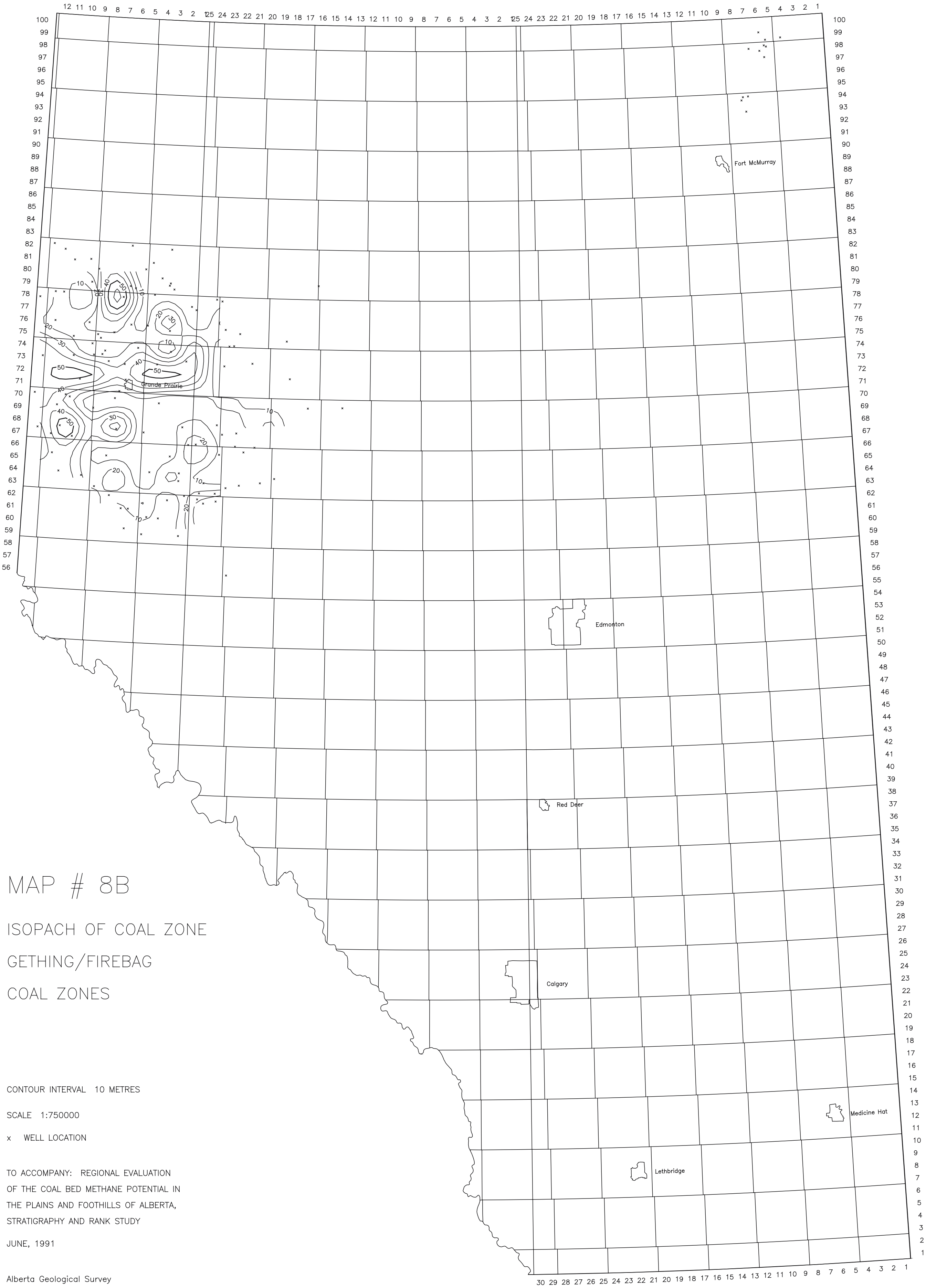

MAP # 8B

ISOPACH OF COAL ZONE
GETHING/FIREBAG
COAL ZONES

CONTOUR INTERVAL 10 METRES

SCALE 1:750000

x WELL LOCATION

TO ACCOMPANY: REGIONAL EVALUATION OF THE COAL BED METHANE POTENTIAL IN THE PLAINS AND FOOTHILLS OF ALBERTA, STRATIGRAPHY AND RANK STUDY

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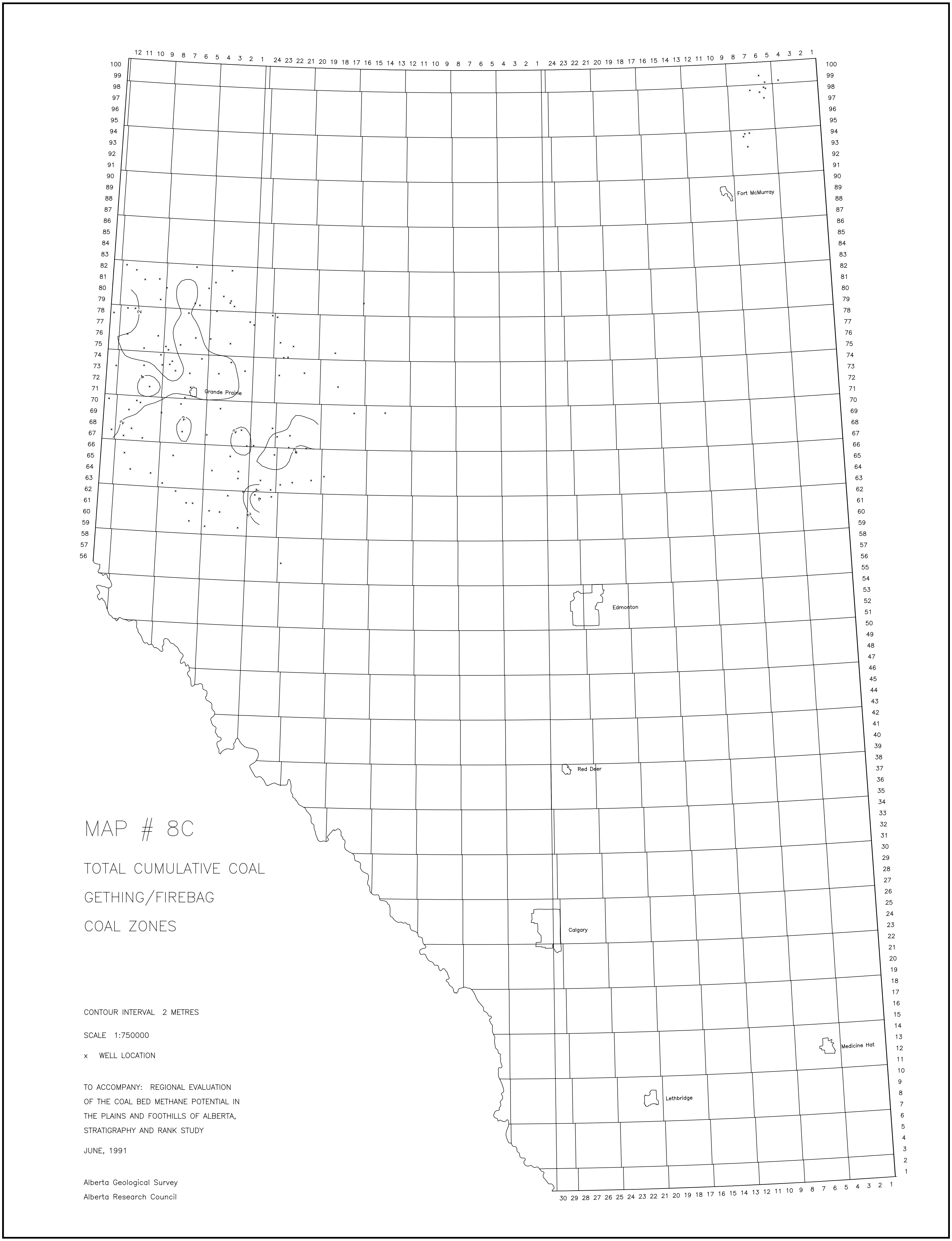
MAP # 8C
TOTAL CUMULATIVE COAL
GETHING/FIREBAG
COAL ZONES
CONTOUR INTERVAL 2 METRES
SCALE 1:750000
x WELL LOCATION
TO ACCOMPANY: REGIONAL EVALUATION
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Calgary
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Lethbridge

15.8.4 Isopach of Thickest Seam

Gething seams range from 0.2 to 2 metres in thickness with large areas having seams in the 1 to 2 metres range (minimum 0.2 m to maximum 3 m). The thickest seams in the Firebag range up to 6.71 metres but are extremely variable in thickness (minimum 0.31). Contour interval is 1 metre.

15.8.5 Iso-Reflectance map

A total of 137 reflectance data sites (181 samples) were available for the Gething and Firebag coals. Many of the reflectance measurements are from thin seams that do not appear on the coal resource maps but provide valuable data. The reflectance maps displays the broadest range of data and some of the most dramatic changes in reflectance values over a short distance. In the east, the shallow Firebag coals range in rank from lignite to subbituminous C rank. In the west the Gething coal zone ranges from lignite to semi-anthracite rank. Differing geothermal gradients and depressed values from 0.1 to 0.4% (see discussion on factors influencing reflectance values in appendix) may account for some of the spectacular change. Other regional factors may include rapidly decreased burial of the coals towards the northeast. Minimum R_{mean} 0.26% and maximum R_{mean} 2.36% can be found in the coal zone.

16. Iso-Reflectance Maps

16.1 Map 1E. Iso-Reflectance of Ardley/Kakwa/Coalspur Coal Zones

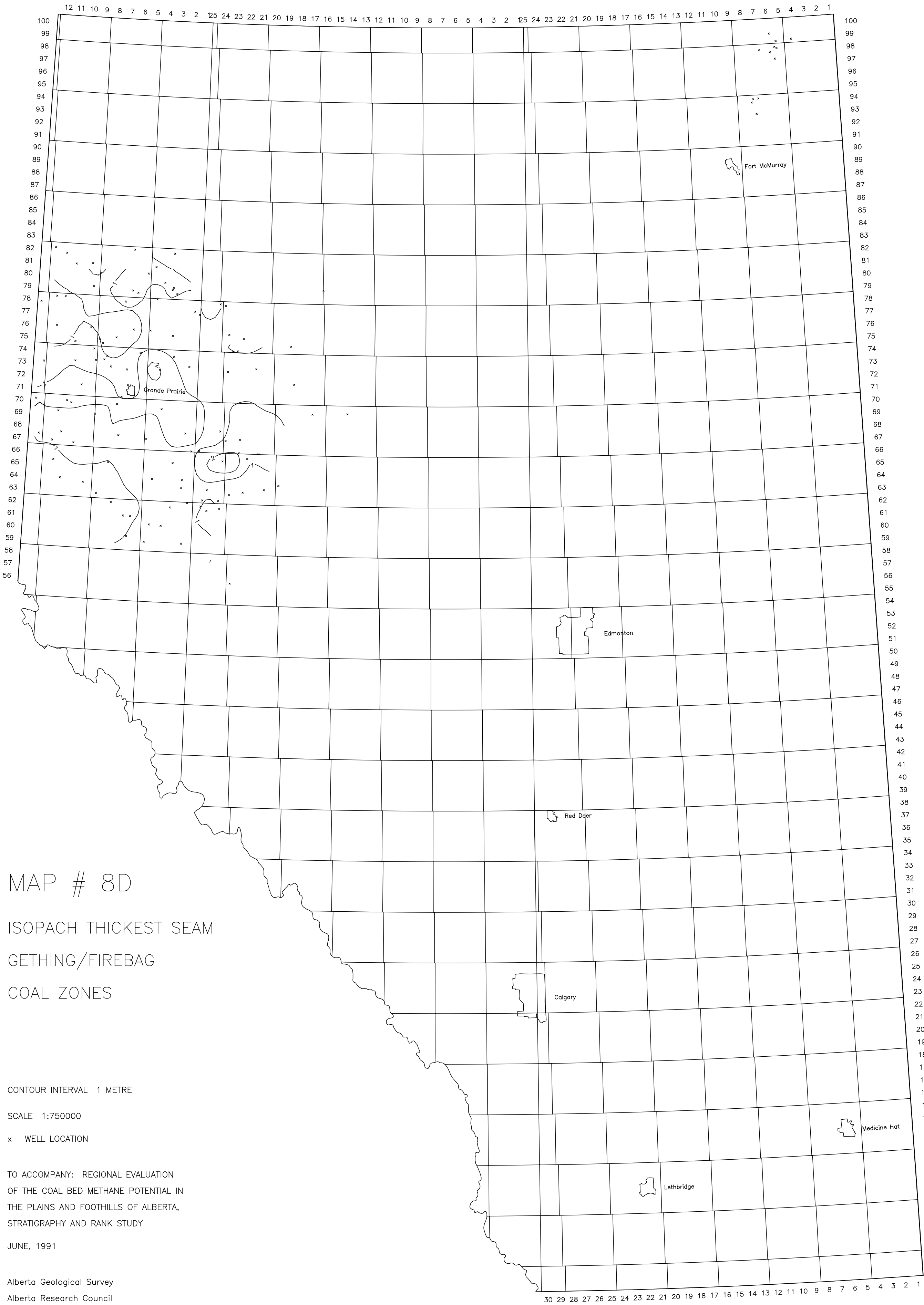
In the foothills the Coalspur Coal Zone could only be sampled in 9 wells in the Grande Cache and Nordegg areas. It was not intersected in the Narraway River area and in the Cadomin area it is most often present in the upper, cased part of the well. Nineteen additional outcrop locations with vitrinite reflectance are available. In the Cadomin area the reflectance of the Coalspur Coal zone has to be determined from outcrops, which are available in mine workings and road cuts. Contouring of the reflectance values shows that these coals are generally high-volatile C bituminous (0.53-0.70% Rmax), coals in the Grande Cache area increase to high volatile A (0.80-1.00% Rmax) and coals in the Nordegg area increase to high volatile B (0.70-0.80% Rmax) bituminous.

16.2 Map 3E. Iso-Reflectance of the Brazeau/Drumheller Coal Zones

The foothills Brazeau map only has 32 data points (19 outcrops and 13 wells). Brazeau samples from the foothills include samples from the Brazeau, Belly River, St. Mary River and Wapiti formations. Consequently, they include samples from intervals equivalent to the Cutbank, Red Willow, Carbon Thompson, Drumheller and Lethbridge coal zones of the plains. It is uncertain if Taber and McKay coal zone equivalents are present. Coals are generally high volatile C bituminous, but in the Narraway River, Cadomin, and southern Alberta regions the rank is high volatile B and locally high volatile A bituminous.

16.3 Map 7E. Iso-Reflectance of the Upper Mannville/Gates/Falher Coal Zones

The Gates isopleth map has a reasonable database. There are 42 wells with reflectance measurements and 80 outcrops. In general the well control is in the area bordering the plains (outer foothills) and the outcrop control is in the inner foothills. The general rank of these coals is medium volatile bituminous (1.0-1.5% Rmax), with a large area of low volatile bituminous (1.5-2.0% Rmax) in the Grande Cache and Cadomin areas. Locally semi-anthracite is present. The Nordegg area shows a local medium volatile



MAP # 8D

ISOPACH THICKEST SEAM
GETHING/FIREBAG
COAL ZONES

CONTOUR INTERVAL 1 METRE

SCALE 1:750000

x WELL LOCATION

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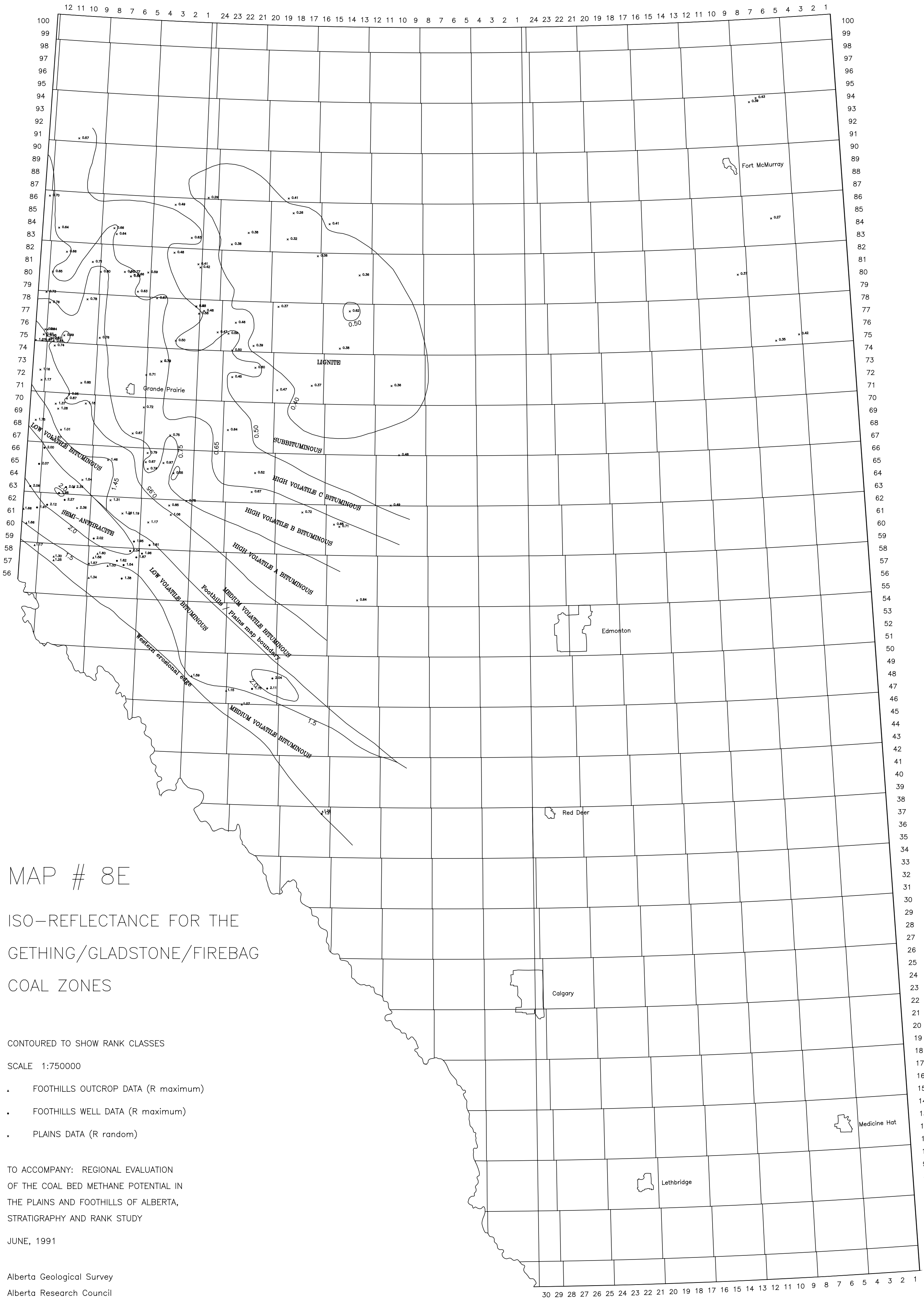
MAP # 8E
ISO-REFLECTANCE FOR THE
GETHING/GLADSTONE/FIREBAG
COAL ZONES
CONTOURED TO SHOW RANK CLASSES
SCALE 1:750000
FOOTHILLS OUTCROP DATA (R maximum)
FOOTHILLS WELL DATA (R maximum)
PLAINS DATA (R random)
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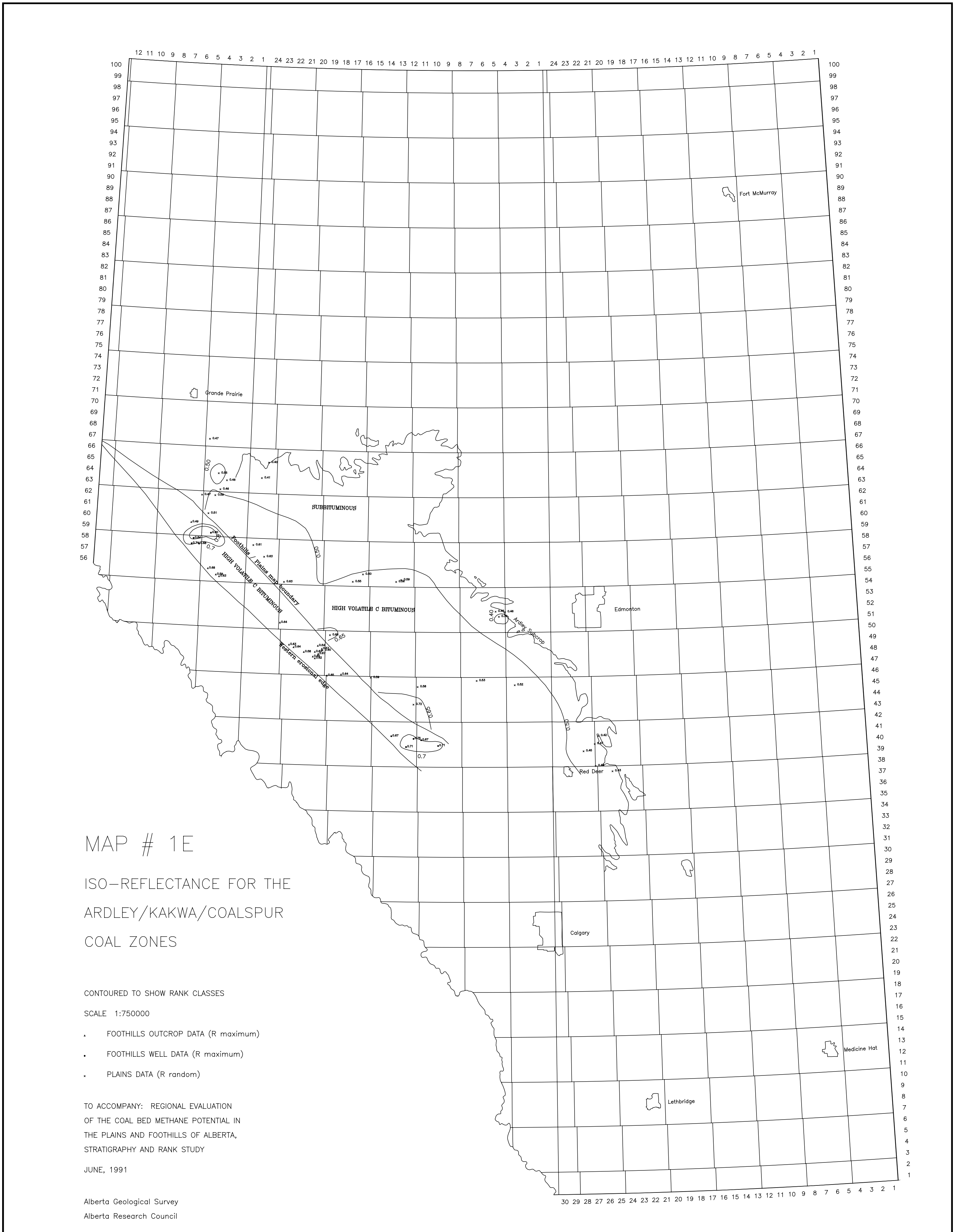
Lethbridge
LIGNITE
SUBBITUMINOUS
HIGH VOLATILE C BITUMINOUS
HIGH VOLATILE B BITUMINOUS
HIGH VOLATILE A BITUMINOUS
MEDIUM VOLATILE BITUMINOUS
LOW VOLATILE BITUMINOUS
SEMI-ANTHRACITE
Foothills / Plains map boundary
Western erosional edge



Fort McMurray
Grande Prairie
SUBBITUMINOUS
HIGH VOLATILE C BITUMINOUS
HIGH VOLATILE C BITUMINOUS
Foothills / Plains map boundary
Western erosional edge
Ardley Subcrop
Edmonton
Red Deer
Calgary
Medicine Hat
Lethbridge
MAP # 1E
ISO–REFLECTANCE FOR THE
ARDLEY/KAKWA/COALSPUR
COAL ZONES
CONTOURED TO SHOW RANK CLASSES
SCALE 1:750000
FOOTHILLS OUTCROP DATA (R maximum)
FOOTHILLS WELL DATA (R maximum)
PLAINS DATA (R random)
TO ACCOMPANY: REGIONAL EVALUATION
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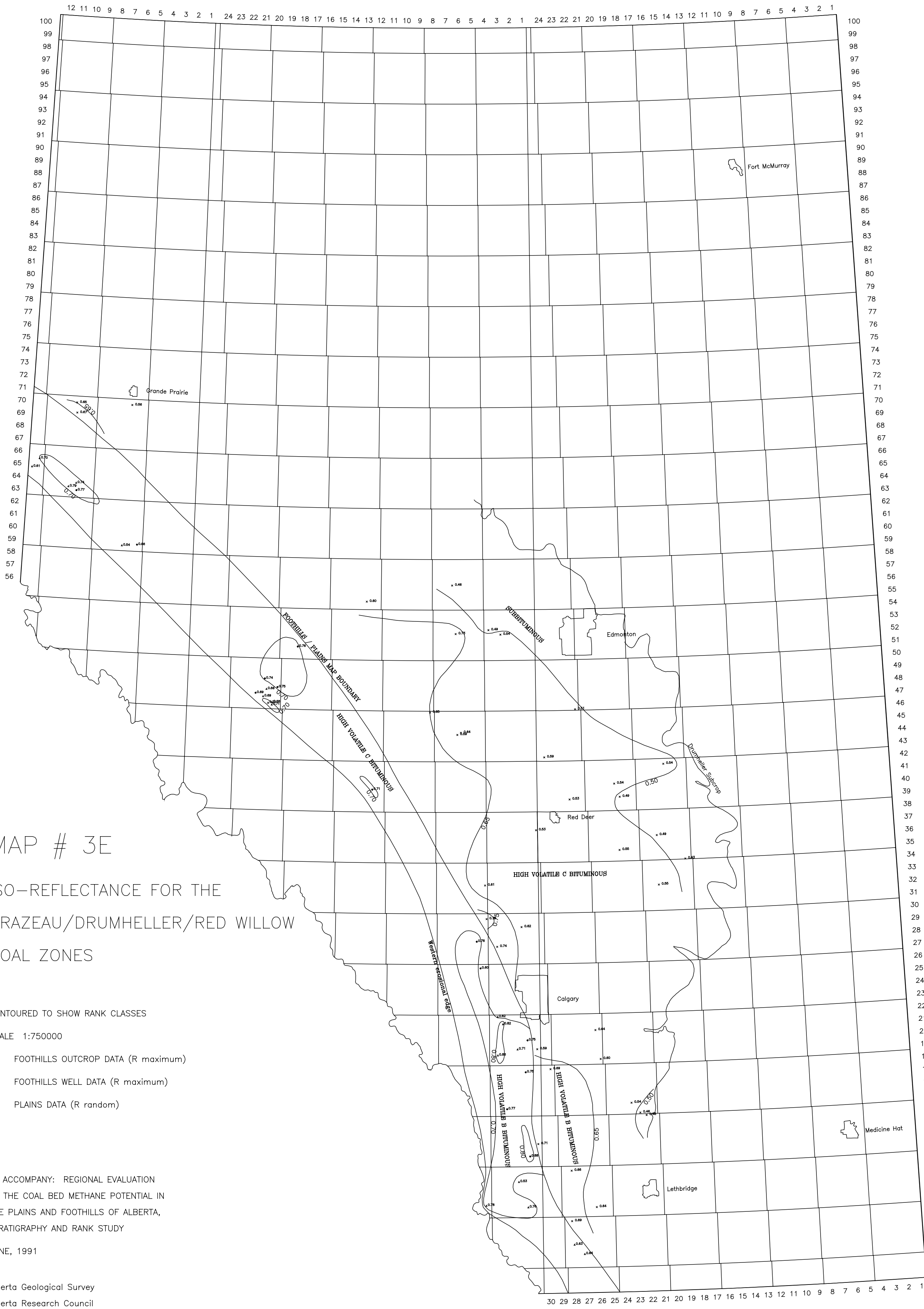

MAP # 3E

ISO–REFLECTANCE FOR THE BRAZEAU/DRUMHELLER/RED WILLOW COAL ZONES

CONTOURED TO SHOW RANK CLASSES

SCALE 1:750000

- FOOTHILLS OUTCROP DATA (R maximum)
- FOOTHILLS WELL DATA (R maximum)
- PLAINS DATA (R random)

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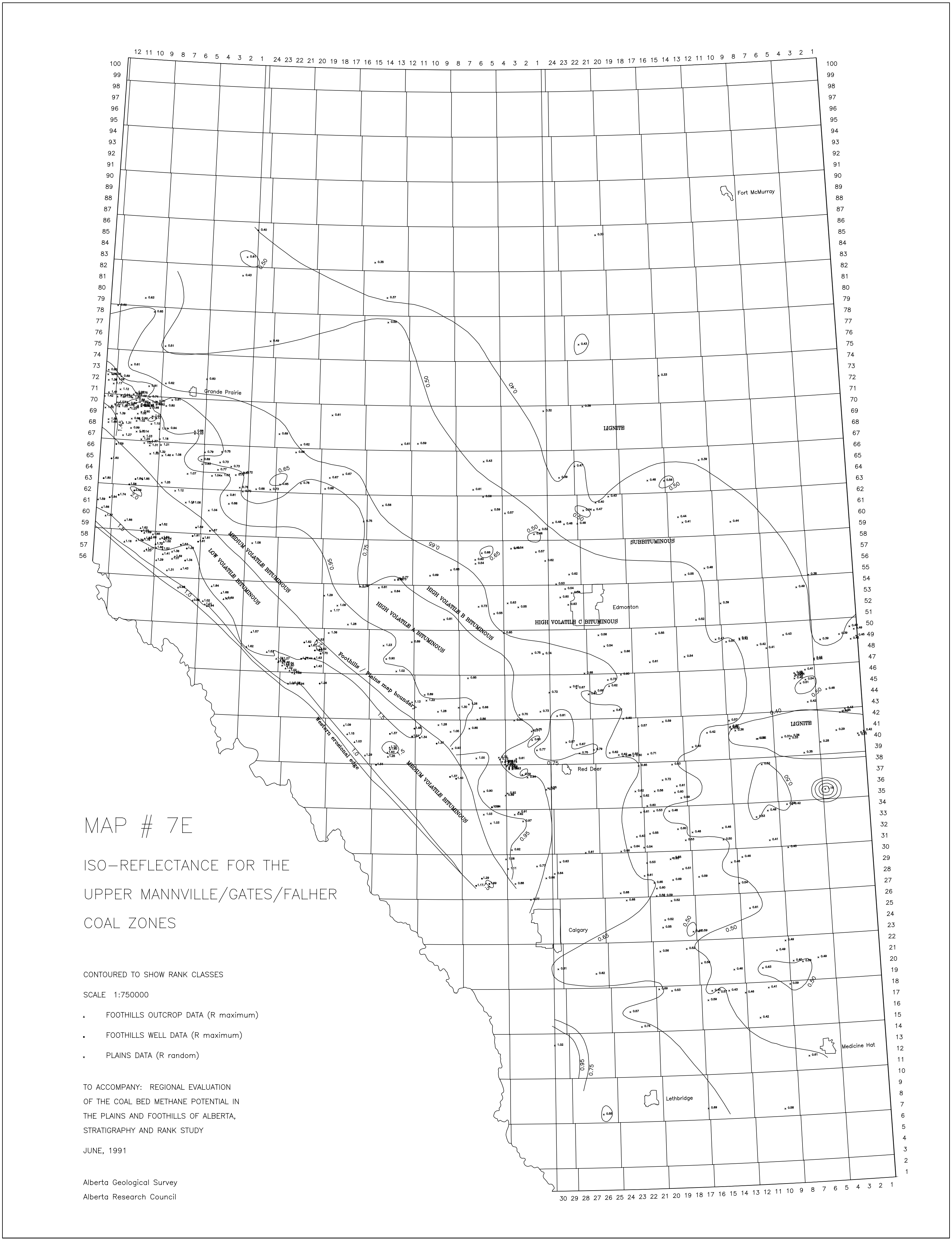
MAP # 7E
ISO-REFLECTANCE FOR THE
UPPER MANNVILLE/GATES/FALHER
COAL ZONES
CONTOURED TO SHOW RANK CLASSES
SCALE 1:750000
FOOTHILLS OUTCROP DATA (R maximum)
FOOTHILLS WELL DATA (R maximum)
PLAINS DATA (R random)
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LIGNITE
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HIGH VOLATILE C BITUMINOUS
HIGH VOLATILE B BITUMINOUS
HIGH VOLATILE A BITUMINOUS
MEDIUM VOLATILE BITUMINOUS
LOW VOLATILE BITUMINOUS
Foothills / Plains map boundary
Western erosional edge

bituminous high around the old minesites. Along the western erosional edge the the rank is high volatile A bituminous.

16.4 Map 8E. Iso-Reflectance of the Gething/Gladstone/Firebag Coal Zones

In the foothills, this stratigraphic interval only shows reasonably developed coals in the Narraway River area, where it is known as Gething Formation. In the Grande Cache, Cadomin and Nordegg area only thin coal seams are developed and the interval is called Gladstone Formation. Our database consists of reflectance measurements from 15 outcrops and 22 wells. The rank is generally low volatile bituminous with a fairly large area of semi-anthracite in the Narraway River and Grande Cache areas and also in the outer foothills of the Cadomin area. This reflectance high is a continuation of the high in the Gething Formation mapped in B.C. by Kalkreuth and McMechan (1988). In the western part of the area the rank is medium volatile bituminous.

16.5 Map 9. Iso-Reflectance of the Kootenay Formation

The Kootenay Formation of southern Alberta has a reasonable database consisting of 67 well locations and 49 outcrops. A clear trend can be seen from high volatile B bituminous ranks in the Waterton area in the south to semi-anthracite in the Canmore area. This trend was known from a regional study of the Kootenay Formation by Gibson (1985) and Macdonald et al. (1989). These studies were based on outcrop samples only. The additional well information confirms this trend. In addition, the high volatile A and B bituminous zones near Waterton are now much better defined.

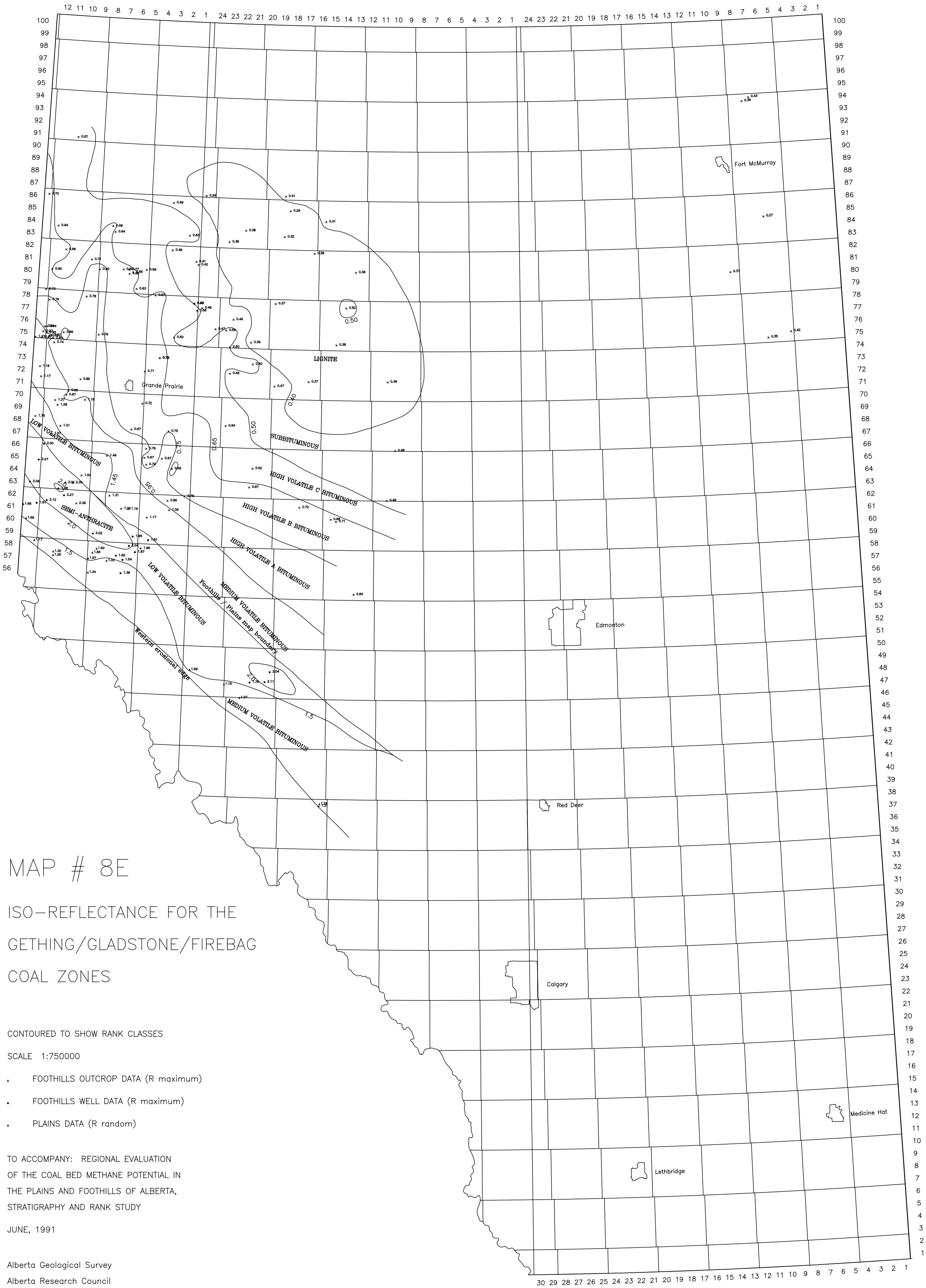
17 Discussion

The bulk of this section will summarize the regional coal geology, depositional models, coal seam development, rank, and coalbed methane potential for each coal zone. In addition to information from the present study, this summary is based on and extracted directly from the work of Alberta Research Council coal geologists (mainly from the Plains Coal Geology studies of the 1980’s), supplemented with recent information from the broader coal geoscience community. The Alberta Energy funded, Plains Coal Geology studies were focussed more heavily on the interpretation of coal geology and are the geologic foundation of the present study. A major portion of the present database was gathered during those studies in the mid 1980’s. Indented sections (in smaller point type) of the following sections are mainly direct or editted quotes from the Plains Coal Geology studies and indicate where additional information is available. The reader is directed to the original texts of the Alberta Research Council Open File Reports: Richardson et al. 1988, (Ardley coal zone); McCabe et al. 1989, (Horseshoe Canyon coal zones); Nurkowski 1980, (Carbon Thompson coal zone); and Macdonald et al. 1987, (Belly River coal zones) for complete information and original interpretations. Those publications (available from the ARC publications) are in the public domain and can be referenced in publication. ARC client reports (including this report) whether confidential or not cannot be directly referenced in publication.

17.1 Ardley/Kakwa/Coal Valley Coal Zones

17.1.1 Regional Coal Geology

The Tertiary Paskapoo Formations contains the locally restricted Obed zone near the top of the formation. There are two coal zones within the Cretaceous-Tertiary Scollard Formation of the plains; the thick and extensive Ardley/Kakwa coal zones at the top of the formation. Equivalent coal-bearing strata



MAP # 8E

ISO-REFLECTANCE FOR THE GETHING/GLADSTONE/FIREBAG COAL ZONES

CONTOURED TO SHOW RANK CLASSES

SCALE 1:750000

- FOOTHILLS OUTCROP DATA (R maximum)
- FOOTHILLS WELL DATA (R maximum)
- PLAINS DATA (R random)

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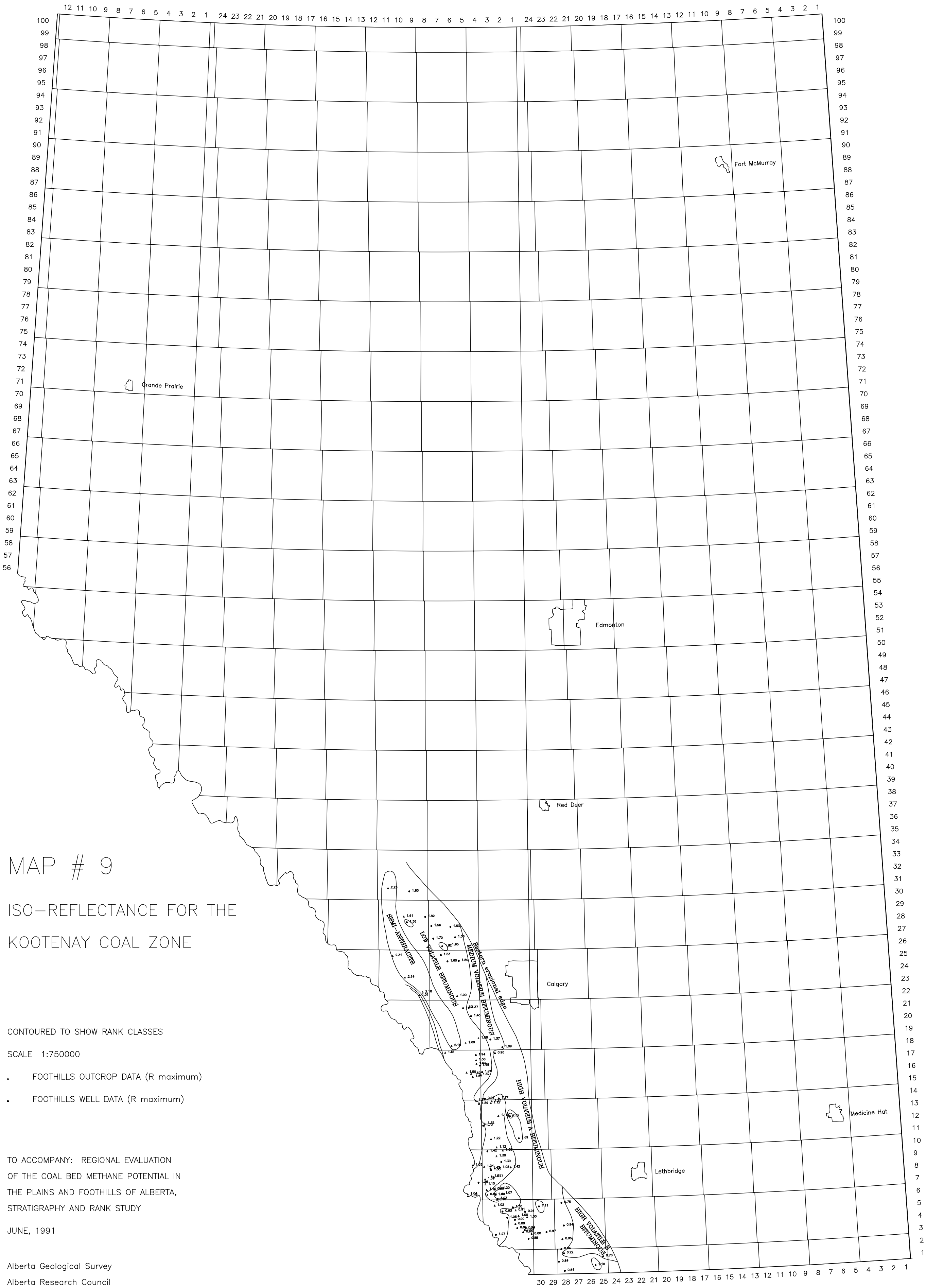

MAP # 9

ISO-REFLECTANCE FOR THE KOOTENAY COAL ZONE

CONTOURED TO SHOW RANK CLASSES

SCALE 1:750000

- FOOTHILLS OUTCROP DATA (R maximum)
- FOOTHILLS WELL DATA (R maximum)

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occur in the Coalspur Formation of the foothills. In the north Dawson et al. (1989) informally defined the Kakwa coal measures, approximately 190 to 250 m above the Cutbank coal measures. In south central Alberta, north of Calgary, the Paleocene Ardley coals dip 150 km southwest into the Alberta Syncline from a 400 kilometre long subcrop. Ardley coals attain a maximum depth of about 900 m at the edge of the tectonically disturbed belt. The Ardley coals are contained in a wedge of fine to coarse grained continental (fluvial and shallow lacustrine) clastic sediments.

Regional stratigraphic studies of the Paskapoo Formation as a whole are not common. Most of the stratigraphic work undertaken is within the coal-bearing Scollard Formation and lateral equivalents. The studies within the Scollard have been undertaken for two main reasons: 1) to better define the coal potential of the Ardley zone and 2) to better define the Cretaceous/Tertiary time boundary that lies near the base of the coal zone. Coal resource studies within the Ardley coal zone have mainly been undertaken by the Alberta Research Council (most recently Richardson, et al., 1988). Studies related to the Cretaceous/Tertiary boundary have largely been undertaken at the University of Alberta and the Geological Survey of Canada (I.S.P.G. in Calgary). The techniques of magneto-stratigraphy, palynology, and geochronology are being used to define an absolute time line within the Scollard Member. This provides better stratigraphic correlations.

The Battle Formation is a very distinct surface and subsurface marker horizon that is widespread throughout Alberta. Few other reliable, widespread markers exist within this part of the stratigraphic sequence, with the exception of a few bentonite horizons below the Battle Formation (Nurkowski, 1980). Studies on individual seam correlations within the Ardley coal zone were included in most of the resource evaluation studies that were previously mentioned. Prior to the work by Richardson et al. (1988), it was widely believed that the Ardley coals were easily correlated throughout the basin and were divisible into an upper and lower unit. The work by Richardson et al. (1988) showed that this simple two-fold division was only applicable, if at all, in the eastern near-subcrop region of the Ardley coal zone. Coal correlations in the deeper regions of the zone, i.e., to the west, are much more complicated. Two small regions had detailed coal seam thicknesses, geometry, and partings mapped in the study by Richardson et al. (1988).

Although stratigraphic markers are not common within the bulk of the Paskapoo/Scollard formations, this does not present a real problem in delineating the Ardley coal zone. This is because of the widespread occurrence of the Battle Formation in close stratigraphic proximity to the Ardley coal zone. This lack of markers is a problem in defining the Obed coal zone. Coal and rock unit correlations within the more western regions are complicated by the fact that sedimentary rock units are wedge shaped, becoming thicker in the west where basin subsidence was greater. Despite the contiguous nature of the coal seams the presence of extensive fluvial channel deposits that have cut out or were laterally equivalent to coals, cause difficulty in seam correlations.

17.1.2 Depositional Model

The Ardley coal zone is associated with mainly fine-grained fluvial sediments. Two areas, in the west-central part of the basin, have particularly great amounts of coal with cumulative amounts of up to 24 m and individual seams to 4 m in thickness.

A depositional model has been developed showing the relationship between coal accumulation and the regional tectonic setting. Major depositional controls appear to relate to variation in subsidence rates and isolation from the effects of clastic deposition in a pervasive peat forming environment. The coal seams are remarkably persistent with thick seams correlatable over tens of miles. The peats were deposited in a tectonically active foreland basin, having greater subsidence towards the west and southwest due to loading and or tectonic influences along the western basin margin. The Ardley coal zone ranges from 25 m thick in the east to more than 200 m thick in the west. The total number of seams increases to the west in response to greater subsidence. The laterally persistent (10's of km) nature of many of the seams suggests development, at times, of extensive peat-forming mires over large areas of the basin. The development of major river systems, running parallel to the paleo-mountain front, is offered as a possible mechanism for sheltering the eastern peat-forming mires from clastic deposition for long periods of time. Areas more proximal to the western basin margin would have a greater influx of clastics preventing the formation of thick coals. A few wells further to the west, in the disturbed belt, provide some substantiation of that idea since they contain lower amounts of cumulative coal. The lack of coal development in the southern part of the basin towards the U.S. border may be related to climatic constraints (Richardson et al., 1986).

Jerzykiewicz and Sweet (1986) suggest that the presence of caliche beds, red beds and impoverished palynological assemblages in Ardley equivalent strata of the southern Alberta foothills may be indicative of a semi-arid environment not favorable for peat development. In the north Dawson et al. (1989) describes a lacustrine floodplain depositional environment for the upper part of the Wapiti strata (top of the Red Willow coal measure upward, eg. Kakwa and Cutbank). Laminated mud-shales and siltstones, which are interpreted in terms of lacustrine rhythmites are very common. Dawson found "the coals are often associated with the rhythmites, suggesting that the coal forming swamps developed in a lake margin depositional setting". He noted that "a variety of meandering and braided channel types occur in the upper Wapiti strata, but that the nonchannelized, flat bounded sandstone bodies with wavy bedding, are associated with the rhythmites, represent a lacustrine environment".

The Coalspur Formation (and Coalspur coal zone) have similar sedimentary environments as the Ardley coal zone.

17.1.3 Coal Seam Development

17.1.3.1 Ardley Coal Zone

Over much of the area at least one Ardley seam 2 m or greater in thickness is present. Areas with seams of 4 m or greater in thickness are commonly located within an east-west trend in the basin southwest of Edmonton. The Ardley coal zone is generally comprised of between 3 and 12 seams but up to 18 seams are present in the west-central part of the basin. The combination of thickest seams and greatest number of seams combine in two well defined trends of thick cumulative coal development illustrated in the Total Cumulative Coal Map. A north-south and an east-west oriented trend containing between 12 to 25 m of cumulative coal can be readily seen.

17.1.3.2 Coalspur Coal Zone

The Coalspur coal zone is between 200 and 300 m thick, with many different coal seams. Its cumulative thickness ranges up to 26 m, while in places it is over 50 m resulting from tectonic thickening.

17.1.3.3 Kakwa Coal Zone

The Kakwa has been described by Dawson et al. (1989) as approximately 100 to 150 m thick with up to seven individual coal 'zones' (seams) observed, with zone thickness ranging from 1 to 6 m.

17.1.4 Rank and Coalbed Methane Potential

Except for the subcrop area, including the major producing Ardley mines, little is known about the rank of Ardley coals. Traditionally the Ardley has been shown everywhere on maps as subbituminous in rank even at depth west of the subcrop edge where no data existed. A petrographic study of coals from the Alberta plains by Parkash (1985) included the examination of five Ardley coals from widely separated areas along the Ardley subcrop edge. The coals ranged from subbituminous C to subbituminous A in rank based on vitrinite reflectance.

Reflectance data was difficult to gather in the shallow Ardley/Kakwa coal zones and data distribution is poor with only 47 sites available (99 samples). The data does support the findings of Nurkowski (1985) in that the deeper Ardley coals have ranks in 0.6 to 0.7% range and generally fall in the High-vol. C bituminous in rank (minimum R_{mean} 0.39%, subbituminous C., maximum R_{mean} 0.72%, high-vol. B bit.) Since most Ardley coals fall in the high volatile bituminous C rank they may be producers of methane gas.

Dawson et al. (1989) reported the Kakwa coal reflectance levels of (0.50-0.59%).

Map 1E shows that the thick Coalspur coals are all high volatile bituminous, with local highs of high volatile A/B bituminous in the Findley area (near Grande Cache) and the Nordegg area. However, it seams likely that the Coalspur coal in the sub-surface of the Cadomin area has higher ranks than the outcrop samples on which our data is based. From the combination of thickness and rank, the best potential for coalbed methane appears to be in the Cadomin and Nordegg areas. Especially near the Ancona gas field of the Nordegg area (structural cross-section 4) and the Entrance Syncline in the Cadomin area (structural cross-section 5). However, the Grande Cache area should not be excluded.

17.2 Carbon Thompson/Cutbankand and Drumheller/Red Willow Coal Zones

17.2.1 Regional Coal Geology

Three major coal zones are found within the Bearpaw/Horseshoe Canyon Formations: a lower Basal zone (McCabe et al., 1989), the Drumheller/Clover Bar zone, and the Carbon-Thompson zone (Gibson, 1976). A large volume of stratigraphic related literature has been written on the Horseshoe Canyon and Bearpaw Formations. Detailed studies have also been undertaken in recent years (Hughes, 1984). The Geological Survey of Canada has tended to undertake this latter type of study, while the Alberta Research Council has tended to undertake coal resource evaluation studies on a wider regional basis. Many of the general stratigraphic relationships of the Bearpaw/Horseshoe Canyon Formations have been revealed by these studies.

Marker horizons within the Horseshoe Canyon continental sediments tend to be scarce. Near the base of this sequence the tops of coarsening-up cycles, marine shale beds, and the top of the underlying Belly River Group are common markers. Near the top of the Horseshoe Canyon Formation, the Battle Formation and a few ash horizons form the only reliable markers.

Individual coal seams within the Horseshoe Canyon/Bearpaw series, have been correlated with some success within small study areas near the outcrop edge (e.g. Hughes, 1984). Very little is known of individual coal seam correlations at deeper stratigraphic levels. Many earlier workers on coal correlations in this sequence, had erroneously correlated seams from as far apart as Edmonton to Drumheller with only a few wells for control. It is now realized that coal correlations within this sequence are much more complex, requiring a much closer spacing of data points to be accurate. The detailed studies being undertaken by the Geological Survey of Canada within the established coal fields, will likely go a long way to providing detailed seam correlations in local areas. Recent regional studies undertaken by the Alberta Research Council (e.g. McCabe et al., 1989, Nurkowski, 1980) have provided general guidelines as to how coals within the Horseshoe Canyon/Bearpaw series, should be correlated.

Palynology has been used by Dawson et al. (1989) as a means of correlating the Cutbank coal measure to both the upper part of the Brazeau and Horseshoe Canyon formations. The palynoflora of the Red Willow coal zone correlates to the latest Campanian Bearpaw Formation and contiguous strata. Dawson et al. (1989) suggests that the Campanian-Maastrichtian boundary probably occurs within or immediately contiguous to this interval. He also noted that “a similar assemblage was found to occur associated with cyclothem 1 and 11a of the Brazeau Formation in the Blackstone River section and in the basal beds of the St. Mary River Formation (Jerzykiewicz and Sweet, 1988)” and (McCabe et al., 1989).

17.2.2 Depositional Model

Deposition of Late Cretaceous sediments over the interior plains of North America was characterized by widespread transgressions and regressions of a broad epeiric seaway. During Late Campanian to early Maastrichtian time, the epeiric sea inundated most of the interior of North America, stretching from the present day locations of the Arctic Ocean in the north to the Gulf of Mexico in the south (Williams and Stelck, 1975). The sediments of the Bearpaw Formation and the lower Horseshoe Canyon Formation in southeastern Alberta were deposited during a final advance and retreat of this widespread seaway. Approximate geographic limits of the final transgression of the sea into southeastern Alberta is represented by the Bearpaw Formation. Williams and Burk (1964) report thicknesses of about 30 m for the Bearpaw Formation in the Pembina oil field (located west of Edmonton) and suggest that the Bearpaw Formation extends another 70 km west of the Pembina field.

Migrating shorelines through time led to the development of diachronous contacts between the Bearpaw Formation and the underlying Belly River Group and between the lower Horseshoe Canyon and Bearpaw Formations. Given and Wall (1971) and Caldwell (1968) suggest that the Bearpaw Sea transgressed gradually causing the base of the Bearpaw Formation to rise to the west.

Several regressive phases began in the early Maastrichtian, possibly due to a eustatic drop in sea level (Hancock and Kauffman, 1979). Basin filling by terrestrial sediments originated from the rising highlands to the west (Williams and Stelck, 1975). The “Lower Tongue” of the Horseshoe Canyon Formation was deposited during one of the earliest regressive phases. Based on Baculite zonation, Russell (1939) and Given and Wall (1971) suggest that the Bearpaw Sea withdrew first from central Alberta, then from southwestern Alberta and finally from southeastern Alberta and southern Saskatchewan. Repeated transgressive-regressive pulses resulted in a series of interfingering zones of terrestrial coal-bearing and marine mudstone successions. These zones migrated progressively upwards and eastwards through time.

Terrestrial sediments dominate the upper part of the Horseshoe Canyon, Battle, and Paskapoo Formations, clearly indicating that regressive conditions persisted after the Early Maastrichtian.

Regression was widespread at this time through all of the North American western interior. Hancock and Kauffman (1979) have suggested that this was a result of dramatic lowering of eustatic sea levels.

The upper Horseshoe Canyon Formation in the Red Deer area was studied by Nurkowski, (1980), to determine successive depositional environments and to relate these environments to the development of Carbon and Thompson coals (Carbon Thompson coal zone). Four informal lithologic units were recognized. In stratigraphic order, these are the lower and upper fine units, consisting mainly of siltstones with minor shales and fine grained sandstones, and an overlying coal-bearing sequence, the Carbon and Thompson coal zones, consisting of coarser grained sandstones, coals, siltstones and shales. Evidence favoured a lacustrine origin for the older fine grained dominated unit. The succeeding coal-bearing sequence accumulated in a meandering fluvial system, with the coarser clastics (sand size and greater) representing active channel fill, the finer clastics (very fine grained sands, silts and clays) representing inactive channel fill and overbank deposits and the coals representing back-levee, channel fill and flood basin swamps, developing parallel to the paleo-channels. Within each coal-bearing zone, there are pronounced northwest-southeast alternating bands, typically 4 to 7 miles (6.4 to 11.3 km) wide, of preferred coal and sandstone development which relate to the spatial distribution of the above-mentioned paleoenvironments. This result agrees with previous findings, notably work on the provenance of Upper Cretaceous sands, in indicating paleodrainage from the northwest.

A geologic model developed for the lower Horseshoe Canyon Formation coals helps to explain some of the depositional trends observed. The model involves a coastal plain setting characterized by elongate, shore-parallel mires, 30 to 50 km inland from actual shorelines. Rising and falling relative sea levels resulted in the deposition of a series of thin (ie. less than 1 m) peat beds. The peats could only accumulate for a relatively short time because of flooding of the mire during a subsequent marine transgression. Repeated transgressive-regressive cycles resulted in an interfingering of the coal-bearing successions of the lower Horseshoe Canyon Formation with thick marine successions of the Bearpaw Formation. Stratigraphically, some of the thickest coal seams identified in this study are located in this zone of interfingering.

Migrating shorelines through time led to the development of a diachronous contact between the lower Horseshoe Canyon and Bearpaw Formations. As a result, the coal seams are generally not parallel to formation boundaries and major marker horizons. Coal development exhibits a progressive migration to the east and southeast following the retreating Bearpaw Sea. Coarsening upward successions within the Horseshoe Canyon/Bearpaw transition can be used for seam correlation, because coarsening upward successions are directly tied to shoreline migration. Coarsening upward successions are produced by progradation of a shoreline over offshore deposits. They have a distinctive signature on the gamma ray geophysical logs, and in core and outcrop, typically consist of offshore mudstones at the base grading to shoreface sandstones at the top (McCabe et al., 1989).

Dawson et al. (1989) describes a lacustrine floodplain depositional environment for the upper part of the Wapiti strata (top of the Red Willow coal measure upward, eg. Kakwa and Cutbank). Laminated mud-shales and siltstones, which are interpreted in terms of lacustrine rhythmites, are very common. Dawson found “the coals are often associated with the rhythmites, suggesting that the coal forming swamps developed in a lake margin depositional setting”. He noted that “a variety of meandering and braided channel types occur in the upper Wapiti strata, but that the nonchannelized, flat bounded sandstone bodies with wavy bedding, are associated with the rhythmites, represent a lacustrine environment”.

The lower part of the Wapiti strata (base of the Wapiti to the top of the Red Willow coals), described by

Dawson et al. (1989), "represents a mainly alluvial plain environment, probably drained by numerous, large, high sinuosity, meandering channels. Fining-upward units of point bar origin are the most common type of sedimentary sequence. The lower members of these sequences are built up with low angle inclined beds of sandstones, laterally infilling large broad channels. The upper is composed of alternating mudstones and very fine grained sandstones. This type of inclined heterolitic stratification illustrated by Thomas et al. (1987, Figure 15), is attributed to mixed to suspended-load meandering rivers of markedly fluctuating discharge (Stewart, 1981). Coals occur in the overbank sediments along with mudstones that are usually dark grey, organic rich and nonlaminated. Upright rootlets, root casts and root burrows indicating autochthonous origin of coal are common."

17.2.3 Coal Seam Development

17.2.3.1 Carbon-Thompson Coal Zone

The Carbon-Thompson coal zone consists of relatively discontinuous, thin and marginally economic coals in the uppermost portion of the Horseshoe Canyon Formation. Nurkowski suggested that exploration for thick Carbon and Thompson coal seams should be concentrated within the northwest-southeast trends of thicker coal accumulation. Maps produced for the coal resources of the lower Horseshoe Canyon Formation, also indicate that the thickest coal measures are commonly oriented north-south in elongate pods. Correlation of individual coal seams is generally easiest in the north-south directions (parallel to paleoshorelines), whereas seams appear to be less continuous and split over shorter distances in the east-west directions (perpendicular to paleoshorelines). The coal zone has total cumulative coal (TCC) in excess of 2 to 3 metres in only a few isolated spots. TCC of 1 to 2 metres are common. Minimum total cumulative coal was 0.2 metres and maximum was 5.5 metres.

17.2.3.2 Daly (Weaver) Coal Zone

The Weaver coal zone consists of relatively discontinuous, thin and marginally economic coal seams. It differs significantly from the Drumheller coal zone in that no marine strata are contiguous with these coals. In the Athabasca River area, these coals likely formed in an alluvial plain setting considerably inland from major shorelines. In that environment of deposition only thin scattered coal seams were formed. In the Drumheller area, a thin succession of marine strata, the Drumheller marine tonque, is present at a similar stratigraphic level as the Weaver zone. The Daly coal zone was not mapped because of it's discontinuous nature but is included on the cross-sections and is in the database.

17.2.3.3 Drumheller Coal Zone

The area with the greatest total cumulative coal, in excess of 18 metres, is located just west of Drumheller (minimum 0.2 to 35.1 metres). The Drumheller contains the largest amount of TCC of any Alberta coal zone (largest TCC at 11 28 28 23 W4M), however, these thick packages of coal are not as extensive as the thick Ardley and upper Mannville coals. A large north south belt of TCC greater than 8 metres can be seen on the map. The thickest seams over much of the area range between 1 and 2 metres. Thicker seams (3 to 4 m) are found in the same area of great TCC. Many seams are however present in those areas. Further south are local areas with seams up to 5 metres thick which account for the bulk of the TCC in those pods. The thinnest seam in the dataset was 0.2 m while the thickest was a substantial 10.5 metres.

17.2.3.4 Brazeau/St. Mary River Coal Zones

The upper Brazeau coal zone of the central Alberta foothills is roughly equivalent to the Carbon Thompson coal zone. The St. Mary River coal zone could be mapped in the Highwood River and Pincher Creek Triangle zone and is equivalent to the Drumheller coal zone.

17.2.3.5 Cutbank Coal Zone

The first major coal-bearing interval (Cutbank coal “measure”) lies approximately 1300 m above the base of the Wapiti Group. These strata contain up to 6 coal “zones” (seams) over an interval of approximately 100 to 150 m. Coal “zones” (seams) up to 6 m thick have been observed in outcrop and exploration boreholes; Dawson et al. (1989).

17.2.3.6 Red Willow Coal Zone

The Red Willow coals appear to be widely variable in thickness and limited laterally to isolated deposits with an areal extent of approximately 5 to 10 km., (Dawson, 1989).

17.2.4 Rank and Coalbed Methane Potential

The range of reflectance values for the Carbon Thompson and Drumheller coals are from subbituminous B at 0.43% to high-vol A at 0.80% R_{mean}. Most of the coals fall in the High-vol. C bituminous rank. Thick shallow coals may result in commercial CBM exploration targets. There are a few mentions of gas from the Horseshoe Canyon coals. Allan (1945) noted one weak gas seepage on the side of the Red Deer River below the mouth of Rosebud River, and thought this gas may have been associated with some of the underlying coal seams. At the top of coarsening upward succession 3 (Drumheller coal zone of McCabe et.al., 1989) thick sandstones with neutron-density crossovers, were thought to possibly indicate the presence of gas. The source of gas was thought to be the underlying and adjacent coal seams of the Drumheller coal zone. It should be noted the coals in that area are very shallow. Deeper targets are present in the west-central part of the basin but the coals may be harder to locate and are thinner but of higher rank. In the northwest the Cutbank (reflectance, 0.63-0.74%; Dawson 1989), and Red Willow coal zones are also potential CBM prospects but will also be challenging to detect.

The Brazeau and St. Mary River formations of the foothills contain coals of high volatile bituminous ranks (see map 2E). They only attain reasonable thicknesses in the Triangle Zone of southern Alberta, where they may be prospective for coalbed methane. However, more needs to be known about these coals in the central Alberta foothills before writing them off completely.

17.3 Lethbridge, Taber and McKay Coal Zones

17.3.1 Regional Coal Geology, Belly River Group

Stratigraphic relationships within the Belly River Group were established from surface outcrops in southern Alberta during the early half of the century. More recently, McLean (1971) provided a regional synthesis of the subsurface stratigraphy of the Belly River in the southern Plains region. A number of coal resource evaluation studies undertaken by the Alberta Research Council (most recently Macdonald, et al., 1987) have helped to further refine the stratigraphic understanding. The latter study has had the largest scope in terms of geography and data point density and much of the following is from that work.

Marker horizons related to the Belly River are generally found immediately above or below the unit, e.g. top and base of the Belly River Group, the Milk River Formation, and the top of the Colorado Group. The three coal zones within the Belly River Group provide approximate stratigraphic placement within the sequence.

The Belly River Group can be recognized into two mappable sub-units within southern Alberta, i.e. Oldman and Foremost Formations. This subdivision cannot be recognized in central and northern Alberta. To the west and northwest of the central Plains area, the entire group cannot be distinguished from the overlying Edmonton Group, due to the absence of any recognizable marine strata. Again, the uppermost coal zone (Lethbridge) often provides approximate stratigraphic placement. The presence of interbedded marine and brackish water sediments within the continental sequence causes correlation problems. In the area of individual coal seam correlations within the Belly River, few of the aforementioned studies have been successful in showing laterally persistent, easily correlated coals within the unit. This may be due to the very nature of the seams and/or the data density of the studies done to date.

The Belly River regressive clastic wedge sequence developed during Upper Cretaceous Campanian time and was deposited in the Alberta Foreland Basin. The Alberta Foreland Basin began to develop from earliest Albian time in response to crustal loading brought on by the rising Cordilleran mountain range to the west. Marine sediments like the Pakowki-Lea Park series, were deposited in the interior Cretaceous seaway. The Pakowki-Lea Park series shows a very thick, upward coarsening sequences into the first basal Belly River sands (see stratigraphic cross-sections). Most of the Pakowki Formation consists of fine-grained clastics. This would suggest slow, but steadily increasing input of coarser clastics into the Pakowki seaway, beginning in late Pakowki time. Most early Belly River shorelines developed in the eastern portions of the study area - near the Sweetgrass Arch and its northern extensions. Throughout most central and western regions of the study area, the first basal Belly River sandstones are relatively flat-lying, continuous and represent a prograding shoreline. Very little interruption in sediment source or in relative change of sea level likely took place in this area.

Williams and Burke (1964) show a series of paleogeographic maps spanning Milk River to upper Belly River time. Sediments during Milk River to Pakowki time were derived mainly from the southwest, and shifted to mainly the northwest during upper Belly River time. Stott (1984) shows a very similar paleogeography for the Campanian. Stelck (1975) suggests a slightly positive expression for the Sweetgrass Arch during Milk River to lower Belly River time, and cites evidence of Milk River and basal Belly River sandstones bifurcating over the arch at these times.

The McKay coal zone represents the first continental sediments within the lower Belly River Group. The coals likely formed as a result of favourable climatic conditions, shoreline positions and geographic locations sheltered from major river systems. McCabe (1984) suggests that for any significant thickness of peat swamps to form, in turn yielding thick coals, this characteristic of sheltered geographic location is vital. The study area was likely relatively sheltered from major river systems. The paleogeographic maps referred to earlier, show source areas in the extreme northwest and extreme southwest of the study. These two regions have very little or no McKay zone development. The combination of the northern and southern clastic source areas, both draining southeastward to the retreating Pakowki sea, may have produced a relatively sheltered central region whcih was conducive to peat swamp development.

The series of maps produced for this study show that the thickest accumulations of McKay coal occur some tens of kilometres westward of the inferred paleoshorelines during McKay time. It is known that the McKay coals pinch out eastward into the Pakowki sediments, and also disappear towards the extreme west in a more continental direction. The McKay coals are, as a result, concentrated in a north-south trending belt but are not present in the extreme south. This belt likely represented a broad coastal plain and appears to have been parallel to the major eastern shoreline development in the Sweetgrass Arch area, at least as far north as about township 54. During McKay time, the shorelines may have been much farther to the west as is suggested by Williams and Burke (1964).

The Belly River regressive sequence continued to prograde eastward during Foremost time, with fine-grained alluvial plain sediments being deposited in the southwestern area, coarser alluvial plain clastics in the northern area and near-shore marine sediments in the eastern regions. Several pulses of marine transgression, or relative sea level rise, are seen in this eastern area. However, most shorelines seem to have developed in the Sweetgrass Arch area and not migrated much farther eastward. Deposition of the Foremost Formation brought an end to favourable peat swamp conditions that prevailed during McKay coal zone time.

By the time of Taber coal zone development, the shoreline features had in general moved eastward to a position east of the Sweetgrass Arch. The Taber coal zone had also migrated eastward, so that the belt of thick, cumulative coal in the Taber zone also lay eastward of the McKay zone belt. The zero line or eastward coal pinch-out of the Taber zone was also situated eastward of the McKay zero line. The Taber coals would also seem to be related to coastal plain environment; however, the extent to whch they may have been sheltered geographically from major river systems is unclear. The thickest peat swamp development did likely lie some distance landward of the active shoreline.

At the end of the Taber coal zone development there was another pulse of tectonic activity, which deposited the coarser clastics of the Oldman Formation. This event effectively ended Taber coal deposition throughout the area. Koster (1983) described the Oldman sediments from the Dinosaur Provincial Park area as being deposited in southeast-draining estuarine channels, as either a coarse clastic or as inclined heterolithic series of channel sediments. Variations between these two end members are also described by Koster (1987). Some evidence of tidal sediments near the top of the Oldman Formation were cited by Koster. Cores examined from the Brooks area for that study, showed sedimentary structures and palynological evidence for brackish or tidal influences within the Lethbridge coal zone.

The Lethbridge coal zone represents a very widespread return to high water tables due to the advancing Bearpaw sea. Most authors agree, that the Bearpaw transgression was a very rapid event, at least throughout Alberta. McLean (1971) shows several tongues of interdigitating continental and marine sediments at the top of the Belly River in Saskatchewan. The lateral continuity and lack of structural relief of the Lethbridge coal zone, as seen in this study, would tend to support the idea of a rapid transgression. The bulk of the Lethbridge coals were, however, likely formed shortly after the last regressive, progradational event and before the Bearpaw transgression.

The three coal zones within the Belly River are all very thin compared to other coal zones in Alberta (e.g. Drumheller or Ardley coal zones). The Belly River Group coal zones also tend to be very isochronous, they do not climb-up section much and show no appreciable thickening towards the west. This suggests that the conditions conducive for peat swamp development were comparatively short lived, during each of the coal zone developments. It also suggests a rather low rate of differential subsidence during these times, as coals within the zones tend to remain parallel to each other throughout the area (Macdonald et al., 1987).

17.3.2 Depositional Model

The Belly River regressive clastic wedge sequence was deposited into the Alberta foreland basin throughout Campanian time for approximately 5 million years (McLean 1971). This regressive cycle corresponds to the Claggett Cycle throughout North America and corresponds to a period of uplift and deformation in the Cordilleran, more specifically, at the time the Front Ranges structures began to develop. The Western Interior Seaway spread throughout North America, before the Claggett Cycle and shorelines were progressively pushed southward and eastward during the regressive phase (Williams and Stelck 1975). The Peace River Arch was apparently not a positive feature during this period, however, some evidence suggests that the Sweetgrass Arch may have been exerting a slightly positive, though not emergent, influence (Wells 1957, McLean 1971). McLean suggests that loading in the Alberta Basin from shedding sediments to the west coupled with sediment loading and downwarp in the Williston Basin may have resulted in a relatively stable region in the middle i.e. the Sweetgrass Arch. The Sweetgrass Arch may also represent a "foreland bulge". The Pakowki Formation shows a sudden thickening over the Sweetgrass Arch region and is thought to be related to a series of stacked shorelines. These shoreline sequences may be related to the arch, controlling the position of shorelines throughout most of "Foremost time". The control of shoreline positions may have influenced where peat, and later coal seams, will develop.

Coal formation in the Belly River coal zones is thought to have taken place in coastal plain settings. The broad north-south trending belts of thick coal, described for the McKay and Taber zones, lie some distance westward of known shorelines. Most shorelines within Foremost-equivalent time seem to have developed in the region of the Sweetgrass Arch and its northern extensions. Peat swamp development was controlled by shoreline placement during Taber and McKay coal zone development. Active peat swamp development may have occurred as much as 20-50 km westward or landward of paleoshoreline positions, which would provide a relatively protected environment. Both the Taber and McKay zones pinch out eastward as they are replaced by Pakowki marine sediments. The Taber and McKay zones also both pinch out to the west. This western pinch-out is thought to be related to better drained alluvial plain conditions in the west. Limited data for the Lethbridge zone make reconstruction of depositional environments difficult, however, these coals also show evidence of having formed as peats in coastal plain environments (Macdonald et al., 1987).

17.3.3 Coal Seam Development

Coals within the Belly River Group have seam thickness most commonly in the 0.5 to 1.5 m range but seams around 3.0 m thick are present. The thickest seam encountered (4.9 m) was from an Alberta Research Council well through the Lethbridge coal zone, in the Brooks area. The thickest accumulations of coal within the Taber and McKay zones are found along northwest to southeast trending belts, with thickest individual seams, largest number of seams, and best seam correlation potential also occurring within these belts. Regional coal distribution patterns within the Lethbridge zone are less clear, but seem to show an increase in amount, thickness, and numbers of seams in a north to south direction. Coal development in the Lethbridge coal zone reaches a maximum in south central Alberta, and then diminishes southward to zero.

17.3.3.1 Lethbridge Coal Zone

The Lethbridge coal zone is the thinnest of the three Belly River Group coal zones, reaching a maximum of 45 m, and averaging 10 to 15 m thick. Between townships 28 and 40, the zone is usually less than 5 m thick. The zone is missing along the extreme southern edge of the area because of non-deposition. A similar zero line cannot be established for the northern, eastern, and western regions due to problems outlined for the two other Belly River coal zone. North of Township 40, the Drumheller and Lethbridge coal zones begin to merge to form a continuous coal-bearing zone up to 150 m thick. In that region the Bearpaw Formation becomes very thin making it difficult to distinguish between Lethbridge and Drumheller (Horsehoe Canyon Formation) coal zones (see McCabe et al., 1989).

Stratigraphic cross-sections show that the zone can be easily correlated throughout most areas south of township 40, where the top of the Belly River sequence can be identified. Where the zone contains only one or two seams, individual coal correlations can be made with some confidence. Multiple seams often occur in this zone over short distances, making individual seam correlation very difficult (Macdonald et al., 1987).

Total cumulative coal, varies from 1 to 3 metres in the coal zone. This coal zone TCC is generally small but (very) local thickening of seams is known to occur (minimum 0.2 m, maximum 6.1 m). The thickest seams over much of the area range between over 1 and less than 2 metres. Large areas have thickest seams of less than 1 metre (minimum 0.2 m, maximum 3 m)

17.3.3.2 Taber Coal Zone

The Taber coal zone, although very widespread geographically, is missing in a number of locations. The zone has been removed by erosion throughout a large area along the Milk River, where the Foremost Formation have been eroded. The zone is also missing at a nonmarine to marine eastward facies change in the area around townships 30 to 40, east of range 10. The Taber zone progressively becomes thinner to the east. Near the Alberta/Saskatchewan border it becomes the first coal zone, stratigraphically, above the marine Pakowki Formation. The zone also shows some stratigraphic upward migration in the south. The northwestern and western area of the basin contains very little Taber coal; it is either missing or consists of one or two scattered seams.

The Taber zone reaches its thickest development along a major northwest-southeast trending geographic belt that lies between the western and eastern zero lines. Minor northeast-southwest trending patterns seem to be superimposed on this regional pattern. Within the major trend, the zone varies from 10 to 70 m thick and averages about 25 m. The distribution and geometry of the Taber zone becomes less clear in the extreme southern part of the province, due to erosional effects and relative scarcity of near surface data in this area.

The Taber zone shows a very similar pattern of coal seam correlation to the McKay zone. Stratigraphic cross-sections show that the region where individual seams are most easily correlated, lies within the major northwest-southeast trending geographic belt (Macdonald et al., 1987).

Total cumulative coal varies from 1 to 3 metres over most of the area with some areas near Medicine Hat having more than 6 metres TCC (minimum 0.1 m, maximum 7.4 m). The greater thicknesses are confined to the broad northwest-southeast belt and within this belt the values tend to increase toward the southeast. Thicknesses tend toward zero east of the nonmarine to marine facies change, along the extreme western edge, in the extreme northwest and in the extreme south (here due to erosion). The thickest seams over much of the area range between over 1 and less than 2 metres (minimum 0.1 m, maximum 3 m). Large areas have thickest seams of less than 1 metre.

17.3.3.3 McKay Coal Zone

The McKay zone thickness (i.e. the distance from the lowermost to uppermost seam in the zone) is generally <30 m thick south of township 34, and is up to 50 m thick in the north. In the south, the zone has two geographic north-south linear trends that roughly parallel ranges 11 to 13W4M and ranges 19 to 23W4M. Within these trends the zone thickens to 30 m and away from these areas it thins to zero. North of township 36, the McKay zone distribution becomes more northwest-southeast trending.

Total cumulative coal varies from 1 to 3 metres over most of the area with some areas near Medicine Hat having more than 4 metres TCC (maximum 6.6 m). The thickest cumulative coal in the southern region lies within a north-south trending band that is confined to the area west of the Sweetgrass Arch. The zero line defines the seaward limit of the coal zone, and is well defined up to about township 42. Some thin, isolated pods of McKay zone coals are found within this area of primarly marine strata east of the Sweetgrass Arch (e.g. townships 20-22). In the western part of this south central region, the cumulative coal again approaches zero. Cross-sections show a similar trend in the number of seams, i.e. all increasing toward a central region and tapering off to the west and east. The northern region shows a progressive thinning of the cumulative coal values in a southeast to northwest direction. The zone disappears in the area around townships 55 to 58.

The thickest seams over much of the area range between over 1 and less than 2 metres (maximum 3.0 m). The majority of the area have thickest seams of less than 1 metre (minimum 0.13 m.) (Macdonald et al., 1987).

17.3.4 Rank and Coalbed Methane Potential

The Belly River coals range in rank from lignite to high volatile bituminous. Small amounts of gas were known to occur in the Lethbridge coal mines particularly in faulted zones; but even a small amount of gas in such shallow mines is somewhat suprising and may indicate greater amounts at depth. Locally thick coals may result in commercial CBM exploration targets. The targets may be common in the west-central and southern part of the basin but may be harder to locate.

Belly River coals (Lethbridge coal zone equivalent) in the southern Alberta Triangle zone have the right rank, but more work is needed to establish accurate thicknesses.

17.4 Upper Mannville/Gates/Falher and Gething/Firebag Coal Zones

17.4.1 Regional Coal Geology

The Early Cretaceous clastic wedge (Aptian to mid Albian) in the Alberta subsurface is known as the Mannville Group. These rocks record a major transgressive-regressive cycle with many local cycles of lesser magnitude. They are generally divided into three units: Lower, Middle and Upper (cf. Putnam, 1982; Jackson, 1984; Cant, 1989). For the purposes of coal characterization the Mannville Group is divided into two units, Lower and Upper, with the stratigraphic components of the Middle Mannville being included in the Upper unit.

The Mannville Group is not generally thought of as one of the main economic coal-bearing units in Alberta. The coals that do occur are generally found at very great depths throughout central and southern Alberta. A great volume of stratigraphic related literature has been published on the Mannville Group because of its importance in being the main reservoir rock for the oil sands deposits in northern Alberta and as a conventional reservoir in the Lloydminster and southern Alberta regions. Marker horizons within the Mannville Group are usually based on marine shale units, locally continuous coal seams, or the tops of coarsening-upward cycles.

The formation overlies a major unconformity that separates Paleozoic from Mesozoic age strata and so there exists a great deal of paleo-topography that has influenced the continuity of sedimentary units. There is thought to be a variety of sediment source areas that contributed to the Mannville sequence. Near-shore and restricted marine sediments are interbedded with the predominantly continental Mannville Group sediments.

Very little has been done on establishing individual coal correlations within the Mannville Group. The Alberta Research Council included an examination of Mannville Group coals (Yurko, 1976) in a regional synthesis of subsurface coals. It was concluded that the coals were mostly found within the upper part of the unit and were generally difficult to correlate due to lateral variability and lenticularity of seams. However, one major coal seam in central Alberta was shown to have good lateral continuity and was easily correlated.

17.4.2 Depositional Model

The sub Cretaceous unconformity is a mature erosional land surface consisting of major northwest trending alluvial valley systems incised into strata of upper Paleozoic to Jurassic age. The Lower Mannville, which infills this topography, consists of the Cadomin, Gething, Ellerslie, McMurray and Dina formations. These formations are characterized by sediments which were deposited in environments ranging from alluvial fans, braided and meandering river systems, lacustrine, delatic, and estuarine settings. In the upper part of many of these formations fluvial sediments are overlain by estuarine and shoreline deposits that were formed in response to a rising base level resulting from the encroachment of the sea from the north.

The Lower Mannville equivalent in southwestern Alberta consists of regional valley-filling sandstones, siltstones, and shales. An upward progression from fluvial to lacustrine marginal-marine environments is recorded by this succession, which is a non-coal bearing interval (Hayes, 1986). The Lower Mannville is absent in southeastern Alberta, which was a topographically high area at that time.

The Lower Mannville in east-central Alberta and west-central Saskatchewan consist of the non-coal bearing, fluvial-estuarine, Ellerslie, Dina, and McMurray Formations (Leung, 1976; Banerjee and Goodarzi, 1990).

Lower Mannville sedimentation was ended by a transgression which pushed regional shorelines southwards as far as the U.S. border. The Middle Mannville refers to the Bluesky, Glauconite, Wabiskaw, and Cummings units, which were deposited during the southward transgression of the Boreal sea (Jackson, 1984). The Mid Mannville formations consist predominantly of offshore bars, beach, and barrier island facies with associated estuarine to fluvial channel deposits. The lack of regional episodes of progradation during the deposition of these units has led to the absence of significant coal deposits capping these sand trends. The exception to this is in southern Alberta where the development of a widespread coastal plain during deposition of the Glauconite Formation led to thick coal deposits capping beach and deltaic systems in that area (Jackson, 1984).

The Upper Mannville in southern Alberta consists predominantly of sandy fluvial and estuarine deposits within incised valleys related to the sea level fall. These units are generally non coal-bearing. In the intervalley areas the disconformity associated with channel incision is typically marked by a coal or paleosol giving rise to thin seams of no regional significance (Karvonen, 1990; Wood and Hopkins, 1989).

The Upper Mannville regressive clastic wedge prograded from south to north into the Boreal Sea. In west cental Alberta and British Columbia the succession is composed of the eight transgressive-regressive cycles that form the Spirit River Formation (Cant, 1989). A similar succession in east-central Alberta and Saskatchewan forms the Lloydminster, Rex, G.P., Sparky, and Waseca formations, with the Grand Rapids in northeast Alberta. These Upper Mannville regressive cycles typically consist of marine shales overlain by either offshore bar, barrier island, or deltaic sandstones with capping coastal-plain coals. These cycles prograded northwards into the Clearwater marine shale basin and they pass southwards into equivalent continental plain deposits. The minor transgressions which separate the regressive cycles often extend far southwards giving rise to estuarine and brackish bay deposits.

17.4.3 Depositional Environments

Macdonald et al. (1988) have shown several transgressive-regressive cycles in an overall prograding shoreline sequence for the Moosebar to Gates transition. Four marine cycles are recognized in outcrop in the Cadomin area, the lower three associated with possible wave dominated prograding deltas and strandlines, the upper one having a more brackish (lagoonal, tidal channels, etc.) association.

Sedimentological examination of the lower three cycles in the Cadomin area shows a progression of offshore to shoreface to foreshore environments (strandplains), culminating in the deposition of peats such as the one of the Jewel Seam. The marine strata of the Moosebar Gates transition at Cadomin are likely correlative with the more regional Wilrich and Falher cycles. These marine strata are divided into the 1st, 2nd and 3rd regional cycles, forming a series of prograding shorelines, coastal plain deposits and possibly tidal deposits. Seaward stepping of coastal shoreline sediments was the most common stratigraphic architectural style.

Sedimentary structures in sandstones of the Torrens Member at the base of the Gates Formation indicate shallow marine conditions. Peat swamps likely developed, initially, some distance landward on this coastal plain and with time prograded northward together with the shorelines. Subsequent marine transgressive periods reached as far south as Grande Cache and one of these reached the Cadomin area, as indicated by marine micro fossils above the lower coal seams (Macdonald et al., 1988).

Most of the coals of the lower Gates Formation are coastal plain coals. Coals higher in the succession were deposited on alluvial plains.

17.4.4 Coal Seam Development

17.4.4.1 Upper Mannville Coal Zone

The Upper Mannville coastal plain coals in west-central Alberta are thicker and are preserved over a greater area in a seaward direction than those in the east (Jackson, 1984; p. 63). Mannville Group strata thicken from east to west across central Alberta, with a concomitant increase in total cumulative coal. Yurko (1975) found that there is an average of two to three thick seams per township, with the number generally increasing toward the Foothills margin. Smaller seams (less than 5 feet thick) are generally found in greater numbers toward the western margin and also in the northwestern region of his mapped area. These coals are back-barrier lagoonal coals capping the wave-dominated shoreface-beach deposits of the Falher Members of the Spirit River Formation (Smith et al., 1974; Cant 1974, Macdonald et al., 1988).

The coals in eastern Alberta are thinner and were prone to removal by extensive transgressions. Leung (1976) in west-central Saskatchewan identifies ten Upper Mannville coal seams of which only two are of regional significance. These are a seam at the top of the Cummings Formation and a seam at the top of the Sparky Formation. Banerjee and Goodarzi (1990) classify Upper Mannville coals into two distinctive suites; (1) those capping coarsening-upward wave dominated sandstones in a 'stacked shoreline' succession. These coals are overlain by marine transgressive surfaces. An example of this type of seam is the Sparky coal which caps the Sparky shoreface sandstone, and has an average thickness between 2 and 3 metres. (2) These coals are deposited within a framework of lagoonal, estuarine, and tidal flat sediments. They are distinctive in that they are not overlain by marine transgressive surfaces. An example of this type of seam is the Lloydminster Formation coal seam which can be correlated throughout the Lloydminster area (O'Connell and Benns, 1988). This is described by Zaitlin and Schultz (1990) as forming a seam up to 4 metres in thickness that was deposited in a fringing intertidal to supratidal facies.

The Upper Mannville in southern Alberta consists predominantly of sandy fluvial and estuarine deposits within incised valleys related to the sea level fall. These units are generally non coal-bearing. In the intervalley areas the disconformity associated with channel incision is typically marked by a coal or paleosol giving rise to thin seams of no regional significance (Karvonen, 1990; Wood and Hopkins, 1989).

The area with the greatest total cumulative coal, between 6 and 12 metres, is located in the Red Deer area. Other areas with large TCC can be found near the edge of the deformed belt and in the deep basin in the northwest. TCC ranges from 0.2 to 16.5 metres; however over most of this extensive area TCC is between 2 and 6 metres and the total volume of coal is enormous. Seams range from 0.2 to 12.2 metres in thickness. The thickest seams range between 2 and 4 metres. The area with the greatest seam thickness values is centered on the Red Deer area. In general, areas with the greatest TCC had also the greatest thickest seam values.

17.4.4.2 Firebag Coal Zone

The Firebag coal zone exhibits highly variable coal seam development and resultant cumulative coal values range from 0.31 to 11.28 metres. The thickest seams in the firebag range up to 6.71 metres but are extremely variable in thickness (minimum 0.31 m). Seam correlations are difficult even over short distances. The Alberta Energy Resources Conservation Board estimates that 40 megatonnes in beds greater than 3.6 m thick, are present between 47 and 126 m in depth. Greater resources may exist at depth but are unknown because of casing problems and a general sparseness of oil and gas exploration wells in the area.

17.4.4.3 Gething Coal Zone

The Gething Formation of northeast British Columbia and west-central Alberta is an important coal bearing unit. At the western edge of the Formation, in northeastern British Columbia, up to a hundred coal seams are present, some of which may attain thicknesses of 18 metres (Duff and Gilchrist, 1981). These were deposited in predominantly upper to lower delta plain environments (Gibson, in press). The regional correlation of coal seams is difficult and unreliable. In general the number of seams decreases to the east. In west-central Alberta, where the Gething consists predominantly of channel, overbank and floodplain deposits (Smith et al., 1984), the coal seams tend to be less than 3 metres in thickness and are laterally discontinuous. Gething seams range from 0.2 to 2 metres in thickness with large areas having seams in the 1 to 2 metres range (minimum 0.2 m to maximum 3 m). The greatest total cumulative coal in the Gething coal zone ranges between 2 and 4 metres (west and north of Grande Prairie), however large areas have TCC values less than 2 metres (minimum 0.2 m to maximum 6.3 m).

17.4.4.4 Gates Coal Zone

The Gates Formation forms part of the Luscar Group of the central and northern Foothills of western Alberta. The Luscar Group is largely confined to the inner foothills, which consist largely of folded and faulted Lower Cretaceous rocks and are topographically higher than the Outer Foothills. In the Outer Foothills and in the Interior Plains the Luscar Group is at depth.

The largely non-marine Gates Formation can be divided into three members, in ascending order: Torrens, Grande Cache and Mountain Park members. The age of the Gates Formation ranges from Early to Middle Albian. The basal Torrens Member, which is thin (about 30 m) compared with the other members, consists of sandstones deposited in a shoreface environment. The Grande Cache Member is characterized by coastal plain sandstones, shales and major economic coal seams. It grades into the Mountain Park Member, which consists of fluvial, fining-upward sandstones, shales and minor coal seams.

17.4.5 Rank and Coalbed Methane Potential

Firebag coals have been consistently referred to as lignites although analysis show them to be subbituminous C rank (Smith, 1989). The Firebag coals are thought to have relatively little potential for coalbed methane production but have been presented in this study for completeness and because they are adjacent to the developing oil sand deposits. However the higher rank of these coals (than commonly acknowledged) and there location at the northeastern margin of the basin are important for a better understanding of the CBM potential of the Basin.

The Gething coal zone has some of the highest rank coal in the Alberta Basin, ranging from high volatile bituminous to semianthracite. Maximum ranks occur near the eastern limit of Laramide deformation (Kalkreuth and McMechan, 1989). The high ranks reflect deep burial of the coal near the axis of the deep basin. The great depth (2500-3400+ m) of these coals make their commercial potential less than it otherwise would be, however, new production technology is rapidly developing. Some lower rank and shallower coals further east are still prime exploration candidates.

The Gething coal zone of the foothills is most prospective for coalbed methane near the British Columbia border, where reasonable thicknesses are found. The rank (low volatile bituminous) indicates that a lot of gas has been produced. In the Muskeg thrust sheet of the Narraway River area, these coals are at 1000-1500 m depth. In this area wells could be completed in both the Gates and Gething coal zones.

Much of the extensive and thick Upper Mannville coals are also prime CBM exploration targets with the bulk of the ranks falling in the high to medium bituminous range. The upper Mannville/Falher coal zone provides the best reflectance data for coals in the Alberta basin (total of 498 sites, 755 samples). In the east and northeast rank ranges from lignite to subbituminous C and B rank are found (minimum R_{mean} 0.28%). In the deep basin to the north west and along the disturbed belt medium-volatile to low-volatile bituminous coals are found (some as high rank as semi anthracite maximum R_{mean} 2.13%). A broad band of coals with reflectance values between 0.50 and 0.80% can be seen in the central part of the map area. It is also possible that many of the reflectance values are in that area are in fact depressed; perhaps as much as 0.4 % (see discussion on factors influencing reflectance values).

Mannville coal occurs over great expanses of the basin at depths shallow enough that should result in the commercial extraction of CBM resources. Some deep coal resources adjacent to producible sands and conglomerates; such as those decribed by Wyman (1984) may prove to be particularly good prospects. Wyman's study showed that three coal samples (15-16-68-13W6M) at 2609 m (vitrinite reflectances; 1.63, 1.65, and 1.43%) indicated methane content at about 500 cu. ft./ton of coal. The desorbed gas was 96% by volume methane. Wyman estimated the coalbed methane resource in the coals of his study area to be about 50 tcf. Within the Alberta part of his study he estimated that an average of 15 bcf per section in the coal where the sum total of all seams was over 5 m. Large areas can be seen to exceed that value on MAP 7C.

The thickness and rank distribution (largely medium volatile and higher ranks) of the Gates coal zone indicates optimal coalbed methane potential for these coals. In the inner foothills of the Narraway River, Grande Cache, Cadomin and Nordegg areas, the coals are at reasonable depth and are the main prospective areas. In the outer foothills these coals are at depths of 3000 to 4000 m, which would make drilling expensive.

17.5 Kootenay Coal Zone

The Kootenay coal zone forms part of the Mist Mountain Formation of the Kootenay Group. The Mist Mountain Formation thins from west to east to a zero erosional edge along the eastern edge of the foothills (Gibson, 1985). Near the North Saskatchewan River, this formation is no longer coal-bearing and grades into the Nikanassin Formation.

The Mist Mountain is composed of a thick, interstratified sequence of predominantly non-marine siltstone, sandstone, shale and coal seams. The coal seams are thickest and most numerous in the western part of the foothills and mountains.

17.5.1 Depositional Environment

The coal-bearing lower Mist Mountain Formation was deposited in a coastal plain setting and passes transitionally upsection into an alluvial plain setting, represented by the upper Mist Mountain Formation (Gibson, 1985). Consequently, some of the peat swamps developed in some kind of marine coastal environment.

17.5.2 Coal seam development

Up to 12.6 m of cumulative coal was encountered in a well in the Pincher Creek area, indicative for the type of thicknesses that can be expected for the western part of the southern foothills and mountains.

17.5.3 Coalbed methane potential

The iso-reflectance Map 9 shows the favorable rank distribution of the Kootenay Formation. This information, combined with the observed cumulative thicknesses of around 10 m, indicates some favorable areas for coalbed methane exploration. A disadvantage for this coal zone might be that large parts of the areas with the thickest coal seams and the highest ranks are in the mountains near the British Columbia border, where stricter environmental guidelines may apply.

18 Conclusions

18.1 Plains

18.1.1 Ardley/Kakwa Coal Zones

The Ardley in general has the greatest and most areally extensive Total Cumulative Coal of any Alberta coal zone. The areas of greatest Coalbed Methane potential are at depth towards the disturbed belt. The Drumheller and upper Mannville coal zones have seams as thick as the upper Ardley but only the upper Mannville seams are as extensive. The deeper Ardley coals have ranks in 0.6 to 0.7% range and generally fall in the High-vol. C bituminous in rank (reflectance ranges from a minimum R_{mean} 0.39%, subbituminous C. to a maximum R_{mean} 0.72%, high-vol. B bit.). Since most Ardley coals fall in the high volatile bituminous C rank they may be producers of methane gas. Thick targets near the disturbed belt are potential CBM targets but should not be considered as great prospects.

18.1.2 Carbon Thompson/Cutbank Coal Zones

The coal zone has total cumulative coal (TCC) in excess of 2 to 3 metres in only a few isolated spots. TCC of 1 to 2 metres are common. Minimum total cumulative coal was 0.2 metres and maximum was 5.5 metres. Reflectance data support those values in the overlying Ardley coals and have reflectance values in the 0.52 to 0.7% range (maximum R_{mean} 0.76%, high-vol. A bit.). The majority of these coals are also likely High-vol. C bituminous in rank. These coals may be producers of methane gas but their thin and discontinuous nature make these coals poor CBM targets.

18.1.3 Drumheller/Red Willow Coal Zones

The area with the greatest total cumulative coal (TCC), in excess of 18 metres, is located just west of Drumheller. The Drumheller contains the largest amount of TCC of any Alberta coal zone, however, these thick packages of coal are not as extensive as the thick Ardley and upper Mannville coals. The thickest seams over much of the area range between 1 and 2 metres. Thicker seams (3 to 4 m) are found in the same area of great TCC. However, many seams are present in those areas; in one instance the thickest seam present was a substantial 10.5 meters. The of the range of reflectance values are from subbituminous B at 0.43% to high-vol A at 0.80% R_{mean}. Most of the coals fall in the High-volatile C bituminous rank. Thick shallow coals may result in commercial CBM exploration targets. There are a few mentions of gas from the Horseshoe Canyon coals. Although these coals cannot be considered prime CBM targets they should not be ignored.

18.1.4 Lethbridge Coal Zone

Total cumulative coal varies from 1 to 3 metres in the coal zone; local thickening of seams is known to occur to a maximum of 6.1 m. The thickest seams over much of the area range between over 1 and less than 2 metres. Large areas have thickest seams of less than 1 metre. The Belly River coals range in rank from lignite to high volatile bituminous B. Small amounts of gas were known to occur in the Lethbridge coal mines particularly in faulted zones. Even a small amount of gas in such shallow mines is somewhat suprising and may indicate greater amounts at depth. Locally thick coals may result in commercial CBM exploration targets. The targets may be common in the west-central and southern part of the basin but may be hard to locate. In general the Belly River Coals should not be considered prime CBM prospects.

18.1.5 Taber Coal Zone

Total cumulative coal (TCC) varies from 1 to 3 metres over most of the area with some areas near Medicine Hat having more than 6 metres TCC (minimum 0.1 m, maximum 7.4 m). The thickest seams over much of the area range between over 1 and less than 2 metres (minimum 0.1 m, maximum 3 m). Large areas have thickest seams of less than 1 metre. The Taber like the Lethbridge should not be considered a prime CBM prospect.

18.1.6 McKay Coal Zone

Total cumulative coal varies from 1 to 3 metres over most of the area with some areas near Medicine Hat having more than 4 metres TCC (maximum 6.6 m). The thickest seams over much of the area range between over 1 and less than 2 metres (maximum 3.0 m). The majority of the area have thickest seams of less than 1 metre. The McKay like the Lethbridge and Taber should not be considered a prime CBM prospect.

18.1.7 Upper Mannville/Falher Coal Zones

The thick and widespread Upper Mannville coals are prime CBM exploration targets. The area with the greatest total cumulative coal, between 6 and 12 metres, is located in the Red Deer area. Other areas with large TCC can be found near the edge of the deformed belt and in the deep basin in the northwest. TCC ranges from 0.2 to 16.5 metres; however over most of this extensive area TCC is between 2 and 6 metres and the total volume of coal is enormous. Over the map area seams range from 0.2 to 12.2 metres in thickness. The thickest seams range between 2 and 4 metres. The area with the greatest seam thickness values is centered on the Red Deer area. In general, areas with the greatest TCC also had the thickest seams.

Much of the extensive and thick Upper Mannville coals are prime CBM exploration targets with the bulk of the ranks falling in the high to medium bituminous range. The upper Mannville/Falher coal zone provides the best reflectance data for coals in the Alberta basin (total of 498 sites, 755 samples). In the east and northeast rank ranges from lignite to subbituminous C and B (minimum R_{mean} 0.28%). In the deep basin to the north west and along the disturbed belt medium-vol. to low-vol. bituminous coals are found (some as high rank as semi anthracite maximum R_{mean} 2.13%). A broad band of coals with reflectance values between 0.50 and 0.80% can be seen in the central part of the map area. It is also possible that many of the reflectance values are in that area are in fact depressed; perhaps by as much as 0.4%.

18.1.8 Gething/Firebag Coal Zones

The greatest total cumulative coal (TCC) in the Gething coal zone ranges between 2 and 4 metres (west and north of Grande Prairie), however large areas have TCC values less than 2 metres (minimum 0.2 m to maximum 6.3 m). Gething seams range from 0.2 to 2 metres in thickness with large areas having seams in the 1 to 2 metres range (minimum 0.2 m to maximum 3 m). The Gething coal zone ranges from lignite to semi-anthracite rank. Differing geothermal gradients and depressed values from 0.1 to 0.4% may account for some of the spectacular change. Other regional factors may include rapidly decreased burial of the coals towards the northeast. Minimum R_{mean} 0.26% and maximum R_{mean} 2.36% can be found in the coal zone.

The Gething coal zone has some of the highest rank coal in the Alberta Basin, ranging from high volatile bituminous to semianthracite. Maximum ranks occur near the eastern limit of Laramide deformation and reflect deep burial of the coal near the axis of the deep basin. The great depth (2500-3400+ m) of these coals make their commercial CBM potential less than it otherwise would be, however, new production technology is rapidly developing. Some lower rank and shallower coals further east are still prime CBM exploration candidates.

The Firebag coal zone is highly variable and TCC ranges from 0.31 to 11.28 metres The thickest seams in the Firebag range up to 6.71 metres but are very variable in thickness. The coals range in rank from lignite to subbituminous C rank. The Firebag coals are thought to have no potential for coalbed methane production.

18.2 Foothills

18.2.1 Coalspur Coal Zone

From the combination of thickness and rank, the best potential for coalbed methane in the Coalspur coal zone appears to be in the Entrance Syncline of the Cadomin area and the Nordegg area. However, the Grande Cache area should not be excluded.

18.2.2 Brazeau Coal Zones

Brazeau coals only attain reasonable thicknesses in the Triangle Zone of southern Alberta, where they may be prospective for coalbed methane. In the central and northern foothills they are not very prospective. However, more needs to be known about these coals in the central Alberta foothills before writing them off completely.

18.2.3 Gates Coal Zone

The thickness and rank distribution (largely medium volatile and higher ranks) of the Gates coal zone indicates optimal coalbed methane potential for these coals in several areas. In the inner foothills of the Narraway River, Grande Cache, Cadomin and Nordegg areas, the coals are at reasonable depth and are the main prospective areas. In the Narraway River area, wells could be completed in both the Gates and

Gething coal zones.

18.2.4 Gething Coal Zone

The Gething coal zone only attains reasonable thickness near the Alberta-B.C. border. In this area, the rank of the coal zone (low volatile bituminous to semi-anthracite) indicates that a lot of gas has been produced. In the Muskeg thrust sheet of the Narraway River area, these coals are at 1000-1500 m depth. In this area wells could be completed in both the Gates and Gething coal zones.

18.2.5 Kootenay Coal Zone

Some favorable areas are present for coalbed methane exploration of the Kootenay Formation. A disadvantage for this coal zone might be that large parts of the areas with the thickest coal seams and the highest ranks are in the mountains near the British Columbia border, where stricter environmental guidelines may apply.

19 References

Allan, J. A., 1921: Geology of Drumheller Coal Field, Alberta; Scientific and industrial, Research Council of Alberta, Report 4.

Allan, J. A., 1924, Carbon, Big Valley, and Ardley coal areas survey; Fifth annual report of the Scientific and Industrial Research Council of Alberta, p. 37-45.

Allan, J. A., and Carr, J. L., 1946, Geology and coal resources of Wapiti Cutbank area, Alberta. Alberta Research Council, Report 43, 43 p.

Allan, J. A., and Carr, J.L. 1947: Geology of the Highwood-Elbow area, Alberta; Alberta Research Council, Report 49, 75 p.

Allan, J. A., and Sanderson, J. O. G., 1925, Geology of Red Deer and Rosebud Sheets, Alberta. Research Council of Alberta, Report 13, 115 p.

Bally, A.W., Gordy, P.L., and Stewart, G.A., 1966: Structure, seismic data, and orogenic evolution of the southern Canadian Rocky Mountains; Bulletin of Canadian Petroleum Geology, V.14, p. 337-381.

Banerjee, I., and Goodarzi, F., 1990. Paleoenvironment and sulfur-boron contents of the Mannville (Lower Cretaceous) coals of southern Alberta, Canada. Sedimentary Geology, v. 67, p. 297-310.

Baofang, L., and Dawson, F. M., 1988, Stratigraphic framework and depositional setting, Judy Creek coalfield, northern Alberta. in Current Research, Part D, Geological Survey of Canada, Paper 88-1D; p. 121-128.

Bustin, R. M., Cameron, A.R., Grieve, D.A. and Kalkreuth, W.D., 1985: Coal petrology, its principles, methods and applications; Geological Association of Canada, Short Course Notes, v.3, 230 p..

Caldwell, W. G. E., 1968, The Late Cretaceous Bearpaw formation in the South Saskatchewan river valley. Saskatchewan Research Council, Report 8.

Cameron, A. R., 1989: Relationship of petrographic and chemical parameters in coal rank evaluation for western Canadian coals; In: Advances in western Canadian coal geoscience - forum proceedings. Alberta Research Council, Information Series No. 103, p. 225-232.

Campbell, J. D., 1972: Coal occurrences and related geology, Fox Creek area, Alberta: Alberta Research Council, Earth Science Report 72-9.

Campbell, J. D., 1974: Coal resources, Hussar-Hanna area, Alberta: Alberta Research Council, Earth Science Report 74-8.

Campbell, J. D., 1975: Coal resources, Tofield-Donalda area, Alberta: Alberta Research Council, Earth Science Report 75-8.

Campbell, J. D., 1962, Boundaries of the Edmonton Formation in the Central Alberta Plains. Journal of the Alberta Society of Petroleum Geologists, 10; p. 308-319.

Campbell, J. D., 1967, Ardley Coal Zone in the Alberta Plains, central Red Deer river area. Research Council of Alberta, Report 67-1, 28p.

Campbell, J. D., and I.S. Almadi 1964: Coal occurrences of the Vulcan-Gleichen area, Alberta: Alberta Research Council, Earth Science Report 64-2.

Cant, D. J., 1984. Development of shoreline-shelf sand bodies in a Cretaceous epeiric sea deposit. Journal of Sedimentary Petrology, v. 54, p. 541-556.

Cant, D. J., 1989. Lower Zuni Sequence: Middle Jurassic to Middle Cretaceous In: Rickets, B.D. (ed.) Western Canada Sedimentary Basin a Case History. Canadian Society of Petroleum Geologists, p. 251-267.

Charlesworth, H. A. K., Guidos, J., Gold, C., and Wynne, D., 1989: TRIPOD 4.0, a microcomputer program for storing, retrieving, displaying and analyzing orientation, stratigraphic and positional data from drill holes, outcrops and seismic lines; Computer Manual, University of Alberta, 111 p..

Christopher, J. E., 1975, The depositional setting of the Mannville Group (Lower Cretaceous) in southwestern Saskatchewan. in W. G. E. Caldwell ed. The Cretaceous System of the western interior of North America. Geological Association of Canada, Special Paper 13; p. 523-552.

Chu, M ,1978: Geology and coal resources of the Wapiti Formation of north central Alberta: Alberta Research Council, Open File Report 1978-12.

Davis, A., 1978: The reflectance of coal; In: C. Karr (editor), Analytical methods for coal and coal products, V.1, Academic Press, p. 27-81.

Dawson, F. M., Jerzykiewicz, T. and Sweet, A. R., 1989, A preliminary analysis of the stratigraphy and sedimentology of the coal-bearing Wapiti Group, Northwestern Alberta, in Advances in Western Canada Coal Geoscience - Forum Proceedings, Alberta Research Council Information Series No. 103, p. 1-11.

Dawson, G. M., 1881: Report on an exploration from Port Simpson on the Pacific Coast to Edmonton on the Saskatchewan; Geological Survey of Canada Report of Progress 1879-1880, Part B, page 1-157.

Demchuk, T., 1986, The Obed-Marsh Mine, in F. M. Dawson, T. Jerzykiewicz, and T. Demchuk, Geology of the Coalspur Formation, Canadian Society of Petroleum Geologists Coal Division Fieldtrip #2.

Demchuk, T., and Strobl, R., 1989, Coal Facies and In-Seam Profiling, Highvale No. 2 Seam, Highvale Alberta, in Advances in Western Canada Coal Geoscience - Forum Proceedings, Alberta Research Council Information Series No. 103, p. 201–211.

Douglas, R. J. W., 1956: Nordegg, Alberta; Geological Survey of Canada, Paper 55-34.

Douglas, R. J. W., 1958: Mount Head map-area, Alberta; Geological Survey of Canada, Memoir 291.

Douglas, R. J. W., 1958, Chungo Creek Map Area, Alberta. Geological Survey of Canada, Paper 58-3.

Duff, P. McL. D., and Gilchrist, R.D. 1981. Correlation of Lower Cretaceous coal measures, Peace River coalfield, British Columbia. British Columbia Ministry of Energy, Mines and Petroleum Resources, Paper 1981.-3.

Erdman, O. A., 1950, Alexo and Saunders map-areas, Alberta. Geological Survey of Canada, Memoir 254.

Gibson, D. W. in press. Stratigraphy, sedimentology, coal geology and depositional environments of the Lower Cretaceous Gething Formation, northeastern British Columbia and west-central Alberta. Geological Survey of Canada.

Gibson, D. W., 1977, Upper Cretaceous and Tertiary coal-bearing strata in the Drumheller-Ardley region, Red Deer river valley, Alberta. Geological Survey of Canada, Paper 76-35, 41p.

Gibson, D. W., 1977: Upper Cretaceous and Tertiary coal-bearing strata in the Drumheller-Ardley region, Red Deer River Valley, Alberta; Geological Survey of Canada, Paper 76-35, 41 p.

Gibson, D. W., 1985, Stratigraphy, sedimentology and depositional environments of the coal-bearing Jurassic-Cretaceous Kootenay Group, Alberta and British Columbia. Geological Survey of Canada, Bulletin 357, 108p.

Gibson, D. W., 1985: Stratigraphy, sedimentology and depositional environments of the coal-bearing Jurassic-Cretaceous Kootenay Group, Alberta and B.C., Canada.,Geological Survey of Canada, Bulletin 357, 108p.

Given, M. M., and J.H. Wall, 1971: Microfauna from the Upper Cretaceous Bearpaw Formation of south-central Alberta: Bulletin Canadian Petroleum Geology, vol. 19, p. 502-544.

Gordy, P. L., Frey, F.R., and Ollerenshaw, N.C., 1975: Structural geology of the Foothills between Savanna Creek and Panther River, S.W. Alberta, Canada; CSPG Guidebook.

Green, R., 1972: Geological map of Alberta, Research Council of Alberta Map 35.

Hacquebard and Donaldson, 1969, Geological Society of America Special Paper #114, p. 143-191.

Hacquebard, P., and Donaldson, J., 1974: Rank studies of coals in the Rocky Mountains and Inner Foothills Belt, Canada; in Carbonaceous materials as indicators of metamorphism; edited by R. Dutcher, P. Hacquebard, J. Schopf and J. Simon: Geological Society of America, Special Paper 153, p. 75-94.

Hacquebard, P., 1977: Rank of coal as an index of organic metamorphism for oil and gas in Alberta; in: G. Deroo et al., The origin and migration of petroleum in the western Canadian sedimentary basin, Alberta: Geological Survey of Canada Bulletin 262, p. 11-22.

Hacquebard, P., and Cameron A. R., 1989: Distribution and coalification patterns in Canadian bituminous and anthracite coals; International Journal of Coal Geology, v.13, p. 207-260.

Hage, C. O., 1943: Beaver Mines, Alberta; Geological Survey of Canada, Map 739A.

Hancock, J. M., and E. G. Kauffman, 1979: The great transgressions of the Late Cretaceous: Journal of the Geological Society, London, vol. 136, p. 175-186.

Hayes, B. J., 1986. Stratigraphy of the basal Cretaceous Lower Mannville Formation, southern Alberta and north-central Montana. Bulletin of Canadian Petroleum Geology, v. 34, p. 30-48.

Hiebert, S. N., and Spratt, D. A., 1990: Study of the Triangle Zone and Foothills structures near Pincher Creek, Alberta; In: Current Research, Part B, Geological Survey of Canada, Paper 91-1B,p. 41-46.

Holter, M.E. and M. Chu 1977: Geology and coal resources of southeastern Alberta: Alberta Research Council, Open File Report 1978-13.

Holter, M.E., M. Chu, and J.R. Yurko, 1976: Geology and coal resources of the Horseshoe Canyon Formation of central Alberta: Alberta Research Council, Open File Report 1976-16.

Hughes, J. D., 1984, Geology and Depositional Setting of the Late Cretaceous, Upper Bearpaw and Lower Horseshoe Canyon Formations in the Dodds-Round Hill Coalfield of Central Alberta - A Computer-Based Study of Closely-Spaced Exploration Data. Geological Survey of Canada, Bulletin 361, 81p.

Jackson, P. C., 1984. Paleogeography of the Lower Cretaceous Mannville Group of Western Canada. In: J.A. Masters (Ed.), Elmworth; Case Study of a Deep Basin Gas Field, American Association of Petroleum Geologists Memoir, v. 38, p. 49–77.

Jerzykiewicz T., and Sweet, A. R., 1986, Caliche and associated improverished palynological assemblages, an innovative line of paleoclimatic research into the uppermost Cretaceous and Paleocene of southern Alberta, in Current Research, Part B, Geological Survey of Canada Paper 86-1B, p. 653-663.

Jerzykiewicz, T., 1985, Stratigraphy of the Saunders Group in the central Alberta Foothills, a progress report. in Current Research, Part B. Geological Survey of Canada, Paper 85-1B: 247-258.

Jerzykiewicz, T., and Sweet, A. R., 1988, Sedimentological and palynological evidence of regional climatic changes in the Campanian to Paleocene sediments of the Rocky Mountain Foothills, Canada. Sed. Geol., 59, p. 29-76.

Jones, P. B., and Workum, R. H., 1978: Geological guide to the central foothills and Rocky Mountains of Alberta; CSPG Guidebook.

Kalkreuth, W., and McMechan, M., 1988: Burial history and thermal maturity, Rocky Mountain Front Ranges, Foothills and Foreland, east-central British Columbia and adjacent Alberta, Canada; AAPG Bulletin, v.72, p. 1395-1410.

Kalkreuth, W., 1982: Rank and petrographic composition of selected Jurassic-Cretaceous coals of B.C., Canada; Bulletin of Canadian Petroleum Geology, v.30, p. 112-139.

Kalkreuth, W., and McMechan, M., 1984: Regional pattern of thermal maturation as determined from coal-rank studies, Rocky Mountain Foothills and Front Ranges north of Grande Cache, Alberta - Implications for petroleum exploration; Bulletin of Canadian Petroleum Geology, v.32, p. 249-271.

Karvonen, R. L., 1990. Stratigraphy and sedimentology of the Lower Cretaceous Mannville Group in the Jenner-Suffield area, southeast Alberta. Unpublished M.Sc. Thesis, University of Alberta, 210 p.

Koster, E. H., 1983. Field excursion guide to the sedimentology of the Oldman Formation, Dinosaur Provincial Park. C.S.P.G. Conference on the Mosozoic of Middle North America, Alberta Research Council Open File Report 1983-12.

Koster, E. H., Currie, P. J., Eberth, D., Brinkman, D., Johnston, P., and Braman, D., 1987, Sedimentology and Palaeontology of the Upper Cretaceous Judith River/Bearpaw Formations at Dinosaur Provincial Park, Alberta. Geological Association of Canada/ Mineralogical Association of Canada, Field Trip Guidebook, Trip 10.

Langenberg, C. W., and Fietz, D. 1990: Geology of the Cadomin East (83F/3) mapsheet. Alberta Research Council, Open File Report 1990-12.

Langenberg, C. W., Kalkreuth, W., and Wrightson, C.B., 1987: Deformed Lower Cretaceous coal-bearing strata of the Grande Cache area, Alberta; Alberta Research Council, Bulletin 56, 54 p..

Langenberg, C. W., Macdonald, D., Kalkreuth, W., and Strobl, R., 1989: Coal quality variation in the Cadomin-Luscar coalfield; Alberta Research Council, Earth Sciences Report 89-1, 65 p..

Langenberg, C. W., Macdonald, D.E., Kalkreuth, W., and Strobl, R.S., and Bahnsen, B., 1988. An Initial Assessment of Controls on Coal Quality Variation in the Cadomin-Luscar Coal Field. Alberta Research Council Open File Report 1988-6, 78 p.

Latour, B. A., 1961, Coal occurrences along St. Mary River on Blood Indian Agency, Alberta, Geological Survey of Canada.

Leung, S., 1976. Coal in the Mannville Group (L. Cretaceous) of west-central Saskatchewan. Unpublished M.Sc. thesis, University of Alberta.

Livingstone, R. D., 1985. The Lethbridge coal field. In: Coal in Canada, Canadian Institute of Mining and Metallurgy Special Volume 31, T.H. Patching (ed), p. 52.

Macdonald, D. E., Langenberg, C. W. and Gentzis, T., 1989, A Regional Evaluation of Coal Quality in the Foothills/Mountains Region of Alberta, Alberta Research Council Earth Sciences Report 89-2, 58 p.

Macdonald, D. E., Langenberg, C. W. and Strobl, R. S., 1988: Cyclic marine sedimentation in the Lower Cretaceous Luscar Group and Spirit River Formation of the Alberta Foothills and Deep Basin; in Sequences, Stratigraphy, Sedimentology: Surface and subsurface, edited by D. P. James and D. A. Leckie: Canadian Society of Petroleum Geologists, Memoir 15, p. 143-154.

Macdonald, D. E., Ross, T. C., McCabe, P., and Bosman, A., 1987. An Evaluation of the Coal Resources of the Belly River Group, to a Depth of 400 m in the Alberta Plains area. Volumes I, II:, Alberta Research Council Open File Report 1987-8.

Mandryk and Richardson 1988 Coal resource data in the Plains area of Alberta (diskette and map) ARC open file report 1988-07]

McCabe, P. J., 1984, Depositional Environments of coal and coal-bearing strata, Spec. Publ. Int. Ass. Sediment. Volume 7, p. 13-42.

McCabe, P. J., 1988, Depositional Environments of Coal and Coal-Bearing Strata, Canadian Society of Petroleum Geologists Short Course, 66 p.

McCabe, P. J., Strobl, R. S., Macdonald, D. E., Nurkowski, J. R., and Bosman, A., 1989, An evaluation of the coal resources of the Horseshoe Canyon Formation and laterally equivalent strata, to a depth of 400 m, in the Alberta plains area, Volumes I, II:, Alberta Research Council Open File Report OFR 1989-07, 75 p.

McLean, J. R., 1971, Stratigraphy of the Upper Cretaceous Judith River Formation in the Canadian Great Plains. Saskatchewan Research Council, Geol. Div., Rep. 11, 96 p.

McLearn, F. H., 1919: Cretaceous, Lower Smoky River, Alberta; Geological Survey of Canada, Summary Report, Part C.

McMechan, M. E., 1985: Low-taper triangle zone geometry: An interpretation for the Rocky Mountain Foothills Pine Pass - Peace River area,B.C.; Bulletin of Canadian petroleum Geology, V.33, p. 31-38.

McMechan, M. E. (in press: Geology of Two Lakes map area, Alberta (83L/5); Geological Survey of Canada, A series 1:50 000 scale maps.

Mountjoy, E. W. and Lebel, D. (in press: Mountain Park (83C/14), Geological Survey of Canada, A series 1:50 000 scale maps.

Mountjoy, E. W., 1978: Mount Robson; Geological Survey of Canada, Map 1499A.

Nurkowski, J. R., 1980, Geology and coal resources of the upper part of the Horseshoe Canyon Formation, Red Deer, Alberta. Alberta Research Council, Open File Report 1980-10.

Nurkowski, J. R., and Rahmani R. A., 1984, An Upper Cretaceous fluvio-lacustrine coal-bearing sequence, Red Deer area, Alberta, Canada, Special Publication 7, International Association of Sedimentologists, p. 163-176.

O'Connell, S. C., and Benns, G., 1988. The geology of the Mid Mannville Subgroup in the west-central Lloydminster heavy oil trend, Alberta. Alberta Research Council Open File Report, Number EØ 1988-1, 34p.

Osadetz, K. G., Pearson, D. E., and Stasiuk, L. D., 1990, Paleogeothermal gradients and changes in the geothermal gradient field of the Alberta Plains; in Current Research, Part D, Geological Survey of Canada Paper 90-1D, p. 165-178.

Parkash, S., 1985, Petrographic studies of coals from Alberta plains; Alberta Research Council, Bulletin No. 50, 47p.

Perkins, M., Martindale, B., Houston, G. and Holland, G., 1984: Foothills belt north - Jumping Pound to Nordegg. CSPG Guidebook.

Price, R. A., and Fermor, P. R., 1985: Structure section of the Cordilleran foreland thrust and fold belt west of Calgary, Alberta; Geological Survey of Canada, Paper 84-14.

Putnam, P. E., 1982. Aspects of the petroleum geology of the Lloydminster heavy oil fields, Alberta and Saskatchewan. Bulletin of Canadian Petroleum Geology, v. 30, p. 81-111.

Rahmani, R. A., 1988, Estuarine Tidal Channel and Nearshore Sedimentation of a Late Cretaceous Epicontinental Sea, Drumheller, Alberta, Canada, in P.L. de Boer et al. (eds.), Tide Influenced Sedimentary Environments and Facies, p. 433-471.

Richardson, R. J. H., Strobl, R. S., Macdonald, D. E., Nurkowski, J. R., McCabe, P. J., and Bosman, 1986. An Evaluation of the Coal Resources of the Ardley Coal Zone, to a Depth of 400 m, in the Alberta Plains area. Volumes I, II:, Maps and cross-sections. Alberta Research Council Open File Report 1988-2.

Rightmire, C. T., 1984: Coalbed methane resource; in: Rightmire et al., eds, Coalbed methane resources of the United States; American association of Petroleum Geologists, Studies in Geology Series, No. 17, p. 1-13.

Russell, L. S., 1939: Land and sea movements in the Late Cretaceous of western Canada: Trans. Roy. Soc. Canada, ser. 3, vol. 33, sec. 4, p. 81-99.

Rutherford, R. L., 1930: Geology and water resources in parts of the Peace River and Grande Prairie districts, Alberta; Research Council of Alberta Report 21, 68 p..

Ryer, T. A., 1981, Deltaic coals of Ferron Sandstone Member of Mancos Shale: predictive model for Cretaceous coal-bearing strata of Western interior, American Association Petroleum Geologists Bulletin, Vol. 65, p. 2323-2340.

Selwyn, A.R.C. 1874: Geological Survey of Canada Report of Progress 1873-1874.

Smith, D. G., Zorn, C. E., and Sneider, R. M. 1984. The paleogeography of the Lower Cretaceous of western Alberta and northeastern British Columbia in and adjacent to the Deep Basin of the Elmworth area. In: J.A. Masters (Ed.). Elmworth; Case Study of a Deep Basin Gas Field. American Association of Petroleum Geologists Memoir, v. 38, p. 79-114.

Steiner, J., J. D. Williams, and G. J. Dickie,1972: Coal deposits in the Alberta plains, in Mellon, G.B., J.W.Kramers and E.J. Segal (eds: Proceedings First Geological Conference on western Canadian Coal, Edmonton, Alberta, Research Council of Alberta, Information Series No. 60, p. 85-108.

Stelck, C. R., 1975, Basement controls on sand sedimentation in the Alberta Basin. in W. G. E. Caldwell ed. The Cretaceous System of the western interior of North America. Geological Association of Canada, Special Paper 13; p. 427-440.

Stott, D. F., 1984, Cretaceous sequences of the Foothills of the Canadian Rocky Mountains. in D. F. Stott and D. J. Glass eds. The Mesozoic of middle North America. Canadian Society of Petroleum Geologists, Memoir 9: p. 85-107.

Strobl, R., 1990, Sedimentary Environments of Coal, in Coal Geology and its Application to Coalbed Methane Reservoirs, Lecture notes for short course, Alberta Research Council, p. 67-83.

Strobl, R., McCabe, P. J., Macdonald, D. E., and Richardson, R. J. H., 1986, Estimate of Inferred Resources of Coal In the Plains region of Alberta to a Depth of 400 Metres; Alberta Research Council, Open File Report 1987-05, 31p.

Ting, F. T. C., 1978: Petrographic techniques in coal analysis; In: C. Karr (editor), Analytical methods for coal and coal products, V.1, Academic Press, p. 3-26.

Van Wagoner, J. C., Mitchum, R. M., Campion, K. M., and Rahmanian, V. D., 1990, Siliclastic Sequence Stratigraphy in Well Logs, Cores and Outcrops, American Association Petroleum Geologists, Methods in Exploration Series, No. 7, 53 p.

Wells, G. C., 1957. The Sweetgrass Arch area - southern Alberta. Watgerton Alberta Society of Petroleum Geologists 7th Annual Field Conference Guidebook, p. 27-45.

Williams, G. D., and Burk, C. F. Jr., 1964, Upper Cretaceous. in R. G. McCrossan and R. P. Glaister eds., Geological history of Western Canada. Alberta Society of Petroleum Geologists, Special Publication: p. 169-189.

Williams, G. D., and C. R. Stelck, 1975: Speculations on the Cretaceous Paleogeography of North America, in W.G.E. Caldwell, ed., The Cretaceous System in the Western Interior of North America: Canada Geological Association Special Paper 13, p. 1-20.

Williams, G. D., and Murphy, M. C., 1981, Deep Coal Resources of the Interior Plains, estimated from petroleum borehole data; Geological Survey of Canada Paper 81–13, 15 p.

Wood, J. M., and Hopkins, J.C., 1989. Reservoir sandstone bodies in estuarine valley fill; Lower Cretaceous Glauconite Member, Little Bow Field, Alberta, Canada. American Association of Petroleum Geologists Bulletin, v. 73 (11), p. 1361-1382.

Wyman, R. E., 1984. Gas Resources in Elmworth Coal Seams. In: J.A. Masters (Ed.), Elmworth; Case Study of a Deep Basin Gas Field. American Association of Petroleum Geologists Memoir, v. 38, p. 173-187.

Yurko, J. R., 1975. Deep Cretaceous coal resources of the Alberta Plains. Alberta Research Council Earth Science Report 75-4.

Yurko, J. R., 1976, Deep Cretaceous coal resources of the Alberta Plains. Alberta Research Council, Report 75-4.

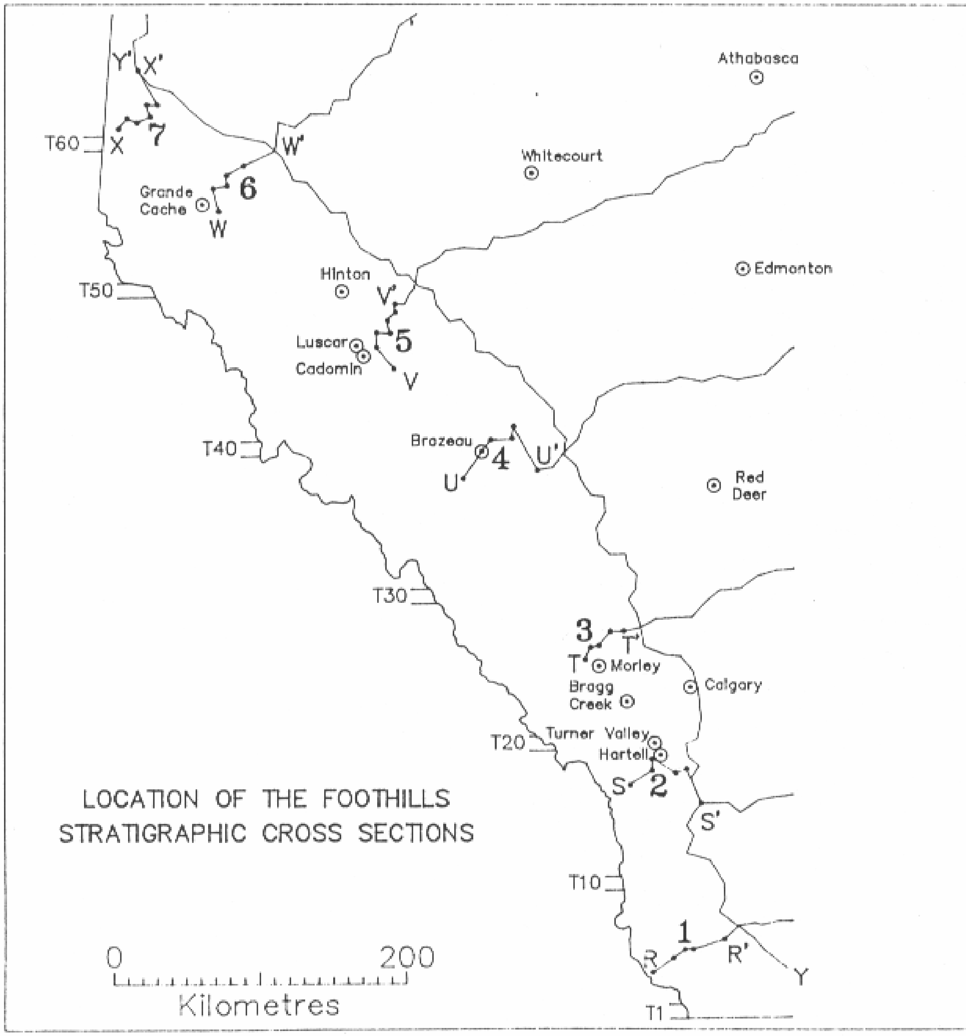
Zaitlin, B. A., and Schultz, B. C., 1990. Wave influenced estuarine sand body, Senlac heavy oil pool, Saskatchewan, Canada. In: J.H. Barwis, J.G. McPherson and J.R. Studlick (Eds.), Sandstone Petroleum Reservoirs. Casebooks in Earth Science, Springer-Verlag New York Inc., p. 363-387.

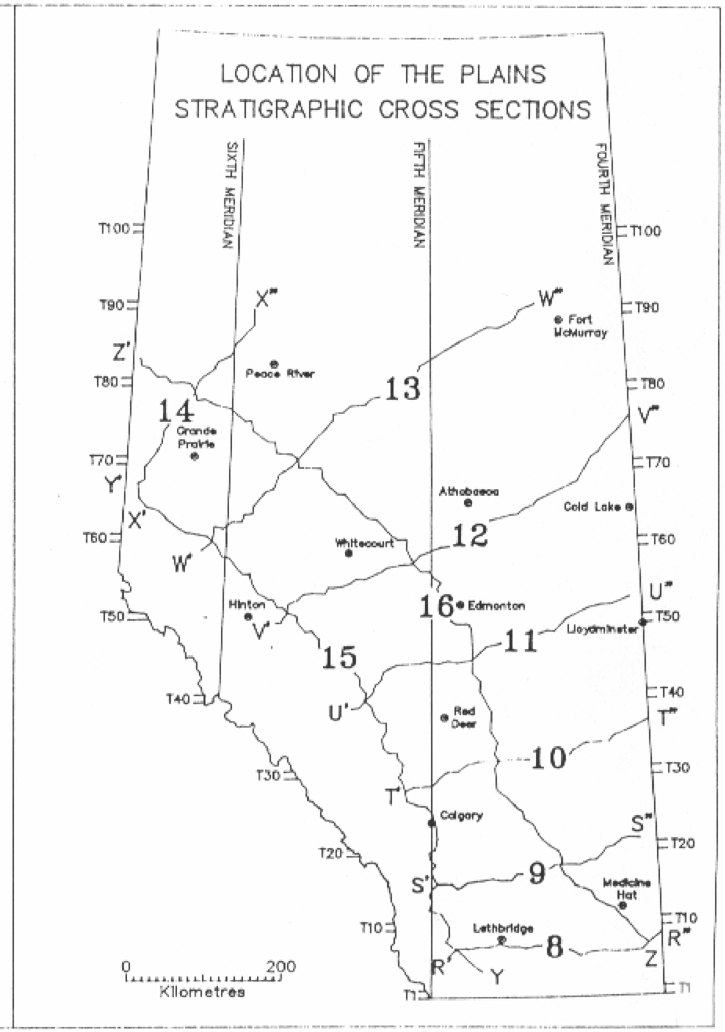
Appendix A

Maps – Page size prints of the 1:750 000 scale maps are included to be used as a guide with the test and for quick reference.

Note: in this digital version of SPE 7, the maps appear in the body of the report with the appropriate section.

STRATIGRAPHIC CROSS SECTIONS





Appendix B

Cross-Sections – Page size prints of the large scale cross-sections are included to be used as a guide with the text for quick reference.

Note: in this digital version of SPE 7, the cross-sections appear in the body of the report with the appropriate section.

Appendix C

Vitrinite Reflectance Data

Discussion of vitrinite reflectance data and the factors affecting it.

POSSIBLE CAUSES OF SUPPRESSION OF VITRINITE REFLECTANCE IN COALS

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The classification scheme used by coal petrologists for the macerals which make up coals, oil shales as well as kerogen dispersed in sediments has been somewhat clouded by a parallel classification scheme developed by petroleum organic geochemists to describe fine-grained “source rocks”. Two end-members exist in the latter case, a hydrogen-rich, oxygen-poor, “amorphous” kerogen (Type I); and a hydrogen-poor, oxygen-rich, “humic” kerogen (Type Ill). Kerogens between the end-members are classified as Type II kerogen. Hydrogen-rich, oxygen-poor macerals fall into the liptinite and exinite groups, and the hydrogen-poor, oxygen-rich macerals fall into the vitrinite group. Thus, liptinite and exinite-group macerals are Tissot and Welte’s (1978) Type I and Type II kerogens, and vitrinite-group macerals are Type Ill kerogen. Macerals of the liptinite group include alginite and of the exinite group include: sporinite, cutinite, resinte, fluorinite, exsudatinite, bituminite, liptodetrinite and suberinite.

Vitrinite reflectance is regarded as one of the most powerful tools available to organic petrologists. However, there are some major recognized and unrecognized problems exist concerning the use of this technique. One such unrecognized problem is the suppression of reflectance by significant concentrations of liptinite and exinite macerals (Type I and Type II kerogen) in association with vitrinite macerals. There are two dominant types of vitrinite present in most sedimentary rocks: vitrinite A which is a hydrogen-poor vitrinite composed of telinite and telocollinite and vitrinite B, which is hydrogen-rich desmocollinite. In coal petrography, vitrinite reflectance measurements are carried out only on vitrinite A macerals because these give higher reflectance values than vitrinite B macerals at the same rank.

The earliest work in which indirect reference to reflectance suppression due to the presence of a significant concentration of macerals of liptinite and exinite group macerals was made is that of Stach et al., (1975) and Ting (1977). These investigators showed that resin-impregnated huminite precursor of vitrinite in lignites had lower reflectance than huminite in lignites which were devoid of resin impregnation. Jones and Edison (1978) noted that reflectance is suppressed in rocks dominated by amorphous (exinitic) organic matter. Hutton and Cook (1980) examined samples from the Joadja torbanite (an oil shale) in New South Wales, Australia, and observed a reflectance suppression. They found a strong decrease (suppression) of Ro, max with increase in the percentage of alginite in the samples, and concluded that the effect was rectilinear and that reflectance was suppressed more for desmocollinite (vitrinite B) than for telocollinite (vitrinite A). Sitler (1979) found that Carboniferous coals had higher Ro values than Upper Cretaceous to Tertiary coals of the same rank. He noted that the effect was due to the fact that Upper Cretaceous to Tertiary coals are dominated by lycopod and articulate wood. Conifer wood is much more hydrogen-rich or resinous compared to lycopod and articulate wood. Furthermore, Kalkreuth (1982) examined coals in east-central and SE British Columbia, Canada, and found that as the percentage of the exinite macerals increased, vitrinite reflectance decreased.

Similar observations have also been made on oil shales from Devon Island, Arctic Canada (Goodarzi et al., 1987), and from marine source rocks of the Triassic Schei Point Group in the Sverdrup Basin, Arctic Canada (Goodarzi et al., 1989; Gentzis, 1991; Goodarzi et al., in press). In addition, Tissot et al., (1978) has observed a reflectance suppression on the Eocene Green River shales of the Unita Basin, Utah, and Jones and Edison (1978) on the Toarcian shales of the Paris Basin. Also, Snowdon et al., (1986) observed a suppression of reflectance in the ‘needle’ coals of the Upper Jurassic-Lower Cretaceous Kootenay Group in British Columbia. The Los Angeles Basin and the Williston Basin (Saskatchewan-North Dakota) are also examples of areas where an Ro retardation due to significant liptinite content is also observed in sediments (Price and Barker, 1985). The reason for the reflectance decrease is the absorption of liquid hydrocarbons by the vitrinite at the time of their expulsion from closely associated liptinite and exinitic macerals. The vitrinites themselves may be perhydrous (hydrogen-rich) (Murchison, 1987). On the basis of extensive data from yields of solvent extracts from source rocks, Teichmuller (1982) attributed the increasing secondary fluorescence of vitrinite to the gradual absorption by vitrinite macerals of bitumens generated from liptinite and exinite macerals.

Organic matter type is one of the dominant, controlling parameters of petroleum generation, and this is directly related to plant types and depositional environment, and the degree of its influence has generally gone unrecognized. The degree of reflectivity of vitrinite is directly influenced by its hydrogen content; as the hydrogen content decreases, so does vitrinite reflectance. When vitrinite reflectance of two coals is equal, the coals are said to have undergone the same degree of coalification. However, if one of the vitrinites began with a higher hydrogen content, a higher degree of coalification is necessary to increase its reflectance to a level equal to that of a vitrinite which began with a lower hydrogen content. Vitrinite reflectance is the same for both coals but the first coal is actually under-ranked when compared to the second. This is an effect of the environment of coal deposition with the more H-rich (perhydrous) vitrinite having been formed from organic matter deposited under anaerobic, anoxic conditions where putrefaction is the dominant process. (Putrefaction or fermentation is the process by which bacteria consume the oxygen of organic substances, transforming them into hydrogen-rich bituminous products. It takes place under reducing conditions only and results in the formation of bituminite and fluorescing vitrinite).

Besides the problem of reflectance suppression, there are a host of other problems associated with vitrinite reflectance. Mud contamination on the drilling chips, especially with lignite-rich additives, is a common problem. Subjectivity on the part of the microscope operator is also a problem, partly caused by the presence of oxidized or recycled vitrinite fragments in the sample. Also, problems arise when there may be two or three distinct maceral populations present in the same sample, which can be caused by differences in organic matter types and depositional environment. Another subjectivity problem lies in choosing the correct maceral type for reflectance measurements. There may be different maceral types each following a different maturation path. As a result, for a given set of burial conditions, different reflectance values will result for each different maceral type.

REFERENCES

Bostick, C., Cashman, S.M., McCulloh, T.H., and Waddell, C.T., 1978 Gradients of vitrinite reflectance and present temperature in the Los Angeles and Ventura Basins, California; In: Symposium in geochemistry: low temperature metamorphism of kerogen and clay minerals, Oltz, D.F. (Ed.), Pacific Section Society of Economic Paleontologists and Mineralogists, p. 65-96.

Gentzis, T. 1991 Regional Maturity and Source-Rock Potential of Palaeozoic and Mesozoic Strata, Melville Island, Arctic Canada, Unpublished Ph.D. Thesis, University of Newcastle-upon-Tyne, UK, 444 p.

Goodarzi, F., Davies, G.R., Nassichuk, W.W., and Snowdon, L.R., 1987 Organic petrology and Rock-Eval analysis of the Lower Carboniferous Emma Fiord Formation in Sverdrup Basin, Canadian Arctic Archipelago, Marine and Petroleum Geology, vol. 4, p. 132-145.

Goodarzi, F., Brooks, P.W., and Embry, A.F., 1989 Regional maturity as determined by organic petrology and geochemistry of the Schei Point Group (Triassic) in Western Sverdrup Basin, Canadian Archipelago, Marine and Petroleum Geology, vol. 6, p. 290-302.

Goodarzi, F., Gentzis, T., Embry, A.F., Osadetz, K.G., Stewart, R., and Skibo, D. (in press) Maturity and source rock potential of the sedimentary succession of Lougheed Island, Central Sverdrup Basin, Arctic Archipelago, Geological Survey of Canada Bulletin.

Hutton, A.C. and Cook, A.C., 1980 Influence of alginite on the reflectance of vitrinite from Joadja, NSW, and some other coals and oil shales containing alginite, Fuel, vol. 59, p. 711-714.

Jones, R. and Edison, T., 1978 Microscopic observations of kerogen related to geochemical parameters with emphasis on thermal maturation, Symposium in geochemistry, low temperature metamorphism of kerogen and clay minerals, Pacific Section Society of Economic Paleontologists and Mineralogists, p. 1-12.

Kalkreuth, W.D., 1982 Rank and petrographic composition of selected Jurassic-Lower Cretaceous coals of British Columnia, Canada, Canadian Petroleum Geology Bulletin, vol. 30, p. 112-139.

Murchison, D.G., 1987 Recent advances in organic petrology and organic geochemistry: an overview with some reference to 'oil from coal'; In: Coal and Coal-beraring Strata: Recent advances, Scott, A.C. (Ed.), Geological Society Special Publication No. 32, p. 257-302.

Price, L.C. and Barker, C.E., 1985 Suppression of vitrinite reflectance in amorphous rich kerogen - a major unrecognized problem, Journal of Petroleum Geology, vol. 8, no. 1, p. 59-84.

Sitler, J.A., 1979 Virginia University, Effects of source material on vitrinite reflectance, M.S. Thesis, West Virginia University, Morgantown, Virginia, 108 p.

Snowdon, L.R., Brooks, P.W., and Goodarzi, F., 1986 Chemical and petrological properties of some liptinite-rich coals from British Columbia, Fuel, vol. 65, p. 460-472.

Stach, E., Mackowsky, M.-Th., Teichmuller, M., Taylor, G., Chandra, D., and Teichmuller, R., 1975 Stach's textbook of coal petrology, Gebruder Borntraeger, Berlin-Stuttgart.Teichmuller, M., 1982 lnkohlungsgrad und Nordrhein-Westfalen, Krefeld.

Fluoreszenz von Liptiniten und Vitriniten in Beziehung zu Verkokungsverhalten, Geologisohes Landesamt

Ting, F.T.C., 1977 Microscopial investigation of the transformation (diagenesis) from peat to lignite, Journal of Microscopy, vol. 109, p. 75-83.

Tissot, B. and Welte, D.H., 1978 Petroleum formation and occurrence, Springer-Verlag, New York, 538 p.

Tissot, B., Deroo, G. and Hood, A., 1978 Geochemical study of the Uinta basin: formation of petroleum from the Green River formation, Geochimica et Cosmochimica Acta, vol. 47, p. 1469-1485.

Appendix D

Project Database Format

The files containing the project database are described in this appendix.

Appendix E

IN PRESS ARTICLES BY ALBERTA GEOLOGICAL SURVEY STAFF

Three In Press articles by Alberta Geological Survey personnel are presented here in pre-print/draft format to provide additional background information for the Phase I study. The articles are a result of preexisting work and ongoing studies that have contributed to the CBM Phase I project but were not funded by, nor used data resulting from, the Phase I program.

1.) Langenberg, C.W., 1991, Coalification Patterns and Coalbed Methane Potential in the Cadomin Area, Alberta, Canada. In press, Journal of Coal Quality, Proceedings of the GSA Symposium on the"Practical Aspects of Coal Geology".

2.) Nikols, D.J. and Rottenfusser, B.A., 1991, Coalbed Methane - A Canadian Resource for the 90's. In press, 1991 RMAG Field Conference Guidebook, Coalbed Methane of Western North America.

3.) Richardson, R.J.H., 1991, Coal Resources and Coalbed Methane Potential of a Major Alberta Coal Zone. In press, 1991 RMAG Field Conference Guidebook, Coalbed Methane of Western North America.

COALIFICATION PATTERNS AND COALBED METHANE POTENTIAL IN THE CADOMIN AREA, ALBERTA, CANADA

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Abstract

The Lower Cretaceous Jewel seam is a 10 meter thick coal seam in the Cadomin-Luscar coalfield. This seam forms a potential coalbed methane reservoir. Coalification resulted largely from sedimentary burial, but tectonic burial also played a role, as illustrated by the intersection of isorank surfaces and the Jewel Seam. The coal rank of the Jewel Seam ranges from low to high volatile bituminous. Syn-deformational coalification is further indicated by the presence of biaxial vitrinite reflectance anisotropy, with R_{max} parallel to fold axes. The biaxial vitrinite reflectance ellipsoids result from superposition of tectonic strains on a primary, sedimentary burial related, uniaxial anisotropy.

Reservoir characteristics of the Jewel seam indicate possibilities for gas production. In the area west of the town of Cadomin at least 20 km^2 is underlain by this 10m thick coal seam at depths of between 100 and 1000 meters and with high to medium volatile bituminous ranks. Consequently, this specific area could contain 3.1 x 10^9 m^3 (about 100 BCF) of methane. Significant additional coalbed methane resources are almost certainly present in the general Cadomin area.

Introduction

Coal-beds generate large quantities of dry gas (largely methane) as a by-product of coalification. In addition, coal plays an important role as reservoir rock for natural gas. This is evidenced by the capacity of coal to hold large volumes of gas (even though coal has low porosity). Coal reservoirs allow flow of gas, if sufficient fracture systems are present in the coal (Levine, 1990)[1].

The geological setting of sedimentary basins will explain the degree of coalification (rank) and predict potential coalbed methane generation. The structural setting can predict reservoir characteristics such as volumes and permeability. Rank variation, reservoir characteristics and coalbed methane exploration targets for the Jewel seam of the Cadomin area in western Alberta will be discussed in this paper.

General geology

The Cadomin area is situated in the Inner Foothills (figure 1). The area is largely underlain by Lower Cretaceous rocks of the Luscar Group. The coal-bearing Luscar Group was deposited in an overall regressive sequence, during Aptian-Albian time. This sequence represents a major, western sourced, Cretaceous clastic wedge, which prograded into the Interior Cretaceous seaway. The Luscar Group comprises the Cadomin, Gladstone, Moosebar and Gates Formations. The Cadomin Formation consists of alluvial conglomerates. The Gladstone Formation consists of alluvial sandstone, shale and minor coal. The Moosebar Formation contains marine shale and minor sandstone. The largely nonmarine Gates Formation consists of sandstones, shales and coal and can be divided into three members, i.e., the Torrens, Grande Cache and Mountain Park members in ascending order. The basal Torrens Member consists of sandstones deposited in a shoreface environment. The Grande Cache Member consists of coastal plain sandstones, shales and major economic coal seams. It grades into the Mountain Park Member, which consists of fluvial, fining-upward sandstones, shales, and minor coal seams. Four regional marine sedimentation cycles can be distinguished in the transition from Moosebar to Gates Formations (Macdonald et al., 1988)[2].

The coal quality of the Cadomin area is presented by Langenberg et al. (1989)[3]. Two open pit coal mines (Cardinal River Coal and Gregg River Resources) are presently producing from the Grande Cache Member. All production comes from the 10m thick Jewel seam at the base of this member and a total of 5.6 million tonnes of raw metallurgical coal was produced in 1989. The R seam (named Rider seam by Cardinal River Coal and Ruff seam by Gregg River Resources) is situated about 60 meters above the Jewel seam. The R seam is highly variable in thickness and mineral matter content, is presently not being mined and is probably not prospective as a coalbed methane reservoir. The other stratigraphic units contain additional, generally thin coal seams.

The rocks of the area are highly deformed by folding and faulting, with major structures such as Cadomin Syncline, Luscar Anticline, Nikanassin Thrust and Drinnan Thrust (figure 1). This deformation has resulted in shortening of 50 percent and in tectonic thickening of the Jewel seam (Langenberg et al., 1989)[3]. In hinges of folds the Jewel seam can attain thicknesses of 30 meters, which is three times normal stratigraphic thickness. Deformation took place during the Paleocene (see also Kalkreuth and McMechan, 1984)[4].

Rank Variation

The degree of coalification (rank) is governed primarily by rise of temperature during (sedimentary and tectonic) burial and the length of time during which this occurs.

Data on coal rank of the Luscar Group of west central Alberta suggest that the degree of coalification was largely achieved prior to deformation during burial in the foreland basin (Hacquebard and Donaldson, 1974[5]; Kalkreuth and McMechan, 1984[4] and 1988[6]). The regional coalification pattern for the Luscar Group in the northern and central Foothills has recently been discussed by Langenberg and Kalkreuth (1991)[7]. They show a very consistent rank pattern for the base of the Grande Cache Member, where the highest rank coals (low volatile bituminous) are present along the northeastern side and the lowest rank coals (high volatile A bituminous) are present along the southwestern side of the Foothills. This rank variation can largely be explained by variation in sedimentary burial in the foreland basin, as indicated by isorank lines running parallel to the trend of the Foothills. This would imply that stratigraphic thicknesses of Late Cretaceous and Paleocene sequences are decreasing in southwesterly direction in the Foothills, indicating that this area was near the deformation front at that time. Significant rank changes over short distances in the Cadomin area (Figure 2) are more difficult to explain by sedimentary burial and may be related to tectonic burial (syn-deformational coalification).

In the Cadomin area, maximum vitrinite-reflectance for the Jewel seam ranges from 0.97 to 1.43 % (Figure 2). The highest rank is found in the central part of this area, with a decrease in rank both to the southwest and the northeast (Langenberg et al., 1989)[3]. Rather than coal rank maintaining a constant value across the folds, as would be the case if coalification preceded folding, the isorank surfaces intersect the folded Jewel seam, as illustrated in Figure 3. This suggests that the central part of the area was buried somewhat deeper than the margins, resulting in the higher rank. This configuration of rank surfaces implies syn-deformational coalification. Consequently, coalification in the Cadomin area results largely from sedimentary burial, but tectonic burial also played a role during the later stages of burial. Variation in burial (and consequently rank) in the Cadomin area results from the folding process.

Another indication of syn-deformational coalification is the presence of biaxial vitrinite reflectance in the area. The biaxial coals display maximum reflectance axes parallel to nearby fold axes (Langenberg and Kalkreuth, 1991)[7], which suggests a relationship between vitrinite anisotropy and deformation. The biaxial vitrinite reflectance ellipsoids result from superposition of tectonic strains on a primary, sedimentary burial related, uniaxial anisotropy. Consequently, a tectonic stress field was present during the later stages of sedimentary burial and subsequent deformation.

The rank pattern in the Cadomin area (Figure 2) may be compared with the regional westward and eastward decrease in maturation of the Lower Cretaceous strata from a maximum near the edge of the deformed belt (Kalkreuth and McMechan, 1988)[6]. It is interesting to note that, in the Cadomin area, the maximum rank for the coals at the base of the Gates formation is exposed at the surface in the Foothills, while in the Grande Cache area the highest rank for coals at the base of the Gates formation is present in the subsurface of the Interior Plains. Subsurface reflectance data from deep oil and gas wells would verify if this decrease in rank eastward continues in the subsurface northeast of Cadomin. Verification of this trend is presently in progress.

Coal reservoir characteristics

One of the major tools in finding hydrocarbons (both petroleum and coal) has traditionally been understanding the geology of the area. Coal reservoir characteristics are discussed under trapping, volumes of gas, structurally thickened coal, depth of reservoir, cleating and shearing.

Trapping

The anticlinal theory of oil entrapment has been used for more than a century and up to the present day the quest for anticlines has been one of the most successful oil and gas exploration concepts. Hydrocarbon traps are generally divided into: 1) structural traps, 2) diapiric traps, 3) stratigraphic traps, 4) hydrodynamic traps and 5) combination traps (Selley, 1985)[8]. Structural traps can be divided into fold and fault traps. The fold trap is synonymous with the traditionally successful anticlinal theory of oil entrapment.

Almost certainly the same mechanisms that trap conventional oil and gas will also play a role in trapping coalbed methane. However, very little is known about it. The main difference between a traditional oil and gas and a coal reservoir is the lower porosity of coal reservoirs (Rightmire, 1984)[9]. Coal generally has porosities of less than 5%, but the open molecular structure of coal can accommodate far greater amounts of gas than conventional reservoirs. Consequently, volumes of coal (together with favorable rank) are probably more important in locating coal- bed methane reservoirs than types of trap.

Volumes of gas

Potential volume of coalbed methane in a coal reservoir is directly related to tonnage and rank of coal. As temperature increases during burial of organic matter, the coal rank also increases. The rank (or maturity) of the coal controls the volume of gas (mainly methane) generated, because these gases originate from thermal alteration of organic matter during the coalification process. The methane generation peak occurs at the medium volatile to low volatile bituminous boundary and at higher ranks no significant amounts of gas are added to the reservoir (Rightmire, l984)[9]. Consequently, the 10m thick Jewel seam with its favorable high to low volatile bituminous rank is the main exploration target of the Cadomin area. A mechanism of increasing coal volumes locally is structural thickening of coal.

Structurally thickened coal

Structurally thickened coal pods can be found in many places, where it forms important exploration targets for the development of open pit mines. Presently there are two structural positions identified where thickening occurs, in fold hinges resulting from dilation and in fold limbs resulting from duplex faulting. Coal pods along fold hinges have been known and explored for many years, while coal pods resulting from duplex thrusting have only been recognized recently.

The prominent deformation process in this part of the Foothills was flexural slip folding, which resulted in chevron folds. Dilation took place at the fold hinges. The dilation zone can be filled in two ways, either by flow of incompetent material (such as coal) into the void or by hinge collapse. In the Foothills a combination of these two processes took place. Good examples of hinge dilations are exposed in open pits of the Cadomin area (Langenberg et al., 1989)[3]. If these structure are at depth, enhanced volumes of gas may be present.

Depth of reservoir

Although no natural limits to the depth of coalbed methane reservoirs seem to exist, costs of development of these reservoirs limit the exploitable depths to between 100 and 1000 meters. At lesser depths the coal is generally degassed and at greater depths the wells become uneconomic (Wallace, 1990)[10].

Cleating

Flow of gas in coalbed reservoirs is determined by permeability, which is primarily determined by fractures called cleats. Cleat is a miners' term for a natural system of fracture (also called joints) perpendicular to the coal- bed and present in most coals. Cleat spacing and orientation are important in reservoir flow. There are usually two cleat sets developed nearly perpendicular to each other. Face cleat is the major cleat and may extend great distances. Butt cleat (also called end cleat) is perpendicular to the face cleat. In the Alberta Plains face cleat is generally perpendicular to the Rocky Mountain front, indicating some relationship to orogenic forces and a northeast directed maximum principal stress (assuming extensional jointing). This is also reflected in the oval shape of drill holes (break-outs) elongated parallel to the mountain front (Bell and Babcock, 1986)[11]. In the Foothills and Mountains similar sets of cleats are present where the coal is not sheared. However, a large proportion of the coal in the deformed belt is strongly sheared and the cleats are no longer present.

Shearing

Shearing of coal, that is related to faulting, has been observed in most areas of the deformed belt (e.g. Bustin, 1982)[12]. Figure 4 shows a section of the Jewel coal seam of the Cadomin-Luscar coal field. A shearing index was used, that describes the coal macroscopically as: undeformed, slightly deformed or strongly deformed (crushed). The hardgrove grindability is a laboratory test, which determines the ease whereby a coal can be ground to a fine powder. Coals with a high Grindability Index are relatively soft and easy to grind. Those with a low value (less than 50), are hard and much more difficult to make into pulverized fuel. Figure 4 shows that there is a good correlation between shearing and grindability. However, no work has been done yet to determine the effects of shearing on permeability of coal. Sheared coal might still have reasonable permeability, because shearing results in a tight network of fractures (Bustin, 1982)[12]. However, drill holes completed in sheared coal might have caving problems. It is clear that more research is needed on possible relationships between shearing and permeability.

Coalbed methane exploration targets

Based on the previously discussed parameters, potential coalbed methane exploration targets can be delineated in the Cadomin area. The map and cross-sections (figures 1-3) show the Jewel seam at varying depth along the Cadomin Syncline, but generally in the range of 100 to 1000 meters in the area of the cross-sections. The general plunge of the fold axes is 10 degrees to the southeast and the Jewel seam is probably at larger depths than l000m in the eastern part of the Cadomin Syncline along the McLeod River. It can be concluded that, in the general area between cross-section XX' and the town of Cadomin, there is at least 20 km^2 underlain by the 10m thick Jewel seam of high to medium volatile bituminous rank (notice that figure 2 predicts the rank of the Jewel seam in the subsurface). This includes areas along the Luscar Anticline and the anticline extending from the Luscar Mine site (see figure 1), that contain structurally thickened coal according to surface exposure to the west of this area (Langenberg et al., 1989)[3]. Consequently this area contains a coal reservoir with a volume of 2×10^8 m^3 and (based on an average density of 1.2 for this type of coal) a mass of 2.4×10^8 tonnes (2.64×10^8 tons) One can assume an average gas content for coals of this rank of 13 cc/gr (Levine, 1990)[1]. Therefore, the small area west of Cadomin could contain 3.1×10^9 m^3 (about 100 BCF) of methane. This resource is comparable in size to well-known gas fields such as Findley, Basing and Mountain (ERCB, 1989)[13]. The area west of section line XX' contains additional coalbed methane resources, but a number of thrust faults disrupts the continuity of the reservoir. Northeast of the area shown in figure 1 the Jewel seam is at greater depth than 1000m and is not prospective.

In conclusion, the Cadomin area contains potentially large resources of coalbed methane at exploitable depths. Exploration work is needed to determine if the reservoir characteristics will allow economic recovery of this resource.

Aknowledgements

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References

1. Levine, J.R. (1990): Generation, storage and migration of natural gas in coalbed reservoirs; *in*: Coal geology and its application to coalbed reservoirs - Lecture notes for short course; Alberta Research Council Information Series No. 109, p. 84-130.

2. Macdonald, D.E., Langenberg, C.W. and Strobl, R.S. (1988 Cyclic marine sedimentation in the Lower Cretaceous Luscar Group and Spirit River Formation of the Alberta Foothills and Deep Basin; *in* Sequences, Stratigraphy, Sedimentology: Surface and subsurface, edited by D. P. J ames and D. A. Leckie: Canadian Society of Petroleum Geologists, Memoir 15, p. 143-154.

3. Langenberg, C.W., Macdonald, D., Kalkreuth, W., and Strobl, R. (1989): Coal quality variation in the Cadomin-Luscar coalfield; Alberta Research Council, Earth Sciences Report 89-1, 65 p.

4. Kalkreuth, W and McMechan, M. (1984): Regional pattern of thermal maturation as determined from coal-rank studies, Rocky Mountain Foothills and Front Ranges north of Grande Cache, Alberta - Implications for petroleum exploration; Bulletin of Canadian Petroleum Geology, v.32, p. 249-271.

5. Hacquebard, P. and Donaldson, J. (1974): Rank studies of coals in the Rocky Mountains and Inner Foothills Belt, Canada; in Carbonaceous materials as indicators of metamorphism; edited by R. Dutcher, P. Hacquebard, J. Schopf and J. Simon: Geological Society of America, Special Paper 153, p. 75-94.

6. Kalkreuth, W and McMechan, M. (1988): Burial history and thermal maturity, Rocky Mountain Front Ranges, Foothills and Foreland, east-central British Columbia and adjacent Alberta, Canada; AAPG Bulletin, v.72, p. 1395-1410.

7. Langenberg, W. and Kalkreuth, W. (1991): Tectonic controls on regional coalification and vitrinite anisotropy of Lower Cretaceous coals in the Alberta Foothills, Canada; Bulletin de la Societe Geologique de France, v.162, n.2.

8. Selley, R.C. (1985): Elements of Petroleum Geology; W.H. Freeman and Company, New York, 449 p.

9. Rightmire, C.T. (1984): Coalbed methane resource; in: Rightinire et al., eds, Coalbed methane resources of the United States; American Association of Petroleum Geologists, Studies in Geology Series, No. 17, p. 1-13

10. Wallace, J.A. (1990): Coalbed methane production - An operator's perspective. In: Coalbed methane in Alberta - What's it all about. Alberta Research Council Information Series No. 108, p. 84-130.

11. Bell, J.S. and Babcock, E.A. (1986): The stress regime of the western Canadian Basin and implications for hydrocarbon production; Bulletin of Canadian Petroleum Geology, v.34, p. 364-378.

12. Bustin, R.M. (1982): The effect of shearing on the quality of some coals in the southeastern Canadian Cordillera; Canadian Institute of Mining and Metallurgy Bulletin, v.75, no.841, p. 76-83.

13. ERCB (1989): Alberta's Reserves of crude oil, gas, natural gas liquids, and sulphur. ERCB Report 90-18.

Figure captions

Figure 1. Simplified geological map of the Cadomin area.

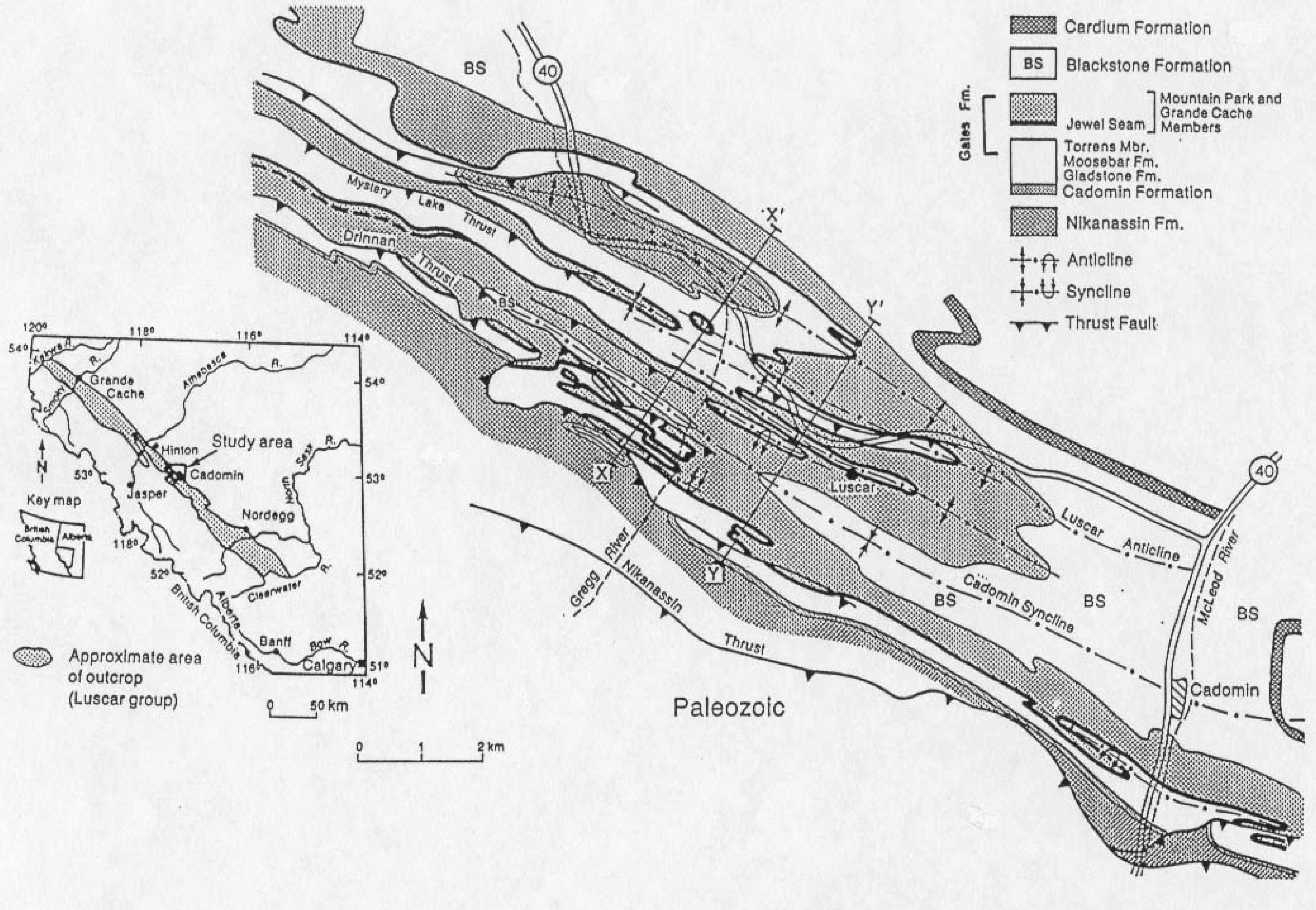
Figure 2. Maximum vitrinite-reflectance variation of the Jewel Seam in the Cadomin area (from Langenberg et al., 1989)

Figure 3. cross-sections through the Cadomin area, showing the relation between rank of the Jewel Seam and deformed strata (from Langenberg et al., 1989). The cross-section lines are shown on figures 1 and 2.

Figure 4. Section of the Jewel seam with Shearing Index and Hardgrove Grindability profiles.

Biography

Willem Langenberg has been a research geologist with the Alberta Research Council since 1976 and has been involved with coal since 1981. He received his PhD. in structural geology in 1972 at the University of Amsterdam, The Netherlands.



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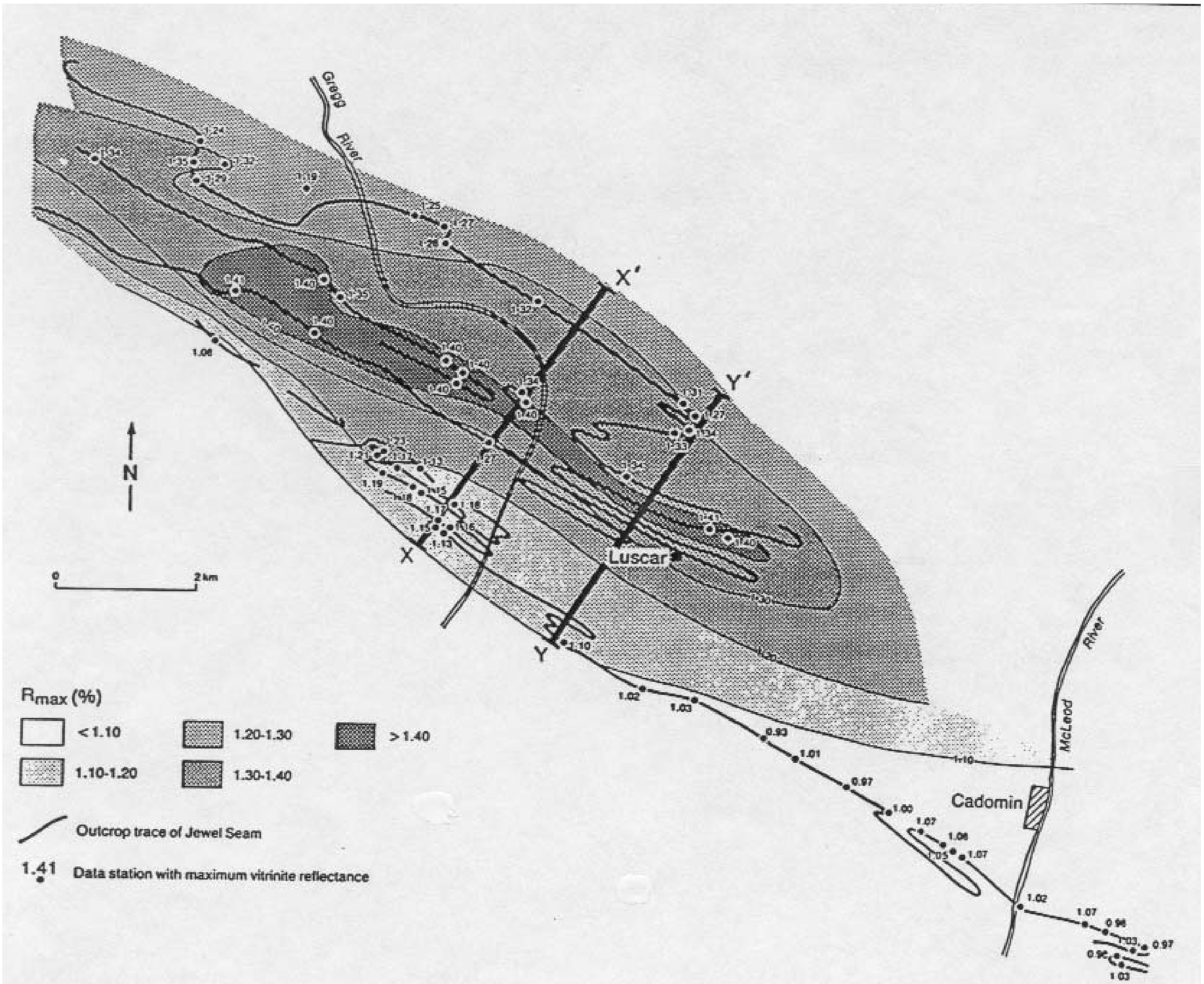

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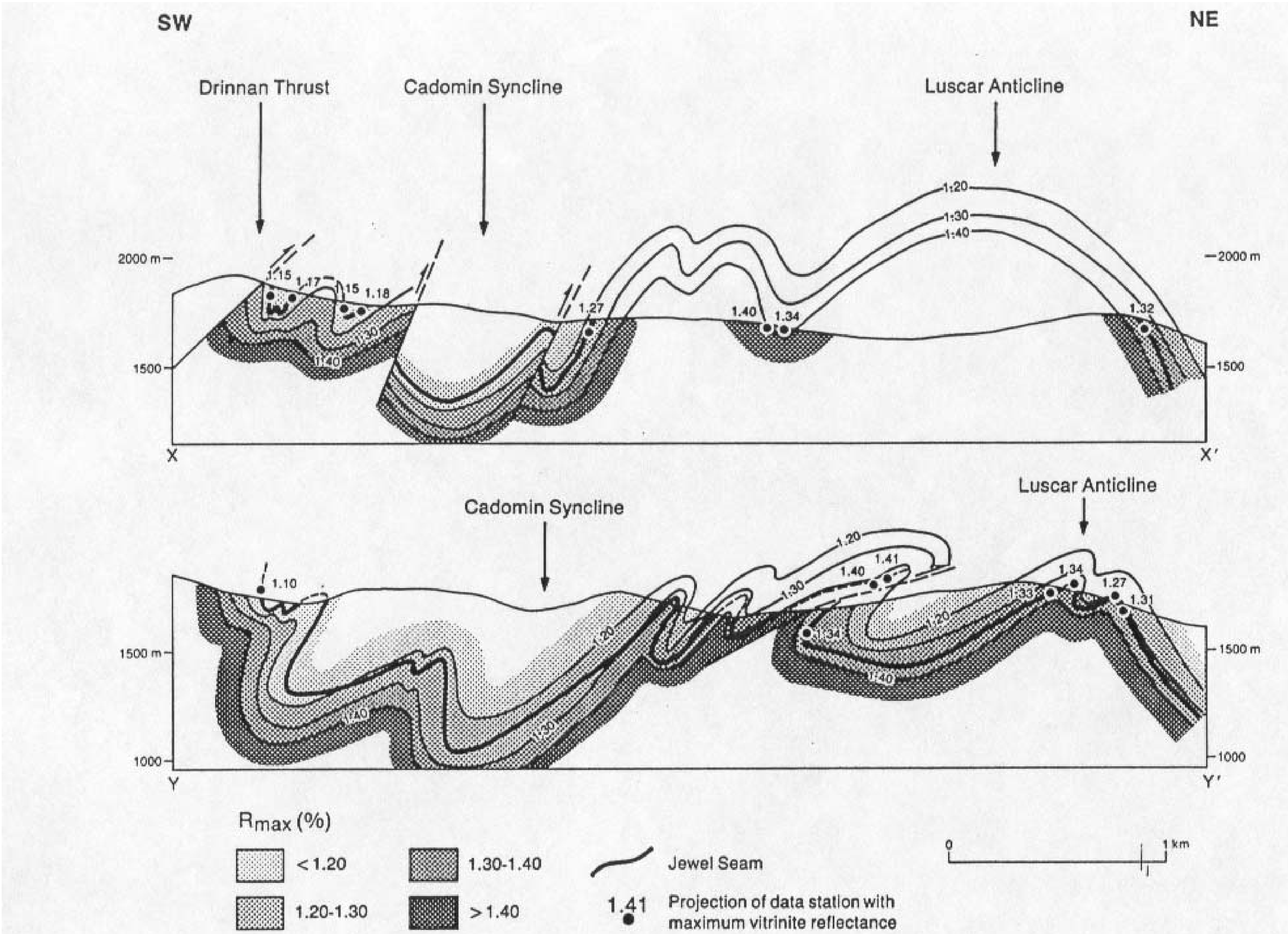

Figure 3. Cross-sections through the Cadomin area, showing the relation between rank of the Jewel Seam and deformed strata (from Langenberg et al., 1989). The cross-section lines are shown on figures 1 and 2 .

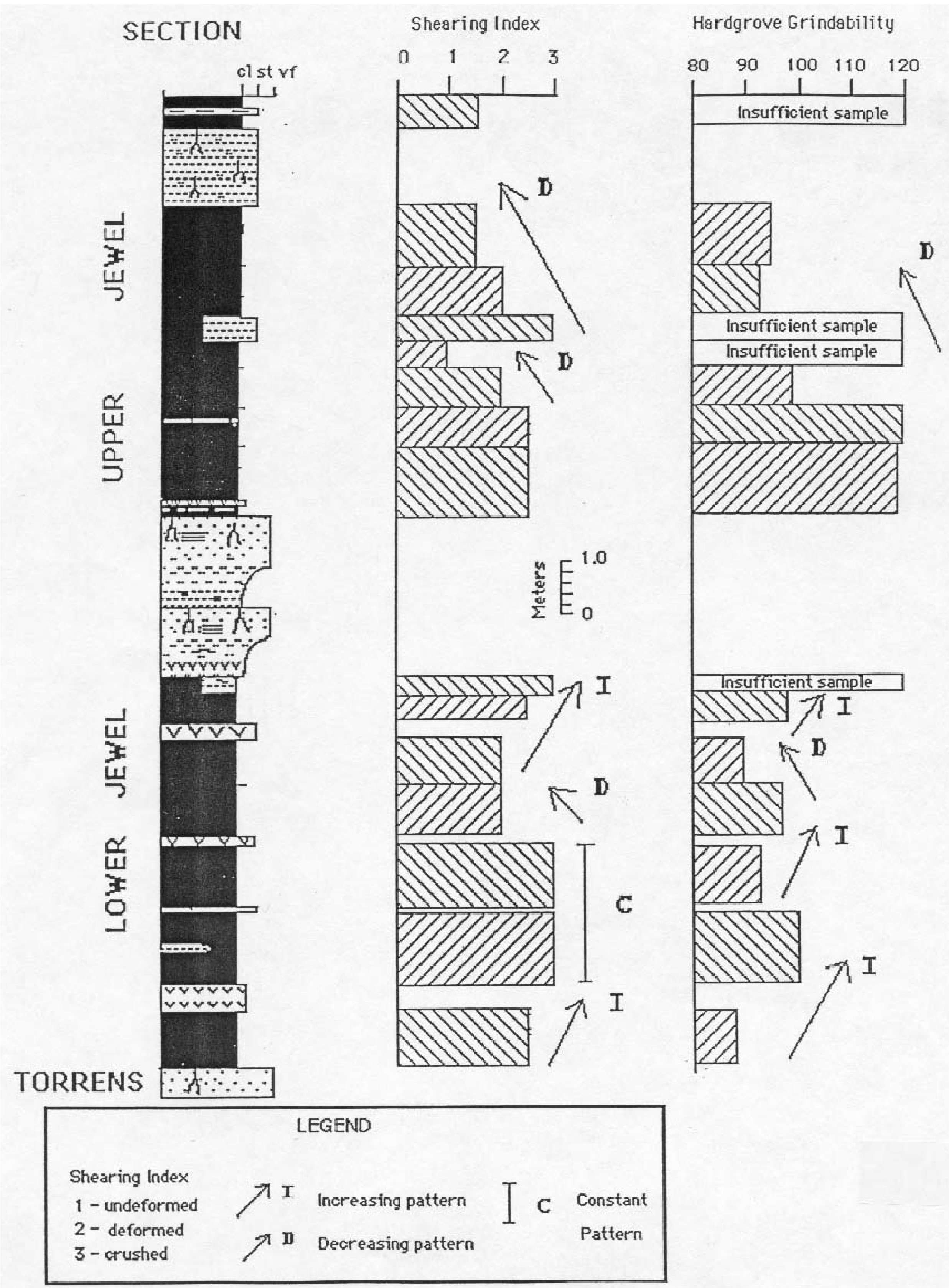

Figure 4. Section of the Jewel Seam with Shearing Index and Hardgrove Grindability profiles.

Coal Bed Methane – A Canadian Resource for the 90's

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ABSTRACT

Alberta holds in excess of 7 x 10^{12} tonnes of coal, distributed over its three physiographic provinces (plains, foothills, mountains). These coals range in age from Jurassic to Tertiary and in rank from sub-bituminous through semi-anthracite. Promising geologic settings for coal bed methane recovery are found in all three regions. The Alberta petroleum industry has recently recognized this potential and companies have begun testing samples and acquiring land positions. Resource estimates of the coal in nontraditional mining areas are currently being revised and improved. A resource evaluation study by the Alberta Geological Survey of the coal bed methane potential of the province has been heavily subscribed to by industry.

Alberta coals have not been extensively tested for gas content. Developing a coal bed methane resource estimate for such large and untested coal resources presents some interesting problems. Indirect evidence has been incorporated such as, depth/rank/gas content, and proximate analysis/gas content relationships. The methods and approaches being used are presented. These results will eventually be verified by direct data and field demonstrations. The 1990 published coal bed methane in-place resource estimate is 4.25 x 10^{12} cubic metres. The estimate from the procedures outlined in this paper is a magnitude larger. The current in-place estimate of coal bed methane in Alberta is 85.75 x 10^{12} cubic metres.

INTRODUCTION

Near surface coal resources in Alberta have been known since 1793. By 1858 Sir James Hector of the Palliser Expedition noted that local coal was already in use by blacksmiths in Edmonton. These resources have been explored and exploited ever since. Measured and indicated reserves as well as potential mining related resources have been well defined. These defined resources are generally near surface, within economic and practical mining depths. The deep resources have received considerably less attention. The deep coal resources have, however been penetrated by thousands of petroleum production and exploration wells over the years but have not been thoroughly studied. These wells and the geophysical logs and chip samples from them, form the basis of the data set available for this study. A program to study and define Alberta's coal and coal bed methane resources at greater depths than past efforts is now underway at the Alberta Geological Survey. This paper is meant to serve as an interim assessment and focal point for discussion until more definitive data becomes available.

GENERAL GEOLOGY

Alberta's coal is concentrated in the southern half of the province. It is distributed between three physiographic regions: plains, foothills and mountains (Fig. 1). Most of the coal resources are found in the plains.

Sedimentation related to the formation of coal in Alberta was largely controlled by mountain building process in the west. Thick clastic wedges from the rising Cordillera prograded into the interior seaway during uppermost Jurassic and Cretaceous times. Peats were developed and buried in the intertonguing of marine and non marine sedimentation as the interior seaway transgressed and regressed. In early Tertiary time, thick accumulations of peat developed on broad interior plains during periods of relative orogenic quiescence (Fig. 2). (Mellon, 1967; Caldwell, 1984; Yurko, 1976)

COAL RESOURCES

Work of the Alberta Energy Resources Conservation Board (ERCB), the Alberta Geological Survey and the Geological Survey of Canada have been combined to derive the coal quantity estimates in this report. The most recent summary of deep coal resources in western Canada appears in Geological Survey of Canada paper 81-13 (Williams and Murphy, 1981). They found coal at depths of greater than 1000 metres in British Columbia, Alberta and Saskatchewan. By far the largest resources are in Alberta.

Accurate figures for shallow coal resources are available (ERCB, 1990; Strobl et al., 1986). These estimates combine measurements made from mines, measured sections and shallow drill holes. Estimates for the deeper resources (those usually considered too deep for economic mining) are based on down hole geophysical logs and limited sampling. Table 1 is a summary of the coal resource estimation criteria used by the different sources being summarized in this report. Since the objective of this paper is an estimation of the coal bed methane potential in Alberta, only the total size of the coal resource and the probable gas content of the coal (based on coal rank) will be addressed.

Table 1. Criteria used for coal resource estimates:

Reference	minimum thickness	depth limit	spacing of observation points	Density	Number of observation points
Williams & Murphy	0.3 m	none	1/93km^2	1.30tonnes/m^3	2448 wells 6593 points
Strobl et al.	0.5 m	400 m	2-3/93km^2	1.37 tonnes/m^3	4737 wells
ERCB	0.3 m	600 m	not stated	1.30 -1.68 tonnes/m^3	not stated

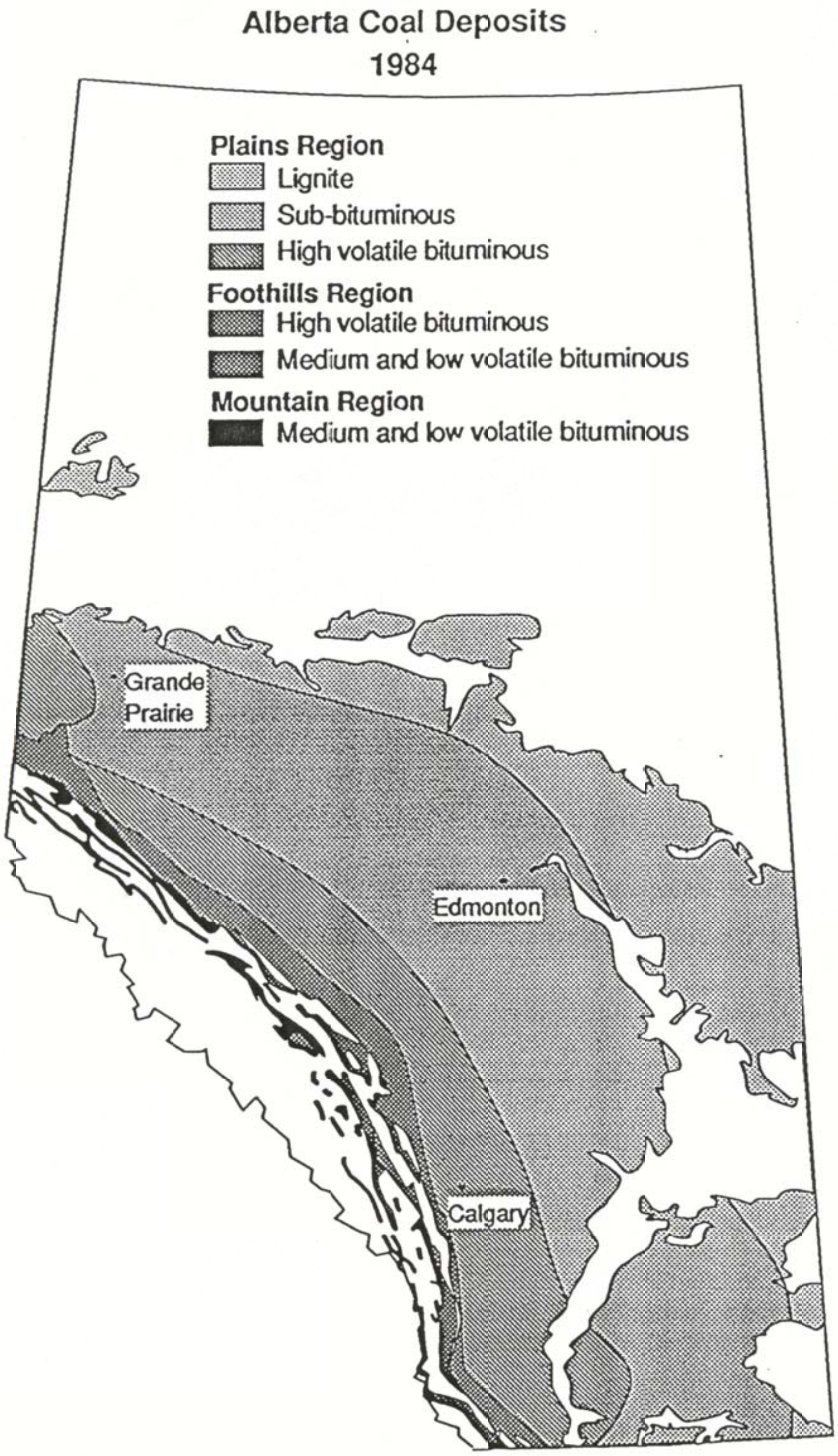

Figure 1. Coal distribution in Alberta by physiographic province and rank (ERCB, 1984)

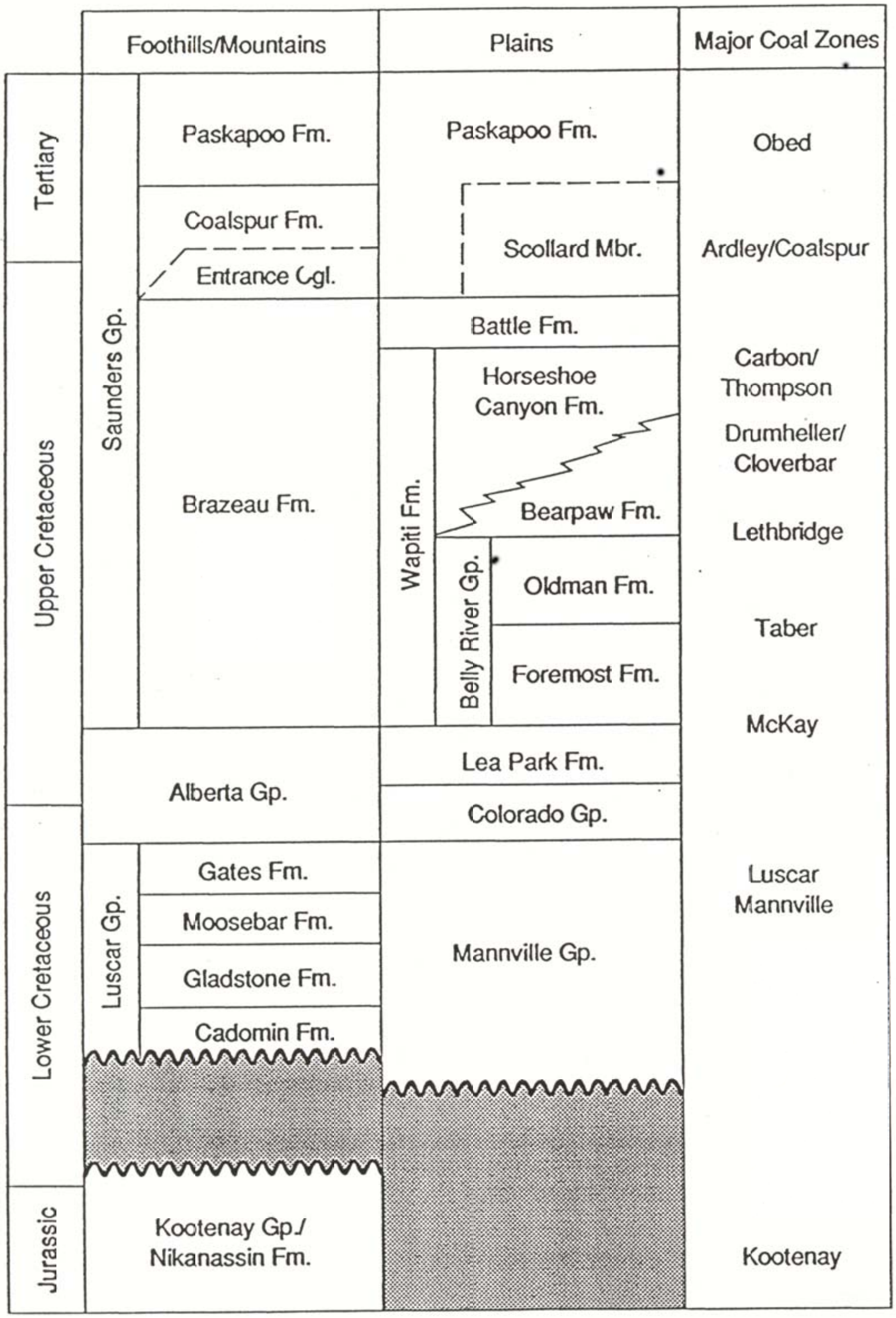

Figure 2. Table of coal-bearing formations and coal zones in Alberta.

It is obvious that the three studies were done using different methods and for different purposes. Williams and Murphy's estimates were chosen as being the most likely to reflect the overall geologic situation. The other estimates, while of very good quality, were too restrictive in scope for our needs. Table 2 illustrates that two of the estimates are only subsets of the third.

Table 2. Estimates of In Place Coal Resources All Ranks:

Reference	Resources
ERCB	2400×10^9 tonnes
Strobl et al.	323×10^9 tonnes
Williams & Murphy	323×10^9 tonnes

We did check with the authors cited and they concurred with our approach. R. Venter of the ERCB (personal communication) suggested that the ultimate potential coal resource in Alberta would be about three times greater than the ERCB's published figures.

The ERCB and Strobl et al. were focused too shallow for a meaningful total coal resource estimate that could be used to estimate the coal bed methane potential of Alberta. Williams and Murphy's estimate appears to be the best available. Since the gas content and recoverability from Alberta's coals are not known, the total coal in place was discounted by 15% and 30% to present a range of possible figures.

COAL RANK

Actual gas content measurements on Alberta coals are not available in the public domain at this time, therefore estimates were made. The first step in the estimation process is the division of the total coal resources into ASTM ranks. Data is not as readily available in the literature for a division of the deep coals by rank as it is for resource quantity estimation. A rather simplistic approach was taken; looking at the coal resource distribution maps as well as cross sections and making some assumptions on the various rank distributions that should be expected.

The rank distribution apparent at the surface has been shown to be misleading when looking at depth (Fig. 3) (Nurkowski, 1985). The most expedient thing to do was arbitrarily divide the resource into likely rank groupings. All references to coal rank in this paper will be made using the ASTM standard designations. Since most of the coal resource lay under the plains we assigned 1/2 of the total to the High-Volatile bituminous (Hvb) and sub-bituminous (Sb) ranks (Table 3). The remaining 50% was divided equally into Medium (Mvb) and Low (Lvb) volatile bituminous ranks. The quantities of lignite and semi-anthracite are believed to be too small to consider.

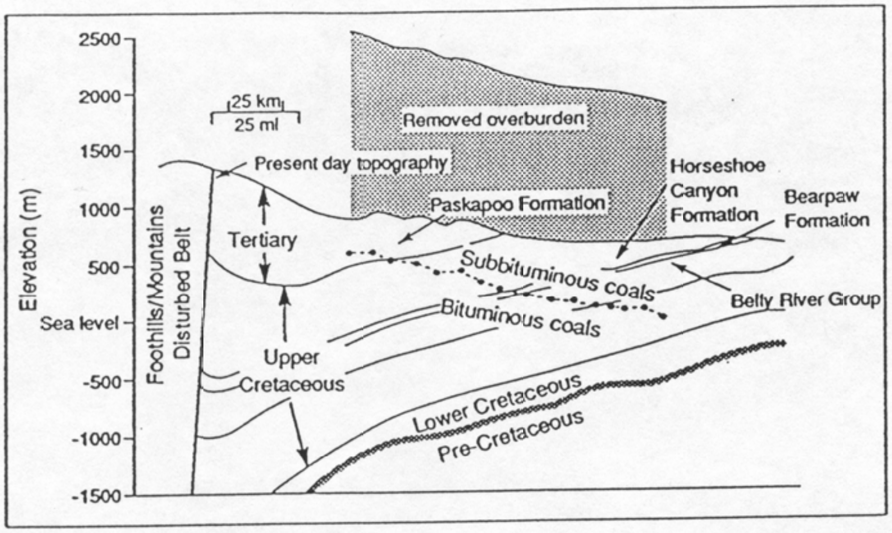

Figure 3. Plains cross-section northeast to southwest showing subsurface stratigraphy, reconstructed overburden, and the west southwest dip of the coal bearing units (Nurkowski, 1985).

Table 3. Resource Division By Rank:

Rank	7×10^{12} tonnes	6×10^{12} tonnes 15% discount	4.9×10^{12} tonnes 30%discount
1. Hvb + Sb	3.5×10^{12} tonnes	3×10^{12} tonnes	2.45×10^{12} tonnes
2. Mvb	1.75×10^{12} tonnes	1.5×10^{12} tonnes	1.225×10^{12} tonnes
3. Lvb	1.75×10^{12} tonnes	1.5×10^{12} tonnes	1.225×10^{12} tonnes
Total	7×10^{12} tonnes	6×10^{12} tonnes	4.9×10^{12} tonnes

GAS CONTENTS

Following a literature review each rank was assigned gas content. Among the sources consulted were: Kim, 1976; et al., 1987; King and Ertekin, 1989. As actual gas content measurements for Alberta coals become available, they will integrated into the coal geologic framework described above.

Values chosen

1. Hvb+Sb = 11 m^3/tonne CH_4
2. Mvb = 13 m^3/tonne CH_4
3. Lvb = 14 m^3/tonne CH_4

RESOURCE ESTIMATION

Due largely to the lack of hard gas content and rank distribution data we are not comfortable in presenting one single value for Alberta's coal bed methane resource. Instead we have provided a range of possible values (Table 4).

Table 4. Gas potential in Alberta: (m^3 CH_4)

Total possible Coal	7×10^{12} tonnes	6×10^{12} tonnes	4.9×10^{12} tonnes
1. Hvb + Sb	38.5×10^{12} m^3	33×10^{12} m^3	26.95×10^{12} m^3
2. Mvb	22.75×10^{12} m^3	19.5×10^{12} m^3	15.925×10^{12} m^3
3. Lvb	24.5×10^{12} m^3	21×10^{12} m^3	17.15×10^{12} m^3
Total	85.75×10^{12} m^3	73.5×10^{12} m^3	460.0259×10^{12} m^3

Starting with the base coal in place we reduced that amount by 15% and 30%. One could reduce the gas content used to achieve the same type of reduction. Figure 4 is provided allow the reader to make his own adjustments to our calculations.

CURRENT RESEARCH

The Alberta Geological Survey is currently conducting an extensive basin wide study of all coal resources, regardless of depth, in Alberta. This study involves the detailed evaluation of petroleum exploration and development wells and development of a stratigraphic framework for the coal zones of the basin. An area covering over 4000 townships is being evaluated. Coals are being picked from geophysical logs and several hundred samples from cuttings and core are being analyzed for vitrinite reflectance. From this extensive data set, a series of planimetric maps showing structure contours, thickness and rank of each coal zone will be produced. A significant refinement in the understanding of the totalcoal resource and rank distribution in the deep coals of the province will result.

All results are being integrated into a sophisticated data base. Mapping and cross sections are also being produced in an electronic form and will be integrated into the Geoscience Information System now being used to provide electronic maps on demand. Information that becomes available in the future can be easily integrated into this new all electronic framework.

CONCLUSIONS

The values used are theoretical and likely to be optimistic under some conditions. A range of possible values could have been used much as a range of coal quantities were used. The question can only be resolved by actual gas content measurements across the basin, combined with a more rigorous survey of coal quantities, qualities and geologic settings. Data is now being collected in different geologic settings across Alberta and integrated into our coal data base and geologic framework. The resource calculations given here will be adjusted and refined in the future as more data becomes available.

REFERENCES

Caldwell, W. G. E., 1984, Early Cretaceous transgressions and regressions in the southern Interior Plains, *in* D. F. Stott and D. J. Glass, eds., Mesozoic of Middle North America: Canadian Society of Petroleum Geologists, Memoir 9, p. 173-203.

Energy Resource Conservation Board, 1989, Reserves of Coal, Province of Alberta: ERCB, 5T90-31. December 1989.

Kim, A. G., 1976, Estimating methane content of bituminous coalbeds from adsorption data: U.S. Bureau of Mines, R1 8245, p. 22.

King, G. R. and Ertekin, T. M., 1989, A Survey of Mathematical Models Related to Methane Production from Coal Seams, Part 1: Empirical and Equilibrium Sorption Models: Proceedings of the 1989 Coalbed Methane Symposium, The University of Alabama/Tuscaloosa, April 17-20, 1989, 8951.

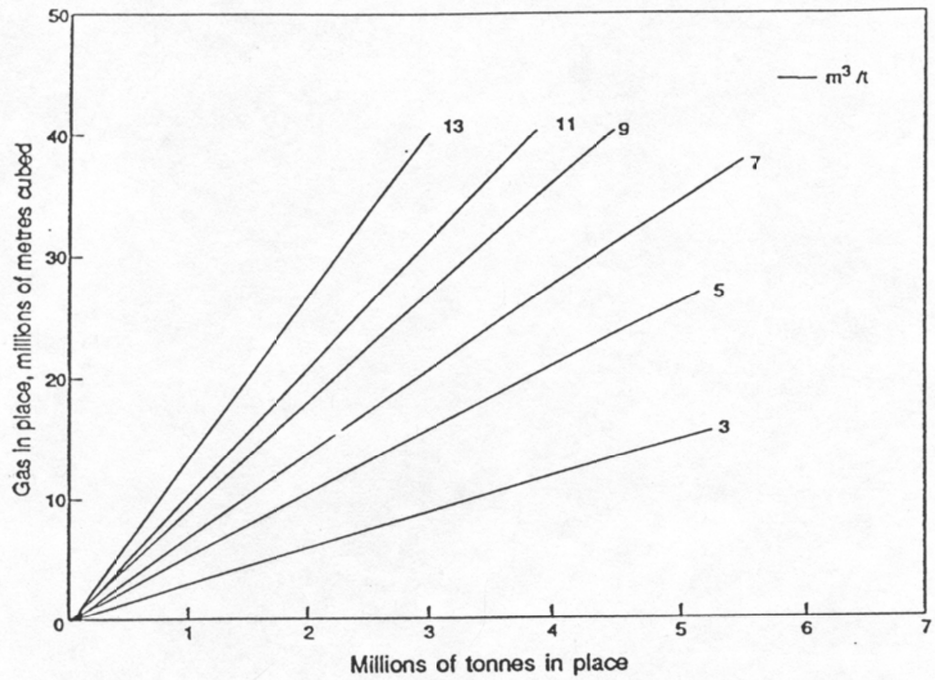

Figure 4. Correlation between coal and gas in-place.

McFall, K. S., Wicks, D. E., Kelso, B. S., Sedwick, K., and Brandenburg, C, 1987, An Analysis of the Coal and Coalbed Methane Resources of the Piceance Basin, Colorado: SPE/DOE 16418 presented at the 1987 SPE/DOE Joint Symposium on Low Permeability Reservoirs. Denver, Colorado (May 18-19, 1987).

Mellon, G. B., 1967, Stratigraphy and petrology of the Lower Cretaceous Blairmore and Mannville groups, Alberta Foothills and Plains: Alberta Research Council, Bulletin 21, p. 270.

Nurkowski, J. R., 1985, Coal quality and rank variation within Upper Cretaceous and Tertiary sediments, Alberta plains region: Alberta Research Council, Earth Science Report 85-1, p. 39.

Smith, G. G., 1989, Coal resources of Canada: Geological Survey of Canada, Paper 89-4, p. 127.

Strobl, R., McCabe, P. J., Macdonald, D. E., and Richardson, R. J. H., 1986, Estimate of Inferred Resources of Coal in the Plains Region of Alberta to a Depth of 400 Metres: Alberta Research Council, Open File Report 1987-05, p. 31.

Williams, G. D., and Murphy, M. C., 1981, Deep Coal Resources of the Interior Plains, estimated from petroleum borehole data: Geological Survey of Canada, Paper 81-13, p. 15.

Yurko, J. R., 1976, Deep Cretaceous Coal Resources of the Alberta Plains: Alberta Research Council, Report 75-4, p. 47.

Coal Resources and Coalbed Methane Potential of a Major Alberta Coal Zone

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ABSTRACT

The total resources of coal in Alberta have been broadly estimated by the Alberta Energy Resources Conservation Board (EROB) at 2400 gigatonnes (billions of metric tons; 1 tonne 1.1 ton). The energy in the coal is 23 times that available in the province's substantial remaining reserves of conventional oil; and more than 3.7 times that of the Alberta's massive oil sands deposits. Although most of the coal resource will never be mined the prospect of recovering coalbed methane from a substantial portion of Alberta's coal is promising both because of the availability of coal and favorable geological conditions. Studies to quantify the gas potential of Alberta coals are now underway for several coal zones.

One such zone, the Paleocene Ardley coal zone, has calculated resources in the order of 425 gigatonnes along a 250 mile (400 kilometre) subcrop and dipping, to about 2950 feet (900 m) depth, 90 miles (150 kin) southwest into the Alberta Syncline. The geologic model developed for the Ardley Coal zone involves a continental setting in an alluvial plain environment characterized by widespread peat swamps that were far removed from marine conditions. Due to extremely low relief, relatively rapid subsidence and sediment starvation, thick and extensive peats developed. In general the seams thicken and more seams are present with increasing depth. These deeper coal resources may contain large volumes of gas.

INTRODUCTION

The total resources of coal in Alberta have been broadly estimated by the Alberta Energy Resources Conservation Board (ERCB) at 2400 gigatonnes. Nikols and Rottenfusser (this volume) have accepted the larger estimate of Williams and Murphy (1981) of 7000 gigatonnes based on recent conversations with the ERCB staff and because that estimate was "most likely to reflect the overall geologic situation" (ie. the estimate included deeper coal resources). Using the lower ERCB estimate the energy in the coal is roughly 23 times that available in the province's substantial remaining reserves of conventional oil (estimated at 25 000 petajoules; ERCB, 1986); and more than 3.7 times that of the Alberta's massive oil sands deposits. The coal resource in place in Alberta is tremendous by whichever estimate is used. A review by Nikols and Rottenfusser (this volume) discusses the Coalbed Methane (CBM) potential of the whole of the Alberta Basin and will not be reviewed here. This paper will instead focus on CBM potential of only one coal zone; the Paleocene Ardley coal zone.

ARDLEY COAL ZONE

Economically, the Ardley is one of the most important coal producing zones in Alberta where near-surface deposits are mined to supply mine mouth power stations. More than 15 million tonnes annually are mined along the subcrop west of Edmonton (Fig. 1).

Previous Work

Research on the Ardley coal zone dates back to the 1920's (Allan,1924). A more recent evaluation of the coal resources by Richardson et. al. (1988) reviews previous work and describes the geology of the coal zone. That study although focussed on the coals to a depth of 1200 feet (400 m) was based on the examination of 1408 oil and gas wells to depths of more than 2950 feet (900 m) and 98 Alberta Research Council coal exploration drill holes in the shallow subcrop area.

Regional Coal Geology

In south central Alberta, north of Calgary, from a 250 mile (400 kilometer) subcrop, the Paleocene Ardley Coals dip 90 miles (150 kin) southwest into the Alberta Syncline (lower Paskapoo Fm.; Figs 1. and 2). They attain a maximum depth of about 2950 feet (900 m) at the edge of the tectonically disturbed. The Ardley coals are contained in a wedge of fine to coarse grained continental (fluvial and shallow lacustrine) clastic sediments (Fig. 3).

Depositional Model

The Ardley coal zone is associated with mainly fine-grained fluvial sediments. Two areas, in the west-central part of the basin, have particularly great amounts of coal with cumulative amounts of up to 80 feet (24 m) and individual seams to 13 feet (4 m) in thickness.

A depositional model has been developed showing the relationship between coal accumulation and the regional tectonic setting. Major depositional controls appear to relate to variation in subsidence rates and isolation from the effects of clastic deposition in a pervasive peat forming environment. The coal seams are remarkably persistent with thick seams correlatable over tens of miles. The peats were deposited in a tectonically active foreland basin, having greater subsidence towards the west and southwest due to loading and or tectonic influences along the western basin margin. The Ardley coal zone ranges from 80 feet (25 m) thick in the east to more than 660 feet (200 m) thick in the west. The total number of seams increases to the west in response to greater subsidence. The laterally persistent (10's of miles) nature of many of the seams suggests development ,at times, of extensive peat-forming mires over large areas of the basin. The development of major river systems, running parallel to the paleo-mountain front, is offered as a possible mechanism for sheltering the eastern peat-forming mires from clastic deposition (Fig. 3) for long periods of time. Areas more proximal to the western basin margin would have a greater influx of clastics preventing the formation of thick coals. A few wells further to the west, in the disturbed belt, provide some substantiation of that idea since they contain lower amounts of cumulative coal. The lack of coal development in the southern part of the basin towards the U.S. border may be related to climatic constraints. Jerzykiewicz and Sweet (1986) suggest that the presence of caliche beds, red beds and impoverished palynological assemblages in Ardley equivalent strata of the southern Alberta foothills may be indicative of a semi-arid environment not favorable for peat development.

Estimate Of Coal Resources

Coal Seam Development

Over much of the area at least one seam 6.5 feet (2 m) or greater in thickness is present. Areas with seams of 13 feet (4 m) or greater in thickness are commonly located within an east-west trend in the basin southwest of Edmonton (Fig. 4). The Ardley coal zone is generally comprised of between 3 and 12 seams (Fig. 5) but up to 18 seams are present in the west-central part of the basin. The combination of thickest seams and greatest number of seams combine in two well defined trends of thick cumulative coal development illustrated in the Total Cumulative Coal Map (Fig. 6). A north-south and an east-west oriented trend containing between 40 and 80 feet (12 to 24 m) of cumulative coal can be readily seen.

Depth to Best 82 Feet (25 m) Zone

A "window" concept was applied in producing the map (Fig. 7), Depth to Best 25 m (82 feet) zone. The term "window" Is defined as a zone of a given interval that contains the most coal. The map is useful in determining the depth of the major pay zone since the total coal zone thickens to more than 660 feet (200 m) in the western part of the basin. An examination of Figures 6 and 7 reveals that the areas of greatest cumulative coal and the depth to the best 25 m (82 feet) zone fall between 1640 feet (500 m) and 2625 feet (800 m)

Pressures, where the greatest cumulative coal and the depth to the best 25 m (82 feet) zone coincide, would be sufficient to contain coalbed gas that may be present.

Coal Resource Totals

The Ardley Coal zone, has calculated resources in the order of 425 gigatonnes (Strobl et. al., 1986; number does not include the equivalent Wapiti and Coalspur coals in the northern and tectonically disturbed parts of the basin). New information based on the same data used in the Strobl et.al., (1986) Ardley resource calculation is presented in Figure 8. The chart shows the estimated resources for Ardley coals in 650 feet (200 m) depth slices down to a maximum depth of 3900 feet (1200 m), although relatively little coal exists below 2950 feet (900 in). The 1.6 feet (>0.5 m) bar shows the total amount of coal, for each depth slice, which added together will approximate the total calculated resource of Ardley coals. The 5 feet (>1.Sm) and 8 feet (>2.5m) bars provide information on resources in each depth slice on seam thicknesses that would be potential coalbed methane targets. The 5 feet (>1.5m) seams can be considered as CBM exploration targets while resources in the 8 feet (>2.5m) seams would form prime targets. Nearly 50 gigatonnes of coal resources, in seams greater than 2.5m (8 feet), are present in a slice at a depth of 1200 feet (400m) to 1970 feet (600m), while approximately 70 gigatonnes are present between 1200 feet (400m) and 2625 feet (800m) in depth.

Rank Of Coals

Except for the subcrop area, including the major producing Ardley mines, little is known about the rank of Ardley coals. Traditionally the Ardley has been shown everywhere on maps as subbituminous in rank even at depth west of the subcrop edge where no data existed. A petrographic study of coals from the Alberta plains by Parkash (1985) included the examination of five Ardley coals from widely separated areas along the Ardley subcrop edge. The coals ranged from subbituminous C to subbituminous A in rank based on vitrinite reflectance. Parkash reviewed rank determination by reflectance and cautioned on the use of the methud for coals of ranks lower than bituminous. There is considerable overlap in reflectance values for subbituminous B and A coals and bituminous C and B coals. Care with the measurement of random measurement of the huminite macerals and a large number of measurements (usually 50) is needed to insure reliable results. Parkash found a good relationship of carbon content to low rank coals supporting the reliability of his rank determinations.

In 1984, Nurkowski reported on 22 Ardley coal samples from four oil and gas wells forming an east-west cross-section (Fig. 9) located near the center of the basin. Samples were within the high volatile bituminous C rank with a few samples nearing the high volatile bituminous B rank (average maximum reflectance R_m 0.48 to 0.63). Higher values in the west are related to a greater depth of burial; while the reflectance gradient (R_m/100m) varied from 0.07 to 0.02 from east to west indicating a higher paleo-geothermal gradient in the east. Six samples in well 46-12W5, having an average reflectance of 0.62, were collected at a depths of 1860 feet (567m) to 2150 feet (655m). Forty miles further west six samples, in well 46-19W5 having an average reflectance of 0.63, were collected at a depths of 2170 feet (661 m) to 2530 feet (771 m). A more recent study of paleogeothermal gradients and changes in the geothermal gradient field of the Alberta plains can be found in Osadetz et.al., (1990).

In Nurkowski, (1985) the relationship between calorific value (moist mineral matter free) and depth of burial was used to determine the thickness of overburden required to mature various low rank coals. Using 685 coal analysis he was able to determine that erosion in the basin has removed between 3000 feet (900m) and 6200 feet (1900m) of sediment since coalification in middle Tertiary time. A map showing the calculated depth to high volatile bituminous C rank coals was produced (Fig. 10). A comparison of Figures 7 and 10 reveals that most Ardley coals should fall in the high volatile bituminous C rank and therefore may be producers of methane gas.

COALBED METHANE

Without actual gas content measurements and a sufficient number of rank distribution data any estimate of the total methane content of Ardley coals must be considered highly speculative. However there is a large quantity of coal available within the Ardley at a rank where thermogenic coalbed gas is normally produced.

Gas Estimates

Based on estimates of 11 m^3 tonne CH_4 for High Volatile Bituminous and Subbituminous coals by Nikols and Rottenfusser (this volume) the 325 gigatonnes of Ardley coal deeper than 1200 feet (400m; Fig. 8) would potentially contain more than 3.5 X 10^{12} m^3 CH_4. About 7.7 X 10^{11} m^3 CH_4 or very roughly 25 trillion cubic feet could be available in seams greater than 2.5m (8 feet) in thickness.

Current Research

The Alberta Geological survey is currently conducting an extensive basin wide study of all coal resources, in Alberta (Nikols and Rottenfusser; this volume). Additional data on the Ardley coal resources and vitrinite reflectance data for rank determination is being collected as part of the study. In the case of the Ardley coal zone relatively little change is expected in our knowledge of coal resource distribution and seam characteristics, however, since virtually no hard data on rank is currently available for the coal zone, new information critical for a realistic assessment of CBM potential is expected. Additional information now being gathered through industry exploration activity will be released over the next year or two as the confidentiality periods expire.

CONCLUSIONS

With approximately 70 gigatonnes of coal resources, in seams greater than 2.5m (8 feet), present between 1200 feet (400in) and 2625 feet (800m) in depth (Fig 8); and areas where up to 18 seams and seams of 13 feet (4 m**)** in thickness can be found, the Ardley coal zone contains abundant resources for a CBM exploration prospect. A very large primary prospect area, in the western part of the basin, at depths of 1640 feet (500 ni) to 2625 feet (800 m) the major pay zone (best 25 m (82 feet)), would have sufficient pressures to contain coalbed gas.

Most Ardley coals at depth should fall in the high volatile bituminous C rank and therefore may be producers of methane gas. The 325 gigatonnes of Ardley coal deeper than 1200 feet (400 m) would potentially contain more than 3.5 X 10^{12} m^3 CH_4 of that about 7.7 X 10^{11} m^3 CH_4 or very roughly 25 trillion cubic feet could be available in seams greater than 2.5m (8 feet) in thickness.

Without actual gas content measurements and a sufficient number of rank distribution data any estimate of the total methane content of Ardley coals must be considered highly speculative.

ACKNOWLEDGMENTS

Rudy Strobl, a major contributor to the original Ardley Coal Resource Study (Richardson et.al., 1988) supervised to production of several of the maps used in this paper. Discussions with Peter McCabe (now of U.S.G.S.) provided a basis for the discussion on the depositional model. Brian Rottenfusser is thanked for reviewing the manuscript.

REFERENCES

Allan, J.A., 1924, Carbon, Big Valley, and ardley coal areas survey; Fifth annual report of the Scientific and Industrial Research Council of Alberta, p.37-45.

ERCB, 1989, Reserves of Coal, Province of Alberta, ERCB ST90-31, December 1989.

Jerzykiewicz T., and Sweet, A.R., 1986, Caliche and associated iinproverished palynological assemblages, an innovative line of paleocliinatic research into the uppermost Cretaceous and Paleocene of southern Alberta in Current Research, Part B, Geological Survey of Canada Paper 86-1B, p.653-663.

Nikols, D.J., and Rottenfusser, B.A., (this volume), Coalbed Methane - A Canadian Resource for the 90's in RMAG, 1991 Guidebook, Coalbed Methane Of Western North America.

Nurkowski, J.R., 1984, Coal quality, coal rank variation and its relation to reconstructed overburden, Upper Cretaceous and Tertiary plains coals, Alberta; MPG Bulletin, v. 68, no.3, p. 285-295.

Nurkowski, J.R., 1985, Coal quality and rank variations within Upper Cretaceous and Tertiary sediments, Alberta plains region; Alberta Research Council, Earth Science Report 85-1, 39p.

Osadetz, K.G., Pearson, D.E., and Stasiuk, L.D., 1990, Paleogeothermal gradients and changes in the geothermal gradient field of the Alberta Plains; h Current Research, Part D, Geological Survey of Canada Paper 90-1D, p. 165-178.

Parkash, S., 1985, Petrographic studies of coals from Alberta plains; Alberta Research Council, Bulletin No. 50, 47p.

Richardson, R.J.H., Strobl, R.S., Macdonald, D.E., Nurkowski, J.R., McCabe, P.J., and Bosman, A., 1988, An evaluation of the coal resources of the Ardley coal zone, to a depth of 400 **in,** in the Alberta plains area; Alberta Research Council, Open File Report 1988-02, 96p.

Strobl, R., McCabe, P.J., Macdonald, D.E., and Richardson, R.J.H., 1986, Estimate of Inferred Resources of Coal In the Plains region of Alberta to a Depth of 400 Metres; Alberta Research Council, Open File Report 1987-05, 31 p.

Williams, G. D., and Murphy, M.C., 1981, Deep Coal Resources of the Interior Plains, estimated from petroleum borehole data; Geological Survey of Canada Paper 81-13, 15p.

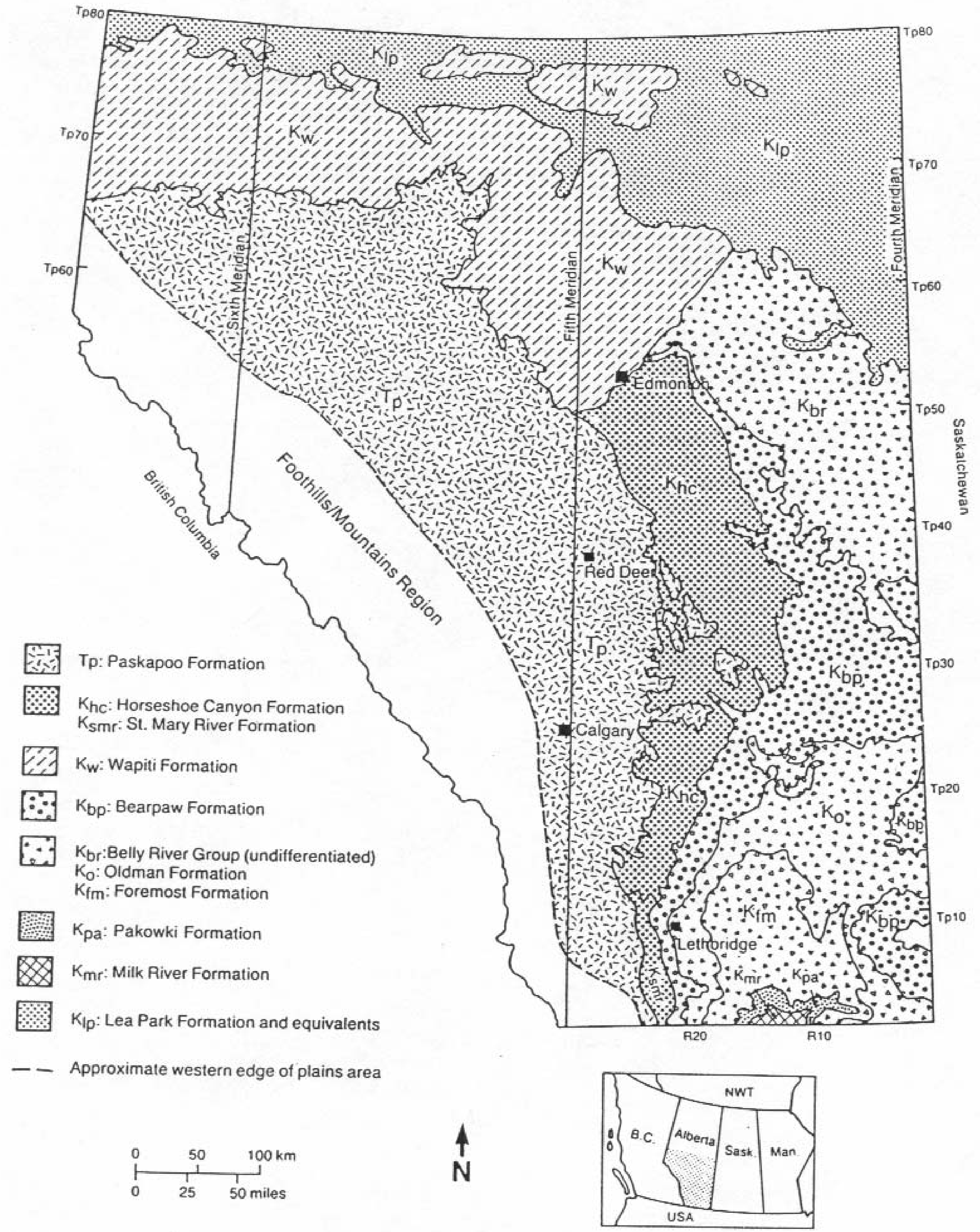

Figure 1. Geological map of the southern half of Alberta. The Ardley coal zone is present north of Calgary near the base of the Paskapoo Formation.

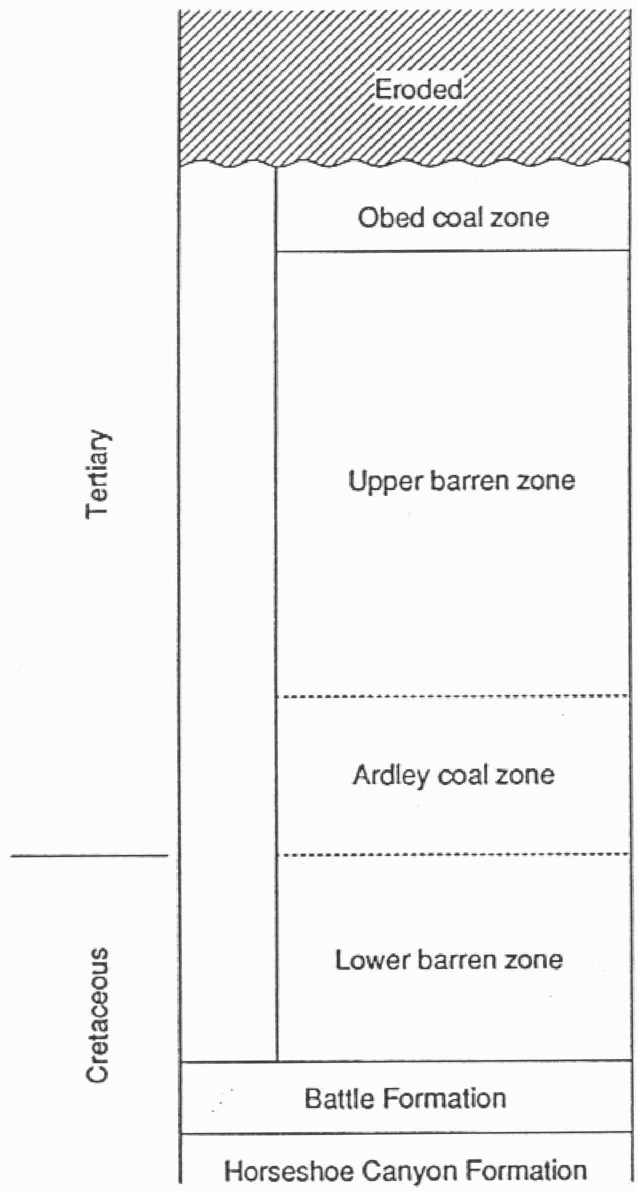

Figure 2. Informal Stratigraphic Units used in this study. The base of the Ardley Coal Zone is at the Tertiary/Cretaceous boundary.

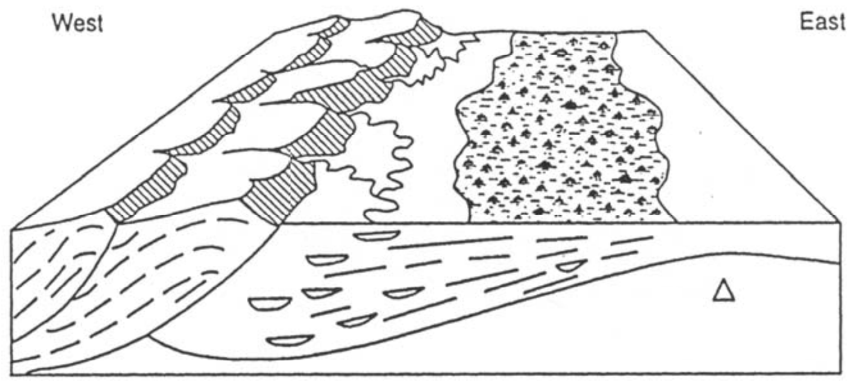

Figure 3. Schematic sketch showing the important tectonic control on coal deposition during the early Tertiary. Increased subsidence related to tectonic loading in the west and a small foreland bulge (not discussed in this paper) helped confine major river systems to areas parallel to the disturbed belt. Peat swamps sheltered from clastic input were extensively developed east of the river systems towards the edge of the eastern edge of the basin.

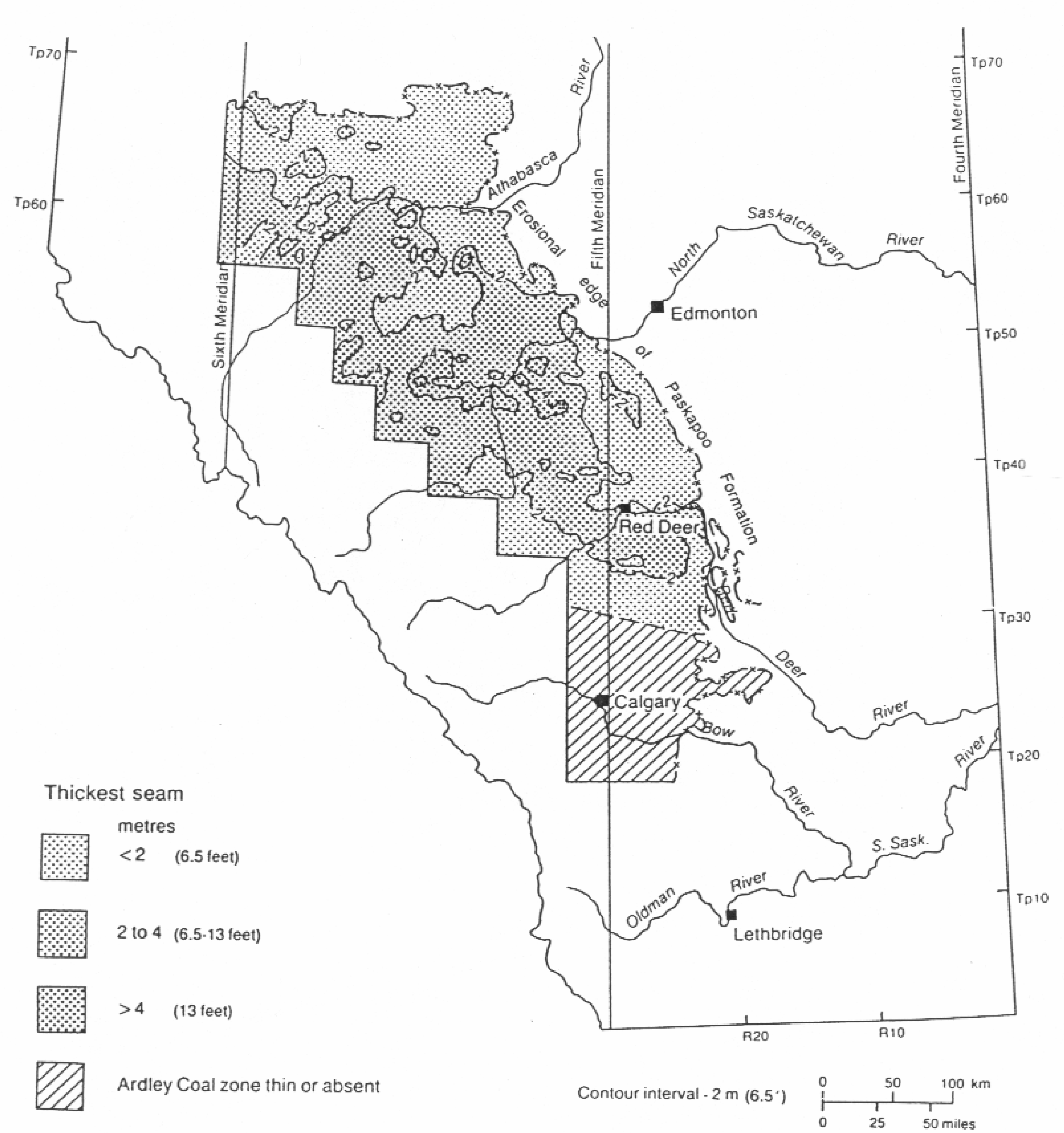

Figure 4. Thickest seam in Ardley coal zone. Areas with seams of 13 feet (4 m) or greater in thickness are commonly located within an east-west trend in the basin southwest of Edmonton.

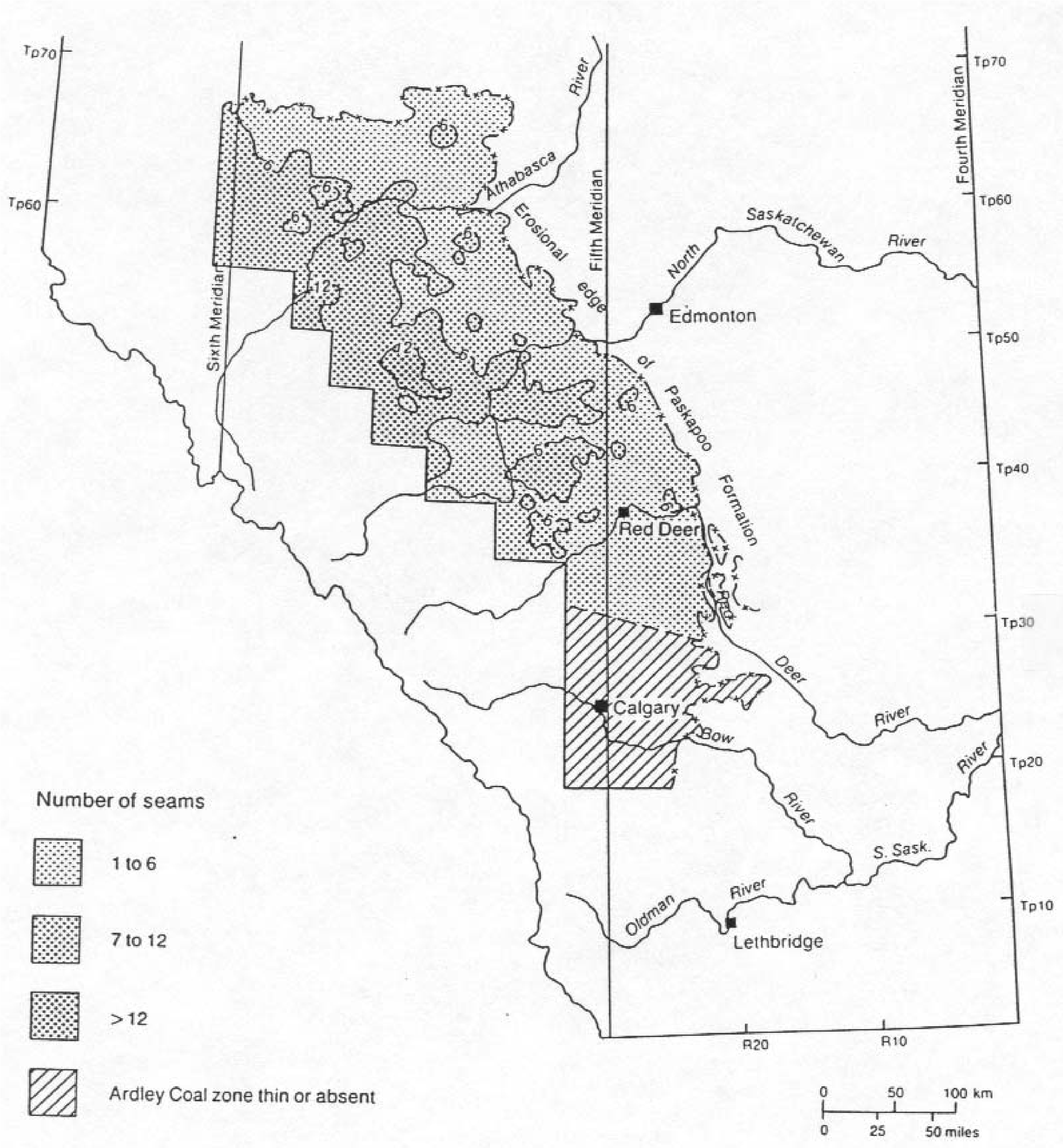

Figure 5. Number of seams in the Ardley Coal Zone. Several areas have more than 12 seams forming the coal zone. Up to 18 seams are present in the west-central part of the basin.

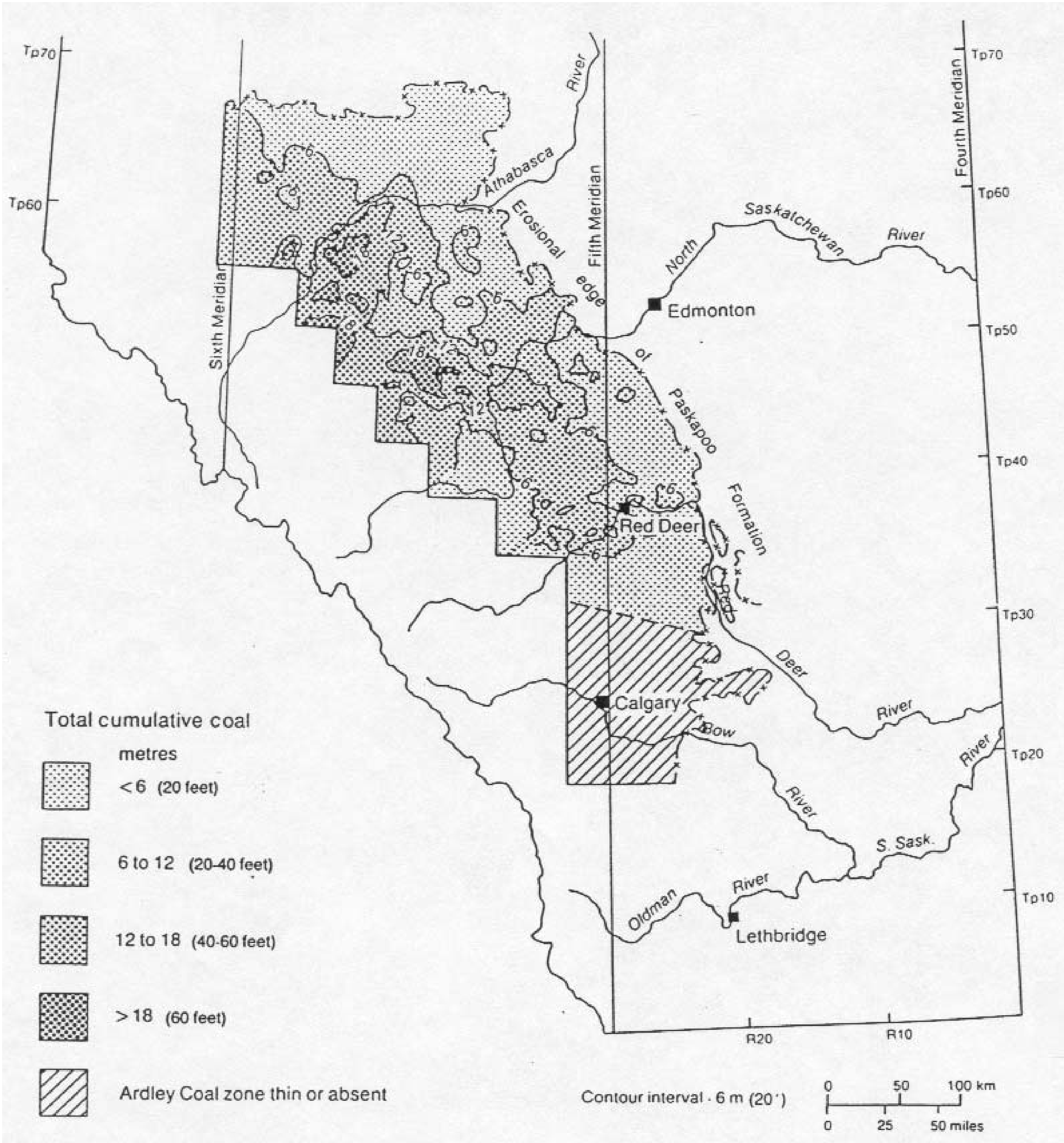

Figure 6. The Total Cumulative Coal Map shows a north-south and an east-west oriented trend containing between 40 and 80 feet (12 to 24 m) of cumulative coal.

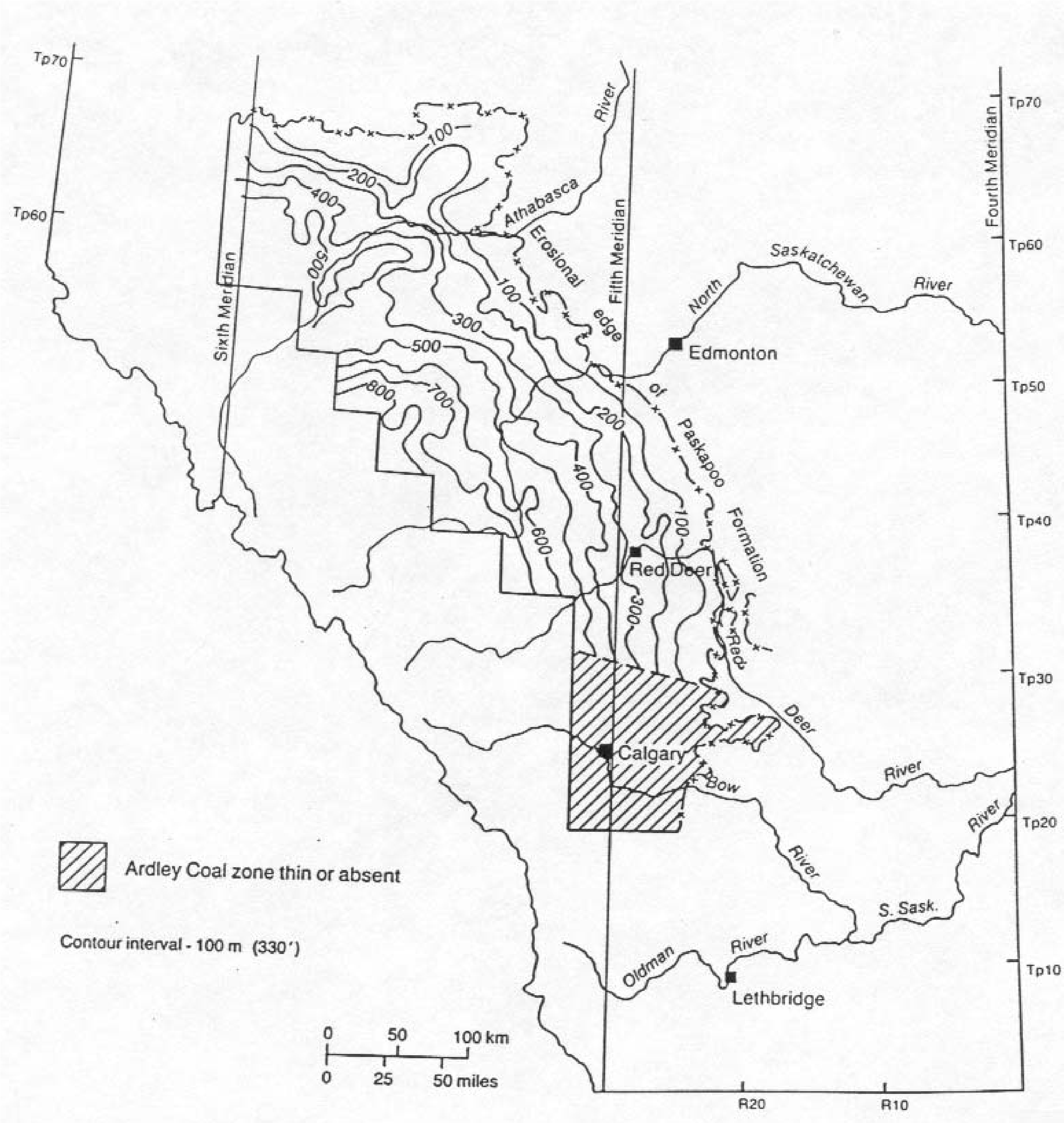

Figure 7. Depth to Best 25 m (82 feet) zone (window). The term ‘window” is defined as a zone of a given interval that contains the most coal. The map is useful in determining the depth of the major pay zone since the total coal zone thickens to more than 660 feet (200 m) in the western part of the basin.

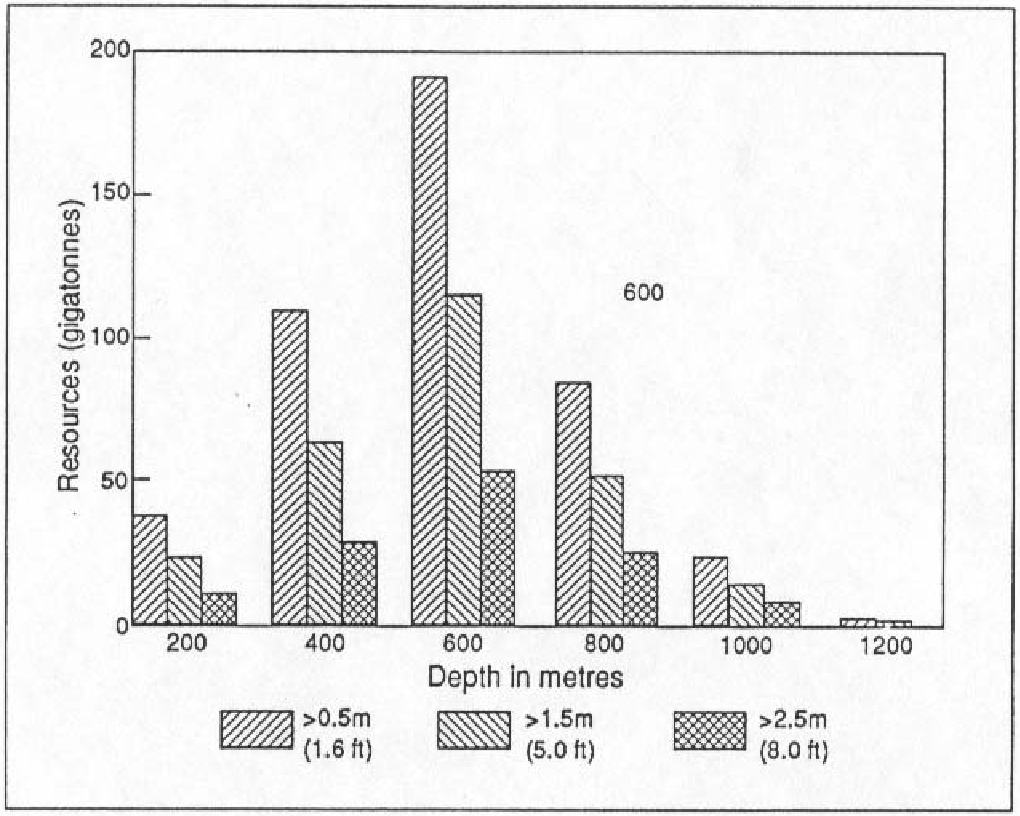

Figure 8. The chart shows the estimated resources for Ardley coals in 650 feet (200 m) depth slices down to a maximum depth of 3900 feet (1200 m). The >0.5 m (1.6 feet) bar shows the total amount of coal, for each depth slice, which added together will approximate the toal calculated resource of Ardly coals.

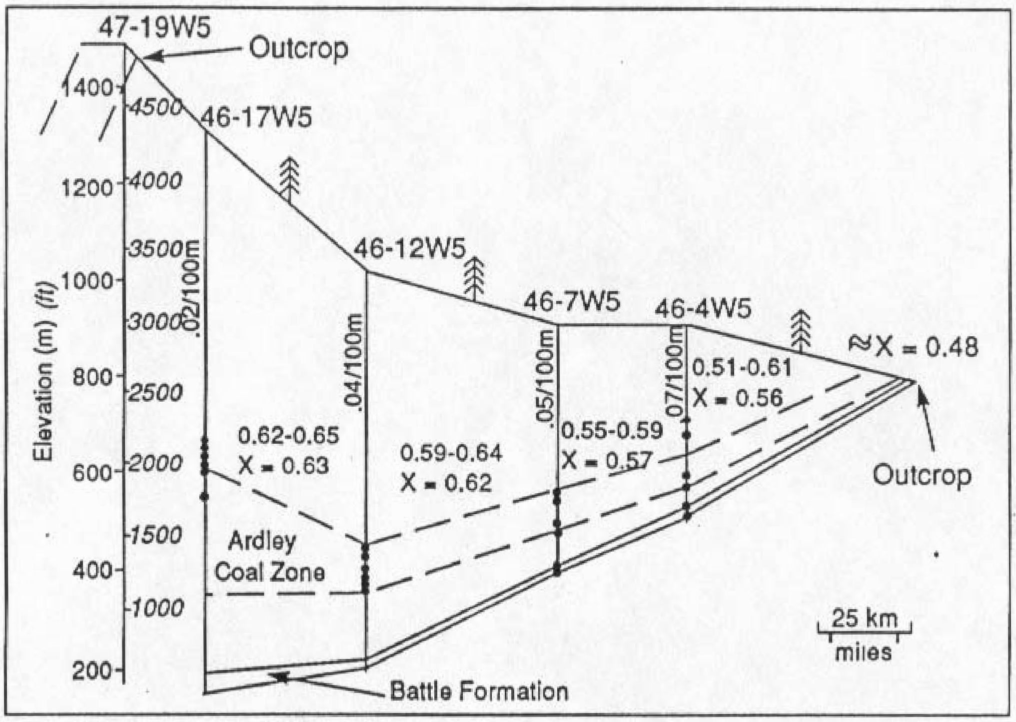

Figure 9. Reflectance of 22 Ardley coal samples within the high volatile bituminous C rank from an east-west cross-section located near the center of the basin. Higher values in the west are related to a greater depth of burial; while the reflectance gradient (on vertical lines) indicates a higher paleo-geothermal gradient in the east; from Nurkowski, 1984.

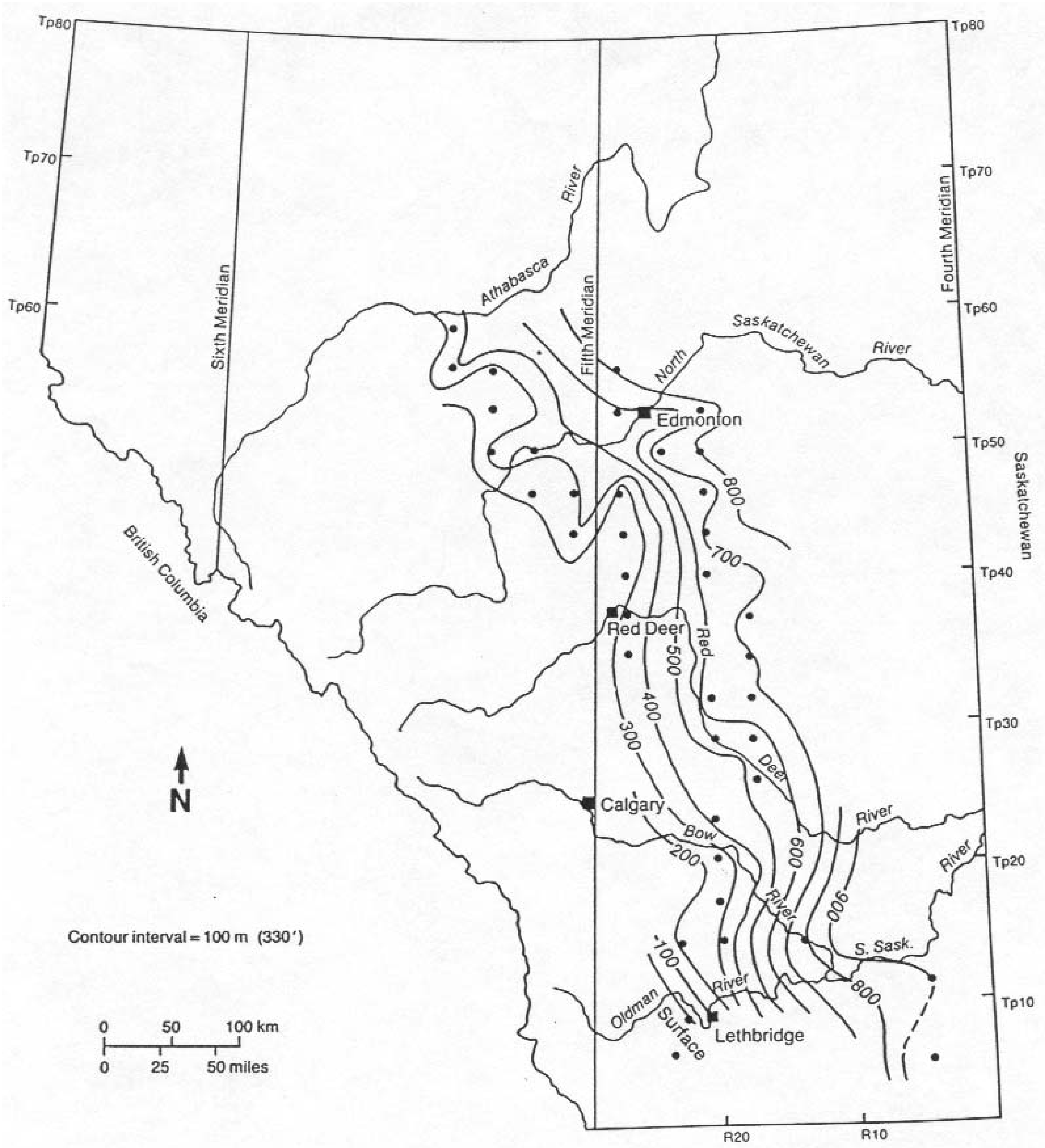

Figure 10. Calculated depth to high volatile bituminous C coals in the plains area of Albera; from Nurkowski, 1985.

Appendix F

BIBLIOGRAPHY OF ALBERTA COAL GEOLOGY LITERATURE FROM THE GEOSCAN DATABASE

The attached bibliography is the result of a search on the GEOSCAN database on May 13th., 1991. It is presented here to provide a guide to additional sources of information. It should be noted that the text is as downloaded from the database and was not edited by the Alberta Geological Survey.

Records without series

CRAWFORD, I D (1947)
THE GEOLOGY AND STRUCTURE OF THE LETHBRIDGE COAL FIELD.

CARR, J L (1946)
THE GEOLOGY OF THE HIGHWOOD-ELBOW AREA, ALBERTA.

BEACH, H H (1934)
THE GEOLOGY OF THE COAL SEAMS OF EDMONTON AND DISTRICT AND A HISTORY OF ITS MINING DEVELOPMENT.

TAYLOR, D A (1934)
DETAILED STRATIGRAPHY OF THE EDMONTON DISTRICT.

HOLLIES, R T (1921)
PRELIMINARY INVESTIGATIONS ON WEATHERING OF ALBERTA COALS.

LEWIS, J W (1921)
FURTHER INVESTIGATIONS OF SOME OF THE PROPERTIES OF ALBERTA COALS.

MACVICAR, J (1916)
THE ORIGIN, COMPOSITION AND OCCURRENCE OF COAL IN ALBERTA.

VAN-DYKE, C W (1981)
A URANIUM RESOURCE EVALUATION OF POST-PROTEROZOIC SEDIMENTARY FORMATIONS IN ALBERTA.

JAMES, D (1977)
THE SEDIMENTOLOGY OF THE MCMURRAY FORMATION, EAST ATHABASCA.

BIHL, G (1968)
PALYNOLOGICAL CORRELATION OF LATE CRETACEOUS BEDS, SHEERNESS, ALBERTA.

ALEXANDER, F J (1977)
STRUCTURAL GEOLOGY OF THE LUSCAR-STERCO MYNHEER A ZONE, COAL VALLEY, ALBERTA.

KILBY, W E (1978)
STRUCTURAL GEOLOGY AND STRATIGRAPHY OF THE COAL-BEARING AND ADJACENT STRATA NEAR MOUNTAIN PARK, ALBERTA.

Records sorted by Series

ALBERTA RESEARCH COUNCIL CONTRIBUTION SERIES

CAMPBELL, J D (1973)
ALBERTA; KEYSTONE COAL INDUSTRY MANUAL, ALBERTA RESEARCH COUNCIL CONTRIBUTION SERIES

VOGWILL, R I J (1978)
HYDROGEOLOGICAL TESTING AND CONSIDERATION ASSOCIATED WITH UNDERGROUND COAL GASIFICATION IN ALBERTA; PROCEEDINGS OF THE 4TH UNDERGROUND CONVERSION SYMPOSIUM. ALBERTA RESEARCH COUNCIL CONTRIBUTION SERIES

HOLTER, M E (1972)
COAL SEAMS OF THE ESTEVAN AREA, SOUTHEASTERN SASKATCHEWAN; PROCEEDINGS OF THE FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL, ALBERTA RESEARCH COUNCIL CONTRIBUTION SERIES

VOGWILL, R; EDWARDS, W C (1978)
HYDROLOGICAL AND AIR ACCEPTANCE TESTING ASSOCIATED WITH THE UNDERGROUND COAL GASIFICATION PROJECT; PROCEEDINGS OF THE NATIONAL HYDROGEOLOGIC CONFERENCE. ALBERTA RESEARCH COUNCIL CONTRIBUTION SERIES

GEOLOGICAL SURVEY OF CANADA CONTRIBUTION SERIES

HUGHES, J D (1987)
GEOLOGY OF THE CASCADE COAL BASIN; GEOLOGY OF THE CALGARY AREA. GEOLOGICAL SURVEY OF CANADA CONTRIBUTION SERIES

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS BULLETIN

LINK, T A; CHILDERIIOSE, A J (1931)
BEARPAW SHALE AND CONTIGUOUS FORMATIONS IN LETHBRIDGE AREA, ALBERTA; STRATIGRAPHY OF PLAINS OF SOUTHERN ALBERTA. AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS BULLETIN VOL. 15, NO. 10

KALKREUTH, W; MCMECHAN, M (1988)
BURIAL HISTORY AND THERMAL MATURITY, ROCKY MOUNTAIN FRONT RANGES, FOOTHILLS, AND FORELAND, EAST - CENTRAL BRITISH COLUMBIA AND ADJACENT ALBERTA, CANADA; AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS BULLETIN VOL. 72, NO. 11

NURKOWSKI, J R (1984)
COAL QUALITY, COAL RANK VARIATION AND ITS RELATION TO RECONSTRUCTED OVERBURDEN, UPPER CRETACEOUS AND TERTIARY PLAINS COALS, ALBERTA, CANADA. AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS BULLETIN VOL. 68, NO. 3

HACQUEBARD, P A (1977)
RANK OF COAL AS INDEX OF ORGANIC METAMORPHISM FOR OIL AND GAS IN ALBERTA, CANADA; AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS BULLETIN VOL. 61, NO. 5

CARLSON, C E (1967)
TRIASSIC-JURASSIC OF ALBERTA, SASKATCHEWAN, MANITOBA, MONTANA, AND NORTH DAKOTA; AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS BULLETIN VOL. 51, NO. 9

CARLSON, C E (1967)
TRIASSIC-JURASSIC OF ALBERTA, SASKATCHEWAN, MANITOBA, MONTANA, AND NORTH DAKOTA (ABS.); AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS BULLETIN VOL. 51, NO. 9

ALBERTA RESEARCH COUNCIL, ASSESSMENT FILE

HAGE, C O (1968)
EXPL PERMIT 32, DOME PETROLEUM L, GEOL AND SCINTILLOMETER SVY REPT. ALBERTA RESEARCH COUNCIL, ASSESSMENT FILE NO. U-AF-009(1)

RAGE, C O (1968)
EXPL PERMIT 33, DOME PETROLEUM L, GEOL AND SCINTILLOMETER SVY REPT. ALBERTA RESEARCH COUNCIL, ASSESSMENT FILE NO. U-AF-010(1)

ALBERTA RESEARCH COUNCIL, BULLETIN

LANGENBERG, C W; KALKREUTH, W; WRIGHTSON, C B (1987)
DEFORMED LOWER CRETACEOUS COAL - BEARING STRATA OF THE GRANDE CACHE AREA, ALBERTA. ALBERTA RESEARCH COUNCIL, BULLETIN VOL. 56

ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE

CAMPBELL, J D (1965)
COAL, ARDLEY COAL ZONE, CENTRAL RED DEER AREA, ALBERTA, GEOLOGICAL REPORT. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. C-IR-001

MELLON, G B (1971)
COAL, THE ENVIRONMENTAL IMPACT OF SURFACE MINING IN ALBERTA. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. C-IR-002

MORRISON, D N (1972)
COAL, PRELIMINARY RESULTS OF ATTEMPTED COAL RECOVERY AND ASH CONTENT REDUCTION OF WASTE MATERIAL FROM THE LUSCAR STRIP MINING OPERATION: ALBERTA, PRELIMINARY REPORT. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. C-IR-003

HUNT, R W (1923)
IRON, REPORT ON COAL IN THE BRAZEAU DISTRICT, TP 44 R2OW5M, 83C/15, ALTA, GEOL REPT. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. FE-IR-01(2)

HALFERDAHL, L B (1967)
LIMESTONE, LIMESTONE ON LEYLAND MOUNTAIN NEAR CADOMIN, TP 46 R24W5M, 83F/3 ALTA, REPT. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. LST-IR-04

HOLTER, M E (1974)
SAND AND GRAVEL, PRELIMINARY REPORT ON THE GRAVEL RESOURCES OF THE RED DEER AREA AND 4 MAP TP 32-42 R23-28W4M AND TP 32-42 R1-3W5M, 83/SE, ALTA. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. SGL-IR-03

RUTHERFORD, R L (1920)
DIMENSION STONE, SUMMARY REPT ON THE SANDSTONE DEPOSITS AT CASTOR, TP 37 AND 38 R13 AND 14W4M, 72D/3 AND 4, ALTA. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. STN-IR-01

ALLAN, J A (1923)
GENERAL, MINERAL INDUSTRY IN ALBERTA IN 1923, REPT. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. ZZZ-IR-001

ALLAN, J A; RUTHERFORD, R L (1924)
GENERAL, MINERAL DEVELOPMENT IN ALBERTA IN 1924, REPT. ALBERTA RESEARCH COUNCIL, ECONOMIIC MINERAL FILE NO. ZZZ-IR-002

DAWSON, A S (1952)
GENERAL, MINERAL RESOURCES OF THE MEDICINE HAT AREA, ALBERTA, NTS 72E/NE AND 72L/SE, SYNOPSIS FROM A REPORT. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. ZZZ-IR-005

MATTHEWS, J G (1954)
GENERAL, MINERAL RESOURCES OF THE VULCAN AREA, ALBERTA, NTS 821, SYNOPSIS FROM A REPORT. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. ZZZ-IR-007

MATTHEWS, J G (1955)
GENERAL, MINERAL RESOURCES OF THE WEST CALGARY AREA, ALBERTA, 082J/NE+0820/SE, ALTA, SYNOPSIS FROM A REPT. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. ZZZ-IR-008

MELLON, G B (1969)
GENERAL, MINERAL RESOURCES OF NORTHERN ALBERTA, REPT+ iMAP. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. ZZZ-IR-011

KRAMERS, J W; MELLON, G B (1972)
GENERAL, GEOLOGY AND MINERAL RESOURCES, NORTHWEST-CENTRAL ALBERTA (HINTON TO GRANDE PRAIRIE), 083M/SE, 083F/NE AND 083F/SE ALTA, REPT AND 3 MAPS. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. ZZZ-IR-012

WARREN, P S (1954)
GENERAL REPORT OF THE SUBCOMMITTEE ON NON-METALLIC MINERAL DEPOSITS, INDUSTRIAL MINERALS, COAL AND OIL. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. ZZZ-IR-015

HAMILTON, W N; MCLAWS, I J (1974)
GENERAL, MINERAL RESOURCES OF THE CALGARY AREA, ALBERTA; REPORT TO THE CALGARY REGIONAL PLANNING COMMISSION. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. ZZZ-IR-020

GOVETT, G J (1959)
GENERAL, NATURAL RESOURCES OF THE DRUMHELLER DISTRICT, ALBERTA: SUMMARY REPORT. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. ZZZ-IR-021

HAMILTON, W N (1974)
GENERAL, ECONOMIC MINERALS IN SOUTHERN ALBERTA. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. ZZZ-IR-022

HAMILTON, W N (1975)
GENERAL, ECONOMIC MINERALS IN NORTH-CENTRAL ALBERTA. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. ZZZ-IR-023

HAMILTON, W N (1972)
GENERAL, MINERAL DEPOSITS IN THE RED DEER AREA, CENTRAL AND WEST CENTRAL ALBERTA, SUMMARY REPORT TO RED DEER REGIONAL PLANNING COMMISSION. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. ZZZ-IR-024

(1971)
GENERAL, NON-METALLIC MINERALS AND INDUSTRIAL DEVELOPMENT IN ALBERTA. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. ZZZ-IR-028

MELLON, G B; KRAMERS, J W; KATHOL, C P (1972)
GENERAL, GEOLOGY AND TERRAIN EVALUATION--ALBERTA RESOURCES RAILWAY AND ALTERNATIVE ROUTES. ALBERTA RESEARCH COUNCIL, ECONOMIC MINERAL FILE NO. ZZZ-IR-039

ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT

PEARSON, G R (1959)
COAL RESERVES FOR STRIP MINING, WABAMUN LAKE DISTRICT, ALBERTA. ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT NO. 59-1

PEARSON, G R (1961)
THE CLOVER BAR COAL ZONE, EDMONTON-MORINVILLE DISTRICT, ALBERTA. ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT NO. 61-1

ALMADI, I S; CAMPBELL, J D (1964)
COAL OCCURRENCES OF THE VULCAN-GLEICHEN AREA, ALBERTA. ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT NO. 64-2

CAMPBELL, J D (1964)
CATALOGUE OF COAL MINES OF THE ALBERTA PLAINS. ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT NO. 64-3

CAMPBELL, J D (1967)
COAL MINES AND COAL LEASES, ALBERTA ROCKY MOUNTAINS AND FOOTHILLS. ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT NO. 66-5

CAMPBELL, J D (1967)
GUIDE TO COAL DEPOSITS, YUKON AND MACKENZIE TERRITORIES. ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT NO. 66-6

CAMPBELL, J D (1967)
ARDLEY COAL ZONE IN THE ALBERTA PLAINS; CENTRAL RED DEER RIVER AREA. ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT NO. 67-01

CAMPBELL, J D (1967)
COAL SURVEY BOREHOLES, VULCAN-OLEICHEN AREA, ALBERTA. ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT NO. 67-3

CAMPBELL, J D (1972)
COAL OCCURRENCES AND RELATED GEOLOGY, FOX CREEK AREA, ALBERTA. ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT NO. 72-09

CAMPBELL, J D (1972)
COAL OCCURRENCES, ATHABASCA-SMITH AREA, ALBERTA. ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT NO. 72-10

CAMPBELL, J D (1974)
COAL RESOURCES, TABER-MANYBERRIES AREA, ALBERTA. ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT NO. 74-03

CAMPBELL, J D (1974)
COAL RESOURCES, HUSSAR-HANNA AREA, ALBERTA. ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT NO. 74-08

YURKO, J R (1976)
DEEP CRETACEOUS COAL RESOURCES OF THE ALBERTA PLAINS. ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT NO. 75-4

CHU, M; HOLTER, M E; YURKO, J R (1975)
GEOLOGY AND COAL RESERVES OF THE ARDLEY COAL ZONE OF CENTRAL ALBERTA. ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT NO. 75-7

CAMPBELL, J D (1975)
COAL RESOURCES, TOFIELD-DONALDA AREA, ALBERTA. ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT NO. 75-8

NURKOWSKI, J R (1985)
COAL QUALITY WITHIN UPPER CRETACEOUS AND TERTIARY SEDIMENTS, ALBERTA PLAINS REGION. ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT NO. 85-01

NURKOWSKI, J R (1985)
COAL QUALITY AND RANK VARIATION WITHIN UPPER CRETACEOUS AND TERTIARY SEDIMENTS, ALBERTA PLAINS REGION. ALBERTA RESEARCH COUNCIL, EARTH SCIENCE REPORT NO. 85-1

ALBERTA RESEARCH COUNCIL, INFORMATION SERIES

HOLTER, M E; MELLON, G B (1972)
GEOLOGY OF THE LUSCAR (BLAIRMORE) COAL BEDS, CENTRAL ALBERTA FOOTHILLS; ALBERTA RESEARCH COUNCIL, INFORMATION SERIES

KRAMERS, J W; MELLON, G B; SEAGEL, E J (1972)
PROCEEDINGS, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO. 060

BROWN, D D (1972)
GEOLOGY AND EXPLORATION TECHNIQUES, SMOKY RIVER COAL FIELD, ALBERTA; PROCEEDINGS, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO. 060

KRAMERS, J W; MELLON, G B; SEAGEL, E J (1972)
PROCEEDINGS, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO. 060

HOLTER, M E; MELLON, G B (1972)
GEOLOGY OF THE LUSCAR (BLAIRMORE) COAL BEDS, CENTRAL ALBERTA FOOTHILLS; PROCEEDINGS OF THE FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. PROCEEDINGS, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO. 60

KRAMERS, J W; MELLON, G B (1972)
UPPER CRETACEOUS-PALEOCENE COAL-BEARING STRATA, NORTHWEST-CENTRAL ALBERTA PLAINS; PROCEEDINGS OF THE FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. PROCEEDINGS, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO. 60

DICKIE, G J; STEINER, J; WILLIAMS, G D (1972)
COMPUTER STORAGE AND RETRIEVAL OF GEOLOGIC DATA ON COAL DEPOSITS; PROCEEDINGS OF THE FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. PROCEEDINGS, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO. 60

LATOUR, B A (1972)
COAL DEPOSITS OF WESTERN AND NORTHERN CANADA; PROCEEDINGS, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO. 60

CAMERON, A R (1972)
PETROGRAPHY OF KOOTENAY COALS IN THE UPPER ELK RIVER AND CROWSNEST AREAS, BRITISH COLUMBIA AND ALBERTA; PROCEEDINGS, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO. 60

WILLIAMS, G D; DICKIE, G J; STEINER, J (1972)
COMPUTER STORAGE AND RETRIEVAL OF GEOLOGIC DATA ON COAL DEPOSITS; PROCEEDINGS, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO. 60

STEINER, J; WILLIAMS, G D; DICKIE, G J (1972)
COAL DEPOSITS OF THE ALBERTA PLAINS; PROCEEDINGS, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO. 60

MELLON, G B; KRAMERS, J W (1972)
UPPER CRETACEOUS-PALEOCENE COAL-BEARING STRATA, NORTHWEST-CENTRAL ALBERTA PLAINS; PROCEEDINGS, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO. 60

HOLTER, M E; MELLON, G B (1972)
GEOLOGY OF THE LUSCAR [BLAIRMORE] COAL BEDS, CENTRAL ALBERTA FOOTHILLS; PROCEEDINGS, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO. 60

JANSA, L F (1972)
DEPOSITIONAL HISTORY OF THE COAL-BEARING UPPER JURASSIC - LOWER CRETACEOUS KOOTENAY FORMATION, SOUTHERN ROCKY MOUNTAINS, CANADA; PROCEEDINGS, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO. 60

SUSKA, M M (1972)
PRELIMINARY GEOLOGY OF THE WHITERABBIT CREEK - UPPER RAM RIVER COAL AREA, ALBERTA; PROCEEDINGS, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO. 60

BROWN, D D (1972)
GEOLOGY AND EXPLORATION TECHNIQUES, SMOKY RIVER COAL FIELD, ALBERTA; PROCEEDINGS, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO. 60

HACQUEBARD, P A; DONALDSON, J R (1972)
RANK STUDIES OF COALS IN THE ROCKY MOUNTAINS AND INNER FOOTHILLS BELT, CANADA; PROCEEDINGS, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO. 60

KRAMERS. J W; MELLON, G B (1972)
UPPER CF ETACEOUS-PALEOCENE COAL-BEARING STRATA, NORTHWEST-CENTRAL ALBERTA PLAINS; ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO.
ARC CONTR SER 0589

KRAMERS, J W; MELLON, G B; SEAGEL, E J (1972)
PROCEEDINGS, FIRST GEOLOGICAL CONFERENCE ON WESTERN CANADIAN COAL. ALBERTA RESEARCH COUNCIL, INFORMATION SERIES NO. RES COUNCIL

ALBERTA RESEARCH COUNCIL, MAP

ALLAN, J A (1923)
COAL AREAS OF ALBERTA. ALBERTA RESEARCH COUNCIL, MAP

ALLAN, J A (1921)
GEOLOGICAL MAP OF THE DRUMHELLER DISTRICT, ALBERTA, NTS 82P. ALBERTA RESEARCH COUNCIL, MAP

ALLAN, J A; SANDERSON, J O (1925)
GEOLOGICAL MAP OF RED DEER SHEET, NTS 82P AND 83A. ALBERTA RESEARCH COUNCIL, MAP NO. 08

ALLAN, J A; SANDERSON, J O (1925)
GEOLOGICAL MAP OF ROSEBUD SHEET, NTS 82P. ALBERTA RESEARCH COUNCIL, MAP NO. 09

ALLAN, J A; SANDERSON, J O (1947)
GEOLOGICAL MAP ROSEBUD AND RED DEER SHEETS, NTS 82P AND 83A. ALBERTA RESEARCH COUNCIL, MAP NO. 09A

RUTHERFORD, R L (1925)
GEOLOGY OF THE AREA BETWEEN ATHABASCA AND EMBARRAS RIVERS, ALBERTA, NTS 83F. ALBERTA RESEARCH COUNCIL, MAP NO. 11

ALBERTA RESEARCH COUNCIL OPEN FILE

CAMPBELL, J D (1970)
ALBERTA FOOTHILLS COAL, EXTRACTS FROM PUBLISHED REPORTS OF RESEARCH COUNCIL OF ALBERTA. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1970-03

CAMPBELL, J D (1972)
ALBERTA PLAIN COALS, EXTRACTS FROM PUBLISHED REPORTS OF RESEARCH COUNCIL OF ALBERTA. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1972-03

MELLON, G B (1972)
MINERAL RESOURCES OF NORTHWEST-CENTRAL ALBERTA. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1972-04

HAMILTON, W N (1973)
MINERAL RESOURCE DEVELOPMENT IN THE KANANASKIS RIVER BASIN. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1973-26

(1974)
MINERAL RESOURCES OF ALBERTA. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1974-43

HOLTER, M E; CHU, M; YURKO, J R (1976)
GEOLOGY AND COAL RESOURCES OF THE HORSESHOE CANYON FORMATION OF CENTRAL ALBERTA. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1976-16

CHU, M (1978)
GEOLOGY AND COAL RESOURCES OF THE WAPITI FORMATION OF NORTH CENTRAL ALBERTA. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1978-12

(1978)
GEOLOGY AND COAL RESOURCES OF SOUTHEASTERN ALBERTA. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1978-13

NURKOWSKI, J R (1980)
GEOLOGY AND COAL RESOURCES OF THE UPPER PART OF THE HORSESHOE CANYON FORMATION, RED DEER AREA, ALBERTA. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1980-10

NURKOWSKI, J (1982)
COAL CHEMISTRY AND COAL QUALITY DATA FROM DRILLING PROGRAMS IN THE PLAINS AREA OF ALBERTA, 1974-1980. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1982-03

BOSMAN, A (1982)
SCOLLARD MEMBER COAL, ALIX AREA. DRILLING REPORT, 1981. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1982-09

NURKOWSKI, J R (1983)
COAL QUALITY, COAL RANK VARIATION AND ITS RELATION TO RECONSTRUCTED OVERBURDEN, UPPER CRETACEOUS AND TERTIARY PLAINS COALS, ALBERTA, CANADA. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1983-11

MACGILLIVRAY, J R (1983)
INDEX OF MINERAL COMMODITY REPORTS FOR ALBERTA. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1983-15

BOSMAN, A (1983)
SCOLLARD MEMBER COAL, ALIX AREA. DRILLING REPORT. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1983-21

BOSMAN, A (1983)
JUDITH RIVER COAL, BROOKS AREA DRILLING REPORT. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1984-22

STROBL, R S; MCCABE, P J; MACDONALD, D E; RICHARDSON, R J H (1986)
ESTIMATE OF INFERRED RESOURCES OF COAL IN THE PLAINS REGION OF ALBERTA TO A DEPTH OF 400 METRES. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1987-05

MACDONALD, D E; ROSS, T C; MCCABE, P J; BOSMAN, A (1987)
AN EVALUATION OF THE COAL RESOURCES OF THE BELLY RIVER GROUP, TO A DEPTH OF 400 M IN THE ALBERTA PLAINS. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1987-08

MACDONALD, D E; CHIDAMBARAM, N; LANGENBERG, C W; MANDRYK, G B; STERENBERG, C B; CAMERON, A (1987)
A REGIONAL EVALUATION OF COAL QUALITY IN THE SOUTHERN AND CENTRAL FOOTHILLS I MOUNTAINS REGION OF ALBERTA. ALBERT RESEARCH COUNCIL OPEN FILE NO. 1987-09

LANGENBERG, W; MACDONALD, D; KALKREUTH, W; STROBL, R; BAHNSEN, B (1988)
AN INITIAL ASSESSMENT OF CONTROLS ON COAL QUALITY VARIATION IN THE CADOMIN - LUSCAR COALFIELD. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1988-06

MANDRYK, O B; RICHARDSON, R J H (1988)
COAL RESOURCE DATA IN THE PLAINS AREA OF ALBERTA [DISKETTE AND MAP]. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1988-07

WONG, R; STROBL, R; KRZANOWSKI, R; CHIDAMBARAM, N (1988)
EXPLORATORY STATISTICAL ANALYSIS OF COAL QUALITY AT THE HIGHVALE MINE, [ARDLEY COAL ZONE], CENTRAL ALBERTA. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1988-09

LANGENBERG, W; MACDONALD, D; KALKREUTH, W (1988)
SEDIMENTATION AND DEFORMATION OF LOWER CRETACEOUS STRATA OF THE CADOMIN - LUSCAR COAL FIELD, ALBERTA. ALBERTA RESEARCH COUNCIL OPEN FILE NO. 1988-10

ALBERTA RESEARCH COUNCIL, REPORT

ALLAN, J A (1920)
FIRST ANNUAL REPORT ON THE MINERAL RESOURCES OF ALBERTA. ALBERTA RESEARCH COUNCIL, REPORT NO. 01

ALLAN, J A (1921)
SECOND ANNUAL REPORT ON THE MINERAL RESOURCES OF ALBERTA 1920. ALBERTA RESEARCH COUNCIL, REPORT NO. 02

ALLAN, J A (1922)
GEOLOGY OF THE DRUMHELLER COAL FIELD, ALBERTA. ALBERTA RESEARCH COUNCIL, REPORT NO. 04

ALLAN, J A; RUTHERFORD, R L (1924)
GEOLOGY ALONG THE BLACKSTONE, BRAZEAU AND PEMBINA RIVERS IN THE FOOTHILLS BELT, ALBERTA. ALBERTA RESEARCH COUNCIL, REPORT NO. 09

RUTHERFORD, R L (1926)
GEOLOGY OF THE AREA BETWEEN ATHABASCA AND EMBARRAS RIVERS, ALBERTA. ALBERTA RESEARCH COUNCIL, REPORT NO. 15

RUTHERFORD, R L (1928)
GEOLOGY OF THE AREA BETWEEN NORTH SASKATCHEWAN AND MCLEOD RIVERS, ALBERTA. ALBERTA RESEARCH COUNCIL, REPORT NO. 19

ALLAN, J A (1943)
GEOLOGY OF ALBERTA. ALBERTA RESEARCH COUNCIL, REPORT NO. 34

ALLAN, J A; CARR, J L (1946)
GEOLOGY AND COAL OCCURRENCES OF WAPITI-CUTBANK AREA, ALBERTA. ALBERTA RESEARCH COUNCIL, REPORT NO. 48

CROCKFORD, M B (1949)
GEOLOGY OF RIBBON CREEK AREA, ALBERTA. ALBERTA RESEARCH COUNCIL, REPORT NO. 52

ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS FIELD CONFERENCE GUIDEBOOK

WICKENDEN, R T D (1954)
COAL DEPOSITS OF THE SOUTHERN ROCKY MOUNTAINS OF CANADA; GUIDEBOOK, BANFE - GOLDEN - RADIUM. ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS FIELD CONFERENCE GUIDEBOOK

BEACH, F K (1959)
ALBERTA ENERGY SOURCES, COAL TO HYDROCARBONS: EXPLORATION, SURFACE AND SUBSURFACE; GUIDEBOOK, MOOSE MTN. - DRUMHELLER. ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS FIELD CONFERENCE GUIDEBOOK

CROCKFORD, M B B; CLOW, W H A (1965)
UPPER CRETACEOUS FORMATIONS OF THE CYPRESS HILLS - MILK RIVER AREA, SOUTHEASTERN ALBERTA AND SOUTHWESTERN SASKATCHEWAN; GUIDEBOOK, CYPRESS HILLS PLATEAU, ALBERTA AND SASKATCHEWAN, PART 1. ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS FIELD CONFERENCE GUIDEBOOK

CAMPBELL, J D (1965)
COAL RESOURCES IN SOUTHEASTERN ALBERTA AND THEIR SETITING; GUIDEBOOK, CYPRESS HILLS PLATEAU, ALBERTA AND SASKATCHEWAN, PART 1. ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS FIELD CONFERENCE GUIDEBOOK

MACKAY, B R (1955)
POCAHONTAS - MOOSEHORN CREEK COAL BASIN, JASPER PARK, ALBERTA; GUIDEBOOK, JASPER NATIONAL PARK. ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS FIELD CONFERENCE GUIDEBOOK

CRABB, J J (1957)
A SUMMARY OF THE GEOLOGY OF THE CROWSNEST COAL FIELDS AND ADJACENT AREAS; GUIDEBOOK, WATERTON. ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS FIELD CONFERENCE GUIDEBOOK

GREEN, R (1958)
BRAZEAU COLLIERIES LIMITED, NORDEGG, ALBERTA~ GUIDEBOOK, NORDEGG. ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS FIELD CONFERENCE GUIDEBOOK

NORRIS, D K (1956)
STRUCTURAL CONDITIONS IN COAL MINES OF THE CANMORE AREA, ALBERTA; GUIDEBOOK, BOW VALLEY. ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS FIELD CONFERENCE GUIDEBOOK

CROCKFORD, M B B (1956)
THE CANMORE COAL BASIN; GUIDEBOOK, BOW VALLEY. ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS FIELD CONFERENCE GUIDEBOOK

ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS GUIDEBOOK

NORRIS, D K (1971)
THE GEOLOGY AND COAL POTENTIAL OF THE CASCADE COAL BASIN; A GEOLOGICAL GUIDE OF THE EASTERN CORDILLERA ALONG THE TRANS CANADA HIGHWAY BETWEEN CALGARY AND REVELSTOKE. ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS GUIDEBOOK

IRISH, E J W (1970)
GEOLOGICAL MAP, DRUMHELLER, GEOL SURVEY CANADA MAP 5-1967; A GEOLOGICAL GUIDE ALONG THE HIGHWAYS BETWEEN DRUMHELLER - CALGARY - LAKE LOUISE. ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS GUIDEBOOK

ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS SPECIAL PUBLICATION
SPRINGER, G D; MACDONALD, W D; CROCKFORD, M B B (1964)
JURASSIC; GEOLOGICAL HISTORY OF WESTERN CANADA. ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS SPECIAL PUBLICATION

WILLIAMS, G D; BURK, C F, JR (1964)
UPPER CRETACEOUS; GEOLOGICAL HISTORY OF WESTERN CANADA. ALBERTA SOCIETY OF PETROLEUM GEOLOGISTS SPECIAL PUBLICATION

CANADIAN GEOTECHNICAL JOURNAL

VOGWILL, R (1978)
HYDROGEOLOGICAL TESTING ASSOCIATED WITH UNDERGROUND COAL GASIFICATION; CANADIAN GEOTECHNICAL JOURNAL VOL. 16 NO. 1

CANADIAN JOURNAL OF EARTH SCIENCES

SMITH, D G; PUTMAN, P E (1980)
ANASTOMOSED RIVER DEPOSITS: MODERN AND ANCIENT EXAMPLES IN ALBERTA; CANADIAN JOURNAL OF EARTH SCIENCES VOL. 17 NO. 10

MACK, G H; JERZYKIEWICZ, T (1989)
PROVENANCE OF POST - WAPIABI SANDSTONES AND ITS IMPLICATIONS FOR CAMPANIAN TO PALEOCENE TECTONIC HISTORY OF THE SOUTHERN CANADIAN CORDILLERA; CANADIAN JOURNAL OF EARTH SCIENCES VOL. 26 NO. 4

WEYER, K U; VONHOF, J A (1980)
THE EFFECTS OF SURFACE MINING OF COAL ON WATER QUALITY NEAR GRANDE CACHE, ALBERTA: DISCUSSION; CANADIAN JOURNAL OF EARTH SCIENCES VOL. 17 NO. 7

KALKREUTH, W; LANGENBERG, C W (1986)
THE TIMING OF COALIFICATION IN RELATION TO STRUCTURAL EVENTS IN THE GRANDE CACHE AREA, ALBERTA, CANADA; CANADIAN JOURNAL OF EARTH SCIENCES VOL. 23 NO. 8

JERZYKIEWICZ, T; SWEET, A R (1986)
THE CRETACEOUS - TERTIARY BOUNDARY IN THE CENTRAL ALBERTA FOOTHILLS. I: STRATIGRAPHY; CANADIAN JOURNAL OF EARTH SCIENCES VOL. 23 NO. 9

<u>CANADIAN JOURNAL OF SOIL SCIENCE</u>

CAIRNS, R R; MOSCHOPEDIS, S E (1971)
COAL, SULFOMETHYLATED COAL AND SULFONATED COAL AS FERTILIZERS FOR SOLONETZ SOIL; CANADIAN JOURNAL OF SOIL SCIENCE VOL. 51 NO. 1

<u>CANADIAN MINING JOURNAL</u>

PABST, M (1980)
HEALTH OF CANADIAN MINES SEEN IN 8.6 BILLION DOLLARS SPENDING PLANS; CANADIAN MINING JOURNAL

DOWLING, D B (1907)
THE COALS AND COAL FIELDS OF ALBERTA, SASKATCHEWAN, AND MANITOBA; CANADIAN MINING JOURNAL VOL. 28

<u>CIM BULLETIN</u>

CAMPBELL, J D (1967)
COAL EXPLORATION PROGRAM OF THE ALBERTA RESEARCH COUNCIL; CIM BULLETIN VOL. 62

HOLTER, M E; KOWALSKI, 33 (1976)
COAL ANALYSIS FROM WELL LOGS; CIM BULLETIN VOL. 69

LANG, W A (1950)
THE BRIQUETTING OF ALBERTA COALS; CIM BULLETIN VOL. 43 NO. 461

HARLE, J A (1951)
THERMAL POWER FOR ALBERTA; CIM BULLETIN VOL. 44 NO. 475

BLACKSTOCK, W J (1956)
STRIP MINING IN THE FOOTHILLS; CIM BULLETIN VOL. 49 NO. 526

LANG, W A (1958)
UTILIZATION OF ALBERTA SUB-BITUMINOUS COAL; CIM BULLETIN VOL. 51 NO. *557*

WILLIAMS, M M (1963)
POWER FROM COAL AT WABAMUN; CIM BULLETIN VOL. 56 NO. 610

RIVA, W J (1965)
METALLURGICAL COALS FROM CANMORE, ALBERTA; CIM BULLETIN VOL. 58 NO. 642

CAMPBELL, J D (1967)
COAL EXPLORATION PROGRAM OF THE RESEARCH COUNCIL OF ALBERTA; CIM BULLETIN VOL. 60 NO. 662

WETHERILL, J M (1968)
FIELD MEASUREMENTS OF RADON IN THE AIR OF A COAL MINE IN SOUTHWESTERN ALBERTA; CIM BULLETIN VOL. 61 NO. 679

BUCHWALD, H; MAY, C R; SCHRAG, K R; SMITH, L K (1969)
HOW CAN WE PROTECT THE HEALTH OF ALBERTA'S COAL WORKERS?; CIM BULLETIN VOL. 62 NO. 690

STEPHENSON, H G; GREGORY, C W; RIVA, W J (1972)
PILLAR EXTRACTION IN THICK COAL AT CANMORE, ALBERTA, ON GRADIENTS BETWEEN 5 AND 30 DEGREES; CIM BULLETIN VOL. 65 NO. 727

WRIGHT, P L (1973)
LAYOUT OF CONTINUOUS MINER OPERATIONS IN THE SMOKY RIVER MINES; CIM BULLETIN VOL. 66 NO. 731

COATES, G D (1973)
CANADA'S FOSSIL FUEL RESOURCES; CIM BULLETIN VOL. 66 NO. 734
SCOTT, D F (1974)
LOWER CRETACEOUS COAL MEASURES OF THE FOOTHILLS OF WEST CENTRAL ALBERTA AND NORTHEASTERN BRITISH COLUMBIA; CIM BULLETIN VOL. 67 NO. 749

GILCHRIST, R D; HORACHEK, J; VENTER, R H (1974)
THE APPRAISAL OF COAL RESOURCES IN ALBERTA; CIM BULLETIN VOL. 67 NO. 750

HORACHEK, V; VENTER, R H; GILCHRIST, R D (1974)
THE APPRAISAL OF COAL RESOURCES IN ALBERTA; CIM BULLETIN VOL. 67 NO. 750

VENTER, R H (1976)
A STATISTICAL APPROACH TO THE CALCULATION OF COAL RESERVES FOR THE PLAINS REGION OF ALBERTA; CIM BULLETIN VOL. 69 NO. 771

SMITH, W K; MULDER, D C; KRUEGER, V P (1977)
GEOLOGICAL PROCEDURES FOR A PREPRODUCTION EVALUATION OF THE THERMAL COAL DEPOSIT AT COAL VALLEY, ALBERTA; CIM BULLETIN VOL. 70 NO. 779

SMITH, W K; MULDER, D C; KRUEGER, V P (1977)
GEOLOGICAL PROCEDURES FOR A PREPRODUCTION EVALUATION OF THE THERMAL COAL DEPOSIT AT COAL VALLEY, ALBERTA; CIM BULLETIN VOL. 70 NO. 779

CAMPBELL, I D (1979)
MAJOR CLEAT TRENDS IN ALBERTA PLAINS COALS; CIM BULLETIN VOL. 72 NO. 80

THURSTON, D N; LATIMER, R C (1978)
A PROGRESS REPORT ON THE COAL VALLEY MINING PROJECT; CIM BULLETIN VOL. 71 NO. 800

CAMPBELL, J D (1979)
MAJOR CLET TRENDS IN ALBERTA PLAINS COALS; CIM BULLETIN VOL. 72 NO. 802

WILLIAMS, C G (1979)
DEVELOPMENT OF THE HIGHVALE MINE FOR THERMAL POWER PLANTS OF CALGARY POWER LIMITED; CIM BULLETIN VOL. 72 NO. 802

JEREMIC, M L; CRUDEN, D M (1979)
THE STRENGTH OF COAL FROM THE STAR-KEY MINE NEAR EDMONTON, ALBERTA; CIM BULLETIN VOL. 72 NO. 802

TRIBE, J (1980)
LUSCAR'S COAL MINING OPERATIONS; CIM BULLETIN VOL. 73 NO. 813

MULDER, D C (1981)
DEVELOPMENT OF THE GENESEE POWER PROJECT; CIM BULLETIN VOL. 74 NO. 832

BERKOWITZ, B E (1982)
PROGNOSES FOR ALBERTA THERMAL AND METALLURGICAL COAL; CIM BULLETIN VOL. 75 NO. 844

<u>CANADIAN INSTITUTE OF MINING AND METALLURGY, TRANSACTIONS</u>

CROCKFORD, M B (1949)
GEOLOGY OF KOOTENAY COAL MEASURES IN SOUTHWESTERN ALBERTA; CANADIAN INSTITUTE OF MINING AND METALLURGY, TRANSACTIONS VOL. 52

CROCKEORD, M B (1941)
GEOLOGY OF KOOTENAY COAL MEASURES IN SOUTHWESTERN ALBERTA; CANADIAN INSTITUTE OF MINING AND METALLURGY, TRANSACTIONS VOL. 52

LANG, W A (1958)
UTILIZATION OF ALBERTA'S SUBBITUMINOUS COAL; CANADIAN INSTITUTE OF MINING AND METALLURGY, TRANSACTIONS VOL. 61

<u>BULLETIN OF CANADIAN PETROLEUM GEOLOGY</u>

LANGENBERG, C W; MCMECHAN, M E (1985)
LOWER CRETACEOUS LUSCAR GROUP [REVISED] OF THE NORTHERN AND NORTH-CENTRAL FOOTHILLS OF ALBERTA; BULLETIN OF CANADIAN PETROLEUM GEOLOGY VOL. 33 NO. 1

CHARLESWORTH, H A K; GAGNON, L G (1985)
INTERCUTANEOUS WEDGES, THE TRIANGLE ZONE AND STRUCTURAL THICKENING OF THE MYNHEER COAL SEAM AT COAL VALLEY IN THE ROCKY MOUNTAIN FOOTHILLS OF CENTRAL ALBERTA; BULLETIN OF CANADIAN PETROLEUM GEOLOGY VOL. 33 NO. 1

ENGLAND, T D J; BUSIN, R M (1986)
THERMAL MATURATION OF THE WESTERN CANADIAN SEDIMENTARY BASIN SOUTH OF THE RED DEER RIVER: I) ALBERTA PLAINS; BULLETIN OF CANADIAN PETROLEUM GEOLOGY VOL. 34 NO. 1

BANERJEE, I (1989)
TIDAL SAND SHEET ORIGIN OF THE TRANSGRESSIVE BASAL COLORADO SANDSTONE [ALBIAN]: A SUBSURFACE STUDY OF THE CESSFORD FIELD, SOUTHERN ALBERTA; BULLETIN OF CANADIAN PETROLEUM GEOLOGY VOL. 37 NO. 1

GOLD, C M; KILBY, W E; CHARLESWORTH, H A K (1981)
COAL RESOURCE EVALUATION IN DEFORMED SEQUENCES, USING DIGITAL TERRAIN MODELS; BULLETIN OF CANADIAN PETROLEUM GEOLOGY VOL. 29 NO. 2

KALKREUTH, W; MCMECHAN, M E (1984)
REGIONAL PATTERN OF THERMAL MATURATION AS DETERMINED FROM COAL-RANK STUDIES, ROCKY MOUNTAIN FOOTHILLS AND FRONT RANGES NORTH OF GRANDE CACHE, ALBERTA - IMPLICATIONS FOR PETROLEUM EXPLORATION; BULLETIN OF CANADIAN PETROLEUM GEOLOGY VOL. 32 NO. 3

LERBEKMO, J F; COULTER, K C (1985)
MAGNETOSTRATIGRAPHIC AND LITHOSTRATIGRAPHIC CORRELATION OF COAL SEAMS AND CONTIGUOUS STRATA, UPPER HORSESHOE CANYON AND SCOLLARD FORMATIONS [MAASTRICHTIAN TO PALEOCENE], RED DEER VALLEY, ALBERTA; BULLETIN OF CANADIAN PETROLEUM GEOLOGY VOL. 33 NO. 3

MCLEAN, J R (1977)
THE CADOMIN FORMATION: STRATIGRAPHY, SEDIMENTOLOGY, AND TECTONIC IMPLICATIONS; CORDILLERAN GEOLOGY OF SOUTHERN ALBERTA AND ADJACENT AREAS. BULLETIN OF CANADIAN PETROLEUM GEOLOGY VOL. 25 NO. 4

<u>CANADIAN SOCIETY OF PETROLEUM GEOLOGISTS CORE CONFERENCE</u>

MCLEAN, J R (1978)
DEPOSITIONAL ENVIRONMENTS OF CRETACEOUS-TERTIARY COAL, ALBERTA FOOTHILLS; DISPLAY SUMMARIES, CSPG CORE AND FIELD SAMPLE CONFERENCE. CANADIAN SOCIETY OF PETROLEUM GEOLOGISTS CORE CONFERENCE

<u>CANADIAN SOCIETY OF PETROLEUM GEOLOGISTS, MEMOIR</u>

SWEET, A R; MCINTYRE, D J (1988)
LATE TURONIAN MARINE AND NONMARINE PALYNOMORPHS FROM THE CARDIUM FORMATION, NORTH - CENTRAL ALBERTA FOOTHILLS, CANADA; SEQUENCES, STRATIGRAPHY, SEDIMENTOLOGY: SURFACE AND SUBSURFACE. CANADIAN SOCIETY OF PETROLEUM GEOLOGISTS, MEMOIR VOL. 15

MCLEAN, J R; JERZYKIEWICZ, T (1978)
CYCLICITY, TECTONICS AND COAL: SOME ASPECTS OF FLUVIAL SEDIMENTOLOGY IN THE BRAZEAU-PASKAPOO FORMATIONS, COAL VALLEY AREA, ALBERTA, CANADA; FLUVIAL SEDIMENTOLOGY. CANADIAN SOCIETY OF PETROLEUM GEOLOGISTS, MEMOIR NO. *5*

POWELL, T G; SNOWDON, L R (1980)
GEOCHEMICAL CONTROLS ON HYDROCARBON GENERATION IN CANADIAN SEDIMENTARY BASINS; FACTS AND PRINCIPLES OF WORLD PETROLEUM OCCURRENCE. CANADIAN SOCIETY OF PETROLEUM GEOLOGISTS, MEMOIR NO. 6

LANGENBERG, C W (198410)
STRUCTURAL AND SEDIMENTOLOGICAL FRAMEWORK OF LOWER CRETACEOUS COAL-BEARING ROCKS IN THE GRANDE CACHE AREA, ALBERTA; THE MESOZOIC OF MIDDLE NORTH AMERICA. CANADIAN SOCIETY OF PETROLEUM GEOLOGISTS, MEMOIR NO. 9

HOFFMAN, G L; JORDAN, G R (1984)
THE COALFIELDS OF THE NORTHERN FOOTHILLS OF THE CANADIAN ROCKY MOUNTAINS; THE MESOZOIC OF MIDDLE NORTH AMERICA. CANADIAN SOCIETY OF PETROLEUM GEOLOGISTS, MEMOIR NO. 9

WAHEED, A; MIALL, A D (1984)
SEDIMENTOLOGY OF COAL-BEARING BEARPAW AND HORSESHOE CANYON FORMATIONS [UPPER CRETACEOUS], DRUMHELLER AREA, ALBERTA; THE MESOZOIC OF MIDDLE NORTH AMERICA. CANADIAN SOCIETY OF PETROLEUM GEOLOGISTS, MEMOIR NO. 9

KALKREUTH, W D; MCMECHAN, M E (1984)
STRUCTURAL CONTROLS ON THERMAL MATURATION AS DETERMINED FROM COAL RANK STUDIES, ROCKY MOUNTAIN FOOTHILLS NORTH OF GRANDE CACHE, ALBERTA; THE MESOZOIC OF MIDDLE NORTH AMERICA. CANADIAN SOCIETY OF PETROLEUM GEOLOGISTS, MEMOIR NO. 9

<u>EDMONTON GEOLOGICAL SOCIETY FIELD TRIP GUIDEBOOK</u>

PEARSON, G R (1960)
LOWER CRETACEOUS COAL DEPOSITS IN THE FOOTHILLS BETWEEN SHEEP CREEK AND WILDHAY RIVER, ALBERTA; GUIDEBOOK, ROCK LAKE. EDMONTON GEOLOGICAL SOCIETY FIELD TRIP GUIDEBOOK

LEESON, J (1959)
ROAD LOG, EDSON TO MOUNTAIN PARK; GUIDEBOOK, CADOMIN AREA. EDMONTON GEOLOGICAL SOCIETY FIELD TRIP GUIDEBOOK

PETERSON, G (1959)
ECONOMIC GEOLOGY; GUIDEBOOK, CADOMIN AREA. EDMONTON GEOLOGICAL SOCIETY FIELD TRIP GUIDEBOOK

PEARSON, G R (1960)
LOWER CRETACEOUS COAL DEPOSITS IN THE FOOTHILLS BETWEEN SHEEP CREEK AND WILDHAY RIVER, ALBERTA; EDMONTON GEOLOGICAL SOCIETY FIELD TRIP GUIDEBOOK

<u>ENERGY MINES AND RESOURCES CANADA, REPORT (1980)</u>

DISCUSSION PAPER ON COAL, 1980. ENERGY MINES AND RESOURCES CANADA, REPORT NO. EP 80-lE

ENERGY SOURCES

<u>DAVIDSON, R (1990)</u>

ELEMENTS AND MINERALS IN COAL MACERALS; ENERGY SOURCES VOL. 12 NO. 1

GOODARZI, F (1990)
VARIATION OF .ELEMENTS IN SELF - BURNING COAL SEAM FROM COALS PUR, ALBERTA, CANADA; GLOBAL CHANGE: THE GEOTHERMAL ASPECTS OF COAL. ENERGY SOURCES VOL. 12 NO. 3

ERDOL UND KOHLE, ERDGAS, PETROCHEMIE VEREINIGT MIT BRENNSTOFF-CHEMIE

KALKREUTH, W (1988)
KANADISCHE KREIDEKOHLEN: INKOHLUNGSGRAD UND PETROGRAPHISCHE ZUSAMMENSETZUNG KANADISCHER KREIDEKOHLEN IN DEN ROCKY MOUNTAIN FOOTHILLS VON NE - BRITISH COLUMBIA UND WESTZENTRALALBERTA; ERDOL UND KOHLE, ERDGAS, PETROCHEMIE VEREINIGT MIT BRENNSTOFF-CHEMIE VOL. 41 NO. 2

FUEL

BERKOWITZ, N; FRYER, J; IGNASIAK, B; SZLADOW, A (1974)
BEHAVIOR DIFFERENCES BETWEEN CARBONIFEROUS AND CRETACEOUS BITUMINOUS COAL OF SIMILAR RANK; FUEL VOL. 53 NO. 2

GEOLOGICAL ASSOCIATION OF CANADA-MINERALOGICAL ASSOCIATION OF CANADA,JOINT ANNUAL MEETING,PROG&ABST

FOX, J C; EDWARDS, W A D (1980)
NATURALLY FIRED TILL; GEOLOGICAL ASSOCIATION OF CANADA-MINERALOGICAL ASSOCIATION OF CANADA,JOINT ANNUAL MEETING,PROG&ABST VOL. 5

WILLIAMS, G D; FLINT, D W; PROUDFOOT, D N; IRVINE, J A; LATOUR, B A (1976)
COAL RESOURCES AND THE COMPUTER; GEOLOGICAL ASSOCIATION OF CANADA-MINERALOGICAL ASSOCIATION OF CANADA,JOINT ANNUAL MEETING,PROG&ABST VOL. 1

GEOSCIENCE CANADA

MOSSOP, G D (1984)
ALBERTA GEOLOGICAL SURVEY RESEARCH, GRANT; GEOSCIENCE CANADA VOL. 11 NO. 1

GEOLOGICAL SURVEY OF CANADA, BULLETIN

NORRIS, D K (1958)
STRUCTURAL CONDITIONS IN CANADIAN COAL MINES. GEOLOGICAL SURVEY OF CANADA, BULLETIN NO. 00044

STOTT, D F (1968)
LOWER CRETACEOUS BULLHEAD AND FORT ST JOHN GROUPS, BETWEEN SMOKY AND PEACE RIVERS ROCKY MOUNTAIN FOOTHILLS, ALBERTA AND BRITISH COLUMBIA. GEOLOGICAL SURVEY OF CANADA, BULLETIN NO. 00152

DEROO, G; HACQUEBARD, P A; MCCROSSAN, R G; POWELL, T G; TISSOT, B (1977)
THE ORIGIN AND MIGRATION OF PETROLEUM IN THE WESTERN CANADIAN SEDIMENTARY BASIN, ALBERTA: A GEOCHEMICAL AND THERMAL MATURATION STUDY. GEOLOGICAL SURVEY OF CANADA, BULLETIN NO. 00262

STOTT, D F (1982)
LOWER CRETACEOUS FORT ST. JOHN GROUP AND UPPER CRETACEOUS DUNVEGAN FORMATION OF THE FOOTHILLS AND PLAINS OF ALBERTA, BRITISH COLUMBIA, DISTRICT OF MACKENZIE AND YUKON TERRITORY. GEOLOGICAL SURVEY OF CANADA, BULLETIN NO. 00328

GIBSON, D W (1985)
STRATIGRAPHY, SEDIMENTOLOGY AND DEPOSITIONAL ENVIRONMENTS OF THE COAL - BEARING JURASSIC - CRETACEOUS KOOTENAY GROUP, ALBERTA AND BRITISH COLUMBIA. GEOLOGICAL SURVEY OF CANADA, BULLETIN NO. 00357

HUGHES, J D (1984)
GEOLOGY AND DEPOSITIONAL SETTING OF THE LATE CRETACEOUS, UPPER BEARPAW AND LOWER HORSESHOE CANYON FORMATIONS IN THE DODDS-ROUND HILL COALFIELD OF CENTRAL ALBERTA: A COMPUTER-BASED STUDY OF CLOSELY-SPACED EXPLORATION DATA. GEOLOGICAL SURVEY OF CANADA, BULLETIN NO. 00361

SWEET,A R; KALGUTKAR,RM (1989)
TRICHOPELTINITE COOKSON FROM THE LATEST MAASTRICHTIAN OF CANADA; CONTRIBUTIONS TO CANADIAN PALEONTOLOGY. GEOLOGICAL SURVEY OF CANADA, BULLETIN NO. 00396

<u>GEOLOGICAL SURVEY OF CANADA, ECONOMIC GEOLOGY REPORT</u>

BELYEA, H R; DOUGLAS, R J W; LATOUR, B A; LITTLE, H W; STOTT, D F (1970)
ECONOMIC MINERALS OF WESTERN CANADA; GEOLOGY AND ECONOMIC MINERALS OF CANADA. GEOLOGICAL SURVEY OF CANADA, ECONOMIC GEOLOGY REPORT NO. 00001

BELYEA, H R; DOUGLAS, R J W; LATOUR, B A; LITTLE, H W; STOTT, D F (1975)
RESSOURCES MINERALES DE L'OUEST DU CANADA; GEOLOGIE ET RESSOURCES MINERALES DU CANADA, PARTIE B. GEOLOGICAL SURVEY OF CANADA, ECONOMIC GEOLOGY REPORT NO. 00001

GEOLOGICAL SURVEY OF CANADA, "A" SERIES MAP

DOWLING, D B (1910)
EDMONTON, ALBERTA, ISOBATHIC LINES SHOWING COVER OVER CLOVER BAR COAL SEAM. GEOLOGICAL SURVEY OF CANADA, "A" SERIES MAP NO. 00006A

MACKENZIE, J D (1913)
SOUTHFORK COAL AREA, OLD MAN RIVER, ALBERTA. GEOLOGICAL SURVEY OF CANADA, "A" SERIES MAP NO. 00103A

LEACH, W W (1913)
BLAIRMORE, ALBERTA. GEOLOGICAL SURVEY OF CANADA, "A" SERIES MAP NO. 00107A

DOWLING, D B (1914)
COAL FIELDS OF ALBERTA AND BRITISH COLUMBIA. GEOLOGICAL SURVEY OF CANADA, "A" SERIES MAP NO. 00129A

DOWLING, D B (1914)
GEOLOGICAL SKETCH MAP OF PART OF BLAIRMORE-FRANK COALFIELDS, SOUTHERN ALBERTA, ALSO GEOLOGICAL AND TOPOGRAPHICAL MAP OF CROWS NEST COAL FIELDS EAST KOOTENAY DISTRICT, BRITISH COLUMBIA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00130A

MACKAY, B R (1929)
MOUNTAIN PARK SHEET, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00208A

MACKAY, B R (1929)
CADOMIN SHEET, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00209A

MACKAY, B R (1929)
BRULE MINES AREA, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES

HUME, G S (1931)
TURNER VALLEY SHEET, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00257A

HUME, G S (1931)
SOUTHWEST QUARTER, TURNER VALLEY SHEET, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00261A

HUME, G S (1931)
NORTHWEST QUARTER, TURNER VALLEY SHEET, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00262A

HUME, G S (1931)
SOUTHWEST QUARTER, FISH CREEK SHEET, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00263A

HUME, G S (1931)
SOUTHEAST QUARTER BRAGG CREEK SHEET, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00264A

HUME, G S (1931)
NORTHEAST QUARTER BRAGG CREEK SHEET, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00265A

MACKAY, B R (1935)
CANMORE AREA, NORTH PORTION, WEST OF FIFTH MERIDIAN. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00322A

MACKAY, B R (1935)
CANMORE AREA, SOUTH PORTION, WEST OF FIFTH MERIDIAN. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00323A

RUTHERFORD, R L (1939)
RED DEER, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00504A

RUTHERFORD, R L (1939)
TOFIELD, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00505A

RUTHERFORD, R L (1939)
EDMONTON, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00506A

MACKAY, B R (1939)
FALLENTIMBER, EAST HALF, WEST OF FIFTH MERIDIAN, ALBERTA.
GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00548A

MACKAY, B R (1939)
FALLENTIMBER, WEST HALF, WEST OF FIFTH MERIDIAN, ALBERTA.
GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00549A

HUME, G S (1941)
FISH CREEK, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00667A

BEACH, H H (1942)
BEARBERRY, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00670A

BEACH, H H (1942)
MOOSE MOUNTAIN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES
MAP NO. 00688A

BEACH, H H; HUME, G S (l944)
MORLEY, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF
CANADA, “A” SERIES MAP NO. 00777A

HAGE, C O (1945)
COWLEY, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF
CANADA, “A” SERIES MAP NO. 00816A

HAGE, C O (1946)
DYSON CREEK, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF
CANADA, “A” SERIES MAP NO. 00827A

IRISH, E J W (1945)
PEDLEY, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF
CANADA, “A” SERIES MAP NO. 00838A

LANG, A H (1946)
ENTRANCE, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF
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CROMBIE, G P; ERDMAN, O A (1947)
ALEXO WEST OF FIFTH MERIDIAN ALBERTA. GEOLOGICAL SURVEY OF CANADA,
“A” SERIES MAP NO. 00884A

ERDMAN, O A (1947)
SAUNDERS, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00885A

IRISH, E J W (1949)
MOON CREEK, WEST OF SIXTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00968A

DOUGLAS, R J W (1949)
GAP, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00978A

IRISH, E J W; LANG, A H (1951)
PIERRE GREYS LAKES, WEST OF SIXTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 00996A

IRISH, E J W (1954)
COPTON CREEK, WEST OF SIXTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 01041A

IRISH, E J W; THORSTEINSSON, R (1957)
GRANDE CACHE, WEST OF SIXTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 01049A

DOUGLAS, R J W (1958)
MOUNT HEAD, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 01052A

ECCLES, J K; IRISH, E J W (1964)
GEOLOGY ADAMS LOOKOUT WEST OF SIXTH MERIDIAN ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 01104A

IRISH, E J W (1965)
ROCKY MOUNTAIN FOOTHILLS, SHEET 1, WEST OF SIXTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 01139A

IRISH, E J W (1965)
ROCKY MOUNTAIN FOOTHILLS, SHEET 2, WEST OF FIFTH AND SIXTH MERIDIANS, ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 01140A

(1965)
GEOLOGY, SOUTH SASKATCHEWAN RIVER, SASKATCHEWAN-ALBERTA. GEOLOGICAL SURVEY OF CANADA, “A” SERIES MAP NO. 01165A

<u>GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP</u>

DAWSON, G M (1881)
MAP OF PART OF BRITISH COLUMBIA AND THE NORTHWEST TERRITORY FROM THE PACIFIC OCEAN TO FORT EDMONTON, SHEET 11. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00151

DAWSON, G M (1881)
MAP OF PART OF BRITISH COLUMBIA AND THE NORTHWEST TERRITORY FROM THE PACIFIC OCEAN TO FORT EDMONTON, SHEET 111. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00152

DAWSON, G M (1883)
INDEX MAP OF COAL AND LIGNITE OUTCROPS, BOW AND BELLY RIVER DISTRICT. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00158

DAWSON, G M; MCCONNELL, R G (1884)
GEOLOGICAL MAP OF THE REGION IN THE VICINITY OF THE BOW AND BELLY RIVERS EMBRACING THE SOUTHERN PORTION OF DISTRICT OF ALBERTA AND PART OF ASSINIBOIA, NORTHWEST TERRITORY. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00171

DAWSON, G M (1886)
RECONNAISSANCE MAP OF A PORTION OF THE ROCKY MOUNTAINS BETWEEN LATITUDES 49 AND 51-30 DEGREES. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00223

DAWSON, G M (1886)
GEOLOGICAL MAP OF PART OF THE CASCADE BASIN, ROCKY MOUNTAINS. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00224

TYRRELL, J B (1887)
GEOLOGICAL MAP OF PART OF NORTHERN ALBERTA AND PORTIONS OF THE DISTRICTS OF ASSINIBOIA AND SASKATCHEWAN, NORTH WEST TERRITORY. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00249

MCCONNELL, R G (1897)
SHEET NO 2 COUNTRY BETWEEN LOWER PORTIONS OF PEACE AND ATHABASCA RIVERS. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00595

DAWSON, G M; MCCONNELL, R G (1897)
MAP SHOWING THE COUNTRY BETWEEN THE LOWER PORTION OF THE PEACE AND ATHABASCA RIVERS, NORTH OF LESSER SLAVE LAKE, SHEET 3. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00596

LEACH, W W (1901)
SECTIONS OF COAL-MEASURES CROWS NEST COAL FIELDS. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00759

LEACH, W W (1903)
GEOLOGICAL SKETCH MAP OF PART OF THE BLAIRMORE-FRANK COAL-FIELDS SOUTHERN ALBERTA. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00808

DOWLING, D B (1904)
SKETCH MAP SHOWING CRETACEOUS COAL-BEARING ROCKS AT HEADWATERS OF ELBOW RIVER, SHEEP CREEK AND KANANASKIS RIVER, DISTRICT OF ALBERTA. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00845

DOWLING, D B (1905)
GEOLOGICAL MAP OF COSTIGAN COAL FIELD ALBERTA. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00892

DOWLING, D B (1907)
GEOLOGICAL MAP OF THE CASCADE COAL BASIN ALBERTA, SHEET 1, PANTHER RIVER. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00929

DOWLING, D B (1907)
GEOLOGICAL MAP OF THE CASCADE COAL BASIN ALBERTA, SHEET 2, CASCADE RIVER. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00931

DOWLING, D B (1907)
GEOLOGICAL MAP OF THE CASCADE COAL BASIN ALBERTA, SHEET 3, CANMORE. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00933

DOWLING, D B (1907)
GEOLOGICAL MAP OF THE CASCADE COAL BASIN ALBERTA, SHEET 4, WIND MOUNTAIN. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00935

CAIRNES, D D (1907)
GEOLOGICAL AND TOPOGRAPHICAL MAP, MOOSE MOUNTAIN REGION OF THE DISTURBED BELT, SOUTHERN ALBERTA. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00963

CAIRNES, D D (1907)
TOPOGRAPHICAL MAP SHOWING COAL AREAS OF THE MOOSE MOUNTAIN REGION OF THE DISTURBED BELT, SOUTHERN ALBERTA. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 00966

DOWLING, D B (1910)
GEOLOGICAL MAP SHOWING COAL AREAS IN ALBERTA, SASKATCHEWAN AND MANITOBA. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 01010

DOWLING, D B (1915)
CROWSNEST AND ELK RIVER COAL-AREAS. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 01413

MACVICAR, J (1916)
COAL AREAS IN THE FOOTHILLS BETWEEN ATHABASKA AND SMOKY RIVERS, ALBERTA. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 01668

SLIPPER, S E (1919)
SHEEP RIVER, ALBERTA. GEOLOGICAL SURVEY OF CANADA MULTICOLOURED MAP NO. 01724

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DOWLING, D B (1910)
EDMONTON COALFIELD, ALBERTA. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00008

DOWLING, D B (1912)
TERRAIN HOUILLER D'EDMONTON. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO.00008

MALLOCH, G S (1910)
BIG HORN COAL BASIN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO.00009

MALLOCH, G S (1912)
BASIN HOUILLER BIGHORN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00009

DALY, R A; MILLER, W G; RICE, G S (1912)
REPORT OF THE COMMISSION TURTLE MOUNTAIN, FRANK, ALBERTA. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00027

DALY, R A; MILLER, W G; RICE, G S (1913)
RAPPORT DE LA COMMISSION NOMMEE POUR FAIRE L'EXAMEN DE LA MONTAGNE A LA TORTUE, FRANK, ALBERTA. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00027

DOWLING, D B (1914)
COAL FIELDS OF MANITOBA, SASKATCHEWAN, ALBERTA, AND EASTERN BRITISH COLUMBIA. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00053

DOWLING, D B (1916)
LES TERRAINS HOUILLERS DE MANITOBA, SASKATCHEWAN, ALBERTA ET DE L'EST DE LA COLOMBIE-BRITANNIQUE. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00053

CAIRNES, D D (1914)
MOOSE MOUNTAIN DISTRICT, SOUTHERN ALBERTA. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00061

DOWLING, D B (1917)
SOUTHERN PLAINS OF ALBERTA. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00093

CAMSELL, C; MALCOLM, W (1921)
MACKENZIE RIVER BASIN. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00108

STEWART, J S (1919)
GEOLOGY OF THE DISTURBED BELT OF SOUTHWESTERN ALBERTA. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00112

DYER, W S; WILLIAMS, M Y (1930)
GEOLOGY OF SOUTHERN ALBERTA AND SOUTHWESTERN SASKATCHEWAN. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00163

BEACH, H H (1943)
MOOSE MOUNTAIN AND MORLEY MAP AREAS, ALBERTA. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00236

LANG, A H (1946)
BRULE AND ENTRANCE MAP AREAS, ALBERTA. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00244

ERDMAN, O A (1950)
ALEXO AND SAUNDERS MAP AREAS, ALBERTA. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00254

DOUGLAS, R J W (1950)
CALLUM CREEK, LANGFORD CREEK AND GAP MAP AREAS, ALBERTA. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00255

IRISH, E J W (1951)
PIERRE GREYS LAKES MAP AREA, ALBERTA. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00258

DOUGLAS, R J W (1958)
MOUNT HEAD MAP AREA, ALBERTA. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00291

IRISH, E J W (1965)
GEOLOGY OF THE ROCKY MOUNTAIN FOOTHILLS, ALBERTA. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00334

PRICE, R A (1965)
FLATHEAD MAP AREA, BRITISH COLUMBIA AND ALBERTA. GEOLOGICAL SURVEY OF CANADA, MEMOIR NO. 00336

<u>GEOLOGICAL SURVEY OF CANADA, OPEN FILE</u>

SMITH, G G (1987)
GEOLOGY AND COAL RESOURCES OF THE SHEERNESS COALFIELD, SOUTH - CENTRAL ALBERTA: VOLUME 1. GEOLOGICAL SURVEY OF CANADA, OPEN FILE NO. 01445

MCMECHAN, M E (1988)
GEOLOGY, TWO LAKES (83L/5), KAKWA FALLS (83L14) AND DRY CANYON (83E/13) MAP AREAS, ROCKY MOUNTAINS, EAST - CENTRAL ALBERTA. GEOLOGICAL SURVEY OF CANADA, OPEN FILE NO. 01710

<u>GEOLOGICAL SURVEY OF CANADA, PAPER</u>

RUSSELL, L S; SPROULE, J C (1937)
GEOLOGY OF THE VICINITY OF TABER, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 37-14

MACKAY, B R (1938)
FALLENTIMBER MAP - AREA, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 38-23

HUME, G S (1940)
FISH CREEK, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 40-05

BEACH, H H; HUME, G S (1940)
BRAGG CREEK, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 40-06

MACKAY, B R (1940)
WAPIABI CREEK, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 40-13

MACKAY, B R (1940)
GRAVE FLATS, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 40-15

MACKAY, B R (1940)
PEMBINA FORKS, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 40-16

MACKAY, B R (1940)
GEORGE CREEK, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 40-17

MACKAY, B R (1941)
BRAZEAU, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 41-04

BEACH, H H; HUME, G S (1941)
MORLEY, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 41-08

MACKAY, B R (1941)
BIGHORN RIVER, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 41-09

HAGE, C O (1943)
COWLEY MAP-AREA, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 43-01

CROMBIE, G P (1944)
ALEXO MAP-AREA, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 44-18

LANG, A H (1945)
ENTRANCE MAP-AREA, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 45-11

IRISH, E J W (1945)
PEDLEY MAP-AREA, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 45-13

HENDERSON, J F (1945)
FALL CREEK MAP-AREA, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 45-19

CROMBIE, G P; ERDMAN, O A (1945)
ALEXO, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 45-23

ERDMAN, O A (1945)
SAUNDERS MAP-AREA, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 45-24

LANG, A H (1946)
BRULE MAP-AREA, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 46-05

ERDMAN, O A (1946)
CRIPPLE CREEK, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 46-22

LANG, A H (1947)
MOBERLY CREEK MAP-AREA, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 47-11

DOUGLAS, R J W (1947)
GAP, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 47-23

IRISH, E J W (1947)
MOON CREEK MAP AREA, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 47-25

IRISH, E J W (1949)
A LA PECHE MAP-AREA, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 49-07

DOUGLAS, R J W (1950)
PRELIMINARY MAP, MOUNT HEAD, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 50-08

IRISH, E J W (1950)
DANIELS FLATS MAP-AREA, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 50-12

DOUGLAS, R J W (1951)
PRELIMINARY MAP, PINCHER CREEK, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 51-22

IRISH, E J W (1952)
COPTON CREEK MAP-AREA, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 52-07

THORSTEINSSON, R (1952)
GRANDE CACHE MAP-AREA, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 52-26

IRISH, E J W (1954)
KVASS FLATS, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 54-02

IRISH, E J W (1955)
ADAMS LOOKOUT, WEST HALF, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 54-19

GREINER, H R (1955)
TWO LAKES, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 55-14

NORRIS, D K (1955)
BLAIRMORE, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 55-18

DOUGLAS, R I W (1956)
GEORGE CREEK, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 55-39

NORRIS, D K (1957)
CANMORE, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 57-04

NORRIS, D K (1958)
BEEHIVE MOUNTAIN, ALBERTA AND BRITISH COLUMBIA, 82J/2E. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 58-05

STOIT, D F (1963)
STRATIGRAPHY OF THE LOWER CRETACEOUS FORT ST JOHN GROUP AND GETHING AND CADOMIN FORMATIONS, FOOTHILLS OF NORTHERN ALBERTA AND BRITISH COLUMBIA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 62-39

BIRMINGHAM, T F (1964)
PETROGRAPHIC INVESTIGATION OF THE SUB-BITUMINOUS COALS OF THE EDMONTON FORMATION, ALBERTA; SUMMARY OF ACTIVITIES: OFFICE AND LABORATORY, 1963. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 64-02

NORRIS, D K (1966)
INTERBED SLIP IN SOME CORDILLERAN COAL MINES; REPORT OF ACTIVITIES, MAY TO OCTOBER, 1965. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 66-01

NORRIS, D K (1967)
STRATIGRAPHIC AND STRUCTURAL STUDIES IN THE SOUTHEASTERN CANADIAN CORDILLERA; REPORT OF ACTIVITIES PART A, MAY TO OCTOBER 1966. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 67-01A

DONALDSON, J R; HACQUEBARD, P A (1968)
COALFIELDS IN WESTERN CANADA; REPORT OF ACTIVITIES PART A, MAY TO OCTOBER 1967. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 68-01A

OLLERENSHAW, N C (1968)
PRELIMINARY ACCOUNT OF THE GEOLOGY OF LIMESTONE MOUNTAIN MAP-AREA, SOUTHERN FOOTHILLS, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 68-24

BARRON, K; NORRIS, D K (1968)
STRUCTURAL ANALYSIS OF FEATURES ON NATURAL AND ARTIFICIAL FAULTS; PROCEEDINGS, CONFERENCE ON RESEARCH IN TECTONICS [KINK BANDS AND BREITLE DEFORMATION]. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 68-52

BIRMINGHAM, T F; CAMERON, A R; DONALDSON, J R; HACQUEBARD, P A (1969)
RADIOACTIVITY OF TERTIARY LIGNITES IN SASKATCHEWAN, ALBERTA AND BRITISH COLUMBIA; REPORT OF ACTIVITIES PART A, APRIL TO OCTOBER 1968. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 69-0lA

NORRIS, D K (1969)
STRUCTURAL STUDIES IN EASTERN AND NORTHERN CORDILLERA OF CANADA; REPORT OF ACTIVITIES PART A, APRIL TO OCTOBER 1968. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 69-0lA

HACQUEBARD, P A (1970)
RANK STUDIES OF COAL AND CARBONACEOUS MATTER, BRITISH COLUMBIA AND ALBERTA; REPORT OF ACTIVITIES PART A, APRIL TO OCTOBER 1970. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 70-0lA

LATOUR, B A; CHRISMAS, L P (1970)
PRELIMINARY ESTIMATE OF MEASURED COAL RESOURCES INCLUDING REASSESSMENT OF INDICATED AND INFERRED RESOURCES IN WESTERN CANADA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 70-58

CAMERON, A R; HACQUEBARD, P A (1971)
STUDIES BY THE COAL RESEARCH SECTION, 1970; REPORT OF ACTIVITIES PART A, APRIL TO OCTOBER 1970. GEOLOGICAL SURVEY OF CANADA, PAYER NO. 71-01A

HACQUEBARD, P A (1972)
STUDIES BY THE COAL RESEARCH SECTION; REPORT OF ACTIVITIES PART A, APRIL TO OCTOBER 1971. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 72-0lA

STOTT, D F (1973)
JURASSIC AND CRETACEOUS STRATIGRAPHY OF ROCKY MOUNTAIN FOOTHILLS, NORTHEASTERN BRITISH COLUMBIA AND ALBERTA (83E,I,931,O,P,94B ,G); REPORT OF ACTIVITIES PART A, APRIL TO OCTOBER 1971. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 72-01A

CAMERON, A R (1972)
PETROGRAPHY OF KOOTENAY COALS IN THE UPPER ELK RIVER AND CROWSNEST AREAS, BRITISH COLUMBIA AND ALBERTA; REPORT OF ACTIVITIES PART B, NOVEMBER 1971 TO MARCH 1972. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 72-01B

DONALDSON, J R; HACQUEBARD, P A (1972)
RANK STUDIES OF COALS IN THE ROCKY MOUNTAINS AND INNER FOOTHILLS BELT, CANADA; REPORT OF ACTIVITIES PART B, NOVEMBER 1971 TO MARCH 1972. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 72-01B

SWEET, A R (1972)
PALYNOLOGIC STUDY OF COALS AND ASSOCIATED CLASTICS OF THE KOOTENAY FORMATION, CROWSNEST AREA; REPORT OF ACTIVITIES PART B, NOVEMBER 1971 TO MARCH 1972. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 72-01B

HACQUEBARD, P A (1973)
STUDIES BY THE COAL PETROLOGY SECTION; REPORT OF ACTIVITIES PART A, APRIL TO OCTOBER 1972. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 73-01A

HARRISON, J E (1973)
ENVIRONMENTAL GEOLOGY - MOUNTAIN COAL MINING, ALBERTA AND BRITISH COLUMBIA; REPORT OF ACTIVITIES PART A, APRIL TO OCTOBER 1972. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 73-01A

MERIAUX, E (1974)
A PROPOS DE QUELQUES TONSTEINS OBSERVES DANS LES VEINES DE CHARBON DE LA FORMATION DE KOOTENAY EN COLOMBIE-BRITANNIQUE ET EN ALBERTA [CANADA]; REPORT OF ACTIVITIES PART A, APRIL TO OCTOBER 1973. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 74-01A

HACQUEBARD, P A (1975)
CORRELATION BETWEEN COAL RANK, PALEOTEMPERATURE AND PETROLEUM OCCURRENCES IN ALBERTA; REPORT OF ACTIVITIES PART B. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 75-01B

GIBSON, D W (1977)
UPPER CRETACEOUS AND TERTIARY COAL-BEARING STRATA IN THE DRUMHELLER-ARDLEY REGION, RED DEER RIVER VALLEY, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 76-35

MCLEAN, J R (1977)
AN OCCURRENCE OF COAL IN THE BLAIRMORE GROUP ON WAIPAROUS CREEK, CENTRAL FOOTHILLS, ALBERTA; REPORT OF ACTIVITIES PART A. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 77-01A

HARRISON, J E (1977)
COAL MINING AND SURFACE WATER QUALITY: CROWSNEST PASS, ALBERTA AND BRITISH COLUMBIA - PRELIMINARY DATA; REPORT OF ACTIVITIES PART A. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 77-01A

JERZYKIEWICZ, T; MCLEAN, J R (1980)
LITHOSTRATIGRAPHICAL AND SEDIMENTOLOGICAL FRAMEWORK OF COAL-BEARING UPPER CRETACEOUS AND LOWER TERTIARY STRATA, COAL VALLEY AREA, CENTRAL ALBERTA FOOTHILLS. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 79-12

MCLEAN, J R (1982)
LITHOSTRATIGRAPHY OF THE LOWER CRETACEOUS COAL-BEARING SEQUENCE, FOOTHILLS OF ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 80-29

HUGHES, J D; CAMERON, A R (1985)
LITHOLOGY, DEPOSITIONAL SETTING AND COAL RANK - DEPTH RELATIONSHIPS IN THE JURASSIC - CRETACEOUS KOOTENAY GROUP AT MOUNT ALLAN, CASCADE COAL BASIN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 81-11

WILLIAMS, G D; MURPHY, M C (1981)
DEEP COAL RESOURCES OF THE INTERIOR PLAINS, ESTIMATED FROM PETROLEUM BOREHOLE DATA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 81-13

JACKSON, L E, JR (1982)
A SUMMARY OF WATER CHEMISTRY DATA FOR UNDISTURBED COAL - BEARING WATERSHEDS AND A SYNOPTIC SURVEY OF OPEN PIT MINE LEACHATES, SOUTHERN ROCKY MOUNTAINS, ALBERTA AND BRITISH COLUMBIA; CURRENT RESEARCH PART B. RECHERCHES EN COURS PARTIE B. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 82-01B

JERZYKIEWICZ, T (1985)
STRATIGRAPHY OF THE SAUNDERS GROUP IN THE CENTRAL ALBERTA FOOTHILLS: A PROGRESS REPORT; CURRENT RESEARCH PART B. RECHERCHES EN COURS PARTIE B. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 85-01B

JERZYKIEWICZ, T; SWEET, A R (1986)
CALICHE AND ASSOCIATED IMPOVERISHED PALYNOLOGICAL ASSEMBLAGES: AN INNOVATIVE LINE OF PALEOCLIMATIC RESEARCH ONTO THE UPPERMOST CRETACEOUS AND PALEOCENE OF SOUTHERN ALBERTA; CURRENT RESEARCH PART B. RECHERCHES EN COURS PARTIE B. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 86-01B

HUGHES, J D; NIEMANIS, V P (1986)
A COMPUTER - BASED SYSTEM FOR QUANTIFYING SURFACE - MINEABLE COAL RESOURCES ACCORDING TO ENVIRONMENTAL CHARACTERISTICS AND OWNERSHIP OF THE OVERLYING LAND SURFACE; CURRENT RESEARCH PART B. RECHERCHES EN COURS PARTIE B. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 86-01B

GOODARZI, F; JERZYKIEWICZ, T (1986)
PETROLOGY OF A BURNING BITUMINOUS COAL SEAM AT COALSPUR, ALBERTA; CURRENT RESEARCH PART B. RECHERCHES EN COURS PARTIE B. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 86-01B

ZOLNAI, A I (1987)
STRUCTURE AND STRATIGRAPHY, MOUNT BRYANT AREA, EASTERN ROCKY MOUNTAIN FRONT RANGES, ALBERTA; CURRENT RESEARCH PART A. RECHERCHES EN COURS PARTIE A. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 87-01A

PRATT, K C (1988)
GEOGRAPHIC VARIATIONS IN RELATIONSHIPS BETWEEN RANDOM AND MAXIMUM VITRINITE REFLECTANCE, WESTERN CANADIAN COALS; CURRENT RESEARCH PART D INTERIOR PLAINS AND ARCTIC CANADA. RECHERCHES EN COURS PARTIE D PLAINES INTERIEURES ET REGION ARCTIQUE DU CANADA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 88-01D

BAOFANG, L; DAWSON, F M (1988)
STRATIGRAPHIC FRAMEWORK AND DEPOSITIONAL SETTING, JUDY CREEK COALFIELD, NORTHERN ALBERTA; CURRENT RESEARCH PART D INTERIOR PLAINS AND ARCTIC CANADA. RECHERCHES EN COURS PARTIE D PLAINES INTERIEURES ET REGION ARCTIQUE DU CANADA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 88-01D

JACKSON, L E, JR (1989)
PHYSICAL AND GEOCHEMICAL OBSERVATIONS ON LAND RECLAMATION OF OPEN - PIT COAL MINES, ALBERTA AND BRITISH COLUMBIA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 88-12

MWENIFUMBO, C J (1989)
THE SYMMETRICAL LATERAL RESISTIVITY LOG IN COAL SEAM MAPPING, HIGHVALE MINE, ALBERTA; CURRENT RESEARCH PART A, ABSTRACTS. RECHERCHES EN COURS PARTIE A, RESUMES. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 89-01A

SWEET, A R; RICKEITS, B D; CAMERON, A R; NORRIS, D K (1989)
AN INTEGRATED ANALYSIS OF THE BRACKEIT COAL BASIN, NORTHWEST TERRITORIES; CURRENT RESEARCH PART A, ABSTRACTS. RECHERCHES EN COURS PARTIE A, RESUMES. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 89-01A

MWENIFUMBO, C J (1989)
THE SYMMETRICAL LATERAL RESISTIVITY LOG IN COAL SEAM MAPPING, HIGHVALE MINE, ALBERTA; CURRENT RESEARCH PART D, INTERIOR PLAINS AND ARCTIC CANADA. RECHERCHES EN COURS PARTIE D, PLAINES INTERIEURES ET REGIONS ARCTIQUE DU CANADA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 89-01D

SWEET, A R; RICKETITS, B D; CAMERON, A R; NORRIS, D K (1989)
AN INTEGRATED ANALYSIS OF THE BRACKETT COAL BASIN, NORTHWEST TERRITORIES; CURRENT RESEARCH PART G, FRONTIER GEOSCIENCE PROGRAM, ARCTIC CANADA. RECHERCHES EN COURS PARTIE G, PROGRAMME GEOSCIENTIFIQUE DES REGIONS PIONNIERES, REGION ARCTIQUE DU CANADA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 89-01G

(1989)
CONTRIBUTIONS TO CANADIAN COAL GEOSCIENCE. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 89-08

KALKREUTH, W; LECKIE, D A; LABONTE, M (1989)
GATES FORMATION [LOWER CRETACEOUS] COALS IN WESTERN CANADA: A SEDIMENTOLOGICAL AND PETROGRAPHICAL STUDY; CONTRIBUTIONS TO CANADIAN COAL GEOSCIENCE. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 89-08

DAWSON, F M (1989)
COAL GEOLOGY AND RESOURCE POTENTIAL OF THE LOWER CRETACEOUS LUSCAR GROUP IN WEST - CENTRAL ALBERTA; CONTRIBUTIONS TO CANADIAN COAL GEOSCIENCE. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 89-08

SWEET, A R; BRAMAN, D R (1989)
A DISTINCTIVE TERRESTRIAL PALYNOFLORAL ASSEMBLAGE FROM THE LOWER CAMPANIAN CHUNGO MEMBER, WAPIABI FORMATION, SOUTHWESTERN ALBERTA: A KEY TO REGIONAL CORRELATIONS; CONTRIBUTIONS TO CANADIAN COAL GEOSCIENCE. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 89-08

JERZYKIEWICZ, T (1989)
SYNOPSIS: "CONTROLS ON THE DISTRIBUTION OF COAL IN THE CAMPANIAN TO PALEOCENE POST - WAPAIBI STRATA OF THE ROCKY MOUNTAIN FOOTHILLS [CANADA]"; CONTRIBUTIONS TO CANADIAN COAL GEOSCIENCE. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 89-08

DAWSON, F M; KALKREUTH, W (1989)
PRELIMINARY RESULTS OF A CONTINUING STUDY OF THE STRATIGRAPHIC CONTEXT, DISTRIBUTION AND CHARACTERISTICS OF COALS IN THE UPPER CRETACEOUS TO PALEOCENE WAPITI GROUP, NORTHWESTERN ALBERTA; CONTRIBUTIONS TO CANADIAN COAL GEOSCIENCE. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 89-08

DAWSON, F M; CAMERON, A R; JERZYKIEWICZ, T (1989) DISTRIBUTION AND CHARACTER OF COAL IN THE BATTLE RIVER COALFIELD, EAST - CENTRAL ALBERTA; CONTRIBUTIONS TO CANADIAN COAL GEOSCIENCE. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 89-08

KALKREUTH, W; MCMECHAN, M (1989)
COALIFICATION PATTERNS IN JURASSIC - LOWER CRETACEOUS STRATA IMINNES, BULLHEAD AND FORT ST. JOHN GROUPS], ROCKY MOUNTAIN FOOTHILLS AND FORELAND, EAST - CENTRAL BRITISH COLUMBIA AND ADJACENT ALBERTA; CONTRIBUTIONS TO CANADIAN COAL GEOSCIENCE. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 89-08

LANGENBERG, C W; MACDONALD, D; KALKREUTH, W (1989)
CONTROLS ON COAL QUALITY VARIATION IN THE CADOMIN - LUSCAR COALFIELD, ALBERTA; CONTRIBUTIONS TO CANADIAN COAL GEOSCIENCE. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 89-08

KALKREUTH, W; ROY, C; STELLER, M (1989)
CONVERSION CHARACTERISTICS OF SELECTED CANADIAN COALS BASED ON HYDROGENATION AND PYROLYSIS EXPERIMENTS; CONTRIBUTIONS TO CANADIAN COAL GEOSCIENCE. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 89-08

DARRAGH, A; HUGHES, J D (1989)
WESTERN CANADIAN COAL MINES - FOR THE RECORD; CONTRIBUTIONS TO CANADIAN COAL GEOSCIENCE. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 89-08

(1990)
CURRENT RESEARCH, PART D, INTERIOR PLAINS AND ARCTIC CANADA. RECHERCHES EN COURS, PARTIE D, PLAINES INTERIEURES ET REGION ARCTIQUE DU CANADA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 90-01D

MCFARLANE, R; GOODARZI, F (1990)
A PHOTOACOUSTIC INFRARED SPECTROSCOPIC STUDY TO DETERMINE VARIATIONS OF THE CHEMICAL STRUCTURES OF SAMPLES FROM WEATHERED OUTCROPS AND FRESH COALS FROM WESTERN CANADA; CURRENT RESEARCH PART D, INTERIOR PLAINS AND ARCTIC CANADA. RECHERCHES EN COURS PARTIE D, PLAINES INTERIEURES ET REGION ARCTIQUE DU CANADA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 90-01D

OSADETZ, K G; PEARSON, D E; STASIUK, D (1990)
PALEOGEOTHERMAL GRADIENTS AND CHANGES IN THE GEOTHERMAL GRADIENT FIELD OF THE ALBERTA PLAINS; CURRENT RESEARCH PART D, INTERIOR PLAINS AND ARCTIC CANADA. RECHERCHES EN COURS PARTIE D, PLAINES INTERIEURES ET REGION ARCTIQUE DU CANADA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 90-01D

GENTZIS, T; GOODARZI, F; LALI, K (1990)
PETROGRAPHIC STUDY OF UPPER CRETACEOUS BRACKISH - WATER COALS FROM VESTA MINE, EAST - CENTRAL ALBERTA; CURRENT RESEARCH PART D, INTERIOR PLAINS AND ARCTIC CANADA. RECHERCHES EN COURS PARTIE D, PLAINES INTERIEURES ET REGION ARCTIQUE DU CANADA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 90-01D

GENTZIS, T; GOODARZI, F; JERZYKIEWICZ, T (1990)
PETROLOGY OF THE ARBOUR AND VAL D'OR COAL SEAMS AT COALSPUR, ALBERTA; CURRENT RESEARCH PART D, INTERIOR PLAINS AND ARCTIC CANADA. RECHERCHES EN COURS PARTIE D, PLAINES INTERLEURES ET REGION ARCTIQUE DU CANADA. GEOLOGICAL SURVEY OF CANADA, PAPER NO. 90-01D

<u>GEOLOGICAL SURVEY OF CANADA, PRELIMINARY MAP</u>

PRICE, R A; WISE, D U (1959)
FLATHEAD, BRITISH COLUMBIA AND ALBERTA. GEOLOGICAL SURVEY OF CANADA, PRELIMINARY MAP NO. 01-1959

ECCLES, J K (1957)
ADAMS LOOKOUT, EAST HALF, WEST OF SIXTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PRELIMINARY MAP NO. 05-1957

NORRIS, D K (1958)
LIVINGSTONE RIVER, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PRELIMINARY MAP NO. 05-1958

IRISH, E J W (1967)
GEOLOGY, DRUMHELLER, WEST OF FOURTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PRELIMINARY MAP NO. 05-1967

DOUGLAS, R J W; MACKAY, B R (1958)
CHUNGO CREEK, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PRELIMINARY MAP NO. 06-1958

NORRIS, D K (1957)
SOUTH PART OF CANMORE AREA, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PRELIMINARY MAP NO. 11-1957

IRISH, E J W (1968)
GEOLOGY, GLEICHEN, WEST OF FOURTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PRELIMINARY MAP NO. 19-1967

IRISH, E J W (1968)
GEOLOGY, LETHBRIDGE, WEST OF FOURTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PRELIMINARY MAP NO. 20-1967

IRISH, E J W (1967)
GEOLOGY, OYEN, WEST OF FOURTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PRELIMINARY MAP NO. 21-1966

IRISH, E J W (1968)
GEOLOGY, MEDICINE HAT, WEST OF FOURTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PRELIMINARY MAP NO. 21-1967

IRISH, E J W (1968)
GEOLOGY, FOREMOST, WEST OF FOURTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PRELIMINARY MAP NO. 22-1967

OLLERENSHAW, N C (1968)
GEOLOGY, PANTHER CULMINATION, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PRELIMINARY MAP NO. 24-1967

MOUNTJOY, E W (1960)
MIETTE, WEST OF FIFTH MERIDIAN, ALBERTA. GEOLOGICAL SURVEY OF CANADA, PRELIMINARY MAP NO. 40-1959

<u>GEOLOGICAL SURVEY OF CANADA SEPARATE REPORT</u>

CAIRNES, D D (1907)
MOOSE MOUNTAIN DISTRICT OF SOUTHERN ALBERTA. GEOLOGICAL SURVEY OF CANADA SEPARATE REPORT NO. 00968

DOWLING, D B (1909)
THE COAL FIELDS OF MANITOBA, SASKATCHEWAN, ALBERTA, AND EASTERN BRITISH COLUMBIA. GEOLOGICAL SURVEY OF CANADA SEPARATE REPORT NO. 01035

<u>GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT</u>

LEACH, W W (1912)
GEOLOGY OF BLAIRMORE MAP - AREA, ALBERTA; GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

DOWLING, D B (1912)
GEOLOGY OF ROCHE MIETTE MAP - AREA, JASPER PARK, ALBERTA; GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

DOWLING, D B (1912)
NOTES ON COAL OCCURRENCES AND THE PROGRESS OF DEVELOPMENT WORK IN ALBERTA AND SASKATCHEWAN; GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

MACKAY, B R (1934)
MICHEL COAL AREA, B C, AND COLEMAN SOUTH COAL AREA, ALBERTA; GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

MACKAY, B R (1929)
BRULE MINES COAL AREA, ALBERTA; GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

MACKAY, B R (1933)
GEOLOGY AND COAL DEPOSITS OF CROWSNEST PASS AREA, ALBERTA; SUMMARY REPORT 1932 PART B. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

MACKAY, B R (1932)
THE MESOZOIC - PALABOZOIC CONTACT AND ASSOCIATED SEDIMENTS, CROWSNEST DISTRICT, ALBERTA AND BRITISH COLUMBIA; SUMMARY REPORT 1931 PART B. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

DOWLING, D B (1924)
BOW RIVER COAL BASIN WITHIN THE ROCKY MOUNTAINS, ALBERTA; SUMMARY REPORT 1923 PART B. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

MACVICAR, J (1924)
PRELIMINARY INVESTIGATION OF COAL DEPOSITS ON SMOKY, HAY, AND BERLAND RIVERS, ALBERTA; SUMMARY REPORT 1923 PART B. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

MARSHALL, J R (1922)
KANANASKIS LAKES-PALLISER RIVER MAP - AREA; SUMMARY REPORT 1921 PART B. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

MACVICAR, J (1920)
COAL AREAS NORTHWEST OF BRULE LAKE, ALBERTA; SUMMARY REPORT 1919 PART C. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

ROSE, B (1920)
HIGHWOOD COAL AREA, ALBERTA; SUMMARY REPORT 1919 PART C. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

ROSE, B (1919)
NORTHERN PART OF CROWSNEST COAL FIELD, ALBERTA; SUMMARY REPORT 1918 PART C. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

MCLEARN, F H (1918)
PEACE RIVER SECTION, ALBERTA; SUMMARY REPORT 1917 PART C. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

DOWLING, D B (1918)
WATER SUPPLY IN SOUTHERN ALBERTA; SUMMARY REPORT 1917 PART C. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

DOWLING, D B (1917)
INVESTIGATIONS FOR COAL, OIL, GAS AND ARTESIAN WATER IN WESTERN CANADA; SUMMARY REPORT 1916. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

DOWLING, D B (1917)
DRUMHELLER COAL AREA; SUMMARY REPORT 1916. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

MACVICAR, J (1917)
FOOTHILL COAL AREAS NORTH OF THE GRAND TRUNK PACIFIC RAILWAY, ALBERTA; SUMMARY REPORT 1916. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

STEWART, J S (1917)
COAL MINES OF WEST CENTRAL ALBERTA; SUMMARY REPORT 1916. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

ROSE, B (1917)
CROWSNEST COALFIELD, ALBERTA; SUMMARY REPORT 1916. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

MCLEARN, F H (1917)
ATHABASKA RIVER SECTION, ALBERTA; SUMMARY REPORT 1916. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

DOWLING, D B (1915)
SOUTHERN ALBERTA; SUMMARY REPORT 1914. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

DOWLING, D B (1915)
NORTH SASKATCHEWAN RIVER COAL AREAS, ALBERTA; SUMMARY REPORT 1913. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

MACKENZIE, J D (1914)
SOUTH FORK COAL AREA, OLDMAN RIVER, ALBERTA; SUMMARY REPORT 1912. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

DOWLING, D B (1911)
COAL FIELDS OF JASPER PARK, ALBERTA; SUMMARY REPORT 1910. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

DOWLING, D B (1910)
COAL FIELDS SOUTH OF THE GRAND TRUNK PACIFIC RAILWAY, IN THE FOOTHILLS OF THE ROCKY MOUNTAINS ALBERTA; SUMMARY REPORT 1909. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

MALLOCH, G S (1909)
THE BIG HORN COAL BASIN, ALBERTA; SUMMARY REPORT 1908. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

DOWLING, D B (1909)
STEAM COALS OF THE CASCADE BASIN, LIGNITE AREAS OF ALBERTA AND SASKATCHEWAN: PRODUCTION OF COAL IN ALBERTA AND SASKATCHEWAN; SUMMARY REPORT 1908. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

STEWART, J S (1916)
THE DISTURBED BELT OF SOUTHWESTERN ALBERTA; SUMMARY REPORT 1915. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

MALLOCH, G S (1908)
THE CASCADES, PALLISER AND COSTIGAN COAL BASINS; SUMMARY REPORT 1907. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

DOWLING, D B (1908)
EXPLORATIONS IN THE ROCKY MOUNTAINS; SUMMARY REPORT 1907. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

DOWLING, D B (1907)
ROCKY MOUNTAIN COAL AREAS; SUMMARY REPORT 1906. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

DENTS, T C (1907)
WESTERN OIL, GAS, AND COAL FIELDS; SUMMARY REPORT 1906. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

DOWLING, D B (1906)
THE NORTHERN EXTENSION OF THE ELK RIVER COAL BASIN, ALBERTA; SUMMARY REPORT 1905. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

CAIRNES, D D (1906)
THE FOOTHILLS OF THE ROCKY MOUNTAINS, SOUTH OF MAIN LINE CANADIAN PACIFIC RAILWAY, ALBERTA AND BRITISH COLUMBIA; SUMMARY REPORT 1905. GEOLOGICAL SURVEY OF CANADA, SUMMARY REPORT

<u>INTERNATIONAL GEOLOGICAL CONGRESS, ABSTRACTS</u>

KAHIL, A A (1980)
EFFECTS OF GEOLOGIC PARAMETERS ON THE ECONOMIC EXTRACTION OF COAL GAS USING SURFACE CORES; INTERNATIONAL GEOLOGICAL CONGRESS, ABSTRACTS VOL. 3 NO. 26

<u>INTERNATIONAL GEOLOGICAL CONGRESS, PROCEEDINGS</u>

DOWLING, D B (1913)
THE COAL FIELDS AND COAL RESOURCES OF CANADA; INTERNATIONAL GEOLOGICAL CONGRESS, PROCEEDINGS VOL. 2

<u>INTERNATIONAL JOURNAL OF COAL GEOLOGY</u>

KALKREUTH, W; LECKIE, D A (1989)
SEDIMENTOLOGICAL AND PETROGRAPHICAL CHARACTERISTICS OF CRETACEOUS STRANDPLAIN COALS: A MODEL FOR COAL ACCUMULATION FROM THE NORTH AMERICAN WESTERN INTERIOR SEAWAY; PEAT AND COAL: ORIGIN, FACIES, AND DEPOSITIONAL MODELS. INTERNATIONAL JOURNAL OF COAL GEOLOGY VOL. 12 NO. 1-4

KALKREUTH, W; LANGENBERG, W; MCMECHAN, M (1989)
REGIONAL COALIFICATION PATTERN OF LOWER CRETACEOUS COAL - BEARING STRATA, ROCKY MOUNTAIN FOOTHILLS AND FORELAND, CANADA - IMPLICATIONS FOR FUTURE EXPLORATION; COAL: CLASSIFICATION, COALIFICATION, MINERALOGY, TRACE - ELEMENT CHEMISTRY, AND OIL AND GAS POTENTIAL. INTERNATIONAL JOURNAL OF COAL GEOLOGY VOL. 13 NO. 1-4

<u>NOVA SCOTIA DEPARTMENT OF MINES AND ENERGY, OPEN FILE REPORT</u>

HACQUEBARD, P A (1982)
COMPOSITION, ORIGIN AND GEOLOGY OF COAL. NOVA SCOTIA DEPARTMENT OF MINES AND ENERGY, OPEN FILE REPORT NO. 88-034

ROYAL SOCIETY OF CANADA, TRANSACTIONS
GOVIER, G W (1977)
THE FOSSIL FUEL RESOURCES OF THE WESTERN PROVINCES; ROYAL SOCIETY OF CANADA, TRANSACTIONS VOL. 15

SEDIMENTARY GEOLOGY
JERZYKIEWICZ, T; SWEET, A R (1988)
SEDIMENTOLOGICAL AND PALYNOLOGICAL EVIDENCE OF REGIONAL CLIMATIC CHANGES IN THE CAMPANIAN TO PALEOCENE SEDIMENTS OF THE ROCKY MOUNTAIN FOOTHILLS, CANADA; SEDIMENTARY GEOLOGY VOL. 59 NO. 1/2

BANERJEE, I; GOODARZI, F (1990)
PALEOENVIRONMENT AND SULFUR - BORON CONTENTS OF THE MANN VILLE [LOWER CRETACEOUSI COALS OF SOUTHERN ALBERTA, CANADA; SEDIMENTARY GEOLOGY VOL. 67 NO. 3/4

SEDIMENTOLOGY
LERBEKMO, I F (1963)
PETROLOGY OF THE BELLY RIVER FORMATION, SOUTHERN ALBERTA FOOTHILLS; SEDIMENTOLOGY VOL. 2.

SASKATCHEWAN RESEARCH COUNCIL, GEOLOGY DIVISION, REPORT
PILON, C A (1977)
BIBLIOGRAPHY AND INDEX OF COAL IN SASK AND ADJOINING PROVINCES AND STATES; SASKATCHEWAN RESEARCH COUNCIL, GEOLOGY DIVISION, REPORT NO. 0018

WESTERN MINER AND OIL REVIEW
GRACE, N H (1957)
COAL - TODAY AND TOMORROW; WESTERN MINER AND OIL REVIEW VOL. 30 NO. 10

Appendix G

GENMAP - SUMMARY OF CONTOUR MAP PRODUCTION

A summary of the map production steps and processes is attached.

Genmap - Summary of Contour Map production

Automated mapping techniques were used to generate most of the maps included with this report. GENMAP, a set of command procedures developed in house, provided the mapping team with a simple interface to the database, the gridding and contouring package used, the cartographic mapping system and the graphics system at the Alberta Research Council. It also provides an interactive and batch mode of operation. In batch mode all of the parameters required to generate a map are defined interactively but the map is actually generated as a batch job.

An iterative process was used to obtain each of the finished maps. Initial maps were printed on a laser printer at a scale of 1:4 000 000. These were used to identify data busts, the boundary of the data sets, and to determine the parameters to be used for gridding and contouring. All problems associated with the data were identified and corrections made to the database before repeating the process. During the later stages maps were plotted using a 36” wide Calcomp pen plotter. These maps included overlays for the DLS township system, subcrop edges, cities etc. The final master copy of the maps were produced on a 44” wide electrostatic printer/plotter.

The steps involved in generating a map are listed below.

1. Map Definition.

The map type, coal zone, data source and all other parameters needed to select the data to be included in a map are specified at this time. This step involves only the use of the GENMAP command procedures. During this step the default parameters to be used in subsequent steps are also defined.

2. Data Extraction.

All data for the maps are in an Ingres database. Special Ingres reports were designed and written for each map type. Various parameters such as coal zone and data source can be specified each time the report is run. The use of database reports makes it very easy, for those on the mapping team, to use the current data in the database each time a map is generated. Ease of access to the database is very important. Corrections to the data which are required to correct problems in one map must be reflected in the next version of associated maps which are based on the same data. The parameters defined in step 1 are used to build the report command which is then processed automatically by GENMAP.

3. Data Preprocessing

The cartographic location of all data in the database is defined by latitude and longitude. It is necessary to transform the data to an engineering coordinate system before gridding, contouring and plotting. This is done by using a cartographic software package developed in-house called AGSSYS. This package uses standard cartographic transformations obtained from the U.S. Geological Survey. The commands need to transform the data are generated and processed automatically by GENMAP.

4. Gridding and Contouring

Gridding ad contouring was performed using Surface II, a contouring package developed by the Kansas State Geological Survey. Most of the parameters for gridding and contouring were predefined at the beginning of the project and were used for most of the maps produced. The mapping team, using GENMAP, can modify the base level contour, the contour increment, the grid spacing, and the search radius to be used at various stages of gridding. After all of the parameters required by Surface II are defined, GENMAP will automatically generate the grid and contour map.

5. Map Generation.

Maps are generated by using AGSSYS to combine the various components which make up a map. These include contours, symbols for the data posting, grids, subcrop edges, cities, labels and a legend. GENMAP enables the user to specify which components will be included in a given map and then automatically generates the map.

6. Map Display

Maps can be previewed on several different graphics terminals, printed on a laser printer (8.5” x 11” or 8.5” x 14” pages), or plotted using 36” wide Calcomp pen plotters. Maps can also be saved as a computer graphics metafile in a standard VMS file. GENMAP is used to select any combination of output formats and to automatically process the required commands. File preview, printing and plotting is performed by graphics support and utility programs developed in-house.

7. Final Master Map Production

The master copy of each map is obtained by converting a computer graphics metafile to DXF format using software developed in-house. This file can be processed by the Series 5000 software package, the CAD component of Geostation, a cartographic system marketed by Auto-troll Technology. The master copies of the maps are plotted on a 44” wide electrostatic printer/plotter at a scale of 1:750 000.