An evaluation of the coal resources of the Ardley coal zone, to a depth of 400 m, in the Alberta plains area.

Volume I

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SUMMARY

This report is one product of a coal evaluation program that has been jointly funded by Alberta Energy and Natural Resources and the Alberta Research Council since 1979. Major objectives of the program were: (a) to evaluate the coal resources of the plains region of Alberta south of Township 64, from the near-surface to depths of about 400 m; and (b) to develop an understanding of the sedimentologic and stratigraphic controls on the distribution and geometry of the coal seams. The Ardley coal zone is one of the most important coal zones of the plains region and is currently being strip-mined for use in electrical power plants. In this report a comprehensive regional assessment is made of the geological character of coals in the Ardley zone. A description of the calculated inferred resources for the Ardley and other coal zones is presented in a separate report.

This report delineates huge resources within the Ardley zone that could be targets for future underground mining. A new understanding of the geometry of the coals and the resource maps and cross sections presented in this report should prove useful in the management of the coal resources of the Ardley coal zone. They will also prove useful in evaluating areas for future exploration.

The study is based on data collected from geophysical logs of wells in 474 townships. In addition, core was examined from wells drilled by the Alberta Research Council in the Alix area. An understanding of the facies present in the core was of considerable help in interpreting the resource maps and cross sections.

The Ardley coal zone was deposited in the Lower Tertiary at a time when terrestrial sedimentation was prevalent throughout Alberta. Clastic sediments associated with Ardley coals are predominantly fluvial in origin. There are also some lacustrine sediments and thin paleosols. Some 20 to 160 m below the Ardley coal zone is the Battle Formation

which, in core, appears to be a complex of stacked paleosols. The Battle Formation has a distinctive signature on geophysical logs and proved to be a useful marker horizon for this study. Examination of core from the Alix region indicates that in this area, sandstones in the interval between the top of the Battle Formation and the top of the Ardley coal zone were deposited by shallow, sluggish rivers. In contrast, the overlying thick sandstones (Paskapoo sandstones) were probably deposited by relatively deep, fast flowing rivers. The development of the Ardley coal zone appears to be the result of some basin-wide control on sedimentation, either tectonic or climatic, which allowed the development of extensive peat-forming mires with little introduction of clastics for a long period of time.

Data on coal seams and marker horizons were collected from geophysical logs of over 1400 oil and gas wells and from 98 logs of shallow coal holes drilled by the Alberta Research Council since 1974. The data were entered into a computer database that was used to generate a variety of coal resource maps, geological structure maps and structural cross sections. A large number of stratigraphic cross sections, showing correlation of coal seams between individual wells, were also constructed.

A variety of maps have been produced that show the extent of coal development: thickest coal seam, cumulative thickness of all seams, and total number of seams. These maps show that the Ardley coal zone extends northward from Township 30 to the outcrop edge and westward to the 'Disturbed Belt' at the margin of the foothills. As a general rule, the amount of coal increases toward the west.

Superimposed on the overall pattern are two areas with particularly high amounts of coal. An east-west trending area between Lodgepole and Coalspur has cumulative coal values up to 21 m and individual seam thicknesses to 4 m. A northeast-southwest trend east of the Athabasca River between Obed and Whitecourt has cumulative coal values to 24 m and individual seam thicknesses to 3 m. The coal zone consists of up to 12 seams in each region. These areas appear to have been sheltered from clastic sedimentation for particularly long periods of time.

Both maps and cross sections show that the Ardley coal zone dips towards the southwest at approximately 5 m per kilometer. The zone thickens to about 14 m near the outcrop edge to more than 200 m near the 'Disturbed Belt' at the margin of the foothills. Strata between the Ardley coal zone and the Battle Formation thickens at a similar rate. The thickening trends of both the coal and coal zone indicate that subsidence in the basin was more rapid in the west, allowing peat to accumulate at faster rates.

Two areas were selected for more detailed study: the Alix area (Twp 34-41, Rg 23-28 W4M and Rg 1-2 W5M) and the Medicine Lake area (Twp 43-47, Rg 5-9 W5M). These studies showed that the Ardley coal seams are more laterally persistent than those of the Horseshoe Canyon Formation or the Belly River Group. Seams could be correlated over several townships but tended to pinchout or split over long distances. The detailed studies have identified relatively large areas that have two or more seams that are potentially suitable for underground mining.

The Ardley coal zone has been shown to be far more complex and varied than had previously been supposed. From an economic standpoint this study is significant in that it shows that Ardley coals are generally thicker and more numerous at greater depth. When economic conditions are favourable, the Ardley zone may well prove suitable for underground mining. However, much more detailed work will be required before the real potential of any area can be evaluated.

1. BACKGROUND TO STUDY

1.1 INTRODUCTION

Alberta Energy and Natural Resources and the Alberta Research Council jointly funded a coal geology program from 1979 to 1986. The program evaluated the coal resources of the Alberta plains south of Tp 64, to a depth of about 400 m. This report describes the Ardley coal zone. Separate reports describe the coal resources of the Belly River Group (Macdonald et al., 1987), and the lower Horseshoe Canyon Formation (McCabe et al., 1988). The main objectives of the study were (a) to make a regional assessment of the extent of potentially mineable coal resources of the Ardley coal zone and, (b) to develop models to predict the distribution, thickness variations and lateral continuity of the coal seams. This volume of the report presents a detailed description of the geologic character of the Ardley coal zone. Full size representative maps and cross sections are in volume 2. A separate report describes the size of the coal resources (Strobl et al., 1987).

Economically, the Ardley is one of the most important coal producing zones in Alberta. Near-surface deposits of thermal coal in the plains region provide fuel for most of Alberta's electrical needs. Although most of the mining activity has been directed to areas where Ardley coals are close to the surface, it has long been realized that thick seams were present at depth. Environmental concerns and advances in underground mining methods, as well as a demand for higher quality or higher rank coals, has led to increasing interest in deeper coals over the last few years.

The wealth of data derived from this study also allowed us to evaluate the basin geometry, relative subsidence rates and environments of deposition during the late Cretaceous and early Tertiary. These are shown to be important controls on the coal resources of the Ardley.

1.2 ACKNOWLEDGEMENTS

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1.3 THE ARDLEY COAL ZONE

The Ardley coal zone is of Paleocene (Lower Tertiary) age and lies near the base of the Paskapoo Formation (figure 1). The outcrop area of the Paskapoo Formation is shown in figure 2. Because the strata dips toward the mountains, the Ardley coal zone crops out along the eastern and northern edges of the Paskapoo outcrop.

Deposition of the Paskapoo Formation was in a foreland basin (Beaumont, 1978) formed between the front of the Western Cordillera and the Precambrian Shield. Active thrusting in the Cordillera, during the late Mesozoic and early Tertiary, resulted in a downward flexing of the continental lithosphere in the mountains relative to the craton. This resulted in an asymmetric basin with strata dipping and thickening towards the mountains.

Paleocene sediments of Alberta are entirely non-marine in nature. The newest marine sediments of this age belong to the Cannonball Member of the Fort Union Formation in North Dakota (Belt et al., 1984). Ardley coals formed, therefore, in mires that were at least 800 km inland. Paleomagnetic work suggests that the paleolatitude of the central Alberta Basin was at about 60° north during the Palocene (Irving, 1979). The absence of a polar ice cap at that time suggests, however, that the climate of the Alberta region was considerably warmer than present day climates at this latitude.

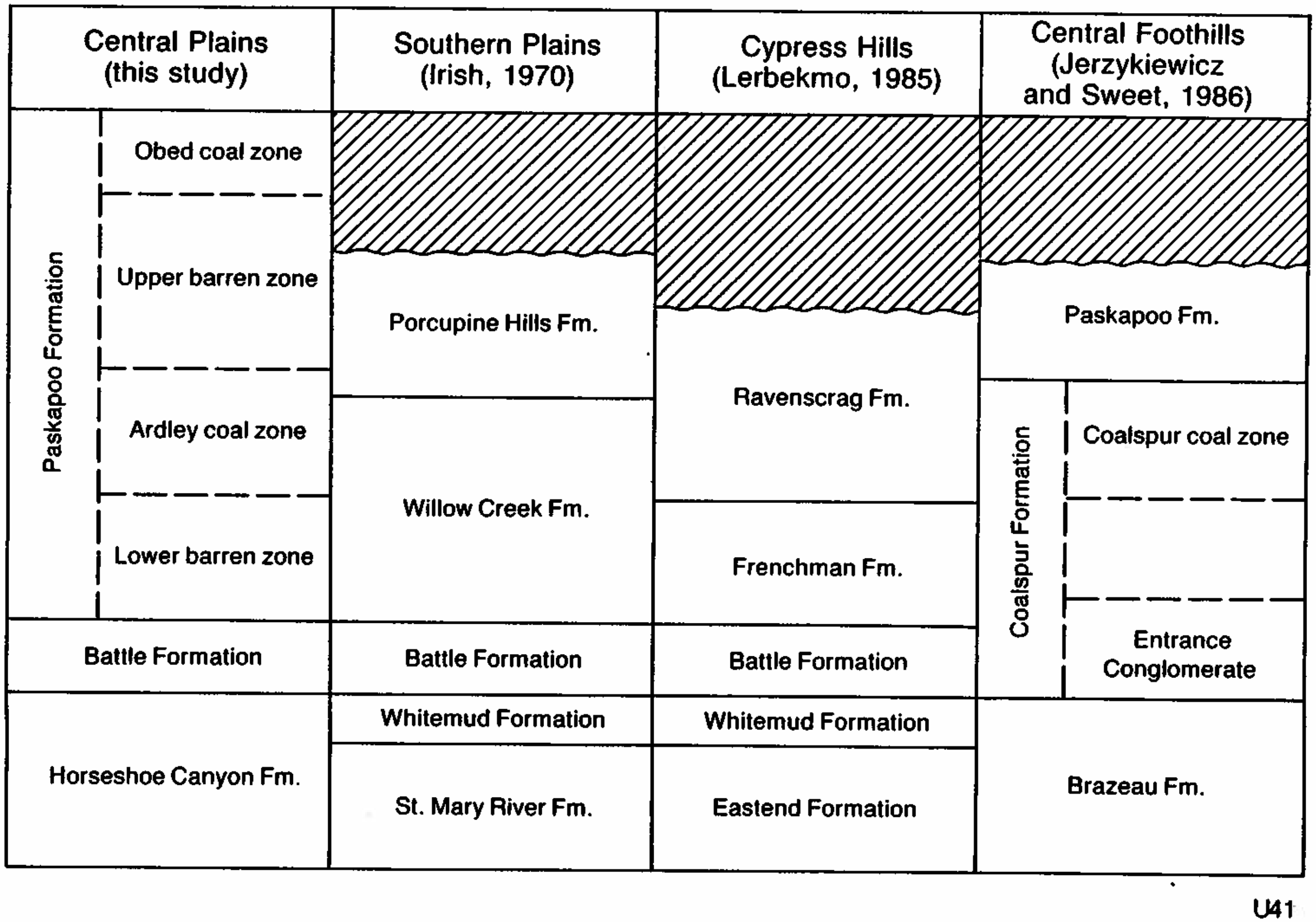

Figure 1. Table of formations for Alberta's uppermost Cretaceous and Tertiary coal-bearing strata. The Ardley coal zone of the plains is equivalent to the coalspur coal zone in the central foothills.

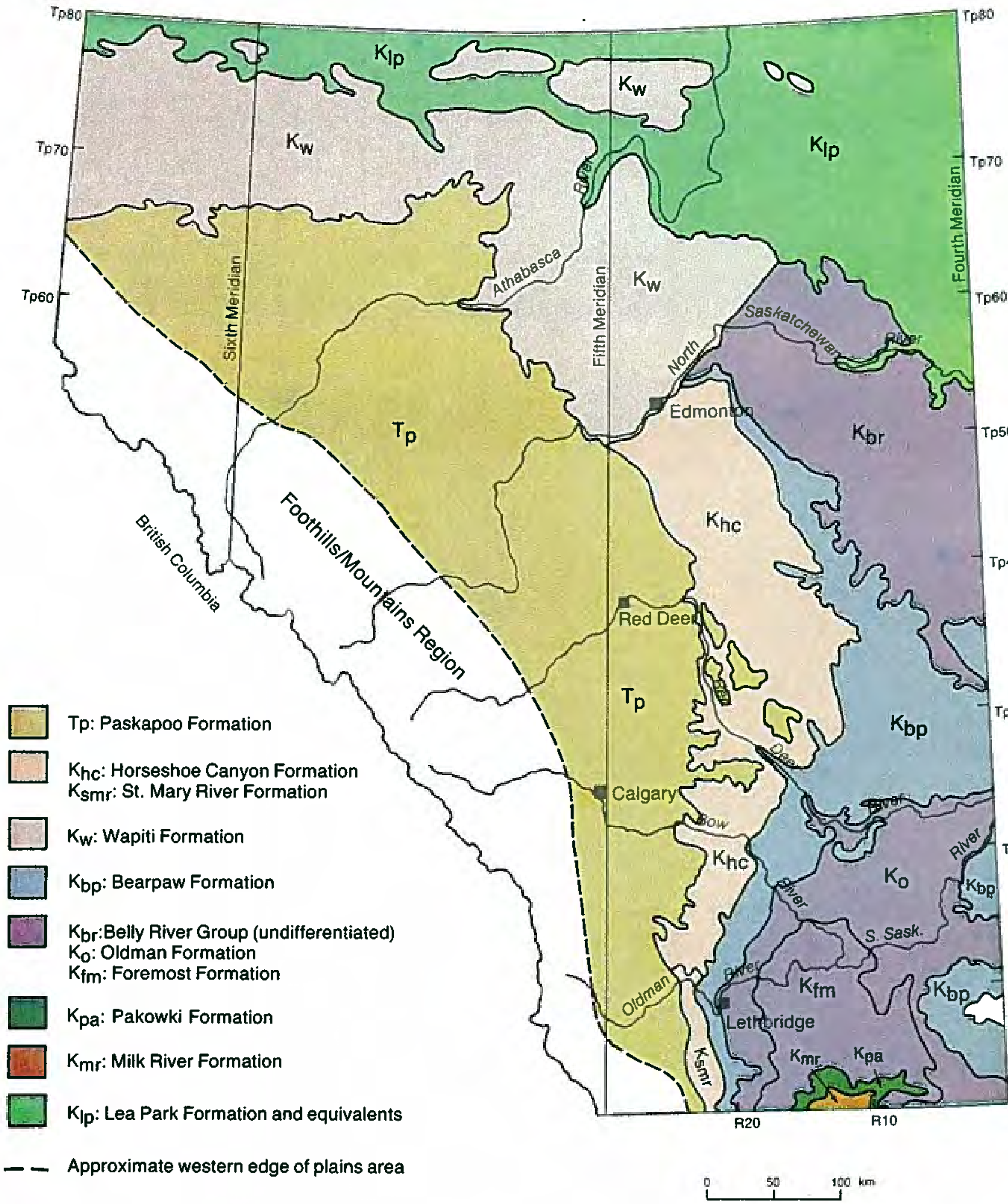

Figure 2. Geologic map of the plains area of southern Alberta. The Ardley coal zone lies at shallow depths along the outcrop edge of the Paskapoo Formation.

1.4 EARLIER COAL RESOURCE STUDIES

Research on the Ardley coal zone by the Alberta Research Council dates back to the 1920's. In one of the earliest Alberta Research Council publications, Allan (1924) described and mapped the Ardley coal zone in the Carbon, Big Valley and Ardley areas. Mapping of the coal zone continued into the 1940's (Allan, 1943). During this time, Allan and Sanderson (1945) established some of the earliest nomenclature for the Ardley coal zone and associated strata. More recent contributions by the Alberta Research Council include resource assessment reports by Campbell (1965, 1967, 1972), Holter, Yurko and Chu (1975) and Chu (1978). The two latter reports include data from Alberta Research Council exploratory drilling.

Regional studies of the uppermost Cretaceous and Tertiary strata include those by Elliott (1960), Ower (1960), Campbell (1972) and Carrigy (1970, 1971). These studies were based mainly on outcrop examination over a large portion of the Alberta plains and foothills. Complimentary work by Irish (1970) incorporated data from oil and gas wells which tied in the subsurface stratigraphy with the stratigraphy observed in outcrop. A detailed study of the upper Cretaceous and Tertiary coal-bearing strata of the Red Deer River valley was carried out by Gibson (1977). One of the latest regional studies of coal resources based on data from oil and gas wells is that of Williams and Murphy (1981). They show a map of the cumulative coal thickness for the Edmonton Group (which includes the Ardley and Horseshoe Canyon coals) and the cumulative amount of coal for broad depth zones.

1.5 METHODOLOGY OF STUDY

The study consisted of (a) a regional subsurface evaluation (b) detailed studies of the Medicine and Alix areas (c) examination of core and (d) interpretation of data.

The regional subsurface study is based on information derived from

1408 oil and gas wells and 98 Alberta Research Council's coal exploration drillholes. The Alberta Research Council's exploration holes are in areas where the Ardley coal zone is relatively shallow. They were drilled between 1961 and 1983, largely on a one-well per township basis. These holes generally had a maximum depth of 150 m, although some reached depths of up to 300 m. Oil and gas wells were used to obtain data in areas where the Ardley coal zone is more deeply buried, generally at depths greater than 200 m. Although useful in evaluating the Ardley coal zone throughout the deeper portions of the study areas, oil and gas wells data could not be used at shallower depths because of the interference of casing near the surface.

The size of the regional study area is 474 townships, from Township 66 in the north to Township 30 in the south and from the erosional edge of the Paskapoo Formation in the east to the disturbed belt in the west (see figure 3). The study did not extend further south because Ardley coals are not present south of Township 30. Although the contract called for an assessment of the Ardley coal zone to a depth of 400 m, some data were collected deeper within the basin. In the central portion of the study area, for instance, the Ardley coal zone was studied to depths of 1000 m or more. The study interval was extended in these areas to delineate more fully the limits of thick coal trends observed in the central area and to give a more complete appraisal of the stratigraphy of the coal zone basinwide. For the regional study, information was collected from one to three wells per township. This produced a random and somewhat regular distribution with well spacings varying from 1 to 10 km.

A total of 40 preliminary cross sections were made to verify correlations and to provide a framework for the geologic picks. A combination of a sonic or density log, natural gamma ray log and normal resistivity log formed the basis for identification of coal seams. Data collected from each well consisted of the location (given in DLS coordinates), kelley bushing elevation, depths to the top and base of each coal seam, and the depths to the top and base of the Battle

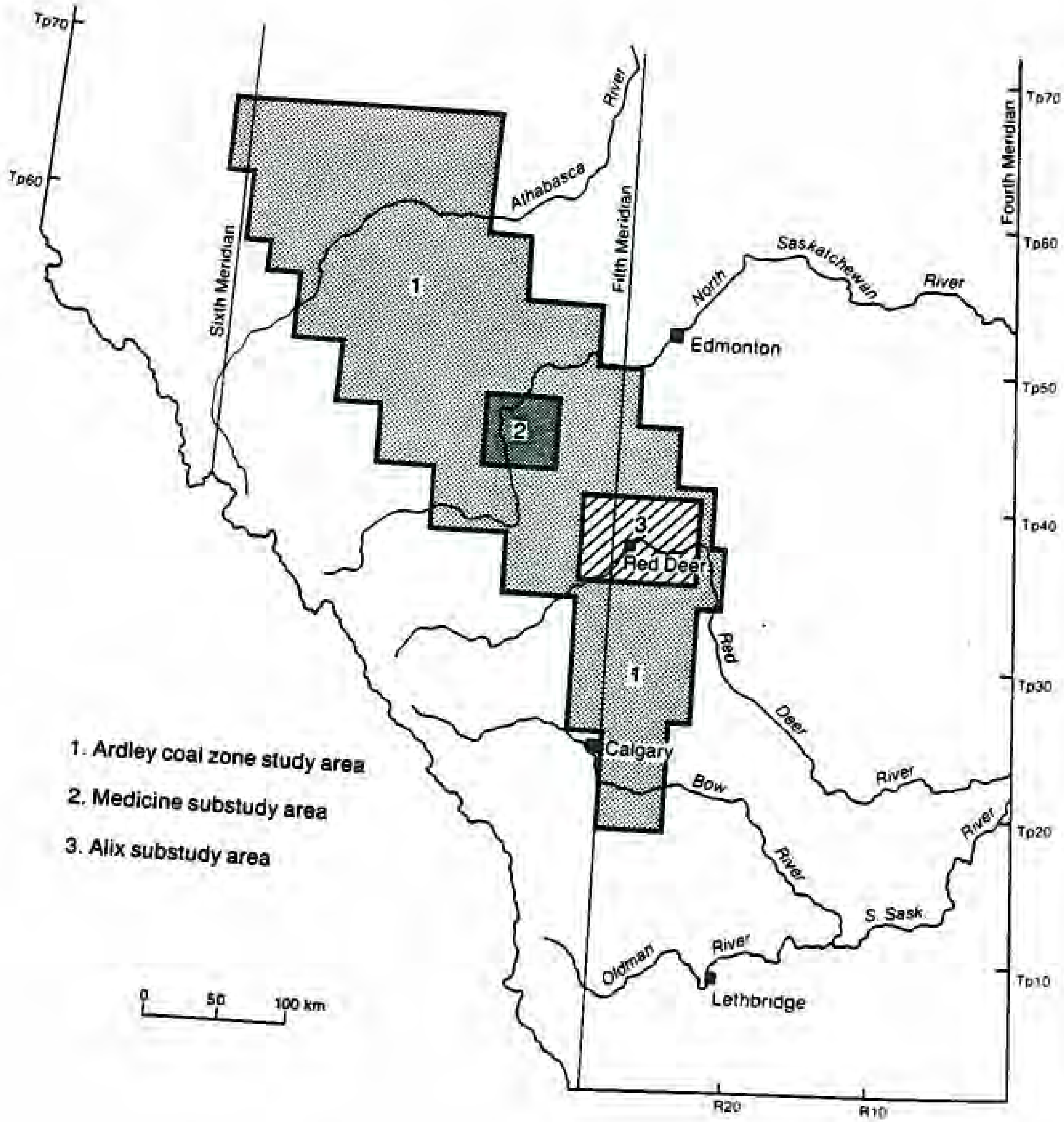

Figure 3. Location map showing the limits of the regional study area and the detailed Medicine and Alix substudies.

Formation which was used as a regional marker. All depth measurements were estimated to the nearest 0.3 m and only seams 0.5 m or greater were entered into the database. These constraints were applied in order to obtain consistent data and to make the more detailed coal exploration data more compatible with oil and gas well data. All the information was compiled into a computer database which was used to generate maps showing various aspects of the geology and coal resources of the Ardley zone. Kansas Geological Survey's Surface II was used to contour the maps and the program was run on a VAX 8600.

In addition to the regional work, two substudies were done to examine the geometry of Ardley coal seams in more detail. These substudies are presented in Appendix I of this report. The Alix substudy covered Tp 36 to 41, R22 W4M to R2 W5M, and the Medicine substudy from Tp 43 to 47, R5 to 9 W5M (figure 3). In these regions, information was selected from every available well intersecting the Ardley coal zone. Correlations were based on closely spaced, interlocking cross sections. As in the regional study, databases were constructed and all maps were computer generated.

During the Alberta Research Council's coal exploration drilling program, core was collected from the Ardley coal zone in the Alix substudy area (Bosman, 1982, 1983). Information on the lithologies, variation in bed thickness, grain size, sedimentary structures and fossil content of the coal-bearing sequence was used for the interpretation of the depositional setting.

1.6 CORRELATION OF SEAMS

In this study, we observed that some seams of the Ardley coal zone were remarkably continuous. Coal seams in most areas could be correlated over 10's of kilometres with a high degree of geologic assurance. When viewed on a basin-wide scale, however, correlation of individual seams becomes more tenuous. The cross sections contained in this report and volume II show the variation in thickness and lateral extent of many of the seams and for the coal zone itself. It must be noted, that not all of the data used are shown on the published cross sections, in order to keep the sections a manageable size. Correlations are based on preliminary cross sections with considerably more data and closer well spacings. Detailed studies are recommended for specific areas of interest, using every available well so that more precise correlations of coals seams can be made. In some areas, few data locations exist so new drilling may be required.

New techniques for correlation may also be utilized for future studies. Palynology, for instance, has been suggested for use in correlations. This method may have some restrictions, however, because spores of the Ardley coal zone appear to contain only two distinct palynofloral zones (Demchuk, 1987). Other promising correlation techniques may include comparisons of trace element concentrations (Goodarzi et al., 1985). Magnetostratigraphy and correlation of bentonites within coals have also been used by Lerbekmo (1985) and Lerbekmo and Coulter (1985) to correlate Ardley coal seams. Such techniques, unfortunately, commonly require representative samples and lengthy analyses. We suggest that these techniques be used to provide checks on correlations required in key areas. Further studies may identify other methods or improvements on existing ones.

2. STRATIGRAPHY

2.1 FORMATION NOMENCLATURE

Stratigraphic nomenclature of the uppermost Cretaceous and Tertiary strata has been reviewed several times over the last thirty years (e.g. Allan and Sanderson, 1945; Ower, 1960; Srivastava, 1968; Irish, 1970 and Gibson, 1977). None of these stratigraphic schemes proved ideal for this study, partly because it covers a much larger area and partly because of notable variation in the stratigraphy basin-wide. For these reasons, informal stratigraphic subdivisions were developed (see figure 4). The stratigraphic units are similar to those of Irish (1970) with the following modifications: (a) because of the difficulty in recognizing the lithology of the Whitemud Formation in the subsurface, it has been included in the uppermost Horseshoe Canyon Formation (following Nurkowski and Rahmani, 1984); (b) the term Scollard Member for the Cretaceous part of the Paskapoo Formation has been dropped because it could not be defined on lithological grounds; and (c) the Paskapoo Formation has been divided into the coal-bearing Ardley zone and the lower and upper non-coal-bearing units (lower barren zone and upper barren zones, respectively).

Gibson's (1977) stratigraphic subdivision cannot easily be applied in the subsurface on a regional basis. The top of his Scollard Formation is defined as "the base of the cliff-forming sandstone marker facies or, in the subsurface, the base of the first prominent thick sandstone unit above the uppermost major coal seam of the Ardley coal zone". On regional cross sections completed for this study, sandstones are commonly irregular in thickness and laterally discontinuous. In some locations, tens of metres of mudstones and thin interbedded sandstones overly the Ardley coal zone.

The stratigraphic units shown in figure 4 are recognizable in the subsurface over wide areas of the Alberta basin. Identified economic seams of the Obed coal zone are, however, restricted to an erosional

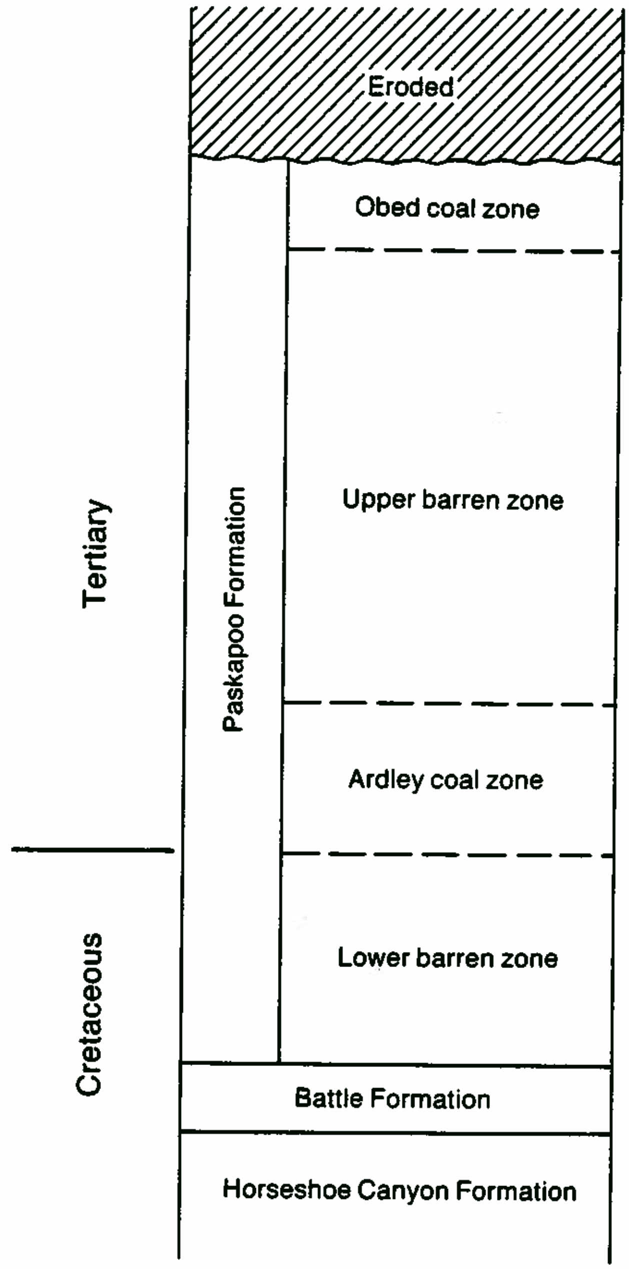

Figure 4. Informal stratigraphic units used in this study. These units can be correlated basin-wide. See text for a description of each unit.

outlier in the Obed area where it is separated from the underlying Ardley coal zone by at least 500 m of barren strata. Similarly, south of Tp. 38 (Red Deer) the Ardley coal zone thins and coals are generally absent south of Tp. 30 (Carstairs). In this portion of the province, even the regional datum, the Battle Formation, becomes very difficult to identify and is commonly absent south of Tp. 24 (Calgary).

2.2 AGE DETERMINATION

The early Paleocene (P1/P2) age of the Ardley coal zone has been inferred largely on the basis of paleontological evidence. Until relatively recently all or part of the coal zone was thought to be Cretaceous in age (Snead, 1969; Holter et al., 1975; Russell and Singh, 1978). Noting the upper limit of the Cretaceous palynomorph genus Aquilapollanites fimbriata at the lowest coal seam (commonly referred to as the Nevis), Lerbekmo, Jarzen and Russell (1979) suggested that the Cretaceous-Tertiary (K-T) boundary was at the top of that seam. More recently, however, after detailed analysis of this interval, the palynological extinction was placed at the base of the Nevis seam (Sweet and Hills, 1984). From New Mexico to Alberta, the shift from a diverse angiosperm-rich late Maastrichtian flora to a low diversity, early Paleocene gymnosperm and miospore dominated flora has been utilized to identify this boundary (Demchuk, 1987).

A relatively thin interval within the zone of extinction (defined on palynological grounds) is characterized by high concentrations of the trace element iridium. Tschudy et al., (1984) suggest that a catastrophic event of global proportions occurred resulting in the destruction of vegetation (and some extinctions) represented by the iridium anomaly. The cause and the significance of the iridium anomaly is under debate and a series of theories exist. It is not in the scope of this paper, however, to go into detail about the K-T boundary. More information is available in Baadsgaard and Lerbekmo (1980), Johnston and Fox (1984), Lerbekmo and Coulter (1985a, 1985b), Russell and Singh (1978), Sweet and Jerzykiewicz (1985) and Hutton (1980).

2.3 LATERALLY EQUIVALENT FORMATIONS

In the southern part of the province the Paskapoo Formation is replaced by the Porcupine Hills and Willow Creek Formations. Irish and Havard (1968) have traced the Battle Formation as far south as Tp. 3. In the Cypress Hills region, of southeastern Alberta and southwestern Saskatchewan, the Battle Formation is overlain by the Frenchman and Ravenscrag Formations. Coals are present in the Ravenscrag Formation close to the K-T boundary (Lerbekmo, 1985).

Strata equivalent to the Paskapoo Formation of the plains crop out in the central Alberta foothills (Hinton, Coalspur and Coal Valley). At the base of the formation is the 12 m thick Entrance Conglomerate, which may be a lateral equivalent of the Battle Formation or may be slightly younger. The rest of the lower part of the Coalspur Formation consists of barren non-marine sandstones and mudstones. The upper part of the formation is coal-bearing. Like the Ardley zone, the coal seams of the Coalspur Formation directly overly the K-T boundary, which has been established on palynological evidence and the presence of the iridium anomaly (Jerzkiewicz and Sweet, 1986). Following Gibson's definition in the plain's region, the base of the overlying Paskapoo Formation in the Coalspur area is at the base of the prominent sandstone layer above the youngest coal (Jerzkiewicz, 1985).

2.4 COAL NOMENCLATURE

In the Red Deer River valley two thick coal seams are generally recognized, although there has been considerable debate about their correlation (Gibson, 1977). The seams have been named by earlier workers. The lower coal has been referred to as the No. 13 or Nevis seam (Allan and Sanderson, 1945; Gibson, 1977), the Lower Ardley (Campbell, 1967) and the Lower Ardley 'A' (Holter et al., 1975). The upper coal has been called the No. 14 or Ardley seam (Allan and Sanderson, 1945; Gibson, 1977), the Upper Ardley (Campbell, 1967) and the Lower Ardley 'B' (Holter et al., 1975). Higher coals have also been recognized. Ower (1960) identified an Upper Ardley seam and a Three Hills seam. Holter et al. (1975) identified an Upper Ardley seam.

The above nomenclature was not followed in this study because of difficulties in correlation on a basin-wide scale. Seams were, however, correlated in the Alix and Medicine substudy areas where closely spaced and abundant data were available. In these areas it was possible to correlate most coal seams with a considerable degree of confidence based on a data density of up to 28 wells per township. Seams in these areas have been informally named by assigning them numbers. See the Appendix of this report for more details.

2.5 DEPOSITIONAL CONTROLS

A regional depositional model was developed during the course of this study, showing the relationship between coal accumulation of the Ardley zone and the regional tectonic setting. Major depositional controls appear to be the variation in subsidence rates and isolation from the effects of clastics during peat accumulation. The Ardley coal zone was deposited in a tectonically active foreland basin, having greater subsidence towards the west and southwest due to loading and/or tectonic influences along the western basin margin. The coal zone generally widens and the number of seams increase towards the western margin where relative subsidence was greater than that in the east. The laterally persistent nature of many of the seams suggests development at times of extensive peat-forming mires over large parts of the basin. The development of major river systems running parallel to the mountain front is offered as a possible mechanism for sheltering peat-forming mires from clastic deposition (see figure 5).

This model is used to explain regional coal accumulation trends observed in this study and can be used as a predictive tool to determine the resource potential in some of the lesser explored areas of the basin. Although useful to explain basin-wide trends, more detailed studies incorporating stratigraphic and sedimentologic data are recommended to assess local variability.

Some general comments on the nature of the depositional environment for the Ardley coal zone are as follows: The Ardley coal zone is associated mainly with fine-grained fluvial sediments. Two areas have particularly high amounts of coal. The east-west trending area between Lodgepole and Coalspur has cumulative coal values of up to 21 m and individual seam thicknesses to 4 m. The northeast-southwest trend trend between Obed and Whitecourt has cumulative coal values to 24 m and individual seam thicknesses to 3 m. In these areas, the Ardley coal zone appears to be the result of some basin-wide control on sedimentation, which allowed the development of extensive peat-forming mires with little introduction of clastics for long periods of time. Many of the Ardley coal seams are remarkably continuous supporting the idea of a major tectonic role in influencing their character. Further studies of local areas will undoubtedly provide a better understanding of the tectonic history as well as the paleogeography (including the location and persistence of fluvial belts) allowing for a more complete appraisal of the Ardley coal zone.

The following descriptions of resource maps (section 3.0) and representative cross sections (section 4.0) progressively illustrate depositional trends, areas of preferred coal development and other evidence supporting the regional depositional model shown in figure 5.

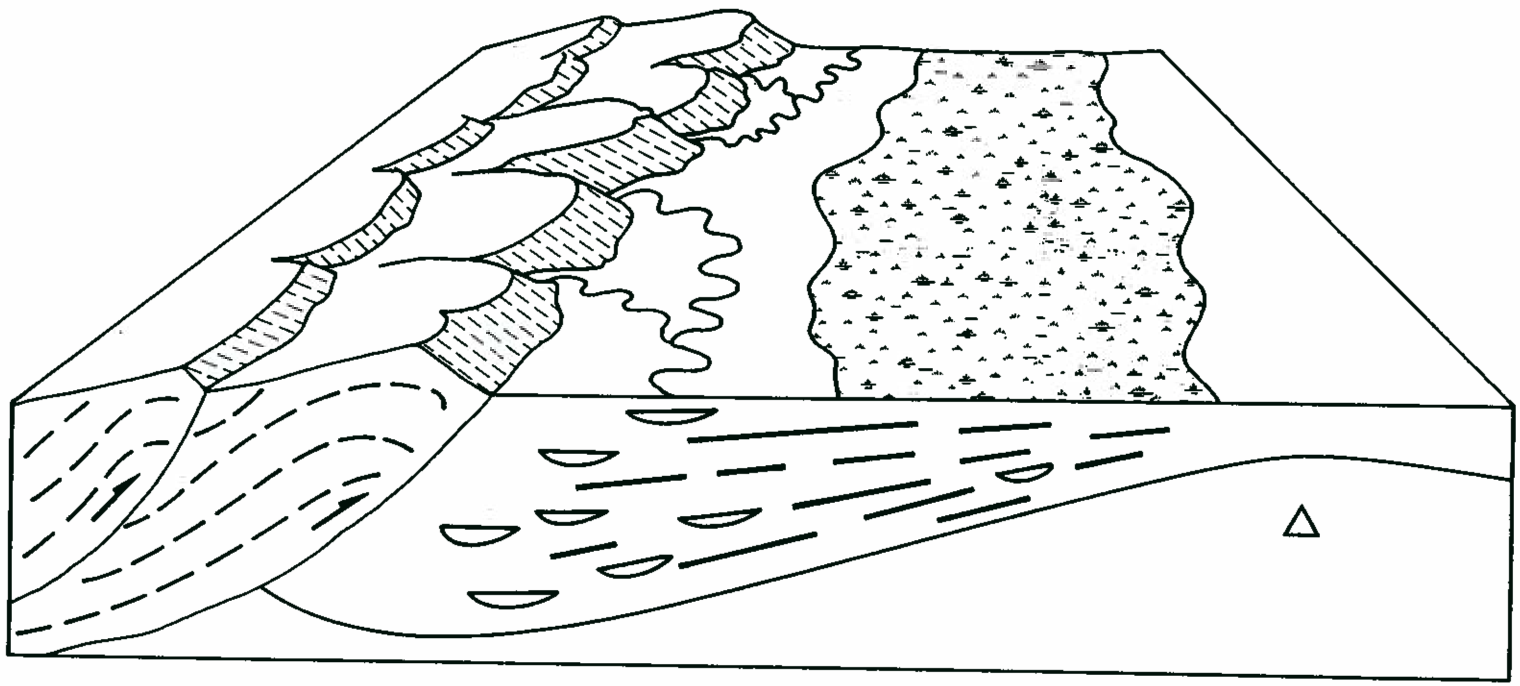

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Figure 5. Schematic sketch showing important tectonic controls on coal deposition during the early Tertiary. Increased subsidence rates towards the disturbed belt and the confinement of major river systems to areas parallel to the belt were contributing factors leading to extensive coal development of the Ardley zone. See text for more details.

3. DESCRIPTION OF MAPS

3.1 INTRODUCTION

In the following section, a brief description of how each map is constructed and some important depositional trends are given. The full sized maps (available in volume 2) were produced on a 1:750 000 scale and include the location and value of each data point used. With these maps the reader can interpret the data independently and obtain more detailed information in selected areas. The page-sized figures accompanying the following descriptions are simplified versions of the full sized maps. These figures were produced to highlight depositional trends important to the study.

3.2 MAP 1. STRUCTURE ON THE BATTLE FORMATION (Figure 6)

This map shows the structural elevation with respect to sea level of the top of the Battle Formation. The Battle Formation is a reliable and easily distinguished basal datum used to correlate the Ardley coal zone. In core and in outcrop the Battle Formation is a distinctive lithologic unit. It is a grey to purplish grey to brown, massive mudstone or argillaceous sandstone, commonly containing rooted zones, peds and slickensides. These features are characteristic of paleosols. On geophysical logs the Battle Formation is recognized as a 6 to 18 m thick zone displaying a low resistivity response, a relatively high natural gamma ray response and a highly variable apparent porosity. The Battle Formation commonly washes out during drillings as indicated by the caliper log.

The generally parallel and regular contour lines indicate that the Battle Formation dips gently towards the disturbed belt and has low relief. Structural highs and lows are present as indicated by some irregular contour lines and anamolies (see map 1, volume 2), but these features are local in nature. The trend and amount of dip of the Battle

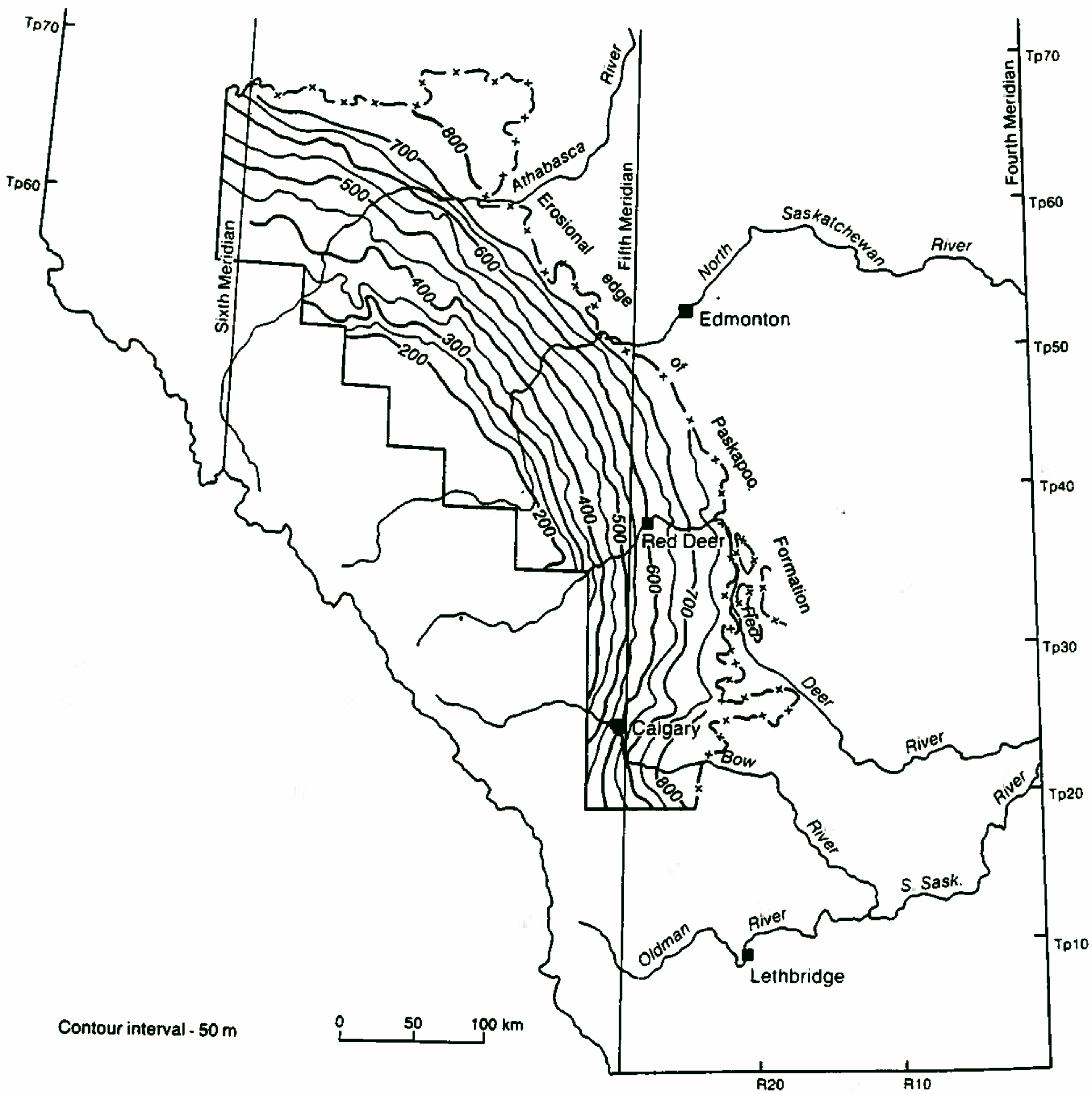

Figure 6. Structure contour map of the Battle Formation. The Battle Formation was used as a basal datum to correlate the Ardley coal zone in this study.

Formation and of the overlying Ardley coal zone are reflected by this map. North of Tp 60 these strata have a southerly dip. Between Tp 60 and 35 a southwesterly dip is present and to the south of Tp 35 these strata have a westerly dip. Dips steepen from about 5 m/km along the erosional edge to 13 m/km or more along the disturbed belt.

This map is useful for interpreting the regional subsidence history of the basin during the latest Cretaceous and early Paleocene. The full-sized map (see volume 2), in particular shows a tightening of the contour lines towards the west, suggesting an increase in subsidence rates in that direction. In general, the map shows that the further away from the erosional edge (ie. towards the west and southwest) the greater is the rate of subsidence. As a result of faster subsidence rates, areas within the deeper portion of the basin contain greater numbers of coal seams and a significant increase in thickness of the Ardley coal zone. The maximum seam thickness, in a general way, also is larger in areas with faster rates of subsidence. More details on the effects of subsidence on coal development are given in the descriptions for the isopach map of total cumulative coal (map 5), the isopach map of total number of seams (map 4), the isopach map of thickest seam (map 7) and the isopach map of the total thickness of the Ardley coal zone (map 3).

3.3 Map 2. STRUCTURE ON THE THICKEST COAL SEAM (Figure 7)

The contour lines on this map are not as regular or as parallel as those in the structure on the Battle Formation map (map 1), however, the general basin geometry and the trend of steeper dips toward the disturbed belt are similarly illustrated. Numerous anomalies (or bullseyes) and irregular contour lines indicate that the thickest seam has a variable stratigraphic position within the coal zone. This variation is to be expected because a single anomalously thick seam is not likely to blanket the basin. Another important consideration is that in some parts of the basin, such as the Medicine substudy area, two or more seams of equal thickness (commonly 4 m or more) may be present at the same location.

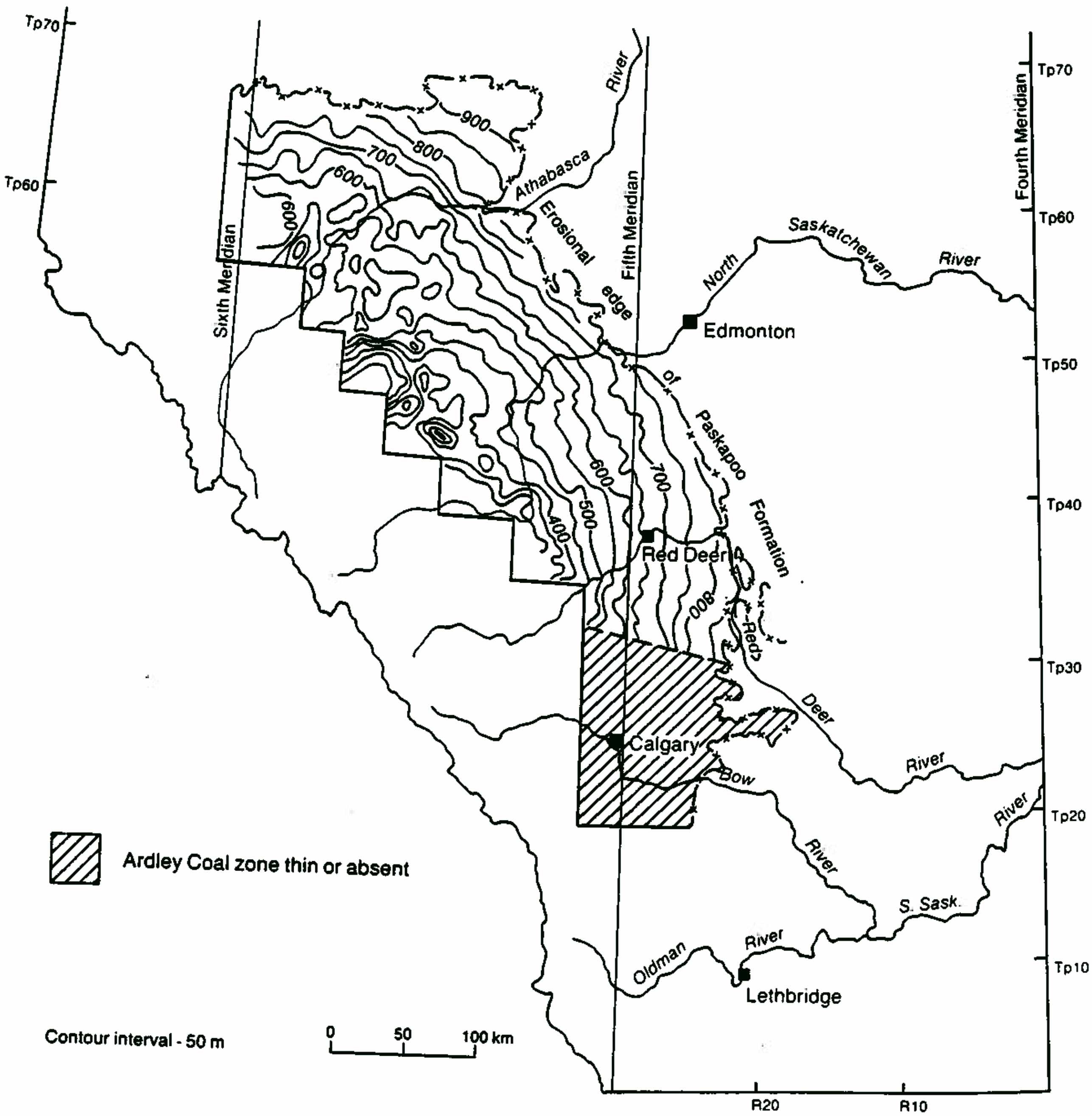

Figure 7. Structure contour map of the thickest seam in the Ardley coal zone. Note the irregularity of the contour lines, suggesting that the thickest seam has a highly variable stratigraphic position within the zone.

When this map is used in combination with the isopach map of the thickest seam (map 7), approximate mining depths can be calculated. One suggestion is to target areas for more detailed studies based on minimum thickness and maximum depth criteria given by these maps.

3.4 Map 3. ISOPACH OF THE ARDLEY COAL ZONE (Figure 8)

This map shows the variation in thickness of the interval between the uppermost seam and the lowermost seam of the Ardley coal zone. There is a general thickening trend of this interval from 15 and 30 m along the erosional edge (eastern flank of the basin) to more than 200 m along the disturbed belt (western flank of the basin). Higher subsidence rates towards the western flank, and hence, a thicker coal zone developed in that direction. Corresponding to the increased thickness of the coal zone is a substantial increase in the total number of seams and total cumulative coal.

Local anomalies and irregular contour lines are present in some parts of the mapping area. These anomalies form where the coal zone is thinned due to non-deposition or erosion of upper and lower seams. One example is the trend oriented east-west from Tp 40 to 44, R 1 to 14 W5M. A similar trend runs from Tp 51 R 17 W5M in the southwest to Tp 56 R 10 W5M in the northeast. In these trends, fluvial sediments are found in place of the lower seams. Cross section H-H' and K-K' (figures 17 and 20, respectively) run through these thinning trends and illustrate how the lower coal seams are picked up to the north and south. The regional depositional model supports the idea that during maximum coal development, clastics derived from the rising cordillera were confined largely to the western margins of the basin. Trends observed in the isopach maps of total cumulative coal, thickest seam and total coal in the best 25 m give strong support for this model. One should not assume, however, that all drainage was confined to the west. The examples shown of fluvial trends oriented perpendicular to the disturbed belt and other smaller systems were likely fed by or were feeding into larger systems located along the early Paleocene syncline.

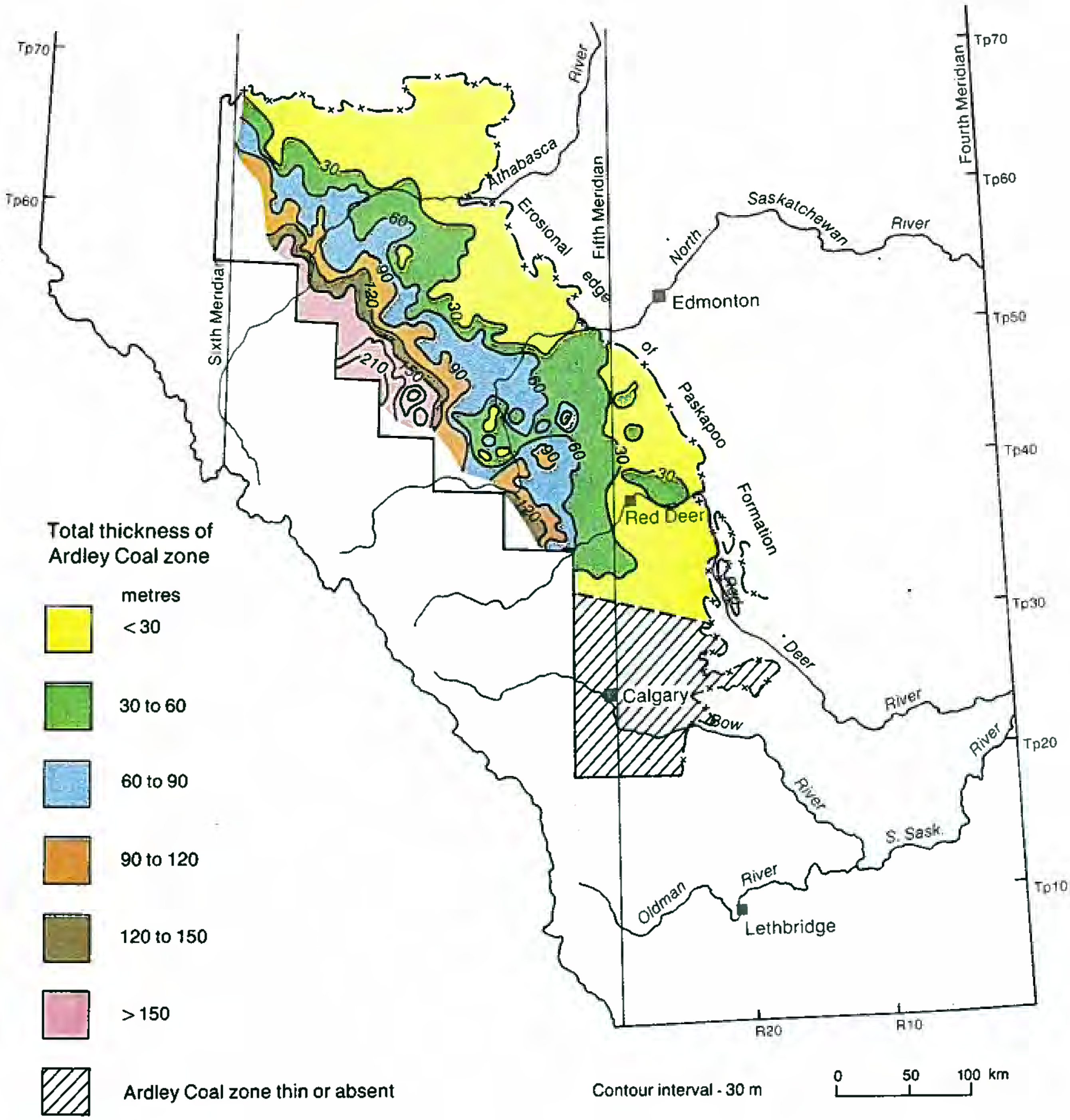

Figure 8. Isopach map showing the variation in thickness of the Ardley coal zone. The westward thickening of the zone is a result of increased subsidence rates in that direction. See text for more details.

More details are included in the following map descriptions.

3.5 Map 4. TOTAL NUMBER OF SEAMS IN THE ARDLEY COAL ZONE (Figure 9)

This map shows the total number of identified seams in the Ardley coal zone in the study area. Each identified seam has a minimum thickness of 0.5 m and the minimum separation between seams is 0.5 m. The Ardley coal zone generally contains between 3 and 12 seams but up to 18 seams are present along the western portions of the study area. The north-south and east-west trends of thick coal development observed for total cumulative coal (map 5) contain a large number of seams. The two trends are considered to represent areas that had particularly good coal development because of favourable subsidence rates, prolonged periods in which these areas were sheltered from clastics and had favourable climatic conditions for the accumulation and preservation of peats. Note also, that many of the coal seams with a thickness of 4 m or more are commonly found within these same trends.

3.6 Map 5. TOTAL CUMULATIVE COAL IN THE ARDLEY COAL ZONE (Figure 10)

This map shows the additive thickness of all coal seams in the Ardley coal zone. Two well defined trends of thick cumulative coal development are illustrated by this map. The north-south oriented trend centred along R 20 W5M from Tp 59 to 47 and the east-west oriented trend centred along Tp 47 from R 1 W5M to R 17 W5M contain between 12 and 24 m of cumulative coal. These areas of maximum coal accumulation coincide with areas with the greatest number of coal seams (map 4) and areas with seams 4.0 m or more thick (map 7).

Near the disturbed belt, fewer wells have been drilled and much of the Tertiary strata has been eroded, but a noticeable decrease in cumulative coal is observed in some of these areas where data are available. Locations proximal to the western basin margin likely had a continuous influx of clastics preventing the formation of economic coal

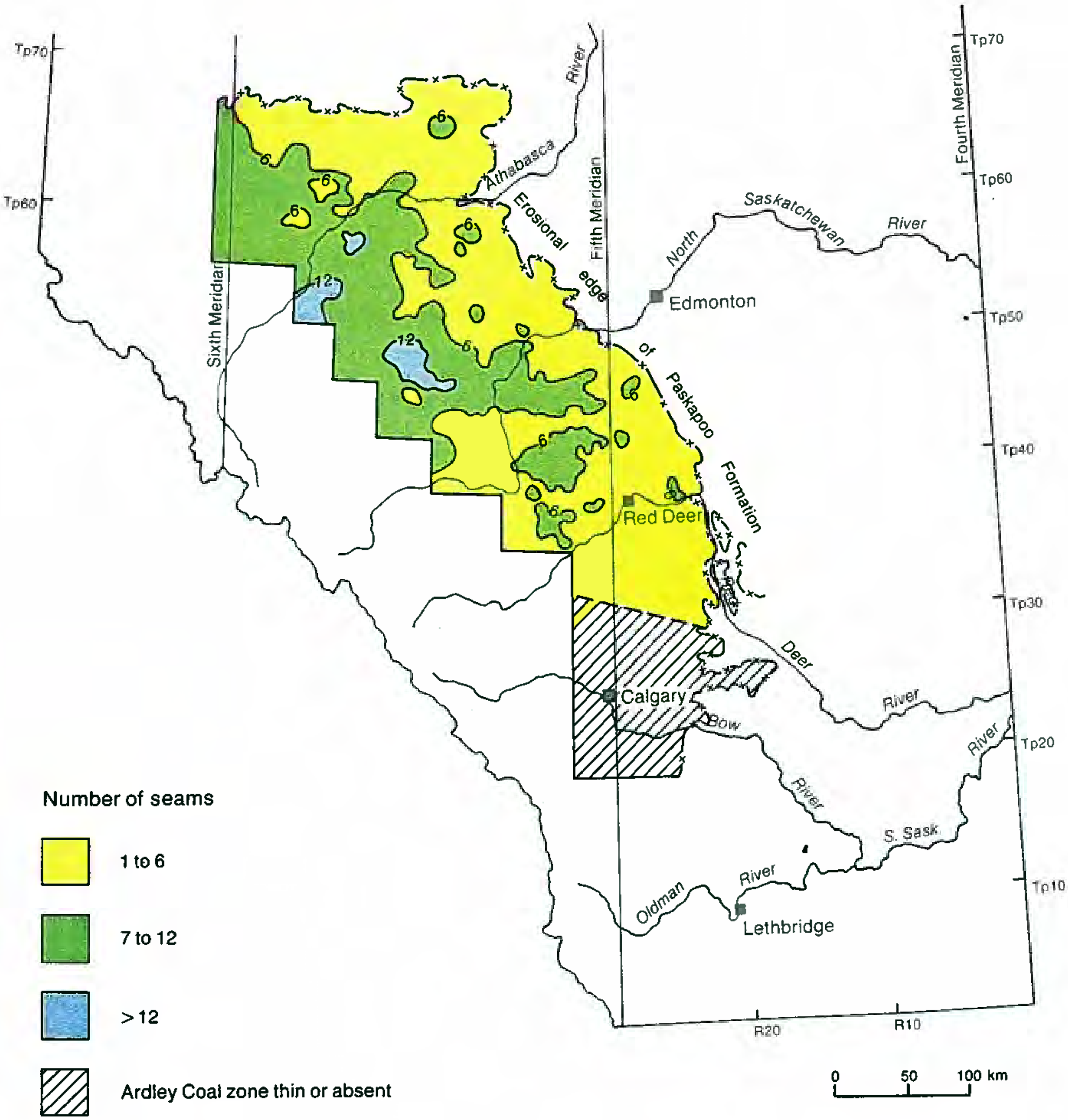

Figure 9. Isopach map showing the total number of seams in the Ardley coal zone. In this study, each identified seam is a minimum of 0.5 metres thick.

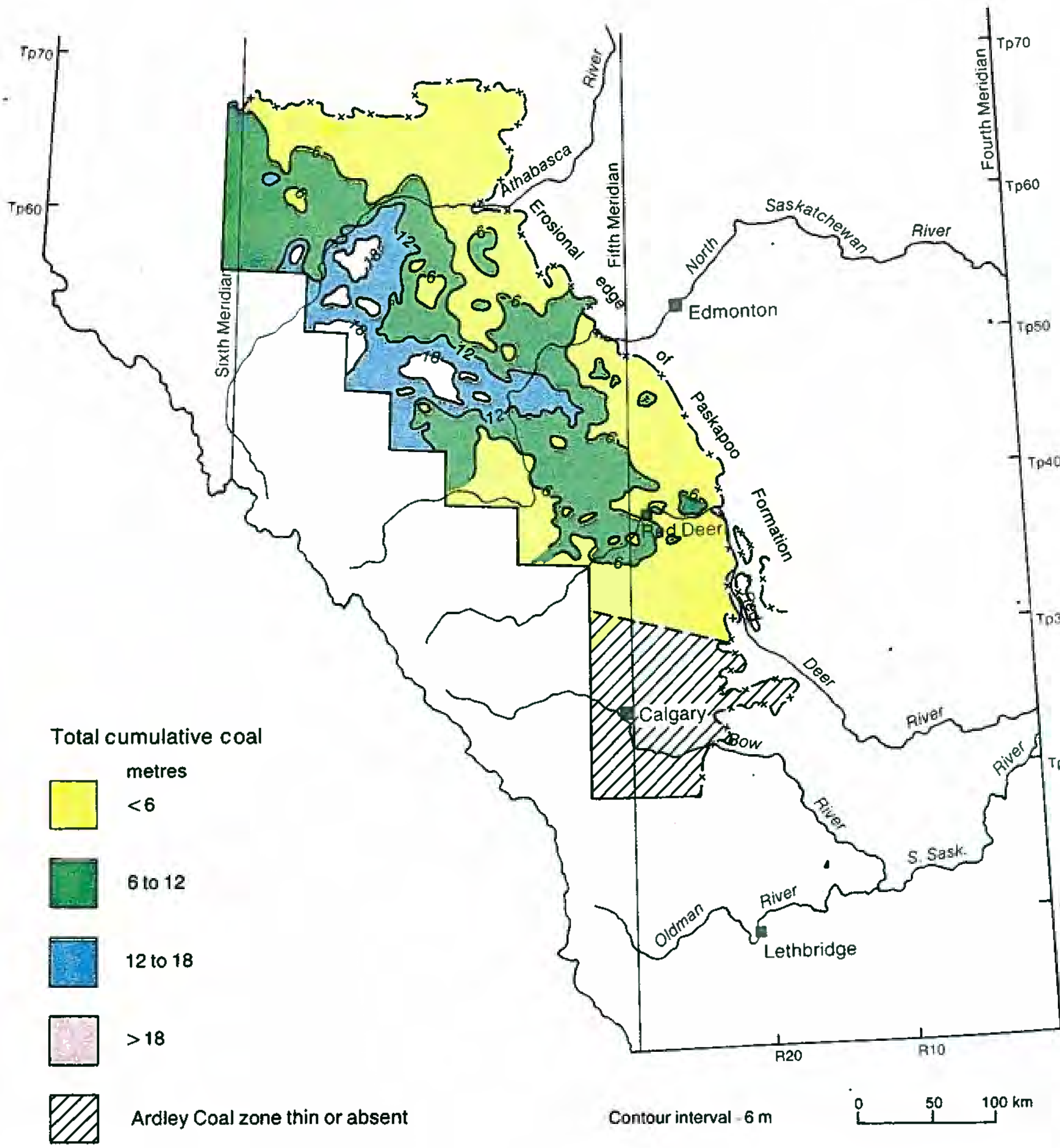

Figure 10. Isopach map showing the total cumulative coal in the Ardley zone. Note the east-west and north-south oriented trends of thick cumulative coal, suggesting that these areas had particularly favourable depositional conditions for coal development.

seams. Between Tp 36 and 43, R 7 to 12 W5M for instance, the Ardley coal zone contains less than 6 m of cumulative coal, has less than 6 seams and has a maximum seam thickness of less than 2 m. A similar trend is shown in cross section H-H' (figure 17), in which the coal seams pinch out and are replaced laterally by clastic sediments. The two trends of thick cumulative coal previously described are located further to the east, well removed from western derived clastics.

Another prominent trend to note on this map is the decline of coal resources from Tp 30 to the U.S. border. Most commonly, no Ardley coals developed in these areas. Jerzykiewicz and Sweet (1986) suggest that a major environmental difference may have existed between the central and southern portions of the basin during Ardley time. Evidence such as caliche beds, red beds and impoverished palynological assemblages in Ardley equivalent strata of the southern Alberta foothills may be indicative of a semi-arid depositional environment. This type of environment would not be favourable for coal development.

3.7 Map 6. ISOPACH MAP OF THE BARREN INTERVAL (Figure 11)

This map shows the variation in thickness between the top of the Battle Formation and the lowest Ardley coal seam. The general trend of thickening from 20 m along the erosional edge to more than 200 m towards the disturbed belt is a reflection of increased subsidence rates along the western basin margin. In areas where lower seams were eroded or were not deposited, pronounced thickening of this interval occurs. Some areas of thickening are very local in nature but some are more extensive and appear to have valley-like trends. An east-west trend running from Tp 40 and 44 R 1 to 14 W5M and a trend running from Tp 51 R 17 W5M in the southwest to Tp 56 R 10 W5M in the northeast coincide with similar trends observed of pronounced thinning of the Ardley coal zone.

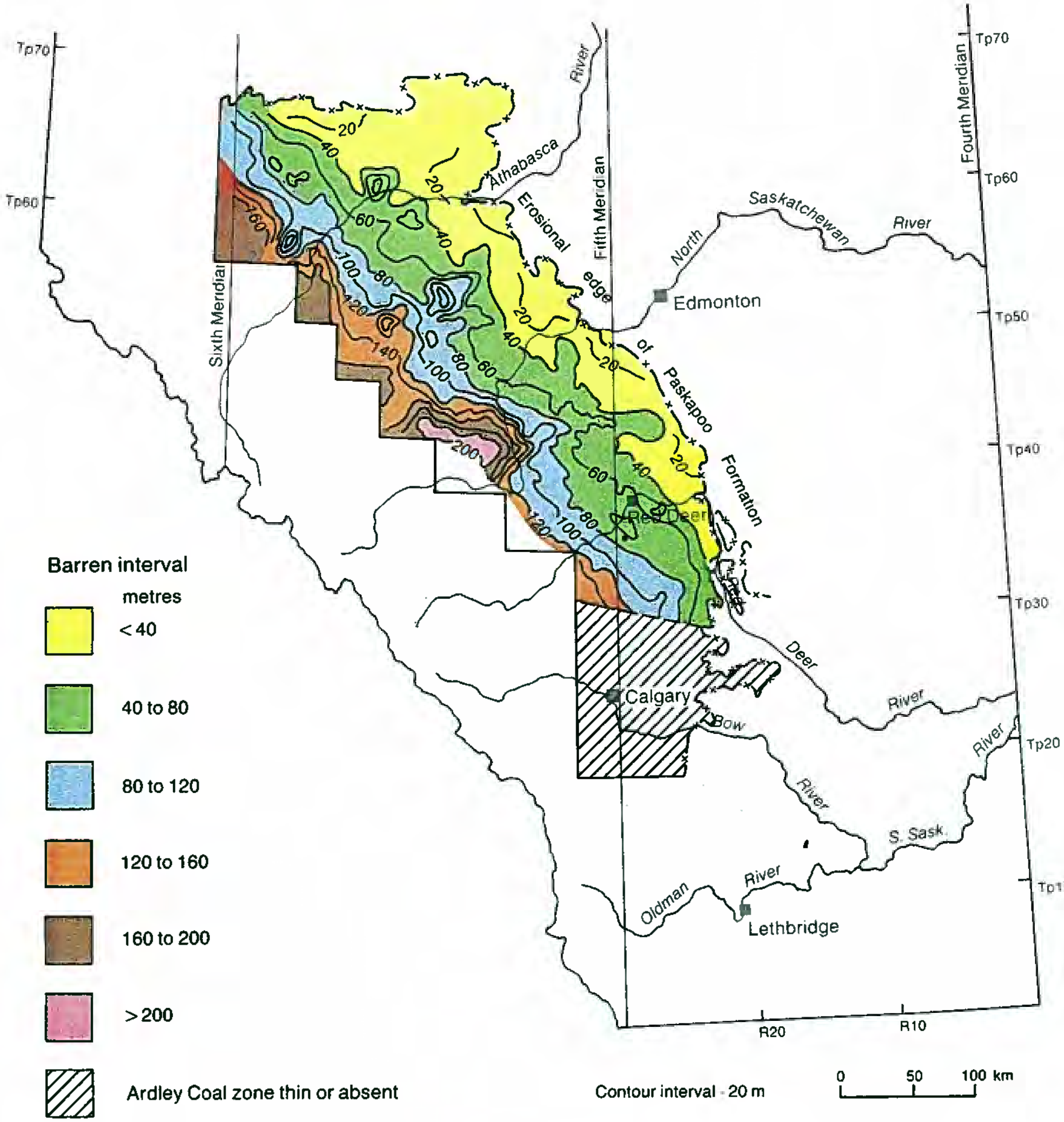

Figure 11. Isopach map showing the variation in thickness of the lower barren zone. This is the interval between the top of the Battle Formation and the lowest Ardley coal seam. The thickening trend towards the west is due to increased subsidence rates due to loading along the western basin margin.

3.8 Map 7. THICKEST SEAM IN THE ARDLEY COAL ZONE (Figure 12)

This map isopachs maximum seam thickness regardless of stratigraphic position or number of seams in the study interval. Areas with thick seams can be easily delineated for their mining potential using this map, however, more detailed studies are recommended to test seam continuity and lateral variations in thickness of seams for each area of interest. Over much of the study area at least one seam 2 m or greater is present in the coal zone. Areas with 4 m seams are commonly located within the east-west and north-south trends described for the isopach of total cumulative coal map (figure 10). The development of thicker seams within these trends are likely the result of favourable subsidence rates and isolation from clastic input over extended periods of time.

Some areas contain several thick seams that are in close proximity to each other. In the Medicine substudy for instance, seam 100 and 150 both exceed 4 m in thickness and are separated by only 2 m (see cross section J-J, figure 19). The thickest seams appear to be concentrated in the central portion of the study area, and not the extreme western portions. The rate of subsidence is an important consideration for coal development but the influence of fluvial activity and environmental constraints must not be overlooked. The depositional model proposed in this paper explains in part why better coal development and the thicker seams are within the central portions of the study area.

3.9 Map 8. ISOPACH MAP OF TOTAL COAL IN THE BEST 25 METRES (Figure 13)

A "window" concept was applied in this map. The term "window" is defined as a zone of a given interval which contains the most coal. A 25 m window was chosen since it represents the average thickness of the coal zone along the erosional edge and because it provides a useful yardstick for comparing the coal resources further to the west where the coal zone widens. The two areas of greatest cumulative coal correlate closely to trends of thickest coal development in this map. The

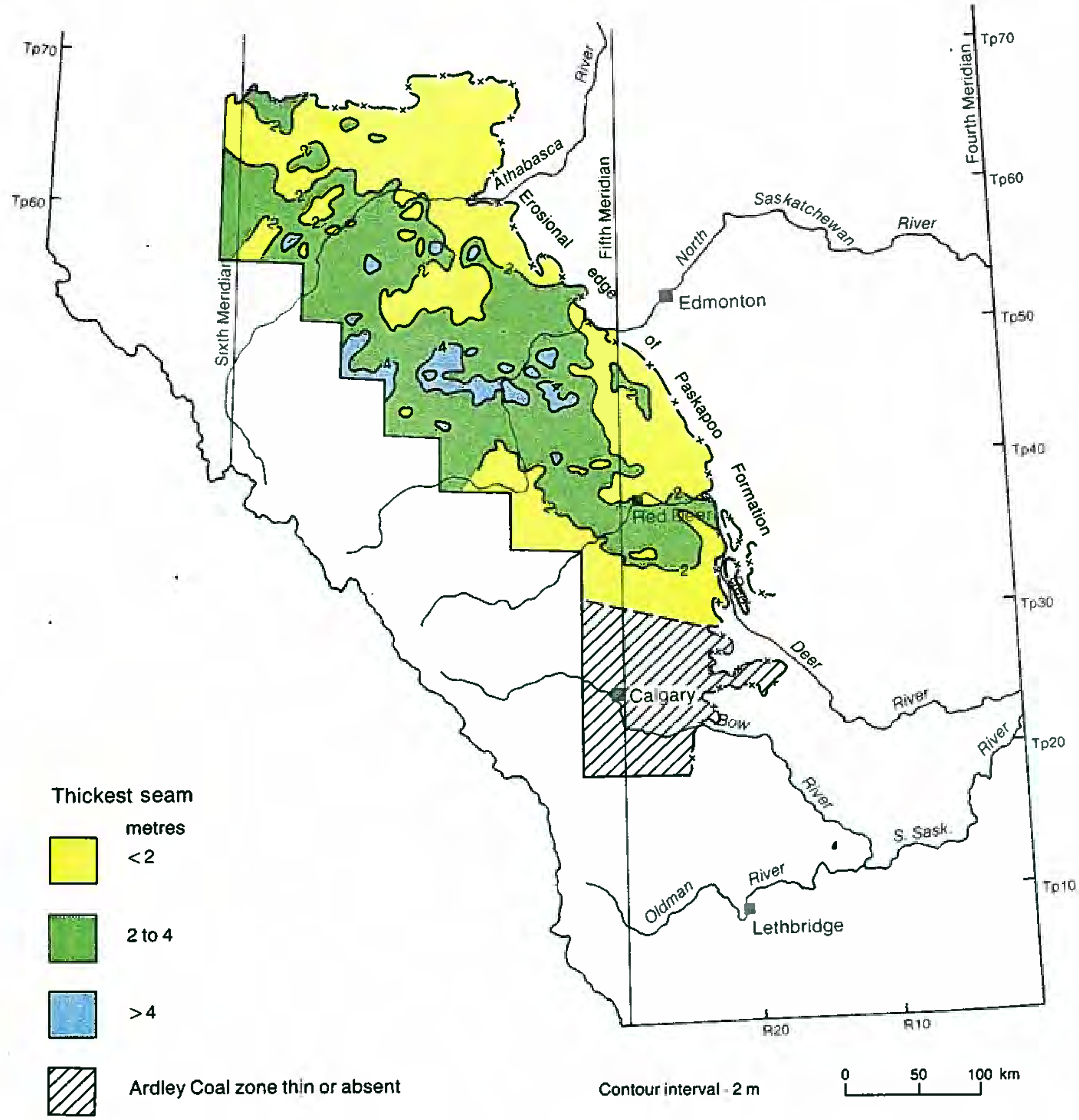

Figure 12. Isopach map showing the maximum seam thickness of the Ardley coal zone. The thickest seams are concentrated within the trends outlined in the cumulative coal map.

similarity in shape and location of the contoured pods having more than 6 m total coal in the best 25 m is indicative of the preferred development of coal in the central portions of the study area.

The best concentration of coal within the 25 m zone appears to be in the pod centred between Tp 40 and 50. As predicted from the generalized subsidence model, the better concentrations are to the west of the erosional edge. A westward limit is, however, indicated on this map. Perhaps the limits are due to the increase in thickness of the Ardley coal zone and the corresponding increase in the separation between seams. Also of interest in this map is the 6 to 9 m pod directly west of Edmonton, along the subcrop edge of the Paskapoo Formation. The Highvale mine, which is noted for its thick and laterally extensive seams, is located within this pod. Similar coal reserves, will likely be found in other 6 to 9 m areas delineated on this map. These areas may be good targets for further exploration.

3.10 Map 9. DEPTH TO BEST 25 METRE ZONE (Figure 14)

The depth to map gives a generalized picture of approximate mining depths to the best 25 m zone. The data density is far less than that available on a topographic map and as a result river valleys and other major topographic features are not as accurately delineated. The best estimates of depth are calculated in local areas by subtracting the surface elevation obtained with a topographic map from the structural elevation.

Trends on this map indicate that some of the best coal resources of the Ardley zone are generally not at surface mineable depths. Areas outlined with the thickest coal seams and greatest number of seams are commonly at depths greater than 100 m.

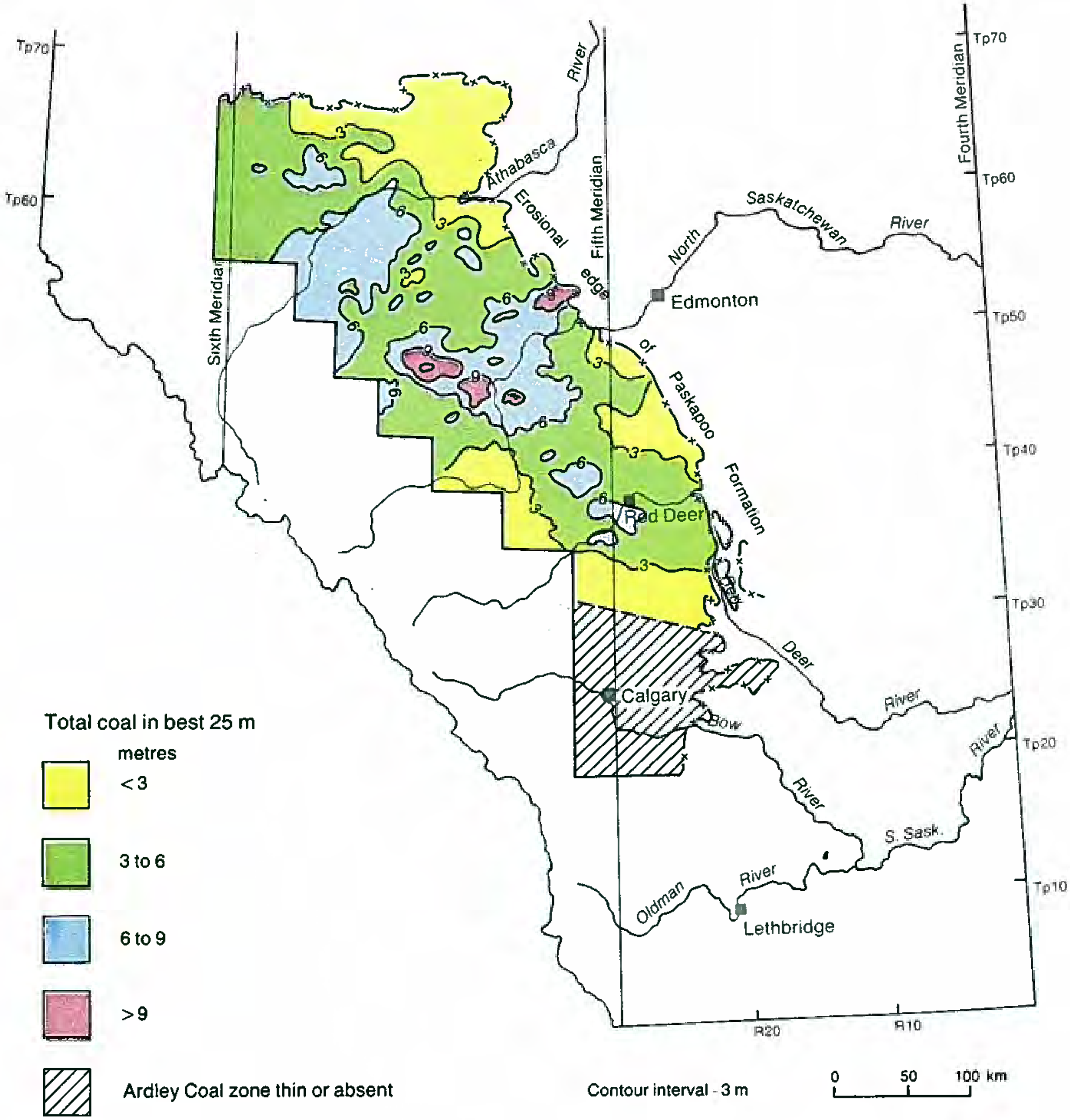

Figure 13. Isopach map of the total thickness of coal within the best 25 metre window. Areas of thick coal seam development coincide with major pods shown on this map.

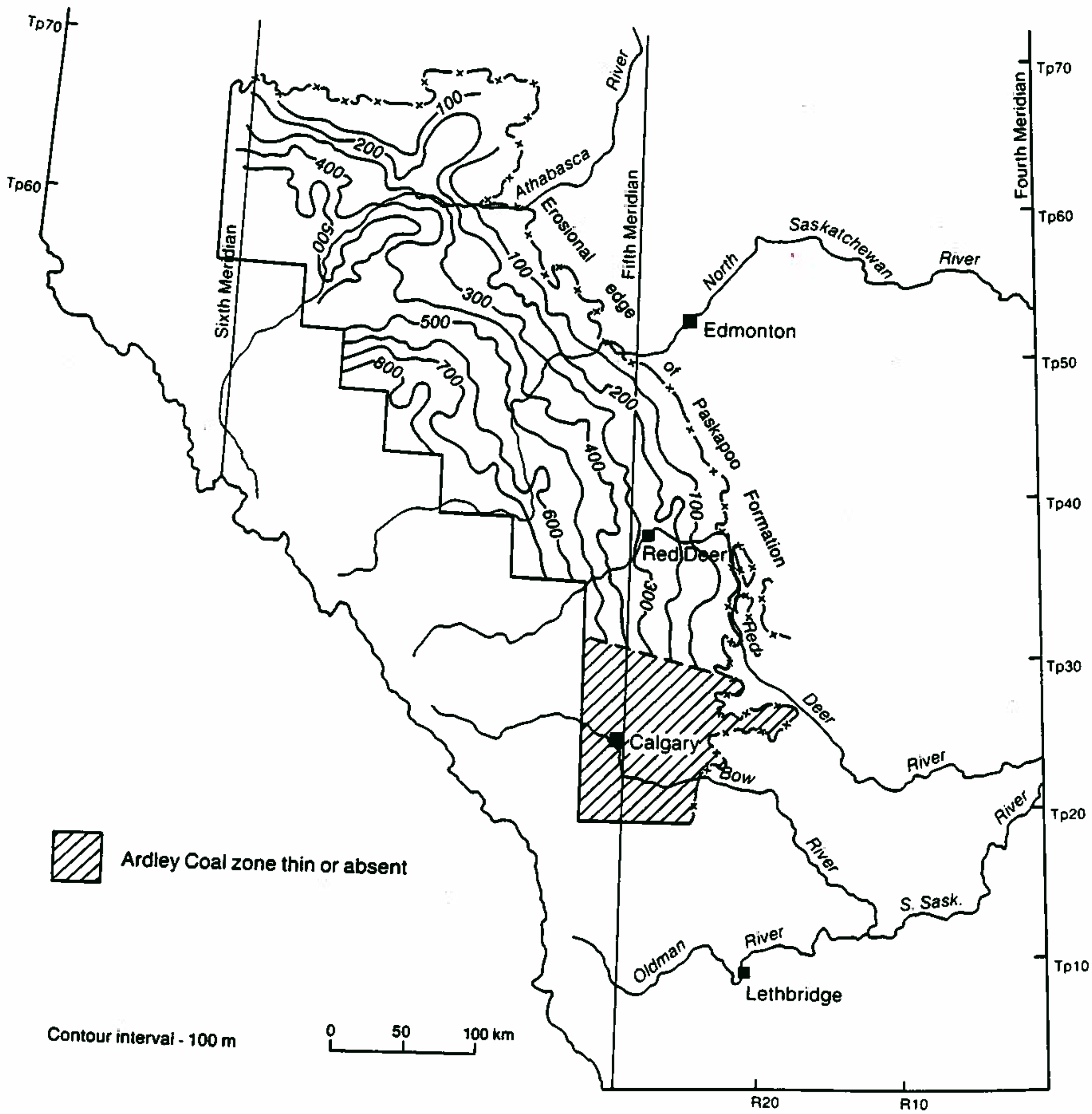

Figure 14. Depth to the best 25 metre zone. The best coal resources of the Ardley coal zone are generally at depths greater than 100 metres.

4. DESCRIPTIONS OF CROSS SECTIONS

4.1 INTRODUCTION

A selection of representative cross sections give a generalized picture of the stratigraphy and geologic nature of the Ardley coal zone and its associated strata. Each cross section is described individually in similar fashion to descriptions of the regional maps. General comments about the major features and uses give the reader a better appreciation of each section.

Eight stratigraphic cross sections are included to illustrate the variation in the thickness, lateral extent and number of seams through various portions of the study area. These were constructed from geophysical logs and the datum used was the top of the Battle Formation. The locations are shown in figure 15. The full collection of stratigraphic cross sections is in Volume 2. Simplified page-sized figures accompanying the descriptions (this volume) were produced to highlight important features of some of these sections.

In addition to the stratigraphic cross sections, there are three structural cross sections to accompany this report. These cross sections were produced by the computer on calculated XYZ variable grids. One advantage of these computer generated cross sections over conventional stratigraphic cross sections is that many more data points are incorporated into them. Since the grids are calculated from a nearest neighbour search, the line of section contains information from every nearby well. A generalized picture of the depth to the coal zone, the variation in thickness of the coal zone and the variation in the thickness of the barren interval are illustrated. The locations of each structural cross section are given in figure 16.

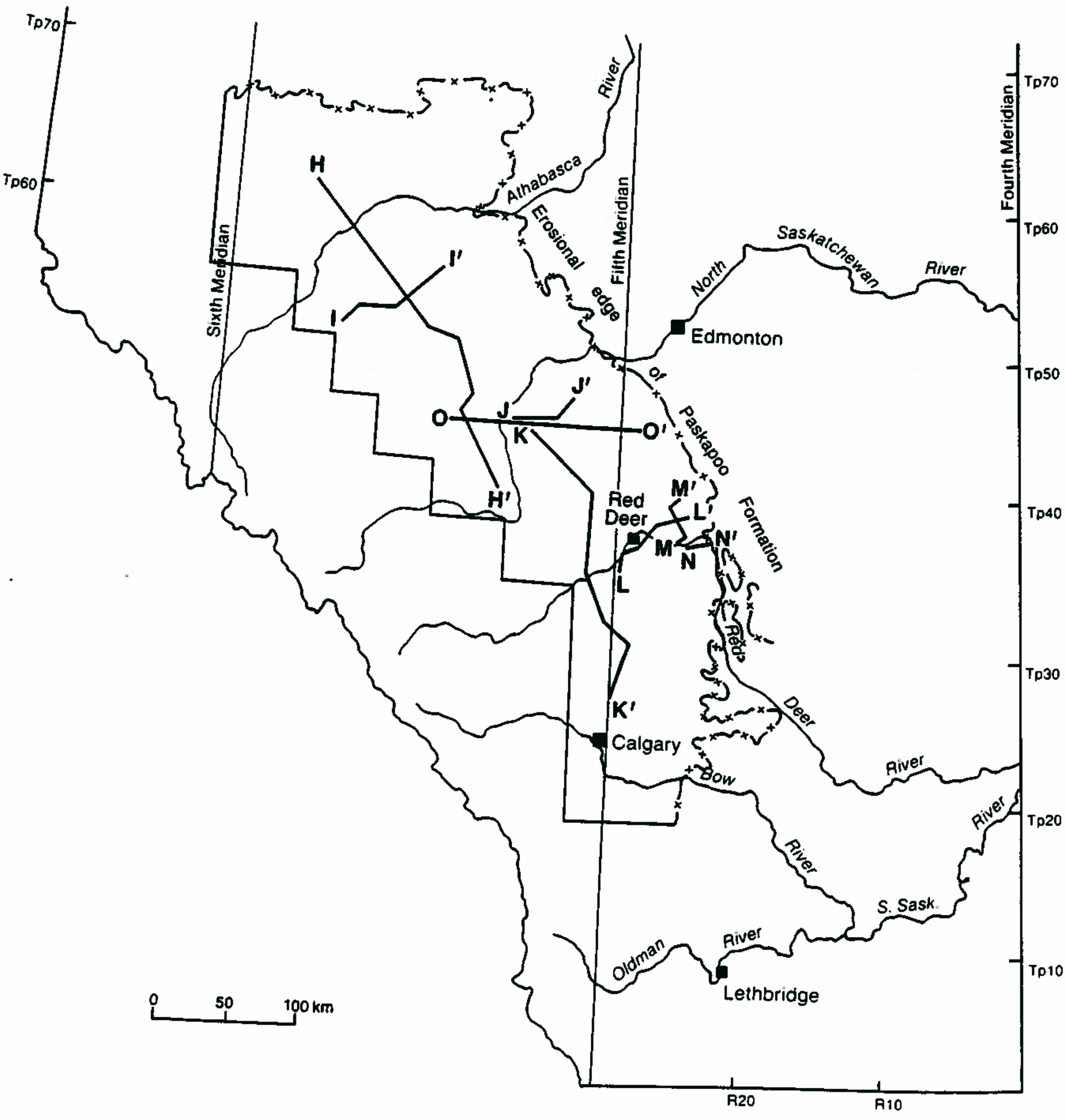

Figure 15. Map showing the locations of stratigraphic cross-sections used in this study. The full collection is contained in volume 2. Simplified page-sized sections highlighting important features are given in the following figures.

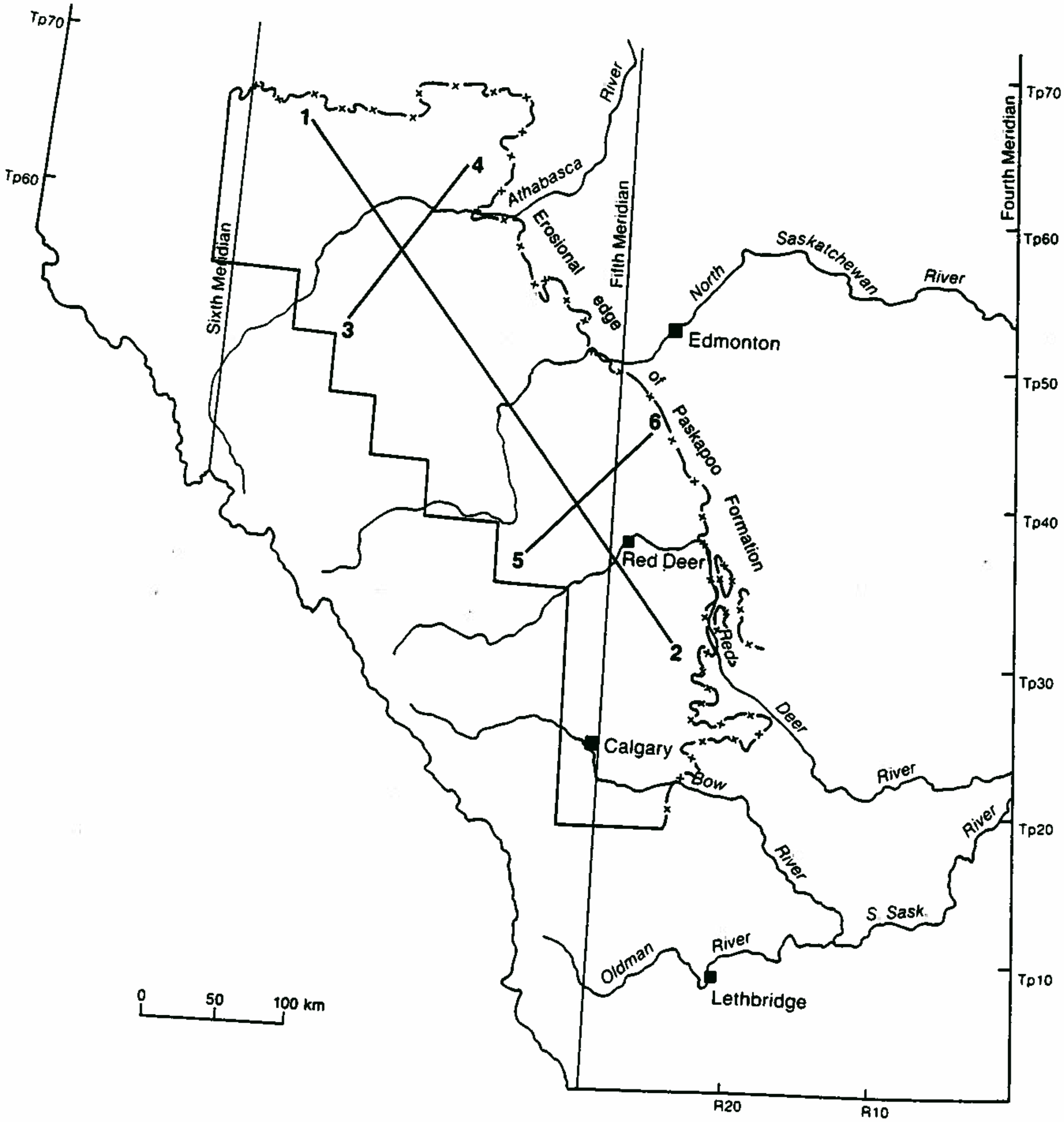

Figure 16. Map showing the locations of structural cross-sections used in this study. These were computer generated, produced from the calculated XYZ variable grids.

4.2 STRATIGRAPHIC CROSS SECTIONS

4.2.1 CROSS SECTION H-H' (Volume 2 and Figure 17)

This stratigraphic cross section is oriented northwest-southeast running from Tp 61 R 24 W5M (near Fox Creek) to Tp 41 R 10 W5M (near Rocky Mountain House). The Battle Formation is positioned close to the Ardley coal zone and is a reliable datum. The wells shown are spaced from 14 to 48 km apart but correlations are based on working cross sections with closer well spacings. Some of the closer spaced wells were excluded in order to keep the representative cross sections to a workable size.

The first portion of the cross section, from Tp 61 to 48, runs parallel to regional dip. The second portion, from Tp 48 to 40, runs down-dip and into the deeper parts of the basin. The first portion shows a relatively consistent thickness of the interval from the top of the Battle Formation to the first coal which is in agreement with trends observed for the isopach map of the barren interval (map 6). The thickness of the interval varies from 70 to 90 m except at 7-33-52-15W5 on the cross section. At this locality fluvial sediments appear to replace the lower seams resulting in the increased thickness of the lower barren zone. Comparison with the isopach map of the barren interval (map 6) and the isopach map of the Ardley coal zone (map 3) indicates that the zone of missing seams at the 7-33 locality is part of a more extensive southwest to northeast oriented valley-like trend. This trend is 1 to 20 km wide and more than 60 km long. A similar east-west trend through Tp 40 to 42 is discussed in the description of cross section K-K'. These valley-like trends are thought to be formed by major river systems that either eroded these lower seams or because of clastic input, did not allow the lower seams to develop. In areas well removed from channelling (ie. to the north and south of these trends) the lower seams are well developed.

The second portion of the cross section runs into the deeper part of the basin in a downdip direction. Due to increased subsidence, the

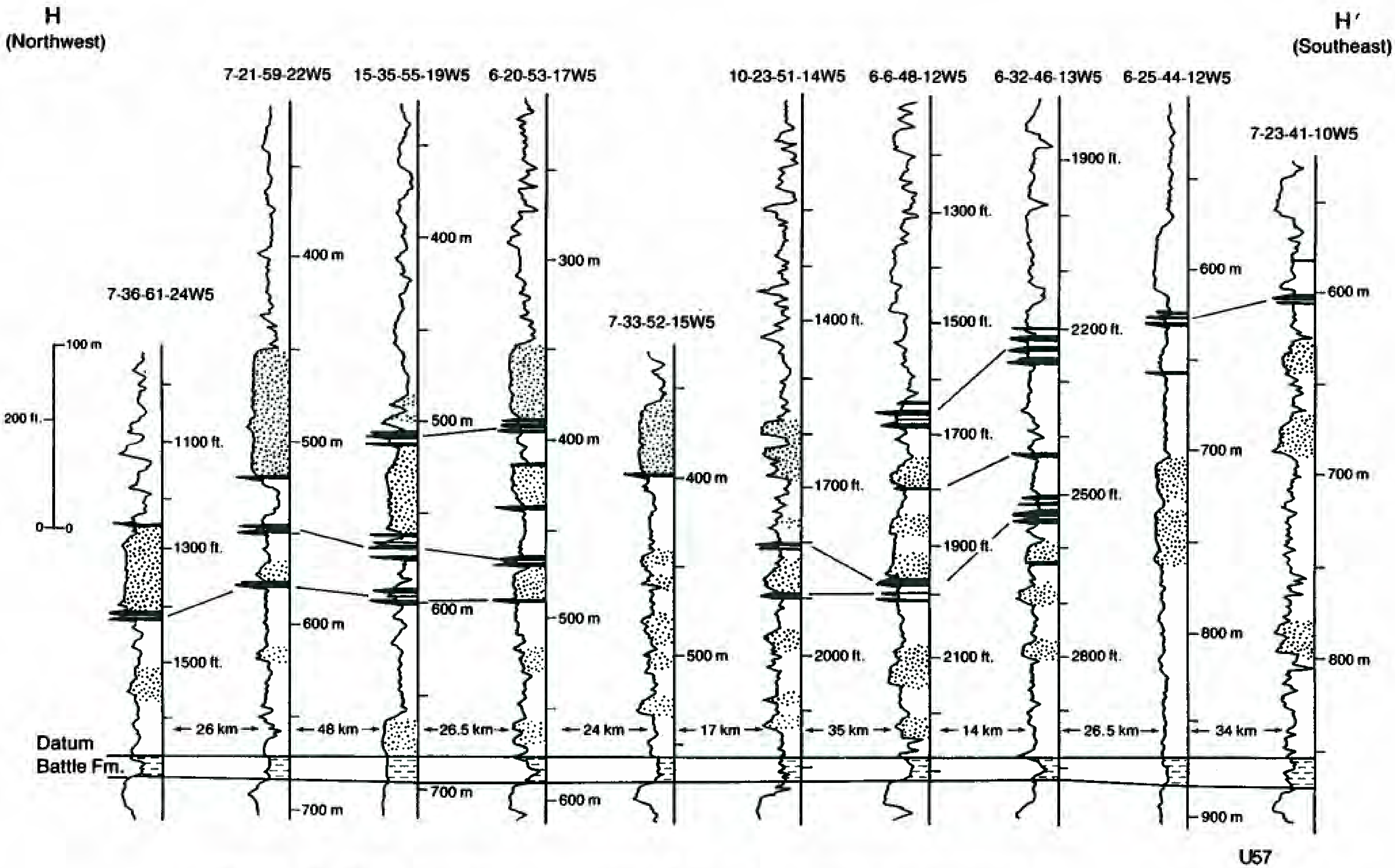

Figure 17. Stratigraphic cross-section H-H'. This section is regional in scope, showing the variation in thickness of the Ardley coal zone and the lower barren zone along the western part of the study area. The geophysical log shown is the natural gamma ray.

barren interval thickens considerably. The thickness of this interval increases from 80 m to over 200 m as seen in the southernmost part of the cross section.

4.2.2 CROSS SECTION I-I' (Volume 2 and Figure 18)

This cross section runs from Tp 47 R 14 W5M in the northeast to Tp 52 R 22 W5M in the southwest. The cross section is oriented perpendicular to regional dip to show the effects of increased subsidence on the nature of the Ardley coal zone. The coal zone thickens from about 50 m in the northeast to more than 150 m in the southwest. Similarly, the barren interval increases from about 60 to 200 m. These trends occur basin-wide as illustrated by the isopach map of the Ardley coal zone (map 3) and the isopach map of the barren interval (map 6). The dramatic increase in thickness of both the Ardley coal zone and the barren interval can be attributed to loading along the western basin margin. Loading was initiated and sustained by mountain building throughout the early Tertiary. More details of the effects of increased subsidence in the west are given in the descriptions of the maps mentioned above.

Along outcrop exposures in south-central Alberta, the Ardley coal zone is characterized by an upper and a lower grouping of seams. These two groupings can sometimes be correlated into the subsurface. Consequently, seam names such as the "Upper Ardley", "Lower Ardley" and the "Nevis" that were based on the two-fold grouping in outcrop studies have also been used to identify seams within some of the near-surface mines. Deeper within the basin, however, the groupings split up and individual seams become highly separated. At 7-33-53-19W5M and further towards the southwest in the cross section, the seams become increasingly separated so that the groupings can no longer be recognized. Seam names derived from outcrop areas and near-surface mines were not used in this study because of the difficulty in correlating them over such a large study area and the problems associated with increased separation with depth.

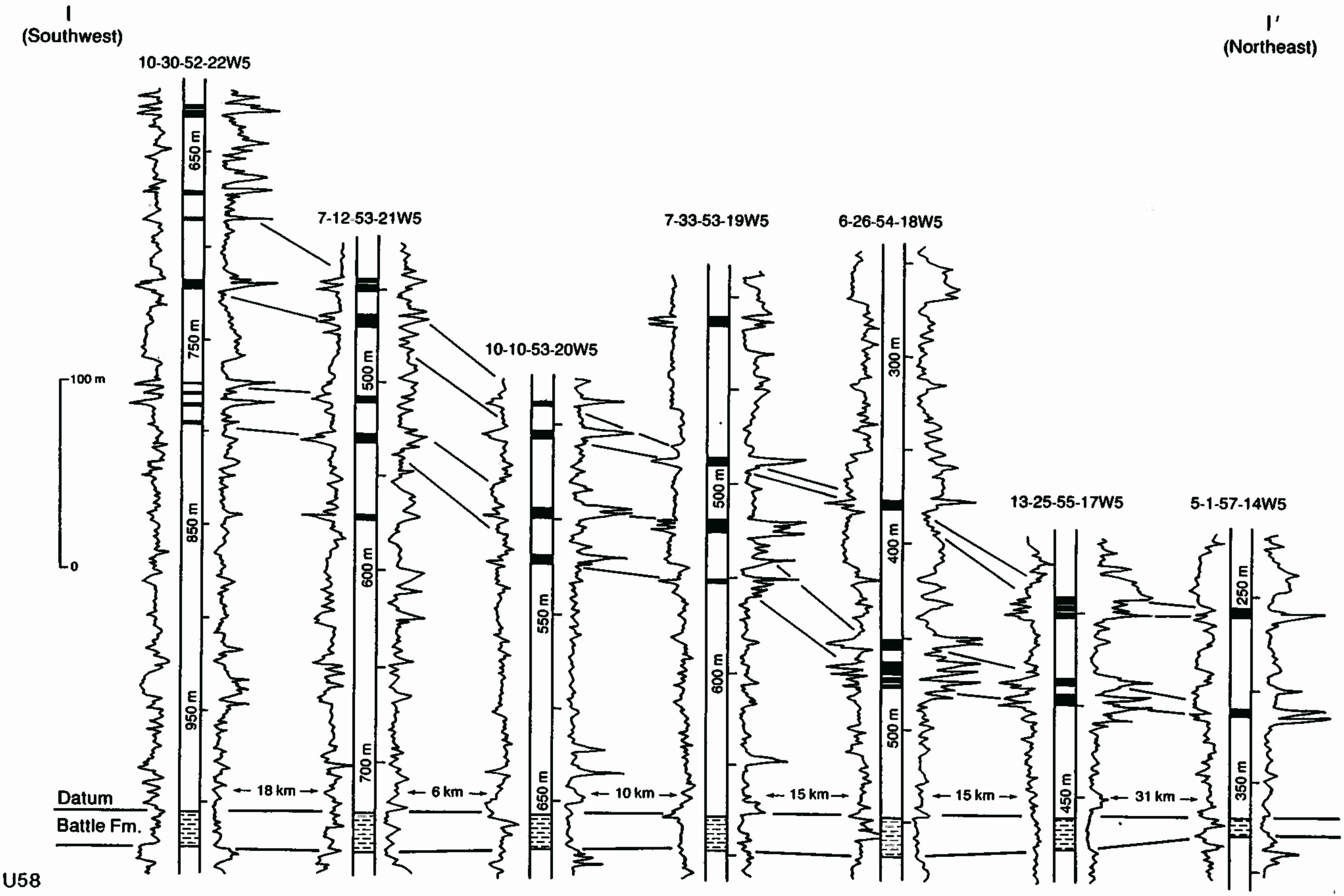

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Figure 18. Stratigraphic cross-section I-I'. Note the thickening trends of the barren interval and the Ardley coal zone towards the disturbed belt. The geophysical log pair is the gamma ray and resistivity, to the left and right, respectively.

4.2.3 CROSS SECTION J-J' (Volume 2 and Figure 19)

This cross section runs through the Medicine substudy, from Tp 47 R 6 W5M in the east (near Buck Lake) to Tp 46 R 9 W5M in the west. With wells spaced 3 to 6 km apart, this cross section shows the advantages of using detailed cross sections for seam correlations. Each major seam was given an identifier (such as seam 100, seam 600 etc.) and was correlated over a study area of 2500 sq km. Expanded scale logs were used to more accurately determine seam thicknesses and to recognize characteristic geophysical responses of many seams. Some seams formed closely spaced pairs (such as seam 100 and 150) that could be correlated with a high degree of confidence. These tightly grouped seams were the easiest to correlate. Seams given an identifier number were checked for proper correlation by a series of interlocking cross sections. Isopach maps of each seam were produced based on data from 185 randomly distributed wells in the Medicine substudy. These maps show the variation in thickness and the lateral continuity of each seam. As seen in cross section O-O', several seams 3 to 4 m thick are present at many localities.

The effects of differential compaction are shown at 11-6-46-8W5 on this cross section. A thick sandstone interval between seam 150 and 500 creates a local structural high. Finer grained sediments in the corresponding intervals to the east and west have undergone more compaction resulting in a smaller separation between seams and a more uniform structural trend. Draping of coal seams over major sandstone bodies results in the variation in stratigraphic position and sometimes makes correlation more difficult. Structure maps of correlated seams were produced in the substudies. Contour lines are generally irregular reflecting, in part, the effects of differential compaction.

Although many Ardley coal seams are laterally extensive, they are difficult to correlate basinwide. Correlation on a seam by seam basis over large areas is difficult because even the well defined groupings of seams separate and splits can be highly variable in thickness (such as the split between seam 500 and 600). In addition, individual seams

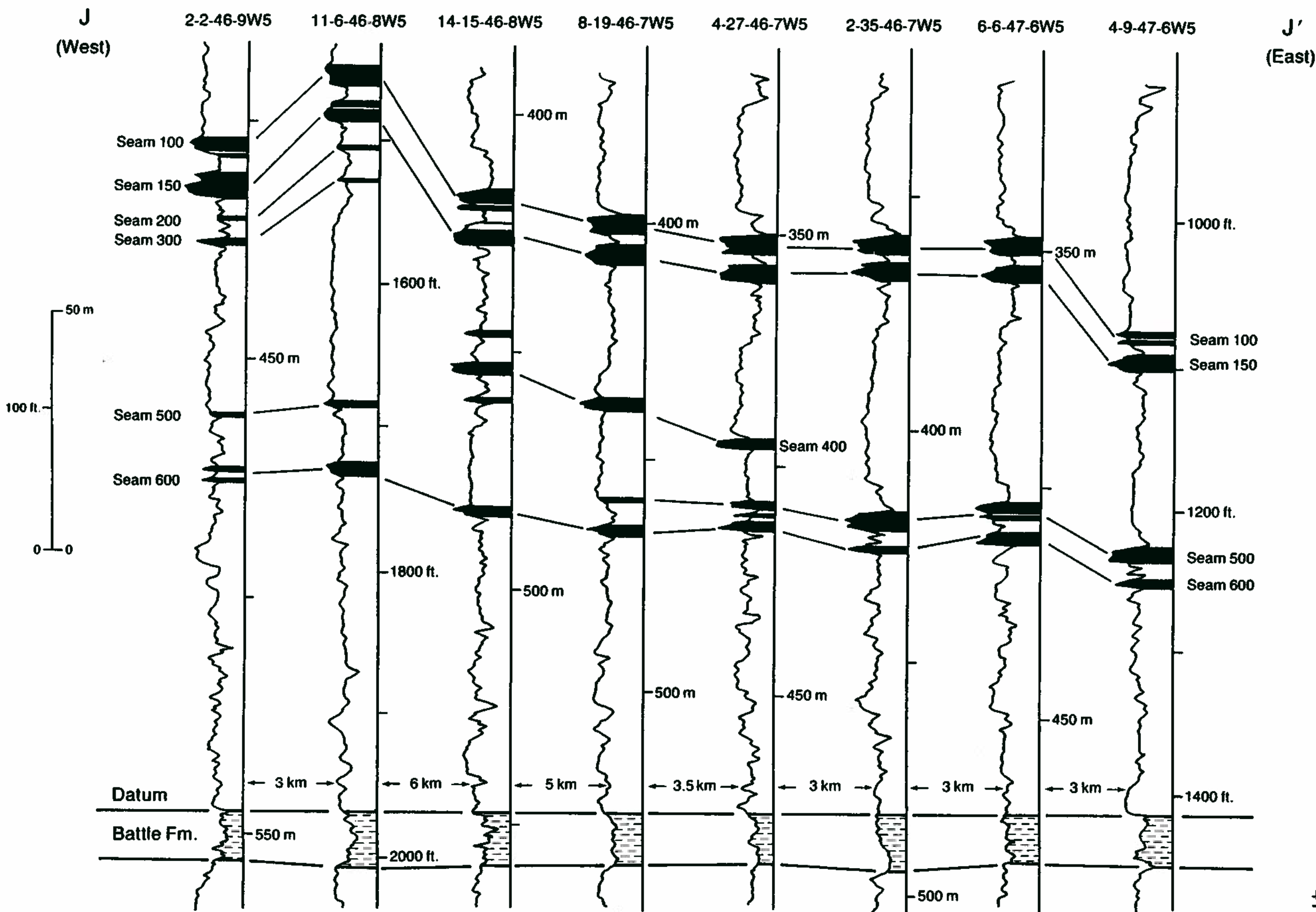

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Figure 19. Stratigraphic cross-section J-J'. Using detailed and closely spaced well logs, individual seams were correlated over large distances suggesting that many seams in the Ardley zone are laterally extensive. The geophysical log shown is the natural gamma ray.

commonly discontinue due to erosion or non-deposition (such as seam 400) and new seams may be added (such as seam 200 and 300). The seams identified in the Medicine substudy were not correlated to the Alix substudy because of some of the problems mentioned. Coinciding seam numbers of the two substudies represent seams at similar stratigraphic positions but do not necessarily refer to the same seam.

4.2.4 CROSS SECTION K-K' (Volume 2 and Figure 20)

This cross section runs from Tp 46 R 8 W5M in the north (Alder Flats) to Tp 27 R 1 W5M in the south (Calgary). As with some previous cross sections, well spacings are relatively large, varying from 8 to 45 km. Correlations shown, however, are based on working cross sections with closer well spacings. Some wells were excluded to keep the representative cross sections to a workable size.

The northern part of the cross section runs through a valley-like trend observed on the isopach map of the barren interval (map 6) and the isopach map of the Ardley coal zone (map 3). This trend is oriented east-west along Tp 40 to 42, R 1 W5M to 14 W5M. At 9-14-44-7-W5M on the cross section, the lower coals are absent and appear to be replaced by fluvial sediments. The interpretation given for this trend and a similar trend oriented southwest-northeast to the north (see the description for cross section H-H') is that river systems either eroded the lower seams or because the clastic influx prevented the lower seams from forming. In areas to the north and south of this trend, the lower seams are well developed.

4.2.5 CROSS SECTION L-L' (Volume 2 only)

This cross section runs downdip from Tp 40 R 24 W4M in the northeast (near Markerville) to Tp 36 R 2 W5M in the southwest (near Alix). The cross section bisects the Alix substudy area. As with the Medicine substudy, seams are identified and correlated based on a series

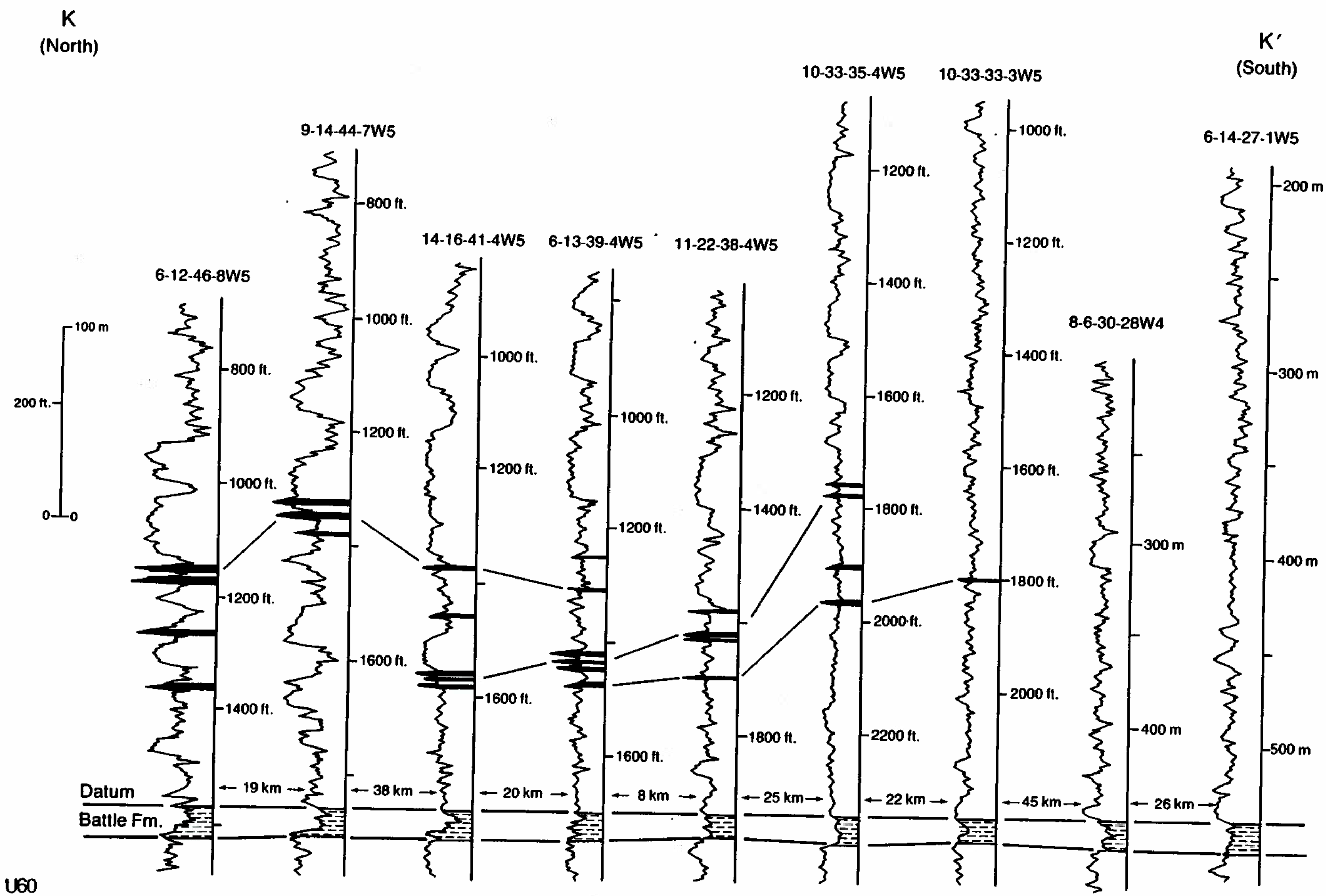

Figure 20. Stratigraphic cross-section K-K'. Note the general decrease in the number and thickness of coals towards the south. No Ardley coals were found south of Township 30. The geophysical log shown is the natural gamma ray.

of interlocking cross sections. Spacing between wells varies from 3 to 13 km.

This section illustrates how tightly grouped coal seams along the erosional edge become widely separated towards the west and southwest. The traditional names applied to seams in outcrop studies (such as the Upper Ardley and Lower Ardley) are difficult to apply at greater depth because of problems encountered in correlation on a seam by seam basis. See the description given for cross section J-J' for more details.

In the deeper portions of the basin (i.e. towards the west and southwest) the coal zone becomes thicker and the thickness of the interval between the Battle Formation and the lowest coal seam also increases. Similar trends are particularly well illustrated in cross section I-I' which extends into the disturbed belt. The amalgamation of coal seams towards the erosional edge and the corresponding trend of increased separation of seams towards the distubed belt reflect the increase in subsidence rates to the west during deposition of the Ardley coal zone.

4.2.6 CROSS SECTION M-M' (Volume 2 only)

This cross section is oriented parallel to regional dip from Tp 41 R 25 W4M in the north (near Red Deer) to Tp 38 R 26 W4M in the south (near Ponoka). The geophysical logs used for this section are from Alberta Research Council exploratory holes. These logs offer much higher resolution of seams in the coal zone than conventional oil and gas logs do. More detail is given about the nature of the lithology between coal seams and partings as thin as 10 cm can be delineated. The seam numbers given here match those shown on cross section L-L' and N-N'. This section demonstrates the conformity and blanket-like geometry of the coal zone parallel to regional dip. In this direction the coal seams remain tightly grouped and are laterally persistent over a distance of over 30 km. Isopach maps of each of the seams identified in this cross section were prepared for the Alix substudy. These maps show the variation in thickness and the lateral continuity of each seam. It is important to note that splits between seams may thicken markedly over relatively short distances. The interval between seam 700 and 750 is one example.

4.2.7 CROSS SECTION N-N' (Volume 2 only)

This cross section is oriented perpendicular to regional dip from Tp 38 R 23 W4M in the east to Tp 38 R 26 W4M in the west. Geophysical logs from Alberta Research Council exploration coal holes were used to construct this section. The eastern most portion of the cross section shows a group of closely spaced seams typically found in outcrop studies. Separation of the seams increases dramatically towards the west which breaks up the grouping. This cross section also gives an appreciation for changes in the distribution and spacing of seams from outcrop areas to the deeper subsurface.

4.2.8 CROSS SECTION O-O' (Volume 2 and Figure 21)

This west to east cross section runs along Tp 46 from R 13 W5M (near the Brazeau Reservoir) to R 27 W4M (near Ma-Me-O-Beach). This cross section compares closely with the more detailed cross section J-J'. Although wells are 10's of kilometres apart, correlation of the tightly grouped seam pair (seam 100 and 150, see inset) could be done. This seam pair was correlated over a distance of over 50 km. One of the outstanding characteristics of the Ardley coal zone is that some of the seams are laterally persistent over long distances. Cross section O-O' runs through a well defined trend of thick cumulative coal (map 5) and a corresponding trend with seams 4 m or more thick (map 7). From this cross section it is apparent that through this trend several seams are 3 to 4 m thick and that these seams appear to be laterally extensive.

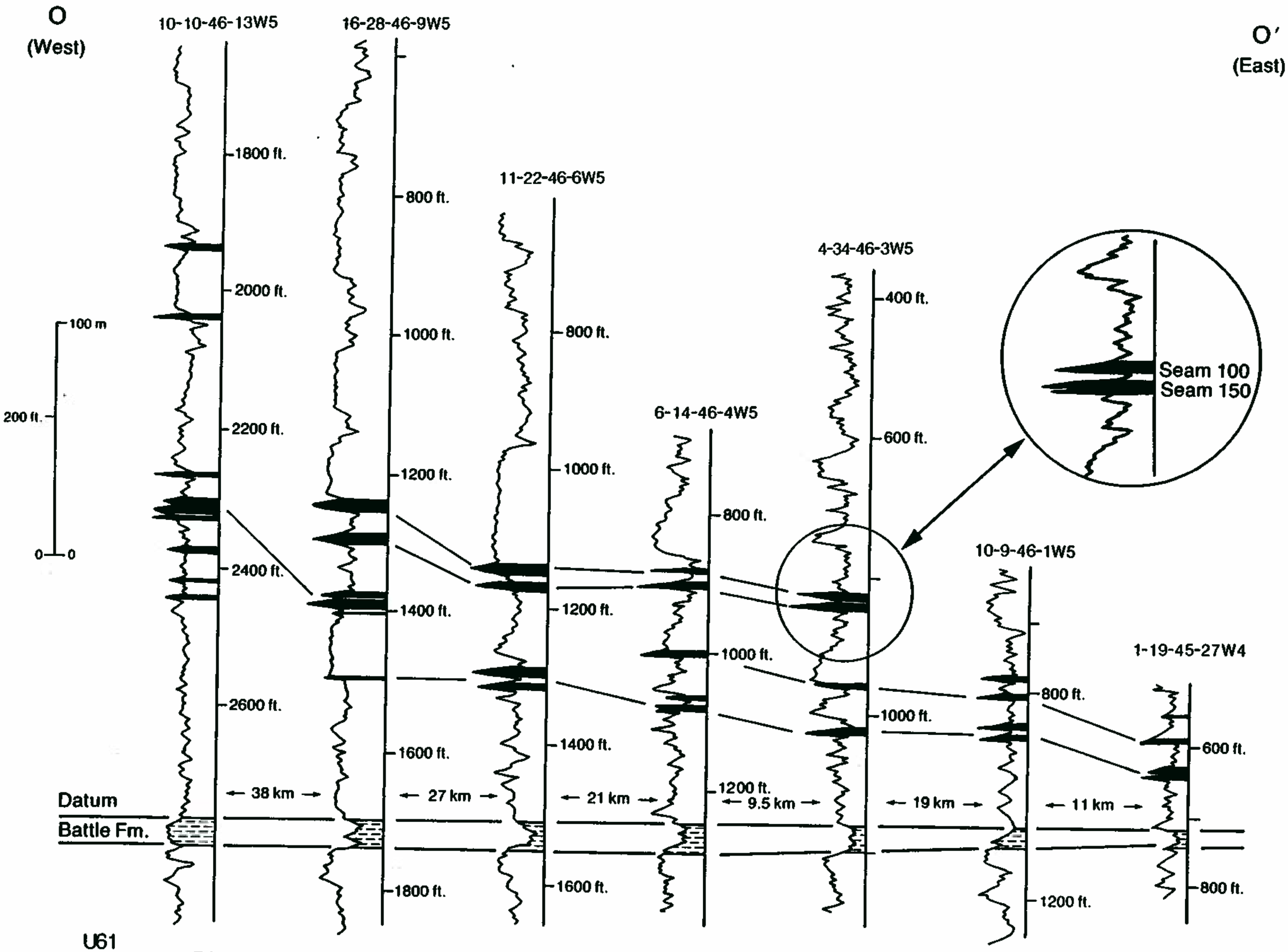

Figure 21. Stratigraphic cross-section O-O'. Note the laterally extensive Ardley coal seams (seams 100 and 150), that were correlated over a distance of over 50 kilometres. The geophysical log shown is the natural gamma ray.

4.3 STRUCTURAL CROSS SECTIONS

4.3.1 CROSS SECTION 1-2 (Figure 22)

This structural cross section is oriented parallel to the disturbed belt from Tp 65 R 25 W5M (near Fox Creek) in the northwest to Tp 31 R 25 W4M (near Three Hills) in the southeast. This line of section was selected to show the variation in coal zone thickness and the relief on the Battle Formation along the full length of the study area. The central part of the cross section is relatively flat lying and runs parallel to regional dip. The northern and southern portions of the cross section climb updip towards the erosional edge of the Paskapoo Formation.

The top of the Battle Formation (the lowest line of the cross section), is shown to have relatively little relief which agrees with trends observed on the structure on top of the Battle Formation map (map 1). The thickness of the coal zone (the shaded portion), varies from 30 to 60 m over most of the cross section. Two areas of local thinning of the coal zone, at the 140 km and at 270 km positions, correspond to the southwest-northeast and east-west valley-like trends discussed in the description of the isopach map of the Ardley coal zone (map 3). The coal zone thins gradually towards the edge of the basin, which is consistent with regional trends.

4.3.2 CROSS SECTION 3-4 (Figure 23)

This structural cross section is oriented perpendicular to regional dip running from Tp 52 R 22 W5M (near Obed) in the southwest to Tp 61 R 14 W5M (near Swan Hills).

The Battle Formation is shown as a relatively flat surface, dipping gently towards the southwest at about 5 m/km. The Ardley coal zone is observed to have a slightly lower dip. The Ardley coal zone thickens from 30 m in the northeast to 120 m in the southwest. Similarly, the

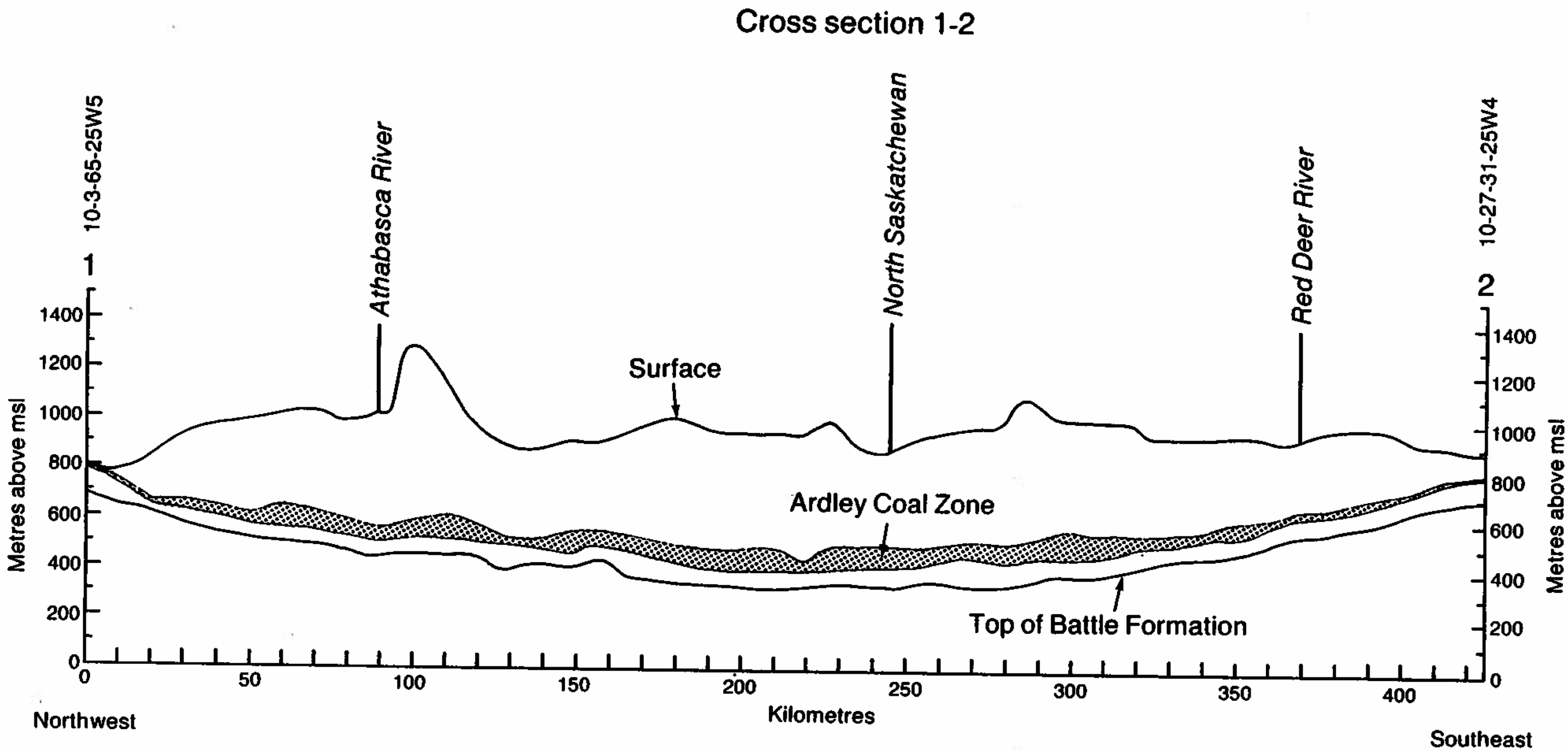

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Figure 22. Structural cross-section 1-2. The line of section runs parallel to the disturbed belt. Note the relatively consistent thicknesses of the Ardley coal zone and lower barren zone.

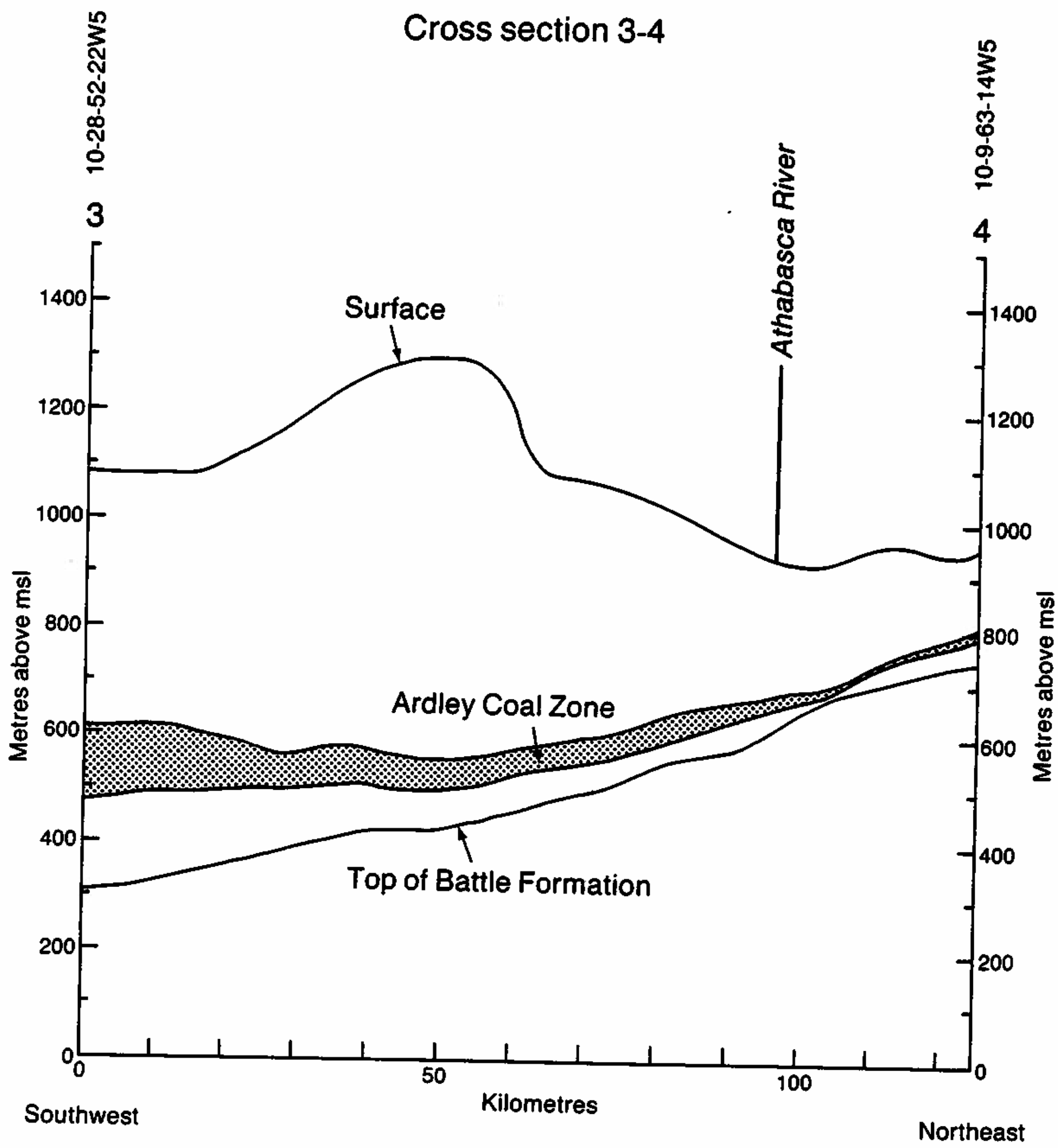

Figure 23. Structural cross-section 3-4. The line of section runs perpendicular to regional dip, from Swan Hills in the northeast to Obed in the southwest. Note the thickening of the Ardley coal zone and the lower barren zone towards the disturbed belt.

barren interval increases in thickness from 20 to 160 m. It is interesting to note that even at the extreme northeast portion of the cross section, the Ardley coal zone is covered by more than a 100 m of bedrock. This offers evidence that the thinning trend of the coal zone towards the east is not caused by post-depositional erosion. The thinning trend toward the east is more likely a result of tectonic controls and lower subsidence rates along the eastern basin margin during the time of Ardley coal development.

4.3.3 CROSS SECTION 5-6 (Figure 24)

This cross section is oriented perpendicular to regional dip running form Tp 37 R 7 W5M in the southwest to Tp 46 R 27 W4M in the northeast. This cross section is very similar to cross section 3-4 to the north. Trends of coal zone thickening and of increasing thickness in the barren interval are similarly illustrated.

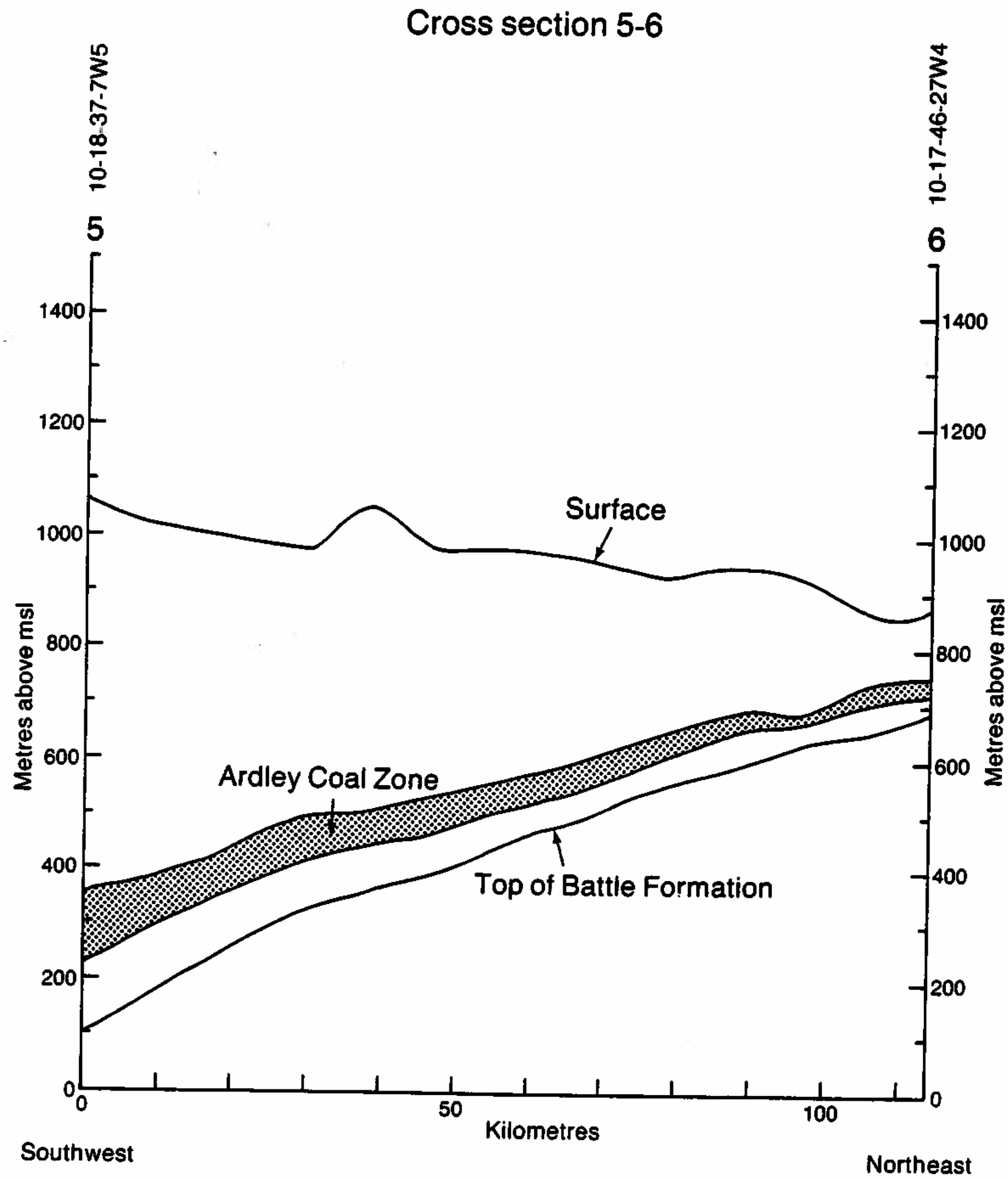

Figure 24. Structural cross-section 5-6. The line of section runs perpendicular to regional dip, from Wetaskiwin in the northeast to Rocky Mountain House in the southwest. Note the thickening of the Ardley coal zone and the lower barren zone towards the disturbed belt.

5. CONCLUSIONS

This study has demonstrated that the Ardley coal zone, although remarkably consistent and relatively easy to correlate over long distances, is not as simple as was previously thought. The Ardley coals, already a major resource in Alberta, will likely maintain their prominence in the future. A summary of some major findings of this study are:

(1) The Ardley coal zone contains major coal resources in terms of both potentially mineable surface and underground coals.

(2) The coals extend over a large part of the west-central Alberta basin between Twp 30 and 66.

(3) The coal zone is about 15 m thick near the outcrop edge, widening to more than 200 m along the Disturbed Belt in the west.

(4) Thicker seams and greater numbers of seams are most commonly found at depths of 100 m or more throughout the central portions of the study area.

(5) Individual seam correlations are possible over several townships but are more tenuous on a basin-wide scale.

(6) Simple subdivision of the Ardley coal zone into an upper main and a lower zone is not supported in this study because of the complexity of seam splitting, addition and removal of seams and the separation of seams with depth. Although this scheme appears to be workable near the outcrop edge, particularly in the Ardley bend area, its use for the description of the coal zone in the deeper subsurface was difficult to apply.

(7) Thick, underground mineable seams are present over wide areas. Areas of special interest include a north-south oriented trend centred along Rg 20 W5M from Tp 47 to 59 and an east-west oriented trend centred along Tp 47 from Rg 1 W5M to Rg 17 W5M. These trends contain cumulative coal values between 12 and 24 m, maximum seam thicknesses of 4 m or more and contain up to 18 seams.

(8) The development of the Ardley coal zone is the result of basin-wide controls on sedimentation, which allowed extensive peat-forming mires to develop. At times, these peat-forming mires blanketed large portions of the basin, especially along the two trends outlined above.

(9) Further detailed work is likely to identify particularly attractive targets for the economic exploitation of the Ardley coal zone.

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APPENDIX - DETAILED SUBSTUDIES

A1.1 INTRODUCTION

Two substudies, the Medicine and Alix, were chosen for a more detailed examination of the Ardley coal zone. In each substudy correlations were done on a seam by seam basis. In addition to being able to measure the lateral continuity and thickness variation of seams, the nature of splits could be characterized. In part, results from the detailed substudies were used to make inferences about the geometry and continuity of seams in other parts of the basin.

A1.2 MEDICINE SUBSTUDY

The Medicine substudy is 5 townships by 5 townships in size. It is located within Tp 43 to 47 and R 5 to 9 W5M (see figure A-1). Data from 185 randomly distributed oil and gas wells were used to create a computer database. Every well containing a complete suite of geophysical logs was used, resulting in a data density ranging from 1 to 28 wells per township. Six interlocking cross sections, four trending perpendicular and two trending parallel to regional dip, formed a network grid from which the seams were correlated. Eight wells at intersecting points of the sections confirm consistent correlation of the seams. This study area is particularly well suited to examine the nature of the Ardley coal zone along the edge of the extensive east-west trend of thick cumulative coal development found in the regional study.

The interval of study is from the top of the Ardley coal zone to the base of the Battle Formation (see figure A-2). A group of three laterally continuous coals named seam 100, 150 and 200 form the top of the coal zone and the top of the interval of study. These upper coals are capped by thick clastic sequences that are generally barren of coals. Seams 400, 500 and 600 form the base of the coal zone. The

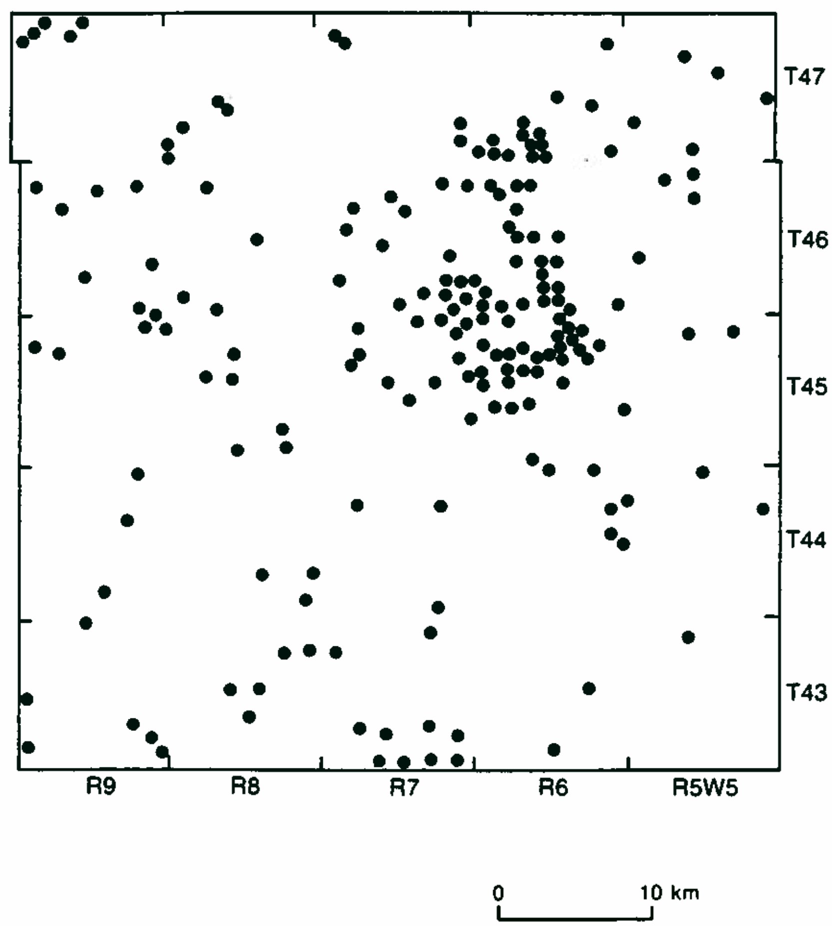

Figure A-1. Location map showing the distribution of data locations used in the Medicine substudy. A total of 185 oil and gas wells were used in the database.

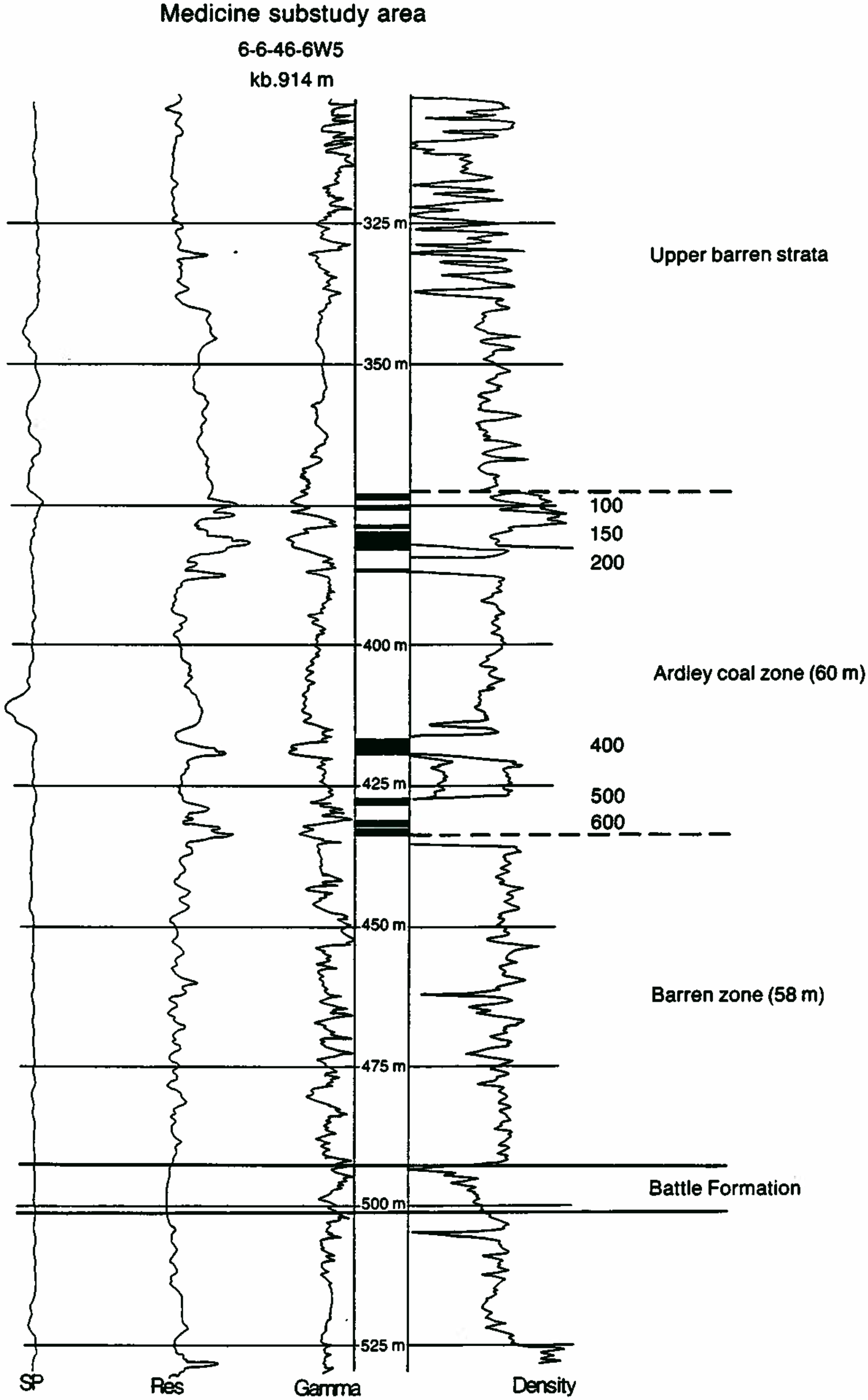

Figure A-2. Representative well logs and unit boundaries used in the Medicine substudy. Individual seams were correlated and mapped interval between seam 600 and the top of the Battle Formation (referred to as the "barren zone") generally consists of mudstones and fine grained sandstones. No coals were identified in this interval.

A1.3 COMPARISON OF STRUCTURE MAPS

A comparison between the structure maps of seams 100 and 500, and the top of the Battle Formation (figures A-3, A-4 and A-5 respectively) suggests that although structural trends are similar, the amount of dip varies for each level. In this comparison each map has a contour interval of 20 m but the number of contour lines increased from 10 to 13 to 18 for the upper, middle, and lower surfaces respectively. A sketch of the dip relationships are shown in figure A-6.

The structure contour lines of the Battle Formation are smooth and regularly spaced suggesting that it is a relatively planar surface dipping to the southwest. The coal seams also dip to the southwest but the structure contour lines are more irregular suggesting that these surfaces undulate more and contain numerous highs and lows. Irregularities on these surfaces are likely the result of differential compaction and the variation in thickness of splits. The implications of these trends are that laterally continuous coal seams often have a highly variable stratigraphic position. A series of highs and lows appear to be the result of differential compaction between locally deposited channel sandstones and finer grained contiguous strata.

A1.4 ISOPACH MAPS OF MAJOR COAL SEAMS.

The isopach maps of seams 100 and 150 (figures A-7 and A-8, respectively) show the variation in thickness of these two tightly grouped seams. Both seams obtain thicknesses of 4.0 m and more over very large areas. The lateral continuity of these seams is also noteworthy. They can be correlated over an area of at least 25 townships (2500 sq km), suggesting that mires developing during the time

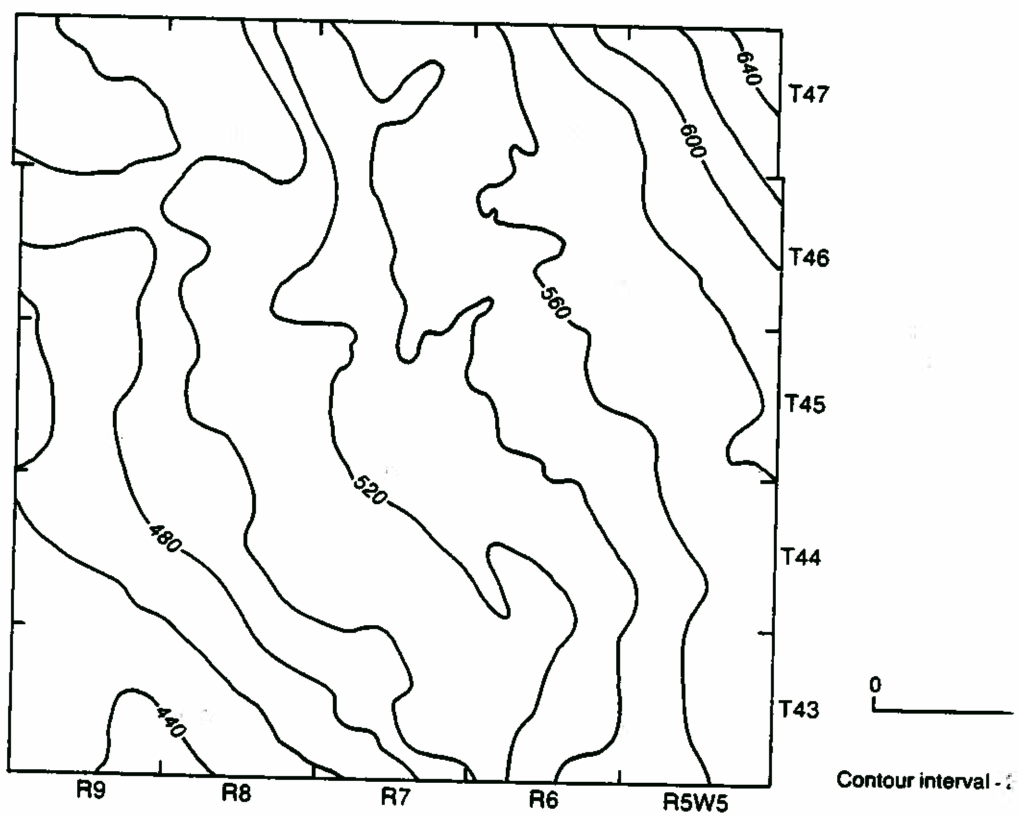

Figure A-3. Structure contour map of seam 100, Medicine substudy. Sea
is laterally continuous throughout the study area.

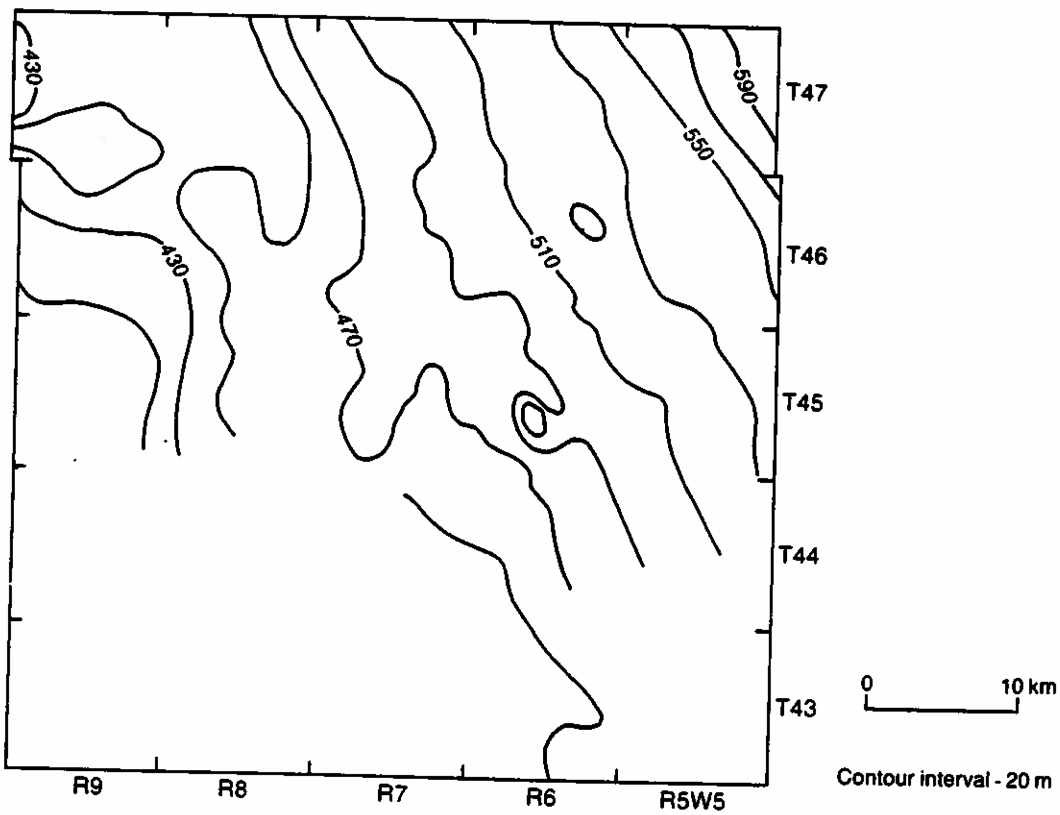

Figure A-4. Structure contour map of seam 500, Medicine substudy. Seam 500 is absent where contour lines are missing.

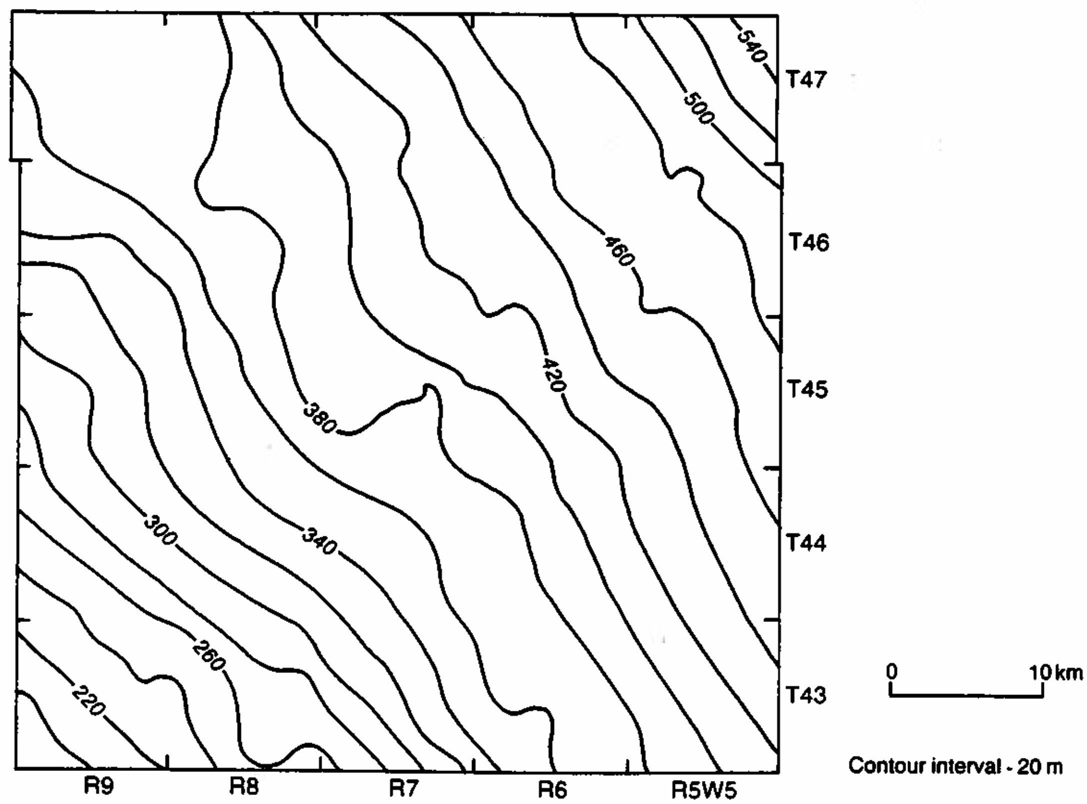

Figure A-5. Structure contour map of the top of the Battle Formation, Medicine substudy. The Battle Formation is a relatively flat-lying and continuous datum used in this study.

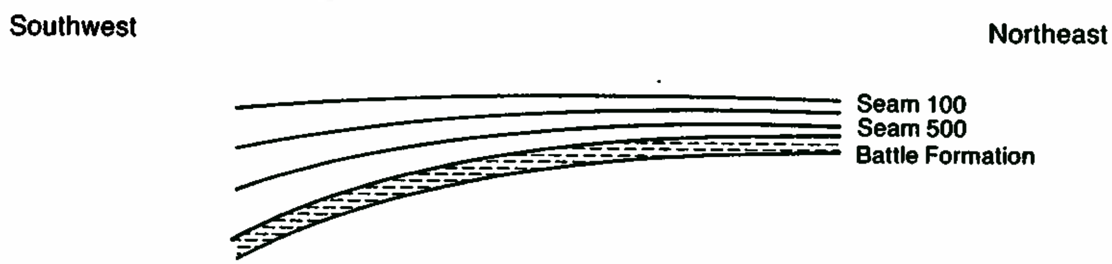

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Figure A-6. Schematic sketch showing the dip relationships between seam 100, seam 500 and the Battle Formation. Comparisons between Figures A-3, A-4 and A-5 indicate that the amount of dip (and consequently, the rate of subsidence) increases from upper to lower surfaces.

of peat formation were equally as extensive. The maximum thickness trends for seams 100 and 150 are concentrated in Tp 44, 45 and 46, R 8 and 9 W5M. The orientation and location of these trends differ from those of seams 400, 500 and 600. These differences are discussed below.

Seams 400, 500 and 600 form a lower grouping of coals in the study area (see figure A-2). The orientation of maximum thickness trends is east-west. The dramatic decrease in thickness and/or absence of seams 400, 500 and 600 throughout the southern portion of the study area (see figures A-9, A-10 and A-11, respectively) appear to be the result of erosion or non-deposition. Amalgamation and overall thickening of these seams is observed towards the north and south (see figure A-12) giving support to this interpretation. It is thought that frequent clastic input prevented the formation of economic coals in the southern region. The absence of the lowermost coals in the Ardley coal zone along this east-west trend was observed in the regional maps. The thickness of the coal zone, the total number of seams, and total cumulative coal decreases dramatically along this trend.

AI.5 PARTINGS BETWEEN MAJOR COAL SEAMS

Isopach maps were constructed for splits (ie. partings greater than 0.5 m) between major coal seams. Even tight groupings such as seams 100, 150 and 200 in the substudy break up and become increasingly separated in certain directions. The splits are made up largely of clastic sediments and were observed to increase in thickness towards the source of the clastics. In figure A-13 the split between seams 100 and 150 increases significantly towards the northwest and southwest suggesting that the clastics were derived from these directions between coal forming episodes. Figure A-14 illustrates a similar thickening trend for the split between seams 150 and 200. Coincident with the thickening of splits is the introduction of new seams. Seam 110, for instance, (figure A-15) underlies seam 100 in the areas of maximum splitting between seams 100 and 150.

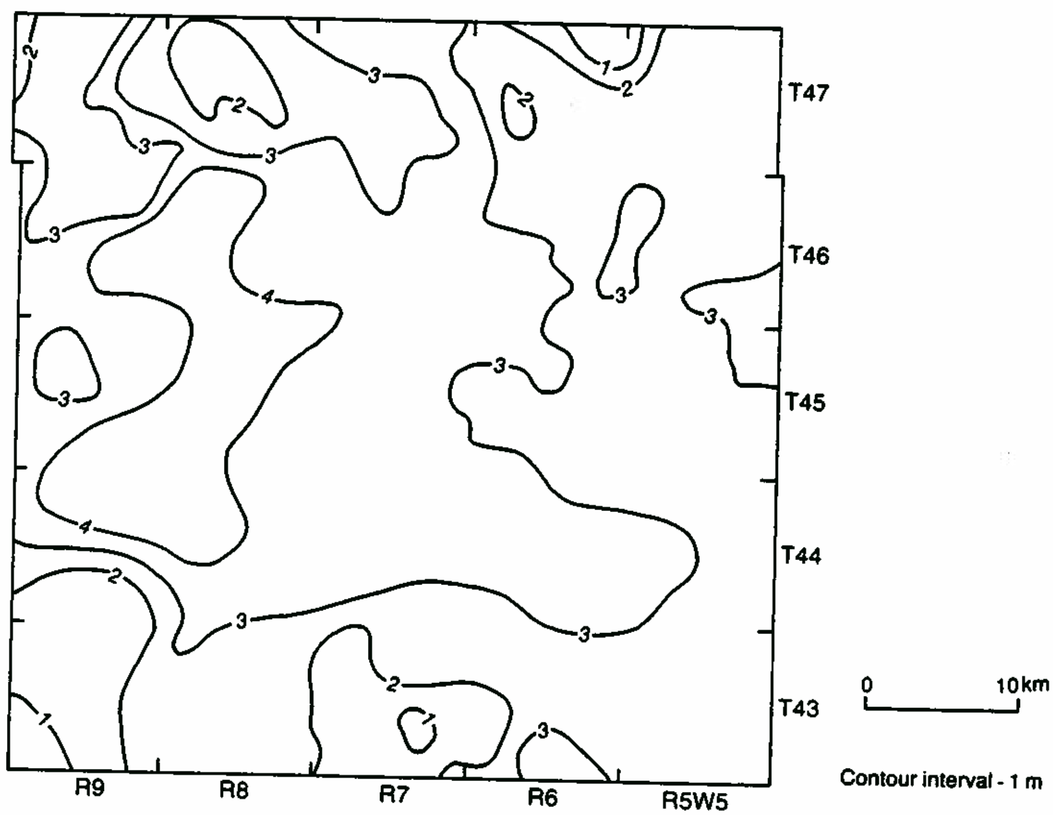

Figure A-7. Isopach map showing the variation in thickness of seam 100, Medicine substudy. Seam 100 is continuous over the entire study area.

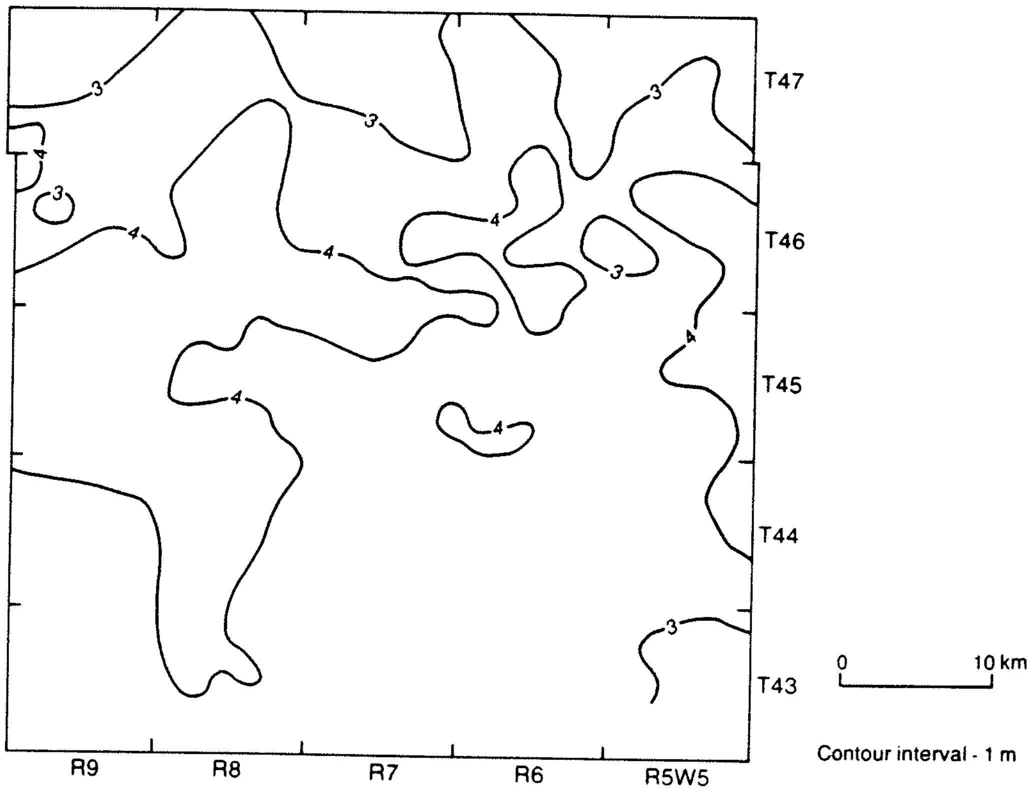

Figure A-8. Isopach map showing the variation in thickness of seam 150, Medicine substudy. Seam 150 is continuous over the entire study area.

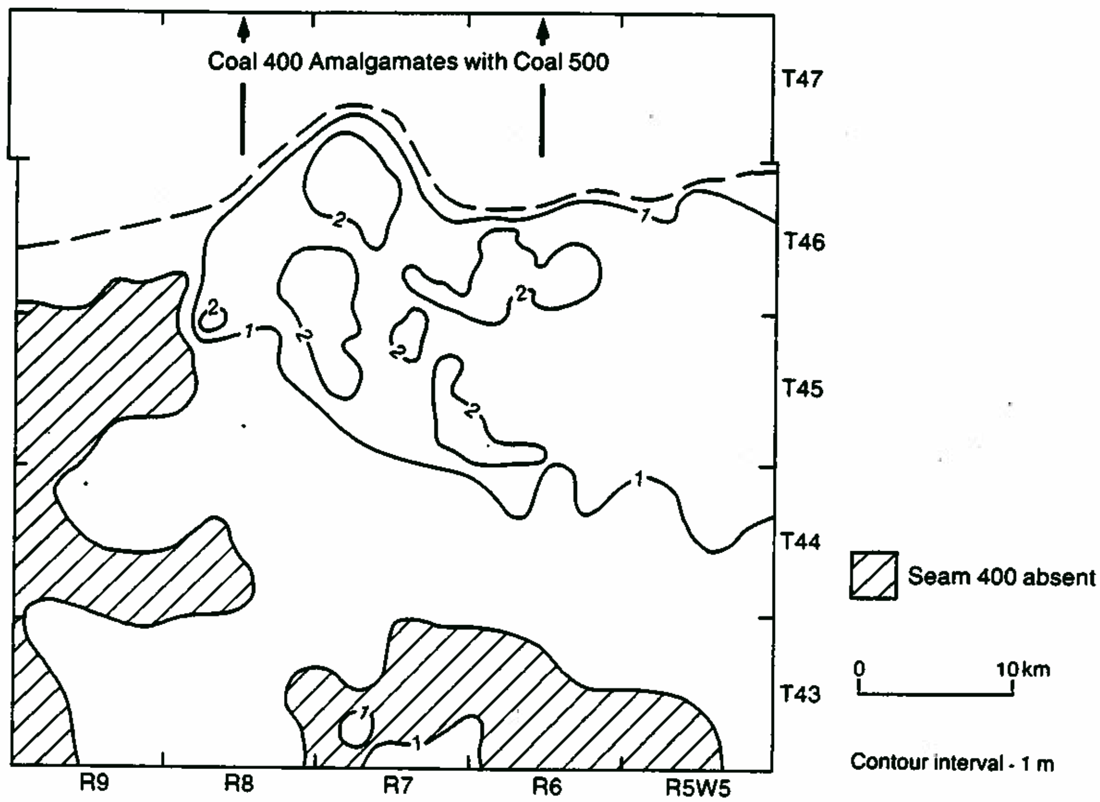

Figure A-9. Isopach map showing the variation in thickness of seam 400, Medicine substudy. Seam 400 is locally absent as indicated on the map. Note the amalgamation of seam 400 to seam 500 to the north.

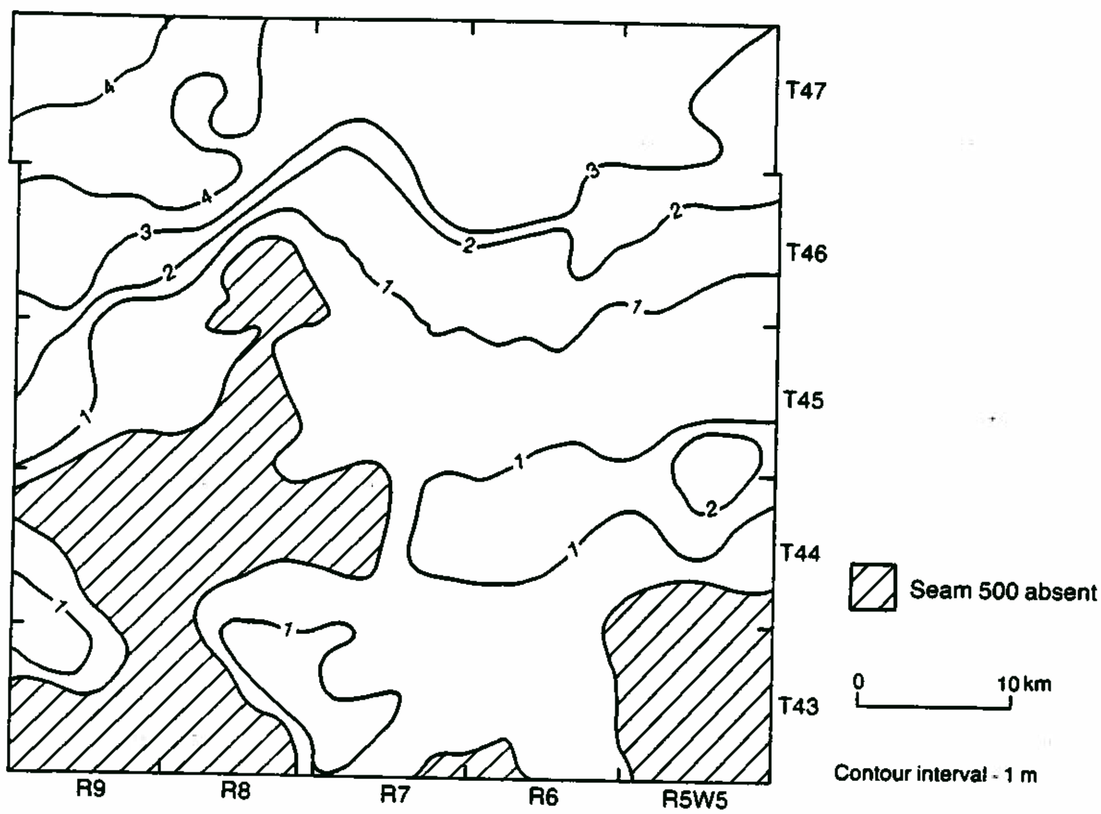

Figure A-10. Isopach map showing the variation in thickness of seam 500, Medicine substudy. Seam 500 is absent locally as indicated on the map.

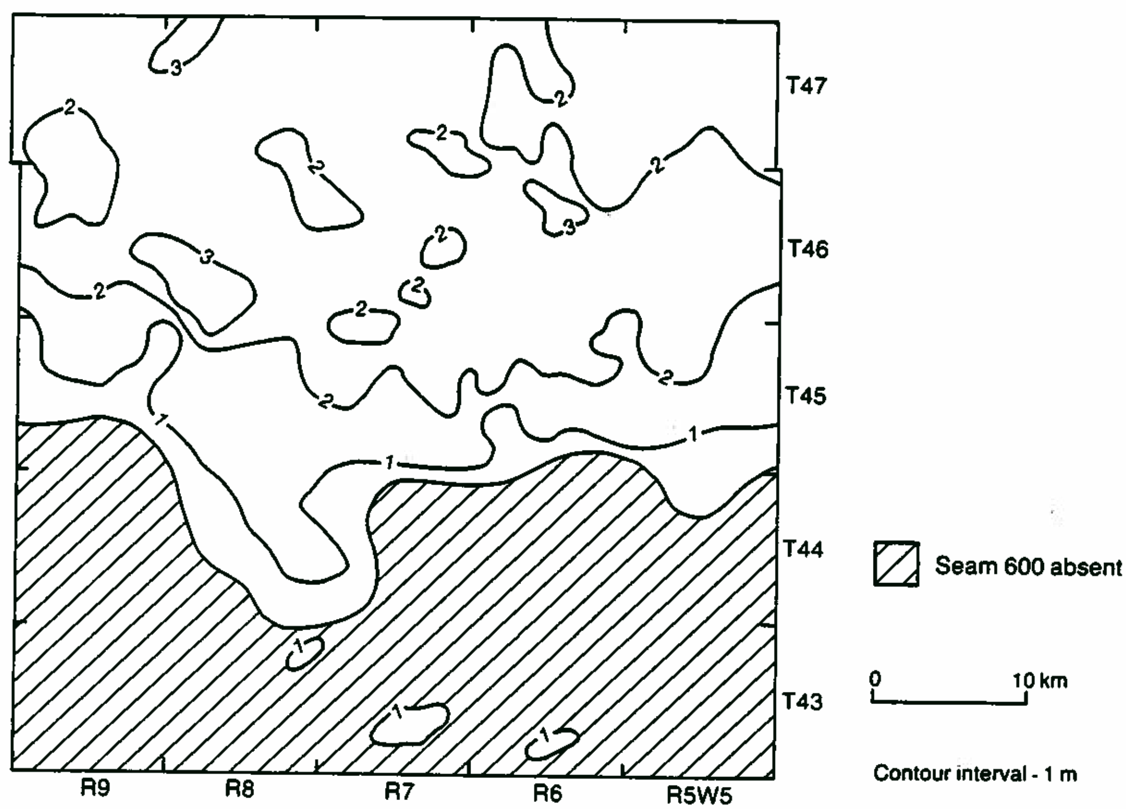

Figure A-11. Isopach map showing the variation in thickness of seam 600, Medicine substudy. Seam 600 is absent locally as indicated on this map.

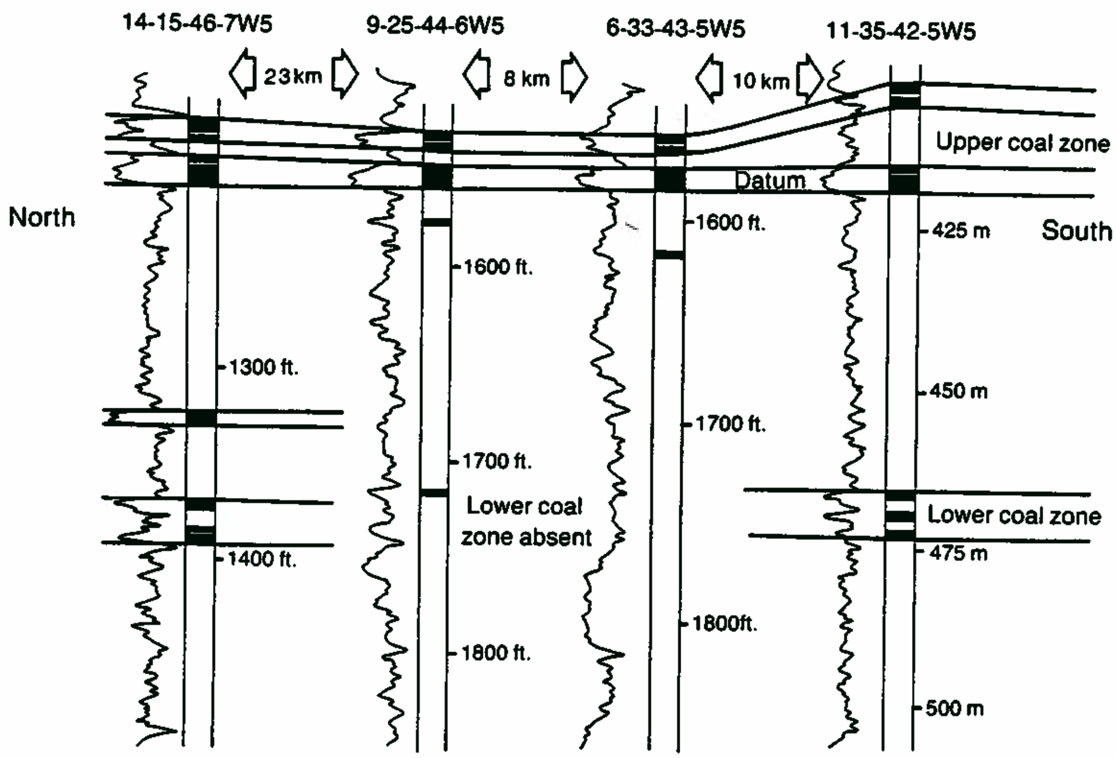

Figure A-12. Simplified cross-section showing an east-west trend of fluvial sandstones found in place of the lower seams in the Medicine substudy area. Amalgamation and overall thickening of seams 400, 500 and 600 occur toward the north and south of this trend. The geophysical log shown is the natural gamma ray.

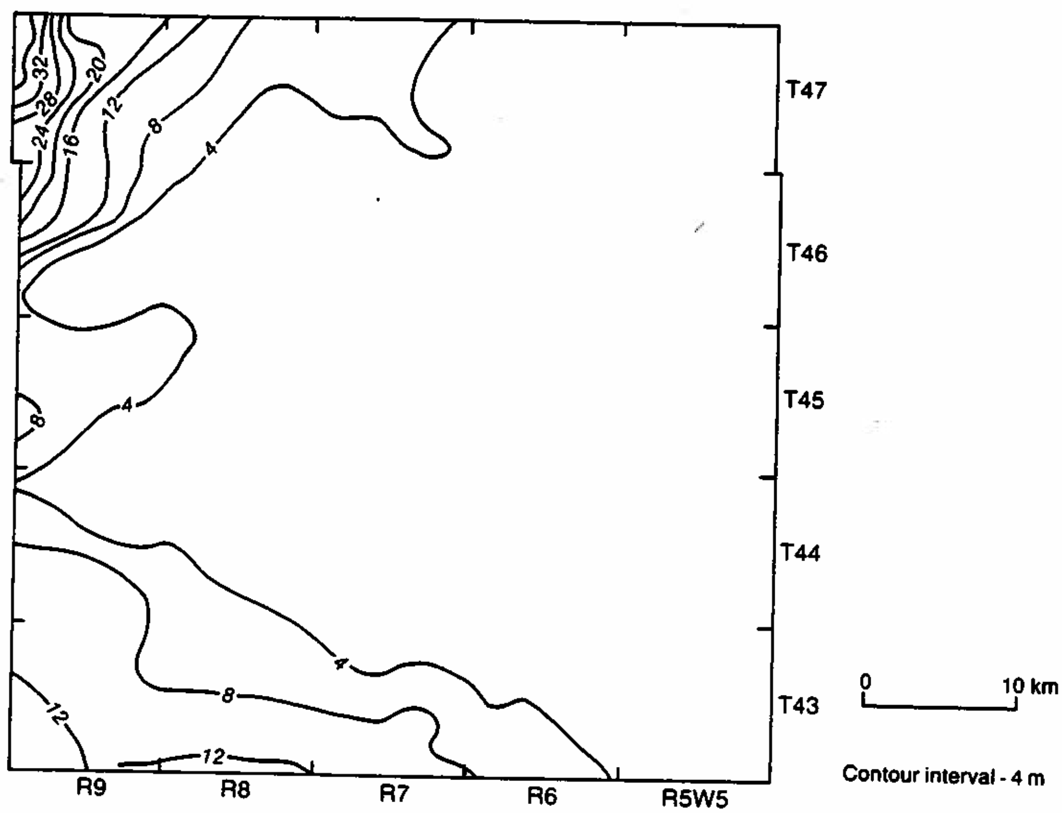

Figure A-13. Isopach map showing the split between seams 100 and 150. The increase in thickness to the northwest and southwest suggest that clastics were derived from these directions.

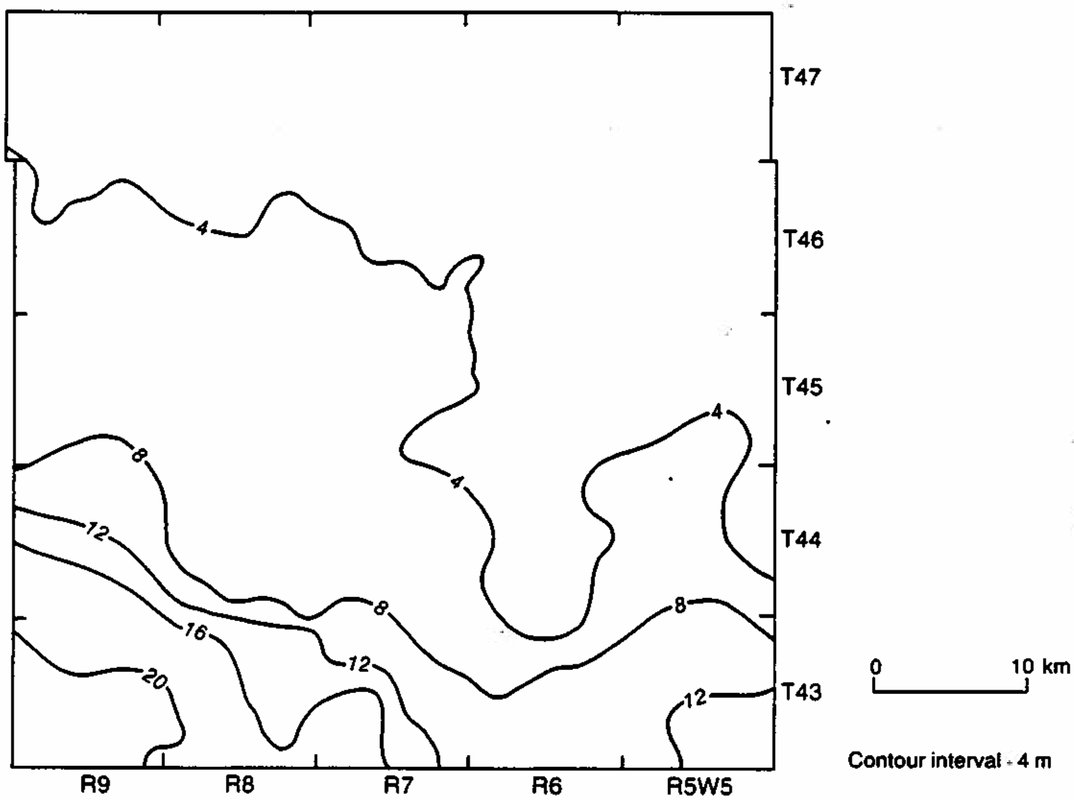

Figure A-14. Isopach map showing the split between seams 150 and 200. The increase in thickness to the south suggests that clastics were derived from the south between coal-forming episodes.

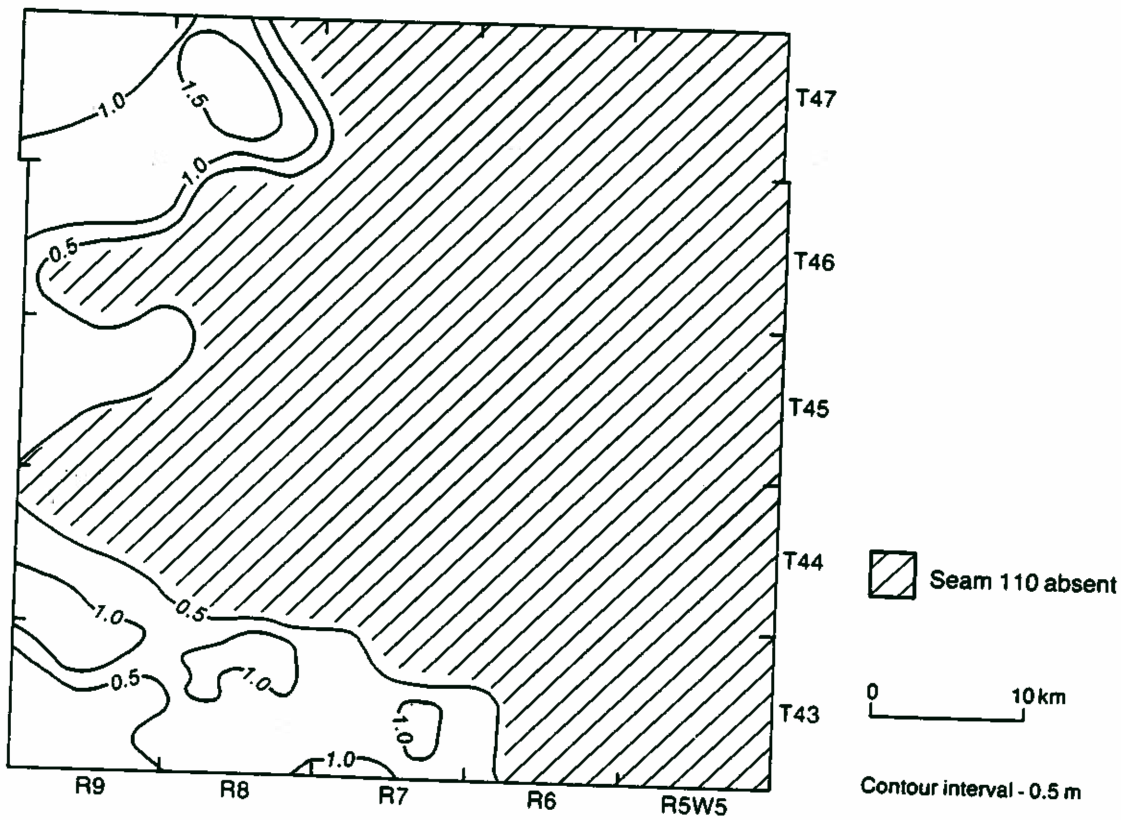

Figure A-15. Isopach map of seam 110. Seam 110 is locally deposited and directly underlies seam 100 in the western portion of the study area. Note that the distribution of this seam coincides with observed thickening of the split between seams 100 and 150.

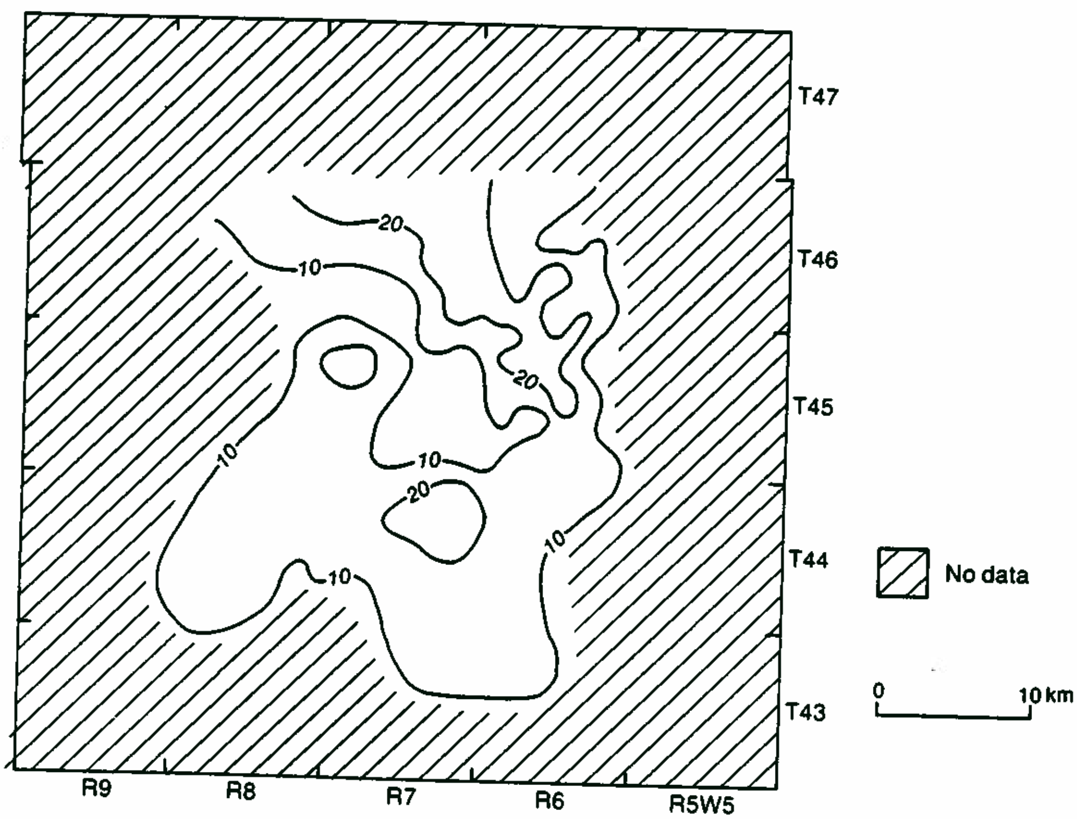

Figure A-16. Isopach map showing the thickness variation of sandstones in the split between seam 200 and seam 400. These sandstones appear to be local channel deposits.

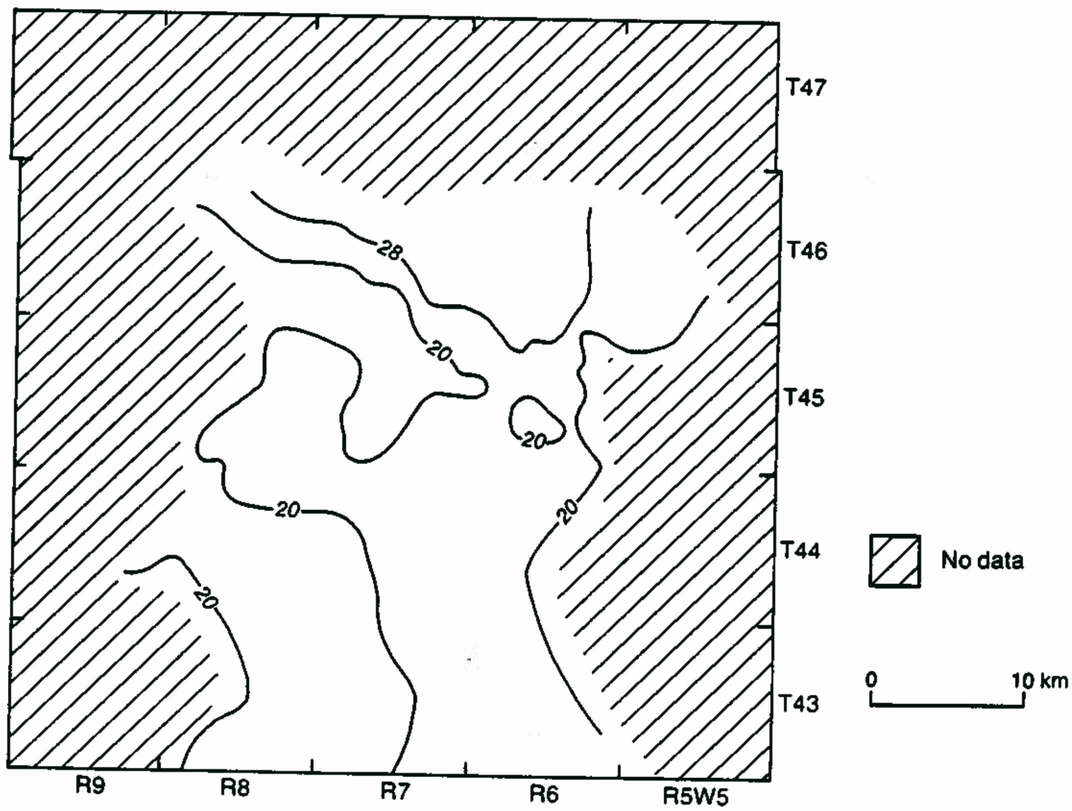

Figure A-17. Isopach map showing the thickness variation of the split between seam 200 and seam 400 (undifferentiated). Comparison with Figure A-16 suggests that sandy intervals make up a large portion of anomalously thick splits in this area.

The split between seams 200 and 400 shows a thickening trend oriented north-south (see figures A-16 and A-17). In this example, thick splits may be attributed to fluvial activity and the subsequent deposition of channel sediments. Comparison between the two maps indicates that sandy intervals may make up a large portion of the anomalously thick splits. Draping over these sandy intervals may also lead to a highly variable stratigraphic positions of coal seams.

A2.0 ALIX SUBSTUDY

The Alix substudy is southeast of the Medicine substudy, and covers an area of 43 townships. It is located within Tp 34 to 41, R 23 to 28 W4M and R 1 and 2 W5M (see figure A-18). Data from 174 oil and gas wells and 59 Alberta Research Council coal exploration holes were used. The data density ranged from 1 to 18 wells per township. As with the Medicine substudy, a series of interlocking detailed cross sections formed a network grid with which to correlate on a seam by seam basis. The seams were given identification numbers that were verified at intersecting wells on the cross sections. A group of four main seams could be correlated over most of the study area (see figure A-19). Coinciding seam numbers between the two substudies do not necessarily refer to the same seams. Correlation of individual seams betweeen substudy areas was complicated by seam splitting and discontinuities of seams between areas.

This area was chosen for detailed study to illustrate the variation in the nature of the Ardley coal zone from where it outcrops in the east to about 400 m depth to the west. Shallow data obtained from closely spaced Alberta Research Council coal exploration and core holes were tied in with the oil and gas well data.

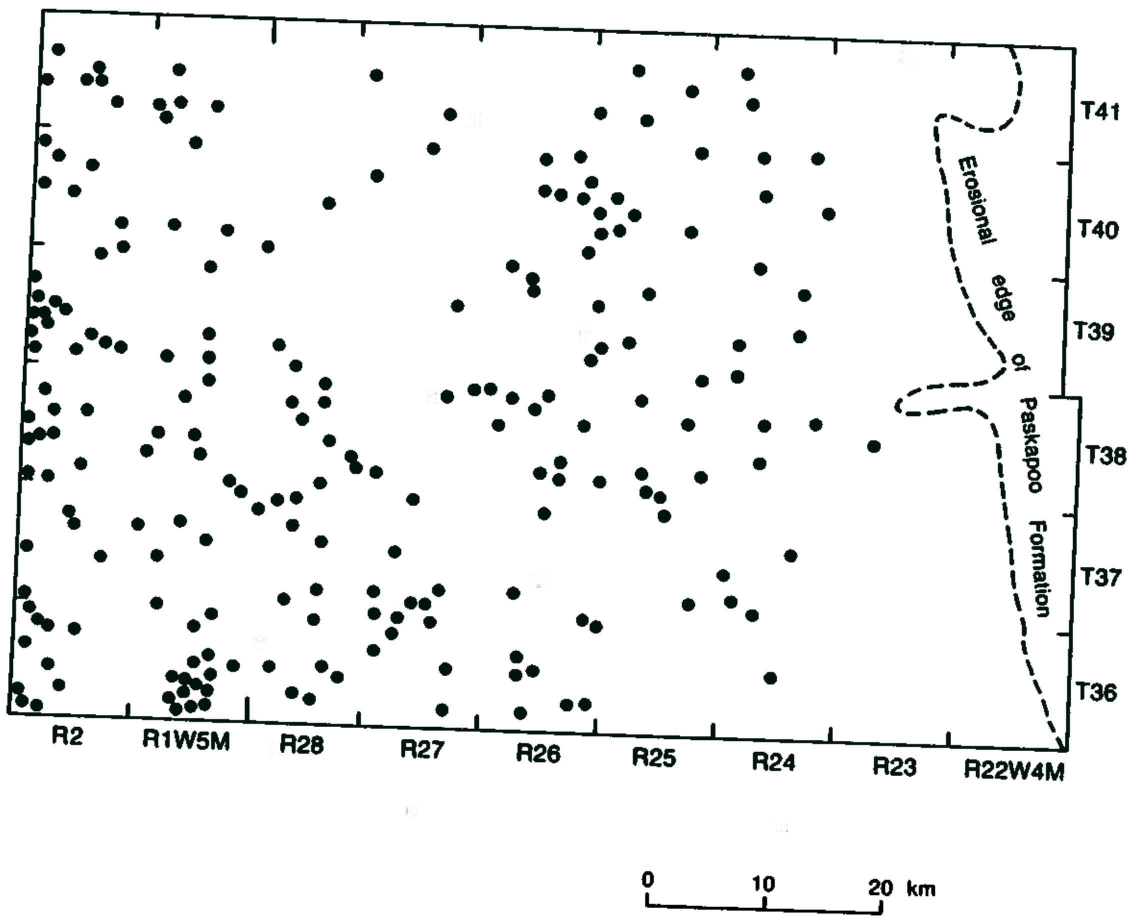

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Figure A-18. Location map showing the distribution of data points in the Alix substudy. A total of 174 oil and gas wells and 59 coal exploration holes were used in the database.

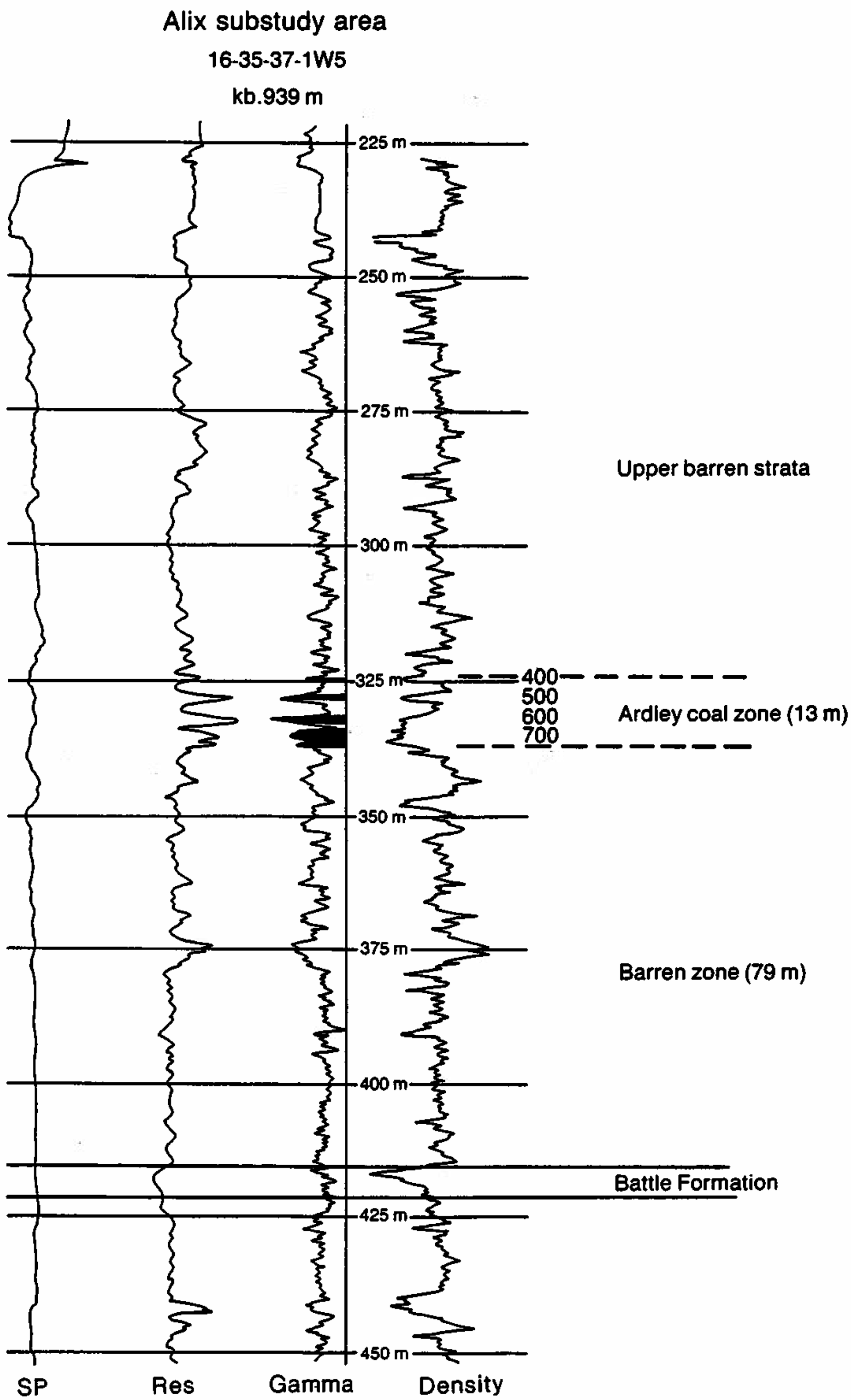

Figure A-19. Representative well logs and unit boundaries used in the Alix substudy. Individual seams were correlated and mapped using interlocking cross-sections.

A2.1 Comparison of Structure Maps

The structure map on seam 600 (figure A-20) is very similar to the structure map on the top of the Battle Formation (figure A-21). Both maps illustrate a gentle dip towards the west-southwest. The closer spaced contour lines of the structure on the Battle Formation map, however, indicates that the Battle Formation has a slightly greater dip than seam 600. This is in agreement findings in the Medicine substudy in which the uppermost coal seams of the Ardley had lower dips than the underlying Battle Formation.

A2.2 Partings between Maps

The isopach map of the strata between the top of the Battle Formation and seam 600 (figure A-22) illustrates the effects of increased subsidence rates towards the western basin margin. The interval thickens from 30 m in the northeast to 120 m in the southwest. The thickening trend is considered to be due to loading (and a corresponding increase in subsidence) towards the western basin margin.

In addition to gradual thickening created by increased subsidence due to loading, dramatic local thickening of splits may develop. The split between seams 500 and 600, for instance, varies from 1 to 2 m over most of the study area but thickens to over 24 m in the southwest corner (see figure A-23). In contrast, the split beween seams 600 and 700 is 1 to 2 m over the entire study area (see figure a-24). Rapid thickening of a split like the one observed between seam 500 and seam 600 is likely a result of the input of clastics between coal forming episodes. The nature of splits and the direction of thickening will be important factors to consider when the resource potential of Ardley seams is studied.

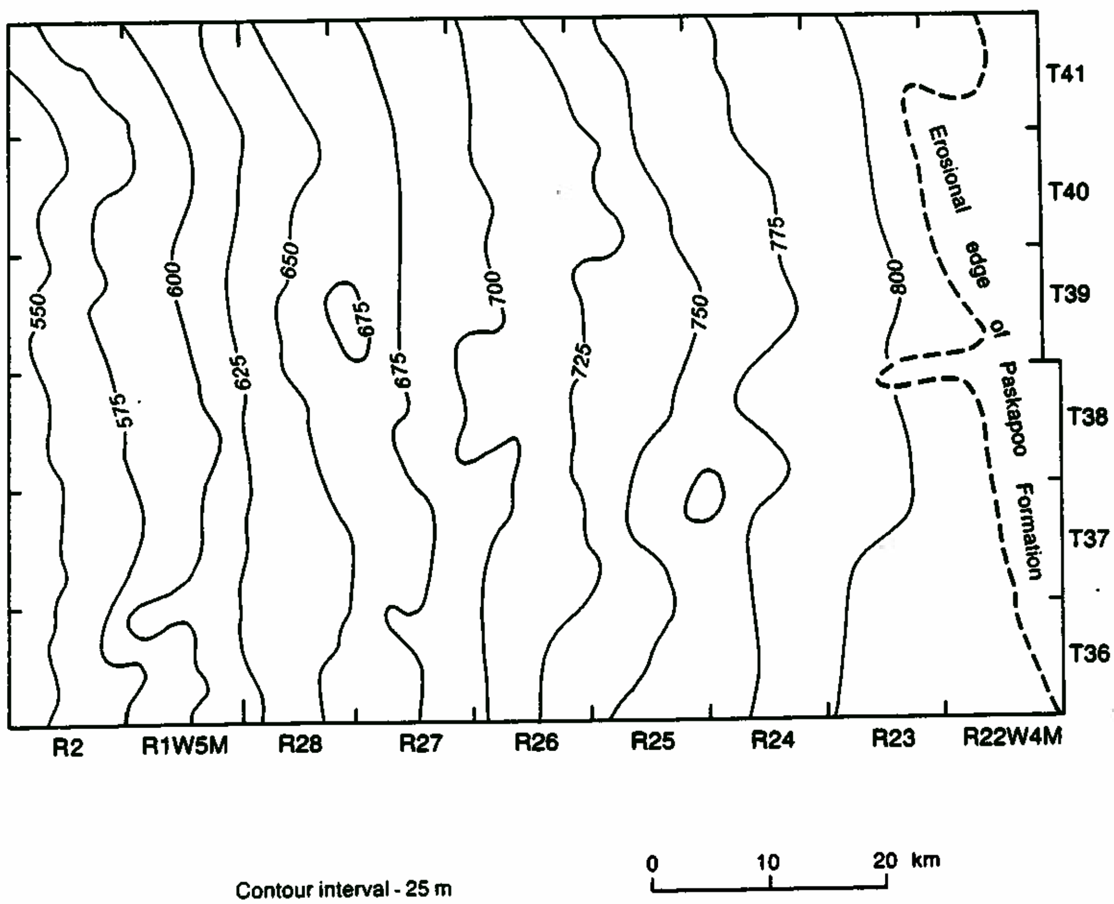

Figure A-20. Structure contour map of seam 600, Alix substudy. Seam 600 is continuous throughout the study area.

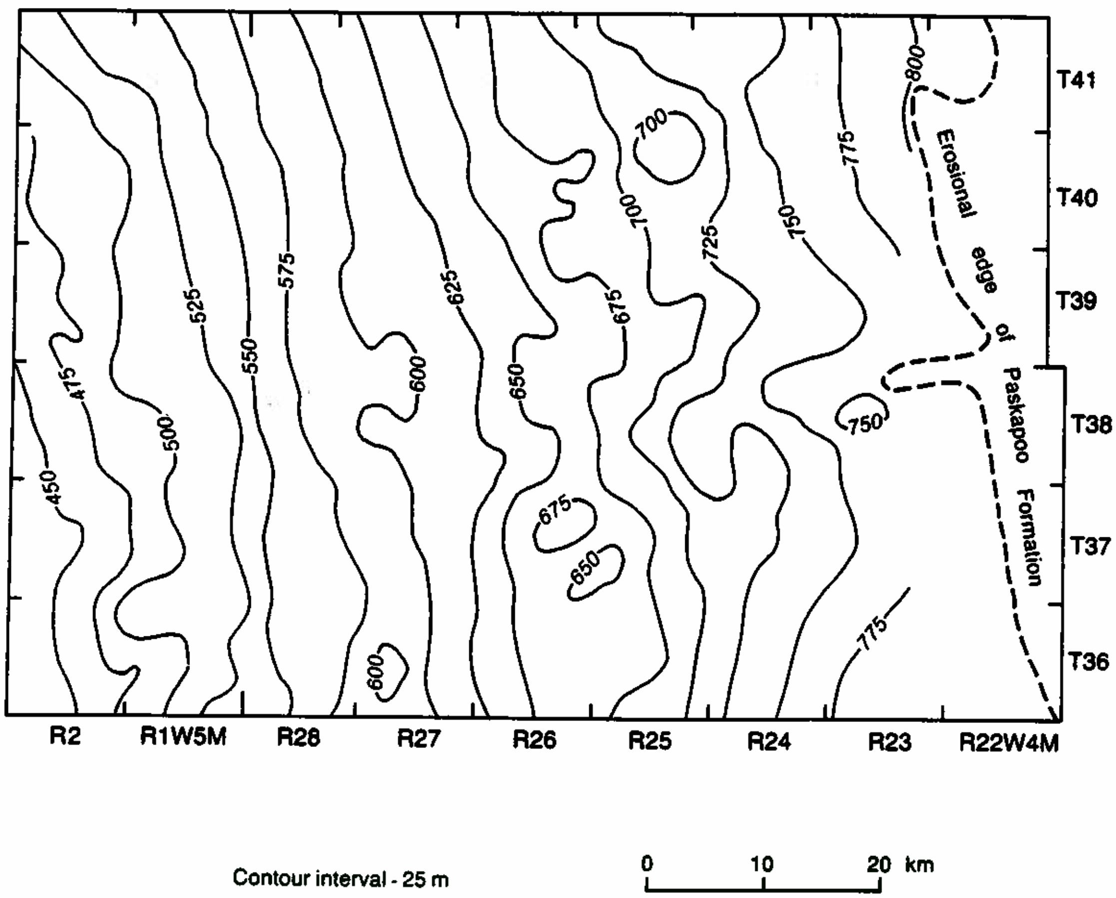

Figure A-21. Structure contour map of the Battle Formation, Alix substudy. The Battle Formation is a relatively flat lying and continuous datum used in this study.

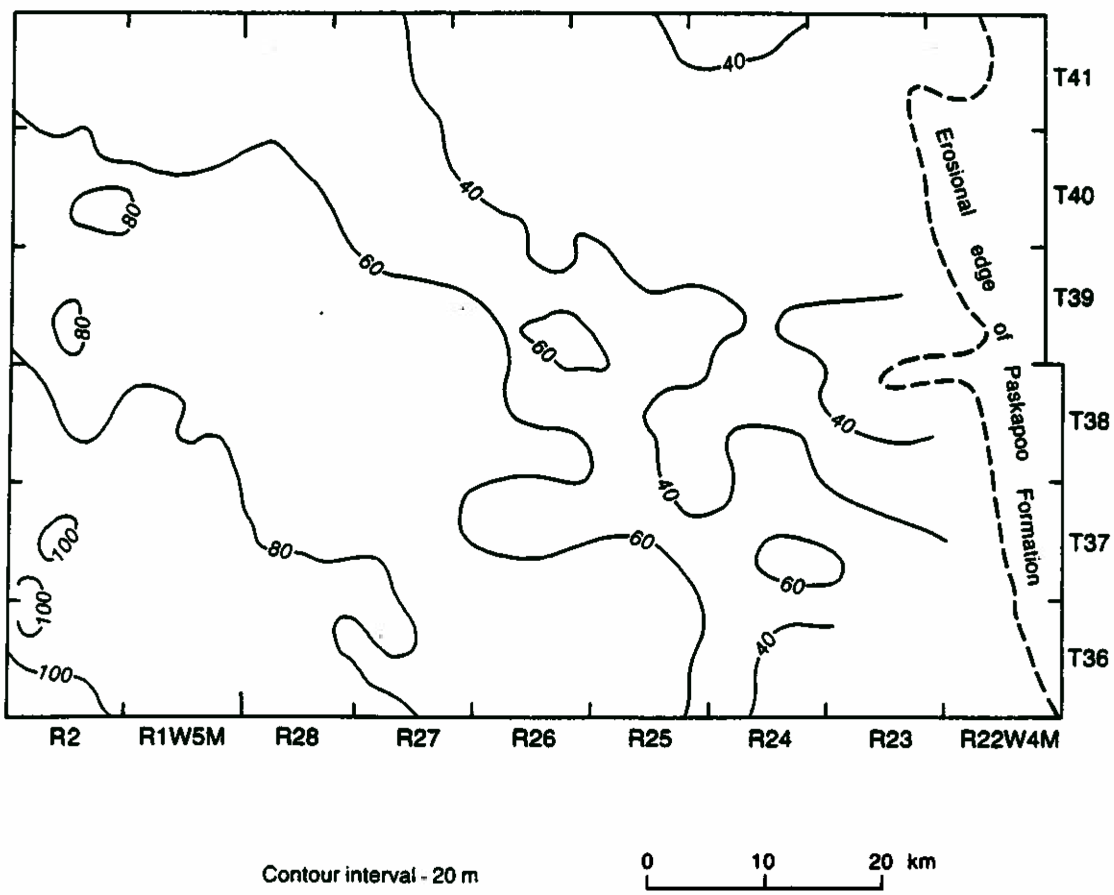

Figure A-22. Isopach map of the lower barren zone, Alix substudy. This is the interval between the Battle Formation and seam 600. The trend of increasing thickness to the southwest is a result of increased subsidence in that direction.

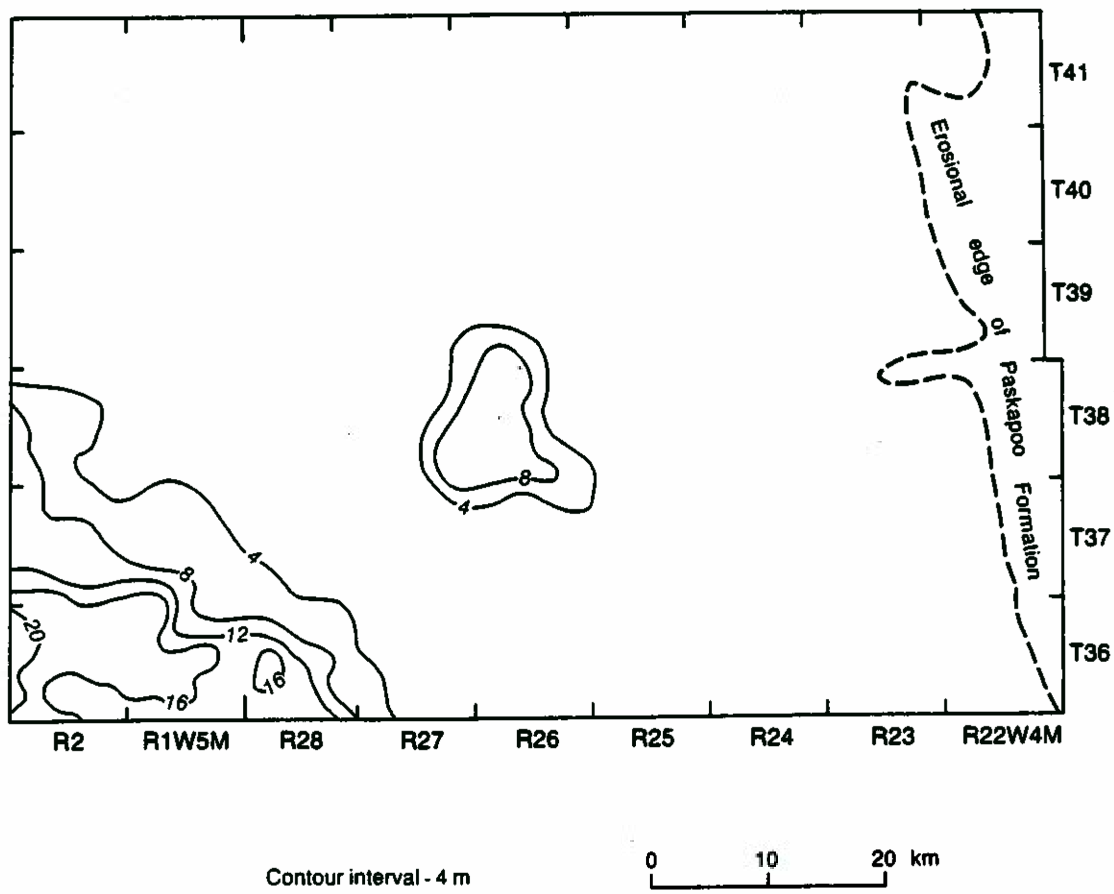

Figure A-23. Isopach map showing the thickness variaiton of the split between seam 500 and seam 600, Alix substudy. The thickening trend towards the southwest suggests clastic input from that direction between coal-forming episodes.

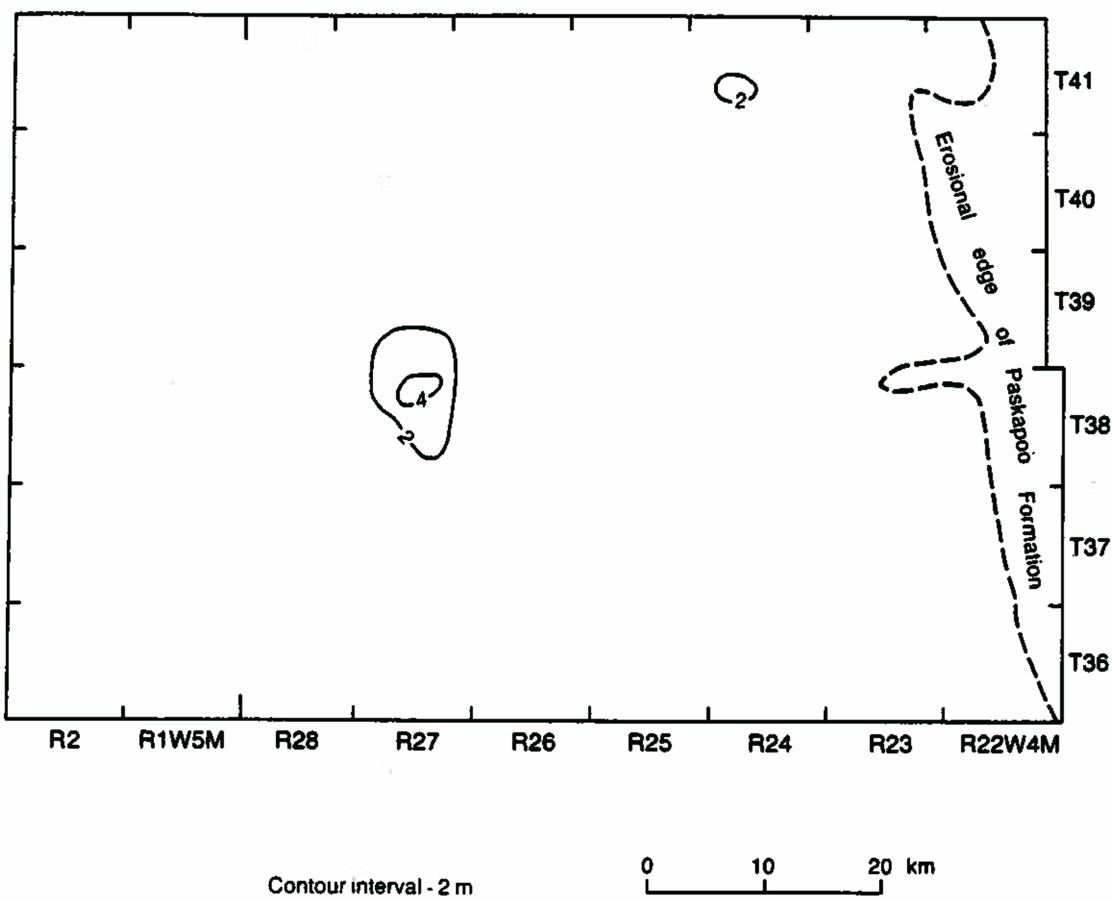

Figure A-24. Isopach map showing the thickness variation of the split between seam 600 and seam 700, Alix substudy. Note the more uniform thickness in contrast to the split between seams 500 and 600.

A2.3 Isopach maps of major coal seams

Seam 700 is continuous over most of the study area and varies from 0.5 m in thickness to more than 3.8 m (see figure A-25). The general thickening trend from 1 m in the northeast to 3 m in the southwest appears to be the result of the addition of mudstone partings and/or associated effects of subsidence to the southwest. Seam 600 is also laterally extensive and ranges from 0.5 m to more than 2.0 m in thickness (see figure A-26). Seam 500 varies from 0.5 to 1.8 m (see figure A-27). Two coinciding trends of thick coal development (figures A-25 and A-27) are oriented east-west possibly representing peat-forming areas that were isolated from clastic input for extended periods of time.

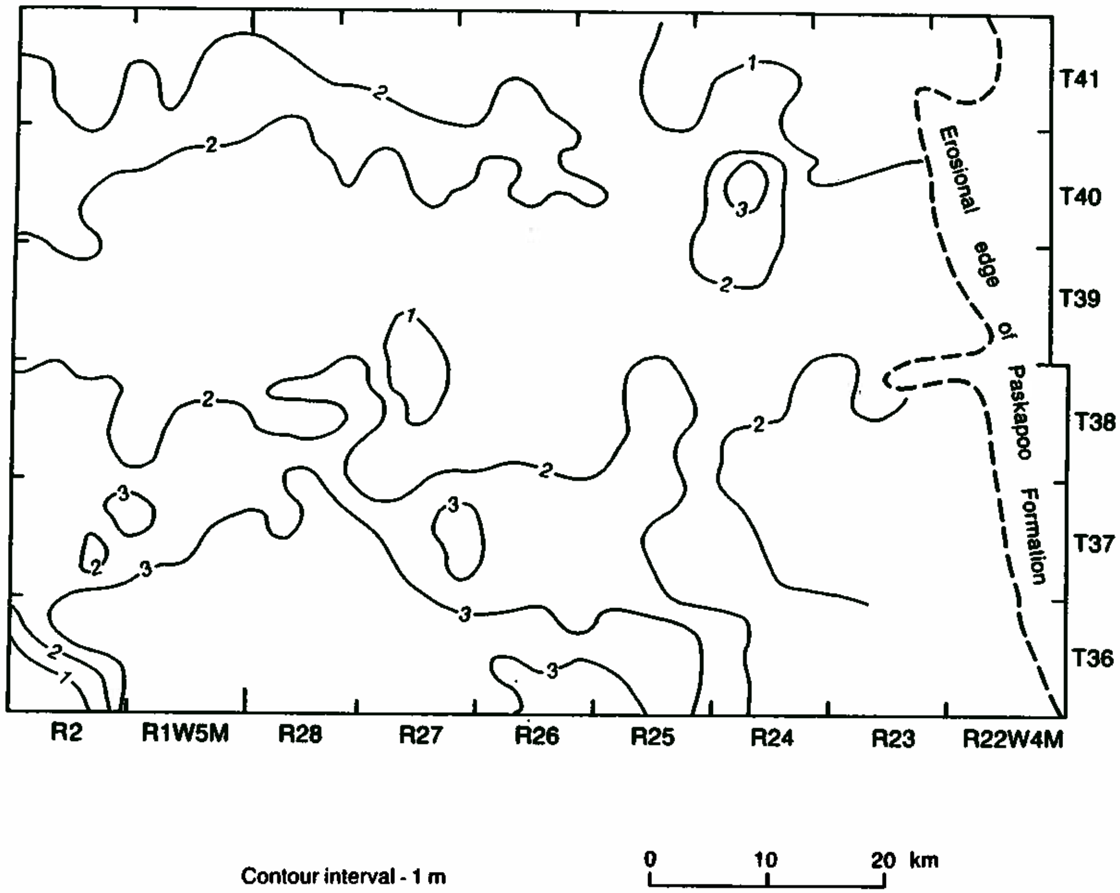

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Figure A-25. Isopach map showing the thickness variation of seam 700. This seam is continuous over most of the study area.

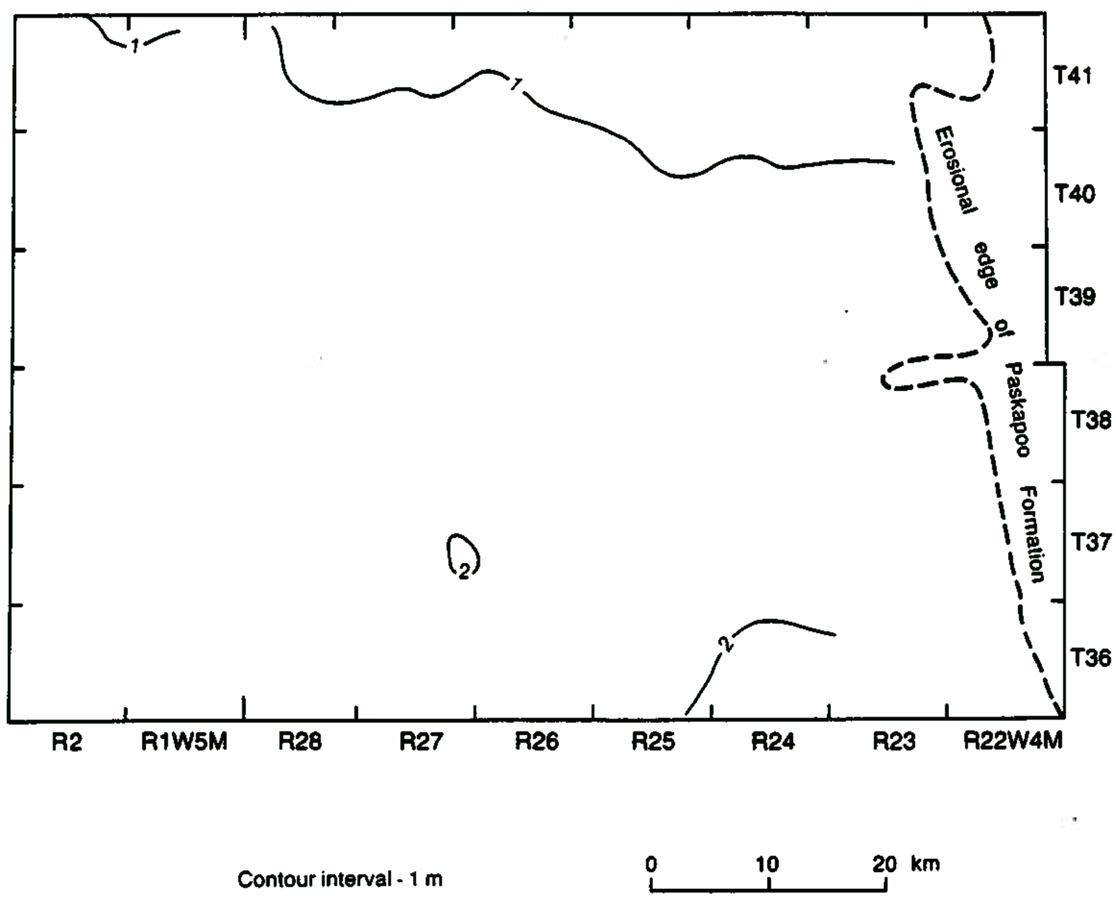

Figure A-26. Isopach map showing the thickness variation of seam 600. This seam is continuous over most of the study area.

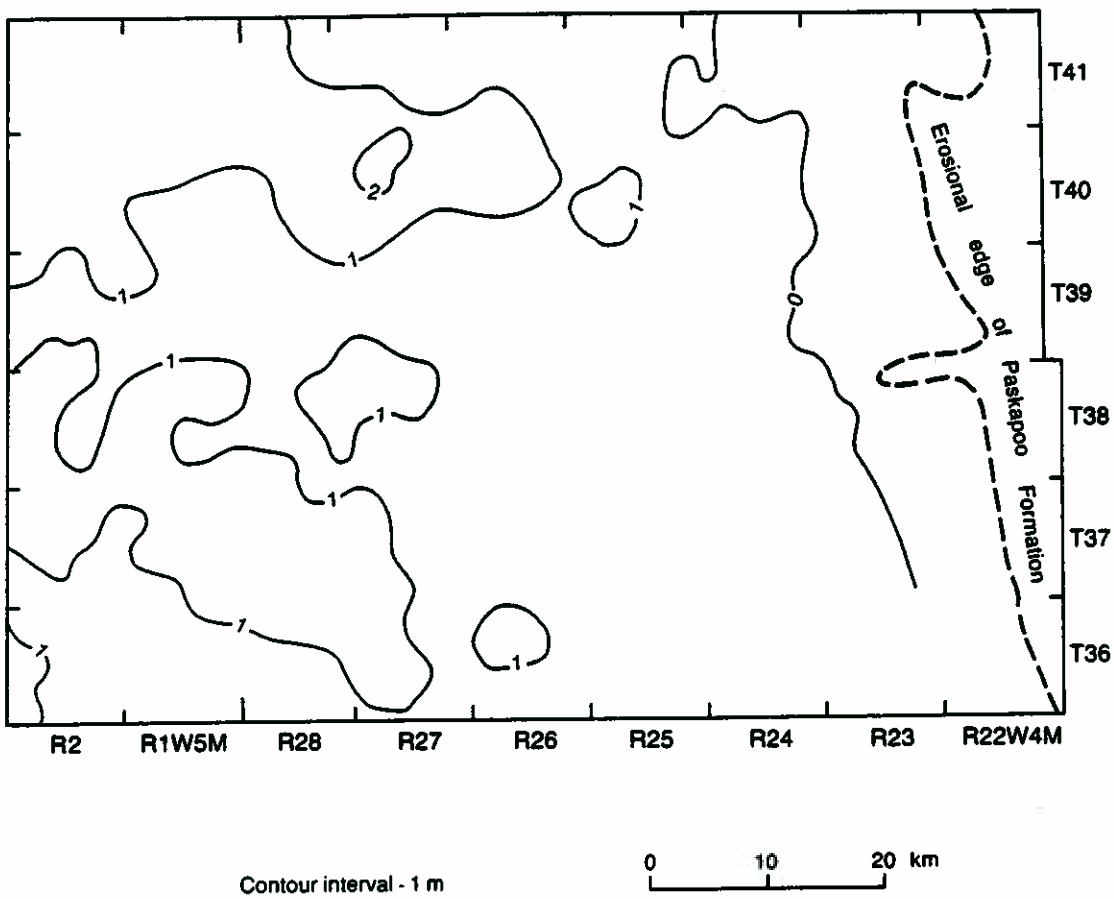

Figure A-27. Isopach map showing the thickness variation of seam 500. This seam is continuous over most of the study area.

Coal resources evaluation, Ardley coal zone, to 400 m depth, Alberta plains area
Stratigraphic cross section H-H′

R.J.H. Richardson, R.S. Strobl, D.E. Macdonald,
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Coal resources evaluation, Ardley coal zone, to 400 m depth, Alberta plains area
Stratigraphic cross section O-O′

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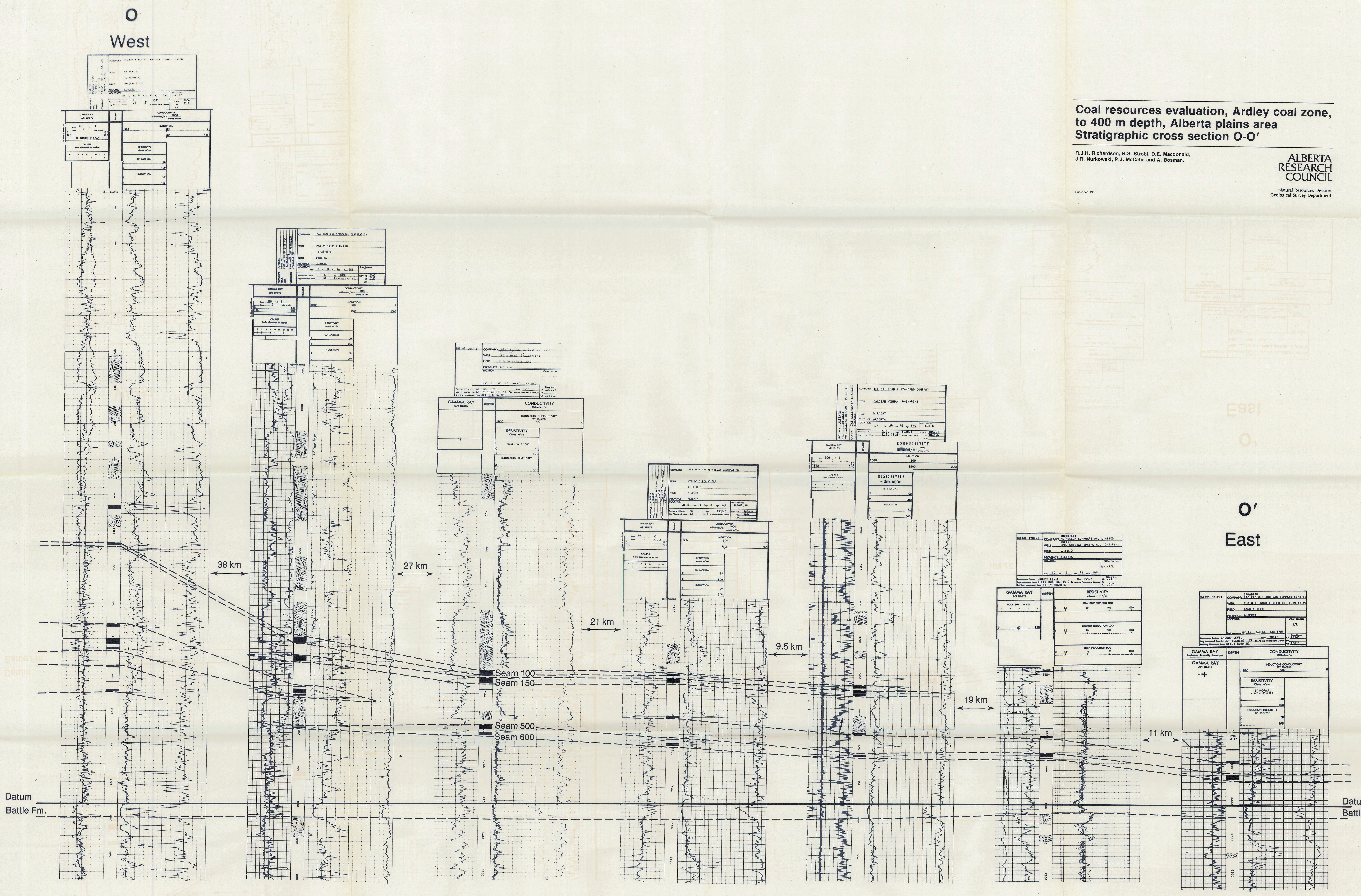

Coal resources evaluation, Ardley coal zone, to 400 m depth, Alberta plains area
Stratigraphic cross section N-N′

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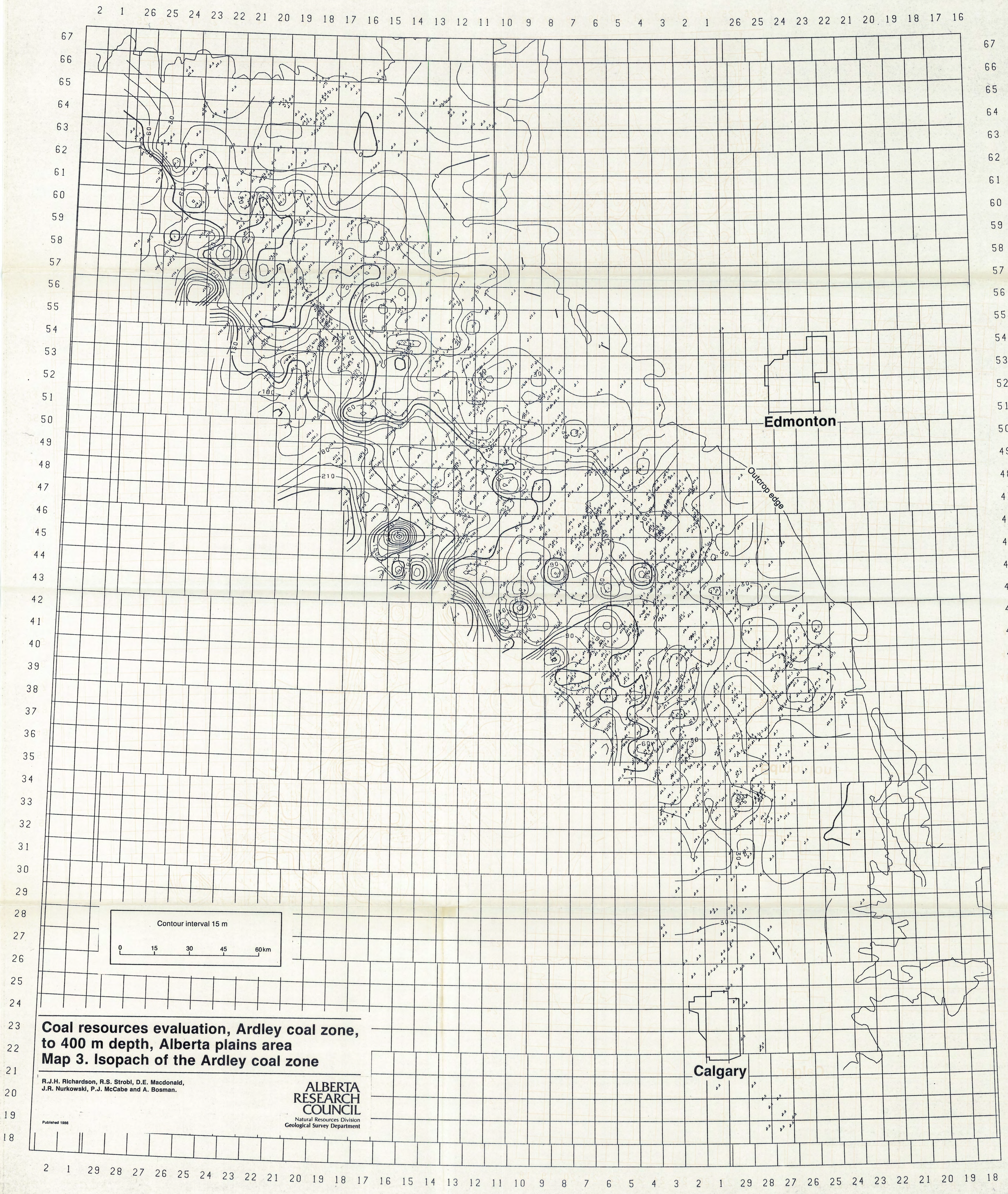

Coal resources evaluation, Ardley coal zone, to 400 m depth, Alberta plains area
Map 3. Isopach of the Ardley coal zone

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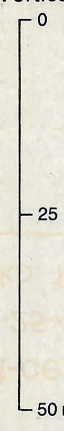
Vertical scale



West-central area

11-25-47-18W5

kb. 1223 m

Upper barren strata

Ardley coal zone (224 m)

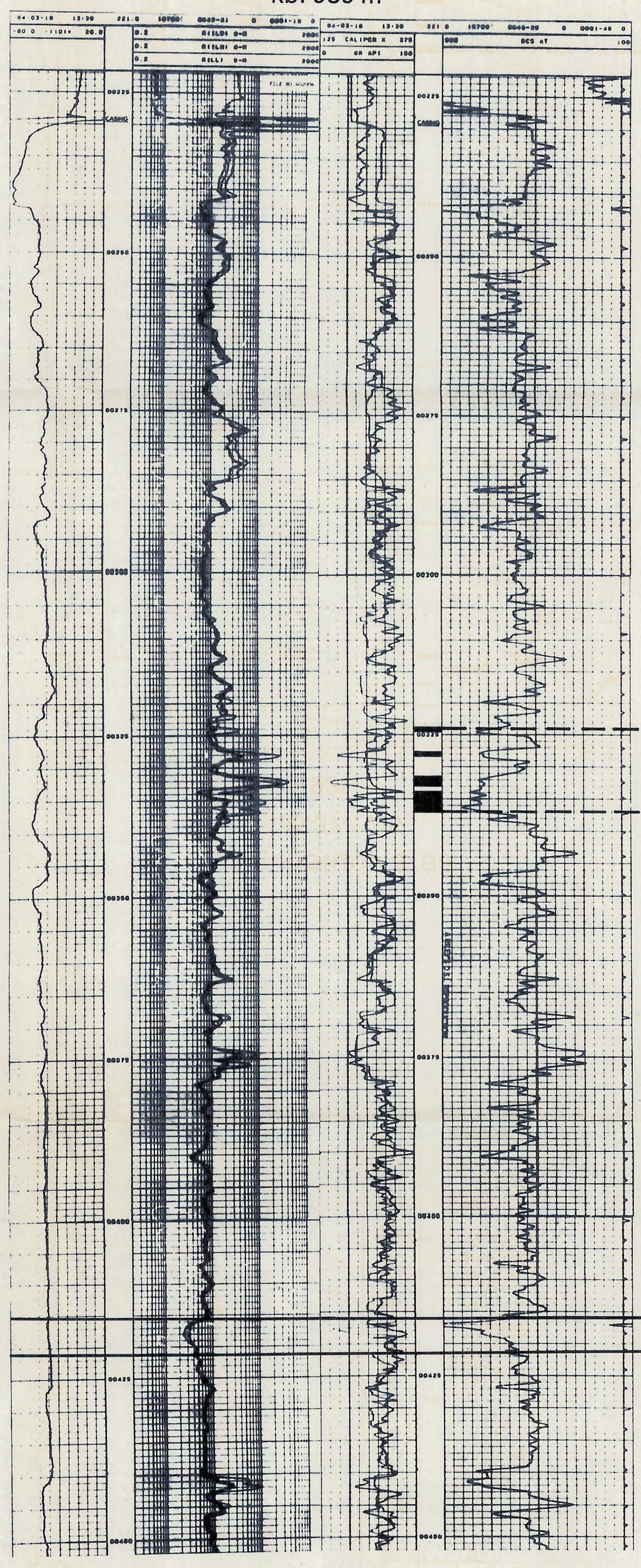
Barren zone (170 m)

Battle Formation

Alix substudy area

16-35-37-1W5

kb. 939 m



Upper barren strata

400
500
600
700

Ardley coal zone (13 m)

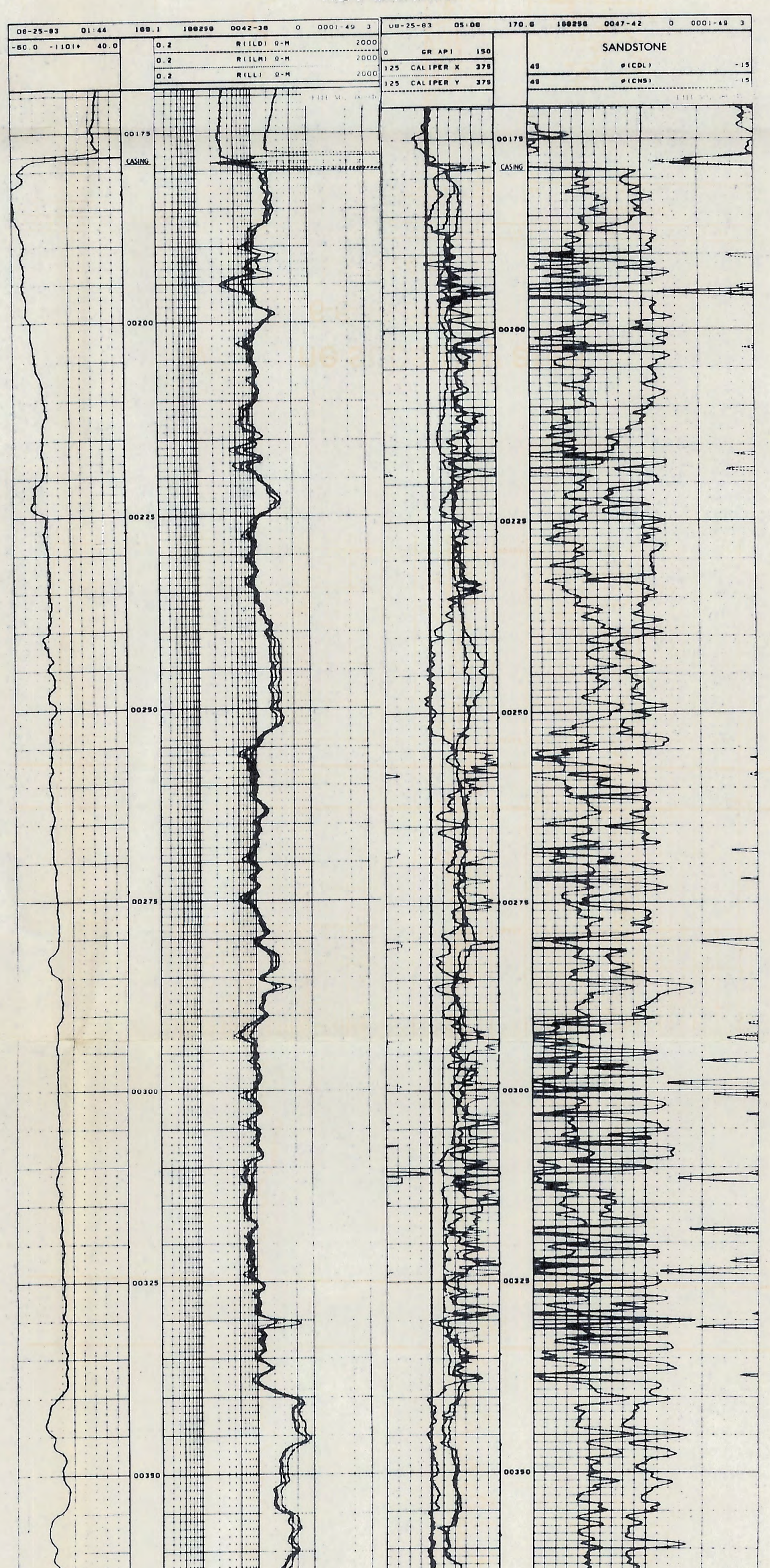
Barren zone (79 m)

Battle Formation

Medicine substudy area

6-6-46-6W5

kb. 914 m



Upper barren strata

100
150
200

Ardley coal zone (60 m)

400
500
600

Barren zone (58 m)

Battle Formation

*Seams do not correlate between substudy areas

Coal resources evaluation, Ardley coal zone, to 400 m depth, Alberta plains area Representative sections

R.J.H. Richardson, R.S. Strobl, D.E. Macdonald, J.R. Nurkowski, P.J. McCabe and A. Bosman.

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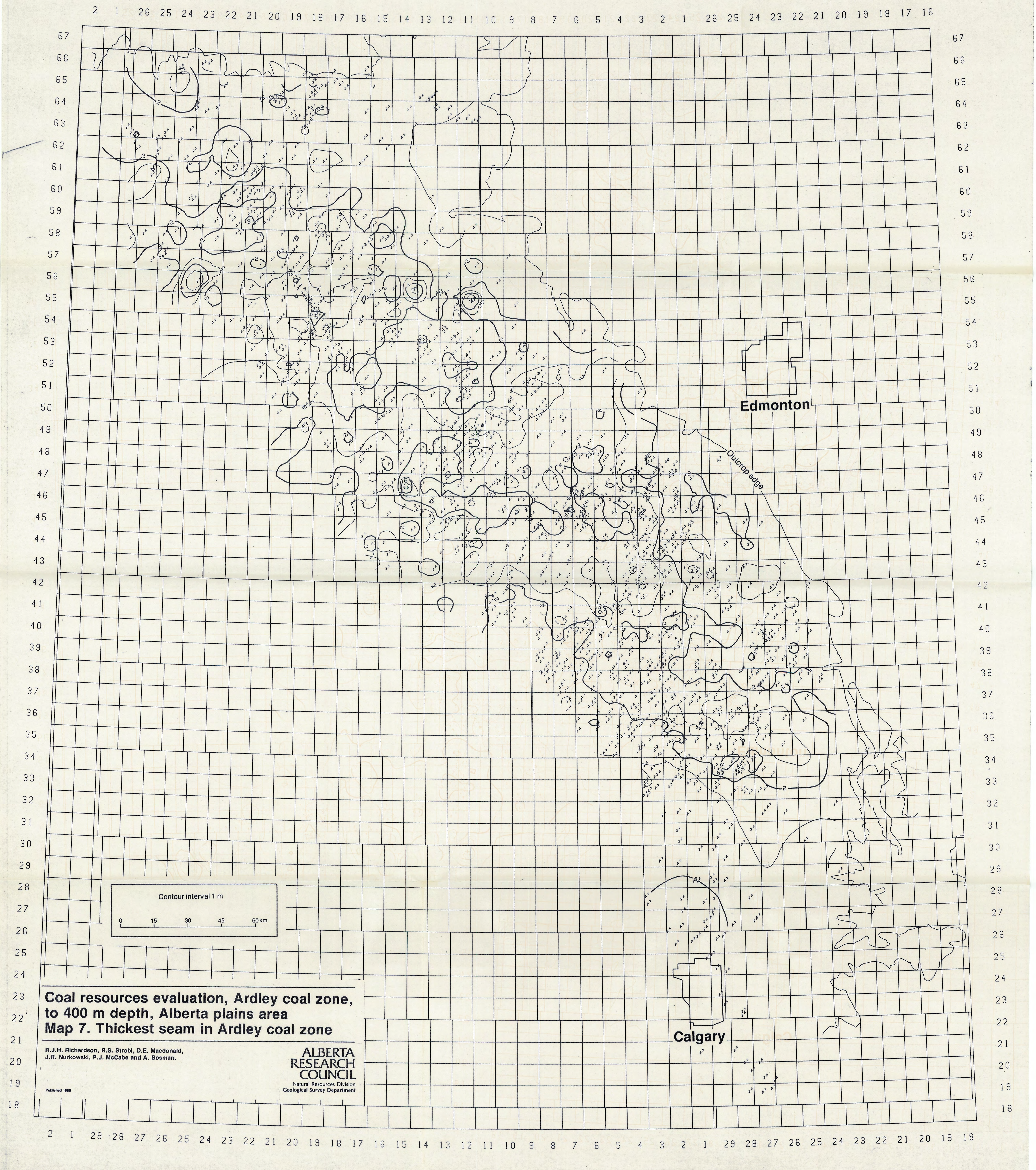

Coal resources evaluation, Ardley coal zone, to 400 m depth, Alberta plains area
Map 7. Thickest seam in Ardley coal zone

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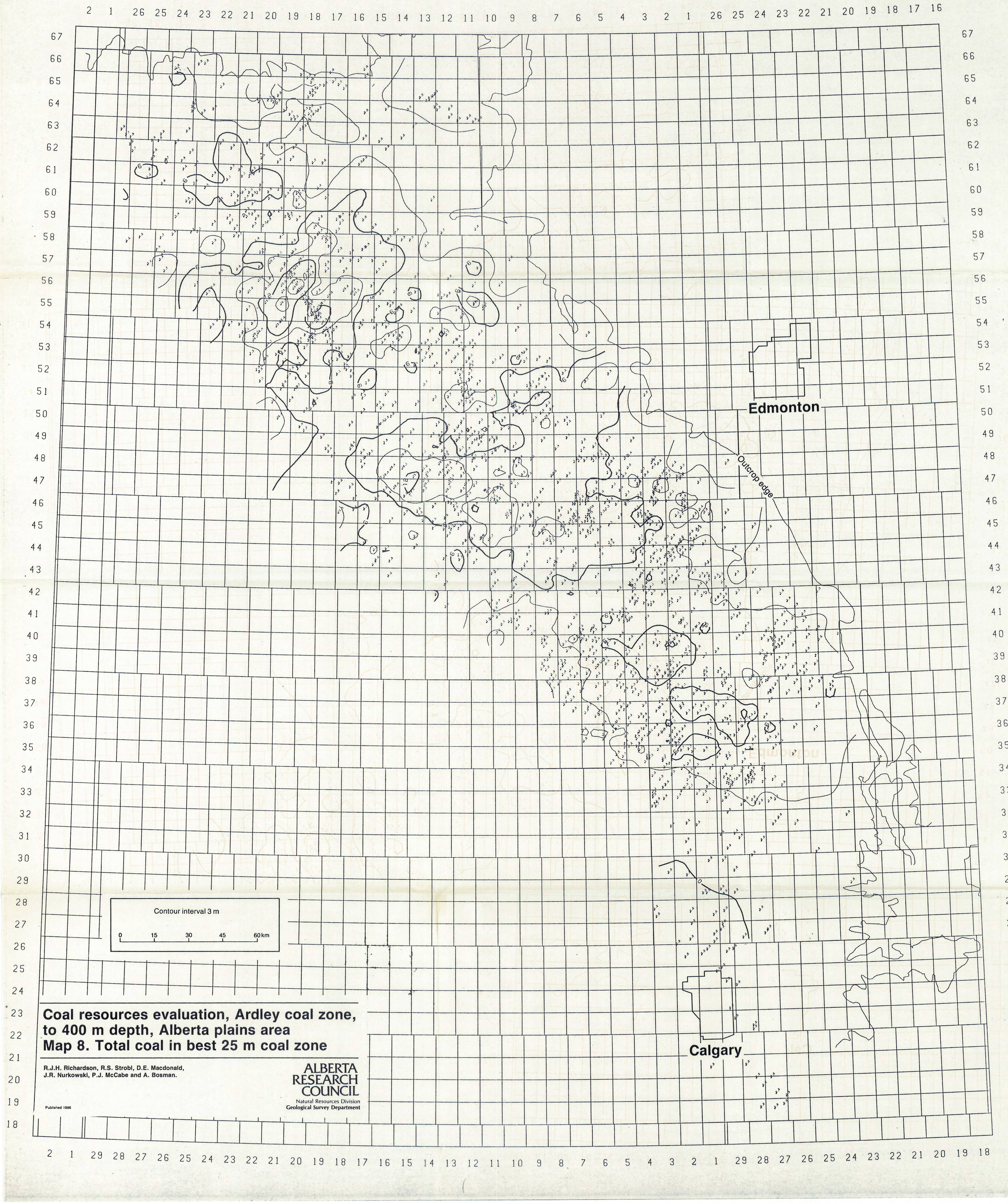

Coal resources evaluation, Ardley coal zone, to 400 m depth, Alberta plains area
Map 8. Total coal in best 25 m coal zone

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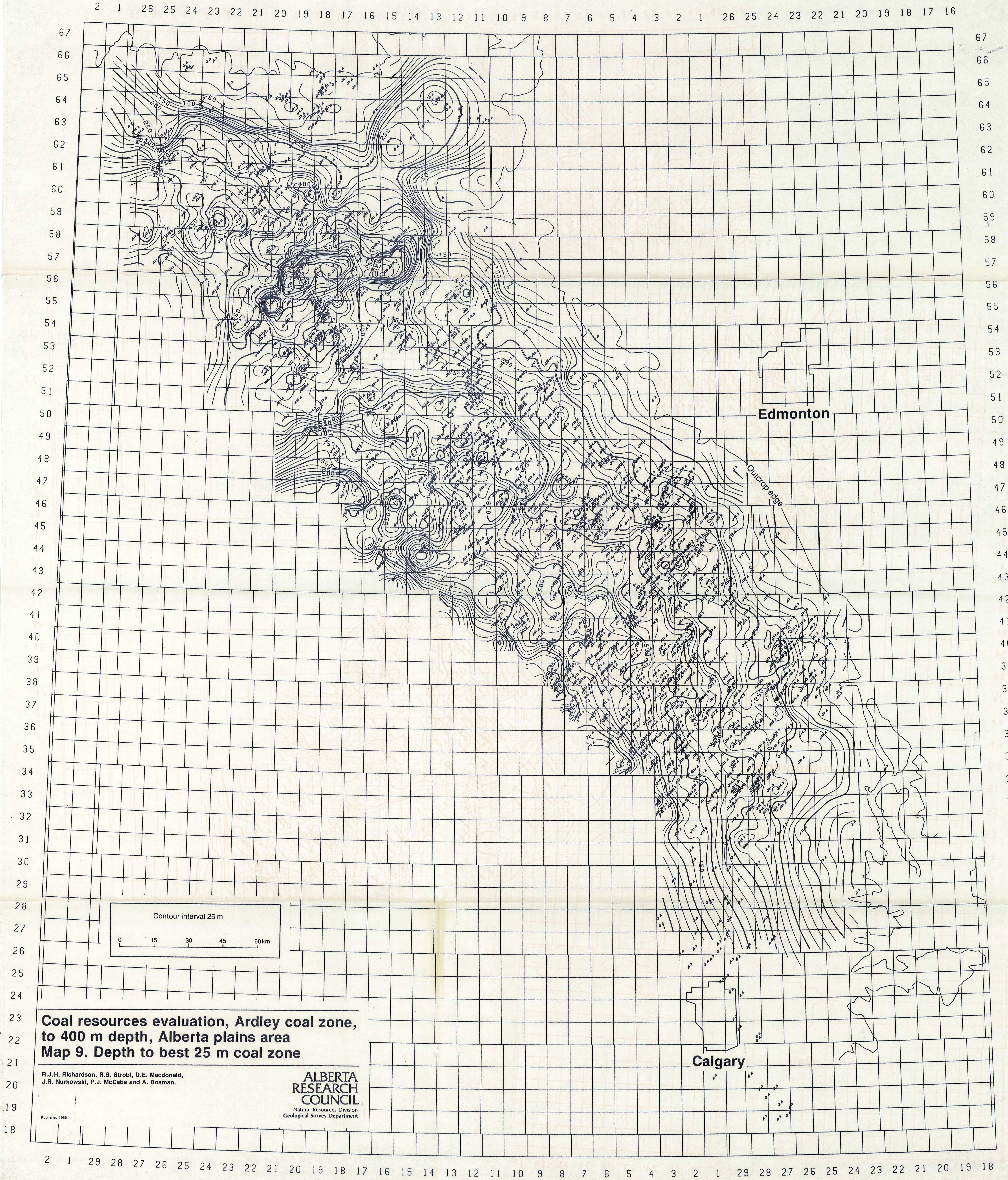

Coal resources evaluation, Ardley coal zone, to 400 m depth, Alberta plains area
Map 9. Depth to best 25 m coal zone

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