An evaluation of the coal resources of the Belly River Group, 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 a depth of about 400 m; and (b) develop an understanding of the sedimentologic and stratigraphic controls of the distribution and geometry of coal seams. This report describes the geological character of coals in one of the major stratigraphic units of the plains region; the Belly River Group. Separate reports describe the geology of other coal-bearing units and present calculated inferred resources for the entire study area.

Coals of the Belly River Group have been of economic interest since the 1870's. Currently the Energy Resources Conservation Board delineates twelve coalfields within strata of the Belly River Group. Prior knowledge about these coals of the group was primarily limited to southern Alberta.

The Belly River Group was deposited during the Upper Cretaceous (approximately 75 million years ago). As a result of mountain building to the west, clastic sediments were deposited progressively eastward through time, infilling a sea that had covered most of Alberta. The Sweetgrass Arch in southern and east central Alberta may well have been an active feature at the time as it appears to have been a control on the position of coal zones.

The Belly River Group is between 200 m and 400 m thick over most of the study area. In the south it is divided into the Foremost and Oldman Formations. Three coal zones are recognized. The McKay zone is the oldest and lies at the base of the Foremost Formation. Coals that lie near the boundary between the Foremost and Oldman Formations are assigned to the Taber zone. At the top of the sequence is the Lethbridge coal zone, which has been the subject of recent industry interest.

In this study data was gathered from geophysical logs of over 2200 oil and gas wells and from 125 logs of shallow coal wells drilled by the Alberta Research Council since 1974. Data were stored and processed electronically in a computer database and a suite of maps was generated that outline the resources of the three coal zones. Various marker horizons were identified: top of the Belly River, top of the Pakowki Formation, top of the Milk River Formation, and top of the Colorado Group. These marker horizons were essential in establishing the framework in which the coal zones are found. Maps were produced showing the structure of each marker horizon, relative to sea level. Stratigraphic and structural cross sections were also constructed to describe the geometry of the coal zones.

The McKay coal zone is present in the study region in a north-south trending belt lying between the towns of Athabasca and Lethbridge. The coal zone is replaced by marine sediments in the eastern and southern regions, and is replaced by continental sediments to the west. Coal seams within the eastern most edge of the north-south trending belt appear to be the most laterally persistent. The total amount of coal within the McKay zone is greatest within the east-central part of the belt, reaching a maximum of 7.0 m. The total amount of coal is directly related to the number of seams within the zone but the thickest seams also tend to be in the same area, reaching a maximum of 2.8 m. In most areas the thickest McKay coal is in the 0.5 to 1.5 m range. Most of the regions of thick cumulative coal, greatest number of seams and thickest individual seams are within 400 m of the present land surface. The most promising areas for future exploration is the region between Townships 12 and 32, within the north-south trending belt. Several locations within this area have more than one seam that exceeds 1.0 m in thickness, however, no area has more than one seam that exceeds 1.5 m within the section. McKay zone coals occupy a position west of the inferred paleo-shorelines that developed at this time.

The Taber coal zone is present over much of the study area but is concentrated in a northwest-southeast trending belt extending from the Edmonton area to the Cypress Hills. To the east the zone is replaced by marine sediments and to the west are continental sediments with few coals. In parts of southern Alberta the zone has been removed by erosion. The main Taber trend is, however, less than 400 m deep.

As in the McKay zone, Taber coal seams are more laterally persistent in the eastern part of the trend. Maximum seam thickness within the Taber zone is up to 2.7 m, but in most areas is 1.0 m or less. Cumulative thickness of coal within the zone has a maximum value of 7.0 m. Maps of cumulative coal thickness show large variations over short distances due to the fact that most seams are variable in thickness and are not laterally extensive.

The distribution and geometry of the Lethbridge coal zone could only be described for a relatively small area due to a number of geological and data availability problems. The zone is absent because of erosion over much of southern Alberta. In oil and gas wells, the zone is extensively cased off in central Alberta. In the area north of Township 40 it becomes difficult to distinguish from the Lower Horseshoe Canyon Formation coals. The Lethbridge zone is relatively thin (10-15 m) and appears to thin and die out south of Lethbridge. The northern, western and eastern limits of the coal zone cannot be established at the present time.

The Lethbridge zone has cumulative coal thickness values that reach a maximum of 5.8 m in the Gleichen - Bassano region, and generally decrease north and south of this area. The number of seams within the Lethbridge zone tend to show a similar relationship to cumulative coal. However, regions of thick cumulative coal do not necessarily have large numbers of seams. Coals within the Lethbridge zone are prone to rapid thickening and thinning over relatively short distances. In most areas the thickest seams within the zone are in the 0.5 to 1.5 m range. In some areas seams are thicker and reach a maximum of 4.9 m north of Lethbridge. Most of the more promising areas, in terms of future coal development, lie at depths of less than 450 m. Several locations in southern Alberta have future potential for coal development based on the presence of thick individual seams.

Coals within the Belly River Group appear to have originated as peats in swamps on coastal plains. In many present-day coastal plains, peat-forming swamps are present some 30 to 60 km inland from the active shoreline. In a seaward direction, the marine influence introduces a large amount of inorganics to swamps. In a landward direction, drainage is usually sufficiently well developed to prevent swamp formation. The position of the coal zones within the Belly River Group appears to reflect these controls on swamp development.

McKay coals formed in coastal swamps associated with the regressive episode that introduced the alluvial sediments of the Foremost Formation into an area previously dominated by the marine sediments of the Pakowki Formation. In opposite fashion, the Lethbridge coals are associated with the marine transgression that introduced the sediments of the Bearpaw Formation to the area after a long period of continental sedimentation. The Taber zone may reflect a smaller transgression towards the end of deposition of the Foremost Formation, preceeding the major regressive episode of the overlying Oldman Formation. Orientations of the coal trends, at least in the McKay and Taber zones, appear to have been controlled by the orientations of the ancient coastlines.

Coals of the Belly River Group are generally thin but are locally thick enough to be considered for mining. The present study has shown that these coals are more extensive than had previously been supposed.

An evaluation of the coal resources of the Belly River Group, to a depth of 400 m in the Alberta Plains

Volume I: Text

D.E. Macdonald, T.C. Ross, P.J. McCabe and A. Bosman

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Alberta Research Council
Alberta Geological Survey

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ABSTRACT

Coals of the Belly River Group were studied over a one-year period as part of a joint Alberta Energy and Natural Resources/Alberta Research Council coal resource evaluation program. The objectives of this program were twofold: (a) to evaluate the coal resource potential south of township 64 and down to a depth of 400 m and (b) to develop geologic techniques to assess the distribution, thickness and continuity of coal seams. Data was gathered from oil and gas well logs and from shallow Alberta Research Council coal well logs. Data was stored and manipulated in a computer database and a suite of maps was generated outlining the coal potential of the three coal zones in the Belly River Group, i.e. Lethbridge, Taber and McKay. Each zone is treated separately and appendices are provided with complete descriptions of all maps and cross sections. Conventional stratigraphic and computer-based structural cross sections were also constructed to show the third dimensional aspect of the coal zones. Geological knowledge about the Belly River coals, before this study, was limited to southern Alberta. With the completion of the present study, a very large additional amount of information on the coals of this geological unit becomes available.

Coals within the Belly River Group have seam thicknesses 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.

Belly River Group coals are thought to have formed from peat swamps in coastal plain environments some distance landward (i.e. westward) of paleoshorelines. The positioning of these shorelines was critical in determining where, and to what extent, these peat swamps would develop, and thus thick coal seams would form.

1. BACKGROUND

1.1 INTRODUCTION

In 1978 the Alberta Research Council, Alberta Geological Survey signed a contract with Alberta Energy and Natural Resources to undertake coal resource evaluations to a 400 m depth in the Alberta plains region. The Belly River Group was identified as one of the coal-bearing sequences to be evaluated. This study deals primarily with the deep coal resource potential and with the stratigraphic, sedimentologic and depositional environments of the Lethbridge, Taber and McKay coal zones.

1.2 ACKNOWLEDGMENTS

The writers would like to express their appreciation to R. Richardson and B. Untergasser for their critical reading of the manuscript. R. Strobl provided very useful discussions on the project. Constructive comments were also received from R. Marsh and T. Yoon. L. Swensen, L. Monteleone, F. Lister, and M. Prentice provided technical assistance on the project. The Graphics Services Department of the Alberta Research Council produced the final maps and cross sections. Maureen FitzGerald and Helen Williams typed the manuscript.

1.3 PREVIOUS WORK

The Belly River coals were first described by Dawson (1880), however the first description of the three coal zones in their proper stratigraphic context was by Dowling (1917). Williams and Dyer (1930), and later Russell and Landes (1940), described the regional geology of southern Alberta, and described several coal-bearing sections in the Belly River Group. Crockford (1949) seems to have been the first to introduce the terms; Lethbridge member or coal zone, Taber coal zone, and McKay coal zone. McLean (1971) described the subsurface stratigraphy of the Belly River Group, suggested a name change to the "Judith River Formation", and made some speculations on the coal depositional environments. In the early 1970's the Alberta Research Council produced a series of reports on the coal geology of the Belly River Group. Campbell (1972) described the resource potential of McKay equivalent coals from the Athabasca-Smith area of northern Alberta. Campbell (1974) reported on Belly River Group coals from the Taber-Manyberries area, as a result of a shallow drilling program jointly funded by industry and the Alberta Research Council. Yurko (1975) was the first to look at Belly River Group coals on a regional basis, utilizing oil and gas well data, and produced a series of maps showing the cumulative coal, number of seams greater than 5 ft, and depth to the top of the coal zone. Yurko concluded that Belly River Group coals had their best potential in southern Alberta. Holter and Chu (1977) studied the coal resources of southern Alberta; particularly those of the Belly River Group. Their work was based on an Alberta Research Council deep drilling program (depth to 300 m). Wells were drilled on a one well/township basis; however, only about 28 townships were investigated. Ogunyomi and Hills (1977) described the sedimentology and inferred depositional environments for the Foremost Formation and Taber coal zone in the Milk River canyon area of southern Alberta. Koster (1983) described the sedimentological setting of the Oldman Formation at Dinosaur Provincial Park, and made some preliminary speculations on the environments of deposition of the Belly River Group coals. Koster (1987) provides a more detailed sedimentologic interpretation for the coarse clastics of the Oldman Formation.

1.4 ECONOMICS AND MINING OF BELLY RIVER COALS

The mining of Belly River Group coals began in 1872 near Lethbridge, reached its peak in the early 1920's, and came to a close in 1974. Mining was confined to southern Alberta primarily in the Lethbridge and Taber areas, with over 400 mines in operation at times during this period (ERCB, 1985). In the early 1980's, Petro Canada and Fording Coal applied for underground mining leases in the Lethbridge area to exploit coal from the Lethbridge coal zone (Livingstone 1985).

The ERCB describes twelve potentially surface-mineable coalfields in southern Alberta, most of which would be from Belly River Group coal zones.

1.5 NATURE OF THE PRESENT STUDY

The present study evaluates coal resources to a depth of 400 m (1200 ft). south of township 64 within the Belly River Group and developes sedimentologic and geologic techniques to predict distribution, thickness, and continuity of coal seams (ENR/ARC contract).

This study utilized some 2200 oil and gas well logs, in addition to approximately 125 Alberta Research Council coal testholes. An attempt was made to collect a minimum of 2 wells/township from the oil and gas well logs. This criteria was met throughout the area except between townships 52 and 64 were sparse well density provided only one well/township. Wells were collected westward until the top of the Belly River Group was deeper than approximately 400 m. As a result, data for the Lethbridge zone stops at about 400 m depth; however, data on the two lower coal zones (i.e.Taber and McKay) extend somewhat deeper. Four core holes, drilled by the Alberta Research Council in 1983, have also been incorporated into the present study. Oil and gas well log data starts from the geographic area downdip from the subcrop edge by some 20 to 50 km, depending on the steepness of the regional dip. This is because of casing being set to depths of up to 200 m or more in oil and gas wells. Alberta Research Council wells are most often located in this 20-50 km wide band where no oil and gas data are available due to casing. Some outcrops were examined during the course of this study. Coal exploration data could not be incorporated into the present study because of project timing.

The area examined lies between townships 1 and 64, west of the fourth meridian. The western boundary of the study area was delimited by the 400 m depth and the eastern boundary was set by the point at which the lowermost coal zone i.e. the McKay zone became cased off (figure 1).

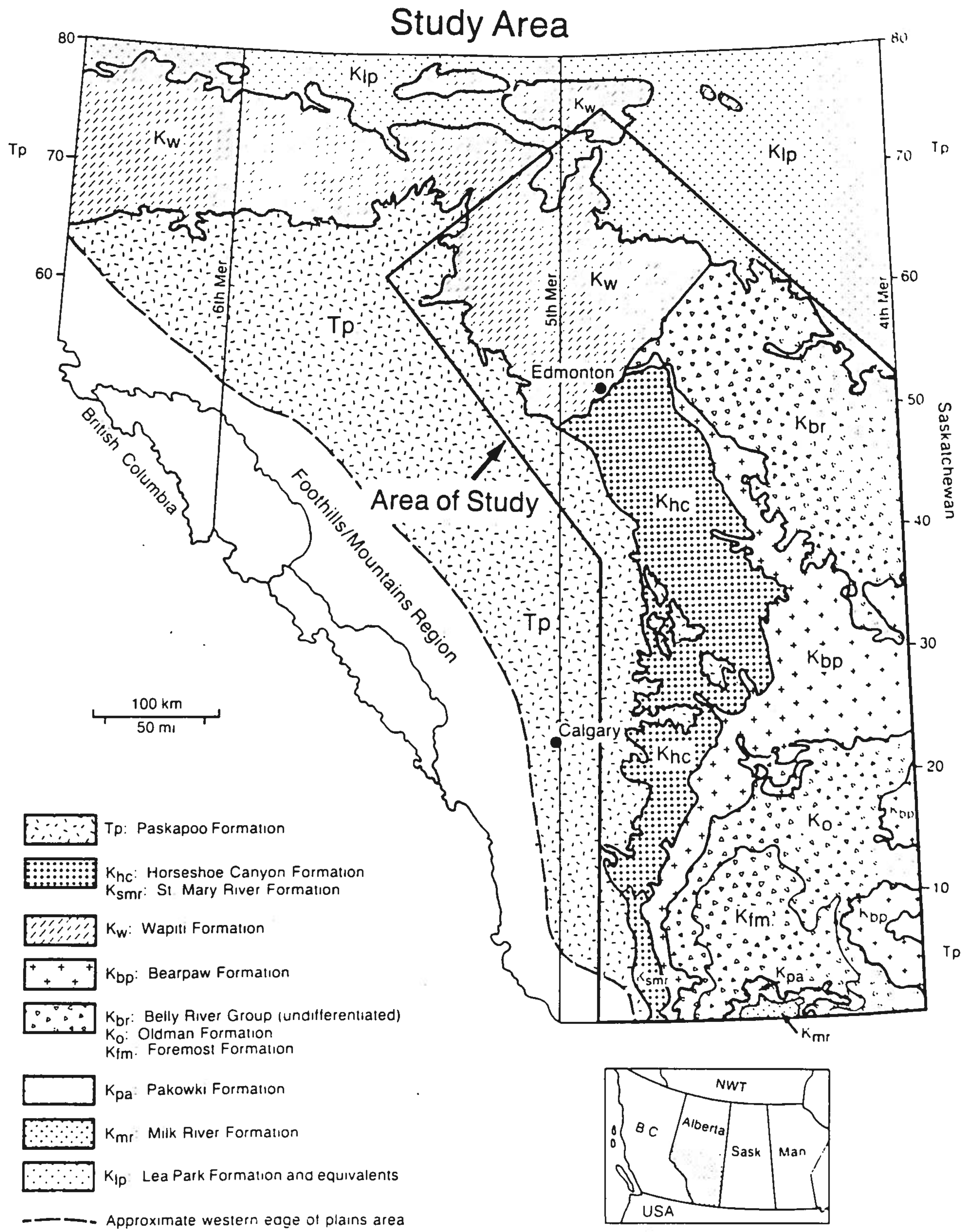

Figure 1. Study area and generalized geology.

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1.6 METHODOLOGY

This project began by constructing 24 regional stratigraphic cross sections using the oil and gas well logs and the Alberta Research Council well logs. This was done to establish the regional stratigraphic framework, reliable marker horizons, locate the major coal zones, and to learn how the individual coal seams should be correlated. The next step was to gather marker and coal picks, location data, and potential gas zones from the well log data. Geologic picks included the top of the Belly River Group, base of the Belly River Group (or top of the Pakowki Formation), top of the Milk River Formation, and top of the Colorado Group. Coal picks were made based on the following criteria: 1) minimum seam thicknesses picked was 0.5 m (deemed to be the resolution limit of these logs), 2) splits within seams that were less than 0.5 m were ignored, 3) top and base of seam based on approximately 1/2 the horizontal distance on the gamma ray curve, and 4) all coals from Alberta Research Council wells were picked, regardless of their thickness (better resolution from coal logs made this possible.) Well logs used to pick coals and formation tops included gamma ray, resistivity, caliper, and one type of porosity logs (sonic, density-neutron). The data was then entered into a database (DATATRIEVE), and a first suite of maps was generated to help purge the database of errors. Fortran programs were used to generate the necessary raw data files, which in turn were used to construct the various computer-generated maps. The computer programs for calculating the cumulative coal and number of seams data for use in the maps were constructed so as to be able to distinguish true zero values i.e. for geological reasons (represented by zeros "0.0" on these maps), from missing data values (-1 on maps) due to casing problems. This was accomplished by making the following assumptions: 1) the thickness of the Colorado Group to the top of the Belly River Group is approximately 500 m, 2) the thickness of the Colorado to the top of the Taber coal zone is approximately 380 m and 3) the thickness of the Colorado Group to the top of the McKay coal zone is approximately 250 m. These assumptions were found to be reasonable throughout most central and western parts of the study area, but become less valid towards the east. Well location and value postings were done using an in-house geographic positioning program - GEOPLOTTER, while the values were contoured using the Kansas Geological Survey mapping package SURFACE II.

2. GEOLOGICAL FRAMEWORK

2.1 STRATIGRAPHIC NOMENCLATURE

A great deal of debate has surrounded the nomenclature of the Campanian clastic wedge sequence referred to in this report as the "Belly River" (McLean 1971, McLean 1977, etc.). McLean argues that the term "Judith River", used in Montana for the equivalent strata, should be applied in Alberta (figure 2), to reduce confusion. In the context of this report it was decided to use the well known Canadian names Belly River Group, Foremost Formation, Oldman Formation and Wapiti Group (figure 2) as these names are most familiar to the coal industry. The Belly River Group has for a long time been divided into an upper coarse clastic unit (Oldman Formation or Pale beds) and a lower finer-grained unit (Foremost Formation) throughout much of southern Alberta (Russell and Landes 1940, McLean 1971 - units II and III).

The top of the Belly River clastic wedge is marked over much of central, southern and, to some extent northern Alberta, by the Lethbridge coal zone. The middle of the clastic wedge, or top of the Foremost in southern Alberta, is marked by the Taber coal zone, while the base is defined by the McKay coal zone (figure 3).

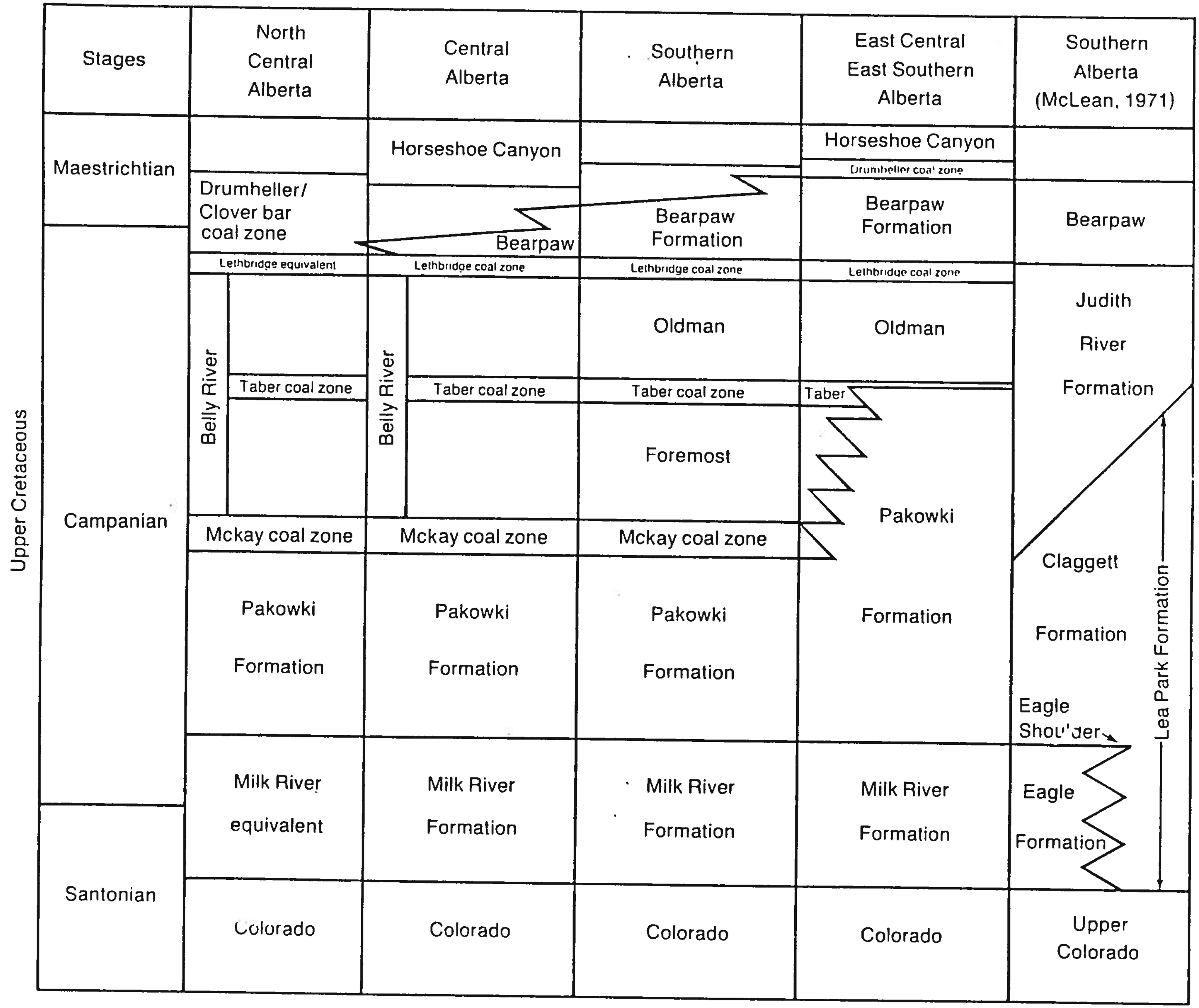

Figure 2. Nomenclature adopted and regional correlation chart.

U # 2

Some problems with these generalities occur. North of about township 30, the Oldman and Foremost Formations can not be recognized and the general term "Belly River Formation" is adopted (Green, 1972). North of about township 54, the distinction between the entire Belly River Formation and the Horseshoe Canyon Formation becomes problematic due to the absence of any intervening marine strata (Bearpaw Formation), and the general term Wapiti Group is applied (Green, 1972). In the context of this report it was felt that Belly River-equivalent strata could be recognized in this northern area, based on the first appearance (going up section) of the Lethbridge or Drumheller coal zones. In this same general area, the Lethbridge coal zone merges with the lower Horseshoe Canyon Drumheller coal zone (McCabe, et al. 1986), making any distinction between the two coal zones difficult (figure 4). Therefore, within this report, Lethbridge - equivalent coals north of about township 45 are not being reported (see McCabe et al., 1986). In spite of these nomenclatural difficulties at townships 30 and 54, the three coal zones, when present, continue to occupy approximately the same stratigraphic level throughout the study area.

Coals in the Belly River Group are also known to crop out in the Foothills region of south-western Alberta (ERCB, 1986). The Bob Creek, Cowley, Lundbreck, Waterton River and Lee Creek isolated deposits and occurrences (ERCB, 1986) are all found in the Belly River Group strata within the foothills. The Lundbreck deposit, at least, is from the Lethbridge coal zone.

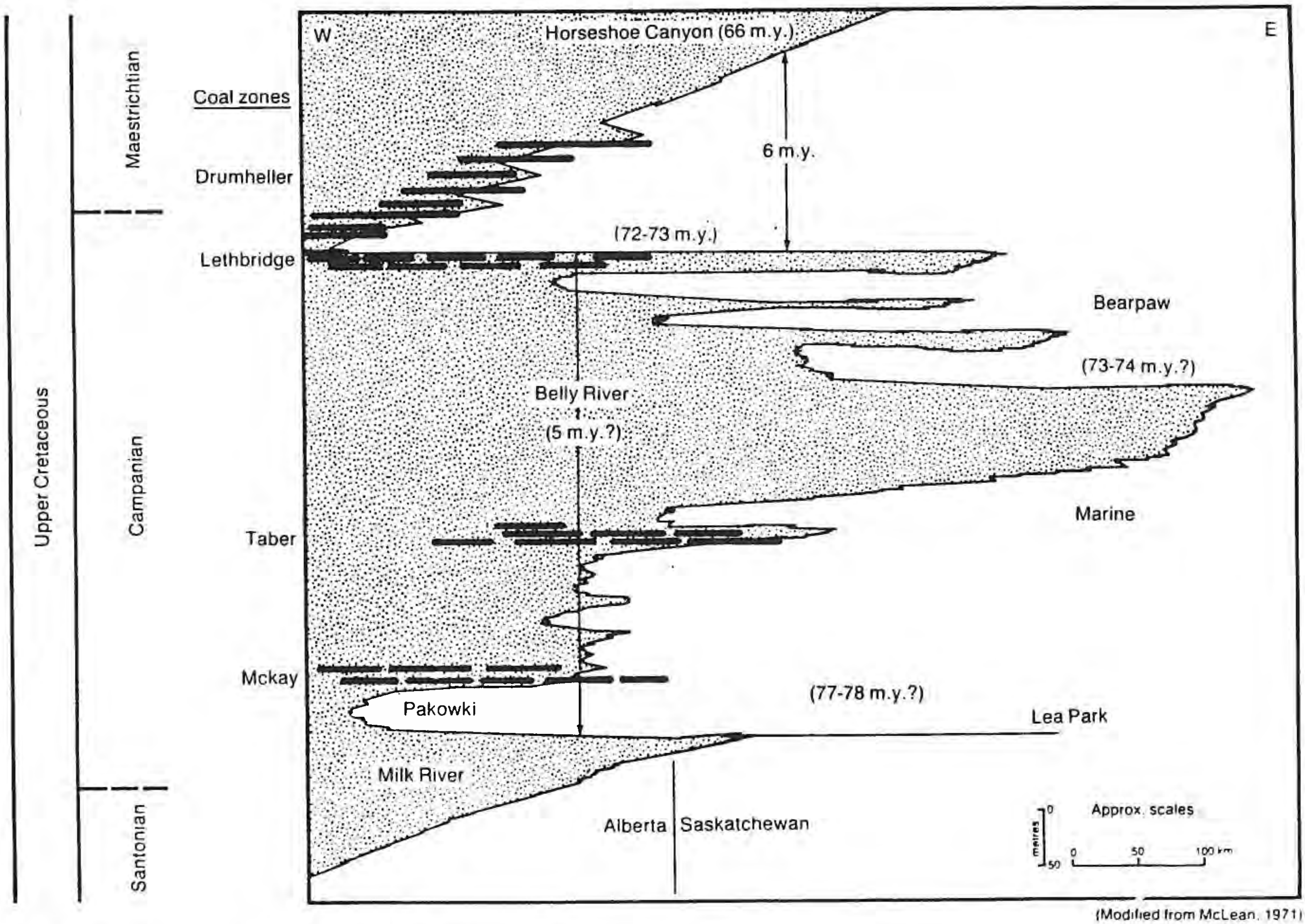

Figure 4. Schematic cross section of the Belly River clastic wedge.

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2.2 REFERENCE SECTION, COAL ZONES AND MARKER HORIZONS

2.2.1 Reference Sections

Two reference geophysical logs have been included to show the various markers, formation picks, coal zones, nomenclature and typical log response (see figure 3 and 5). Reference section A is from the northern part of the study area (10-9-49-21W4) and shows the difficulty in distinguishing the Belly River Formation from the Horseshoe Canyon Formation in this area. Reference section B (figure 5) is from the southern part of the study area (16-3-23-17-4W4) and shows the typical log response for relevant formations and coal zones.

2.2.2 Marker Horizons And Coal Zones

2.2.2.1 Belly River Group marker

The top of the Belly River Group, where identifed, is based on recognition of either a marine sequence separating the Horseshoe Canyon Formation from the Belly River Group and/or the presence of the Lethbridge coal zone (figure 5). Marine sequences are identified by low resistivity flat responses and/or gamma-ray upward-coarsening sequences. Marine sequences overlying the Belly River Group are easily recognized south of about township 40, but north of this point it becomes increasingly difficult. A coal or a coal zone at about the stratigraphic level of the Lethbridge coal zone is, however, very widespread throughout the area.

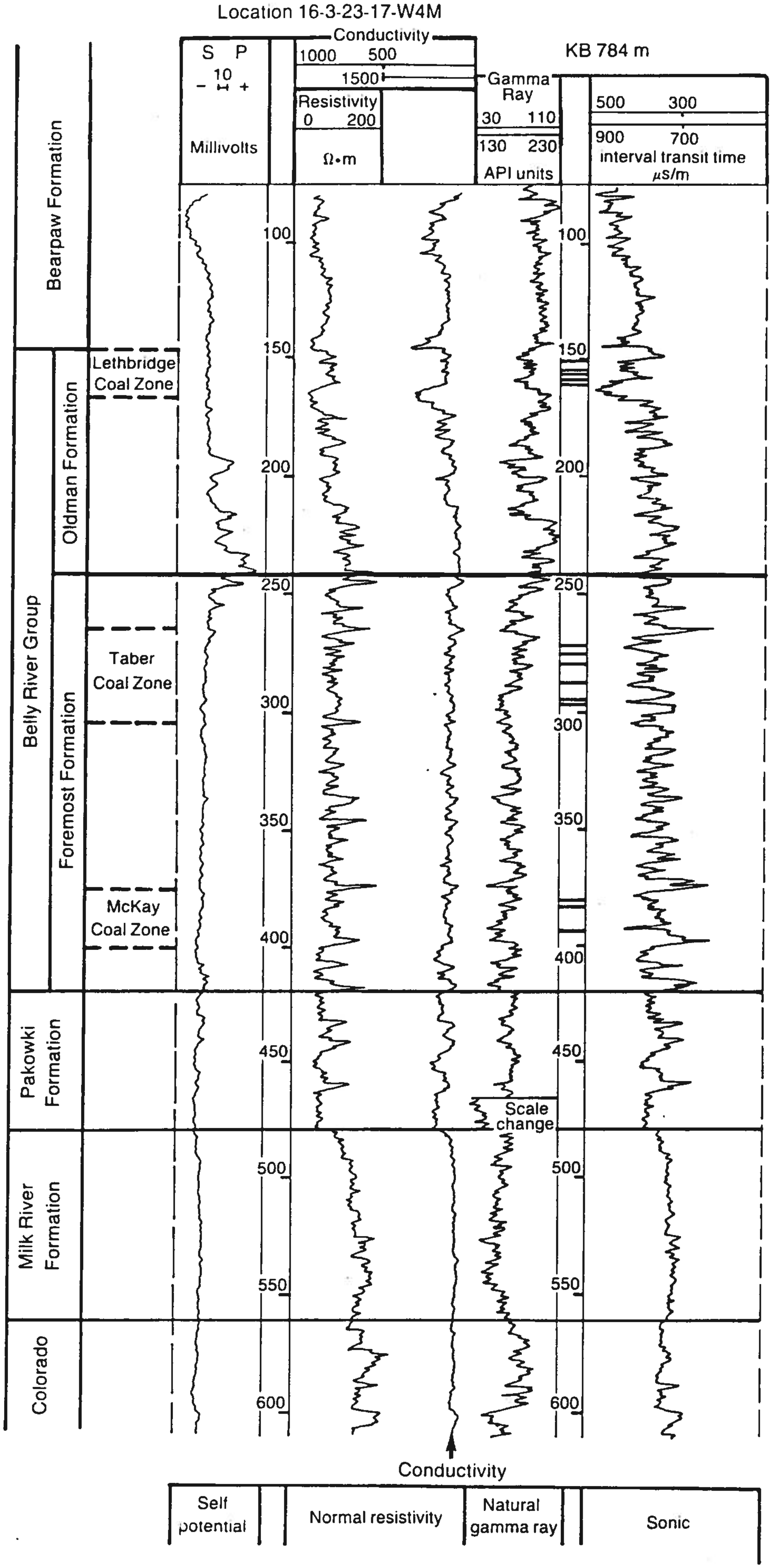

Figure 5. Reference geophysical log B, southern Alberta.

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2.2.2.2 Lethbridge coal zone

The Lethbridge coal zone is easily recognized south of township 40 by its stratigraphic position at the top of the Belly River sequence; and a high resistivity, low gamma-ray, high porosity log response (figure 5, log B). A very low resistivity, high conductivity 10-20m thick shale commonly overlies the Lethbridge coal zone, producing a very distinct cuspate shape on the electric and induction logs. Alberta Research Council corehole 4-83 (NE-31-16-17W4), from the Brooks area, shows this interval to be a massive mudstone, with occasional bentonitic ash layers, and containing marine invertebrate remains. The strata below the Lethbridge coal zone (McLean's 1971, unit IV?) consist of a predominantly fine grained unit with minor interbedded sandstones and up to 6 bentonitic ash layers. These ash horizons are very distinctive on the induction log and stand out as distinct spikes to the left. Alberta Research Council corehole 3-83 (3-34-17-16W4) shows this bentonitic ash zone to consist of a series of 1-2m thick, scour based, ripple laminated sandstones with interbedded mudstones of about the same thickness. These mudstones are massive and display many paleosol structures such as roots, peds, and lime accumulation horizons.

2.2.2.3 Taber coal zone

The Taber coal zone lies approximately midway within the Belly River clastic wedge sequence. In those areas were the Oldman Formation is distinguishable from the Foremost Formation, the Taber coal zone lies at the top of the Foremost Formation (figure 5). The Taber coal zone is the second major coal zone above the Pakowki contact in the central and western areas, and the first major coal zone above the same contact in the easternmost wells. In extreme eastern regions near the Saskatchewan border, the Taber coal zone appears to be replaced by marine sediments of the Pakowki/Lea Park Formations (figure 4).

2.2.2.4 McKay coal zone

The McKay coal zone lies at the base of the Belly River clastic wedge sequence in the western and central areas, and is replaced by marine strata of the Pakowki Formation in the eastern regions (figure 4 and 5). This was first reported by Holter and Chu, 1977. The zone generally overlies a very thick (25-30 m), upward-coarsening sequence within the Pakowki Formation, with the lowest coal sitting on a basal sandstone (basal Belly River gas sands in some areas). These general recognition criteria become less reliable in the east were the McKay zone gradually becomes replaced by marine sediments. In this zone, several tongues of continental (or shallow marine) coarse clastics interdigitate with finer marine sediments. It is not uncommon to find an isolated or transgressed coal within a predominantely marine sequence.

2.2.2.5 Top of the Pakowki Formation marker

The top of the Pakowki Formation is a difficult pick because of the aforementioned interdigitation of marine, near-shore marine, and continental sediments. For the purpose of this study, the top of the uppermost shale (going upsection), of assumed marine origin, was chosen as the top of the Pakowki Formation (figure 3).

This shale appears on the resistivity log as a low, flat response and on the gamma-ray as a high zone. It is often, though not always, found in association with an upward-coarsening cycle (figure 3 and 5). The Belly River clastic wedge can easily be mapped, by using the top of the Pakowki Formation as the base of the Belly River Group, however, as a result, some of the previously mentioned transgressed coals will not lie, strictly speaking, within the Belly River Group.

2.2.2.6 Milk River Formation marker

The Milk River Formation pick is very distinctive over most regions except in the north. This pick is distinguished on most logs by an abrupt decrease in resistivity, which tends to form a shoulder on the resistivity log, a flat conductivity response followed by a sharp increase at the contact, and by a sharp decrease in the gamma-ray log at the contact (all criteria relative to an upsection view, see figure 3 and 5). The Milk River Formation over much of southern Alberta consists of a continental clastic sequence of interbedded sandstones, mudstones and minor coals. The high gamma-ray response is somewhat anomalous, and may reflect a high K-feldspar content.

The Milk River Formation is generally not recognized in central and northern Alberta, with the term Lea Park Formation being used to describe those sediments between the top of the Colorado Group and the base of the Belly River Group. Within the context of this study; however, the Milk River geophysical marker could be identified throughout the area and the terms Milk River Formation and Pakowki Formation retained (figure 2).

2.2.2.7 Top of the Colorado/First White Speckled Shale

The "First White Specs" are well known throughout the Alberta Basin as a resistivity inflection, below the Milk River (going down section). This inflection point yields a shoulder on the resistivity log. The First White Specs are also characterized on the gamma-ray log by a sharp increase in log response at the contact (see reference log A, figure 3). This pick was found to be very reliable and easily mapped over the entire area (figure 6).

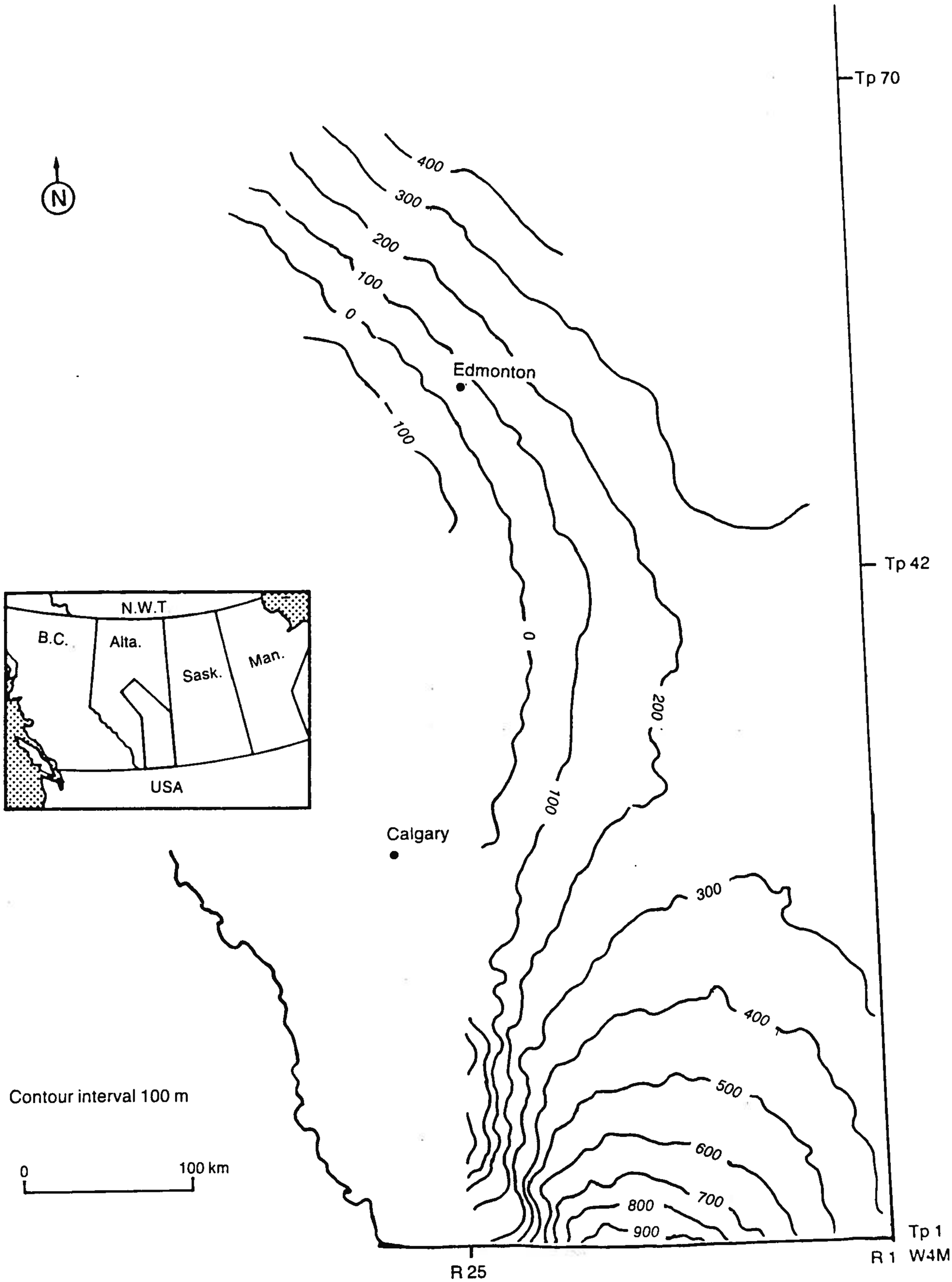

Figure 6. Structure on the Colorado Group.

J # 5

2.2.3 Tectonic Setting

The Belly River regressive clastic wedge sequence was deposited into the Alberta foreland basin throughout Campanian time (figure 5) 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 (figure 7). These shoreline sequences may be related to the arch, controlling the position of shorelines throughout most of "Foremost time". The control of shoreline positions has in turn influenced on where peat, and later coal seams, will develop.

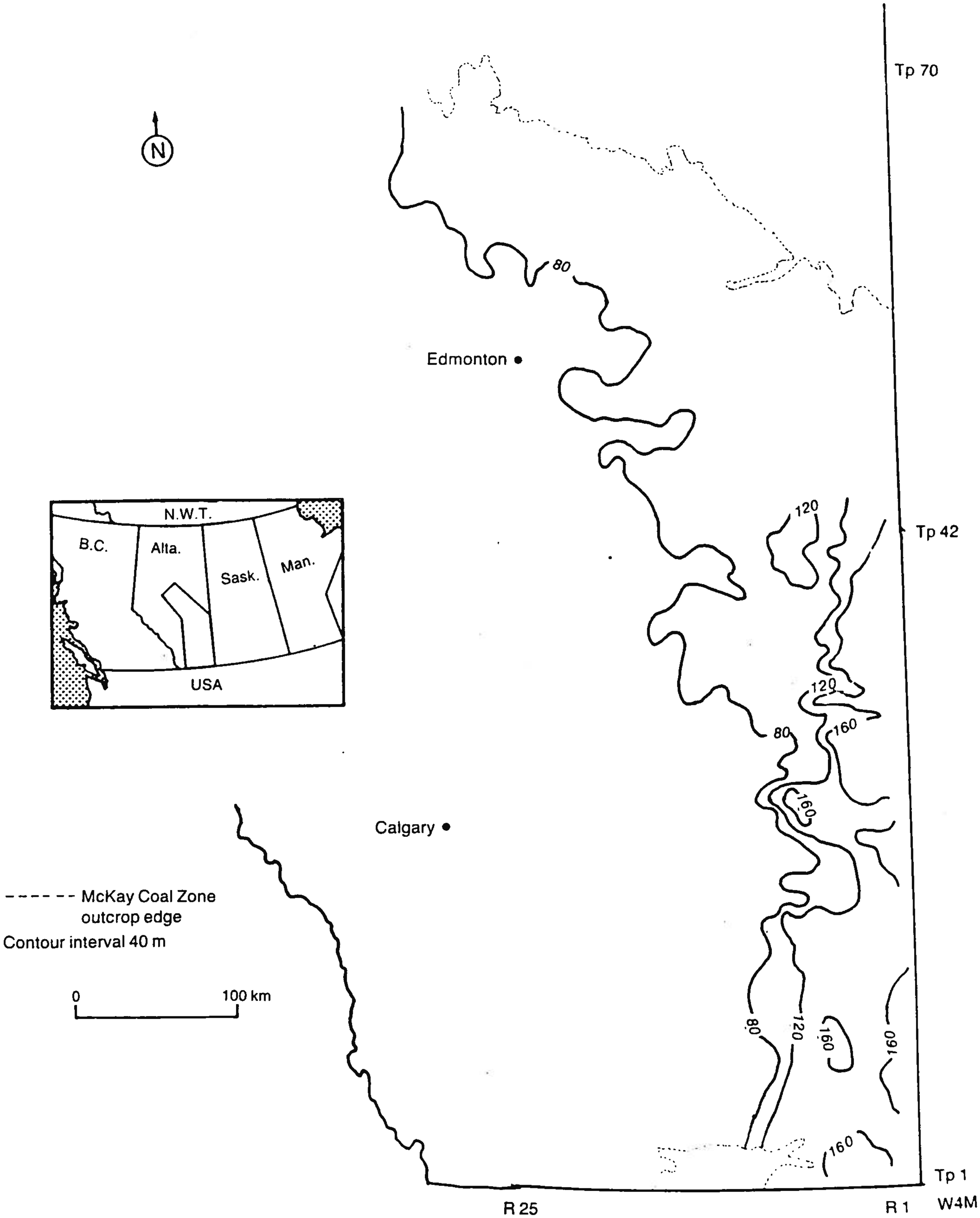

Figure 7. Isopach of the Pakowki Formation.

U # 6

3. RESOURCE EVALUATION

3.1 INTRODUCTION

The deep subsurface coal resources of the Belly River Group, within the three major coal zones; McKay, Taber and Lethbridge are discussed in the following section. The zones are discussed from oldest (i.e. McKay) to youngest (Lethbridge).

3.2 MCKAY COAL ZONE

3.2.1 Distribution And Geometry Of Zone

The McKay zone is generally present throughout the study area. The zone is not present east of the region where the previously discussed stacked shorelines occur (figure 8). This is a result of a facies change from continental coal-bearing to marine non-coaly strata. This facies change is fairly well defined in the southern region by the Pakowki Formation isopach map (figure 7), but is less clear north of about township 54. In the northern region, the coal zone is in part replaced by Lea Park Formation/ Pakowki Formation marine sediments and in part steps up to a higher stratigraphic level above the shoreline deposits (figure 9). This latter feature of the coal zone migrating up section is not seen in the south. 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 13W4 and ranges 19 to 23W4. 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.

The stratigraphic cross sections (volume II) show that along the easternmost edge of the data distribution, in the northern area, individual coal seams within the McKay have the best correlation potential. In the south, the region of best seam correlation lies within about 4-5 townships west of the zero contour line as shown on map 3 (i.e. west of the seaward pinch out of the zone).

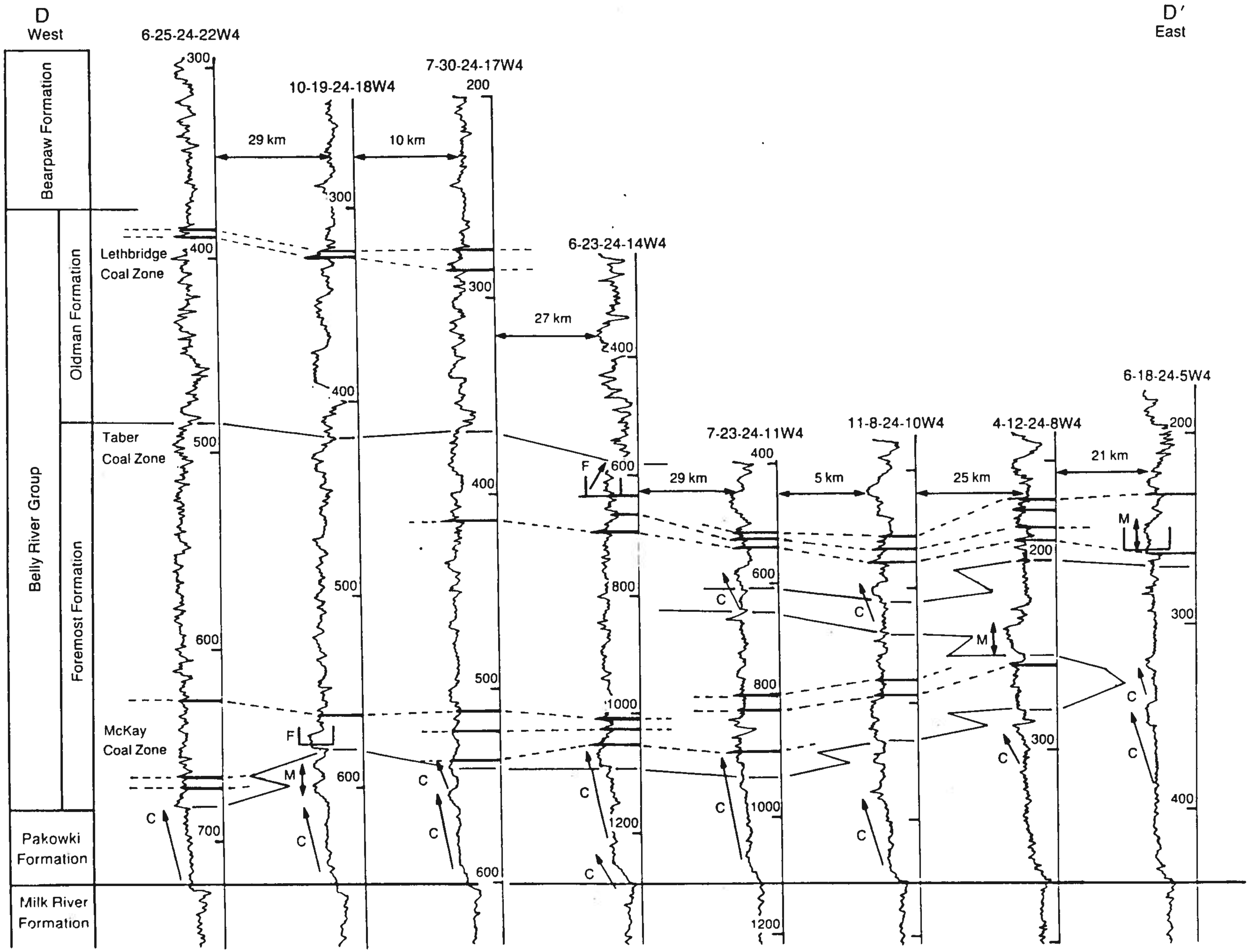

Figure 8. Stratigraphic cross section D-D′.

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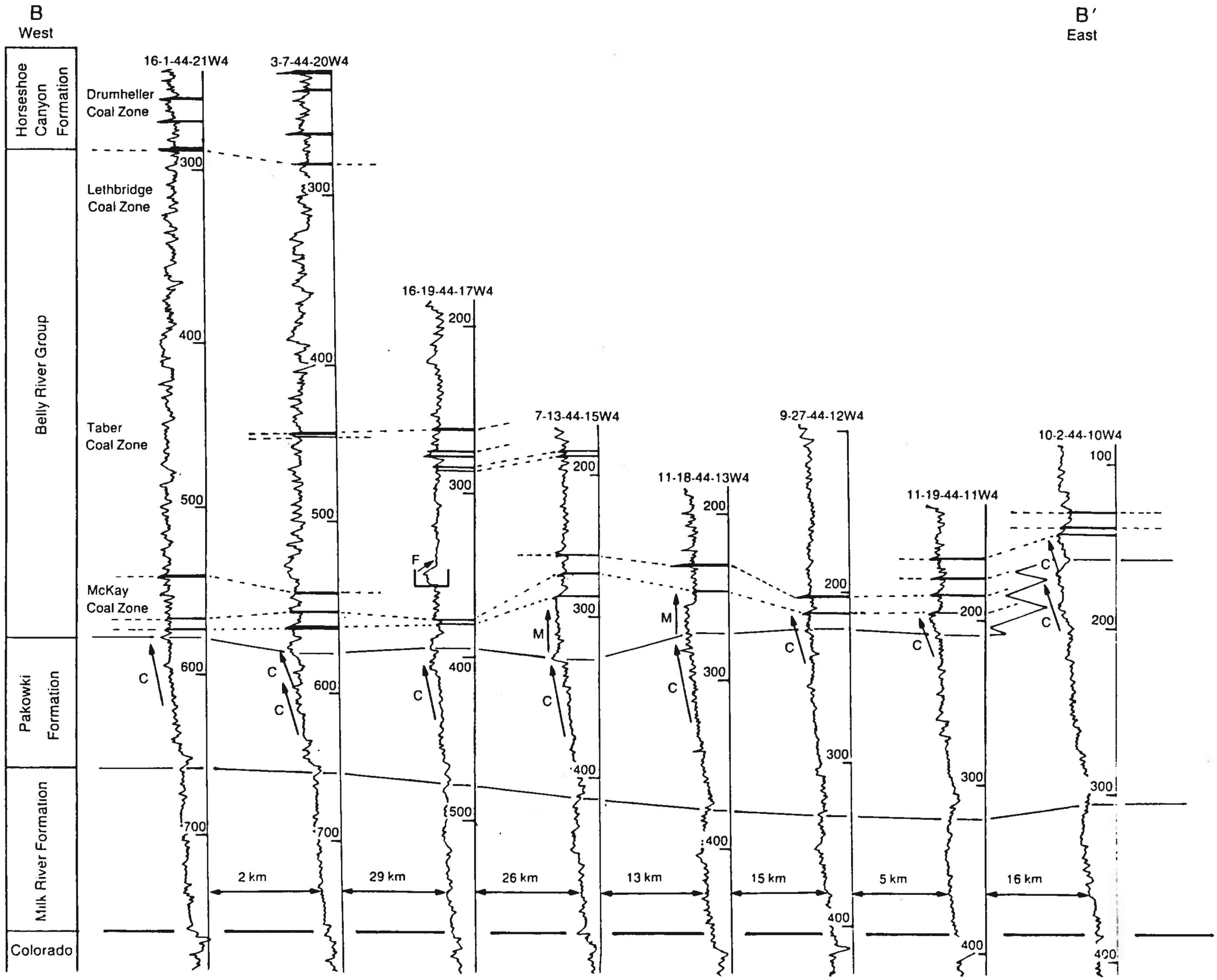

Figure 9. Stratigraphic cross section B-B′.

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3.2.2 Thickness And Number Of Seams

The McKay coal zone has an total coal thickness (termed cumulative coal, this report) that varies from 0.5 to 7.0 m (figure 10 and map 3). 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 (figure 10) 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 (volume II) show a similar trend in the number of seams, and thickness 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 disapears in the area around townships 55 to 58 (figure 10).

The number of seams map (map 4), when compared to the cumulative coal map 3 shows a nearly one-to-one relationship of thick cumulative coal versus greater number of seams. The regions of thick cumulative coal would, therefore, seem to be more related to increased numbers of seams having developed rather than the thickening up of individual seams. The number of seams map can also be used to point to areas were seams within the zone may easily be correlated. Large geographic areas that have a constant number of seams are often more correlatable.

The isopach of thickest seam map (map 5) shows the thickness of the single thickest seam within the zone. The map has been contoured to show an areal distribution of this property; however, the values shown at any two given wells may not necessarily be the same coal seam. They will both be from the McKay coal zone though. Map 5 shows that the maximum seam thickness throughout the McKay zone is 2.8 m (Tp 15, R 21), but in most most locations the maximum thickness is between 0.5 and 1.5 m. A number of isolated locations have maximum thicknesses between 2.0 and 2.5 m.

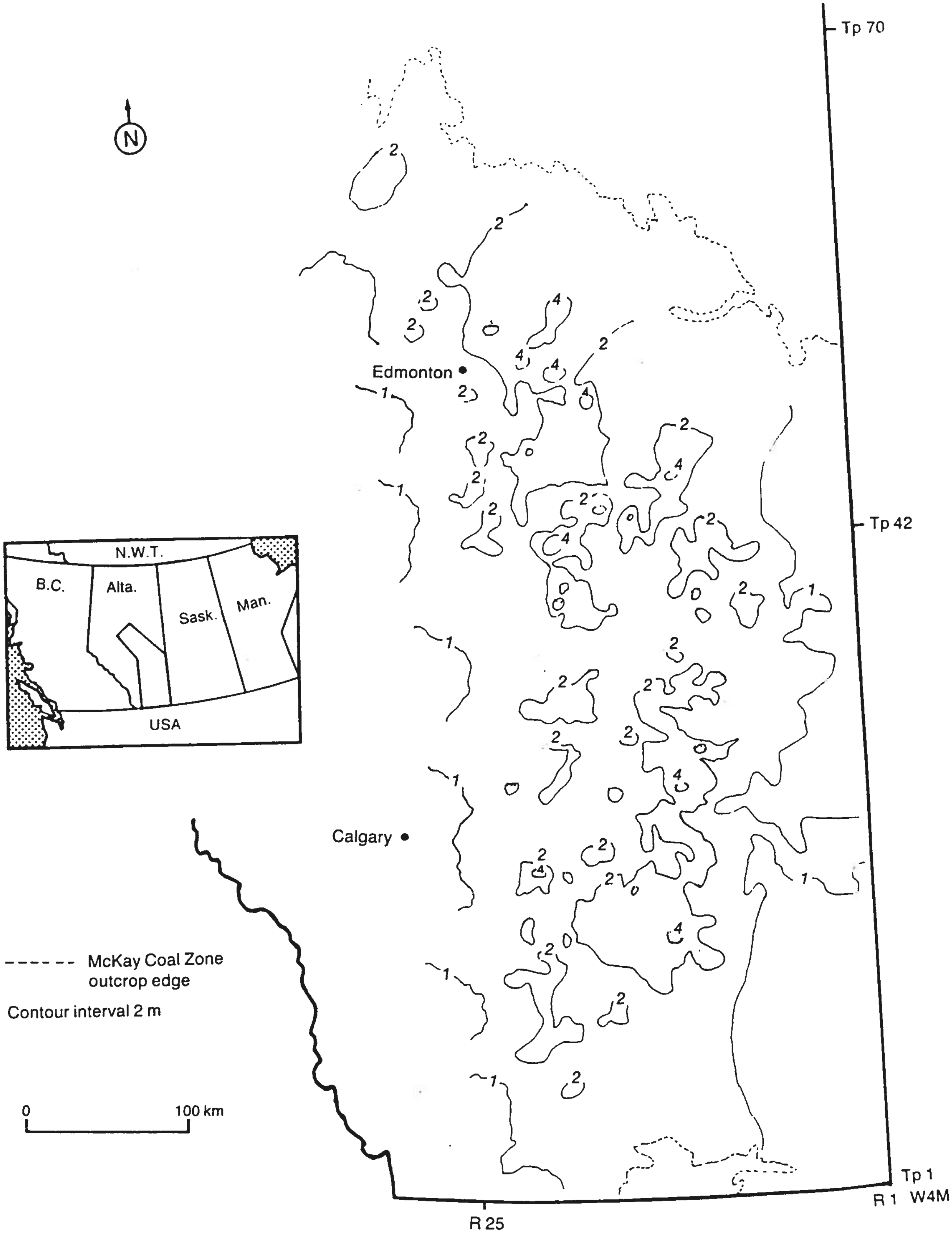

Figure 10. Cumulative coal in the McKay coal zone.

3.2.3 Structure And Depth To The Zone

Map 6 shows the regional structure on top of the McKay coal zone. By comparing map 6 with the structure on the Colorado Group (map 1), it can be seen that the coal zone very closely parallels the regional structure (see also structural cross sections figure 11 and appendix 2). Minor structural ridges and valleys within map 6 are likely due to an incomplete development of the coal zone or an anomalously higher stratigraphic seam being developed. The contours on this map east of the Sweetgrass Arch are unreliable, as the coal zone is not well developed in this seaward region. The cumulative coal map (map 3) zero line should be referred to in judging the reliability of the structure contour lines.

The stratigraphic cross sections show very little up or down section migration of the McKay zone throughout the area. The structure contour map (map 6) for the McKay zone can also be used, in conjunction with a topographic base map, to predict the outcropping or subcropping of the zone.

Map 7 shows the depth to the thickest coal in the McKay zone and is based entirely on the drilled depths as picked from geophysical logs. The map, therefore, is in part a reflection of regional topography. This map can be used as a guide in determining the overburden thickness in regions of thick cumulative coal (map 3) or the thickest seam within the zone (map 7). In comparing these maps, it can be seen that most areas having the thickest cumulative coal lie within 400 m depth.

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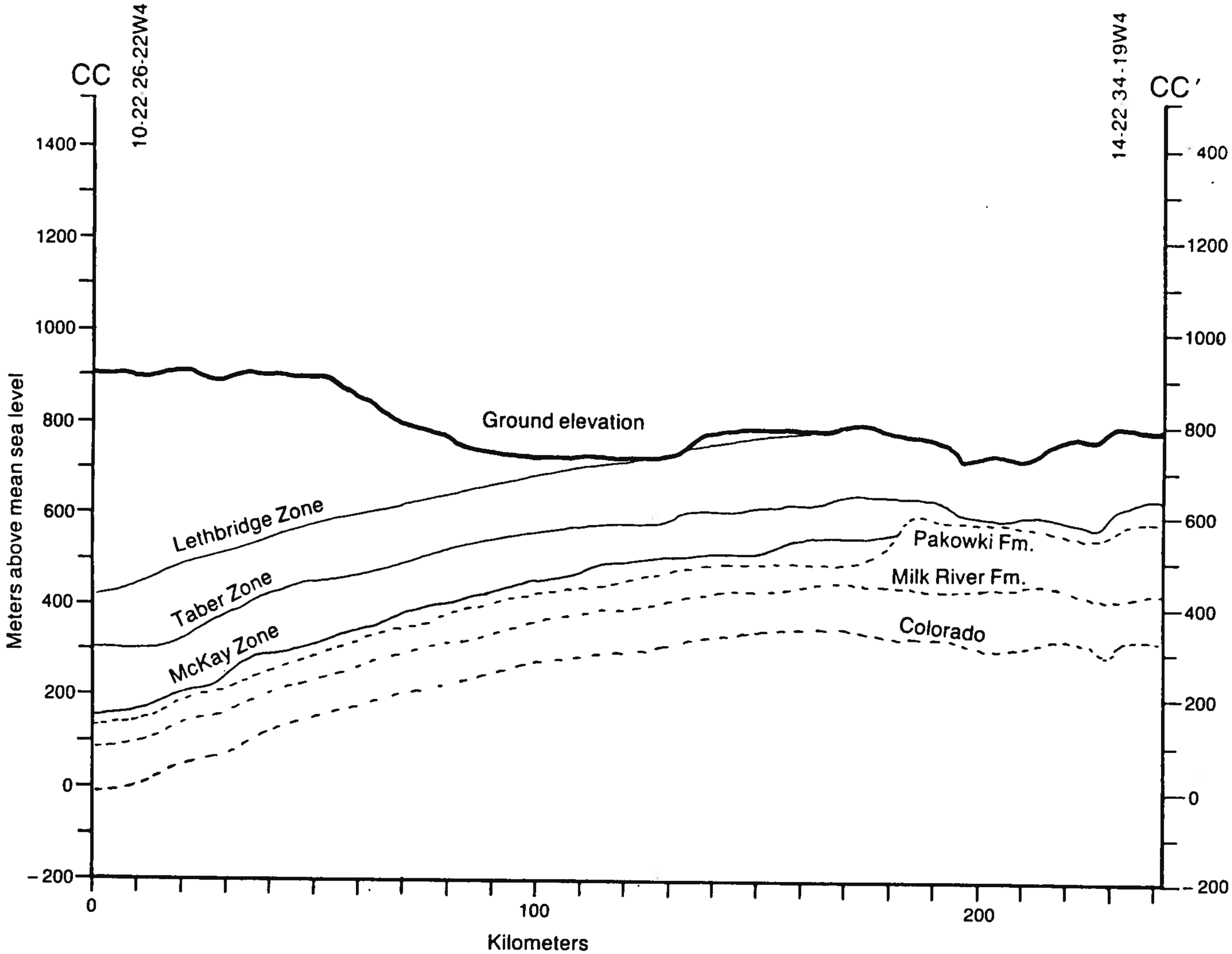

Figure 11. Structural cross section CC-CC′.

3.2.4 Interesting Areas

By utilizing the cross sections and maps together, a number of prospective areas can be delineated, while other areas can be eliminated as having limited potential. The area east of the zero line on the cumulative coal map 3, can be immediately eliminated as this area is east of the coal zone pinch out. Only a few of the transgressed type coals can be expected in this area. The extreme western areas also has low potential, due to the disapearance of the zone. The two most promising areas, within the McKay coal zone are: 1) between townships 12 and 32, just west of the zero line (map 3) and 2) in the northern region between townships 40 and 54 along the eastern edge of the study area. Those areas have relatively thick cumulative coal, individual thickest seams up to 2.8 m thick, multiple seams over 1m thick within the sequence, good internal seam correlations within the zone and are at depths generally less than 400 m.

3.2.5 Inferences And Conclusions

Map 8 (figure 12) is an example of a derivative map where two types of data are combined; showing the number of coal seams within the McKay coal zone that are greater than 1.0 m thick. Once more, the contouring of such values is not based on some constant stratigraphic datum. The map shows that in the northern region (north of township 40), areas having more than one seam greater than 1.0 m are not common and are isolated. In contrast, the southern region shows larger areas that contain 2 to 3 seams greater than 1.0 m thick, which occur in a geographic pattern that is curvilinear. This curvilinear pattern runs roughly north-south to northeast-southwest, parallel to the major shoreline development near the Sweetgrass Arch.

A similar derivative map (not included) based on the number of seams with a 1.5 m seam or greater, showed few areas that had more than one seam greater than 1.5 m.

It can be concluded that the McKay coal zone is best developed within 400 m of the surface. Individual seams are easiest to correlate along the eastern edge in the north, and west of the seaward pinch-out in the south. Very few geographic regions have more than one coal seam greater than 1.5 m thickness, however, several areas have multiple seams that exceed 1.0 m. The coal zone shows a very uniform, even structure that closely parallels the regional structure, having only minor indications of stratigraphic upward migration.

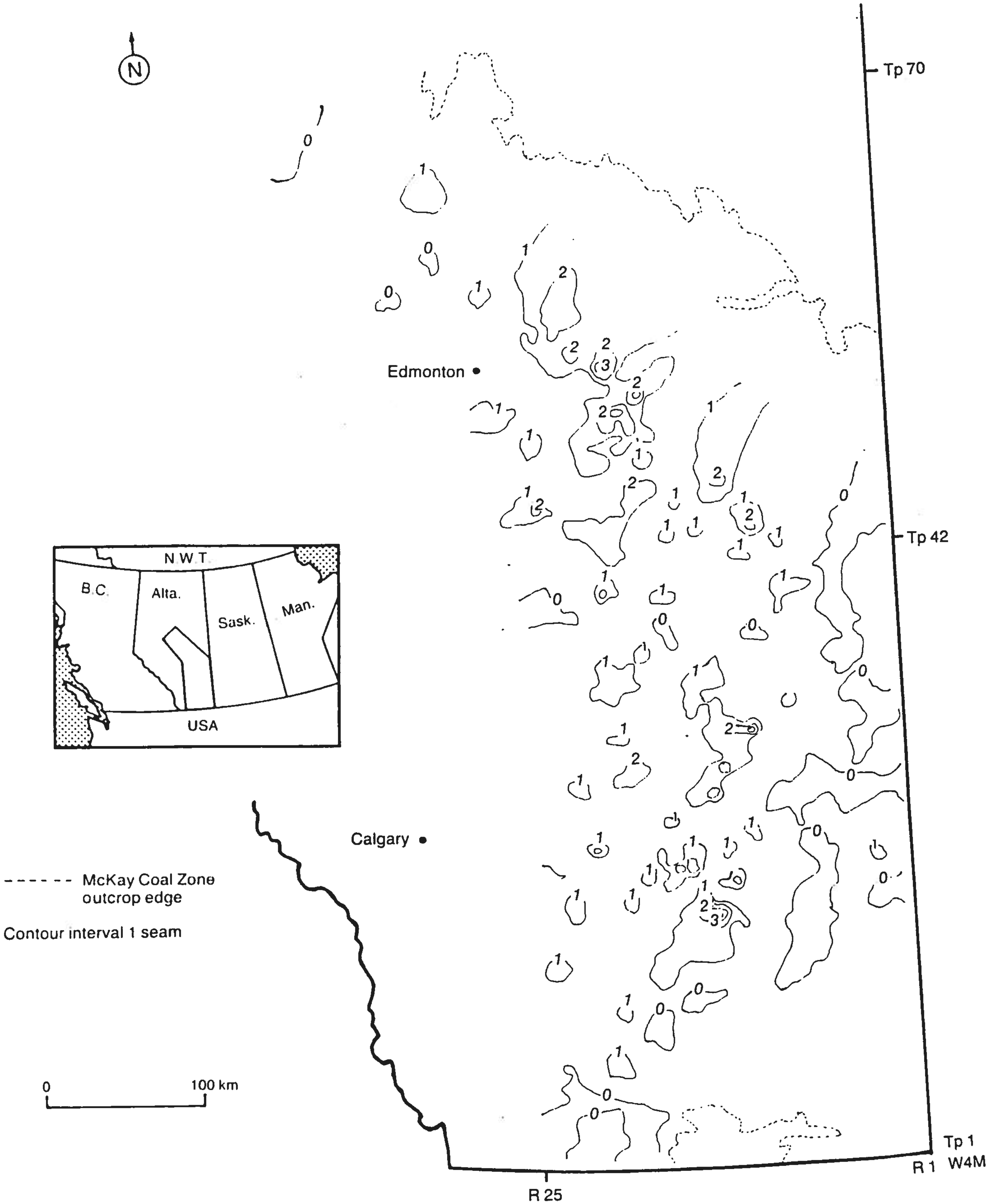

Figure 12. Number of seams greater than 1 m thick, McKay coal zone.

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3.3 TABER COAL ZONE

3.3.1 Distribution And Geometry of 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 has been eroded (figure 1). 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 (figure 8). This can be seen on the number of seams map (map 9) and the cumulative coal map (figure 13, map 10). Stratigraphic cross section C-C' (volume II) shows the Taber zone progressively becoming thinner to the east. Near the Alberta/ Saskatchewan border it becomes the first coal zone, stratigraphically, above the marine Pakowki Formation. The eventual replacement of the Taber zone by the Pakowki Formation marine sediments is seen in stratigraphic cross section D-D' (figure 8). The zone also shows some stratigraphic upward migration in the southern area (figure 8). The extreme northwestern and western region of the study area contains very little Taber coal, it is either missing or consists of one or two scattered seams (maps 9 and 10).

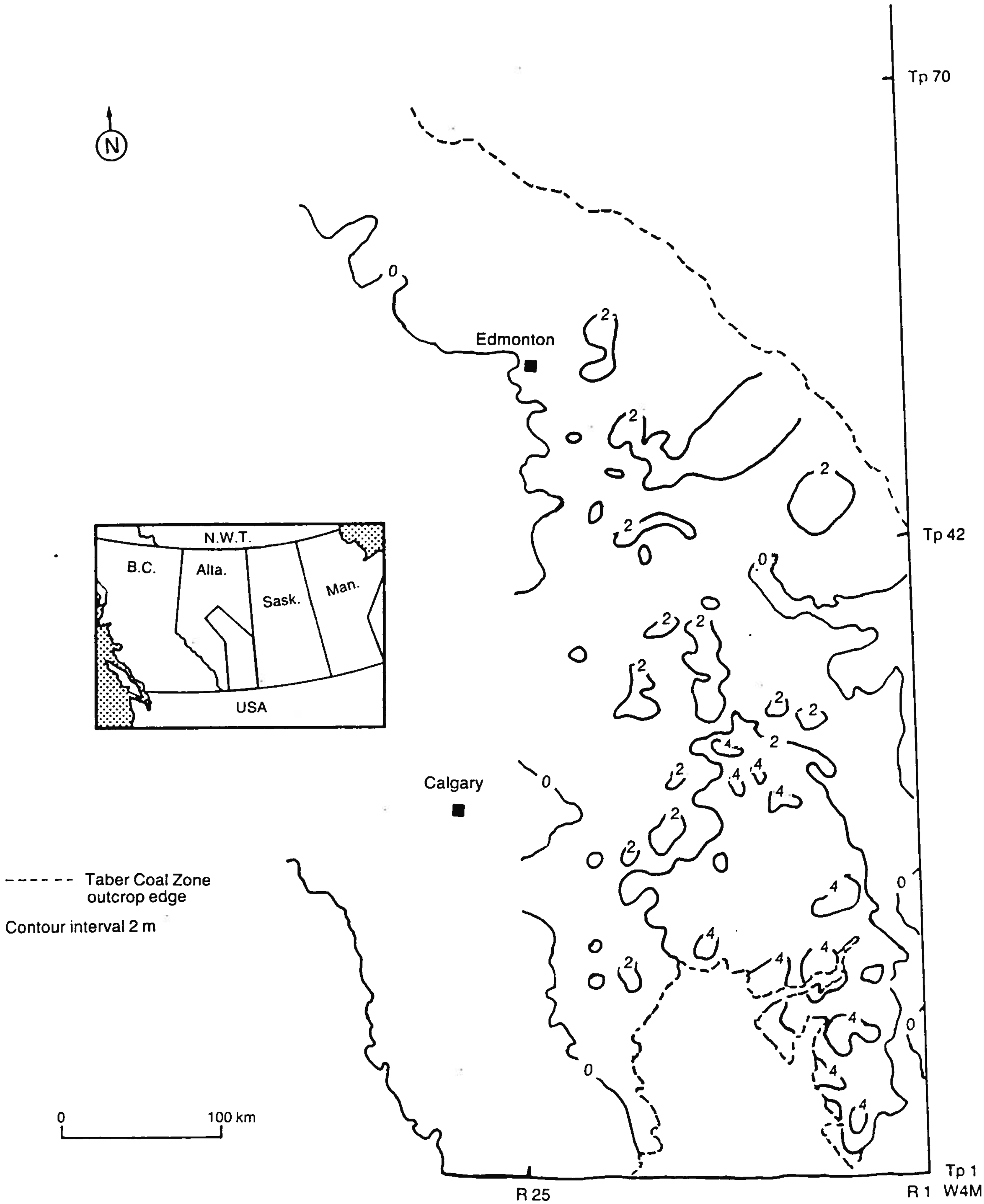

Figure 13. Cumulative coal in the Taber coal zone.

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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. As a result, the contours on some of the maps (maps 9 and 10) become somewhat distorted. The reader is referred to publications by Campbell (1974) and Holter and Chu (1977) who describe the shallow coal resources in this region.

The Taber zone shows a very similar pattern of coal seam correlation to the McKay zone. Stratigraphic cross sections (volume II) show that the region where individual seams are most easily correlated, lies within the major northwest-southeast trending geographic belt (maps 9 or 10).

3.3.2 Thickness And Number Of Seams

Cumulative coal for the Taber zone varies from 0.5 to 7.0 m thick (map 10, figure 13). 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). Individual thickness values within the belt are generally variable, resulting in a chaotic appearing map, however, between townships 30 and 50 the values become somewhat more orderly, yielding a more curvilinear shaped distribution.

The number of seams map (map 9) shows a positive relationship between increased cumulative coal with increased number of seams. The broad northwest-southeast distribution belt is still apparent on the number of seams map, although perhaps less convincingly so. Seven isolated locations south of township 20 have up to two seams that exceed 1.5 m thick (map 9).

The thickest seam within the Taber zone shows that the maximum seam thickness rarely exceeds 1.0 m in the study area, except south of township 30 - within the broad belt mentioned earlier (map 11). A few isolated exceptions to this generality occur around township 45. Three locations south of township 30 have seams that are equal to, or greater than 2.0 m thick. The thickest seam encountered over the entire area, within the Taber zone, is 2.7 m (Tp 6, R 6 W4).

3.3.3 Structure And Depth To The Zone

The structure on the thickest coal, within the Taber zone (map 13), closely approximates the structure on the Taber coal zone itself and closely parallels the regional structure (map 1). Structural ridges and embayments on this map are likely due to local absences or additions of seams within the zone, at a given location.

This map can be used together with a topographic map to assess where the coal zone should subcrop and to determine the approximate subsurface stratigraphic position. The Taber zone, coal and non-coal sediment, has an average thickness of only 25 m throughout the area. The map can also be used in determining the precise stratigraphic position of the thickest seam within the Taber zone.

Nearly all thick cumulative coal, thickest individual coal seams, and greatest number of seams for the Taber zone, occur at depths less than 400 m (map 12). Map 12 is based solely on drilled depth measurements and does not include any topographic data, as a result is only an approximation. Some topographic features, such as the Cypress Hills (extreme southeast corner), and wells drilled in river valleys (Tp 28, R 18 W4) show as conspicuous "bulls-eyes" on the map.

3.3.4 Interesting Areas

By comparing the suite of maps and cross sections (volume II), a number of potentially attractive areas can be delineated. All of the most promising areas lie within the northwest-southeast trending belt that runs through the center of the study area. The seven areas that have two seams, each exceeding 1.5 m thick (map 9), and the area containing the single thickest seam (Tp 6, R 6 W4), are attractive exploration targets.

3.3.5 Inferences And Conclusions

It can be concluded that the Taber coal zone has its best development, in terms of cumulative coal, thickest seam, and number of seams at a depths less than 400 m. The zone is best developed, geographically, in a northwest-southeast trending belt. This region has individual seams that are easiest to correlate along the eastern edge of the data in the north, and west of the seaward pinch out in the south. Seven areas in the south have more than one seam with greater than 1.5 m thick coal. The Taber coal zone shows a very uniform, even structure that closely parallels the regional structure.

3.4 LETHBRIDGE COAL ZONE

3.4.1 Distribution And Geometry Of Zone

The extent to which the Lethbridge coal zone could be delineated was limited by the following factors: 1) over much of southern Alberta erosion and removal of the coal zone over the Sweetgrass Arch, 2) a large area over much of central Alberta where wells have the zone cased off, and 3) the 400 m-depth cutoff in the west, 4) Lethbridge-equivalent coals were not picked north of about township 40, as in this region the Bearpaw Formation becomes very thin making it difficult to distinguish between Lethbridge and Drumheller (Horseshoe Canyon Formation) coal zones. North of township 40, the

Drumheller and Lethbridge coal zones merge to form a continuous coal-bearing zone up to 150 m thick (see McCabe et al., 1986).

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 5m 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 (figure 14).

Stratigraphic cross sections (volume II) 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. Stratigraphic cross section E-E' (volume II) illustrates this point and also shows how quickly the Lethbridge zone becomes cased off towards the east.

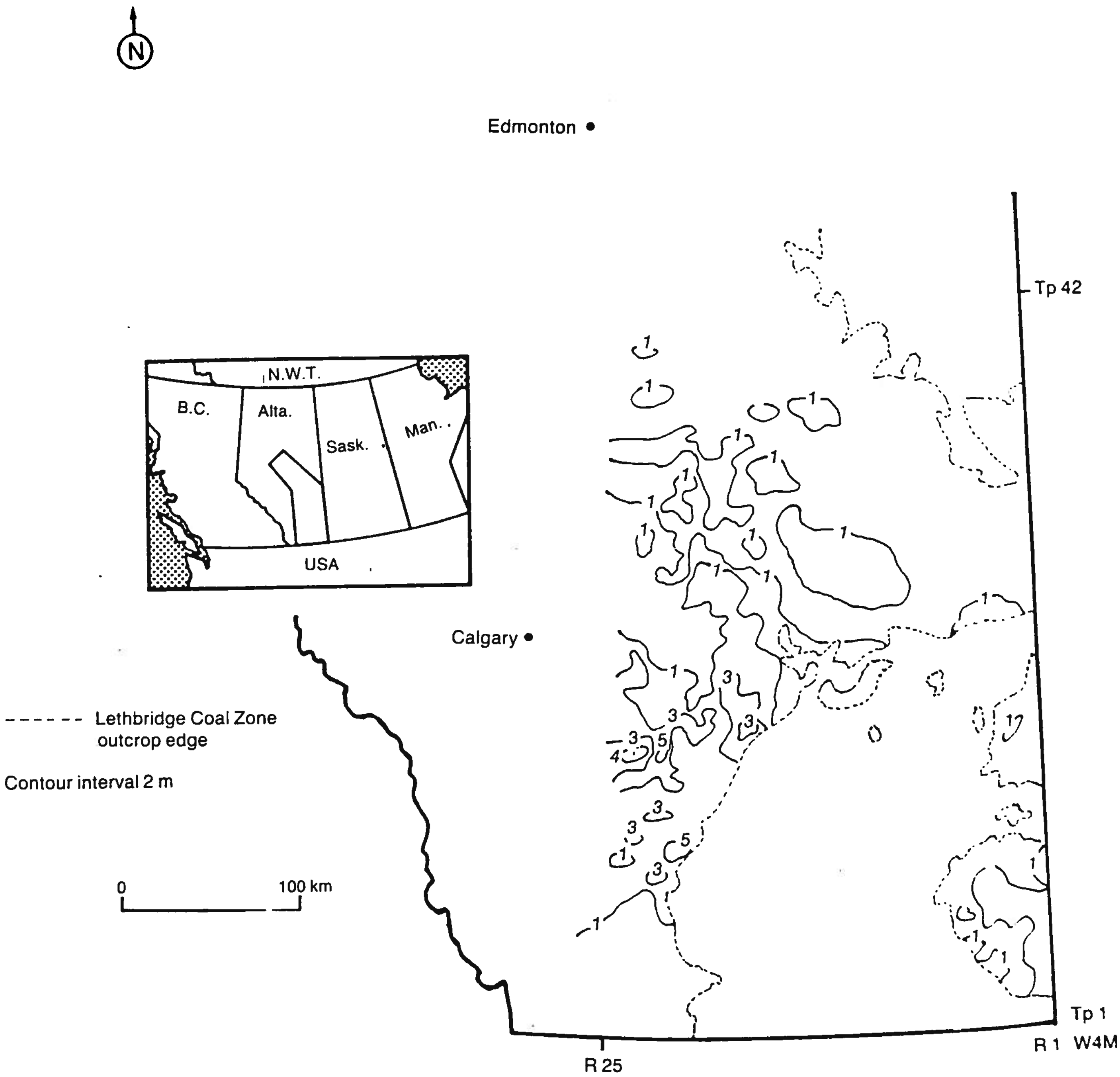

Figure 14. Cumulative coal in the Lethbridge coal zone.

J # 13

3.4.2 Thickness And Number Of Seams

The Lethbridge coal zone has its thickest cumulative coal development (up to 5.8 m) in the Gleichen - Bassano region (Tp 15 to 21, R 16 to 24) and in the Lethbridge area (figure 14, map 15). Within these relatively thick areas of cumulative coal, the local variation in individual values is high. A given township with a high cumulative coal value may be adjacent to a township having only 1 or 2 m of cumulative coal. The cumulative coal map; therefore, suggests a pod-like geometry to the coal zone. Rapid disappearance and emergence of seams within the zone can explain this distribution pattern.

The number of seams map (figure 15, map 14) shows that in the northern region the zone consists of one or two seams, progressively increasing to a maximum of seven seams toward the south in the Bassano area. South of Lethbridge, in the Cardston area, the number of seams in the zone again decreases to zero i.e. the coal zone is missing. Comparing the number of seams map (figure 15) with the cumulative coal map (figure 14) shows that, in general, regions of thick cumulative coal can directly be related to increased number of seams. Some local areas, however, show thick cumulative coal with only one or two seams present. This suggests that thick cumulative coal is not always related to increased number of seams, but rather to local thickening of individual seams. A few locations have two seams greater than-or equal to 1.5 m thick in the Lethbridge zone (map 15).

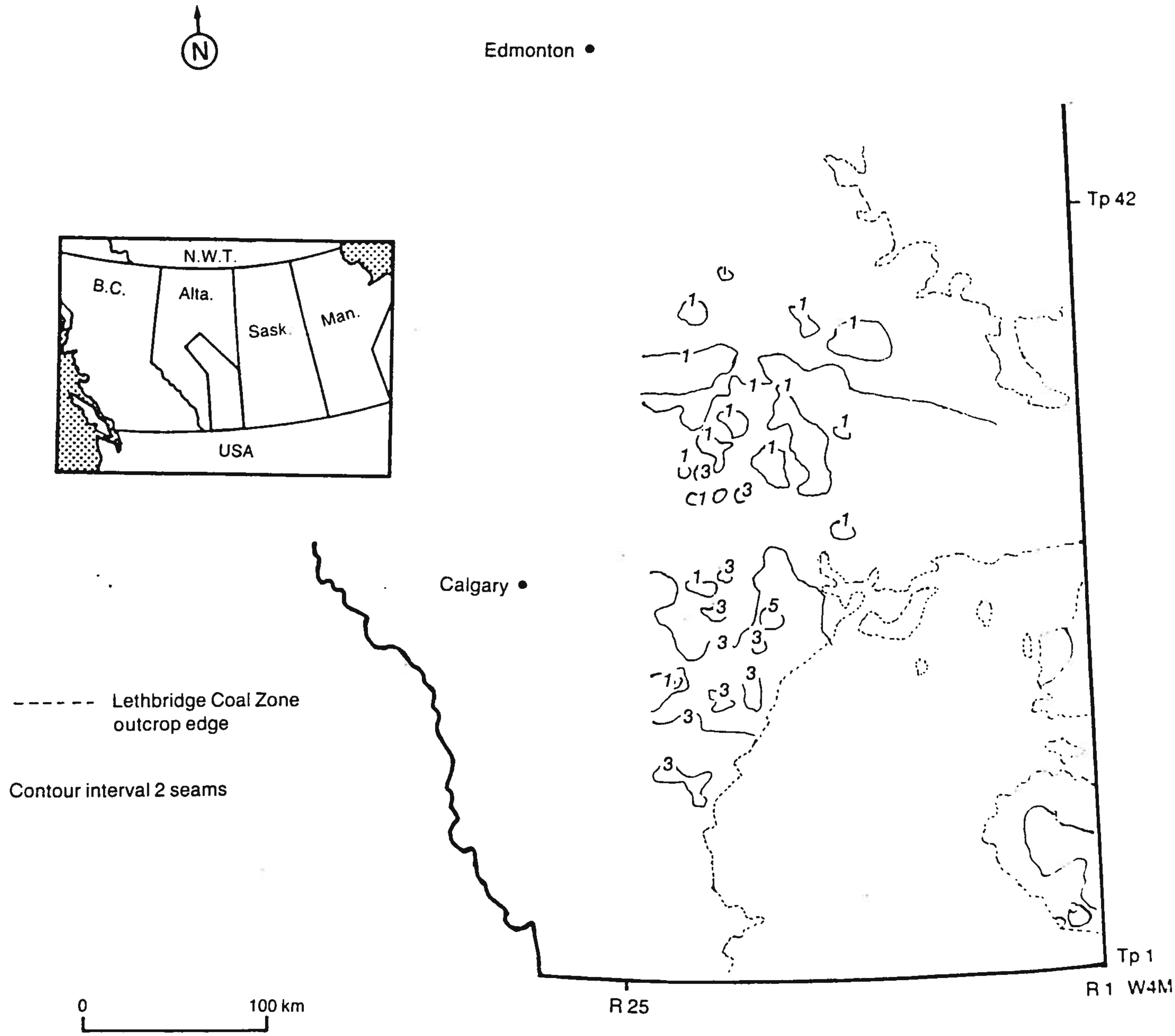

Figure 15. Number of seams in the Lethbridge coal zone.

Most Lethbridge zone coals have maximum seam thicknesses in the 0.5 to 1.5 m range (map 16), however, north of Lethbridge the maximum seam thickness reaches 4.5 m. This area was the site of at least three coal company leases in the early 1980's, and two companies (Fording Coal and Petro-Canada) were in the advanced stages of developing underground mines (Livingstone, 1985). This thick seam within the Lethbridge coal zone has been mined in the past from 1885 to 1965 and was referred to as the "Galt" seam (Livingstone, 1985).

Very few locations, within the Lethbridge coal zone, have more than one seam greater than 1.5 m thick (map 14). The area around Lethbridge, with its extensive mining history, has only one seam exceeding 1.5 m.

3.4.3 Structure And Depth To The Zone

The Lethbridge coal zone is very thin and commonly consists of only one or two seams. The structure on the coal zone and structure on the individual thickest seam are as a result nearly identical. Similarly, the depth to the zone and depth to the thickest seam are also nearly identical. The structure on the thickest seam (map 17) shows a structure nearly parallel to the regional structure (map 1). The structural and stratigraphic cross sections support this view (volume II).

The Lethbridge zone appears to be an essentially planer surface with very few irregularities. The detailed section F-F' shows a minor stratigraphic drop of the zone at exactly the point where the underlying Taber zone abruptly changes from one seam in the west to six seams in the east; this is likely related to increased preferential compaction over coaly sequences versus non-coaly sequences. Throughout the study area the zone does not exhibit any major upward or downward stratigraphic migration, as was the case in the Taber and McKay zones. The Lethbridge zone appears isochronous, at least over the study area.

3.4.4 Interesting Areas

The most promising areas for future work are in the following areas: 1) Lethbridge area, 2) four regions in the Gleichen-Vulcan area, and 3) an area close to the subcrop edge near Bow City.

The Lethbridge area has one very thick seam ("Galt" seam- up to 4.5 m) at a depth of about 200 m, has a potentially high variability in seam thickness over several contiguous townships, and has a structural configuration that is smooth and even but relatively steeply dipping (6.1 to 22.5 m/km). Several areas in the Gleichen-Vulcan region have up to two seams that are greater than or equal to 1.5 m thick, are at depths from 250-450 m, and are in regions where the dip is more moderate (4.5 m/km). An area near Bow City contains two locations that have up to two seams exceeding 1.5 m thick, are very near the subcrop edge and less than 40 m deep, and have very shallow dips (2.2 m/km). The Bow City location is being developed by Fording Coal Ltd. as a thermal coal project at the present time.

3.4.5 Inferences And Conclusions

The Lethbridge zone has its best development, in terms of cumulative coal, thickest seam, and numbers of seams at a depth of less than 400 m in the region between townships 15 to 21. Several localized areas within this southern region contain more than one seam with greater than 1.5 m thicknesses. The Lethbridge zone shows a very uniform, even structure that closely parallels the regional structure.

4. DEPOSITIONAL AND EXPLORATION MODELS

4.1 DEPOSITIONAL HISTORY

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, and figure 8 and 9). 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 which 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 has also been shown that the McKay coals pinch out eastward into the Pakowki sediments, and also disappear towards the extreme west in a more continental direction (figure 4). 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. This study suggests that, 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 favorable 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 (figure 4). 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 (figure 3 and 10). The Taber coals would also seem to be related to coastal plain environment; however, the extent to which 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 this 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 inter-digitating 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.

4.2 EXPLORATION MODELS

4.2.1 McKay And Taber Zones

In developing an exploration strategy, it is always imperative to combine information from several maps and sections to arrive at a suitable exploration target. As described earlier, the cumulative coal maps should be used together with the thickest individual seam, number of seams, structure on the coal zone and depth to the coal zone to gain the maximum benefit. Examination of the cross sections will help to understand facies changes that occur.

Regional exploration of the McKay and Taber zones should concentrate on those areas outlined within the large regional northwest-southeast or north-south trending belts described earlier. The thickest coals within this belt tend to be west of the seaward pinch out of the coal zone by several 10's of kilometers. The thickest coals within this belt also tend to be within the region where individual coal seam correlation potential was the highest (appendix 2). Exploration too far to the east of the coal zone pinch-out region i.e. east of the Sweetgrass Arch and its northern extensions, would not likely be productive. North of about township 54, the easternmost pinch out, for either coal zone, is not well known because of the erosion of the formation in this area. Similarly, exploration in the far western, northern and southern areas, where the zone is replaced by continental clastic sediments would not be productive.

4.2.2 Lethbridge Coal Zone

The Lethbridge coal zone is very poorly understood because of the extensive casing problem outlined earlier, and by its geological amalgamation with the lower Horseshoe Canyon Drumheller in the northern region. It has been shown that the zone can be expected to exhibit a high degree of variability (at least on a township scale) with respect to the thickness of the zone, cumulative coal, and the thickest seam within the zone. Localized regions of very thick coal do occur in the Lethbridge coal zone, however. Exploration should stay well north of the southern zero line developed in the Cardston area.

5. COAL QUALITY

This study was not specifically designed to examine the quality of Belly River Group coals quality, however, a few observations are described in this section.

Campbell (1972) reports that McKay-equivalent coals in the Athabasca-Smith area are lignites to sub-bituminous "C." in rank. Low rank coals may be the norm along this north-eastern outcrop/subcrop edge (i.e. north of about township 35), however, this is uncertain. Some bituminous high volatile "C" coals are know to exist within the Lethbridge coal zone near the City of Lethbridge. Nurkowski (1985) summarized available data statistically based on a province-wide study. Nurkowski's study contained 32 analyses from Belly River coals, many having insufficient data to provide a rank determination. Nurkowski reports the following data for the Belly River coals: mean calorific value (DAF, kJ/kg) = 29226 mean sulfur (D, % at 95% confidence) = 0.66 mean ash (D, %) = 16.6 mean volatile matter (DAF, %) = 44.6 mean fixed carbon (DAF, %) = 55.3 and mean equilibrium moisture (%) = 14.0.

6. FUTURE WORK

Future research work within the Belly River Group should concentrate on filling in the large regions in the near-surface having missing data. More specifically, the region between the outcrop/subcrop edge and the deeper subsurface where oil and gas well logs can be used. This problem has resulted in only scanty details in the east-central area regarding, in particular the coal potential of the Lethbridge zone. The same problem has also affected the Taber and McKay coal zones to some extent, and as a result very little is known about the near-surface properties of the coals in these zones, in east central Alberta. McKay zone-equivalent coals have been evaluated in only a few regions in east-central and northern Alberta (see Campbell 1972).

The rank and quality of Belly River coals has been documented to some degree in and around the outcrop edge in southern Alberta. However, very little is known about the coal quality in east-central, northern and deeper subsurface regions to the west. Much more work in the area of coal quality should be done on the Belly River Group coals.

Belly River coal exploration targets will in all likelihood be very localized as many of the trends seen in this study were of a pod-like geometry within a more regional linear belt. Some regions of very thick coal do exist and a more detailed examination of prospective areas will be required.

Individual coal seam correlations could only be attempted at a cursory level within the time frame of this study. Generally speaking, very little is known about individual coal seam correlations within the Belly River coals and much more work needs to be done in this area.

7. CONCLUSIONS

Coal seams within the three major coal-bearing zones of the Belly River are generally between 0.5 and 1.5 m thick. Seams in the 1.5 to 3.0 m thick range occur less frequently and the single thickest seam is in the Lethbridge zone (4.9 m thick), in the vicinity of Lethbridge. Seams of more than 3.0 m thick, however, are not common in any of the zones.

The regions of thickest cumulative coal, within the McKay and Taber zones are found in broad north-south trending geographic belts that pinch out to the east and west. Both zones are very poorly developed in the extreme northwest corner of the study area. Within these belts, lies an inner region where individual coal correlations are possible. The thickest seams within the zone often fall within this inner belt of optimal seam correlations and always fall within the more regional north-south trending belt.

The Lethbridge coal zone is poorly understood in terms of its regional geometry and lateral extent. From the available data it appears that the cumulative coal and individual thickest seam thicknesses within the Lethbridge zone tend to be low in the northwest, increasing toward the south to its maximum, and diminshing to zero (i.e. no-coal zone present) near the U.S. border. The number of seams within the Taber and McKay zones is found to be directly related to the cumulative coal values. This is not necessarily the case in the Lethbridge zone where increased cumulative coal values are often related to increased thickening of one or two seams, without addition of any seams.

The structure of each of the three coal zones conforms very closely to the regional structure, with no apparent major up-section migration of the zones. Minor variations in the structure of the coal zones is attributed to the appearance or disappearance of seams within the zone. The Sweetgrass Arch dominates the structural style throughout southern Alberta, and the Belly River coal zones have became very gently folded to conform to this style. Throughout the rest of the study region, the coal zones dip to the west to southwest into the Alberta basin. Most regions with thick cumulative coal, within all three coal zones, lie within 400 m from the surface.

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.

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9. APPENDIX 1. DESCRIPTIONS OF MAPS

9.1 Map 1. STRUCTURE OF THE COLORADO GROUP

The structure on the top of the Colorado Group forms one of the most reliable markers throughout the study area and shows the regional structure that underlies the three main coal zones. The Colorado is also used as the datum for many stratigraphic cross sections. The map shows: 1) the major Sweetgrass Arch feature in the south and a nearly flat area to the north representing a northern extension, 2) the nearly flat-lying strata in the east-central region and 3) the west to southwest- dipping structure throughout the rest of the area.

Map 1 can be used to calculate the regional dip at any location, and also provides the elevation of the Colorado Group.

9.2 Map 2. ISOPACH OF THE PAKOWKI FORMATION

The isopach of the Pakowki Formation shows the extent of the predominantly fine-grained marine strata that immediately underlies the Belly River Group. The top of the Pakowki Formation is very difficult to pick in the eastern areas of the study as continental, near-shore and marine sediments interdigitate with one another. A somewhat arbitrary criterion - " the top of the uppermost (going up section) shale that was deemed to be marine" - was applied in this study to mark the top of the Pakowki Formation. Map 2 shows a fairly consistent pattern of decreasing thicknesses to the west and increasing to the east. The Pakowki Formation, as defined, becomes dramatically thicker in the east-central region of the map area, as reflected by the tightened contours. The ridges and troughs developed along this north-south trend of tightened contours are very likely an example of the subjectivity in making this pick, and do not represent real geological anomalies. This north-south linear feature of tightened contours lies on the Sweetgrass Arch and reflects the position of multiple shorelines developed in this area. Poor data distribution south of township 11 make the contours in this area unreliable.

The isopach of the Pakowki map can be used in conjunction with the cumulative coal maps, in particular the McKay and Taber maps, to better understand why and where the marine pinch-out of these coal zones occurs. The map is also useful in showing the westward extent of the Pakowki sea, before coal formation in the Belly River.

9.3 Map 3. CUMULATIVE COAL MCKAY ZONE

This map shows the total amount of coal picked in each well, cumulatively added together, and then contoured. It does not represent a single correlated coal seam. Zero values ("0") on this map are locations where the coal zone is missing for sedimentological-depositional reasons, and values of "-1" are missing data values most likely related to recent erosion or the zone being cased off.

The map displays the broad outline of the McKay coal zone, as bounded by zero contours, and shows that the total thickness of coal in this zone never exceeds 7 m. Map 3 shows the broad arcuate-shaped, north-south band of thick cumulative coal which is replaced by marine sediments to the east of the Sweetgrass Arch, and by continental clastic sediments in the south, northwest and western regions.

The cumulative coal map can be used in conjunction with, the number of seams, thickest coal, depth to, and structure maps to outline initial exploration targets. The zero contours on this map are particularly important in placing absolute limits to reasonable exploration programs. "Bulls-eyes" on the map may be good first target areas in planning an exploration strategy. The cumulative coal map, used on its own in planning an exploration program, can be very misleading. Detailed studies should be undertaken once a favorable area is blocked out. This map can also be used in regional basin-analysis studies of coal deposition and in defining the general geographic-subsurface limits of the McKay coal zone.

9.4 Map 4. NUMBER OF SEAMS MCKAY ZONE

Map 4 represents the number of individual coal seams in each well, within the McKay zone. These values have been contoured. Comparing this map with the cumulative coal map 3, shows a strong correlation between increased number of seams and increased cumulative coal. This then suggests that thick cumulative coal is related to increased numbers of seams, as opposed to a thickening of individual seams. The map also shows the regions with no coal seams present, and where the zone consists of only a single seam.

The number of seams map can be used with the cumulative coal map to obtain a better understanding of prospective areas, by determining whether increased cumulative coal is related to increased number of seams or to thickening of a single seam. Those areas with high cumulative coal values and low number of seams would suggest good exploration targets.

9.5 Map 5. ISOPACH OF THICKEST SEAM MCKAY ZONE

This map shows the thickest seam, within the McKay coal zone, at every well location, regardless of its stratigraphic position within the zone. Values are then contoured to give a general idea of where, geographically, the thickest seam lies. Throughout most areas the thickest seam within the McKay zone is less than 1.5 m, however, there are a number of localized regions where the thickest seam is 2.0 m or more. The overall thickest seam (maximum 2.8 m) underlies townships 16 and 17. Contours extending into areas of no data or missing data, should be scrutinized carefully, as the mapping program used to generate this series of maps tends to over extrapolate into these regions. Missing data on this map is marked by a "0.0".

Map 5 can be used in conjunction with the cumulative coal and number of seams maps to further define potential exploration targets. In doing this it is apparent that all three variables are related i.e., areas having the thickest seam also have the most cumulative coal and the highest number of seams. It should be stressed that a region that is contoured as having thick individual seams may not constitute the same seam throughout the contoured area, although over small areas - such as one or two townships, it likely is the same seam. Detailed stratigraphic sections should be constructed over a prospective area to establish individual seam correlations.

9.6 Map 6. STRUCTURE ON THE MCKAY ZONE

This map displays the general structure of the top of the McKay coal zone as defined by the uppermost seam within the zone. Map 6 shows that the McKay zone very closely parallels the regional structure, a conclusion supported by the structural and stratigraphic cross sections (volume II). Minor ridges and troughs in the overall structure are likely related to the addition or deletion of a seam(s) within the zone, leading to a localized anomaly. The structure on the zone south of township 13 is poorly defined, due to insufficient data as the coal zone subcrop is approached. However, this structure is expected to closely follow the structure of the Sweetgrass Arch. The contours along the northeastern edge of the data become very regularly spaced and should be viewed with some suspicion as most of this regularity is based on computer extrapolation beyond available data. These contours do, however, provide a reasonable extrapolation into unknown areas. Missing data are represented by a "-1" on this map.

Map 6 may be used to determine the stratigraphic position of the McKay zone and the approximate position of an individual seam within the zone. This map could be used in conjunction with a detailed topographic map to more accurately predict where the zone should subcrop. The outcrop edge shown on this map, is the base of the Belly River Group and should approximate the subcrop of the McKay coal zone (based on Green, 1972). The eastern seaward pinch-out of the zone, as shown on map 3, should be considered when making subcrop projections.

9.7 Map 7. DEPTH TO THE THICKEST SEAM MCKAY ZONE

This map shows the approximate depth to the thickest coal seam within the McKay zone, based on drilled depths only. Prominent topographic features, like the Handhills, show up very clearly. However, more subtle features, such as river valleys, in general do not appear. This is because few wells are drilled in river valleys, and so no data is available. Comparing this map with the cumulative coal map 3, shows that much of the thickest cumulative coal, throughout the area, lies at depths of less than 400 m. The western zero edge of the McKay coal basin is at a depth of 600-700 m, representing an absolute maximum depth where the coal zone is likely to be found. Missing data on this map are represented by a "0".

This map can be used together with the isopach of the thickest seam (map 5) to estimate the depth to the thickest seam for any given area, or more generally, to estimate the approximate depth to the entire coal zone. The zone rarely exceeds 40 m thick. The depth values obtained will only be approximations, and more detailed topographic information is necessary to obtain a more accurate estimate.

9.8 Map 8. NUMBER OF SEAMS >1.0 m MCKAY ZONE

This map shows how many seams within the McKay coal zone have individual seams that are 1.0 m thick or more. It can be seen that the geographic distribution of seams meeting these criteria is somewhat scattered and occurs in pods. However, there is a north-south band of such occurrences in the region south of township 35. This north-south band parallels the eastern zero edge of the coal zone, approximately 3 to 4 townships to the west. Some multiple occurrences of >1.0 m seams are also found in the north-central part of the region (townships 41 to 52), but occur in a much more irregular pattern. Very few seams meeting this thickness criteria are found in the extreme northwestern or western parts of the study area.

This map can be used in conjunction with the other maps to locate regions containing multiple seams in the zone having seams of 1.0 m or more thick. A similar map using a 1.5 m cut off (not present), showed that no locations had more than one seam exceeding the 1.5 m cut off.

9.9 Map 9. NUMBER OF SEAMS TABER ZONE

This map is based on the same criteria as outlined in map 4 (McKay zone) and shows the total number of seams within the Taber zone. The zone tends to have the greatest number of seams along the eastern margin of the northwest to southeast trending central belt. The numbers of seams to the extreme east and west tend to diminish. The extreme northwest part of the study area contains only one or two seams within the Taber zone. This map also shows regions where two seams, within the Taber zone, exceed 1.5 m thick. All other regions contain only one seam exceeding 1.5 m thick or none at all.

The number of seams map showing the Taber coal zone has similar uses as was outlined for map 4 (McKay zone). In this map; however, because areas with two seams of 1.5 m thick or more, are plotted, this information can be used to select target areas containing thick seams at multiple stratigraphic levels.

9.10 Map 10. CUMULATIVE COAL TABER ZONE

The cumulative coal map for the Taber zone was constructed in the same way as for the McKay zone cumulative coal map (map 3). Values of "-1.0" represent missing data values. This map shows the thickest cumulative coal trend lying along a broad northwest to southeast trending belt, and situated slightly farther to the east than the McKay zone belt described earlier. Total cumulative coal tends to increase towards the southeast along this belt, reaching a maximum of 6.9m thick in township 13. Within the belt, the thickest trends tends to be near the eastern margin of the region, but slightly west of the zero edge. This zero edge is reasonably well defined along the western boundary, but less clear in the eastern region. The eastern zero edge must lie not too far eastward into western Saskatchewan, as values in Alberta along this eastern edge are decreasing.

The cumulative coal map can be used as a "first look" in exploring for good coal prospects within the Taber zone. It should, however, always be used in conjunction with other maps. The cumulative coal map can also serve to define the approximate limits of the Taber coal basin on a regional basis.

9.11 Map 11. ISOPACH OF THE THICKEST SEAM TABER ZONE

This map shows the thickest individual seam within the Taber coal zone, and was constructed identically to the equivalent McKay map (map 5). The thickest individual seams throughout the area tend to be located in the southern region - south of township 28, and the single thickest seam is found in township 7, (2.7m). Throughout most northern regions, the thickest individual seam, tends to be less than 1.5 m. Missing data are expressed by "0.0" values on this map.

This map can be used to better define exploration targets that may have emerged by using the cumulative coal or any of the other maps. Obvious targets would include those seams over 2.0 m thick in the southern part of the area. Individual seam continuity should be established over areas which are contoured as having thick individual seams, as seam continuity is not implied on this map.

9.12 Map 12. DEPTH TO THE THICKEST SEAM TABER ZONE

This map shows the approximate depth to the thickest coal within the Taber zone, based on drilled depths only. This map, compared to the cumulative coal map 10, shows that most thickest cumulative coal throughout the area lies at <300 m. The western zero edge of the Taber coal basin is about 350-400m deep, and represents an absolute maximum depth for the zone. Missing data on this map are represented by a "0".

This map, together with the isopach map 11, is useful in estimating the depth to the thickest seam and more generally, to approximate the depth to the entire coal zone. It should be stressed that all depth values obtained from this map will only be approximations.

9.13 Map 13. STRUCTURE OF THE THICKEST SEAM TABER ZONE

This map displays the structure of the thickest coal within the Taber coal zone, and closely approximates the structure on the entire Taber coal zone. Map 13 suggests that the Taber zone closely parallels the regional structure. The structure of the zone south of township 20 is not well defined, because of the very shallow depths to the coal zone in this area resulting in insufficient oil and gas well data. The general pattern is; however, revealed by sporadic, shallow testholes (ARC) and shows that the zone closely follows the structure of the Sweetgrass Arch. Missing data are represented by a "0" on this map.

Map 13 is useful in determining the stratigraphic position of the thickest seam within the Taber zone, as well as the approximate position of the entire Taber zone. Used in conjunction with a detailed topographic map, this map would prove useful in predicting where the zone may subcrop. The outcrop edge shown on this map is the base of the Belly River Group, and is not the predicted Taber subcrop (based on Green, 1972). Figure 13 shows a more reliable estimation of the Taber subcrop edge. The eastern seaward pinch out of the zone, as shown by the zero edge on map 10, should be considered when making any subcrop projections using map 13.

9.14 Map 14. NUMBER OF SEAMS LETHBRIDGE ZONE

This map shows the total number of seams present within the Lethbridge coal zone throughout the area. The data distribution for the Lethbridge zone is very limited due to (1) the northern stratigraphic merger with the Lower Horseshoe Canyon Formation coals, (2) lack of data in east-central Alberta data related to the zone being cased off in oil and gas well, and (3) the extensive erosion of the zone, in the south, over the Sweetgrass Arch. It is very difficult to recognize any systematic pattern in this map, however, a slight trend in the numbers of seams to be low in the north, increasing towards the region of township 16 and then diminishing again towards the south to become zero near the U.S. border can be recognized. Several anomalous pockets can be found within this generalized trend. Locations having two seams within the Lethbridge zone greater than or equal to 1.5 m thick are also indicated. Missing data are represented by a "-1".

The number of seams map can be used with the cumulative coal map (map 15) and thickest seam map (map 16) to help delineate better exploration targets. More specifically, the occurrence of thick cumulative coal within the zone, combined with low numbers of seams and high individual seam thickness, in a region that has more than one seam thicker than 1.5 m, would all seem to point towards a promising exploration target. One such location is in township 11, range 21, where 5.8 m of cumulative coal is found within two seams, the thickest seam being 4.9 m. The coal industry showed some interest in this area in the early 1980's. Several other attractive areas are located in this region including Tp. 17, R. 16 (two seams exceeding 1.5 m near the outcrop edge) and Tp. 17, R. 22 (two seams exceeding 1.5 m, cumulative coal between 4.0-8.0 m, thickest seam 3.0 m). Other prospective areas can be found by using a similar approach.

9.15 Map 15. CUMULATIVE COAL LETHBRIDGE ZONE

The cumulative coal map exhibits a somewhat chaotic distribution as did the number of seams map. The weakly defined trend outlined on the number of seams map appears to be generally applicable to the cumulative coal distribution. This would suggest that increased cumulative coal values can generally be attributed to increased number of seams. Numerous examples of exceptions to this generality occur, whereby regions of thick cumulative coal are related to one or two seams only. The example outlined in the previous section (Tp.11, R. 21) is a case in point. Coals within the Lethbridge zone are, therefore, somewhat prone to rapid individual seam thickening over relatively short distances.

The best use of the cumulative coal map is to get a preliminary look at an area to determine the general potential for thick coal deposits. More detailed comparison with other maps, as exemplified in the previous section, is a necessary second step. The cumulative coal map can also be used to get an idea of the regional distribution and geometry of the Lethbridge coal basin, although with the data distribution available, its usage is limited. The western and eastern zero edge of the Lethbridge coal basin cannot be established with the present data distribution due to casing problems in the east and the 400m-depth cut off established for this particular study. Cumulative coal values do not show any signs of decreasing towards the western limit of the data on this map and the zone may well extend some distance to the west. The northern zero edge is not known; however, the Lethbridge-equivalent coals do extend as far north as township 64 as they merge with the Drumheller zone of the lower Horseshoe Canyon Formation (McCabe et al., 1986). Only the southern zero edge has been established.

9.16 Map 16. ISOPACH OF THE THICKEST SEAM LETHBRIDGE ZONE

The isopach of the thickest seam map shows that throughout much of the area north of township 27, the thickest seam is less than 1.5 m. Between townships 26 and 10, the values tend to be greater than 1.5 m; while in the extreme south the values drop off to less than 1.0 m. Thus it appears that a simlar trend as observed in the cumulative coal and number of seams distribution, can be applied to the thickest seam distribution. Missing data on map 16 are represented by "0.0".

The application of the isopach of the thickest seam map has been discussed in previous sections, and in general, is most valuable when compared with the other maps. This map gives an indication of where the thickest individual coal seam can be expected at any given location, and can be very useful where a pre-determined minimum seam cut off has been established. The map is not necessarily contouring a single coal seam, but rather the thickest seam within the Lethbridge zone.

9.17 Map 17. STRUCTURE OF THE THICKEST SEAM LETHBRIDGE ZONE

The structure of the thickest seam within the Lethbridge zone provides information on the stratigraphic level of the thickest seam within the zone, and very closely approximates the stratigraphic level of the zone in general. The Lethbridge zone is generally between 1.0 and 10.0 m thick and only rarely approaches 30.0 m thick. Caution must be exercised in evaluating contours that have been extrapolated into areas where data are not available.

The outcrop edge shown on this map is the top of the Belly River Group (as defined by Green, 1972) and should approximate the subcrop edge of the Lethbridge coal zone, as the Lethbridge coal zone marks the top of the Belly River Group. Map 17 could be used, together with a detailed topographic map, to more accurately predict the subcrop edge of the zone.

9.18 Map 18. DEPTH TO THE THICKEST SEAM LETHBRIDGE ZONE

This map shows the approximate depth to the thickest coal within the Lethbridge zone, based on drilled depths only. The Cypress, Hand and Wintering Hills are well reflected on this map. Comparing this map with the cumulative coal map 15, it becomes evident that much of the thickest cumulative coal throughout the area lies within 400 m of the surface. However, the zone plunges steeply to much greater depths, particularly in the region south near township 15. Missing data on this map are represented by a "0".

This map, together with the isopach map 16, is useful in estimating the depth to the thickest seam for a given area. This map can also be applied to approximate the depth to the coal zone.

10.0 APPENDIX 2. CROSS SECTION DESCRIPTIONS

10.1 STRATIGRAPHIC CROSS SECTION A-A'

Stratigraphic cross section A-A' runs east-west through township 54 and shows the difficulty in separating the Oldman Formation from the Foremost Formation in this area. This is the region where the entire Belly River Group appears as a continuous sequence of interbedded fine and coarse clastics. In the westernmost wells (e.g. 16-18-54-27W4), the distinction between the Drumheller coal zone of the Horseshoe Canyon Formation and the Lethbridge coal zone of the Belly River Formation becomes very difficult. As a result, the Horseshoe Canyon/Belly River contact is equally difficult to determine. The overall thinning of the Belly River Group is not apparent from this section, however, the underlying Pakowki, Lea Park, and Milk River Formations thicken from 150 m in the west to over 200 m towards the east (see also figure 4). The main region of this thickening is located between ranges 17 and 18, where the McKay coal zone is replaced eastward by Lea Park coarsening-up cycles (e.g. 1-13-54-18W4 and 9-1-54-17W4).

The McKay zone is generally present throughout this section, but attains its best seam correlation, greatest number of seams and thickest coal development between ranges 18 and 21. The Taber zone is very poorly developed throughout the section. The Lethbridge coal zone, is only sporadically developed along this section, and is difficult to distinguish from the Drumheller coal zone. The Lethbridge zone is cased off on this section at about range 26.

A structural section constructed along this township (not included) reveals all markers and the coal zones dipping gently westward, with the base of the Belly River Group and the McKay coal zone climbing upward at about range 17. This structural rise constitutes the same shoreline series as shown in the stratigraphic section. The Milk River and Colorado markers remain parallel.

10.2 STRATIGRAPHIC CROSS SECTION B-B'

Stratigraphic cross section B-B' (also figure 9), runs east-west through township 44, demonstrates the difficulty in separating the Oldman Formation from the Foremost Formation in this region, and the difficulty in establishing the precise top of the Belly River Group. In the westernmost wells (e.g. 7-25-44-24W4) a thin marine shale unit occurs below the Drumheller coal zone with the Lethbridge coal zone lying below this shale. The underlying Pakowki/Lea Park Formations dramatically thickens in the eastern sections between ranges 11 and 10. This represents the same shoreline series as reported in cross section A-A'.

Along the eastern edge of this section, the McKay coal zone is in part replaced seaward by thick, sandy marine sequences and in part climbs to a higher stratigraphic level. The McKay zone contains two to three seams throughout the section, but only between ranges 11 and 15 can the seams easily be correlated. This area of well-developed McKay zone occurs westward of the shoreline. The Taber zone is cut off by casing east of about range 15, contains four seams in range 16 and is virtually absent between ranges 18 to 24. The Lethbridge zone is only present in westernmost wells, because of casing off of the zone east of about range 20. Where present, it is represented by one or two thin seams and is very difficult to distinguish from Horseshoe Canyon coals.

The structural cross section AA-AA' runs through the same township as B-B'. The section shows the Colorado and Milk River markers running smooth and parallel to one another, dipping at at rate of about 2.9 m/km (15ft/mile). The base of the Belly River Group becomes more irregular, particularly towards the west. This is likely a reflection of some thick, basal Belly River sands that occur in this region (see stratigraphic section B-B'). The top of the McKay zone, as displayed on the structural section, is also very irregular and undulating. This is likely due to poor individual seam continuity, resulting in abrupt appearance and disappearance of seams. Similar irregularities of the Taber and Lethbridge zone tops are probably related to poor seam continuity. These computer-generated structural sections also tend to extrapolate beyond the limits of the data available. As a result, structural trends in the eastern region, where no data is present, appear a little smoother than perhaps they really are.

10.3 STRATIGRAPHIC CROSS SECTION C-C'

Stratigraphic cross section C-C', crosses township 34, shows that the Oldman and Foremost Formations, in this area, can now be distinguished in the western part of the section. Stratigraphic thickening of the Milk River/Pakowki Formation (and Lea Park-equivalent) again increases from west to east by approximately 140 m. Several shorelines are present in this cross section, between ranges 4 and 5 and ranges 8 to 10. Another shoreline features on a smaller scale is present between ranges 15 and 16, however, this appears to be a local occurrence - perhaps an individual delta lobe. The major shoreline trends are located in ranges 4 to 9. This region also shows a major tongue of marine shale extending westward, emphasizing the difficulty in placing a lower Belly River Group boundary in this area.

The McKay zone is persistent throughout this section, however, correlation of individual seams is generally difficult, except in the region between ranges 10 and 13. This region with good correlation potential lies westward of the major shoreline developed in range 9. East of this shoreline, the McKay zone thins, and eventually dies out seaward (eastward). The Taber zone is persistent throughout the western and central parts of the section, becoming intermittent and difficult to trace in the eastern region. The Taber zone has its thickest seam development, greatest number of seams, and can be best correlated in the region between ranges 13 and 15. This prospective region also lies west of the upper marine tongue, previously mentioned. Coal seams east and west of this region have a tendency to be fewer, less thick, and more intermittent in occurrence. Due to casing problems, the Lethbridge zone is only preserved in the three westernmost wells. The Bearpaw Formation marine shales are clearly defined in this area, thus making the Lethbridge zone coals easily recognizable.

The structural section BB-BB', runs through this township, shows the Milk River and Colorado markers to be even and parallel, gently dipping to the west and nearly flat-lying in the east. The Pakowki Formation parallels the other markers in the west and central areas, but rises in the eastern areas as a result of the multiple shorelines, as seen in the stratigraphic section C-C'. The McKay coal zone closely parallels the Pakowki Formation, except in the eastern area where the coal zone becomes truncated by the Pakowki Formation. This truncation indicates that the coal zone is terminating seaward - as was seen in the stratigraphic section. The Taber zone roughly parallels the regional structure; however, minor rises occur in the west and central areas. These rises likely reflect the varying numbers of seams in the coal zone. The Taber zone appears to flatten out in the eastern part of the cross section. However, this is only a computer projection of the coal zone position based on available data from the east and central areas. The stratigraphic section C-C' shows that the Taber zone becomes very thin and remains at a constant stratigraphic level in this area, thus explaining the flat appearance on the structural section. The Lethbridge zone is shown to be fairly smooth, and the structural section suggests the zone outcropping or subcropping in the eastern part of the section. No data are available for the Lethbridge zone east of about range 14, therefore, the line shown on BB-BB' east of this area is only a projection.

10.4 STRATIGRAPHIC CROSS SECTION D-D'

Stratigraphic cross section D-D' runs east-west through township 24, across the north end of the Sweetgrass Arch in southern Alberta. The section exhibits a clear distinction between the Oldman and Foremost Formations in the western regions, before casing causes interference. In this section, the stratigraphic thickening of the Milk River/Pakowki Formation interval is such, that nearly the entire Foremost Formation is replaced by marine Pakowki sediments in the eastern part of the section. At least three shorelines are developed east of range 11 and the upper marine shale tongue, as seen in section

C-C', is also present in this area. The shorelines begin to develop immediately east of the Bow Island Arch, a sub-structure on the Sweetgrass Arch. Localized shoreline developments are present in ranges 16, 17 and 18, causing local truncations of the McKay zone. The major shoreline developments in the eastern part of the section are responsible for the McKay and Taber zones becoming truncated, with the Taber zone truncating in a more easterly position than the McKay (figure 4).

The McKay zone is continuous throughout this cross section; however, individual seams are very difficult to correlate west of range 16 and east of range 9. The Taber zone is not developed west of range 17, has an irregular development between ranges 17 and 15, is well developed with easy individual seam correlation between ranges 15 and 8, and thins and eventually replaced by marine sediments east of range 8. The Lethbridge zone consists of one or two seams throughout the area west of range 16, but becomes cased off east of range 16.

The structural section DD-DD'(see also figure 8) shows the regional structure, as defined by the Colorado and Milk River markers, to be nearly flat in the east-central area, dipping gently to the west in the western region, and dipping inconspicuously to the east in the eastern part of the area. This section reflects the structure of the Sweetgrass Arch. The Pakowki Formation marker, again, shows an abrupt stratigraphic climb up-section over about 25 km in horizontal distance. The McKay and Taber zones are also truncated by the Pakowki Formation marker, again representing the transition from nonmarine to marine conditions with several shorelines being developed. The Taber and McKay zones show a relatively flat, even structure in the region immediately west of the point where the zone is truncated by the Pakowki Formation marker. These flat regions indicate that the coal zone has good correlation potential as shown in stratigraphic section D-D'. West of these flat even regions, both coal zones have much more irregular structural tops on the section. This is attributed to the more chaotic stratigraphic distribution of coals in this area, as was seen in the stratigraphic section.

10.5 STRATIGRAPHIC CROSS SECTION E-E'

The stratigraphic cross section E-E' is a detailed section across the Sweetgrass Arch and to show; the relative thickening and thinning of individual seams, how well and to what lateral extent individual seams can be correlated, coal seam splits, controlling factors on seam development and features about laterally equivalent sediments to the coal zones. Using detailed logs, the section was constructed in such a manner as to be perpendicular to the Sweetgrass Arch to see if the structure was having any influence on coal and clastic sedimentation. The section shows the same phenomenon as seen in the other cross sections e.g., numerous stacked shorelines within a relatively narrow region between ranges 10 and 12. Other shoreline trends appear between ranges 18 and 20, but these are minor features compared to the eastern developments.

The McKay zone is, in general, a fairly fine-grained clastic unit, containing some bentonitic ash horizons, coal seams and to a lesser extent, coarser channel sand bodies. These sand bodies are found within and laterally to the McKay zone in the western part of the section. The channel sand bodies appear to have removed some of the upper coals in the western region and were; therefore, developed after the peat swamps. Some of the other sands were likely contemporaneous with the original peat swamp development, as coal seams grade more gradually into channel sand bodies. Contemporaneous sands would cause more splits in coals and generally make seams more argillaceous. Generally, seam splitting becomes more pronounced west of the stacked shoreline region. The McKay zone coal seams are, for the most part, not easy to correlate, even when well-spacing is relatively close. A central region between ranges 11 and 15 has the best correlation potential; however, even within this area it is not possible to correlate all seams present from well to well. Individual seam thickness reach its maximum westward of the stacked shoreline region. No coal occurrence at the level of the McKay zone should be expected east of about range 10.

The Taber coal zone is likewise found within a predominantly fine-grained interval, immediately underlying the coarse clastics of the Oldman Formation. On this cross section the coal zone begins rather abruptly at about range 17, with only sporadic development west of this point. The coals within the zone are very difficult to correlate between ranges 13 and 16, but are much easier to correlate in the eastern region (east of range 10). Splits within correlated seams become more pronounced and more frequent west of the easternmost well. The zone descends slightly east of range 7, due to compaction of the shales within the Pakowki Formation overlying some very thick sand bodies in this region. The Taber zone is known to continue eastward before being replaced laterally by Pakowki Formation marine sediments. The thickest, cleanest Taber coal seams are found within the region between ranges 7 and 9.

The Lethbridge zone is only present in four of the westernmost wells in this cross section and shows variation from one to four seams. The seams in general can be correlated in the western region, although some additional seams are introduced. Everywhere throughout this section, the Lethbridge zone is overlain by Bearpaw Formation marine sediments. The zone remains at a fairly constant stratigraphic level, except in a few locations where the zone is located higher or lower. This seems to be related to differential compaction of more coaly or shaly sections of Belly River Group versus the more sandy sections. For example, the Lethbridge coal zone drops by about 7 m, between ranges 17 and 18. This is exactly where the Taber zone begins its abrupt development that extends eastward. Similarly, the Lethbridge coal zone continues eastward at this new stratigraphic level.

The structural section CC-CC' traverses the same area as the stratigraphic section E-E'. This section shows the general structure of the Sweetgrass Arch, i.e. gently dipping in the west and flattening out in the east. The stacked shoreline position, where the Pakowki Formation interval increases abruptly, is also shown by the structure on the top of the Pakowki Formation. The eastward truncation of the McKay zone is also evident as well as the fact that the Taber zone becomes the first coal zone above the Pakowki Formation in this area. The Taber zone does not; however become truncated throughout the length of this section. The section also shows the predicted subcrop of the Lethbridge zone in the central region. Comparing these predictions with the geological map of Alberta (Green 1972), shows the prognostications to be reasonably accurate. The Lethbridge zone is known to be eroded and to underlie thin outliers of Bearpaw Formation sediments throughout much of the central and eastern areas of the section. Much of this is demonstrated in the structural section, proving that such sections can be useful tools in predicting outcrop or subcrop regions for the coal zones.

10.6 STRATIGRAPHIC CROSS SECTION F-F'

The stratigraphic cross section F-F' was constructed across the Sweetgrass Arch, combining oil and gas well logs and Alberta Research Council shallow coal drilling logs. The Sweetgrass Arch structure, as it appears today, is believed to have formed sometime after Campanian time, probably simultaneous with the onset of the Laramide Orogeny (Tovell 1958). Wells (1957) felt that the structure was primarily a Tertiary feature. Because of post-Tertiary erosion over the arch, a large portion of the Belly River Group sequence is missing over much of southern Alberta (figure 1). The Lethbridge, Taber and parts of the McKay zones are missing over this area (figure 1). Utilizing shallow drillhole data with deeper oil and gas well data provides a more complete picture of the coal zones in this area. The western part of the section shows the complete Belly River Group sequence with all three coal zones present.

The McKay zone is found at a constant stratigraphic level and thickness (10-15 m) throughout the cross section. In the western part of the section, the number of seams is very small (commonly one to two) and the individual seam thickness is thin (<1.0 m). As the zone is traced to the east, the numbers and thicknesses of seams increase up to about range 11, whereupon the trend reverses. The McKay zone, east of range 11 becomes thinner, has fewer seams, thinner individual coals, and becomes progressively replaced by the Pakowki Formation marine sediments.

The Taber zone is characterized in the west by thin seams, a widely scattered stratigraphical distribution, and a general lack of number of seams in the zone. As the zone is traced to the east, the thicknesses of the individual seams increase, the zone tends to become more tightly concentrated stratigraphically, and the number of seams increases dramatically. At the far eastern end of the section, the Taber zone coals are the first ones encountered above the Pakowki Formation marine sediments. The Taber coal zone rises very close to the surface between ranges 6 and 11 over the Sweetgrass Arch, descending to deeper levels east of the Sweetgrass Arch.

The Lethbridge zone is well developed in the west, as shown by Alberta Research Council logs. Seven individual seams, with thicknesses up to 1.8m, can be distinguished. Alberta Research Council borehole Th78-76 (NE-34-16-18W4) is located very near the subcrop edge of the Lethbridge zone, as shown by the shallow depth to the coal.

10.7 STRUCTURAL CROSS SECTION EE-EE'

The structural crosss ection EE-EE' runs approximately north-south, and was constructed to roughly parallel the axis of the Alberta Basin. The markers and coal zones show the general basin geometry, with the Sweetgrass Arch dominating the southern (right hand) side of the section. The reliability of the Milk River and Colorado as marker horizons is reflected in this section in that both horizons remain parallel throughout the basin (some exceptions in the far north). The Pakowki Formation marker closely parallels the McKay zone over most of the basin, except in some instances where they merge or cross over. These cross-over regions likely represent areas were the McKay zone is poorly (or not at all), developed or where a local shoreline is intersected. The Taber and Lethbridge zones maintain a relatively constant distance from the Milk River Formation marker throughout the section. Rises and hollows in the structure on top of the coal zones likely represent regions where coals, within a given zone, are more sporadically developed. Where the structure on top of the zone is smoother and regular, the coal zone -- including the seams -- are likely more regularly developed and more easily correlated. The Lethbridge zone was only mapped northward to the turning point "B", however, south of here the structure becomes very regular and uniform. This uniformity disappears as the Milk River Ridge/Sweetgrass Arch region is approached and is likely due to the lack of data in this near subcrop area.

An evaluation of the coal resources of the Belly River Group, to a depth of 400 m in the Alberta Plains

Volume II: Maps and cross sections

D.E. Macdonald, P.J. McCabe and A. Bosman

March 1986
Alberta Research Council

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Location map of stratigraphic cross sections

D.E. Macdonald, P.J. McCabe, A. Bosman

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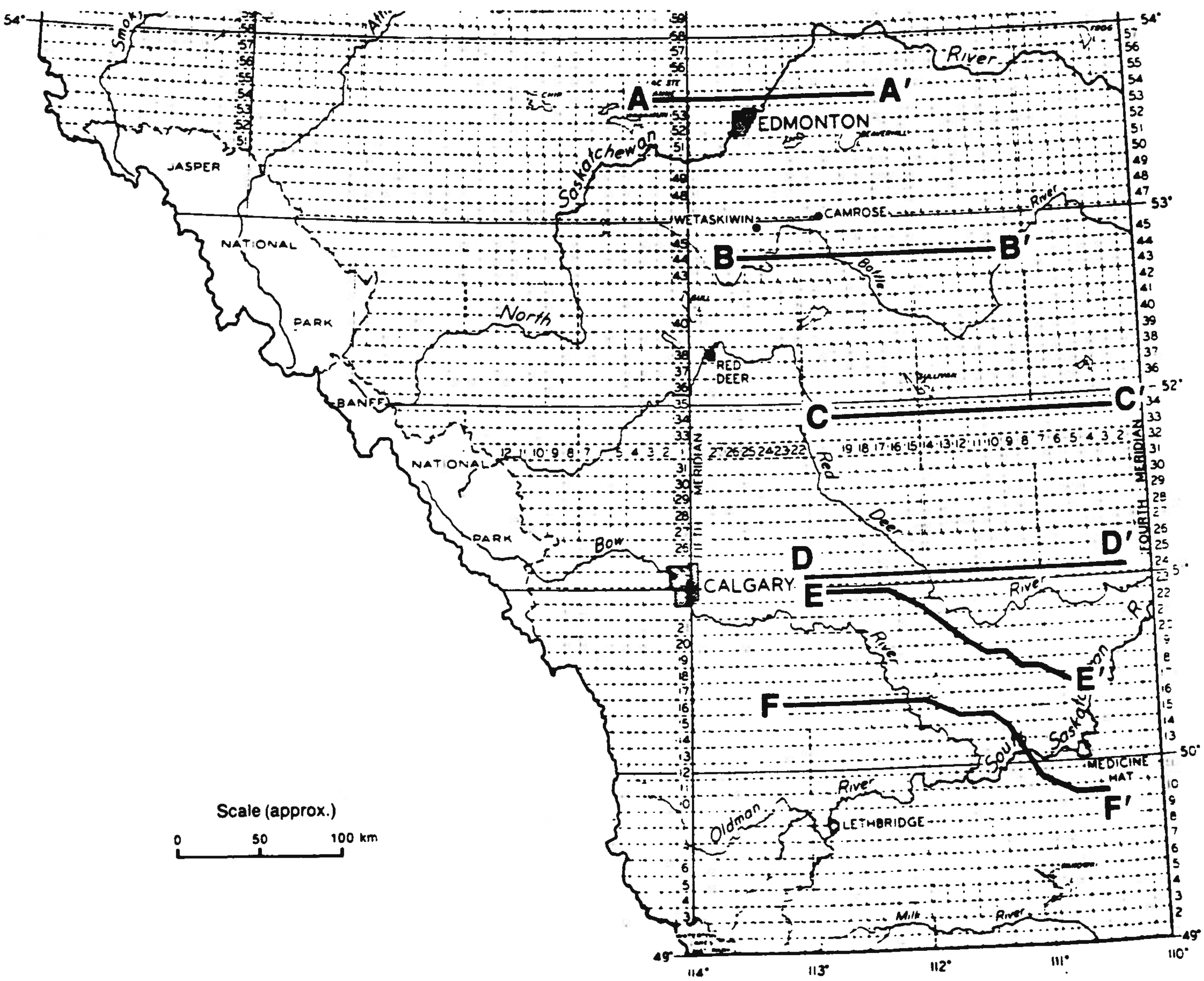

Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Map 1. Structure on the Colorado

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Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Map 2. Isopach of the Pakowki Formation

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Edmonton
Fifth Meridian
Calgary
0 15 30 45 60 km
missing data = −1.0
Contour interval 1 metre
Outcrop edge
Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Map 3. Cumulative coal McKay zone
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Map 4. Number of seams McKay zone

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Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Map 5. Isopach thickest seam McKay zone

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Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Map 6. Structure on the McKay zone

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Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Map 7. Depth to the thickest seam McKay zone

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Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Map 8. Number of seams >1.0 m
McKay zone

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Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Map 9. Number of seams Taber zone

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Map 10. Cumulative coal Taber zone

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Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Map 11. Isopach thickest seam Taber zone

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Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Map 12. Depth to thickest seam Taber zone

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Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Map 13. Structure on the thickest seam Taber zone

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Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Map 14. Number of seams Lethbridge zone

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Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Map 15. Cumulative coal Lethbridge zone

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Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Map 16. Isopach thickest seam Lethbridge zone

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Edmonton
Calgary
Fifth Meridian
0 15 30 45 60 km
missing data = 0
Contour interval 25 metres
Outcrop edge
Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Map 17. Structure on the thickest seam Lethbridge zone
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Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Map 18. Depth to thickest seam Lethbridge zone

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Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Stratigraphic cross section A-A′

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Legend

- Coal Seam Correlation
- Uncertain Coal Seam Correlation
- Formation Boundary Correlation
- C Upward Coarsening Unit
- F Upward Fining Unit
- M Massive Sand Unit
- Channel Sand Unit
- Coal
- Carbonaceous Shale, Shaly Coal

Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Stratigraphic cross section B-B′

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Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Stratigraphic cross section D-D′

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Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Stratigraphic cross section E-E′

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Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area Stratigraphic cross section F-F′

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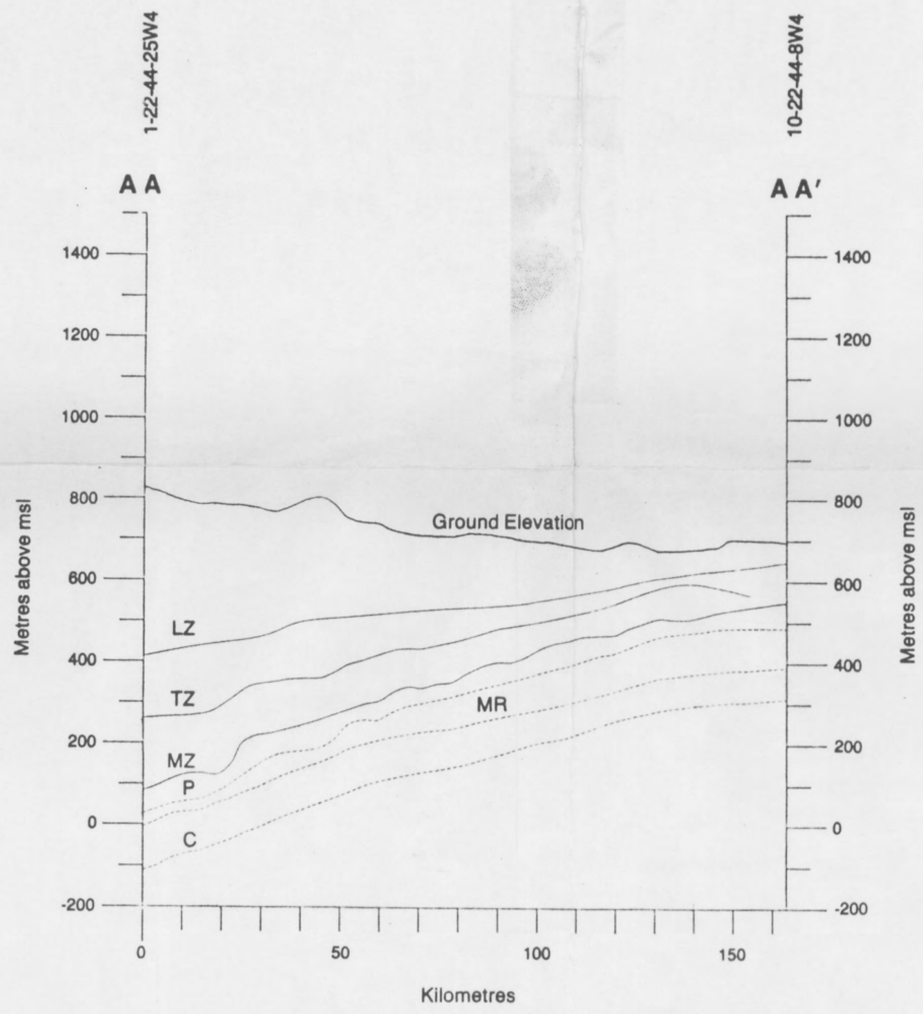

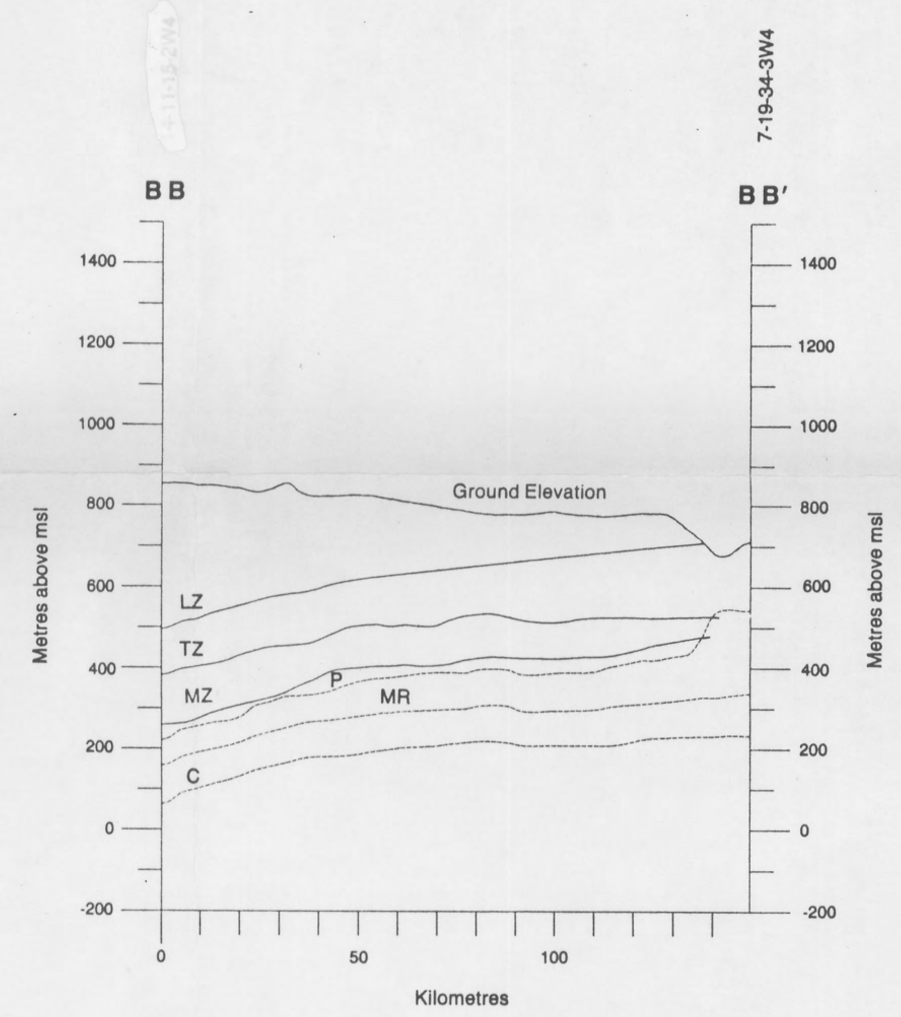

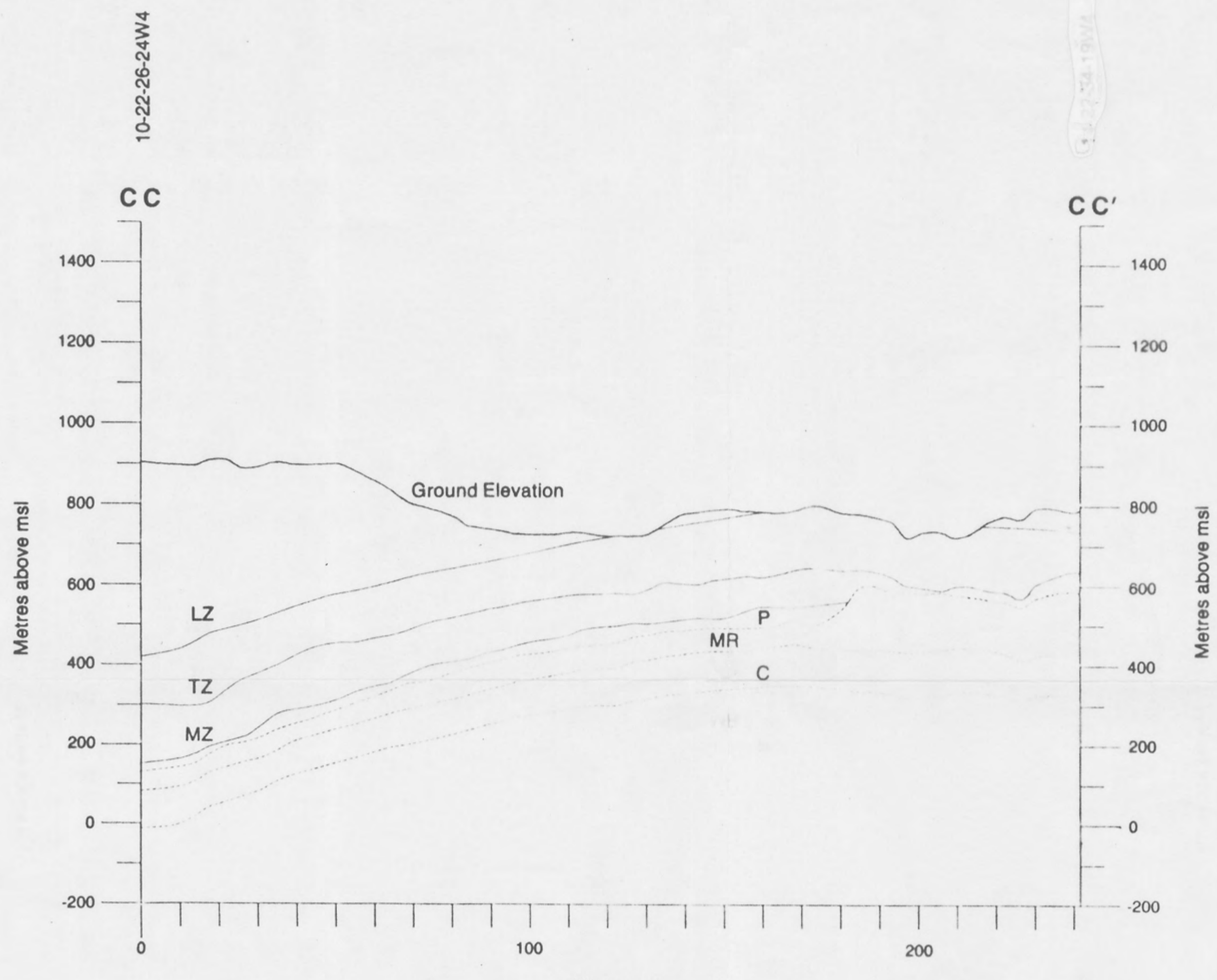

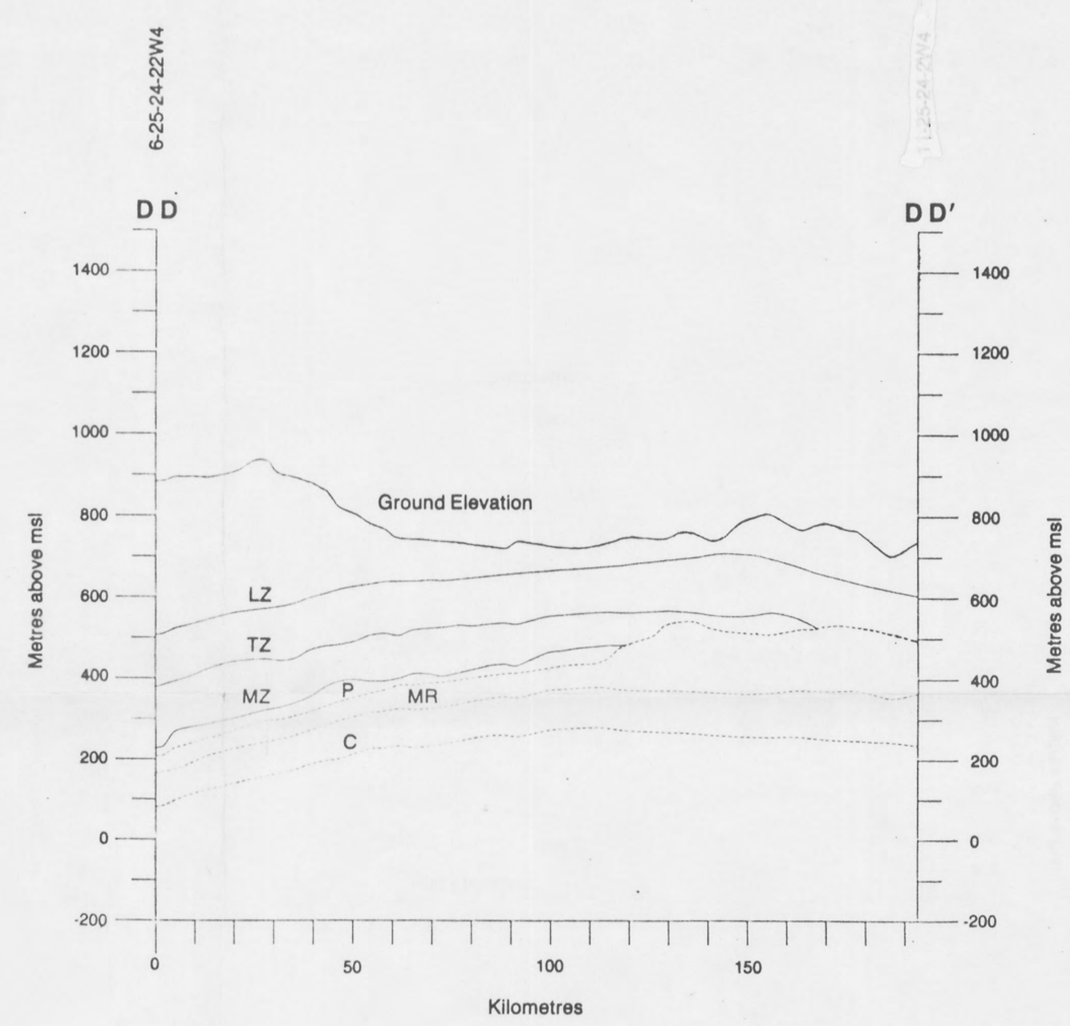

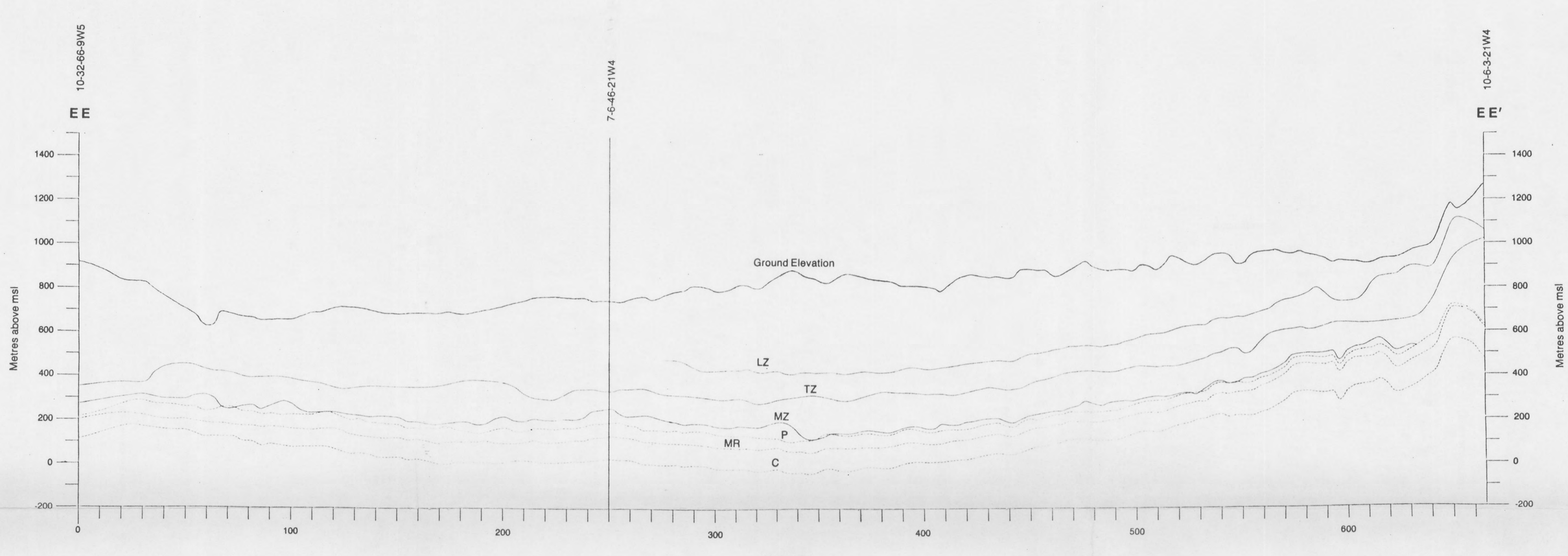

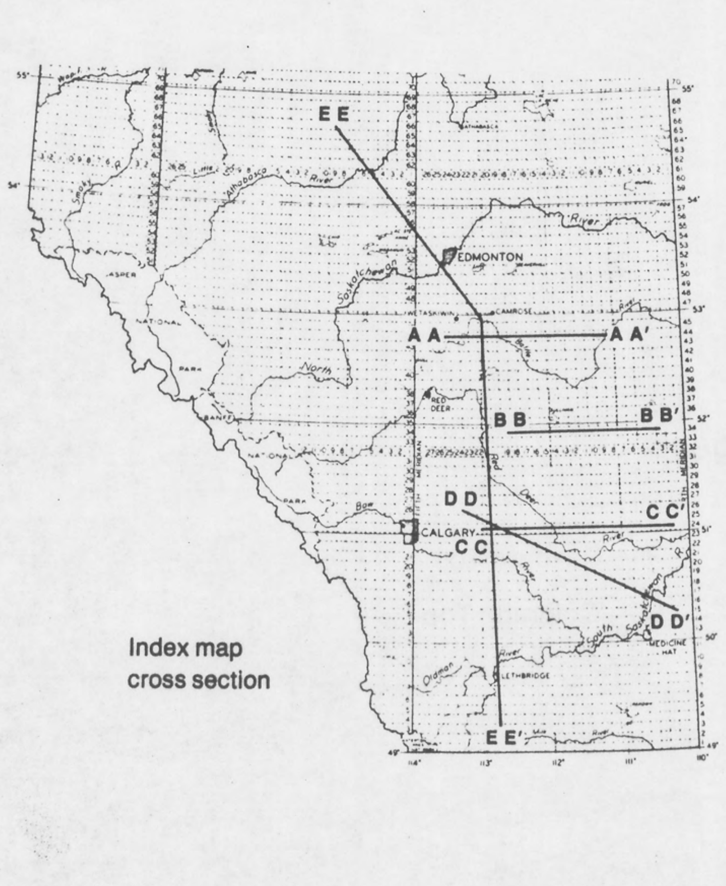

Index map
cross section

Legend

LZ — Lethbridge Zone	MR—Milk River Top
TZ — Taber Zone	P — Pakowki Top
MZ — McKay Zone	C — Colorado Top

Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Structural cross sections A A-A A′ to E E-E E′

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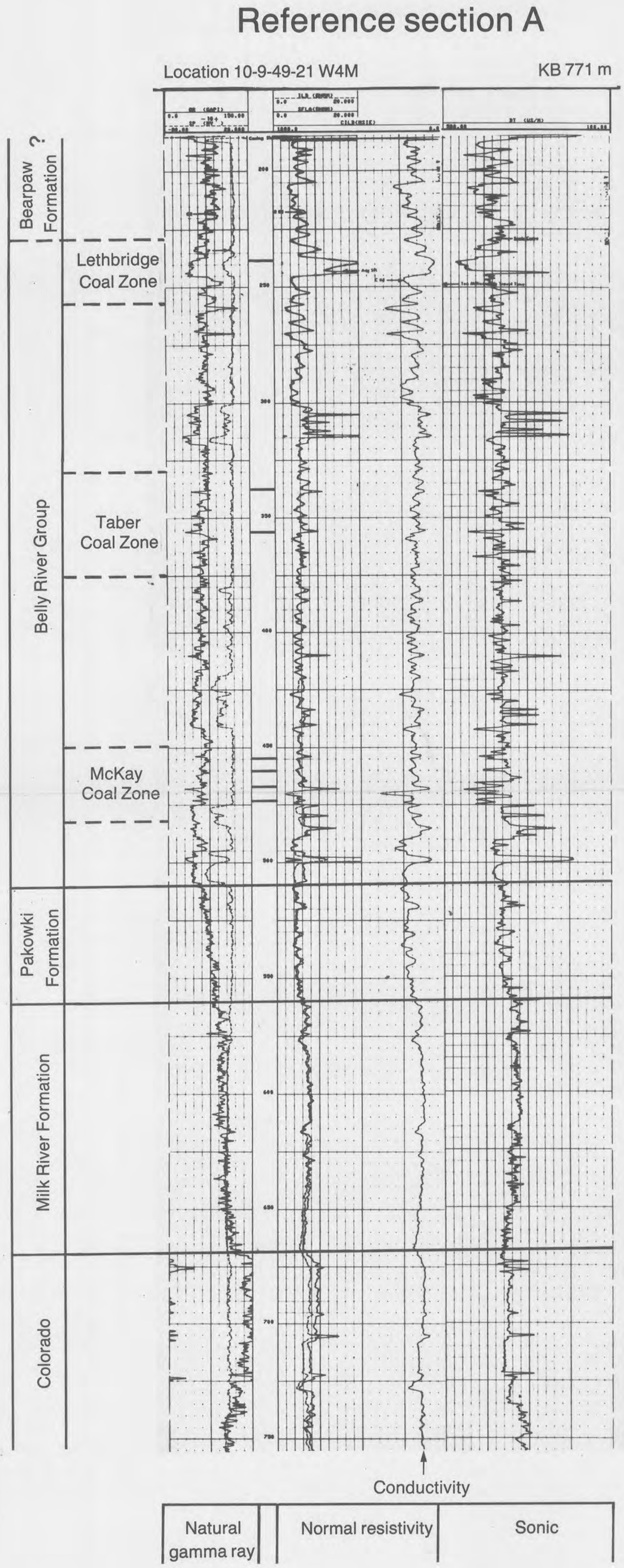

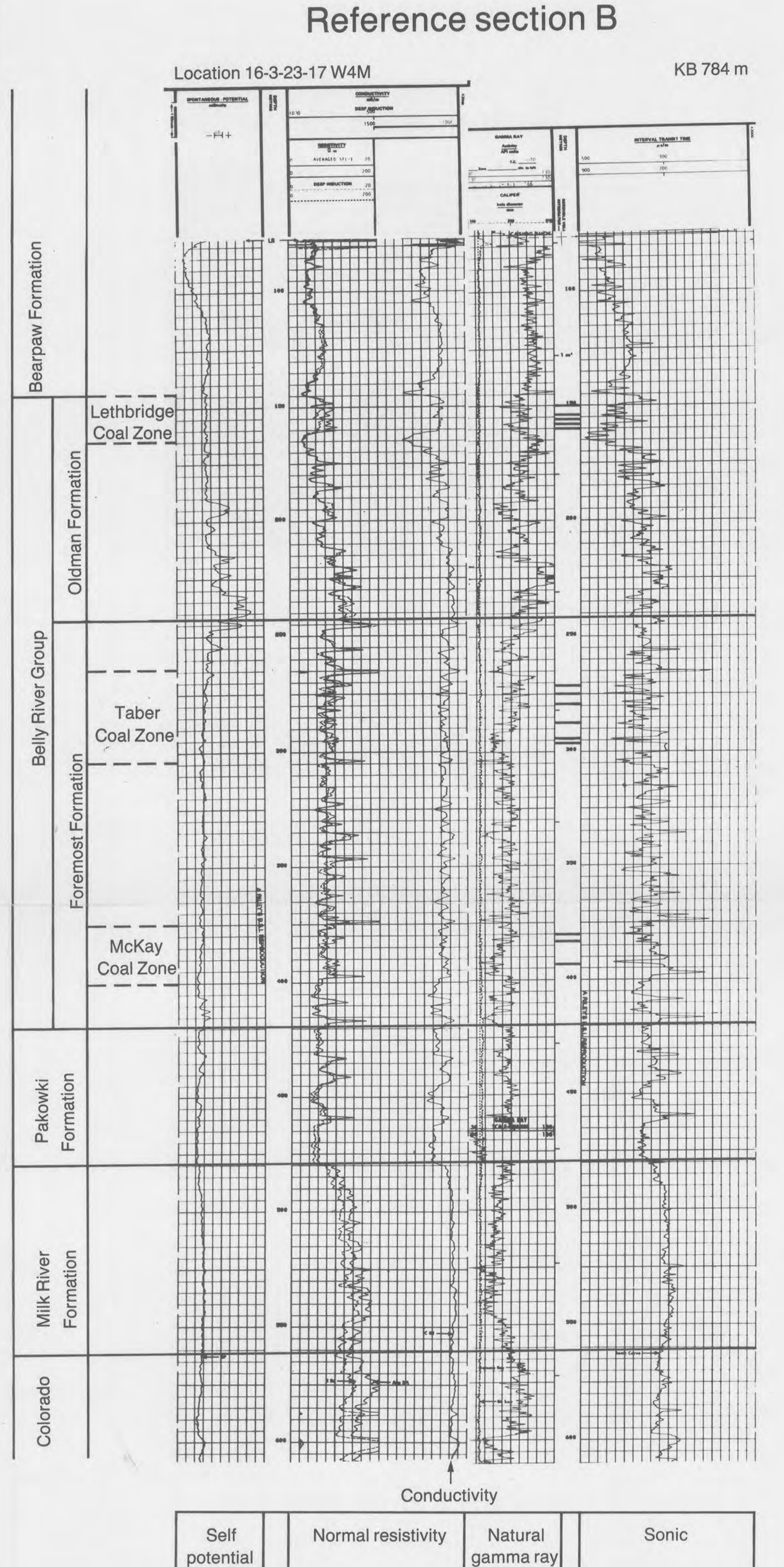

Coal resources evaluation, Belly River Group, to 400 m depth, Alberta plains area
Figure 3. Reference geophysical logs A and B

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