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.

Executive Summary

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EXECUTIVE SUMMARY

A coal evaluation program has been jointly funded by Alberta Energy and Natural Resources and the Alberta Research Council since 1979. The major objectives of the program have been to: (a) evaluate the coal resources of the plains region of Alberta south of Township 64, from near surface to depths of about 400 m; and (b) develop an understanding of the sedimentologic and stratigraphic controls on the distribution and geometry of coal seams. This report describes the geological character of coals in one of the major coal-bearing units in the plains region; the lower Horseshoe Canyon Formation and its lateral equivalents. Separate reports describe the geology of other coal-bearing units and present the calculated inferred resources for the entire study area.

Results of this study delineate huge coal resources in the lower Horseshoe Canyon Formation. Most previous assessments were based on data from presently designated coalfields. These are areas close to the outcrop edge where the coals are relatively shallow. In contrast, this study is an assessment of coal resources over a much larger area. Boundaries of the study area are from the outcrop to between 100 km and 150 km west (downdip) of the outcrop. The present study identifies deposits of coal that could be early targets for underground mining in the province and points out favourable areas for future exploration. The coal resource maps, representative cross sections, and the exploration and depositional models presented should prove useful in the management of the coal resources of the province and in evaluating areas for future coal exploration.

A computer database was generated with information from 812 oil and gas wells and 108 coal exploration wells. The latter were drilled by the Alberta Research Council to identify coal resources at relatively shallow depths. Over the past 9 years, these wells were drilled on a one hole per township basis parallel to the outcrop edge. Depending upon the location drilled, maximum depths range from 150 m to 300 m. Oil and gas well data are used where the coals are deeper

within the basin, generally at depths greater than 200 m. Incorporating information from oil and gas wells enables the delineation of coal resources beyond the depths of conventional coal exploration drilling. Every attempt was made to establish a regular and random distribution of data points. Generally, one to three wells per township (100 km^2) were used. The total study area was 490 townships in size.

In addition to using well logs, a large amount of outcrop and core examination was done, especially in the Drumheller area. These outcrop and core studies proved to be valuable in developing an understanding of the depositional environments during the time of coal development. This resulted in the formation of a depositional model for the lower Horseshoe Canyon Formation coals. Interpretation of the various resource maps and cross sections is largely dependent on the application of this model.

The most economically attractive resources of the lower Horseshoe Canyon Formation are present in the Drumheller/Clover Bar coal zone. Coals present above this zone are considered part of the Weaver coal zone. The lowermost coals, located near the base of the Horseshoe Canyon Formation are part of the Basal coal zone.

Maps produced of the coal resources of the lower Horseshoe Canyon sequence indicate that the best coal developments are present in north-south oriented, elongate pods. Although coal seams 3 m or more thick have been identified in these areas, most seams are between 0.5 and 1.0 m thick. Individual coal seams also exhibit an elongate geometry. Several seams that were studied in detail appear to split and thin over short distances to the east or west but are more laterally continuous in a north/south orientation.

Areas with particularly thick coal seams have been identified close to Wetaskiwin, Alix, Delburne, Bashaw, Strathmore, and Milo. Maximum seam thickness in these areas is commonly between 2 and 4 m, however, in a few wells, seams between 6 and 10 m thick were identified. This evidence suggests that large areas have excellent potential for underground mining.

A geologic model developed for the lower Horseshoe Canyon Formation coals helps to explain many of the depositional trends observed. The model involves a coastal plain setting characterized by shore-parallel peat swamps, 30 to 50 km inland from actual shorelines. Frequent transgressions and regressions of the ancient seas resulted in deposition of many thin peat beds. The peats could only accumulate for a relatively short time because of frequent periods of marine transgression. Repeated transgressive-regressive cycles resulted in an interfingering of the coal-bearing sequences of the lower Horseshoe Canyon Formation with thick marine sequences of the contiguous Bearpaw Formation. The best coal deposits are located in this zone of interfingering. The north-south orientation of the ancient peat swamps, parallel to the shorelines, explains the elongate geometry of coal trends.

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 zones are not parallel to major marker horizons. The general area of coal development progressively migrated to the east and southeast through time. Correlation of coarsening upward sequences within the Bearpaw Formation was found to be essential for proper correlation of coals in the Horseshoe Canyon Formation. Coarsening upward sequences are produced by progradation of a shoreline. They have a distinctive signature on the gamma logs, with decreasing shaliness upwards.

Several sets of maps are based on a "window" concept. The term window is used here for that zone within a stratigraphic sequence which contains the most coal. The computer was programed to search out windows of varying thicknesses for each of the wells in the database. Two thicknesses were found to be useful in the study: 150 m and 25 m. Some of the difficulties encountered in assessing the coal resources in the study include the variable concentration of coal seams, relatively rapid thickening and thinning of coal zones over short distances, and the diachronous nature of coal development. Maps based on the 150 m and 25 m windows are more meaningful than simple cumulative maps. The 150 m window will usually capture most of the coal seams which are associated with the zone of interfingering between the lower Horseshoe Canyon and Bearpaw Formations. The 25 m window has a more variable stratigraphic position than the 150 m window because it is more sensitive to small changes in sequences. It generally captures important clusters of coal seams and usually includes the major economic seams. A set of maps shows the geographic variation in several aspects of the coal resources of each window. It is important to use the full suite of maps in combination with geological cross sections, when assessing the potential of coal resources in any area.

This study has delineated the major coal resources of the lower Horseshoe Canyon Formation to depths of at least 400 m. Much more detailed work will, however, be required before the real potential of any area can be evaluated. The new understanding of the geological controls on coal distribution allows more precise correlation of coal seams. This will be important in future coal exploration and may well prove significant in leasing coal zones for underground mining.

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EXECUTIVE SUMMARY

This study is the result of a coal evaluation program jointly funded by Alberta Energy and Natural Resources and the Alberta Research Council between 1979 and 1986. The major objectives of the program were to: (1) evaluate the coal resources of the plains region of Alberta south of Township 64, from the near surface to depths of about 400 m; and (2) develop an understanding of the sedimentologic and stratigraphic controls on the distribution and geometry of the coal seams. This report describes the coal resources in the lower Horseshoe Canyon Formation and its lateral equivalents, from the outcrop areas to between 100 km and 150 km west (downdip) of the outcrop.

A computer data set containing information from 812 petroleum wells and 108 coal exploration holes is used to generate a series of coal resource maps included in this study. Most of the coal exploration holes were drilled by the Alberta Research Council in previous programs. The Alberta Research Council drilled, on a one hole per township basis, parallel to the outcrop edge in central and southern Alberta. Depending on the location drilled, maximum depths range from 150 m to 300 m. Petroleum well data are used where the coals are deeper within the basin, generally at depths greater than 200 m. Emphasis during the study was to establish a regular and random distribution of data points. Generally, one to three wells per township (100 km^2) are used. The total study is 490 townships in size.

In addition to using well logs, outcrop and core evaluations are incorporated into the study to develop an understanding of the depositional environments during the time of coal accumulation and to produce depositional models. Interpretation of the various resource maps and cross sections is largely dependent on the application of these models. Understanding the regional geologic controls on coal distribution gives the explorationist a tool assessing these coal resources on a deposit scale.

The most economically attractive resources of the lower Horseshoe Canyon Formation are found in the Drumheller coal zone. Coals present above this zone, are commonly considered part of the Weaver coal zone. The lowermost coals, located near the base of the Horseshoe Canyon Formation, make up the Basal coal zone. This study assigns these names informally, and assesses the resource potential of each coal zone separately.

Maps produced for the coal resources of the lower Horseshoe Canyon Formation, 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).

Most coal seams in the Horseshoe Canyon Formation have thicknesses

between 0.5 m and 1.0 m, with notable exceptions in anomalous wells and specific deposits. Areas with particularly thick coal seams have been identified close to Wetaskiwin, Alix, Delburne, Bashaw, Strathmore and Milo. Maximum seam thickness in these areas is commonly between 2 and 4 m, and in some wells, seams between 6 and 10 m thick were identified. This evidence suggests that many areas in Alberta have excellent potential for surface and underground mining of Horseshoe Canyon coal seams.

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. This relationship is observed in the representative cross sections and the resource maps produced in this study.

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 were found to be useful tools 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.

Some of the difficulties encountered in assessing the coal resources in the study include the variable concentration of coal seams within the succession, thickening and thinning of coal seams over short distances, and the diachronous nature of coal development. For these reasons, several sets of maps are based on a "window" concept. The term "window" is used here to represent a specified interval, calculated at each drill hole location, which contains the most coal. Computer programs were created to search out windows of varying widths for each of the drill holes in the data set. Two windows were found to be useful in the study: 150 m and 25 m.

The 150 m window will usually captures most of the coal seams which are associated with the zone of interfingering between the lower Horseshoe Canyon and Bearpaw Formations. The 25 m window has a more variable stratigraphic position than the 150 m window, but has the advantage of capturing clusters of coal seams and usually includes major economic seams. It is essential to use the full suite of maps in combination with geological cross sections, when assessing the coal resource potential in any area.

This study has delineated attractive coal deposits in the lower Horseshoe Canyon Formation to depths of 400 m on a regional scale. Regional scale investigations serve as a guide for the more detailed work required for an economic assessment or minability study of a particular area.

1. INTRODUCTION

1.1 BACKGROUND

From 1979 to 1986 a coal resource evaluation program was conducted for the Upper Cretaceous and Tertiary strata of the Alberta plains. The program was jointly funded by Alberta Energy and Natural Resources and the Alberta Research Council. The major objectives were to: (a) evaluate the coal resources of the plains region south of Township 64, from near surface to depths of about 400m; and (b) develop an understanding of the sedimentologic and stratigraphic controls on the distribution and geometry of the coal seams. This report, which describes the major coal zones of the lower Horseshoe Canyon Formation, is one of four reports resulting from the program. Two similarly styled reports (Macdonald et al., 1987 and Richardson et al., 1988) were prepared for the Belly River Group and the Ardley coal zone of the Paskapoo Formation, respectively. A fourth report (Strobl et al., 1987) describes the size of the calculated inferred resources for each of these major coal-bearing units.

The Horseshoe Canyon Formation and the coal contained within has been of great interest both economically and scientifically since the early part of this century. During the early years, coal mining in the Horseshoe Canyon Formation was used to fuel steam locomotives and to heat homes. Now these coals provide much of Alberta's electrical needs.

Scientifically, the zone of interfingering between the Horseshoe Canyon and Bearpaw Formations has attracted sedimentologists, stratigraphers, paleontologists, and ichnologists alike. Outcrop exposures in the badlands of the Drumheller area are particularly well preserved and have been extensively studied.

1.2 ACKNOWLEDGMENTS

The writers would like to express their appreciation to R. Richardson and D. Nikols for critically reviewing this report. The Graphics Services Department of the Alberta Research Council produced the final maps and cross-sections. Maureen FitzGerald typed the manuscript.

1.3 PREVIOUS WORK

Research on the stratigraphy and coal resources of the lower 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.

Studies done on the sedimentology and stratigraphy of the basal St. Mary River Formation coals (lower Horseshoe Canyon Formation equivalent in southern Alberta) and the underlying Blood Reserve Sandstone include those by Latour (1961), Young and Reinson (1975) and Lerand (1983).

Papers addressing regional paleogeography and paleoenvironmental aspects during the time of deposition of the Horseshoe Canyon Formation and its equivalents include works by Williams and Burk (1964), Wall, et al., (1971), Williams and Stelck (1975), Rahmani and Lerbekmo (1975), Irving (1975) and Stott (1984).

Comprehensive basin-wide stratigraphy of the Upper Cretaceous and Tertiary strata has been completed by Ower (1960), Elliott (1960), and Irish (1970). A regional study describing the stratigraphy of the lower Horseshoe Canyon Formation and the contiguous Bearpaw Formation throughout southern Alberta is given by Lines (1963).

Local studies describing the stratigraphy and sedimentology of the transition zone between these two formations include works by Shepheard and Hills (1970), Gibson (1976), Rahmani (1982, 1983, 1988) and Hughes (1984). Studies based primarily on paleontology include those by Srivastava (1967), Caldwell (1968), Given and Wall (1971), Hills and Levinson (1975) and Wall (1976).

1.4 SCOPE OF PRESENT STUDY

A computer database was generated with information from 812 oil and gas wells and 108 coal exploration holes. The latter were drilled by the Alberta Research Council on a one hole per township basis to identify the coal resources at relatively shallow depths in the intervening areas between identified deposits. Coal exploration holes generally have a maximum depth of 150 m but some were drilled to 300 m. Oil and gas well data are generally used at depths exceeding 200 m. This source of data was very useful to evaluate the coal resources throughout the deeper portions of the study area but could not used at shallower depths because of the interference of casing. Merging the two types of data allowed the delineation of coal resources on a basin-wide scale, well beyond the limits of most previous studies.

The size of the study area is 490 townships and incorporates one to three data locations per township. Limits of the study area extend from the erosional edge to between 100 km and 150 km west (downdip) of the erosional edge. All coal picks were generated by the Alberta Geological Survey staff, from publicly available geophysical logs and were subsequently entered into a computer data set to produce the resource maps. Twenty-eight preliminary cross sections were made to provide a framework for the geologic picks used to create this data set. These data are available on computer diskette in Mandryk and Richardson (1988).

In addition to using geophysical data, outcrop and core evaluations from the Drumheller area were incorporated into a sedimentology study. Results of these evaluations proved to be valuable in developing an understanding of the depositional controls that operated during the time of peat development. The depositional model proposed for lower Horseshoe Canyon coals is one product of this work. In addition, interpretations made for various maps produced and the correlations shown in the cross-sections are largely derived from these studies.

2. GEOLOGICAL FRAMEWORK

2.1 CORRELATION OF THE HORSESHOE CANYON FORMATION AND ITS EQUIVALENTS

This study covers a large geographic area in which several stratigraphically equivalent formations are represented. Emphasis is placed on the lower Horseshoe Canyon Formation of the central plains area and its equivalent, the St. Mary River Formation of the southern plains. The Horseshoe Canyon equivalent in the foothills and more western areas is the Brazeau Formation. In the northwest and north-central plains area, the equivalent is the Wapiti Formation (See Figure 1). The approximate stratigraphic position of the major coal zones investigated in this report are shown in Figure 2. This investigation is subdivided into four main study areas. Study area boundaries and the locations of the eight representative cross-sections are shown in Figure 3.

2.2 GEOLOGICAL SETTING

Deposition of Late Cretaceous sediments over the interior plains of North America was characterized by widespread transgressions and regressions of a broad epeiric seaway (Figure 4). 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 (Figure 5). 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. The maximum transgression limits estimated by Williams and Burk (1964) and Stott (1984) agree with the findings of this study.

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. The diachronous contact between the Bearpaw Formation and the underlying Belly River Group is identified as "A-top" in this study.

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, described in

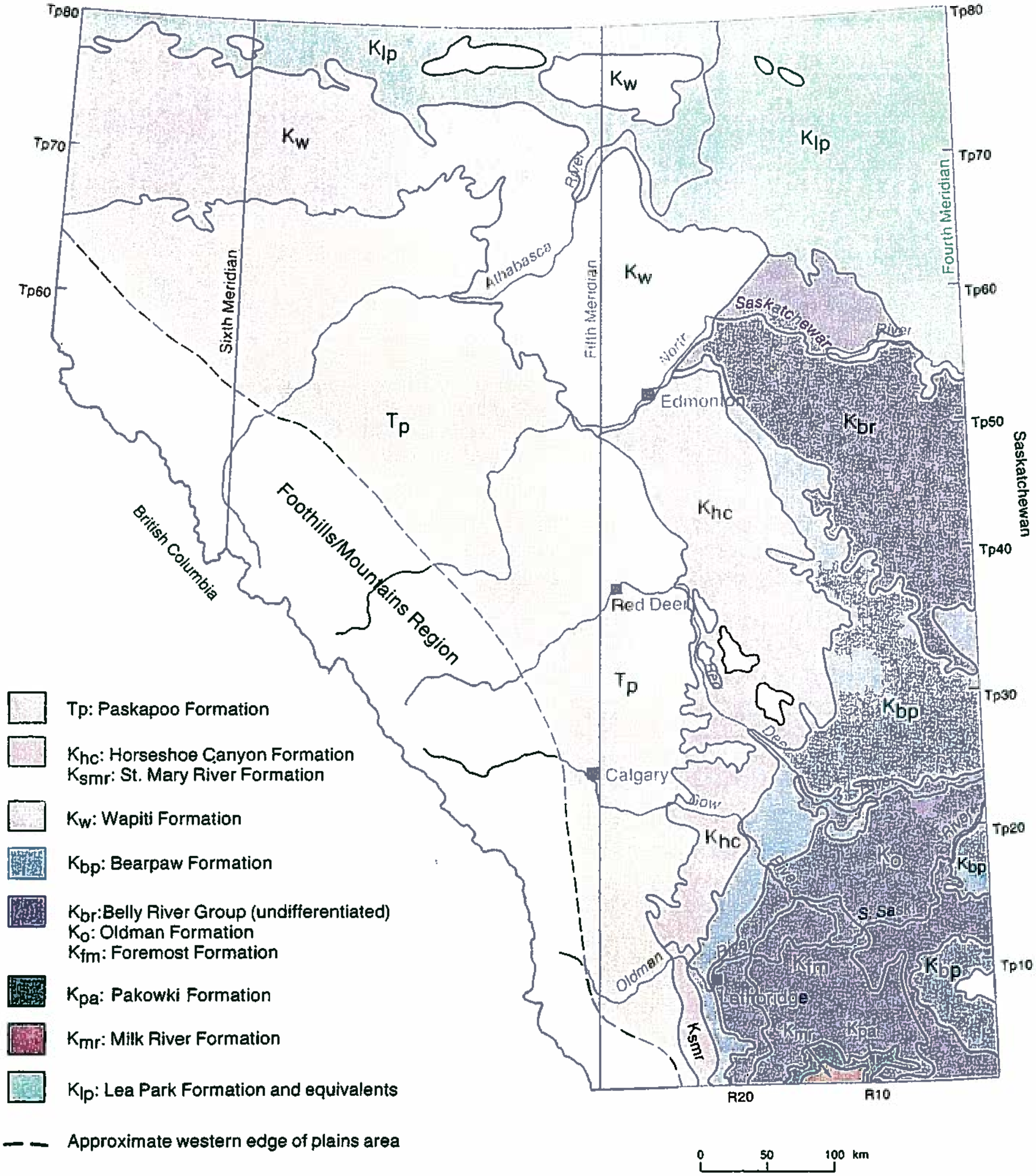


Figure 1. Geologic map of the plains area of southern Alberta. The coal resources of the Horseshoe Canyon Formation (K_{hc}) and St. Mary River Formation (K_{smr}) are investigated in this study.

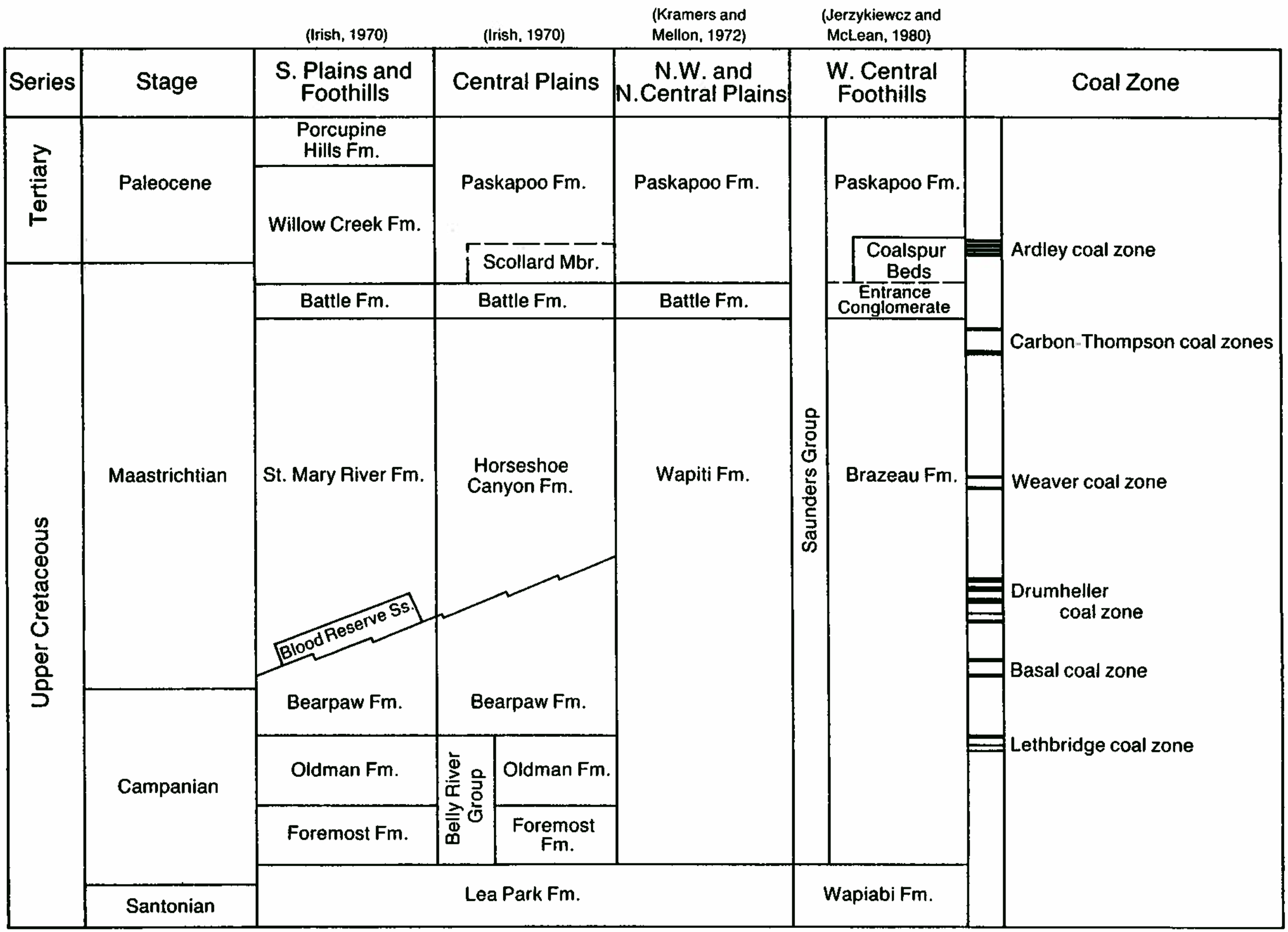


Figure 2. Correlation chart of the Upper Cretaceous and lowermost Tertiary strata in Alberta, showing relative positions of the major coal zones addressed in this study.

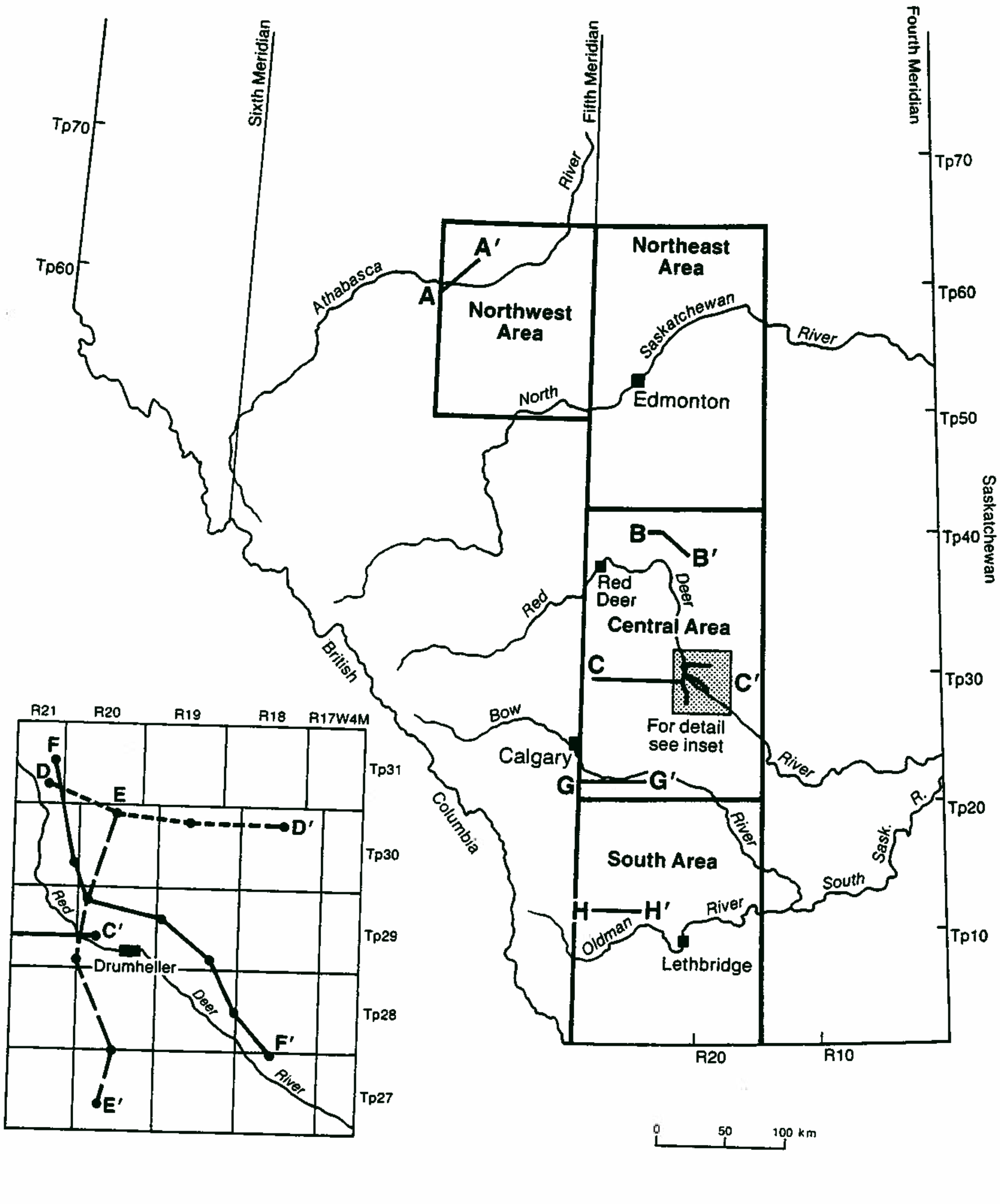


Figure 3. Location map showing the lower Horseshoe Canyon Formation study areas and representative cross sections.

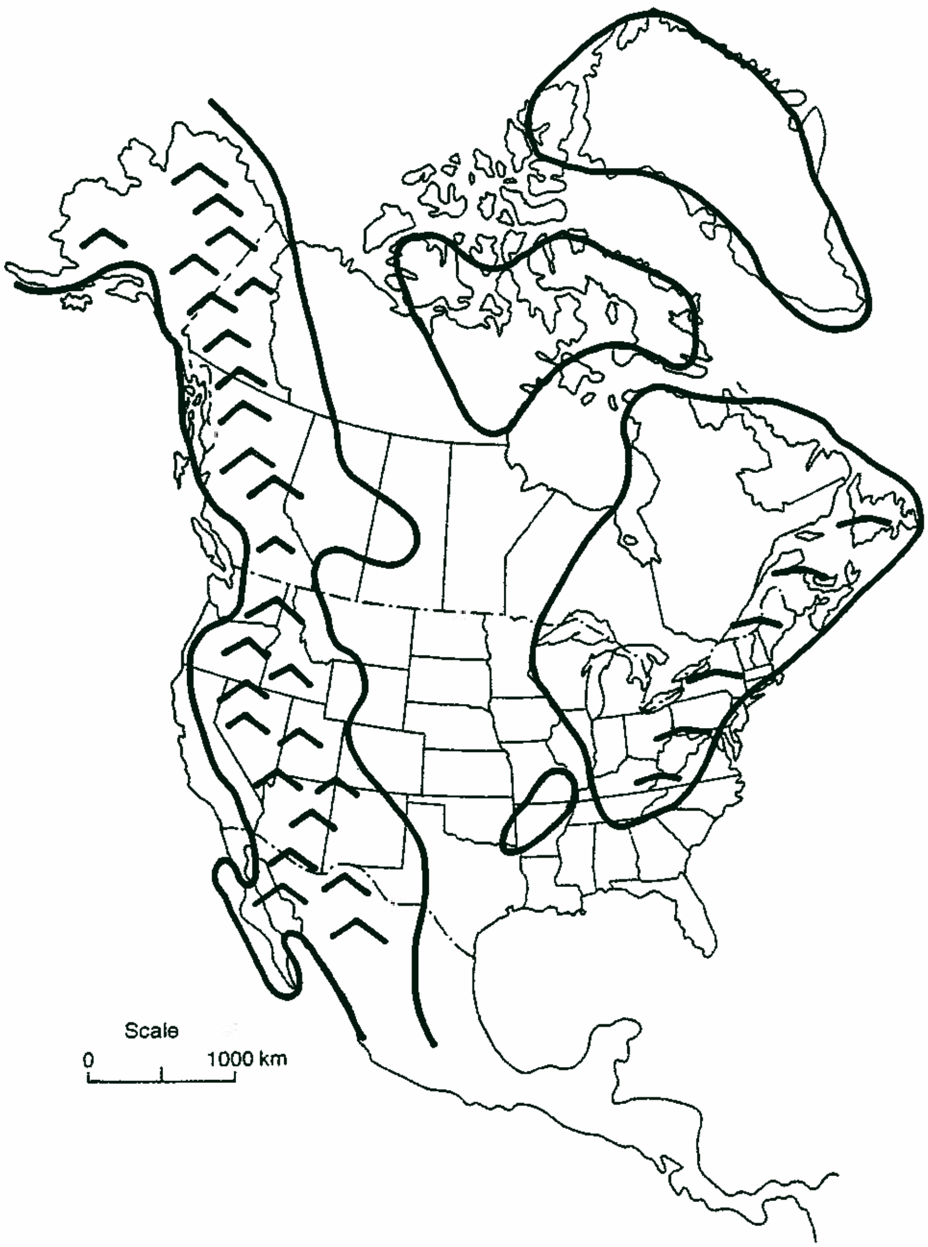


Figure 4. Map showing extent of early Maastrichtian seas at the time of *Baculites baculus* (Williams and Stelck, 1975).

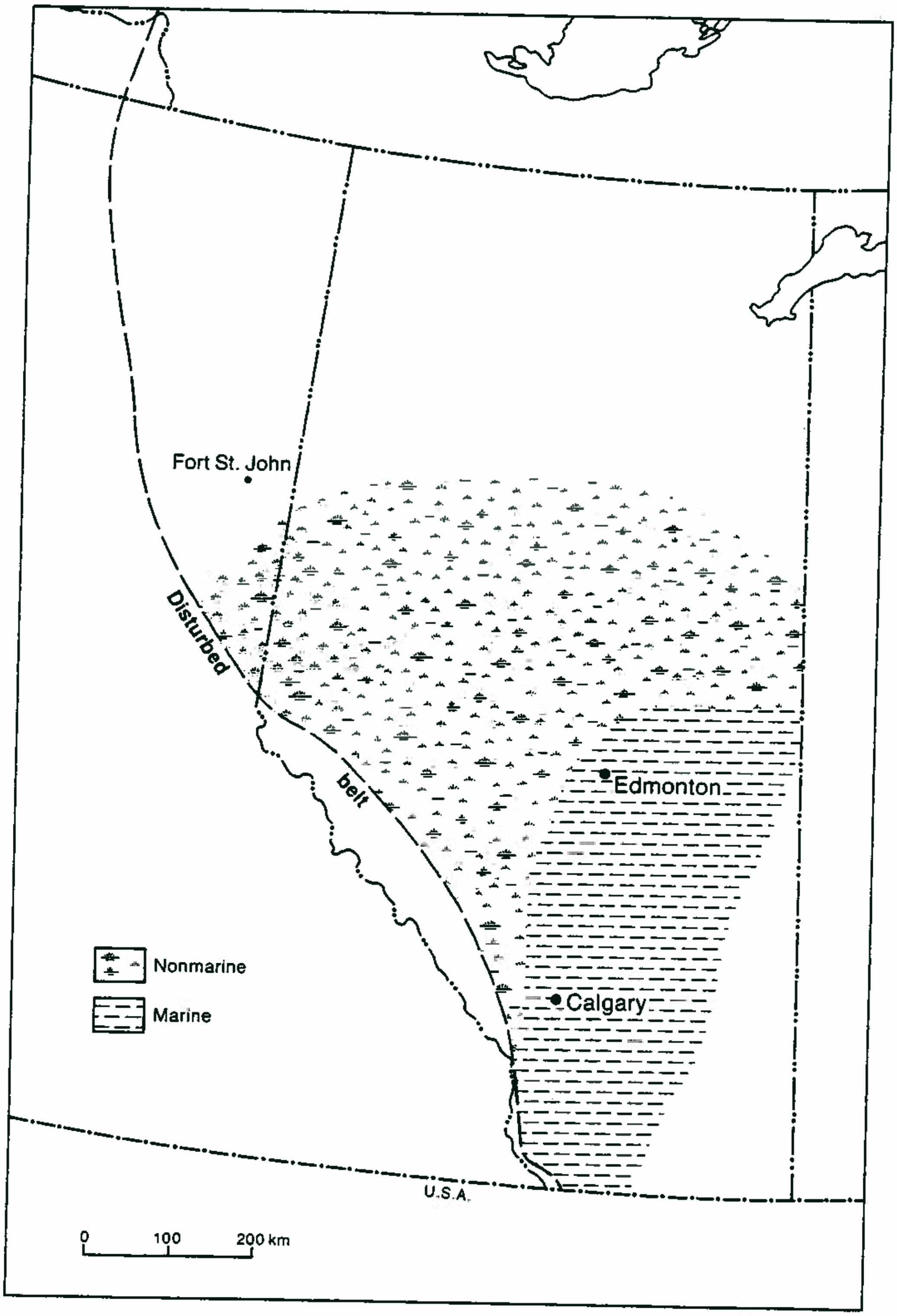


Figure 5. Paleogeography of the late Campanian-Early Maastrichtian transgression recorded in shales of the Bearpaw Formation of central and southern Alberta (Williams and Stelck, 1964 and Stott, 1984).

this report, 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.

2.3 REFERENCE SECTION, COAL ZONES AND MARKERS

Figures 6 and 7 show typical study intervals of the coal-bearing succession. Types of geophysical logs used, the relative positions of major coal zones and markers, and the formation/zone names used in this report are outlined in these figures. Boundaries between coal zones are the major markers used to correlate strata throughout much of the study area. A brief description of each zone and marker is given starting from the base of the study interval. The typical geophysical responses and the character of each marker are summarized in Table 1.

2.3.1 Upper Belly River Clastics

The term "Upper Belly River clastics" was used for the zone containing the uppermost sandstones of the Belly River Group. This zone is characterized by the high resistivity and relatively low natural gamma ray responses on geophysical logs (See Figure 7).

Descriptions from core samples taken from the Brooks area (CH 83-3, 83-4 and 83-5) suggest that the Upper Belly River clastics zone consists mainly of fine to medium grained sandstones, making up a series of stacked channel successions. Each channel succession is 2 to 8 m thick, fines upward in grain size and commonly has a sharp erosional base. Palynological findings indicate a continental environment of deposition.

2.3.2 Bentonitic Zone

The "Bentonitic zone" is 30 to 60 m thick, containing numerous bentonitic beds. It is recognized as a zone of low resistivity and relatively high natural gamma ray responses on geophysical logs (Figure 7). Descriptions from Alberta Research Council core holes 83-2, 83-3 and 83-4 indicate that the Bentonitic zone consists largely of fine grained sandstones and mudstones. Commonly the Bentonitic zone contains small scale (<2m thick) channel successions

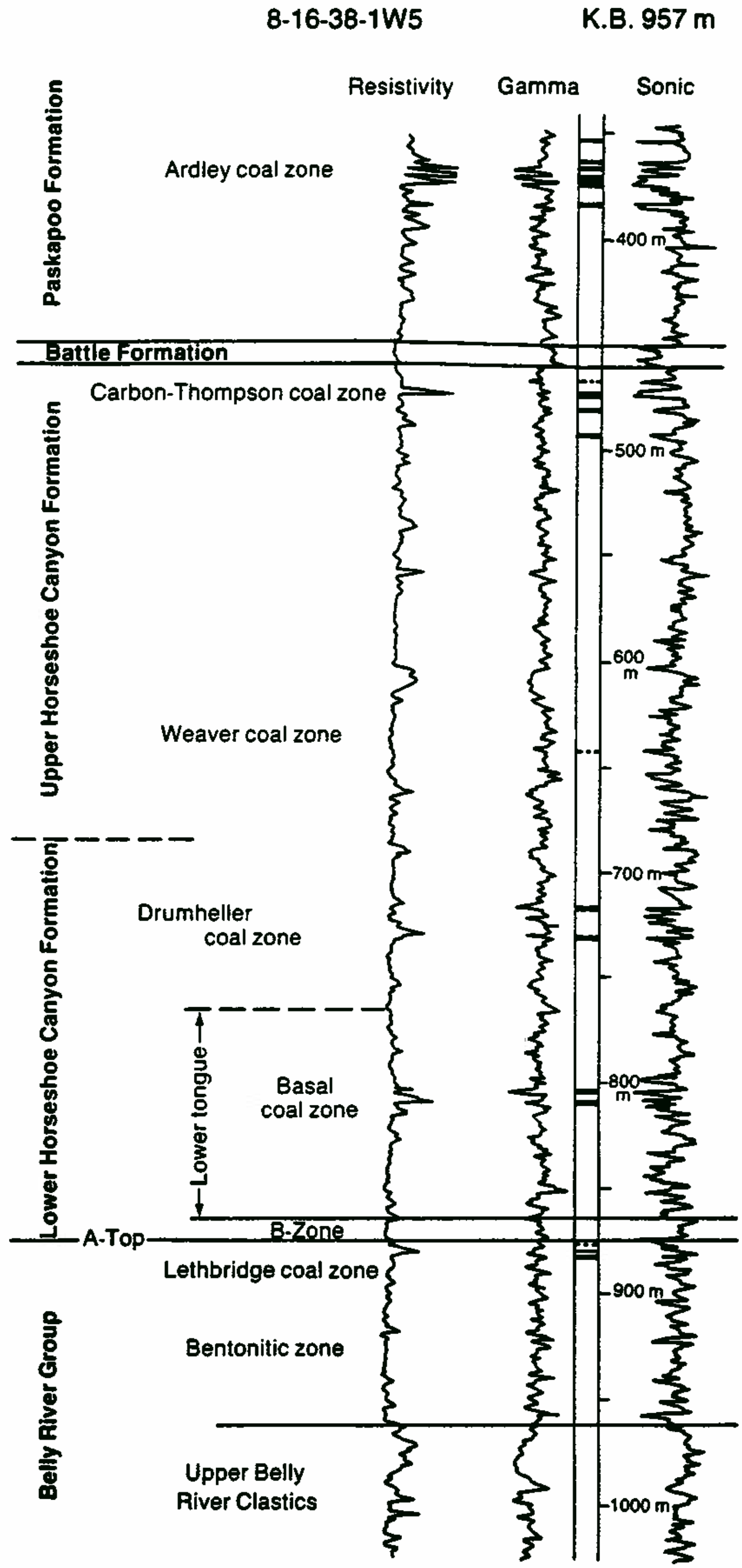


Figure 6. Stratigraphic section of the study interval showing the major zones and marker horizons. The Paskapoo Formation, Battle Formation and Belly River Group are included for correlation purposes.

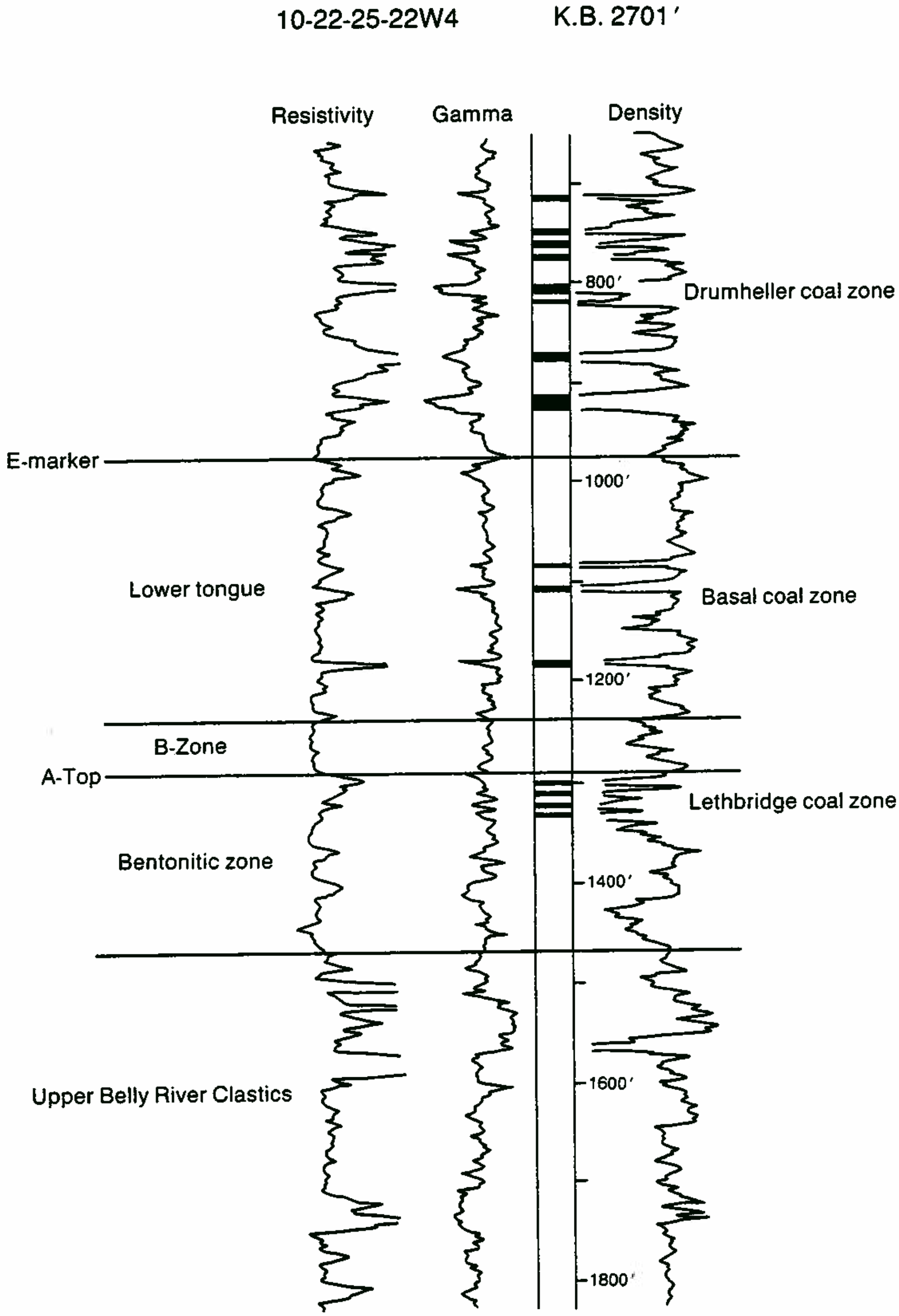


Figure 7. Stratigraphic section of the study interval. An expanded view showing the major zones and marker horizons of the lower Horseshoe Canyon Formation and the upper portion of the Belly River Group.

capped by coals and rooted zones. Palynological results for samples taken from the core indicate a continental depositional setting.

2.3.3 Lethbridge Coal Zone and A-top

The "Lethbridge coal zone" is recognized as a high resistivity zone (10 to 15 m thick) containing 4 or more thin coals (Figure 7). In Alberta Research Councils's coreholes 83-3 and 83-4, the Lethbridge coal zone consists of thin coals (with a maximum thickness of 1 m) interbedded with mudstones and sandstones. Palynology results from samples taken from these cores at the upper contact, indicate that the zone represents a transition between the continental depositional environment of the Belly River Group below to a marine depositional environment of the Bearpaw Formation above.

The top of the Lethbridge coal zone (A-top) defines the base of the lower Horseshoe Canyon Formation. A-top is important in this study because it is one of the most continuous and reliable datums. For this reason A-top is used as a basal datum on many of the cross sections included in this report.

2.3.4 B-Zone (Lower Bearpaw Formation)

B-zone directly overlies the Lethbridge coal zone, consisting of a 5 to 15 m thick massive mudstone, sometimes grading to a sandy coarsening upward succession. B-zone is recognized by its low resistivity and high natural gamma ray responses on geophysical logs (Figure 7). The zone thins and becomes less recognizable towards the west where sandy coarsening upward successions predominate. Palynological findings from samples taken in coreholes 83-3 and 83-4, indicate a fully marine depositional environment. B-zone is considered to represent an early transgression of the Bearpaw Sea following deposition of the Lethbridge coals.

2.3.5 Lower Tongue and Basal Coal Zone

The Bearpaw Formation and the lower Horseshoe Canyon Formation have an interfingering relationship, with thick marine strata to the east laterally equivalent to terrestrial strata in the west. In the lower part of the study interval, an extensive tongue of terrestrial strata overlies the B-zone and/or Lethbridge coal zone. The lower tongue is present over much of the western parts of the study area but may be replaced by marine strata of the Bearpaw Formation to the east.

Where it is recognized, the lower tongue varies in thickness from 20 to 60 m. The lower tongue is believed to represent an early regressive episode following deposition of the B-zone and is recognized in most areas as a coal-bearing interval underlying a series of coarsening upward successions.

2.3.6 Upper Bearpaw and E-Marker

The upper Bearpaw zone consists of one to four coarsening upward successions. In cores from the Alberta Research Council coal exploration program in the Drumheller area, the sedimentary structures and assemblage of trace fossils indicate a marine environment. Strata of this zone are well exposed in the East Coulee area (southeast of Drumheller), showing marine trace fossils such as *Skolithos* sp., *Diplocraterion* sp., *Planolites* sp. and *Chondrites* sp. Palynological samples taken from both the outcrop exposures and core samples also indicate a marine depositional environment.

The upper Bearpaw is absent in the western and northern parts of the study area. It thickens towards the east with the addition of coarsening upward successions.

E-marker is present in the lower part of the basal coarsening upward succession. It is recognized by its low resistivity and high natural gamma ray response in geophysical logs (See Figure 7). In a westward direction, the marine strata die out and the E-marker is absent. In an eastward direction the basal coarsening upward succession of the upper Bearpaw zone grades into thick marine shales and becomes unrecognizable. In this study, the E-marker and the coarsening upward successions are used to help correlate individual coal seams within the Drumheller coal zone.

2.3.7 Drumheller Coal Zone

In the Drumheller area, all coals adjacent to and overlying major coarsening upward successions (upper Bearpaw zone) are considered part of the Drumheller coal zone. In the Edmonton area, stratigraphic equivalents were in the past called the Clover Bar coal zone. Much of the economically attractive coals of the Horseshoe Canyon Formation are in the Drumheller zone.

2.3.8 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 Drumheller area, a thin succession of marine strata, the Drumheller marine tongue, is present at a similar stratigraphic level as the Weaver zone.

2.3.9 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 (Figure 6). The coal resources of this zone are described in an Alberta Research Council report by Nurkowski (1980).

2.3.10 Battle Formation

The base of the Battle Formation defines the top of the Horseshoe Canyon Formation and is a reliable datum over a large portion of the Alberta plains. The Battle Formation is recognized on geophysical logs as a zone with a low resistivity, high natural gamma ray and high apparent porosity responses (See Figure 6).

Table 1. Summary of major markers and zones used in correlations

ZONE NAME	TYPICAL GEOPHYSICAL LOG RESPONSES	COMMENTS
Upper Belly River clastics	High resistivity with abrupt kicks. Relatively low natural gamma ray response.	Series of stacked sandy channel successions (terrestrial).
Bentonitic zone	Relatively low resistivity. Relatively low natural gamma ray response. Sharp resistivity, induction, gamma, porosity kicks at bentonitic shale horizons.	Fine grained throughout. Bentonitic throughout. May contain thin coals and rooted zones (terrestrial).
Lethbridge coal zone and A-top	High resistivity with abrupt kicks. Low natural gamma ray responses at coal zones. Identification based mainly on stratigraphic position.	Most continuous datum for the HSC mapping area. Top of the zone (A-top) defines the base of the study interval (transitional).
B-zone	Low and flat resistivity. Relatively high natural gamma ray response.	Massive mudstone. Only recognized in transitional areas (marine).
Lower tongue and Basal coal zone	Relatively high resistivity. Variable natural gamma ray response. Identification based mainly on strati-graphic position.	Major regressive succession above A-top. Coals in this zone considered part of the Basal coal zone. (terrestrial/transitional)
E-Marker	Flat, low resistivity response. High natural gamma ray response. Identification based on stratigraphic position.	Marine mudstone forming the base of a major coarsening upward succession. Datum for correlation of Drumheller zone coals. (marine/transitional)
Drumheller coal zone	High resistivity response. Variable natural gamma ray response. Identification based on stratigraphic position.	Economically attractive. Overlies or are adjacent to major coarsening upward successions (transitional)

Table 1. Continued ...

Weaver coal zone	Relatively low resistivity zone, with kicks for coals or carbonaceous shales. Natural gamma ray response is generally low.	Generally consists of discontinuous, thin and marginally economic coal seams (terrestrial).
K, L and M markers	Low resistivity responses. Sharp induction kicks. Relatively low natural gamma ray responses.	Bentonitic shales or bentonites. Time-stratigraphic markers for the Carbon-Thompson coal zone (terrestrial)
Carbon-Thompson coal zone	High resistivity response. Variable natural gamma ray response.	Uppermost coal zone of the HSC Formation. Coal seams are generally thin and uneconomic for mining (terrestrial).
Battle Formation	Low resistivity response. High natural gamma ray response. High apparent porosity response.	Base of the Battle Fm. defines the top of the Horseshoe Canyon Fm. (composite paleosol - terrestrial).

3.0 RESOURCE EVALUATION

3.1 INTRODUCTION

Three major coal zones within the lower Horseshoe Canyon Formation are addressed in detail in this paper. From oldest to youngest, these are the Basal, Drumheller and Weaver coal zones. The most economically attractive coal resources of the lower Horseshoe Canyon Formation are commonly located in the zone of interfingering between marine and nonmarine strata. The depositional model proposed for these coals (Drumheller coal zone) suggests that transitional conditions between marine and nonmarine depositional environments during the Early Maastrichtian led to the development of shore-parallel mires some distance landward (30 to 50 km) from actual shorelines. Peat development within these mires was frequently interrupted during periods of marine transgression. Repeated transgressive-regressive cycles resulted in a series of interfingering coal-bearing successions (coastal plain) and coarsening upward successions (marine shoreface).

Much of the upper Horseshoe Canyon coals and landward equivalents of the coastal plain coals (Weaver and Basal coal zones) are generally thinner and less continuous. For the most part, they are uneconomic in the areas covered in this study. An alluvial plain setting is proposed with active channel fill represented by the deposition of sandstones and the overbank and lateral accretion deposits represented by the finer-grained sediments.

3.2 BASAL COAL ZONE

The Basal coal zone represents a coal-bearing interval at the base of the lower Horseshoe Canyon Formation. Where it is present, the Basal coal zone is associated with a terrestrial tongue, approximately 20 to 60 m thick, between the top of the Belly River Group (A-top) and the coarsening upward successions associated with the Horseshoe Canyon/Bearpaw transition (Figure 8). The Basal coal zone is commonly present in the western parts of the study area but may be replaced by marine Bearpaw strata to the east.

The Basal coal zone typically consists of relatively thin and uneconomic coal seams. Thicknesses of the seams are commonly less than 1 m. Characterized by relatively continuous coal seams which run essentially parallel to the Lethbridge coal zone and A-top, the Basal coal zone can often be used as a datum. Along Township 20 and 21, for example, three coal seams of the Basal coal zone can be correlated over a distance of 35 km, providing a datum for correlation of the thicker, more economic coal seams of the Drumheller coal zone (Figure 9).

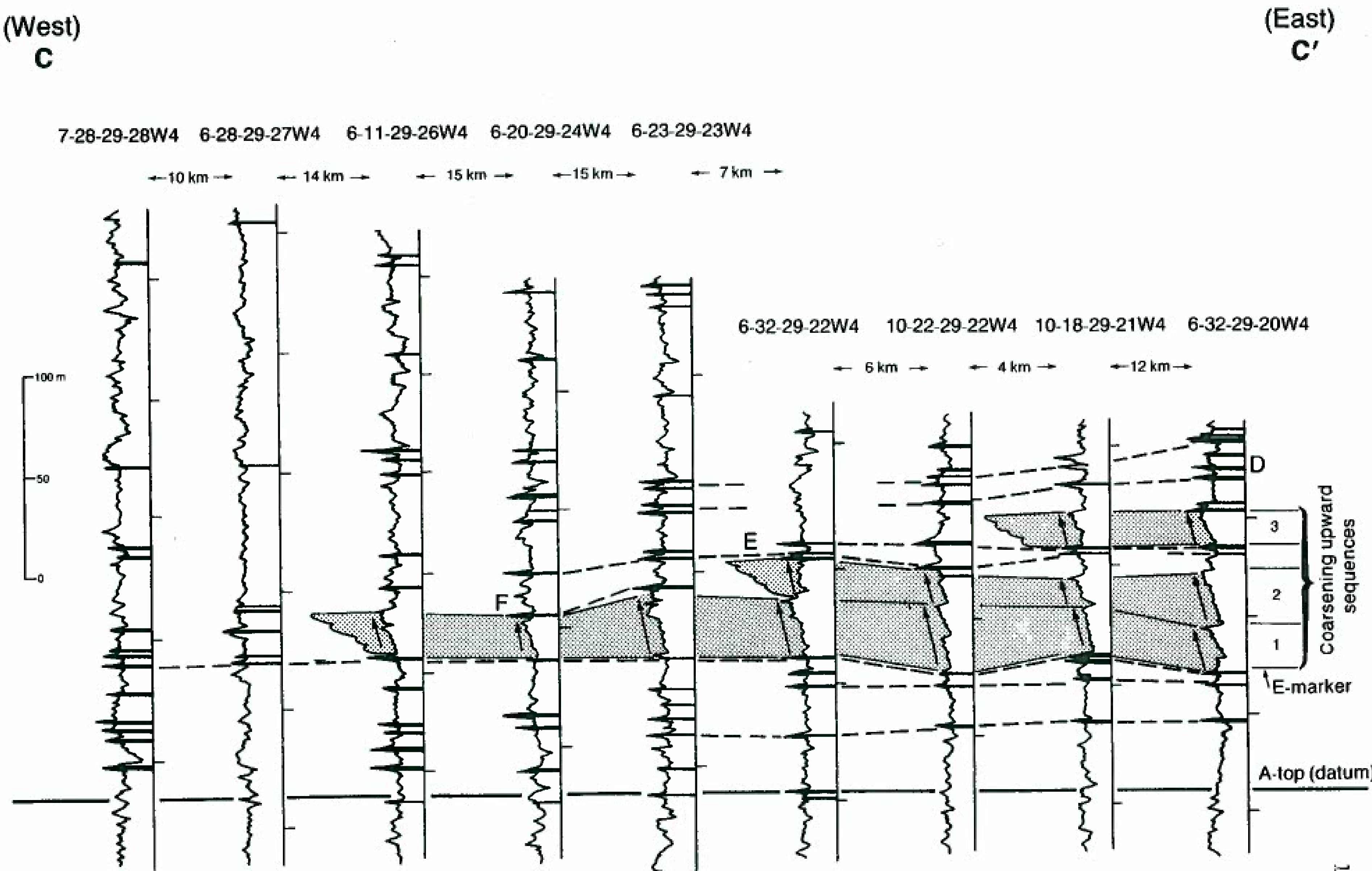


Figure 8. Cross-section C-C' oriented perpendicular to regional shoreline trends (near Drumheller). Coarsening upward successions, E-marker and A-top are used to correlate coal seams.

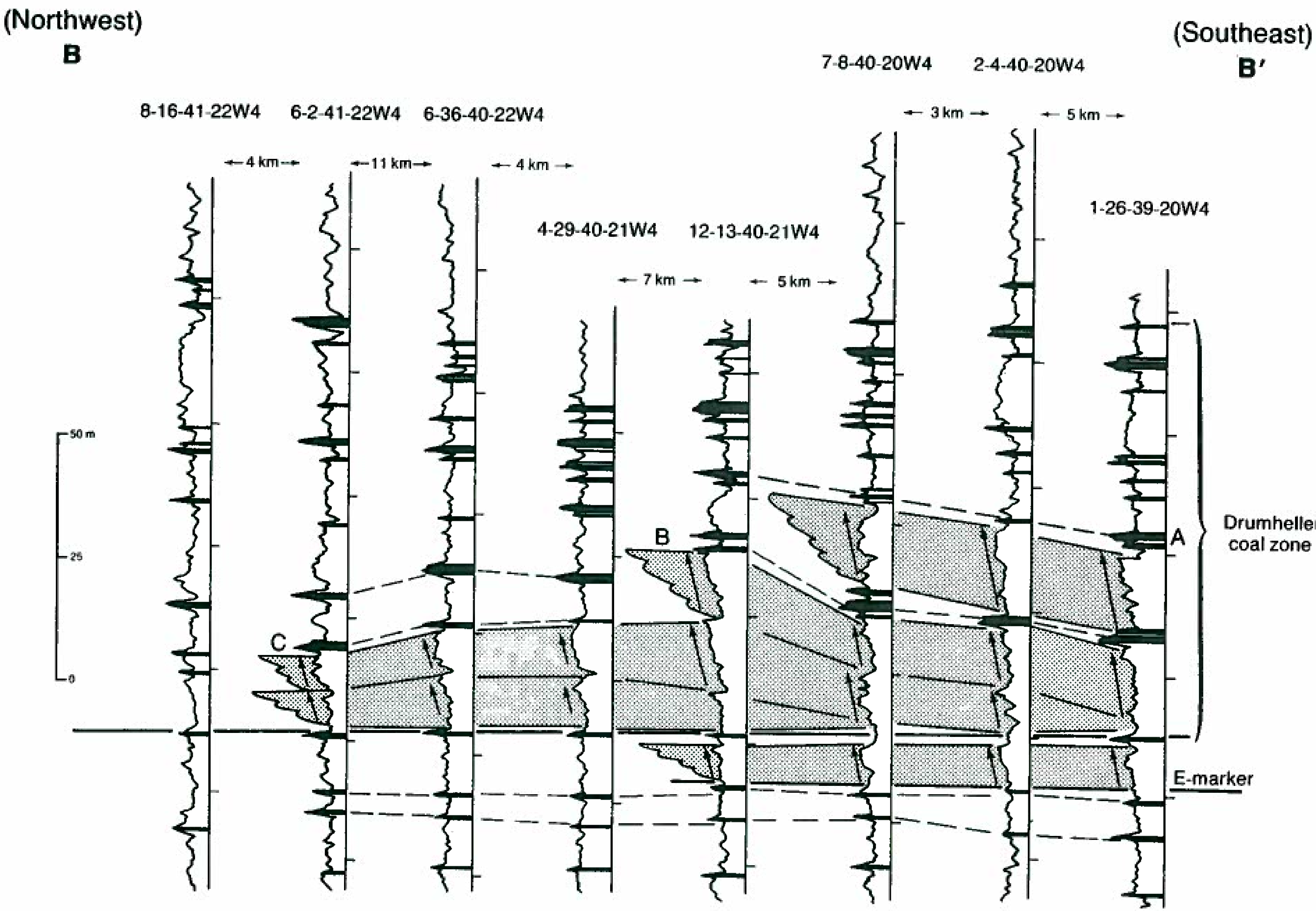


Figure 9. Cross-section B-B' oriented perpendicular to regional shoreline trends (near Red Deer). Coarsening upward successions and E-marker are used to correlate coal seams.

3.3 DRUMHELLER COAL ZONE

In this study, all coals adjacent to and directly overlying major coarsening upward successions (Horseshoe Canyon/Bearpaw transition) are considered part of the Drumheller coal zone. The best coal development in the lower Horseshoe Canyon Formation is in the Drumheller zone.

A detailed cross section in the Red Deer area indicates how coarsening upward successions can be used to correlate individual seams in the Drumheller coal zone. Coal A, for example, does not correlate to Coal B or Coal C (Figure 9). These seams overly thick sandy successions but are at different stratigraphic positions. Also note the degree of variability in thickness of seams over relatively short distances in the east-west direction.

Three major coarsening upward successions are used to correlate individual coal seams of the Drumheller zone in Figure 8. Perpendicular to paleoshorelines, the maximum lateral extent of seams in this example, is about 16 to 24 km, as indicated by Coal D, E and F (Figure 8). Coals D, E and F can be correlated with a reasonable degree of confidence because they directly overly coarsening upward successions. Seams which do not overly coarsening upward successions are usually more difficult to correlate. Accurate correlation of individual seams in the Drumheller coal zone, commonly requires close well spacings (3 km or less) because of limited lateral extent, development of multiple splits, variable thickness and variable stratigraphic position resulting from differential compaction.

In Figure 10, the Drumheller coal zone overlies the top of the uppermost coarsening upward succession. Major coal development in the south (Township 11, for example) appears to occur only for the Lethbridge coal zone (top of the Belly River Group) and for the Drumheller coal zone, after deposition of the interdigitating Horseshoe Canyon/Bearpaw successions.

3.4 WEAVER COAL ZONE

The Weaver coal zone consists of relatively thin, discontinuous and generally uneconomic seams. Coal seams of the Weaver zone in the upper half of the 7-28, 6-28, 6-11, 6-20 and 6-23 wells in Figure 8 are typical of what is found elsewhere in the study area. Coal seams of the Weaver zone contrast with the Drumheller coal seams associated with coarsening upward successions in the 6-32, 10-22, 10-18 and 6-32 wells. Coals of the Weaver zone likely formed in an alluvial plain setting considerably inland from shorelines.

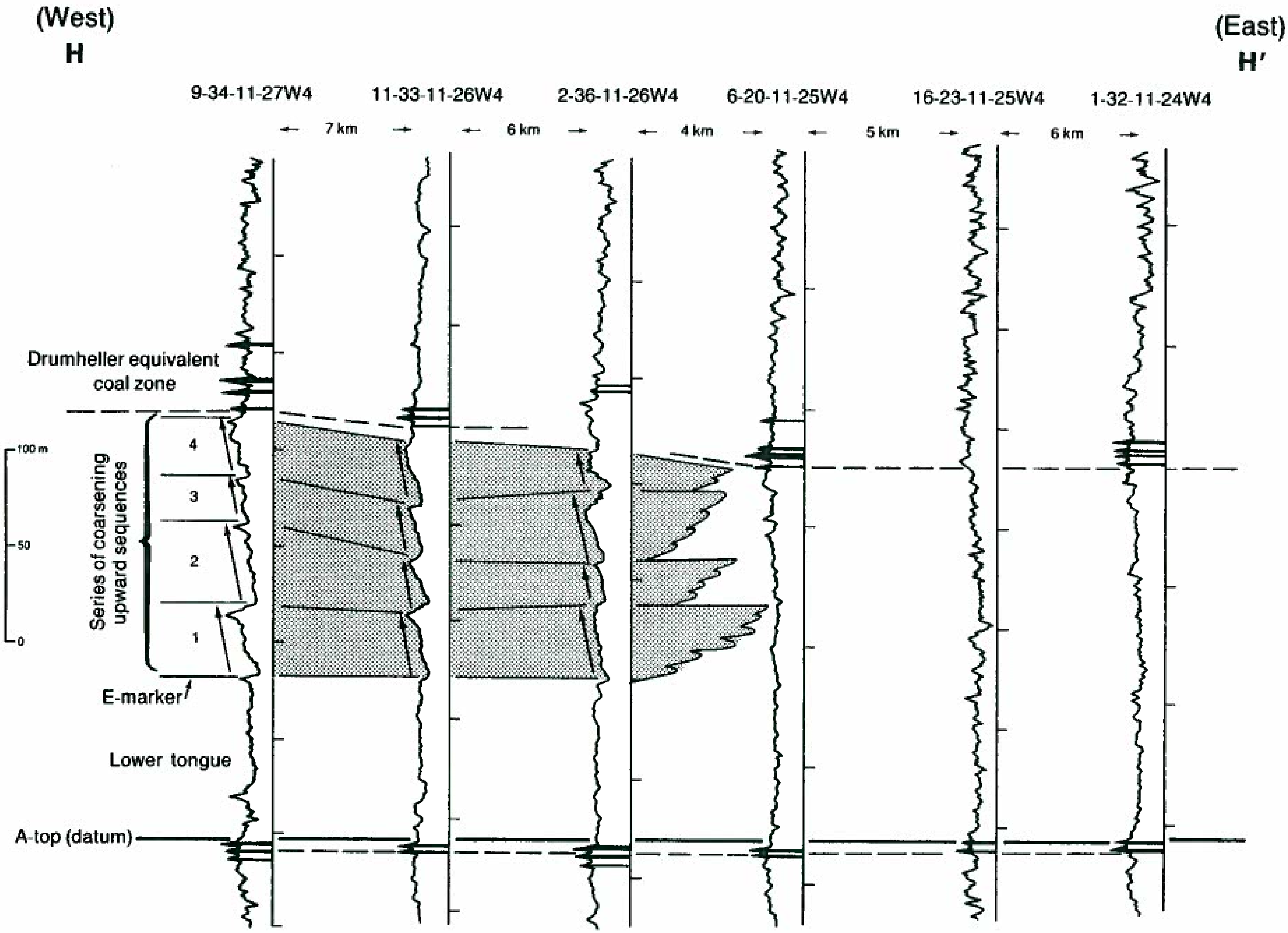


Figure 10. Cross-section H-H' oriented perpendicular to regional shoreline trends (near Lethbridge). Coarsening upward successions, E-marker and A-top are used to correlate coal seams.

4.0 MODELS FOR LOWER HORSESHOE CANYON COALS

4.1 LOWER HORSESHOE CANYON DEPOSITIONAL MODEL

The most economically attractive coals of the Horseshoe Canyon Formation are present in the Drumheller coal zone. The depositional model envisaged for these coals is presented in Figure 11. Transitional conditions between marine and nonmarine depositional environments during the Early Maastrichtian led to the development of shore-parallel, peat-forming mires 30 to 50 km inland from actual shorelines. Peat development was interrupted during marine transgressions. Repeated cycles of relative rise and fall of sea levels resulted in a series of interfingering coal-bearing successions (coastal plain) and coarsening upward successions (marine shoreface).

The thickest and most laterally continuous coals in the Drumheller zone likely originated in peat forming mires isolated from clastics deposited by active fluvial systems (Figure 11). Basin-wide controls on coal formation and relative sea levels include the effects of loading along the western basin margin, clastics derived from the rising mountain front and to some extent, eustatic sea level variations.

4.2 EXPLORATION MODEL

As mentioned for the depositional model, the most economically attractive coals are commonly within the lower part of the Horseshoe Canyon Formation. Trends with a large number of seams (15 or more) and with maximum seam thicknesses of 2.0 m or more (best developed in a north-south direction) commonly are within zones of interfingering between the Horseshoe Canyon and Bearpaw Formations. Representative cross sections in the central and southern study areas (Figures 8 and 9) illustrate relatively thick but laterally restricted coal seams in the zone of interfingering.

Regional cumulative coal trends of 6.0 m or more are commonly oriented in a north-south direction extending from Township 52 (Edmonton area) to Township 14 (Lethbridge area). These thicker cumulative measures are 3 to 6 townships wide and are generally located 60 km or more from the erosional edge where the designated coal fields are located (Figure 12). A large portion of the Horseshoe Canyon Formation's optimal coal resources are located too deep for surface mining. Optimal coal resources of the Horseshoe Canyon Formation appear to be between Township 10 to Township 55 and between Range 15 W4M and Range 25 W4M (Figure 12).

Comparison of cumulative coal to thickest coal seam trends (Figures 12 and 13) suggests that areas with thicker cumulative coal commonly have the thickest seams. Exceptions to this association, however, are noted. For example, a pod of cumulative coal 10 to 17 m thick in Township 48 Range 23 W4M contains coals that have a maximum

Upper Cretaceous

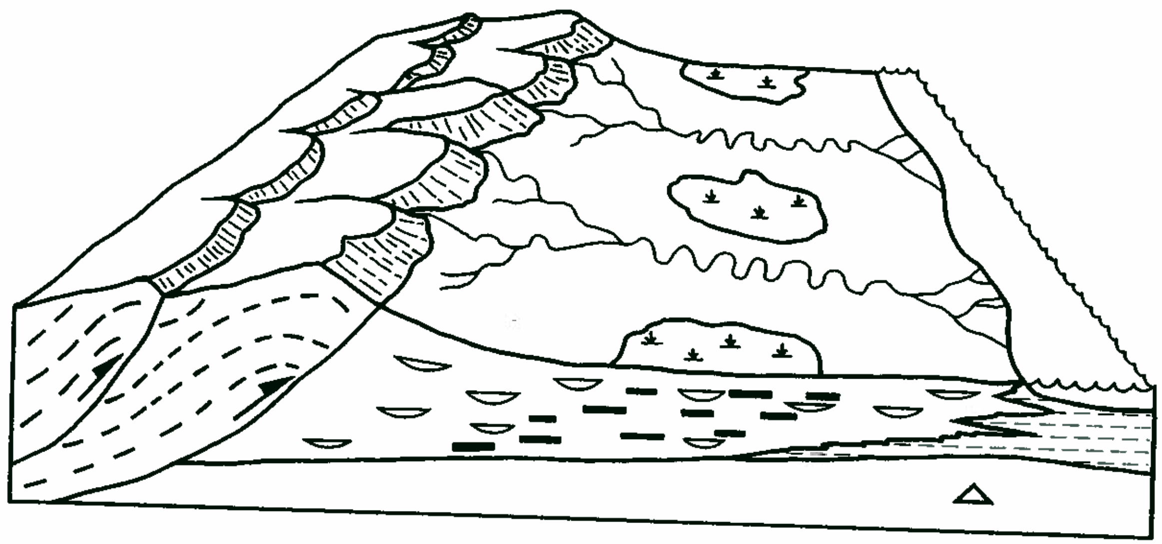
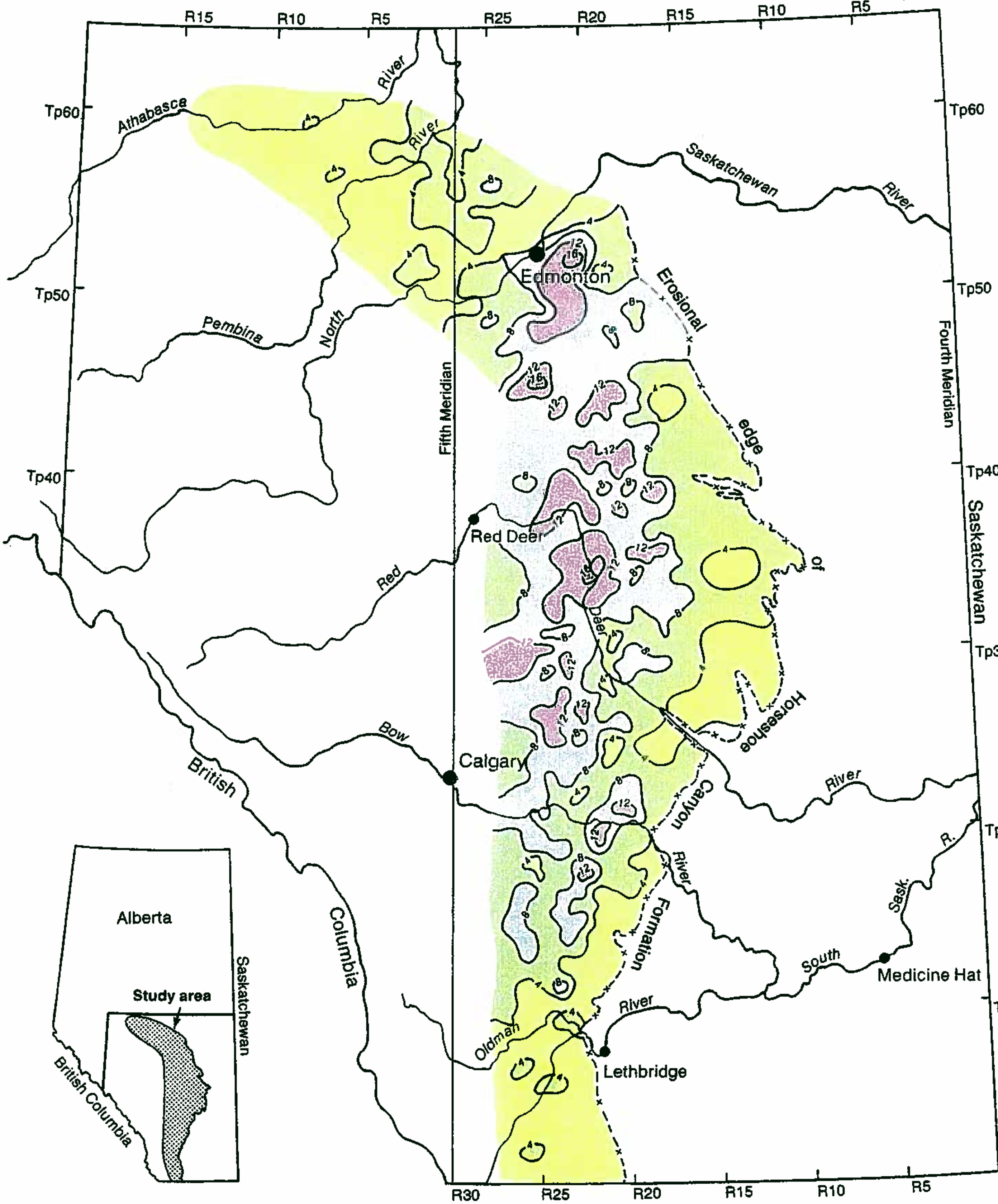


Figure 11. Generalized depositional setting for the lower Horseshoe Canyon Formation coals. See text for details.



Cumulative coal within the 150 m window

- <4 m
- 4-8 m
- 8-12 m
- >12 m

Contour interval = 4 m

0 — 60 km

Figure 12. Isopach map of the cumulative coal within the best 150 m window.

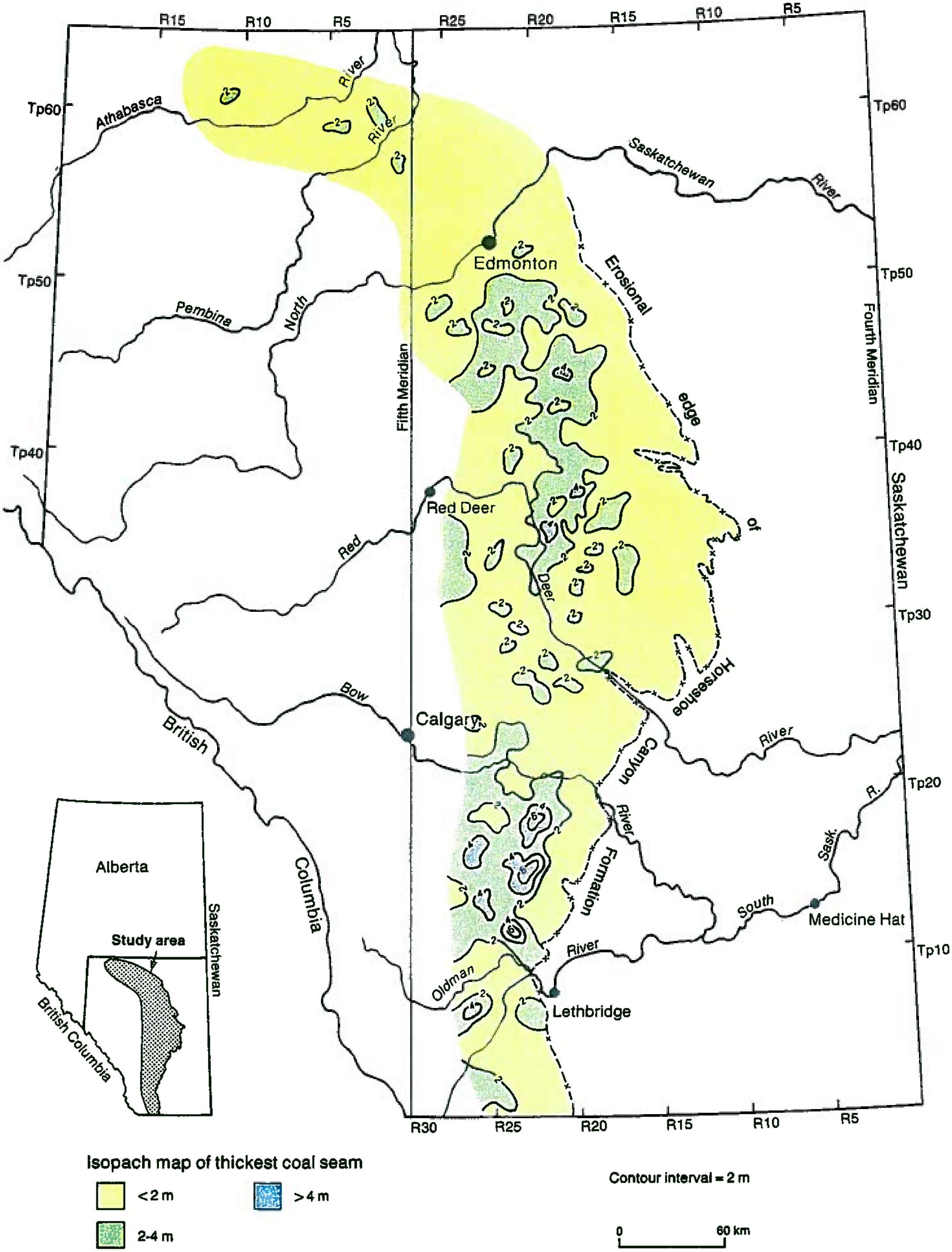


Figure 13. Isopach map of the thickest seam. Note that several seams of equal thickness may be at any given location.

thickness of 2.0 m or less. A pod of cumulative coal only 8 m thick at Township 11 Range 24 W4M contains coals that have maximum seam thicknesses of more than 4 m.

Generally, the best coal resources are found within the central and southern study areas, and the lower portion of the northeastern study area (up to and including the Edmonton vicinity) formed in a coastal plain depositional setting. Coals formed landward (west) of coastal coals are often thinner and less continuous compared to coals formed in a coastal plain setting. Dominance of terrestrial environments and abundance of clastics may have prevented the formation of thick and economically attractive coal seams further inland.

4.3 LIMITATIONS OF REGIONAL COAL RESOURCE MAPS PRODUCED

The localized nature of seam development and variable thickness of seams within deposits can be seen in Figure 14. The general north-south orientation of seams is also shown. Considering that the data set used to generate these maps commonly consist of only 1 to 3 wells per township where data are available and that limitations are imposed by casing in petroleum wells and shallow drilling depths in coal exploration holes, we can expect some locally anomalous areas (consisting of thick and economic seams), to be missed in this evaluation. Detailed geology and exploration drilling will undoubtedly find many more potentially economic coal deposits at depth as well as along the erosional edge. The maps in this report are regional and were produced to illustrate trends, more so than accurate or detailed evaluations on a seam by seam basis.

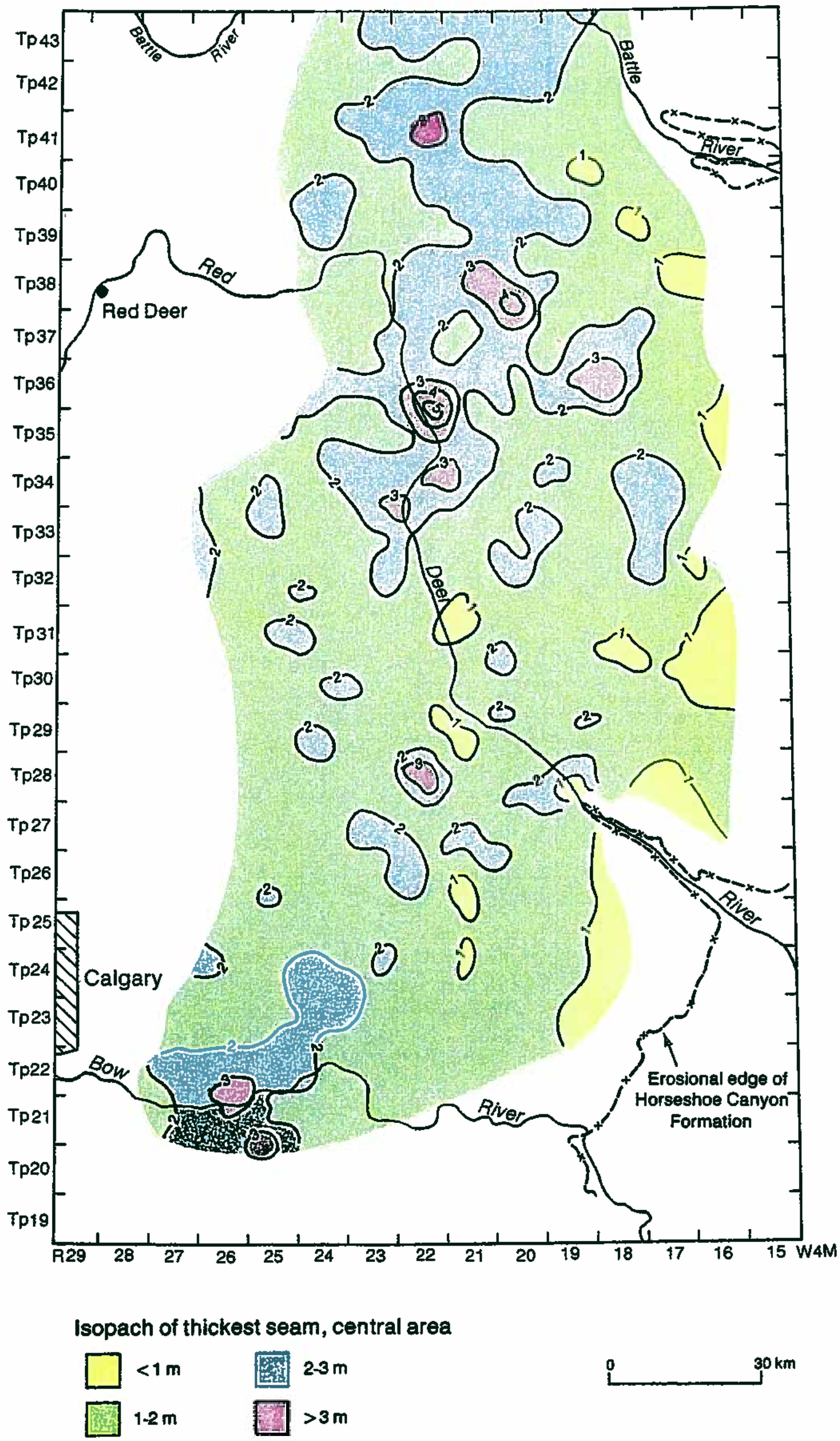


Figure 14. Isopach map of the thickest coal seam, central area.

5.0 SUMMARY AND CONCLUSIONS

The most economically attractive coals are within the lower part of the Horseshoe Canyon Formation. Trends with a large number of seams (15 or more), with maximum seam thicknesses of 2.0 m or more are commonly within zones of interfingering between marine and nonmarine sediments. Representative cross-sections in the central and southern study areas illustrate relatively thick but laterally restricted coal seams in these zones of interfingering.

Correlation using all tools available is very important in the evaluation of Horseshoe Canyon Formation coal resources. This study is regional in nature and restricted to 1 to 3 wells per township, where and when data is available in the study area. Also, given the limitations of a regional data set, some prime deposits of Horseshoe Canyon coal resources may be missed both for the deeper subsurface and the near surface. This is simply because of the well density (maximum of 3 wells per township), undetected coal seams hidden by casing in petroleum wells, limited depth of drilling in coal exploration holes, and the lack of data for some townships in the intervening areas between known deposits.

Examples are given to illustrate how coarsening upward successions can be used to correlate individual seams across a deposit. This method works well when seams directly overly or are near coarsening upward successions. Examples from exploration studies and deposits, indicate that some mineable seams must be correlated with what ever datum is available in the local area. The use of A-top and E-marker, coarsening upward successions, and the use of the informally named Basal, Drumheller and Weaver coal zones is for reference in the regional scale investigations. Results of this study will hopefully provide the stimulus for detailed evaluations on a deposit scale. Regional trends illustrated in this study, will bring to light new areas with thick cumulative coal measures in the Horseshoe Canyon Formation, especially in the deeper subsurface.

A geologic model developed for the lower Horseshoe Canyon Formation coals helps explain many of the depositional trends observed. The model involves a coastal plain setting characterized by shore-parallel peat-forming mires, 30 to 50 km inland from actual shorelines. Repeated transgressive-regressive cycles resulted in an interfingering of coal-bearing successions of the lower Horseshoe Canyon Formation with thick marine successions of the contiguous Bearpaw Formation.

The north-south orientation of the ancient mires, parallel to the shorelines, explains the elongate geometry of coal trends. Coals formed landward of coastal depositional settings are commonly thinner and more discontinuous. Perhaps lower subsidence rates, fluctuating ground water levels and/or abundance of clastic input prevented the formation of widespread economically attractive coal zones at locations further inland.

This study has delineated major coal resources of the lower Horseshoe Canyon Formation to depths of 400 m. Results of this regional study indicate deposition trends, basin-wide geologic controls and delineate potentially economic areas with extensive coal measures. Regional cumulative coal trends of 6.0 m or more are oriented in a north-south direction extending from Township 52 (the Edmonton area) to Township 14 (the Lethbridge area). These thicker cumulative trends are 3 to 6 townships in width and are generally located west of presently designated coal fields. Areas in Alberta with particularly thick coal measures have been identified close to Wetaskiwin, Alix, Delburne, Bashaw, Strathmore and Milo. Maximum seam thickness in these areas is commonly between 2 and 4 m, and in some wells, seams between 6 and 10 m were identified. This evidence suggests that large areas in Alberta have excellent potential for resource development of the lower Horseshoe Canyon Formation.

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APPENDIX ONE

(IDENTIFICATION OF COAL SEAMS AND THICKNESS CRITERIA)

A1 IDENTIFICATION OF COAL SEAMS AND THICKNESS CRITERIA, DESCRIPTION OF THE DATA SET

A1.1 Coal resource data set description

The coal resource data set contains marker and coal picks generated by the Alberta Geological Survey staff, from publicly available geophysical logs. The method of picking coals for this data set is described below. Twenty-eight preliminary cross sections were made to provide a framework for determining the formation and marker picks. These data are available on computer diskette in Mandryk and Richardson (1988).

A1.2 Identification of coal seams and thickness criteria

A combination of a sonic or density, natural gamma ray, normal resistivity and caliper logs forms the basis for identification of coals in this study. The following is a list of criteria used to identify each coal seam.

(1) The density log, which measures the electron density of a formation, shows a much lower density response for coal than for surrounding formations and typically records values of less than 1.8 gm/cc.
(2) The sonic log, which measures the interval transit time of an acoustic wave through a formation, shows a higher transit time for coal than for surrounding formations and typically records values greater than 120 microseconds/foot.
(3) The natural gamma ray log, which measures the natural radioactivity of a formation, records a much lower radioactivity level for coal than for surrounding formations and typically measures values approaching zero A.P.I. units.
(4) The normal resistivity log, which measures the resistivity of a formation to an electric current, typically measures a much higher resistivity response for coal than for surrounding formations.
(5) The caliper log, which measures borehole diameter, often shows large washouts in coal zones.

The top and base of each coal seam were consistently picked at the inflection point (X's in Figure A-1) on the gamma ray curve for the petroleum wells and on the density curve for the coal exploration holes. The normal resistivity and porosity logs were used to confirm the presence of coal in each case.

The seam picks are estimated to the nearest 0.3 m or nearest foot (1 ft.) depending upon the log scale. In this study, partings less than 0.5 m or 1 1/2 feet were ignored

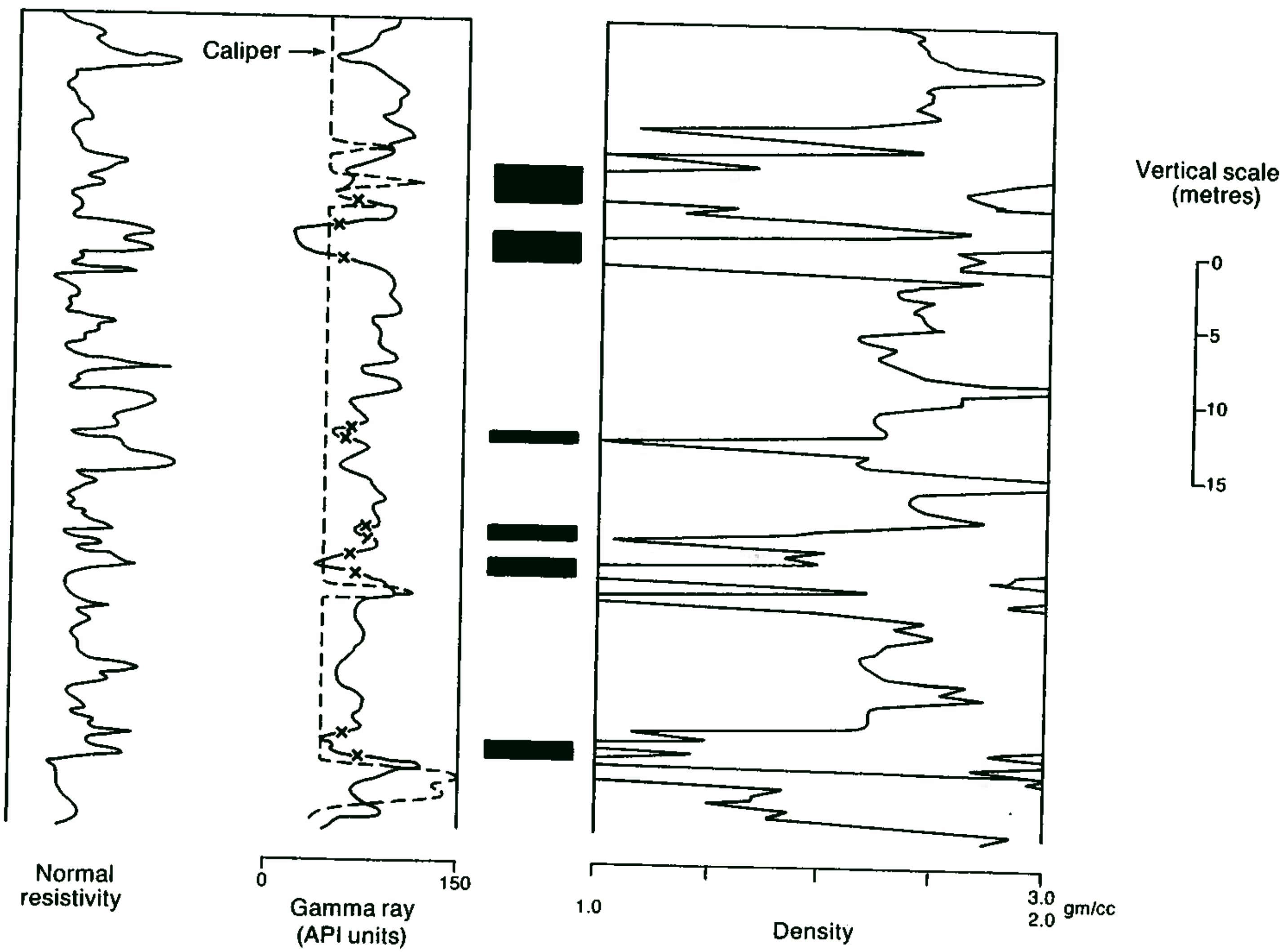

Figure A-1. Example of coal seams picked from geophysical logs to produce the coal resource data set for this study.

because of the difficulty in resolving such thin layers on many of the petroleum logs. For similar reasons, no coal seams less than 0.5 m or 1 1/2 feet were entered into the database. These constraints were thought to be necessary in order to obtain consistent data and to make the detailed coal exploration data more compatible with oil and gas well data.

APPENDIX TWO

(DESCRIPTION OF CROSS SECTIONS IN VOLUME TWO)

A2 DESCRIPTION OF REPRESENTATIVE CROSS-SECTIONS (VOLUME TWO)

Eight representative cross sections are included in Volume 2 in this report (See Figure A-2). Five of the cross-sections (A-A', B-B', C-C', G-G' and H-H') are based on relatively widely spaced oil and gas well data to illustrate broad stratigraphic relationships. The other three cross-sections (D-D'. E-E' and F-F') are based on more closely spaced coal exploration holes (some with available core) to show facies relationships in more detail. General comments about how the cross-sections are constructed and some of the major features are described in the following section. The full collection of cross-sections is found in Volume 2. Some simplified page sized figures accompanying these descriptions were produced to highlight certain features and trends.

A2.1 CROSS SECTION A-A' (Volume 2 only)

Cross section A-A' is located near the Athabasca River, trending southwest to northeast, from Township 59 Range 13W5M, to Township 61 Range 10W5M, respectively. In this region of the basin only a series of thin, discontinuous and generally uneconomic coal seams are present. A-top is used as the datum. In this area, major coarsening upward successions, the E-Marker and the B-zone are not present.

Comparison with cross sections C-C', G-G' and H-H' indicates that the best coal development occurs in areas where the coal-bearing succession of the lower Horseshoe Canyon Formation interdigitates with marine strata of the Bearpaw Formation. In the Athabasca River area, coals likely formed in an alluvial plain setting considerably inland from major shorelines. In this environment of deposition only thin scattered coal seams of the Weaver zone were formed.

A2.2 CROSS SECTION B-B' (Volume 2 and Figure A-3)

Cross section B-B' is located near Red Deer, trending northwest to southeast from Township 41 Range 22W4M to Township 39 Range 20W4M respectively. A continuous coal seam near the base of the Drumheller coal zone is used as a datum. In this section the value of using coarsening upward successions to correlate coal seams is demonstrated. Coal A for instance (See Figure A-3) does not correlate with Coal B or Coal C. All three coals overly thick sandy successions but are at different stratigraphic levels. Overlying coal seams not associated with coarsening upward successions are commonly more difficult to correlate. It is also important to note the degree of variability in the thickness of seams from well to well.

Five major coarsening upward successions are recognized within

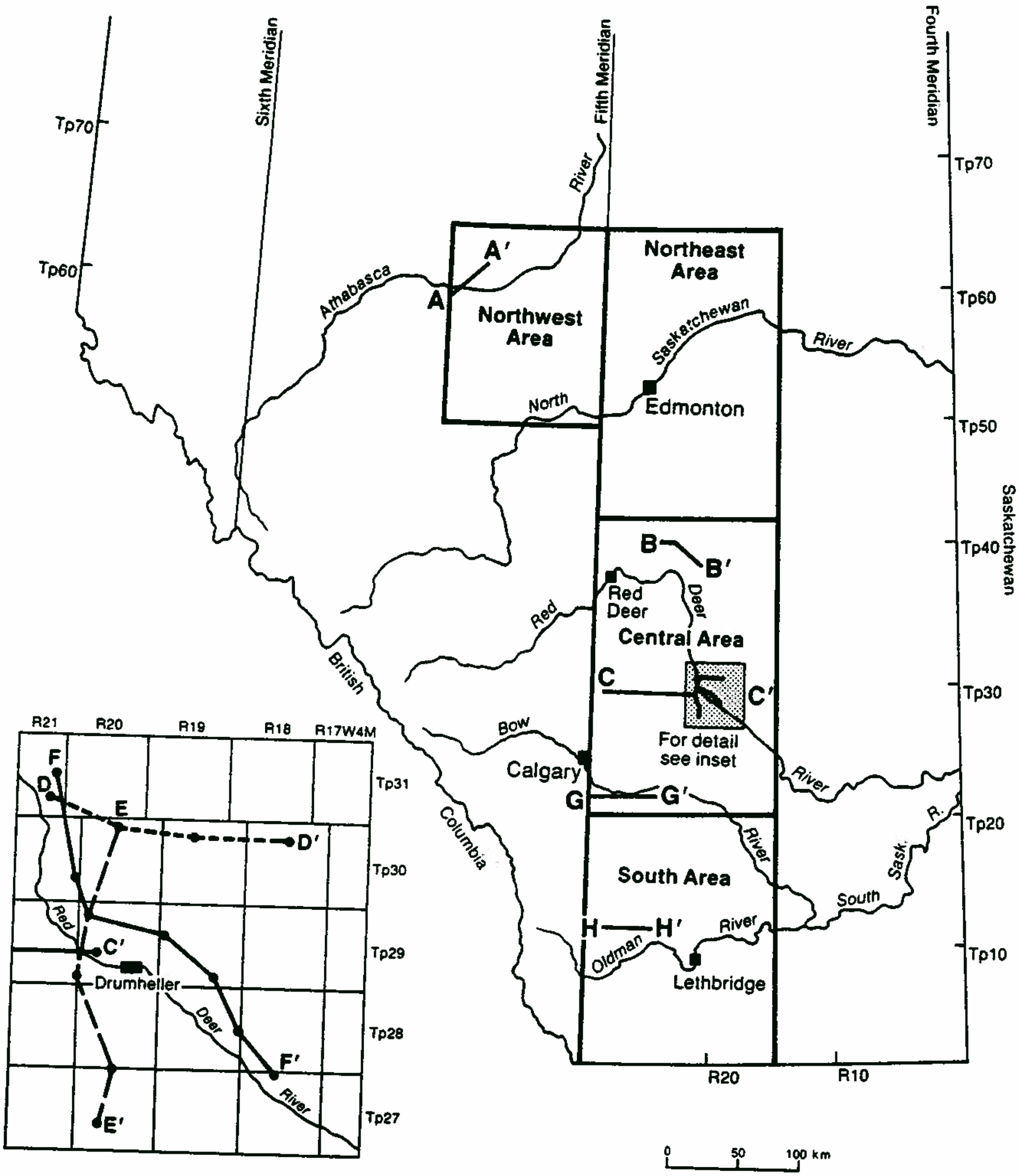

Figure A-2. Location map showing the lower Horseshoe Canyon Formation study areas and representative cross sections.

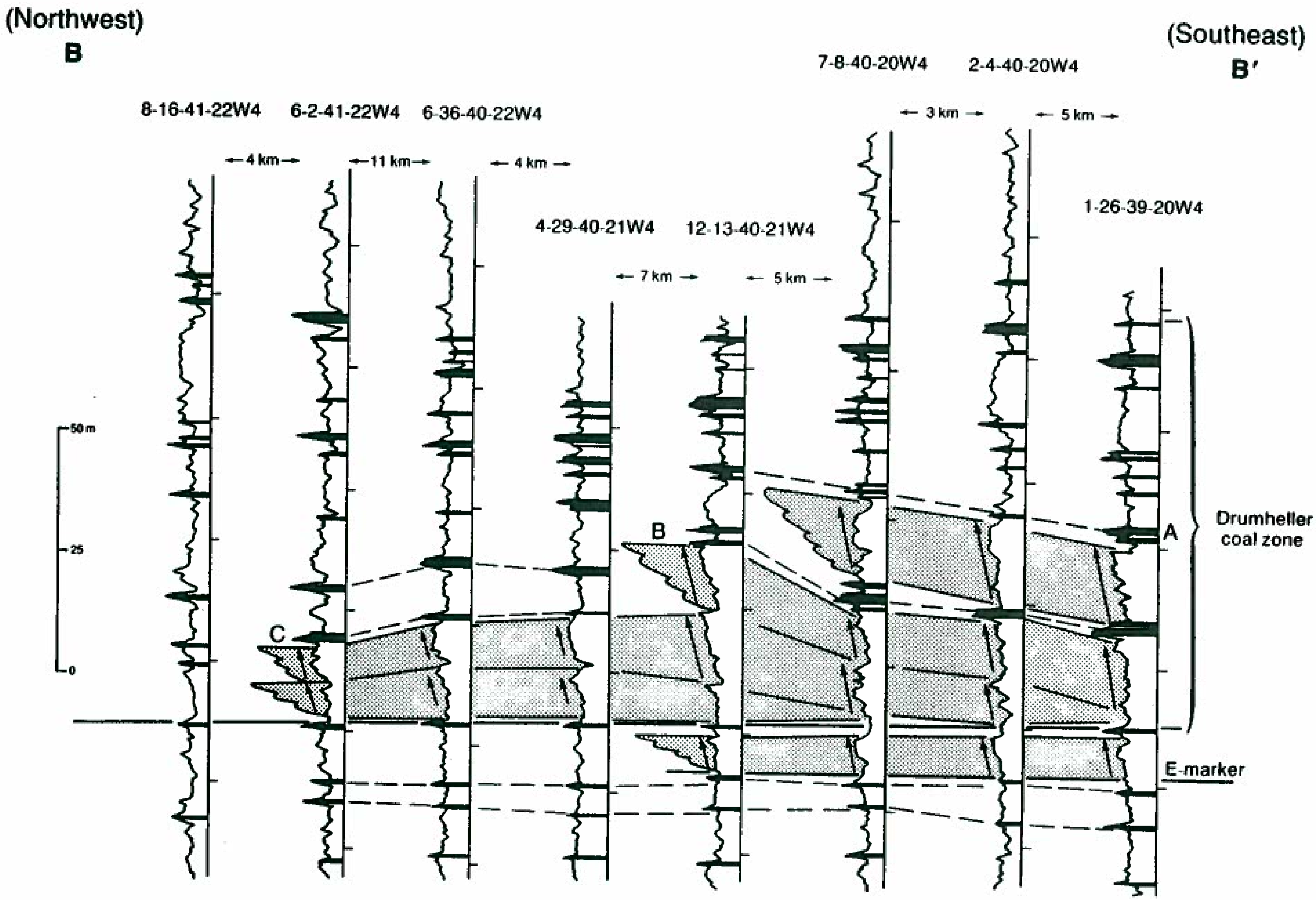

Figure A-3. Cross-section B-B' oriented perpendicular to regional shoreline trends (near Red Deer).

this cross section. The upper four successions progressively migrate upwards and to the east reflecting the eastward shift of shoreline positions through time.

The top of coarsening upward succession 3 contains thick sandstones with neutron-density crossovers, possibly indicating the presence of gas. If this is the case, a high gas content would be expected in mining activities in the vicinity of these sandstones. The source of gas may be the underlying and adjacent coal seams of the Drumheller coal zone.

A2.3 CROSS SECTION C-C' (Volume 2 and Figure A-4)

Cross section C-C' is located north of Drumheller, trending east-west across Township 29. In this section, the upper Horseshoe Canyon strata consists largely of thin discontinuous coal seams (Weaver zone), whereas thicker, more laterally extensive coal seams (Drumheller zone) are contained within the lower Horseshoe Canyon Formation. Coal seams appear to be best developed in the Drumheller zone.

The cross section is oriented perpendicular to paleoshoreline trends. With this orientation the relationship between marine strata of the Bearpaw Formation represented by a series of coarsening upward successions and the coal-bearing terrestrial strata of the lower Horseshoe Canyon Formation is illustrated. Three coarsening upward successions are recognized. Coal seams overlying the coarsening upward successions such as Coal D, E and F are correlated with a high degree of confidence. A similar example in Figure A-3 shows how the tops of major coarsening upward successions are used to correlate coals A, B and C.

This cross section also shows a step-up zone between coarsening upward succession 2 and coarsening upward succession 3. Step-ups are recognized as zones in which a series of coal seams jump stratigraphically to a higher level. These zones are often created in areas where coarsening upward successions overlap. In these zones a younger coarsening upward succession capped by a series of relatively thick coal seams, overlaps an older coarsening upward succession capped by a series of thinned coal seams. On maps such as the Structure on the Best 25 m (which measures the elevation of the 25 m window), step-ups are recognized as north-south trends of closely spaced contour lines.

The limited lateral continuity of coal seams in the east-west orientation (perpendicular to paleoshoreline trends) compared to the north-south orientation (parallel to paleoshoreline trends) is an important consideration as this cross section points out. In addition, this cross section can be used as a reference and to correlate major markers when doing coal resource evaluations in the Drumheller area.

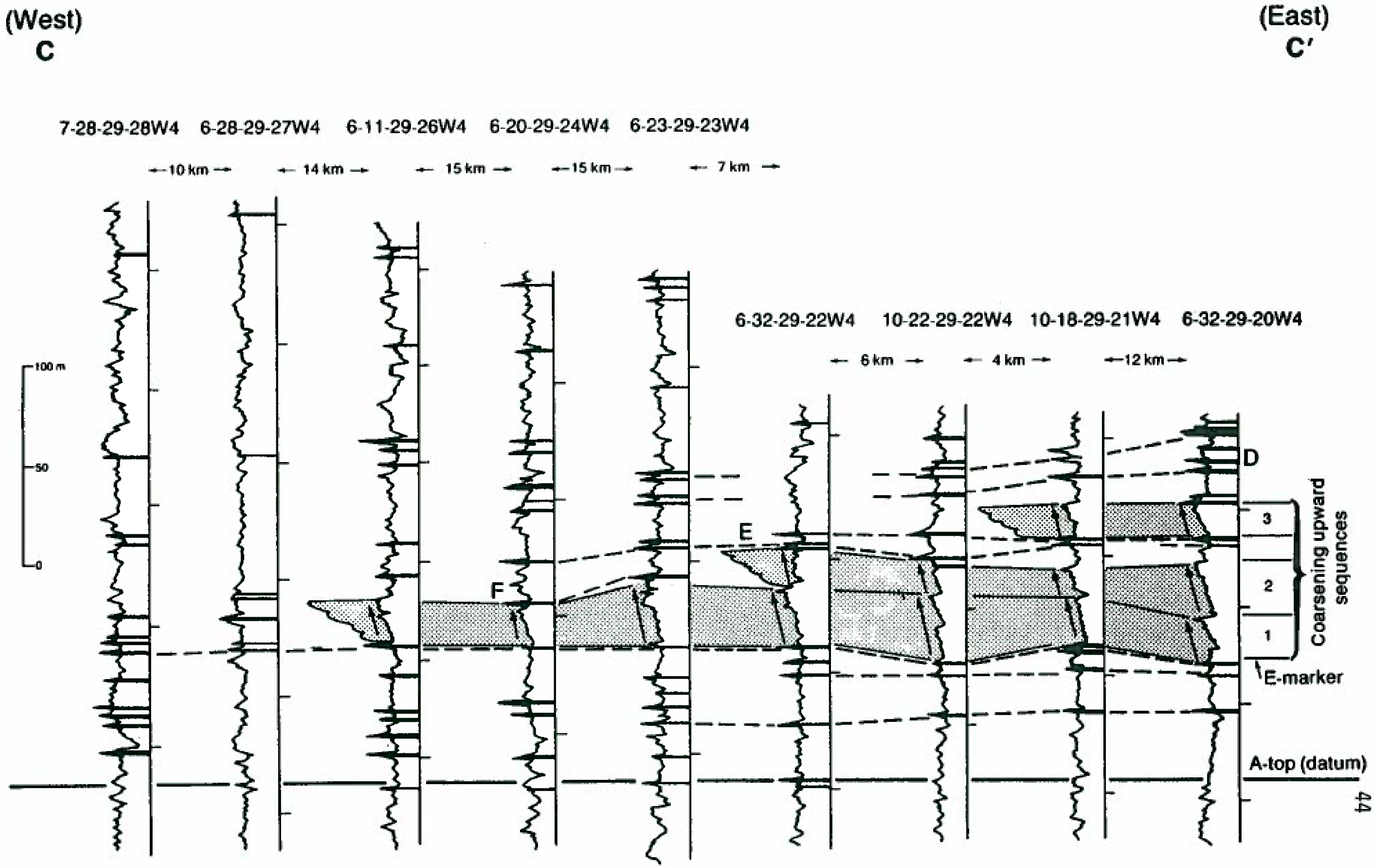

Figure A-4. Cross-section C-C' oriented perpendicular to regional shoreline trends (near Drumheller).

A2.4 CROSS SECTION D-D' (Volume 2 only)

Cross section D-D' is a detailed cross section based on closely spaced Alberta Research Council coal exploration holes, located north of Drumheller. It is oriented east-west to show the position of coal seams with respect to major coarsening upward successions. The datum used is the uppermost coal seam of the lower tongue (Basal coal zone). From working cross sections it is known that A-top is essentially parallel to the datum used here.

Using coal exploration data for this cross section has several advantages. The detailed scale of the geophysical logs, for instance, allows us to more accurately determine the thickness of the coal seams and to delineate thin partings within seams. The Drumheller coal zone, which is of most economic interest in this area was chosen for detailed examination. Many of the seams that are 2m or more thick in the west thin substantially towards the east. Comparison with cross-section E-E' indicates that coals are more laterally continuous in north-south directions (parallel to paleoshoreline trends) than in east-west directions (perpendicular to paleoshoreline trends). These findings are in agreement with trends observed on the coal resource maps generated in this study.

A2.5 CROSS SECTION E-E' (Volume 2 only)

Cross section E-E' is a detailed cross section based on closely spaced Alberta Research Council coal exploration holes. It is oriented north-south (Parallel to paleoshoreline trends) tying into intersecting wells of cross-sections D-D' and F-F'. As with cross-section D-D' and F-F', the detailed information available from the exploration holes allows for more accurate delineation of coal seams and partings. Trends observed on this section indicate a greater lateral continuity and smaller thickness variation of coal seams in the north-south direction. The thickness and extent of the coarsening upward successions also appear to be more consistent along north-south trends. Evidence from outcrop studies in the Drumheller area suggests that coal seams developed in elongate pods parallel to regional paleoshoreline trends.

A2.6 CROSS SECTION F-F' (Volume 2 only)

Cross section F-F' is based on closely spaced coal exploration holes. The datum used is the uppermost seam of the Basal coal zone. In this cross section emphasis is placed on the correlation of and thickness variation of seams in the Drumheller coal zone. It is oriented northwest to southeast, running parallel to the Red Deer River Valley, allowing us to compare parts of the cross-section with outcrop studies. As with cross section D-D', coarsening upward successions were useful markers with which to correlate seams. Similarly, the large thickness variation of seams in the east-west direction is illustrated. The thinning of seams and the addition of thick partings in an eastward direction are common in this portion of the study area. See the descriptions given for cross sections D-D' and E-E' for more details.

A2.7 CROSS SECTION G-G' (Volume 2 only)

Cross section G-G' is located south of Calgary, trending east-west across Township 21. A-top is used as the datum. This cross section is oriented perpendicular to paleoshoreline trends to show the relationship between coal development and migrating shoreline positions. In this section the continuity and distribution of seams in the Basal and the Drumheller coal zones are emphasized. The Drumheller coal zone appears to be best developed in areas of interfingering between the nonmarine and marine strata of the lower Horseshoe Canyon and the Bearpaw Formations. Discontinuous and more sparsely distributed coal seams are generally formed in the upper Horseshoe Canyon interval and areas more landward (Weaver coal zone).

Six major coarsening upward successions are recognized. The three lower coarsening upward successions associated with the lower tongue are shown to pinch out towards the east. The sandy intervals at the top of each succession gradually thin so the coarsening upward succession can no longer be distinguished from massive mudstone intervals. Coal-bearing wedges are commonly sandwiched between coarsening upward successions, likely as a result of relatively rapid transgressive episodes and the in-place drowning of the peat-forming mires. A partially preserved terrestrial wedge with an associated coal seam is present at the top of coarsening upward succession 3.

A step-up zone is also shown on this cross-section. The step-up is recognized where coal seams above coarsening upward succession 4 pinchout against coarsening upward succession 5. The next major coal development overlies coarsening upward succession 6. In this example the coal zone has a vertical shift of about 50m.

A2.8 CROSS SECTION H-H' (Volume 2 and Figure A-5)

Cross section H-H' is located north of Lethbridge trending east-west across Township 11 and is one of the most southerly cross sections provided in this report. The cross section is oriented perpendicular to paleoshoreline trends, using A-top as the datum. Unlike cross sections B-B', C-C' and G-G', no coal seams are associated with the lower tongue (ie. the Basal coal zone is absent) and fewer coals are observed in the Lethbridge coal zone Figure A-5). In this example there are no coals capping the coarsening upward successions immediately above E-Marker. suggesting that coal seams appear to be best developed above the uppermost coarsening upward succession.

The concentration of seams of the Drumheller coal zone at the

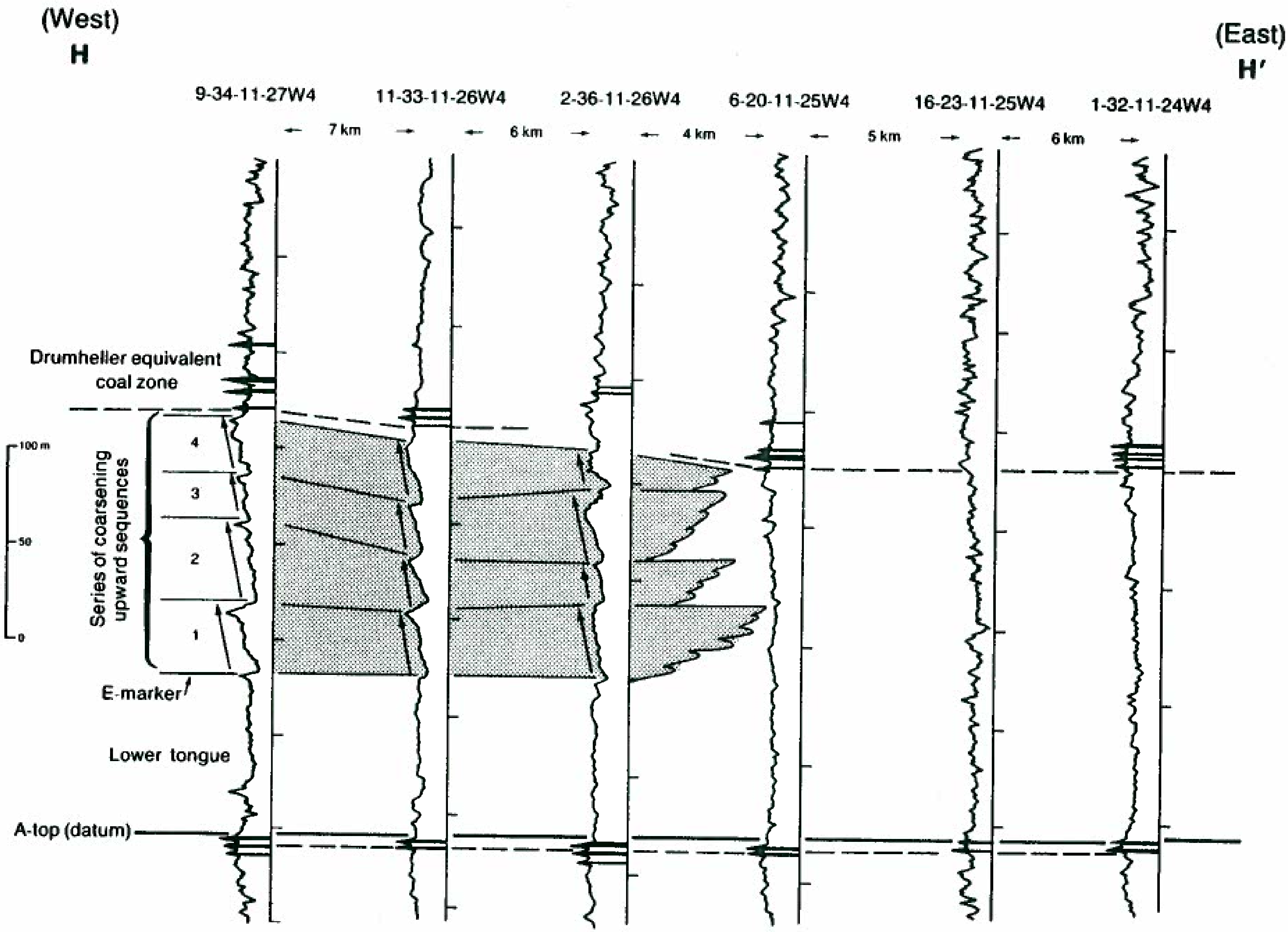

Figure A-5. Cross-section H-H' oriented perpendicular to regional shoreline trends (near Lethbridge).

top of coarsening upward succession 4 indicates that correlation may be simpler in southern parts of the study area than in central and northern areas. Coal resource maps from the southern area likely outline coals from a similar stratigraphic level.

APPENDIX THREE

(DESCRIPTION OF MAPS IN VOLUME TWO)

A3 DESCRIPTION OF MAPS IN VOLUME TWO

A3.1 INTRODUCTION

Computer generated maps that were produced include structure contour maps of marker horizons and sets of coal resource maps. A listing of the maps provided in this report is given in Table 2. Structure contour maps of markers such as A-top and E-marker are useful for basin-wide correlations and the coal resource maps outline potential targets for coal exploration and illustrate regional trends. Simplified page sized figures are provided in the text to highlight important trends of each map. The reader is referred to the full sized maps in Volume 2 for the exact locations and values of each data point used.

Because of the variable number of coal seams within the study section and the variable concentration of seams within each coal zone, several sets of maps are used in combination. Each set of maps shows the variation in a particular parameter. It is important to use the full suite of maps in combination with geologic cross sections when assessing the potential of coal resources in a given area. It is hoped that the suites of maps will help identify those areas worthy of detailed study. A detailed study would require examination of every available well and construction of detailed cross sections to map the zone of interest.

A3.2 PURPOSE AND FUNCTION OF THE WINDOW CONCEPT

The term "window" is used here for that zone within a stratigraphic succession which contains the most coal. If windows are compared between wells it is necessary to define a maximum thickness for the zone. The computer was programmed to search out windows of varying thickness for each of the wells in the data set. Two thicknesses were found to be useful in the study: 150 m and 25 m (See Figure A-6). Maps that plot the structure of a window are useful in understanding strata like the Horseshoe Canyon Formation where coal zones are diachronous and are not always parallel to major markers.

The maps of the 150 m window in the central and southern parts of the study area usually capture most of the coal seams which are associated with the Horseshoe Canyon/Bearpaw Formation transition zone. In these areas the 150 m window captures the Basal and Drumheller coal zones. In the northwest and most of the northeast parts of the study area, the Bearpaw Formation is absent. In these areas the coal seams are not concentrated within a 150 m zone, so the 150 m window is not as applicable.

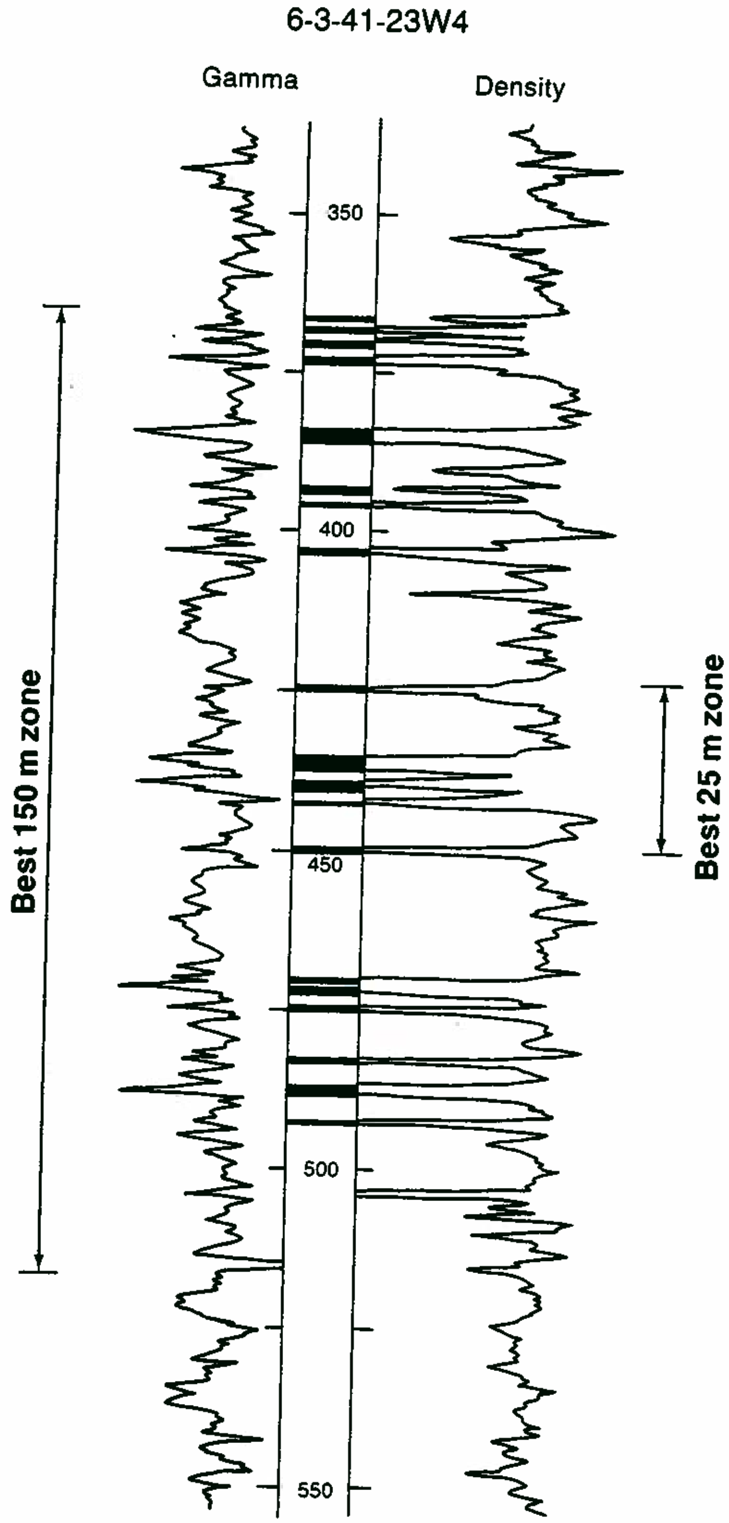

Figure A-6. Comparison between the 150 m and 25 m windows in the lower Horseshoe Canyon Formation.

Table 2. Listing of maps in volume 2.

The 25 m window has a more variable stratigraphic position than the 150 m window because it is more sensitive to variation in the number of seams and seam thickness in the sequence. It generally captures relatively thick and closely spaced seams. The 25 m window concept is useful in evaluating the coal resources throughout the study area in that it usually captures major clusters of coals that have potential economic interest.

A3.3 MAP 1. STRUCTURE ON A-TOP, REGIONAL AREA (Volume 2 and Figure A-7)

A-top is a regional datum used for most cross sections and is a major marker used to correlate coal zones within the lower Horseshoe Canyon Formation. Contour lines on this map join points of equal elevation, showing the present day position of the A-top surface with respect to sea level. Smooth and regularly spaced contour lines suggest that A-top is a consistent marker. Uniform and gentle dips on A-top indicate that strata of the Horseshoe Canyon Formation throughout the study area are relatively flat lying and undeformed. A-top defines the base of the Horseshoe Canyon Formation, so this map can be used to determine the stratigraphic position of the lower Horseshoe Canyon coal-bearing interval over much of the study area.

A3.4 MAP 2. STRUCTURE ON E-MARKER, REGIONAL AREA (Volume 2 and Figure A-8)

E-marker is defined as the base of one of the most widely distributed coarsening upward successions. "0" values plotted on the map (Volume 2) are locations where E-marker is not present or could not be readily identified. Results of this study indicate that the best coal resources of the lower Horseshoe Canyon Formation are in areas of interfingering with the Bearpaw Formation. In these areas the E-marker is commonly present and is a valuable tool for correlation of coal seams. The tops of coarsening upward successions and A-top are also useful to correlate coal seams in this study. These markers and datums are generally parallel, whereas coal seams have more variable stratigraphic positions within the sequence.

A3.5 MAP 3. STRUCTURE ON TOP OF THICKEST COAL SEAM, REGIONAL AREA (Volume 2 and Figure A-9).

The thickest seam may have a highly variable stratigraphic position as the numerous anomalies and irregular contour lines point out. Some areas, however, contain a cluster of data points with similar structural values. Thick seam trends in these areas may be given priority for more detailed studies because a continuous seam is likely represented.

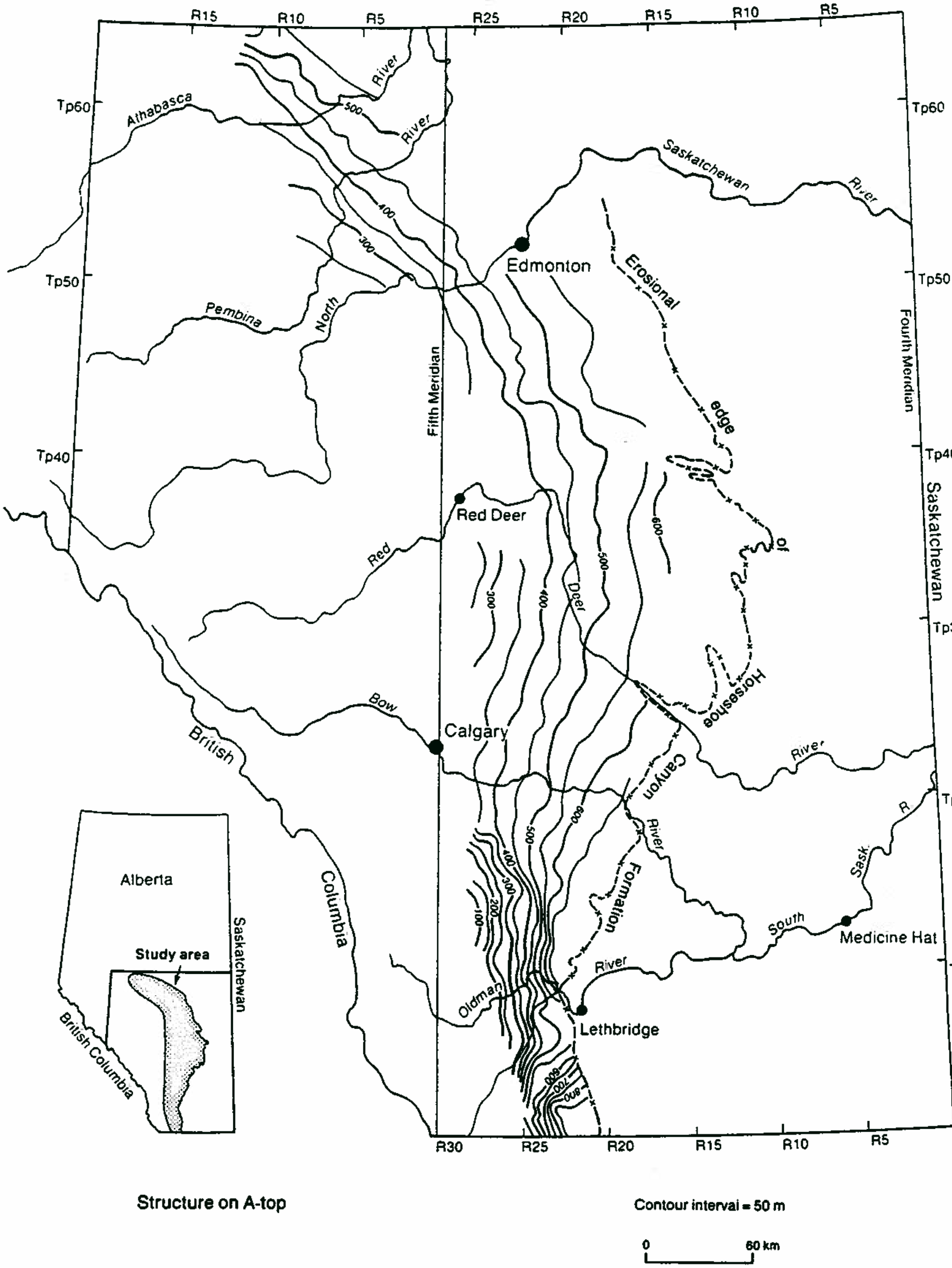

Figure A-7. Structure map on A-top. A-top is a regional datum used to correlate coal zones within the lower Horseshoe Canyon Formation.

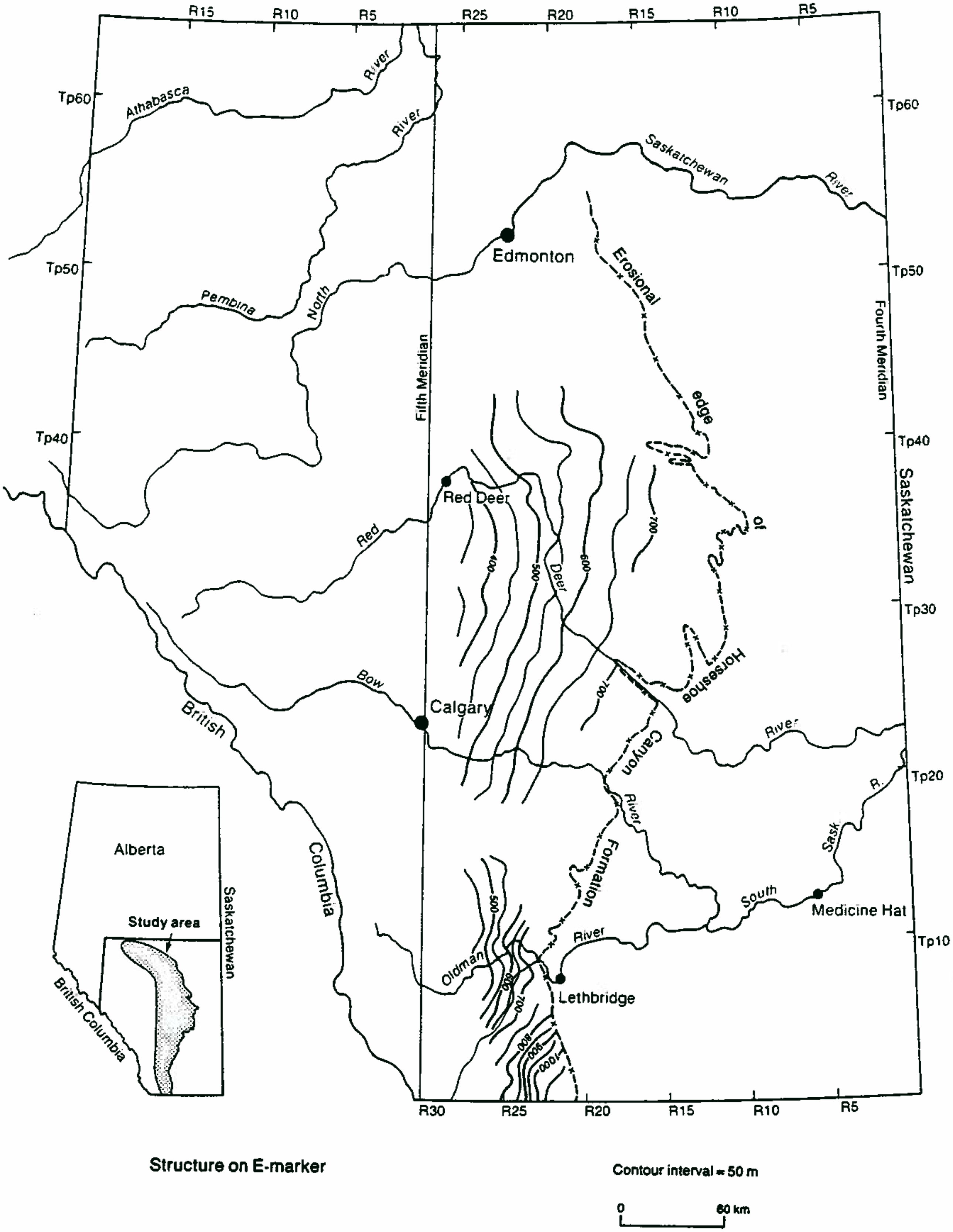

Figure A-8. Structure on E-marker. E-marker is defined as the base of one of the most widely distributed coarsening upward successions.

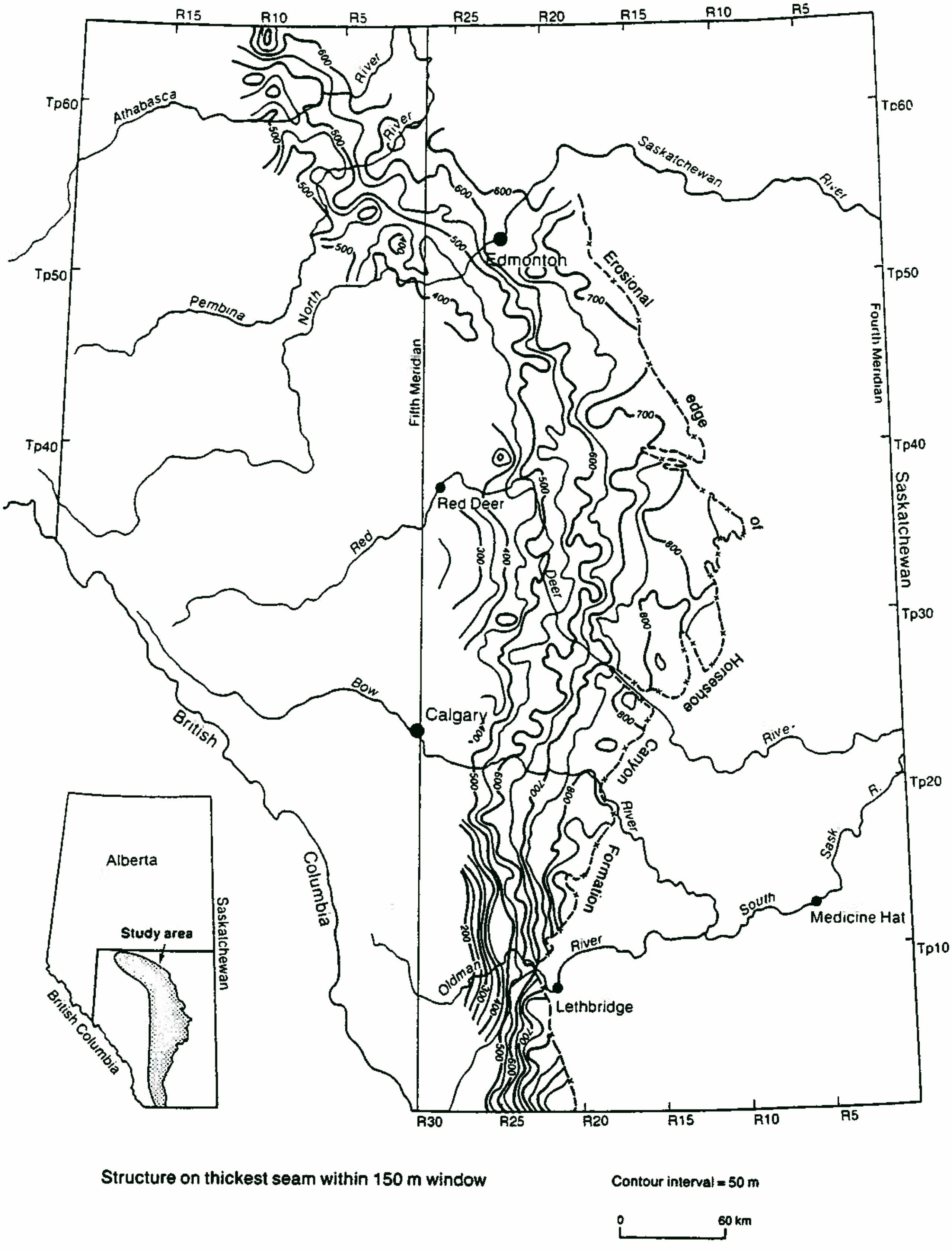

Figure A-9. Structure map on the thickest coal seam within the best 150 m window.

A3.6 MAP 4. ISOPACH OF THICKEST COAL SEAM, REGIONAL AREA (Volume 2 and Figure A-10)

In this map, it is important to note that several thick seams may be present at any given location. This map does not depict a single seam, but rather the maximum seam thickness encountered in each drill hole. The variable stratigraphic positions of thick seams within a single drill hole and between drill holes is observed on the representative cross sections included in this report. The irregular contour lines and anomalies on the Structure on the thickest seam map (Figure A-9) indicate the variable stratigraphic position.

A comparison was made between the maps showing the variation in maximum seam thickness for the lower Horseshoe Canyon Formation to maximum seam thickness of Paleocene coals of the Ardley coal zone. Contour lines for the Ardley coal zone (See Richardson et al., 1988) were observed to be smoother and relatively free of anomalies, reflecting a smaller variation in thickness. Most seams contained in the north-south oriented pods in the Horseshoe Canyon Formation are 2 to 3 m but in isolated locations exceed 4 m, resulting in a series of anomalies. Because the database used to generate this map is restricted to 1 to 3 wells per township, it is expected that many more anomalies are present than those shown here.

A3.7 MAP 5. STRUCTURE ON TOP OF BEST 150 M, REGIONAL AREA (Volume 2 and Figure A-11)

The contour lines are irregular and the map contains numerous anomalies suggesting that the 150 m window has a variable stratigraphic position. The diachronous nature of coal development is well illustrated in the representative cross sections included in this report. Associated with the diachronous coal development is the formation of step-up zones. Step-up zones are recognized as north-south trends of closely spaced contour lines, commonly representing sharp changes in stratigraphic position of the 150 m window. Recognition of step-up zones may have direct implications for coal resource exploitation because of discontinuities in coal seams associated with them.

A3.8 MAP 6. CUMULATIVE COAL IN BEST 150 M, REGIONAL AREA (Volume 2 and Figure A-12)

This map shows the total thickness of all coal seams within the best 150 m window. Based on the representative cross sections the 150 m window generally captures most of the coal-bearing interval of the lower Horseshoe Canyon Formation. Regional cumulative thickness trends have a north-south orientation, coincident with the zone of interfingering between the lower Horseshoe Canyon and the Bearpaw Formations. Cumulative thickness values thin towards the east and west of these main trends

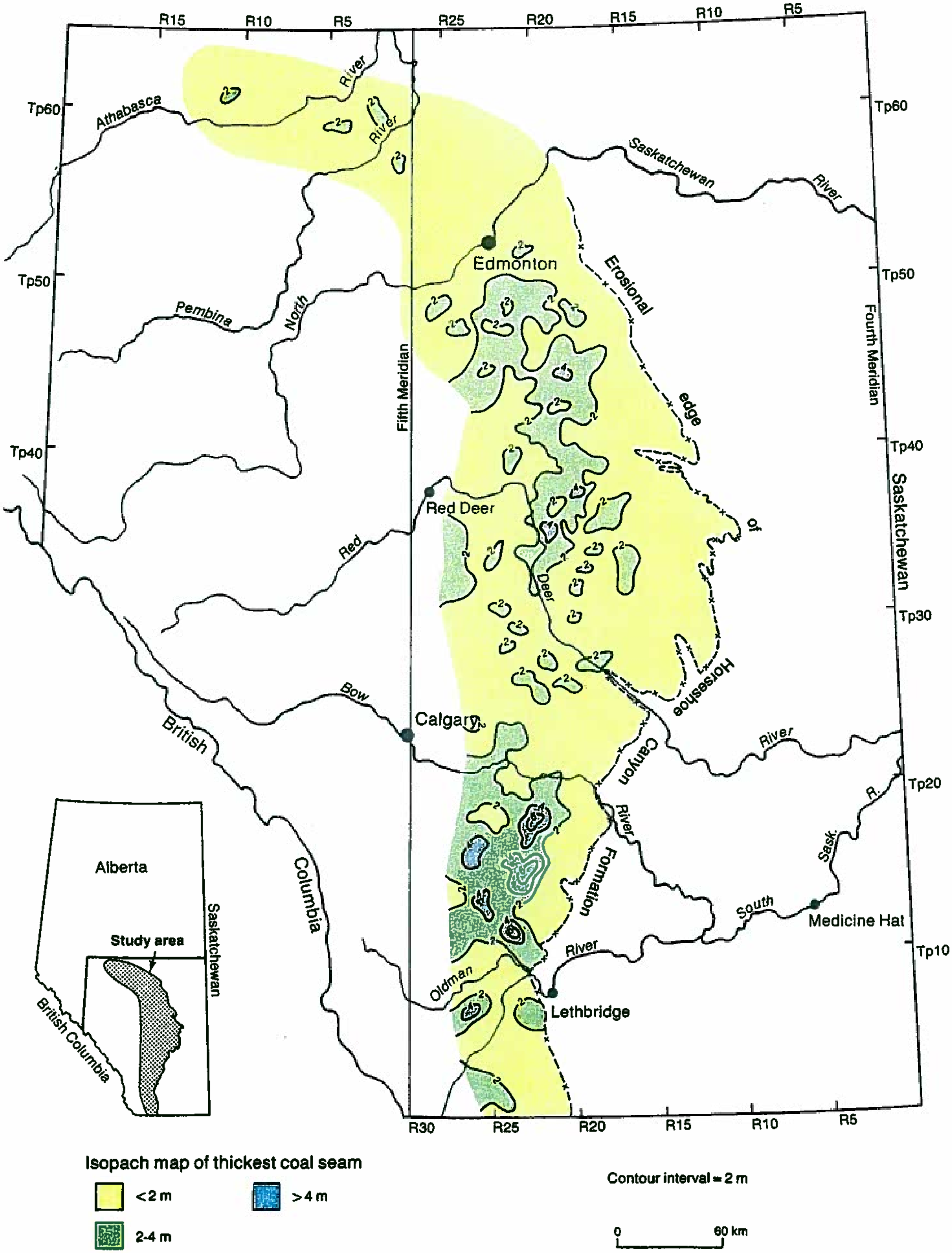

Figure A-10. Isopach map of the thickest seam. Note that several thick seams may be at any given location.

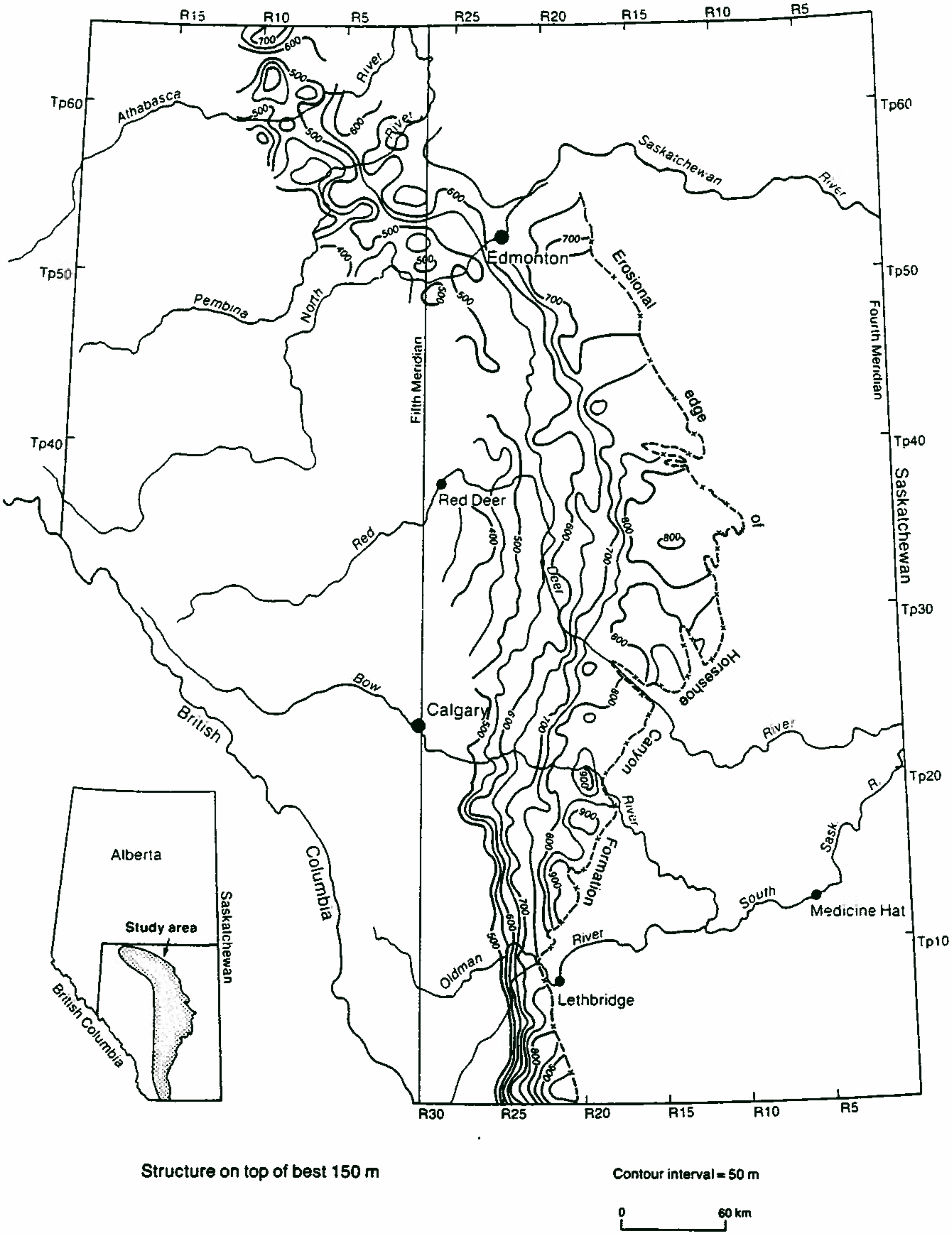

Figure A-11. Structure map on the best 150 m window.

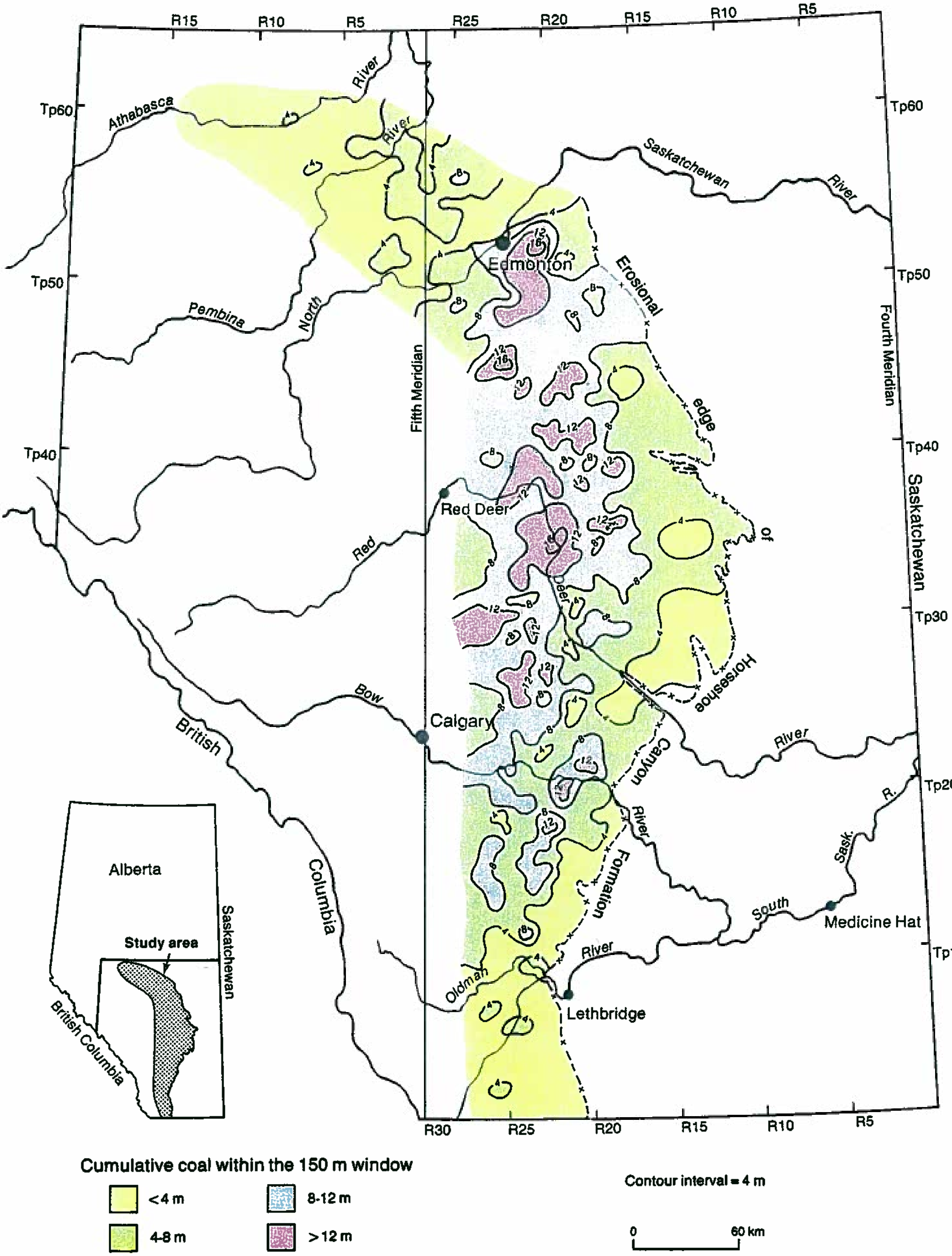

Figure A-12. Isopach map of the cumulative coal within the best 150 m window.

suggesting that the coal zones are not as well developed outside of the zone of interfingering. For similar reasons, the areas north and northwest of Edmonton exhibit a marked decrease in cumulative coal. Another observation from this study is that some of the best coal resources are located in the deeper portions of the basin and not along the erosional edge where the presently operating Horseshoe Canyon coal mines are located.

Comparison between the isopach map of thickest seam (Map 4) and this map shows that there is a close correlation between maximum seam thickness and cumulative coal trends. Many of the areas with 8 m or more cumulative coal contain seams that are 2 m thick. In areas with less than 8 m cumulative coal the maximum seam thickness is commonly less than 2 m. One example of eastward thinning is illustrated in cross section F-F' (of Volume 2), where coal seams develop thick splits and thin dramatically where coarsening upward sequences pinchout.

Regional cumulative trends are useful for basin-wide coal studies, relating subsidence rates and sea level fluctuations to coal deposition. Cumulative coal trends of 4 m or more are commonly the most attractive targets for exploration. Some exceptions are noted, especially in the southern parts of the study area.

A3.9 MAP 7. STRUCTURE ON TOP OF BEST 25 M, CENTRAL AREA (Volume 2 and Figure A-13).

A variable stratigraphic position of the 25 m window is suggested by numerous anomalies and zones of closely spaced contour lines (possibly step-ups). Shifts in stratigraphic position are a reflection of the sensitivity of the 25 m window to changes in the sequence. Recognition of step-up zones may have direct implications for coal resource exploitation. Some coal seams may thin or discontinue along step-up zones and new, thicker seams may develop at a higher stratigraphic level. The structure map on the best 150 m window has fewer step-up zones identified because of the wider zone investigated.

This map may be useful to compare with the cumulative coal map in the best 25 m (Map 9). The depth to the best 25 m may be calculated by subtracting the structural elevation from the surface elevation obtained from a topographic map.

A3.10 MAP 8. STRUCTURE ON TOP OF BEST 150 M, CENTRAL AREA (Volume 2 and Figure A-14)

This map is similar to the structure on the best 150 m window for the entire region (Map 5) but because of the larger scale used, the central area map can better emphasize local anomalies. This version is also more easily compared to the other central area maps.

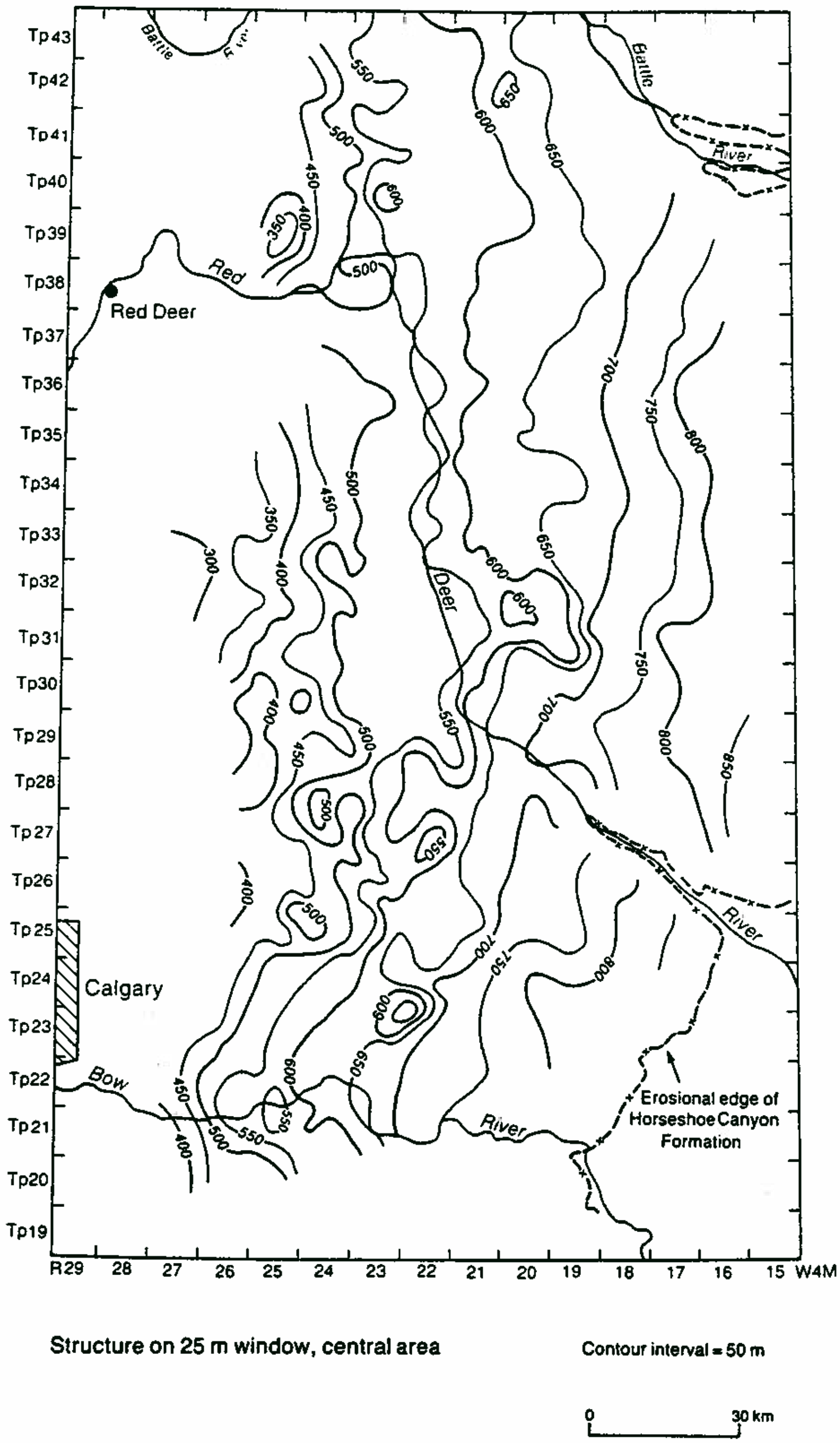

Figure A-13. Structure map on the best 25 m window, central area.

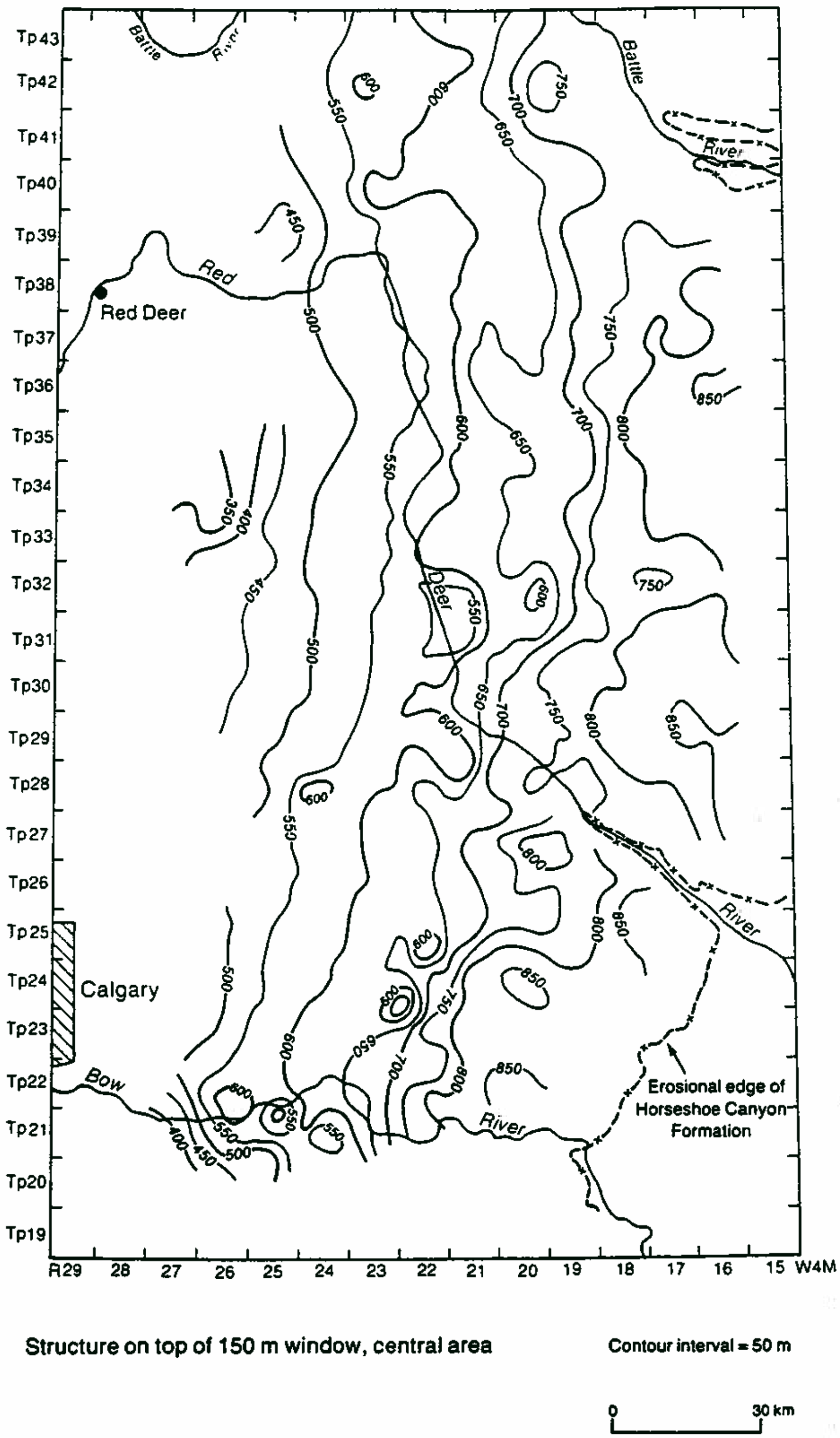

Figure A-14. Structure map on the best 150 m window, central area.

Major north-south oriented trends of the top of the 25 m window (Map 7) are similar to trends of the 150 m window shown on this map. Structure contour lines of the 25 m window, however, are more irregular and more anomalies are present. The 25 m window appears to be more sensitive to small changes in the sequence and picks up more possible step-up zones than the 150 m window. A major step-up zone is more likely to be present where the trends of closely spaced contour lines of both maps overlap.

A3.11 MAP 9. CUMULATIVE COAL IN BEST 25 M, CENTRAL AREA (Volume 2 and Figure A-15)

This map show the total thickness for all coal seams within the 25 m window for the central study area. As it is shown in the structure map of the best 25 m for this area (Map 7), the 25 m window may have a highly variable stratigraphic position.

Cumulative thickness trends generally have a north-south orientation. The 25 m window, however, has a more variable thickness in this area than the 150 m window. The 150 m window generally captures most of the coal-bearing zone and averages out the differences between local concentrations of seams, giving smoother and more regular contour lines. One advantage of the 25 m window is that it commonly contains clusters of thicker seams that are potentially economic.

In cross sections C-C' and G-G', the 25 m window changes in stratigraphic position of window capture, from the Basal coal zone in the west to the upper portion of the Drumheller coal zone in the east. This indicates that the 25 m window is useful to pick up the better coal developments at any given location because it is more sensitive to the clustering of thicker seams.

Areas with cumulative trends ranging from 4 to 10 m appear to be good prospects for more detailed evaluation. As it was observed in the structure map of the 150 m window, the best coal developments are located at depth, west of the presently designated coal fields.

A3.12 MAP 10. DEPTH TO TOP OF BEST 25 M, CENTRAL AREA (Volume 2 and Figure A-16).

This map shows very generalized depth estimates from the surface to the top of the 25 m window. For first look evaluations this map shows the estimated depths to the 25 m window at any given location. Because relief on the ground surface is variable and irregular, depth calculations based on the appropriate structure and topographic maps are recommended for more detailed studies.

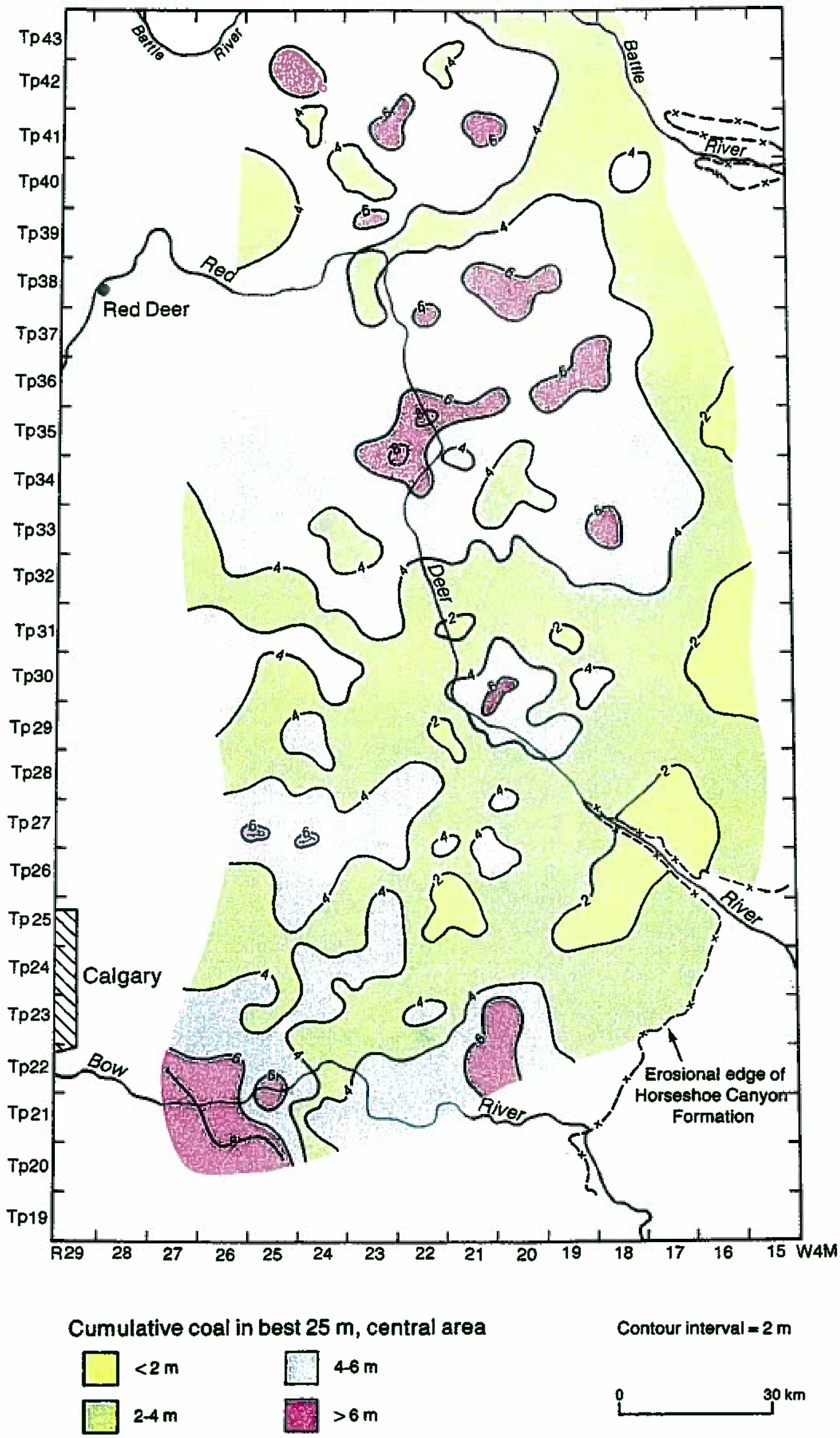

Figure A-15. Isopach map of cumulative coal in the best 25 m window, central area.

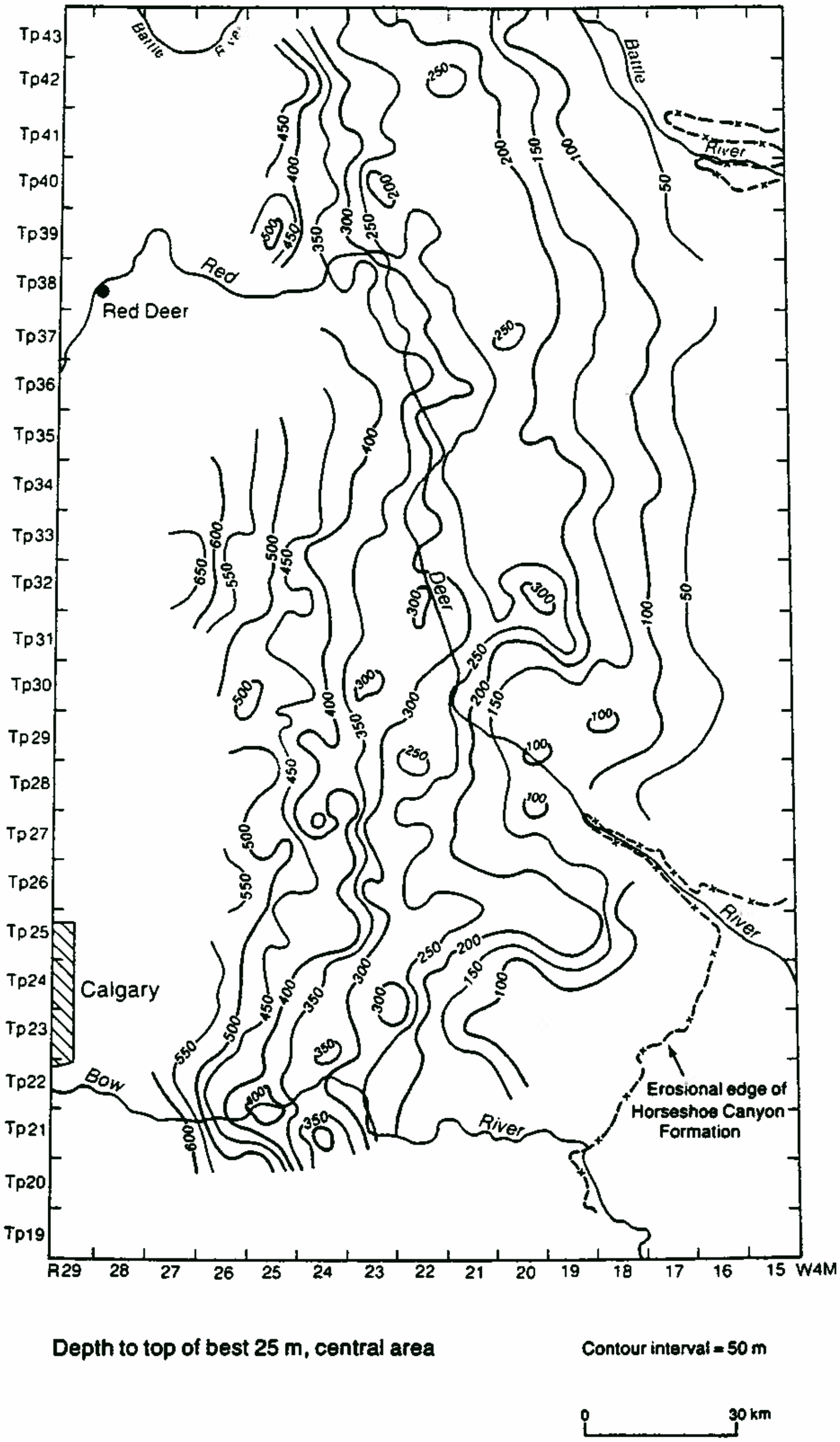

Figure A-16. Depth to the best 25 m window, central area.

A3.13 MAP 11. ISOPACH OF THICKEST COAL SEAM, CENTRAL AREA (Volume 2 and Figure A-17).

This map measures the maximum seam thickness within the 150 m window. The larger scale of this map offers better resolution and more detail than the regional area map (Map 4). Also, direct comparison can be made with the other central area maps.

Emphasis is placed on the central study area because some of the thickest and most extensive coal zones are developed in that area. In this example, a series of well defined north-south oriented trends containing seams 2 m or more thick are shown. The best seam developments appear to be concentrated at depth, well to the west of the erosional edge and the presently designated coal fields.

A3.14 MAP 12. DEPTH TO TOP OF BEST 25 M, SOUTH AREA (Volume 2 and Figure A-18)

This map shows the depth from surface to the top of the 25 m window, in the south study area. Unlike the central study area, the concentration of seams in the south appear to be from one major coal zone. As a result, contour lines are more regular and are evenly spaced. Cross section H-H' is a useful reference to visualize the geometry of the coal seams in the south study area.

A3.15 MAP 13. STRUCTURE ON TOP OF BEST 25 M, NORTHEAST AREA (Volume 2 and Figure A-19).

The 25 m window varies in stratigraphic position from portions of the Basal coal zone, to the Drumheller coal, to the Weaver coal zone in the eastern, central and western regions respectively. The best coal development appears to be in the zone of interfingering between the lower Horseshoe Canyon and Bearpaw Formations where the Clover Bar coal zone is well developed.

Depth to the 25 m window may be calculated at any given location using the structural elevation and the surface elevation derived from a topographic map. This structure map is useful to compare with the cumulative coal map of the best 25 m (Map 14).

A3.16 MAP 14. CUMULATIVE COAL IN BEST 25 M, NORTHEAST AREA (Volume 2 and Figure A-20).

This map shows the total thickness of all coal seams within the 25 m window for the northeast study area. As observed in the structure map on the 25 m window (Map 13), the 25 m window has a highly variable stratigraphic position. In the extreme southwestern parts of the study area, the 25 m window appears to

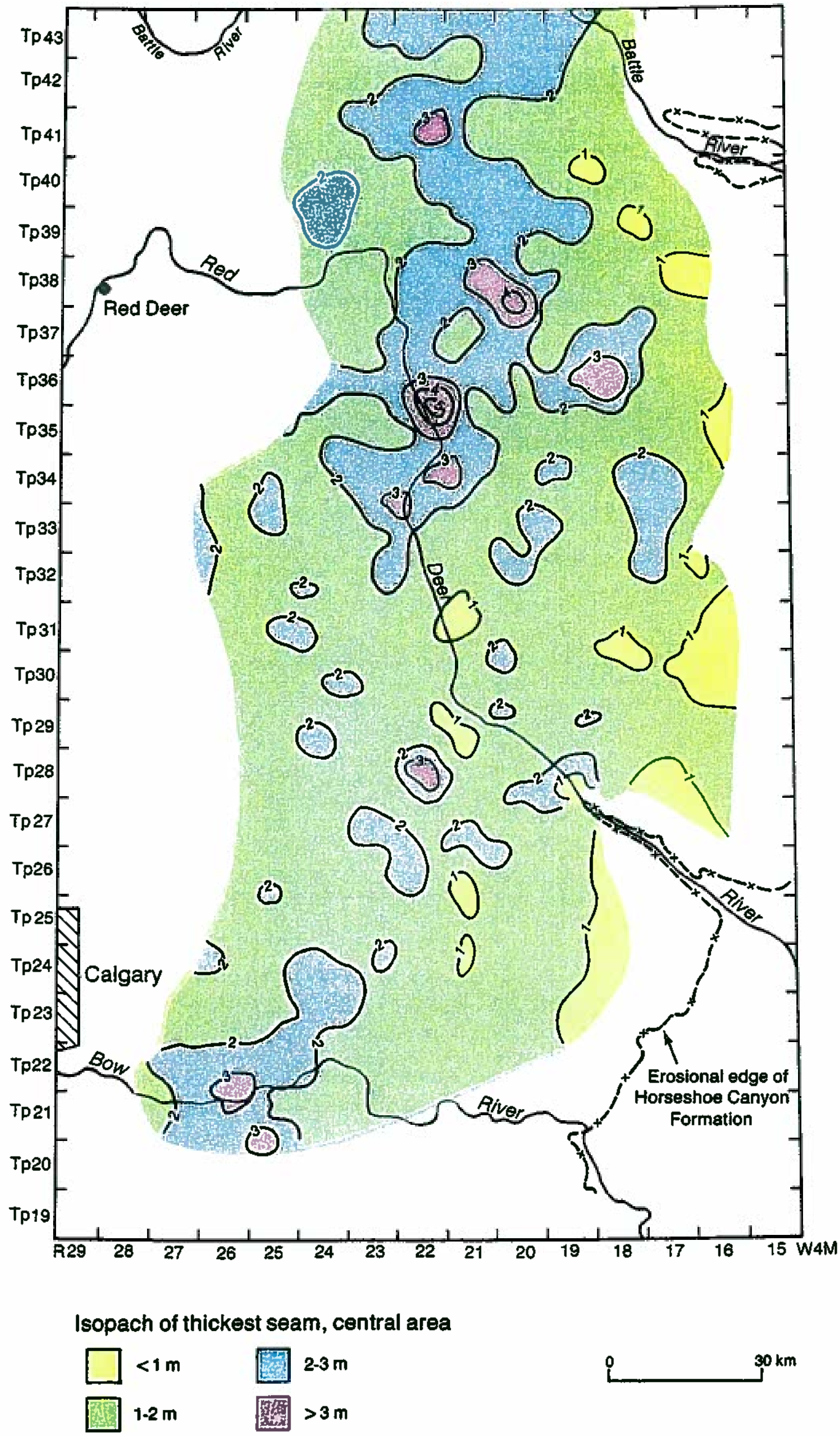

Figure A-17. Isopach map of the thickest coal seam, central area.

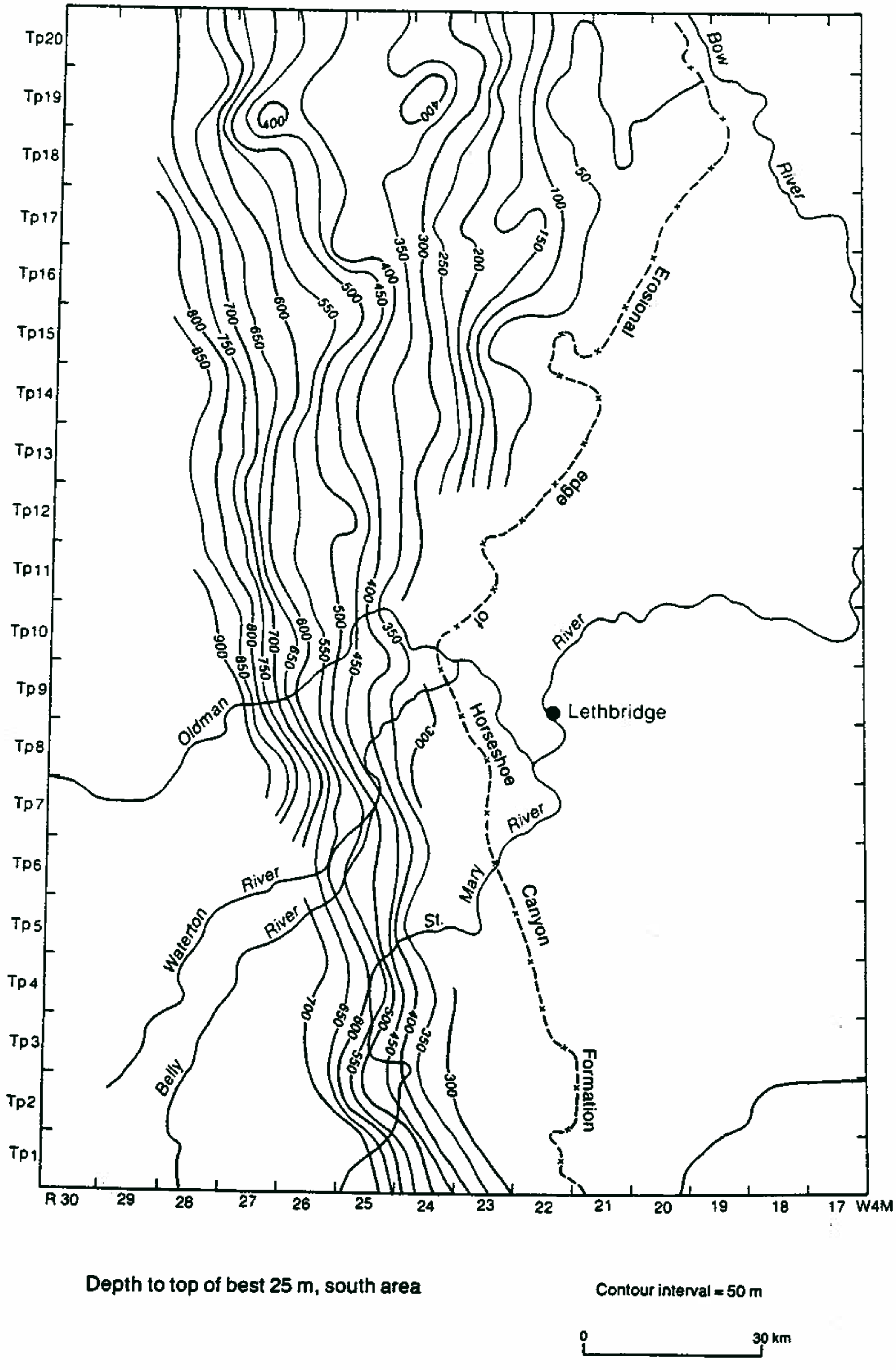

Figure A-18. Depth to the best 25 m window, southern area.

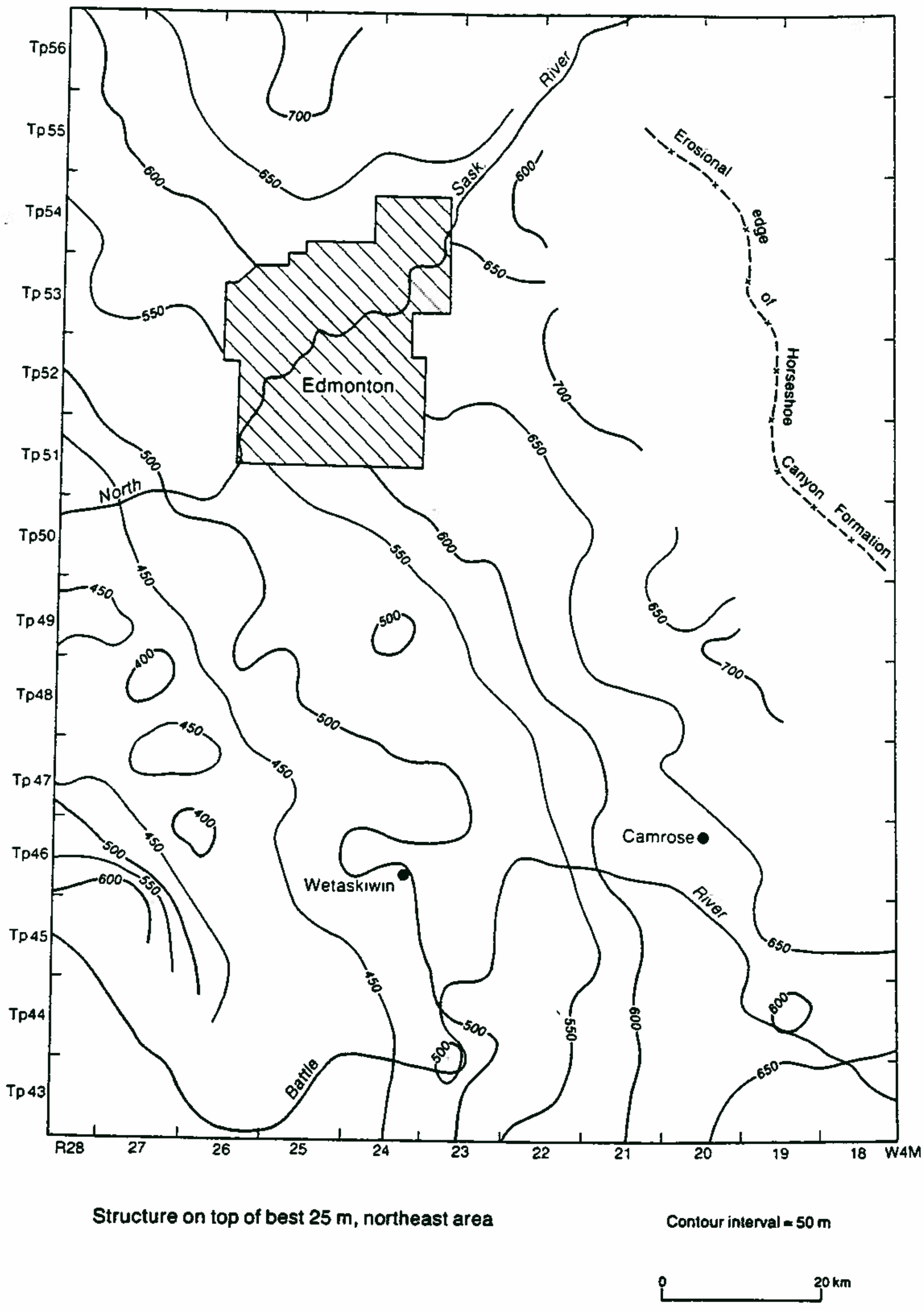

Figure A-19. Structure map on best 25 m window, northeast area.

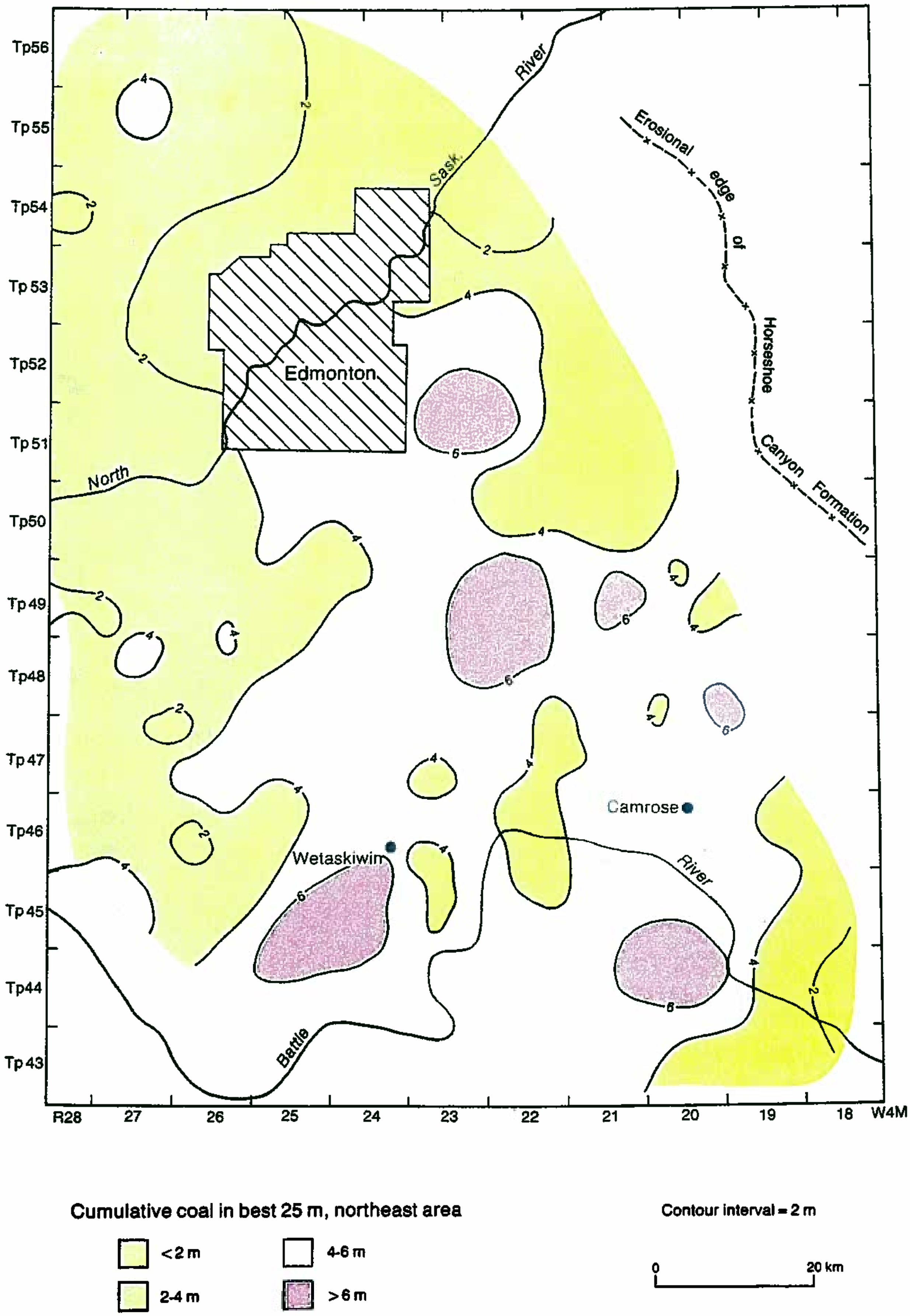

Figure A-20. Isopach map of cumulative coal in the best 25 m window, northeast area.

capture clusters of seams in the Basal coal zone. In central portions of the study area, the 25 m window captures clusters of seams (Drumheller coal zone). Towards the northern parts of the study area, the 25 m window captures more isolated seam developments in the Weaver coal zone.

As predicted from our depositional model, some of the best coal resources in the northeast study area are located in the Drumheller coal zone. The thicker cumulative trends are in the zone of interfingering between the lower Horseshoe Canyon and Bearpaw Formations. The marine influence, represented by sediments of the Bearpaw Formation, however, extends only as far north as Township 52. Areas outside of the marine influence, such as those areas north of Edmonton have cumulative coal values of less than 4 m. Few economic prospects were found in those areas. More economically attractive areas containing thicker cumulative values (4m to 7m) are located south of Edmonton in the zone of interfingering.

A3.17 MAP 15. DEPTH TO THICKEST COAL SEAM, NORTHEAST AREA (Volume 2 and Figure A-21)

This map shows the depth from surface to the top of the thickest coal seam. Coal seams north of Township 52 and along the western edge of the study area are known to be relatively thin and less continuous compared to coals in the central parts of the study area.

A3.18 MAP 16. STRUCTURE ON TOP OF BEST 25 M, NORTHWEST AREA (Volume 2 and Figure A-22)

A series of anomalies along the western portions of the mapping area shows the extreme variation in stratigraphic position of the 25 m window, where relatively discontinuous but locally thick seams are picked up. The position of the 25 m window is much more predictable towards the east and south where the lower Horseshoe Canyon and Bearpaw Formations interfinger.
Cross section A-A' is a useful reference to understand the distribution of coal seams in this area.

A3.19 MAP 17. DEPTH TO THICKEST COAL, NORTHWEST AREA (Volume 2 and Figure A-23)

This map shows the generalized depths from surface to the top of the thickest coal seam. More accurate depths for any given location can by calculated using the appropriate structure and topographic maps.

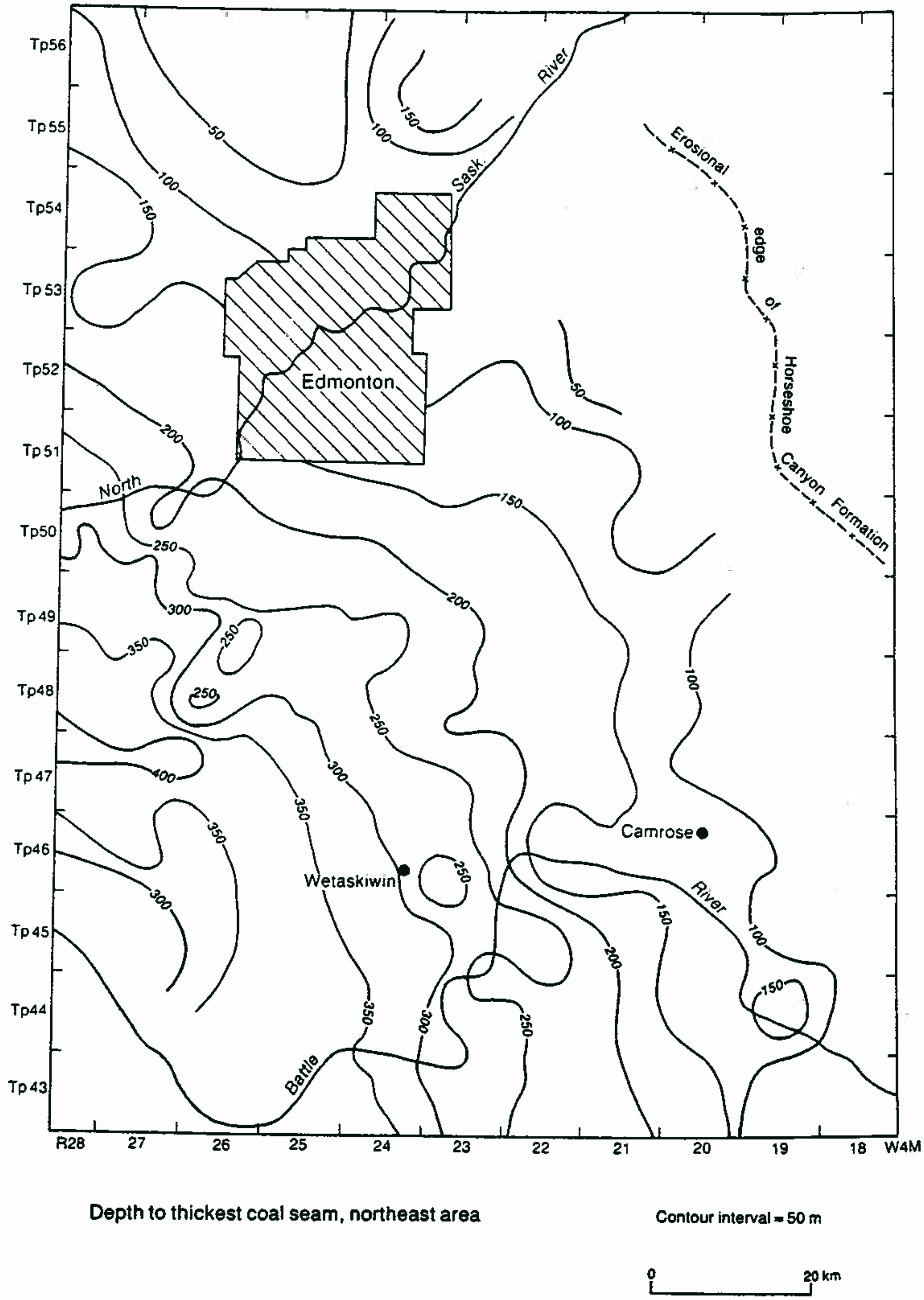

Figure A-21. Depth to the thickest coal seam, northeast area.

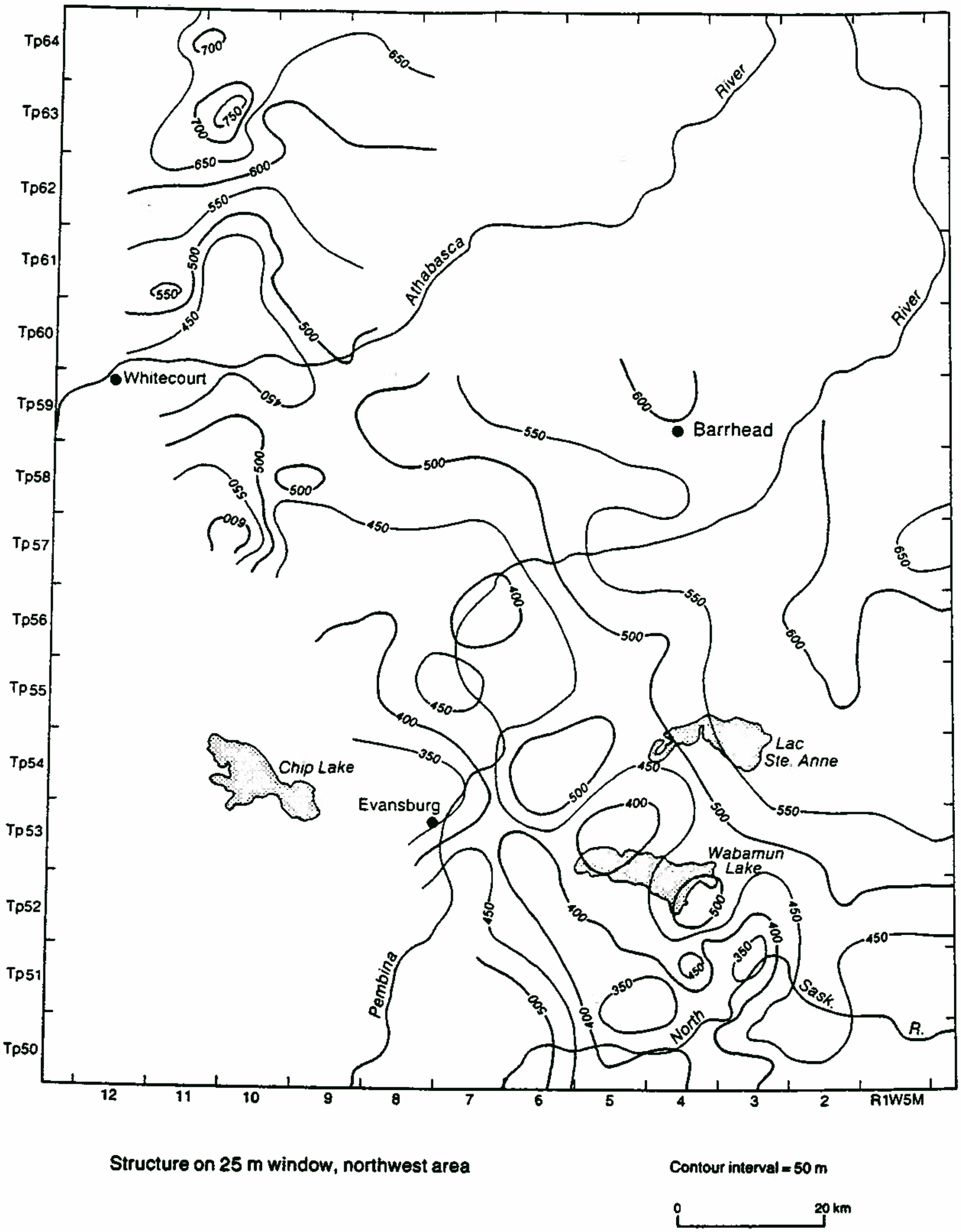

Figure A-22. Structure map on the best 25 m window, northwest area.

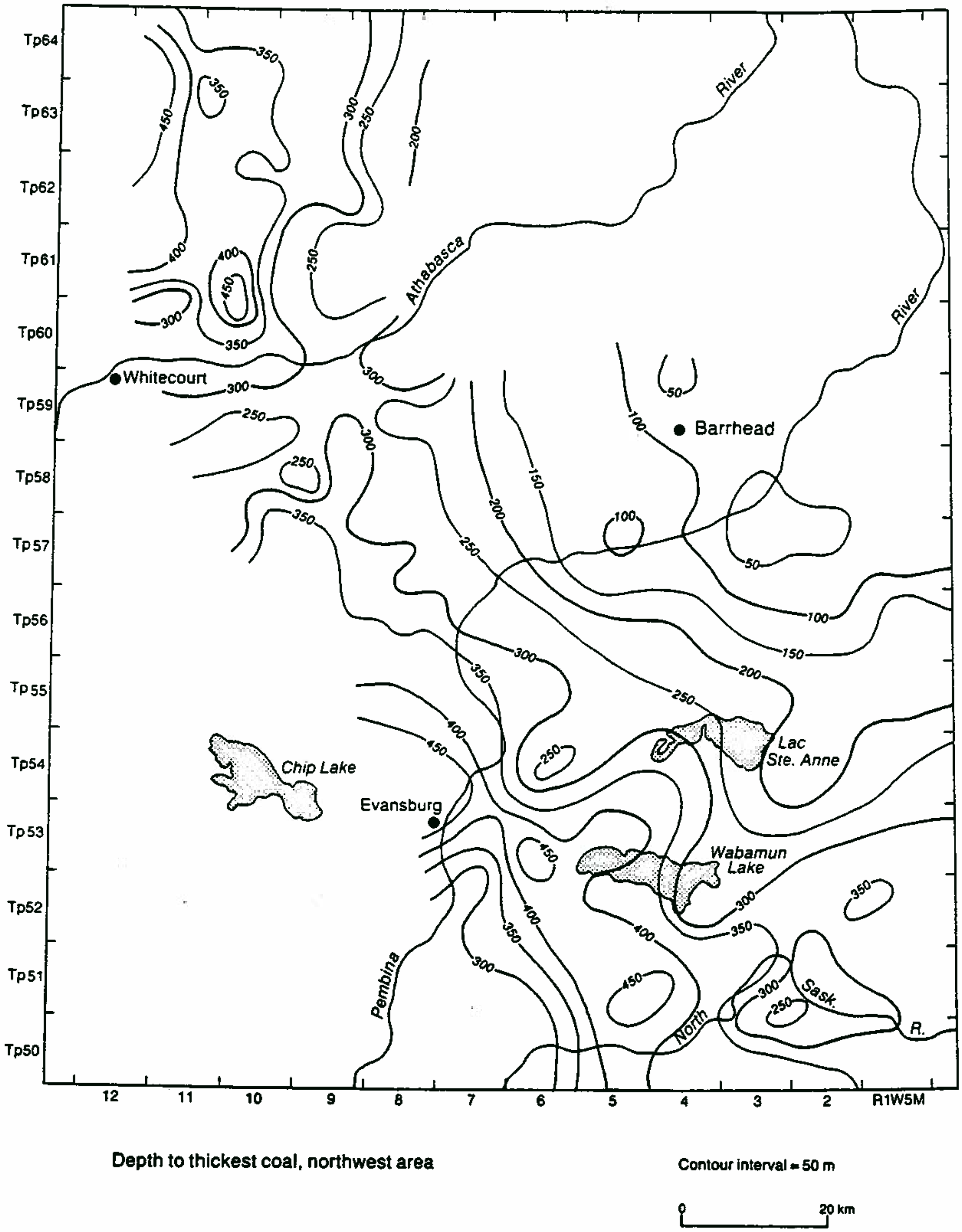

Figure A-23. Depth to the thickest coal seam, northwest area.