EUB/AGS Earth Sciences Report 2002-06

Coalbed Methane Potential of Upper Cretaceous-Tertiary Strata, Alberta Plains

Alberta Energy and Utilities Board
Alberta Geological Survey

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Alberta Geological Survey

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Abstract

This study was undertaken as a joint project of the Alberta Scientific Research Authority (ASRA) and the Alberta Geological Survey (AGS) to evaluate the coal resources and potential coalbed methane resources within Upper Cretaceous–Tertiary strata of the Plains region of Alberta. The uppermost Cretaceous–Lower Tertiary stratigraphic interval in the Alberta Plains can be divided into seven discrete groups and formations: the Lea Park Formation, Belly River Group Bearpaw Formation, Horseshoe Canyon Formation, Whitemud and Battle formations, Scollard Formation and Paskapoo Formation. The Lea Park, Bearpaw and Whitemud-Battle formations consist of relatively fine grained siliciclastic sediments deposited in a marginal marine or lacustrine environment. The Belly River Group and the Horseshoe Canyon, Scollard and Paskapoo formations consist of interbedded sandstone, siltstone and mudstone of terrestrial origin.

Within the Uppermost Cretaceous–Lower Tertiary formations, seven coal zones were identified and correlated. The McKay Coal Zone lies in the lowest part of the Belly River Group. The Taber Coal Zone occurs in the upper part of the Belly River Group (Foremost Fm.), below the finer grained uppermost Belly River Group (Oldman Fm.). The Lethbridge Coal Zone is located in the uppermost Belly River, below the Bearpaw Formation in the southern Plains. The lower Horseshoe Canyon Formation contains the Drumheller Coal Zone. The upper Horseshoe Canyon contains the Daly-Weaver Coal Zone in its lower part and the Carbon-Thompson Coal Zone near the top. The Ardley Coal Zone, one of the most prospective coal zones in central and northern Alberta, occurs within the upper Scollard Formation. There are also some minor coals in the lower Paskapoo Formation.

Maps presenting coal-zone distribution and thickness, net coal and depth to top of each coal zone were generated from the AGS CBM-coal database (EUB/AGS 2002), an extensive database including more than 7500 oil and gas wells, 32 000 coal picks, 1500 vitrinite reflectance results and 16 000 stratigraphic picks compiled under the current ASRA-AGS joint project. Cross-sections showing basin geometry, stratigraphy and coal-zone distribution were constructed to verify coal zone correlations (not included in this report).

Gas potential within the basin is poorly understood, with less than 20 wells having publicly available gas-concentration data for the Upper Cretaceous–Tertiary strata in the Plains. Utilizing existing public-domain data, and data collected under the current ASRA-AGS collaborative project, gas-concentration and resource distribution maps and summations were generated for each of the seven coal zones within the study area.

Potential gas resources for the Upper Cretaceous–Tertiary strata of the Alberta Plains total 186 trillion cubic feet (Tcf), ($5.27*10^{12}m^3$). This number includes all potential coal-gas resources contained within the seven coal zones evaluated, regardless of depth and net coal thickness. Shallow coals generally have lower gas potential than deeper coals, although biogenic methane may be a contributor to shallow coal-gas resources. Furthermore, net coal thicknesses of less than 1 m are unlikely candidates for production completions. Considering these two factors, resources were also calculated by omitting coals less than 1 m in net thickness and less than 200 m in depth to provide a ‘constrained’ gas-resource potential of 147 Tcf. ($4.16*10^{12}m^3$). No data are currently available to evaluate gas potential of interbedded clastic rocks associated with the coal zones.

The majority of the potential gas resources are held within the Horseshoe Canyon Formation (40%); however, only 22% of the potential gas resources occur within the Drumheller Coal Zone. The Ardley Coal Zone of the Scollard Formation contains 34% of the total potential gas resources, and the McKay Coal Zone of the Belly River Group contains 13% of the total potential gas resources. Maps of gas-

resource potential indicate numerous areas of potential interest for coalbed methane (CBM) exploration within the Alberta Plains.

1 Introduction

The Canadian Gas Potential Committee estimated that the Western Canada Sedimentary Basin contains 142 trillion cubic feet (Tcf), ($4.02*10^{12}m^3$) of gas reserves and potential resources (Woronuk, 2001). Alberta's remaining gas resources are estimated to be in the order of 98 Tcf ($2.78*10^{12}m^3$) (Alberta Department of Energy, 2002), of which 42 Tcf ($1.19*10^{12}m^3$) are established reserves (AEUB, 2002) Other estimates of current gas potential reserves within Alberta suggest up to 183 Tcf ($5.18*10^{12}m^3$), of which 45 Tcf ($1.27*10^{12}m^3$) are established reserves and 138 Tcf ($3.91*10^{12}m^3$) are classified as 'undiscovered resources.' Production of gas in Alberta was 5.2 Tcf ($1.47*10^{11}m^3$) in 2001 and is expected to increase to between 8 and 9 Tcf (2.27-$2.55*10^{11}m^3$) by 2010. Although resource estimates vary somewhat, the data suggest Alberta should have sufficient gas supply for the next 18 to 25 years.

Government and industry are starting to evaluate unconventional gas sources for future supply. A potential resource showing great promise is coalbed methane (CBM). Coal has the potential to generate and retain significant quantities of methane, and this gas may be produced if suitable geological and hydrogeological conditions are met. The CBM industry in the United States has grown significantly over the past 20 years, to the point where CBM accounts for approximately 7% of total gas produced (1300 bcf of CBM produced in 2001).

Drawing on the earlier American successes in CBM production, Alberta experienced limited exploration activity in the late 1980s into the early 1990s, resulting in approximately 60 wells being drilled and tested for CBM. Exploration stagnated soon thereafter, in part due to unencouraging initial results, and to the onset of low gas prices.

Predictions of supply shortages and increasing gas prices have again sparked interest in CBM potential. There has been a resurgence in exploration over the past 2 to 3 years in Alberta. Furthermore, the possibility of utilizing coal beds to sequester greenhouse gases while simultaneously enhancing CBM production has drawn the interest of government and industry alike.

Alberta has substantial coal resources in the Plains and Foothills. The potential gas held within these coal deposits has been estimated to range from 100 Tcf ($2.83*10^{12}m^3$) to more than 550 Tcf ($1.56*10^{13}m^3$) (Woronuk, 2001). The wide range in estimates of gas potential stems from the sparse data available on CBM content; even less is known about coal-reservoir characteristics and producibility of the potential resource.

The Alberta Science and Research Authority (ASRA), the Alberta Research Council (ARC) and the Alberta Geological Survey (AGS) have initiated studies to investigate coalbed methane potential within Alberta. This report focuses on defining coal and CBM resources for the Upper Cretaceous to Tertiary strata of the Alberta Plains (Figure 1). Coal distribution within the Plains was mapped, and resources were determined for the seven major Upper Cretaceous–Tertiary coal zones. Coalbed methane potential was not evaluated for the thick Lower Cretaceous (Mannville Gp.) coals which underlie much of the current study area. Utilizing public-domain data, and data collected in part to support the ASRA-ARC greenhouse-gas sequestration and enhanced CBM project, gas-resource potential and distribution were determined for these coal zones within the Alberta Plains.

2 Coalbed Methane Overview

2.1 Coal and Coalbed Methane Potential

Coal is a rock derived primarily from plant material that underwent burial and compaction, which

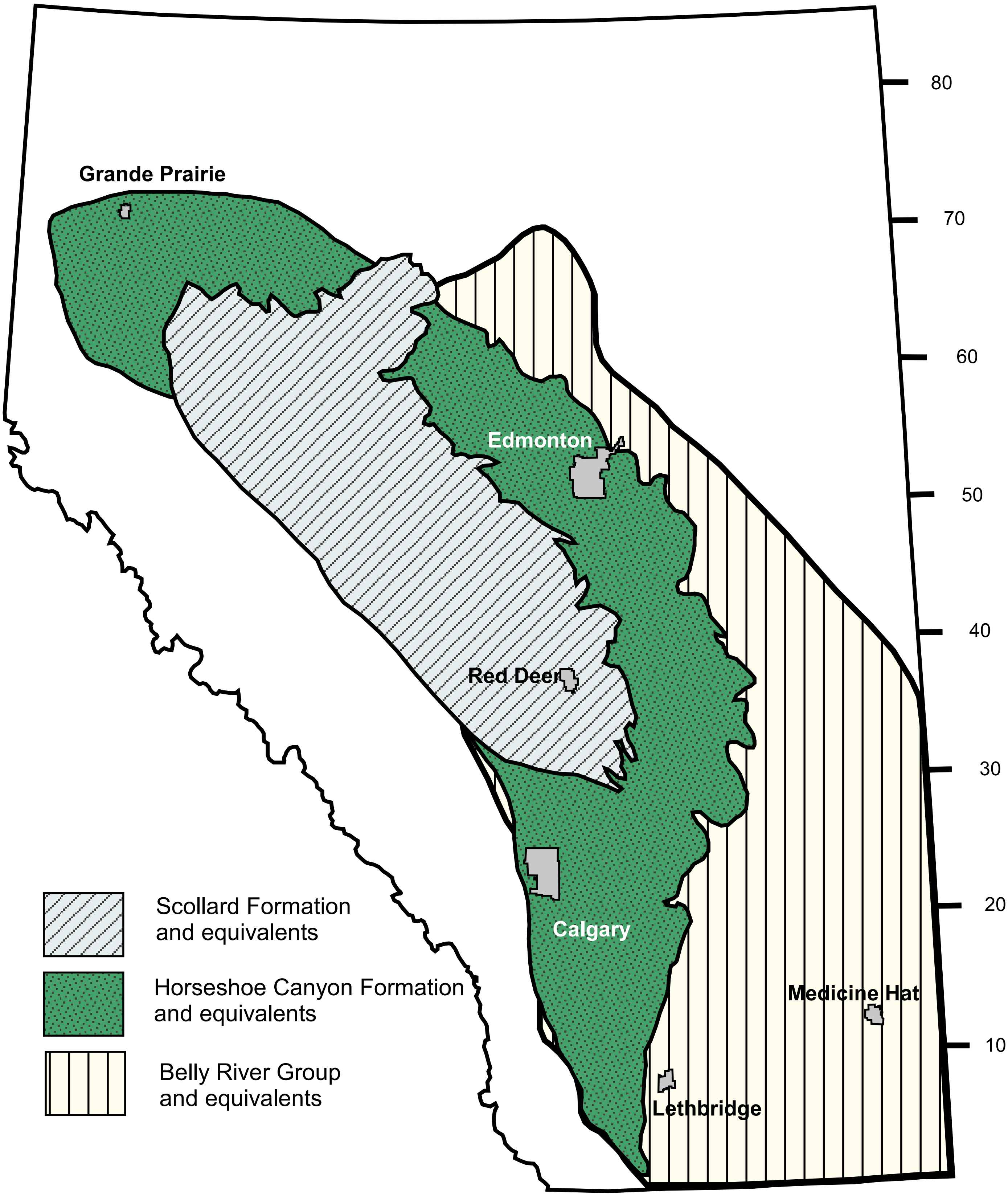


Figure 1. Distribution of Upper Cretaceous-Tertiary coal-bearing strata, Alberta Plains.

resulted in progressive physical and chemical changes within the original plant material. With increasing depth of burial, the plant material undergoes coalification, progressively losing moisture and volatile matter, while increasing its heating value, carbon content and reflectance properties (Levine, 1993). Generation of methane gas is also a result of coalification. Coal rank refers to the degree of physical and chemical alteration the plant matter has undergone. Coal-rank classification identifies the general properties of a given coal, and also indicates the changes and maturation stages that coal has undergone (Figure 2, next page).

As plant matter (peat) undergoes progressive burial and compaction, it passes through the stages of peatification and dehydration, where the plant material undergoes humification, gelification and loss of volatiles from the organic matrix, as the material begins to transform into coal. These stages are represented by peat and lignite on the rank chart. With ongoing coalification through the subbituminous to bituminous ranks, coal becomes progressively enriched in carbon and continues to expel volatile matter (water, CO_2, CH_4). Generation of methane and hydrocarbon is a result of thermal maturation in coals, and is initiated at a rank of high-volatile bituminous C (reflectance >0.6%), with amounts generated increasing significantly throughout the medium- to low-volatile bituminous ranks (Figure 3). Coals may produce anywhere from 100 to 300 cc gas per g coal throughout the coalification process.

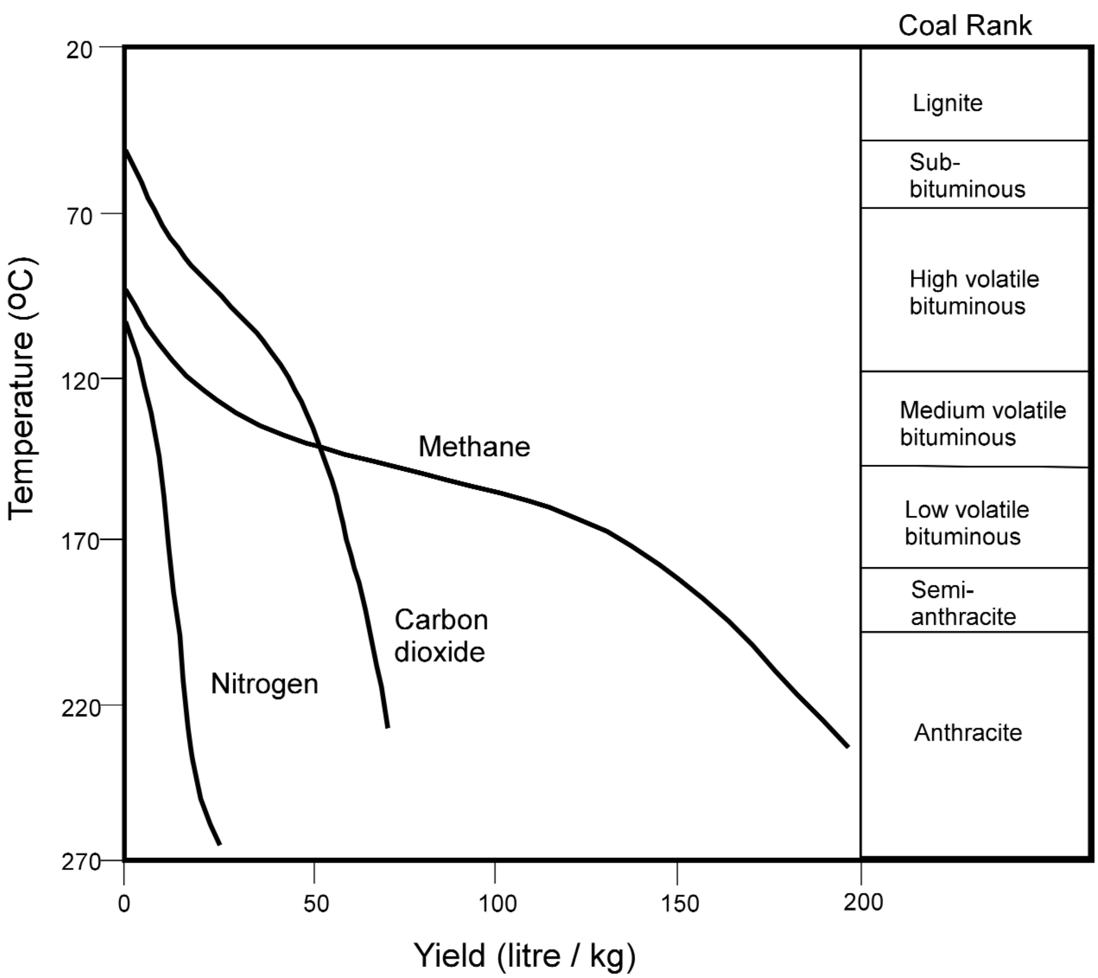


Figure 3. Gas generation potential as a function of coal rank (modified from Hunt, 1991).

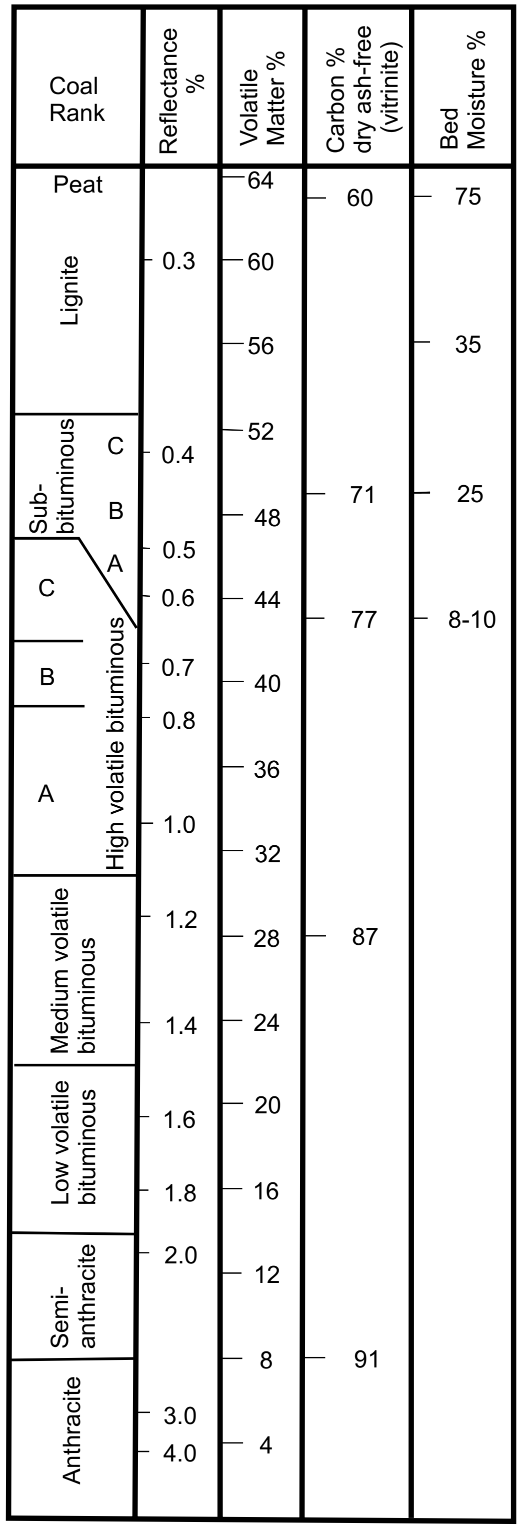


Figure 2. Coal classification and characteristics (modified from Stach et al., 1982).

Biogenic gas may be produced in the early stages of peat through to lignite (Rice, 1993), and be retained in the coal. Late-stage biogenic gas may occur within coals as a secondary product associated with active groundwater systems, that initially allow aerobic-oxidation microbial processes to occur, the by-products of which provide energy supplies for anaerobic (methanogenic) bacteria (Rice, 1993).

Gas is stored in coal as an adsorbed component on or within the coal matrix, and as a free gas within the micropore structure or cleats within a coal bed. The capacity of coal to adsorb gas is dependent on pressure, temperature and coal rank. Increasing reservoir temperature restricts adsorption capacity, whereas increasing pressure increases adsorptive capacity (Bustin, 2001). Medium-volatile bituminous coals may have generated more gas than they actually have the capacity to store.

2.2 Gas Content and Capacity

In general, gas content is typically determined by cutting a core of the coal, quickly retrieving it to surface, and placing intervals of the core in sealed canisters. Gas released from the core is determined by measuring cumulative gas bled from the canister over controlled time intervals. Corrections are made for gas lost prior to sealing the sample, pressure-temperature variations and residual gas (Gas Research Institute, 1997).

Maximum gas capacity of a coal sample is obtained from adsorption isotherm analysis. A coal sample is crushed, brought to equilibrium moisture, and placed in a pressure vessel held to reservoir temperature. Gas is introduced into the vessel at specific pressure intervals. The amount of gas the sample adsorbs upon equilibrium is determined. Adsorbed gas volumes with increasing pressure follow Langmuir equations of gas adsorption (Bustin, 2001); from these, Langmuir volume (maximum saturation) and Langmuir pressure (pressure at half the maximum adsorption capacity) can be derived. Langmuir pressure and volume can be used to calculate gas concentrations of similar coals occurring at different depths if the depth-pressure relationship is known for the area of investigation.

The adsorption isotherm provides maximum gas capacity. By comparing maximum gas capacity to results obtained from the desorption analysis, the gas saturation of a sample can be determined.

The adsorption isotherm plot (Figure 4) provides an indication of reservoir potential. Gas concentration derived from desorption analysis is plotted against reservoir pressure. A saturated coal will fall on the isotherm curve, whereas an undersaturated sample will plot below the curve. Reservoir pressure increases adsorptive capacity of the coal, so that, in order for a coal to release the adsorbed gas, pressure must be reduced to the point where the sample will fall on the isotherm curve. Pressure is commonly reduced in CBM wells by pumping water from the seam.

In Alberta, public domain CBM data is available for approximately 60 wells (Dawson et al., 2000), although many more have been tested (data is not available or still held confidential. Sixteen of these wells are from the Foothills. Of the wells from the Plains, the majority target the coals of the Lower Cretaceous Mannville Group. Less than 20 wells are available within the public domain that report adequate data on Upper Cretaceous–Tertiary strata, all from the Ardley Coal Zone (Figure 5). Data reported from these wells, and from recent testing under the collaborative ASRA-AGS project, were used in the current resource evaluation.

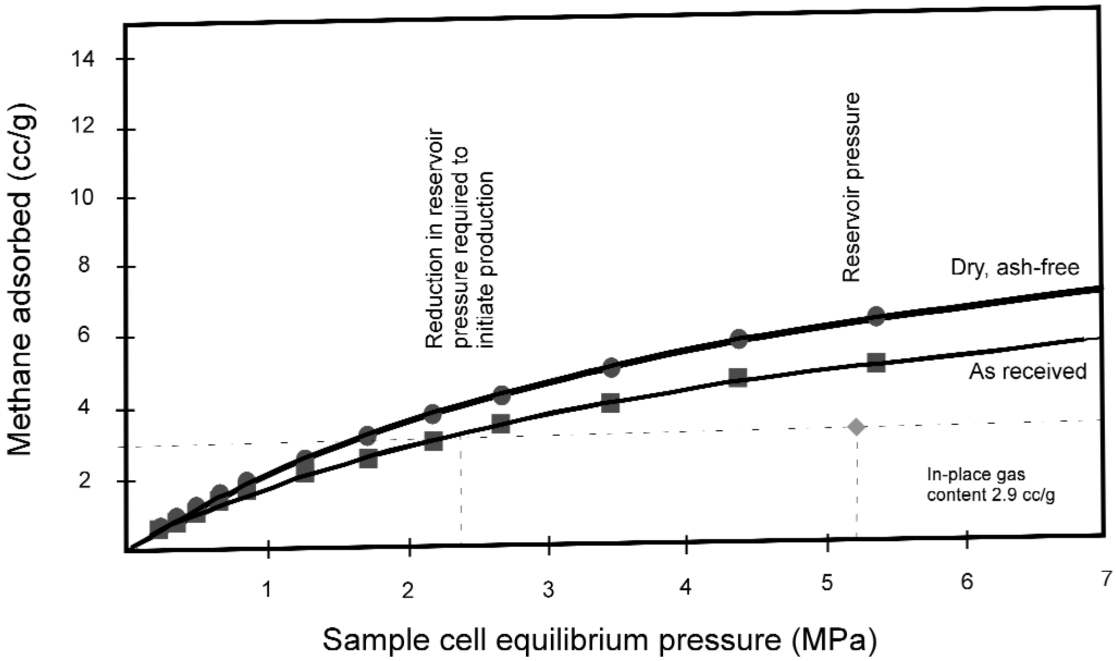


Figure 4. Example of adsorption isotherm plot.

3 Geology of Upper Cretaceous–Tertiary Coal-Bearing Strata of the Alberta Plains

3.1 Introduction

The Alberta Plains covers a geographic area of approximately 250 000 km^2 (Figure 6). The Plains area is included within the larger Western Canadian Sedimentary Basin, which contains a thick succession of westerly-dipping marine and nonmarine sedimentary rocks.

Upper Cretaceous sedimentary rocks within the Alberta Plains represent a foreland-basin fill sequence derived from clastic sedimentation into the Western Canada Sedimentary Basin, as a result of uplift in the Cordillera to the west (Mossop and Shetsen, 1994). Sedimentation from the west continued throughout the Tertiary, accompanied by an eastward migration of the basin's western margin. Distinct Upper Jurassic and Lower Cretaceous sedimentary wedges are present in the basin, as well as an Upper Cretaceous and a Tertiary wedge, the latter containing the coal and coalbed methane resources evaluated in this report. Eastward from the present Rocky Mountain front, the Upper Cretaceous succession forms a progressively thinning wedge of sedimentary rocks that extend 1600 to 2500 km eastward and decreases in thickness from a maximum of about 5000 m near the western extremity to only a few metres at the present erosional edge.

3.2 Stratigraphic Nomenclature

The geology of the coal-bearing succession, encompassing the Belly River Group (uppermost Cretaceous) through the Scollard Formation (Lower Tertiary), in the Plains region of Alberta is examined in a regional context, in order to establish the framework for evaluation of CBM potential. Figure 7 presents the stratigraphic nomenclature used in the present study.

In the central Alberta Plains, the late Campanian to early Paleocene sequence is divided into the Lea Park Formation, Belly River Group, Bearpaw Formation and Edmonton Group. In the northern Plains,

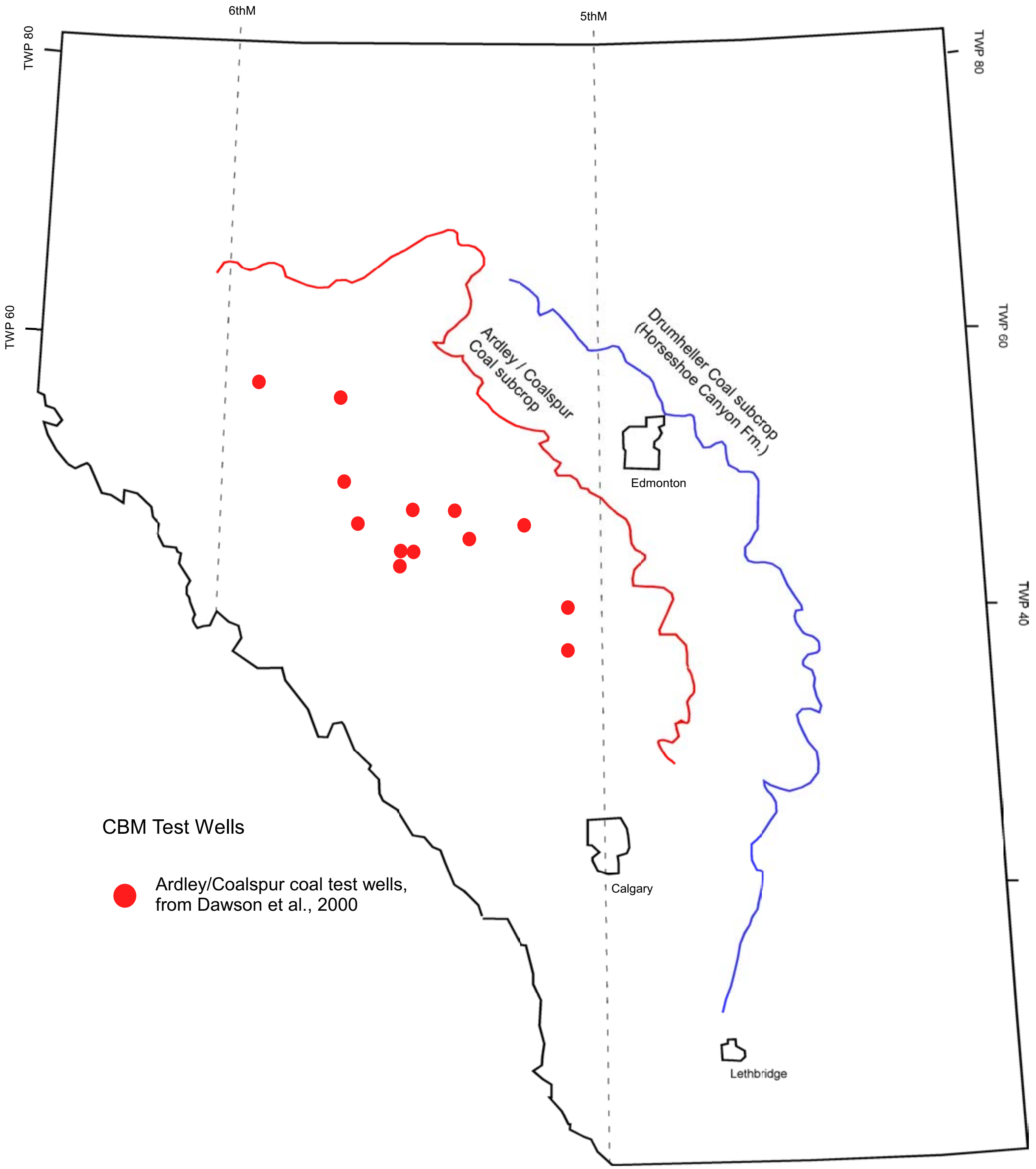


Figure 5. Distribution of coalbed methane test wells in Upper Cretaceous-Tertiary strata, Alberta Plains.

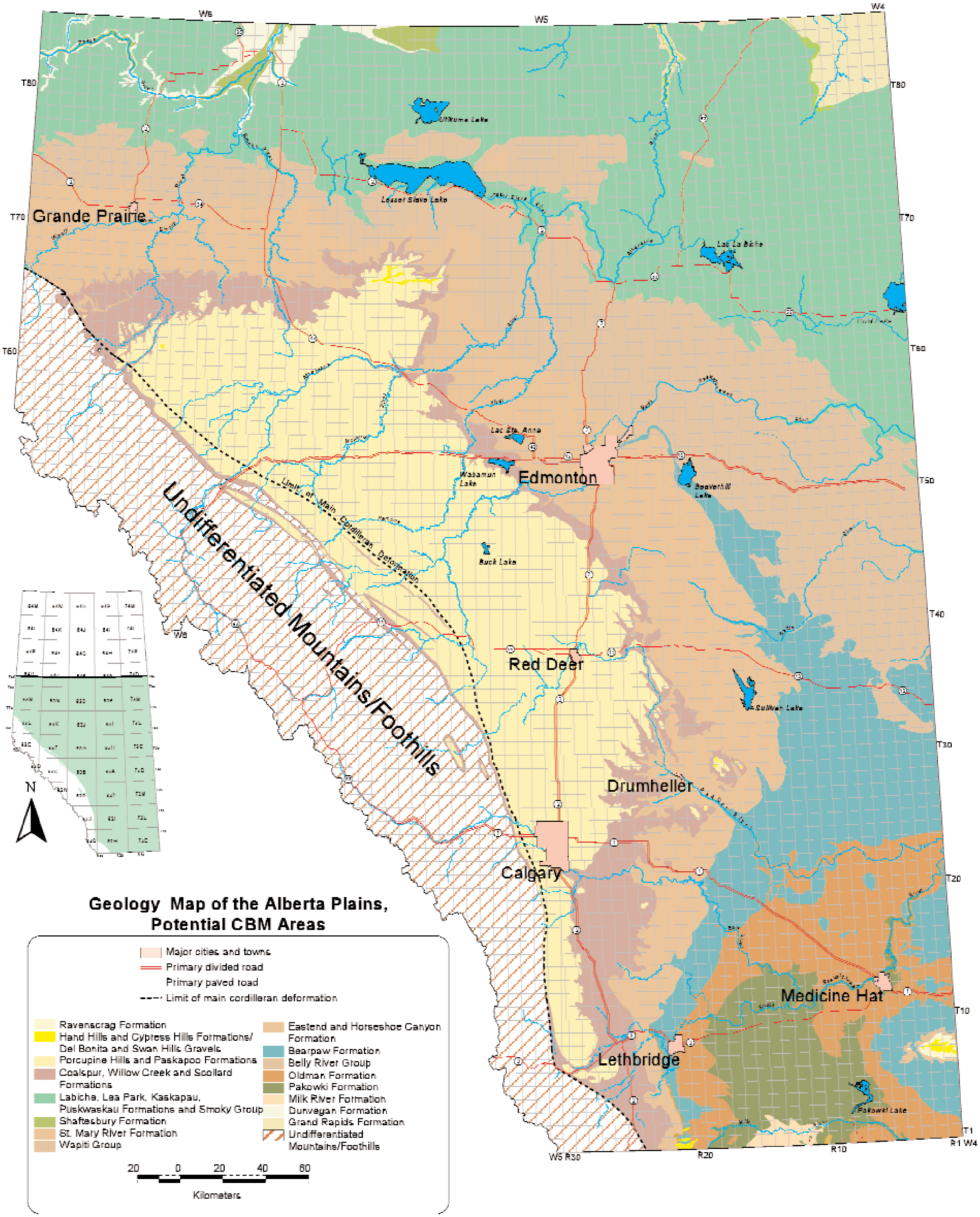


Figure 6. Geology of the Alberta Plains coalbed methane study area (modified from EUB/AGS Map 236).

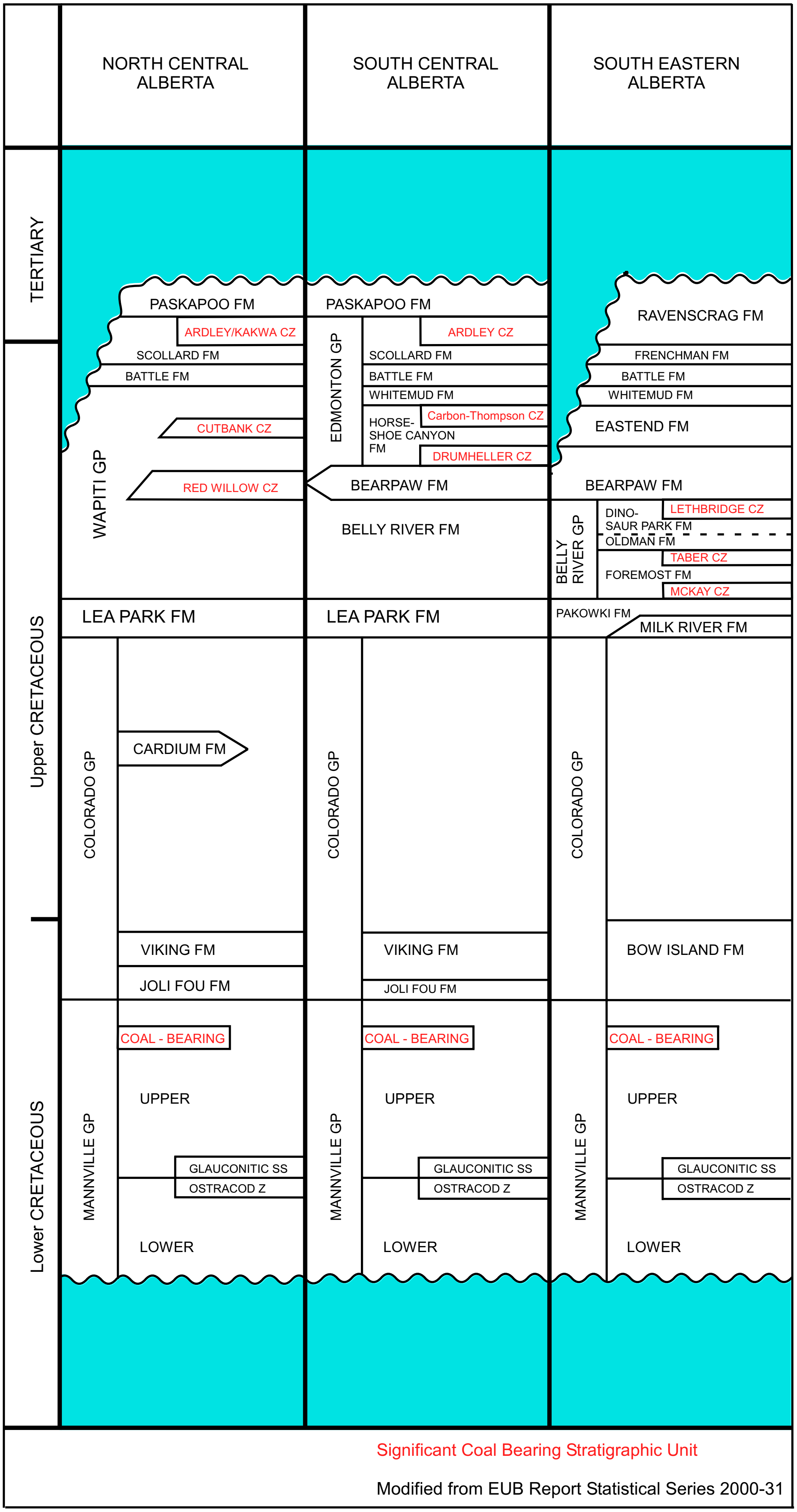


Figure 7. Stratigraphic correlation chart of the Alberta Plains.

the Bearpaw Formation is absent; the interval encompassing the Belly River and Edmonton groups is undifferentiated and identified as the Wapiti Group (Dawson et al., 1994). The Belly River Group in the central Plains is divided into the Foremost Formation and the overlying Oldman Formation (and the Dinosaur Park Formation; Hamblin and Abrahamson, 1996) in the southern Plains and is equivalent to the lower part of the Wapiti Group in the northern Plains. In the central Plains, the Edmonton Group is subdivided into the Horseshoe Canyon, Whitemud, Battle and Scollard formations. The Horseshoe Canyon Formation in the central Plains is equivalent to the upper part of the Wapiti Formation in the northwestern Plains.

Strata of the Alberta Plains dip gently westward towards the Foothills. Stratigraphic trends and coal-zone and coal-seam distribution were determined from constructing 9 cross-sections generated by sectioning a geological model of the Alberta Plains. The new sections were used in conjunction with existing cross-sections of Rottenfusser et al., 1991. The model was generated from the AGS-CBM database (EUB/AGS 2002), using modelling software from ViewLog® Systems Ltd., with wells projected onto sections in a grid-centred, 1 km x 1 km modelling grid.

3.3 Stratigraphic Descriptions

3.3.1 Colorado Group

The top of the Colorado Group was used as the stratigraphic datum for constructing the Upper Cretaceous–Tertiary model for the Alberta Plains coalbed methane study. The Colorado is easily recognizable in the Plains by a very high gamma response at the base of the Milk River Formation coarsening-upward sequence. The uppermost Colorado Group consists predominantly of marine shale.

3.3.2 Milk River Formation

The lower boundary of the Milk River Formation disconformably overlies the Colorado Group. In the Alberta Plains, the Milk River Formation has a specific signature on the gamma-ray geophysical log trace, depicting a smooth coarsening-upward sequence. The Milk River Formation is disconformably overlain by marine shale of the Lea Park Formation. The top of Milk River Formation includes a strong shift from the lower conductivity values characteristic of the Milk River Formation to the high conductivity values of the Lea Park Formation. This abrupt change is informally named the 'Milk River Shoulder' and occurs basin wide. In southeastern and eastern Alberta, the Milk River Formation changes laterally into the silt-shale succession of the Pakowki Formation.

3.3.3 Lea Park Formation

The Lea Park Formation is the lowest stratigraphic interval within the Upper Cretaceous succession. Marine sedimentary rocks in the formation are predominantly fine grained, consisting of dark grey to brown mudstone and siltstone (Rosenthal et al., 1984) that were deposited during a marine transgression in early late Campanian time. The formation can be divided into lower and upper parts by the 'Milk River Shoulder' marker in the southern Alberta Plains. The lower Lea Park Formation is the coarser-grained equivalent equivalent of the Milk River Formation. The upper Lea Park is the equivalent of the Pakowki Formation, consisting of finer grained sediments that reflect a rapid marine transgression onto the underlying Milk River succession. The Lea Park Formation thins toward the west and becomes thicker toward the east. The top of this interval grades into the coarser clastic rocks of the Belly River Formation.

3.3.4 Belly River Group

The Belly River Group is an eastward-thinning sedimentary wedge, composed of clay, silt and sand deposited in a predominantly nonmarine environment. This succession occurs stratigraphically between the overlying Bearpaw Formation and the underlying upper Lea Park Formation.

In this report, the basal contact of the Belly River Formation is placed at the base of the lowest prominent and persistent sandstone (‘Basal Belly River Sand’) below the lowest carbonaceous interval (McKay Coal Zone). When the basal sandstone is not present, the contact is placed at the top of the first marine shale below the lowest carbonaceous zone.

The Belly River Group has two distinctive lithological units. The lower unit (Foremost Formation) represents a succession of amalgamated fluvial channels, and contains two coal zones. The upper unit (Oldman Formation) consists of fine-grained floodplain and lacustrine deposits containing one coal zone near the top. The contact between the upper and lower units is distinguishable on geophysical logs by a change in grain size of the two units; this contact also corresponds to the top of the Comray sandstone. Recent studies (Eberth and Hamblin, 1993; Hamblin and Abrahamson, 1996) considered the base of the unit as the base of the Oldman Formation. Hamblin and Abrahamson (1996) suggested a more detailed subdivision of the Belly River Group by including the Dinosaur Park Formation in the uppermost part of the succession, above the Oldman Formation. This refinement is generally applicable only to the southern areas of the Plains, and was not used in this study in order to maintain consistency with Alberta Energy and Utilities Board (EUB) stratigraphic nomenclature, which was followed for most of the historical data compiled within the AGS CBM-coal database (EUB/AGS 2002).

3.3.5 Bearpaw Formation

During latest Campanian time, transgression of the Bearpaw Sea commenced in Saskatchewan and southeastern Alberta. The marine transition resulted in the deposition of fine-grained marine strata on the underlying coarse-grained strata. Widespread and rapid transgression followed throughout southern and central Alberta (McLean, 1971). Bearpaw strata consist predominantly of laminated shale and siltstone with some sandstone beds and lenses of kaolinitic claystone, deposited in nearshore or marginal marine environments (Habib, 1981; Macdonald et al., 1987).

The presence of the Bearpaw Formation helps to differentiate the younger Horseshoe Canyon Formation from the older Belly River Group in southern Alberta. Marine shale and silt of the Bearpaw Formation are not present in the central and northern Alberta Plains, making differentiation of the Horseshoe Canyon Formation and Belly River Group difficult. Across the southern Plains, the base of the Bearpaw Formation is abrupt and lies just above the Lethbridge Coal Zone. Three regionally traceable flooding surfaces were recognized in the study area. The first flooding surface caps the Belly River Group. The second separates the lower Bearpaw Formation from the underlying ‘Belly River–Bearpaw transitional zone.’ The third, the maximum flooding surface, divides the Bearpaw Formation into lower and upper parts. The maximum flooding surface can be traced to the Athabasca River and west of Edmonton (Catuneanu, 2002) and can be used as a marker for differentiating the Belly River Group from the Horseshoe Canyon Formation.

A distinct coarsening upward unit (‘CU1’ of Langenberg et al., 2001) was recognized by McCabe et al. (1989) as a useful marker across southern Alberta. It represents shoreface sandstone, overlapping in a southeasterly trend, indicative of the direction of terrestrial progradation. This unit, which outcrops near the town of Dorothy, represents the second Bearpaw transgressive event within the Alberta Plains (Pana et al., 2001). This coarsening upward unit serves to differentiate coals of the lower and upper Drumheller coal zones (the Drumheller from the 'lower tongue' coal zones of McCabe et al., 1989) within the Horseshoe Canyon–Bearpaw Formation interfingering transition zone.

3.3.6 Horseshoe Canyon Formation

During early Maastrichtian time, the Bearpaw Sea retreated from the Alberta Plains. The marine regression was accompanied by Horseshoe Canyon Formation clastic sediments prograding into the basin in an east-southeasterly direction (Nadon, 1988). The Horseshoe Canyon Formation type section at East Coulee consists of a 250 m thick succession of nonmarine sandstone, siltstone, shale and mudstone that contains coal, coaly shale, ironstone concretions and isolated bentonite beds (Gibson, 1977). Up to ten potentially economic coal seams have been identified in the Horseshoe Canyon Formation. The presence of several coarsening-upward cycles and marine transgressive pulses makes recognition of the Horseshoe Canyon–Bearpaw formation contact difficult in the subsurface. In this study, the transition from the Bearpaw marine strata to the Horseshoe Canyon continental strata was recognized by the major regressive sequence on the maximum flooding surface immediately underlying the lower Drumheller Coal Zone.

Beyond the zero edge of the Bearpaw Formation in the northwestern Plains, strata equivalent to the Horseshoe Canyon are included as part of the Wapiti Group. Interbedded, medium to light grey, fine-grained sandstone and dark grey mudstone with carbonaceous horizons are typical rock types in the upper Wapiti Formation (Dawson et al., 1994).

In central Alberta, the thick Drumheller Coal Zone was developed in the lower Horseshoe Canyon Formation. The Red Willow Coal Zone in the Wapiti area is considered equivalent to the Drumheller Coal Zone. The lower part of the Horseshoe Canyon Formation includes characteristics of a deltaic environment, which includes alluvial, lacustrine, lagoonal, swamp and beach facies (Rahmani, 1988). Toward the top of the Horseshoe Canyon Formation, clastic sediments were deposited in a fluvial environment, the inland extension of the aforementioned deltaic environment. The top of the Horseshoe Canyon occurs just above the Carbon-Thompson Coal Zone.

3.3.7 Whitemud and Battle Formations

The white, kaolinitic, sandy silt of the Whitemud Formation and the overlying fine-grained silt and shale of the Battle Formation occur between the Horseshoe Canyon Formation and the Scollard Formation. These distinct strata have been mapped over much of southern Alberta and Saskatchewan (Irish and Havard, 1968). The Battle Formation includes both lacustrine and paleosol facies throughout the Plains (Binda, 1991). Several tuffaceous beds (e.g., Kneehills Tuff, occur throughout the Battle Formation. In the subsurface, the Battle Formation has a distinctive, low-resistivity log response; however, tuffaceous beds produce a high gamma-ray log response. In northwestern Alberta, the Whitemud and Battle strata are difficult to recognize owing to regional facies variation and depositional erosion (Baofang and Dawson, 1988). However, Dawson et al. (1994) indicated that Battle Formation strata may attain a thickness in excess of 40 m.

3.3.8 Scollard Formation

The Scollard Formation disconformably overlies the Battle Formation and consists of thick, grey- to buff-coloured sandstone and siltstone interbedded with thin, olive green mudstone beds and coal.

Two units are recognized in the Scollard Formation. The lower (barren interval) and upper (coal-bearing) members are separated by the basin-wide Cretaceous-Tertiary (KT) boundary (Sweet and Braman, 1992). The KT boundary is located near the base of the Ardley Coal Zone. Both upper and lower members of the Scollard Formation thicken from east to west.

The lower Scollard is generally barren of coal and comprises primarily thin, fining-upward cycles of fine-grained, buff-coloured sandstone overlain by medium to dark grey mudstone and greenish grey siltstone (Dawson et al., 1994). The upper Scollard contains the thick, widespread, Ardley Coal Zone. Based on palynology, the Ardley Coal Zone has been correlated with the Kakwa Coal Zone in the Wapiti area (Dawson et al., 1994).

The Scollard Formation of the central Plains correlates with the Coalspur Formation of the central Foothills, and the Willow Creek Formation of the southern Foothills and Plains (Jerzykiewicz, 1997). In Saskatchewan, the lower member is equivalent to the Frenchman Formation and the upper member is correlative with the lower part of the Ravenscrag Formation.

3.3.9 Paskapoo Formation

Renewed tectonic activity in the Paleocene resulted in deposition of fine to coarse-grained Paskapoo strata. The Scollard-Paskapoo contact is defined at the base of the thick massive sandstone above the Ardley Coal Zone. In outcrop, this contact is marked by the thick, buff-coloured sandstone of the Paskapoo lying directly on the coal-bearing strata of the Ardley Coal Zone (Demchuk and Hills, 1991). The Paskapoo-Scollard boundary has been described as abrupt and disconformable (Lerbekmo et al., 1990).

In the Paskapoo Formation, thick (>15 m), tabular, buff-coloured sandstone beds are commonly stacked into successions more than 60 m thick and overlain by interbedded siltstone and mudstone, resulting in deposition of nonmarine strata up to 3800 m. Laterally, the Paskapoo Formation thickens from east to west. Several thin coal beds occur throughout the Paskapoo Formation (Demchuk and Hills, 1991). In Eocene to Miocene time, widespread uplift and erosion related to the Cordilleran Orogen resulted in the removal of up to 3000 m of strata (Nurkowski, 1984; Bustin, 1992). Within the Plains, the Paskapoo Formation is commonly covered by Late Tertiary–Quaternary sediments or till.

3.4 Coal Zones of the Upper Cretaceous–Tertiary Strata of the Alberta Plains

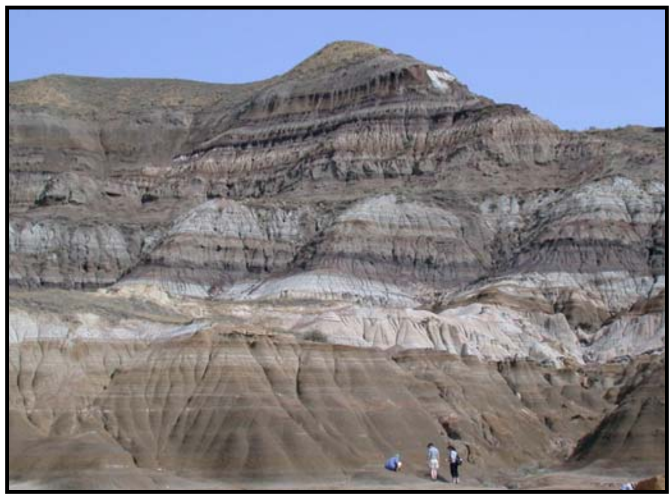
Packages of coal occur within distinctive horizons of the Scollard, Horseshoe Canyon and Belly River strata in the Alberta Plains (Figures 8 and 9**)**. These coal packages are referred to as ‘coal zones,’ which are laterally continuous intervals of interbedded coal and inorganic partings. There is no defined minimum or maximum thickness of interbedded sediment; however, the individual zones commonly contain greater than 50% coal (by volume) and are separated from one another by several metres of rock.

3.4.1 Coal Zones of the Scollard Formation

There is one coal zone within the Scollard Formation, the Ardley Coal Zone. The Ardley Coal Zone consists of four individual ‘packages’ of coal seams (essentially distinct coal zones themselves) and related interburden associated with fluvial and lacustrine continental clastic sediments. The Scollard Formation is an eastward-thinning clastic wedge. Coal seams are laterally continuous and thick. Maximum individual seam thickness and number of seams are greatest in the western area of the Plains, where peat accumulation was accentuated by increased subsidence, coupled with protection from clastic input by major river systems running parallel to the mountain front (Richardson et al., 1988). Seam

Ardley Coal Zone,
Scollard Formation,
Whitewood mine.

Drumheller Coal Zone,
Horseshoe Canyon
Formation,
Willow Creek.



Taber Coal Zone,
Belly River Group,
Taber

Figure 8. Coal-bearing strata of the Alberta Plains.

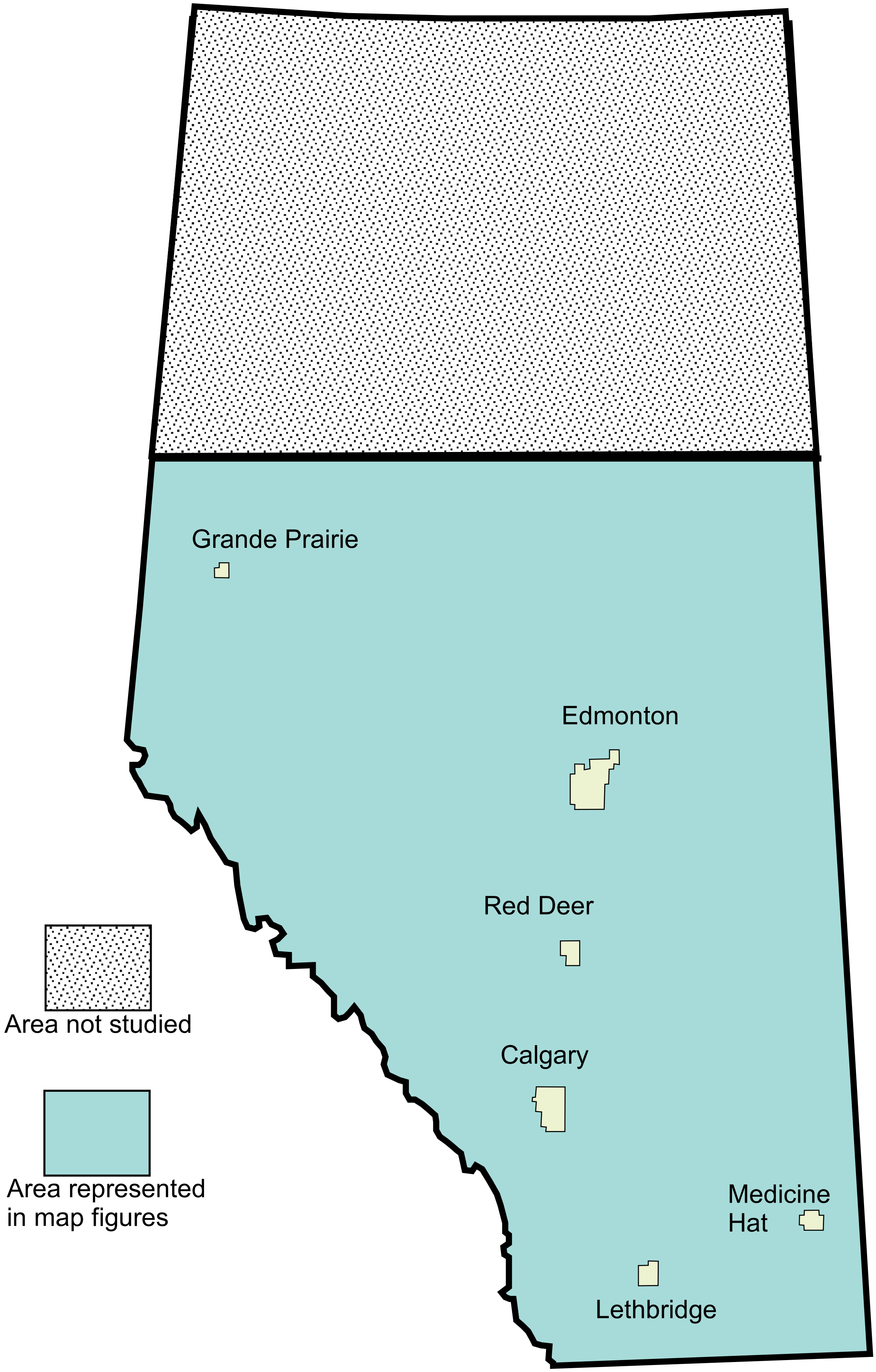


Figure 9 - Index map of Upper Cretaceous-Tertiary study area

thickness and number of seams decrease eastward in the Plains.

The Coalspur Formation is the Foothills equivalent of the Scollard Formation. The Ardley Coal Zone is continuous across the Coalspur and Scollard formations. Coalspur Formation nomenclature subdivides the coal zone into four coal 'subzones.' These 'subzones' are identified as the Val d'Or, Ardley, Silkstone and Mynheer coal zones. These seams/zones represent up to 18 individual seams that occur as a closely spaced package. All seams/zones are present in the western and central portion of the Plains, although the upper seams are not present towards the east. Proximal to outcrop, Scollard Formation nomenclature identifies only the 'Upper' and 'Lower' Ardley Coal Zones. Recent compilations by Dawson et al., 2000, have extended Coalspur Formation seam nomenclature eastward toward outcrop. This report utilizes the extended Coalspur Formation nomenclature to emphasis the continuity of Ardley 'subzones' across the Alberta Plains.

The average thickness of the Ardley Coal Zone ranges from 14 m near outcrop to greater than 200 m at the western margin of the Plains. Furthermore, the number of seams increases from an average of 4 near outcrop to as many as 18 near the western limit of the Plains. The increased number of seams corresponds to increasing net coal thickness within the Ardley Coal Zone. The Ardley Coal Zone is correlative with the Kakwa Coal Zone of the Wapiti area (Dawson et al., 1994).

Coal rank within the Ardley (Figure 10) ranges from subbituminous near outcrop (reflectance <0.5%) to a maximum of high-volatile bituminous B in the western, deepest areas containing Ardley coals. Most of the area underlain by Ardley coal falls within reflectance range 0.5% to 0.65% (high-volatile bituminous C rank; Figure 3), just within the onset of thermogenic gas generation (Rice, 1993).

3.4.2 Coal Zones of the Horseshoe Canyon Formation

Three coal zones were identified within the Horseshoe Canyon Formation: the lower Drumheller Coal Zone (divisible into upper and lower intervals), the Daly-Weaver Coal Zone, and the uppermost Carbon-Thompson Coal Zone.

The base of the Horseshoe Canyon Formation is identified by the contact with the Bearpaw Formation in the southern Plains area; however, the Bearpaw Formation does not extend into the northern Plains and the separation of the Horseshoe Canyon Formation from the underlying Belly River Group becomes difficult. To complicate matters, there are several upper Bearpaw marine tongues that interfinger with Horseshoe Canyon sedimentary units. This results in difficulty in seam correlation and, where the Bearpaw is absent, assignment of coals to appropriate coal zones. Peat accumulation occurred in conjunction with intermittent regressive-transgressive pulses of the Bearpaw sea, where water table levels allowed peat accumulation for short periods in north-trending, shoreline-parallel mires, commonly 30 to 50 km inland from the shoreline (Rottenfusser et al., 1991). These peat deposits produced coals that were generally elongate, interfingered with clastic and marine strata and, although generally thin, could attain local thicknesses exceeding 4 m. The 'lower tongue', capped by the E-marker (the second major Bearpaw transgression) of McCabe et al. (1989) and the 'CU1' coarsening-upward unit of Langenberg et al. (2001), effectively subdivides the upper and lower Drumheller coal zones.

Thick net coal accumulations are present in the Drumheller Coal Zone, with greatest accumulations (18 m) found near 28-23W4[1], but the coals are discontinuous. A north-trending zone of thick net coal, which averages 8 m, occurs in the southern region of the Drumheller Coal Zone. Individual seams average 1 to 2 m thick, although seams may be up to 5 m thick in areas of greatest net coal (McCabe et

[1] Tw. 28, Rge. 23, W 4th Mer

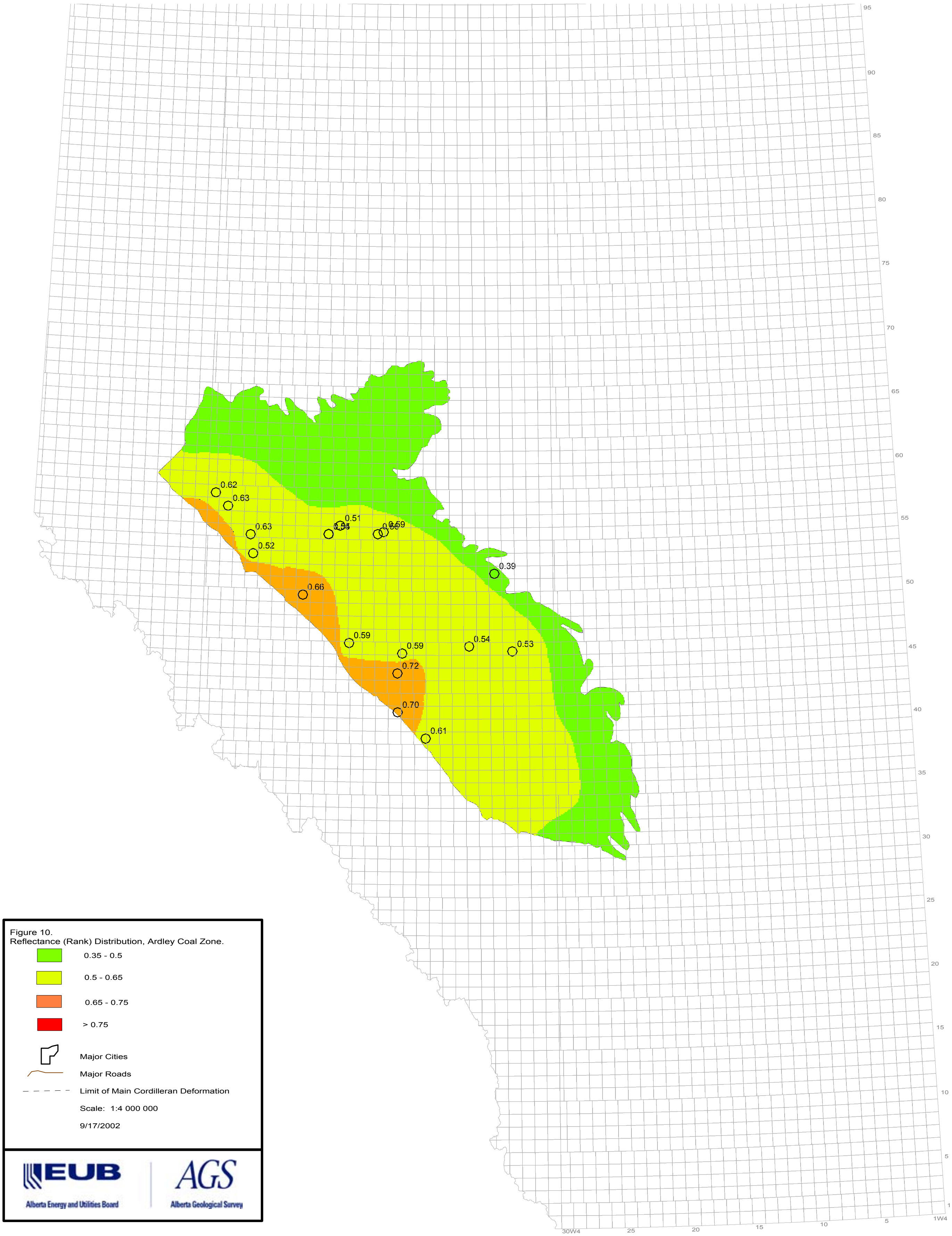


Figure 10.
Reflectance (Rank) Distribution, Ardley Coal Zone.

al., 1989; Rottenfusser et al., 1991). The lower Drumheller includes relatively thin coals (commonly <1 m) that are relatively continuous; the upper Drumheller seams, although commonly thicker than those of the lower Drumheller, tend to be less continuous (McCabe et al., 1989). Drumheller coals were developed along coastal plains, commonly associated with coarsening-upward successions, representative of migrating and stacking paleoshorelines. The Drumheller Coal Zone correlates with the Red Willow Coal Zone of the Wapiti area (Dawson et al., 1994).

Discontinuous coal seams occur stratigraphically above the Drumheller Coal Zone. Informally referred to as the Daly-Weaver Coal Zone, these coals were mapped and evaluated in this study for their CBM potential. McCabe et al. (1989) suggested that the Daly-Weaver Coal Zone formed in an alluvial plain setting, where only thin, discontinuous seams are developed. The distinction between the Daly-Weaver Drumheller coal zones is based, in part, on the absence of marine strata in the Daly-Weaver succession, and fewer coal seams associated with its coarsening-upward successions.

The upper Horseshoe Canyon Formation contains the discontinuous but laterally persistent Carbon-Thompson Coal Zone. Upper Horseshoe Canyon strata reflect the gradual progradation of terrestrial sediments, with peat deposition and accumulation associated with lacustrine and fluvial depositional environments.

The thickest coals in the Carbon-Thompson Coal Zone occur in northwest-trending ‘bands’ that coincide with northwest-trending paleochannels associated with fluvial depositional environments. Thickest coals rarely exceed 1 to 2 m, and net coal for the zone averages 2 to 3 m. The Carbon-Thompson Coal Zone correlates with the Cutbank Coal Zone of the Wapiti area (Dawson et al., 1994).

Rank of coals in the Horseshoe Canyon Formation is presented in Figures 11 and 12. Carbon-Thompson coals are primarily within the ‘upper bounds’ of high-volatile bituminous C rank, with reflectance values typically falling within the 0.6% to 0.65% reflectance range (Figure 11), indicating slightly higher rank than the Ardley coals. With increasing depth toward the west, the coal rank increases to high volatile bituminous B, suggesting increased gas-generation potential in these areas.

Data are sparse for the Daly-Weaver Coal Zone; however, it is expected to follow a similar rank trend to the Carbon-Thompson Coal Zone.

The Drumheller Coal Zone includes low-rank coal (subbituminous B) at shallow depths, with the majority of coals having a rank of high-volatile bituminous C in the central Plains region (Figure 12). Coal rank increases both westward and northward, where a rank of high-volatile bituminous B is attained.

3.4.3 Coal Zones of the Belly River Group

The McKay Coal Zone represents the first major peat accumulation in continental sediments of the lower Belly River Group (Foremost Formation), with sediment sources derived from the northwest and southwest. The peat accumulated several tens of kilometres westward of the paleoshoreline, in a north-trending belt associated with a coastal-plain depositional environment. The McKay Coal Zone ranges from 30 to 50 m thick. Average net coal thickness ranges from 1 to 3 m; however, in some local areas, up to 4 m net coal may be present. Individual seams typically range between 1 and 3 m thick (Macdonald et al., 1987).

The Taber Coal Zone, which also which accumulated in a coastal-plain environment, eastward of the McKay Coal Zone in response to continued regression of the interior seaway. The Taber Coal Zone

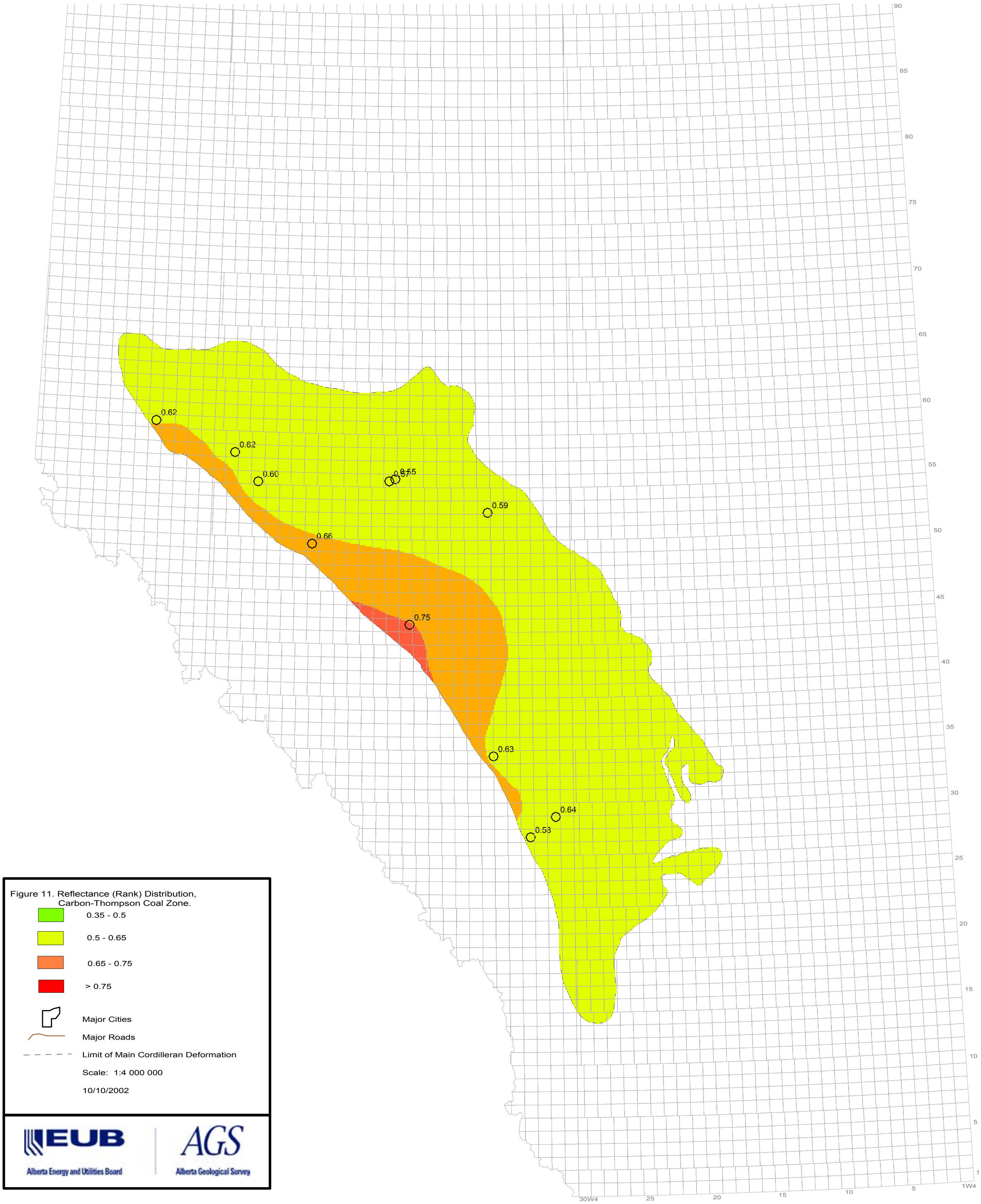


Figure 11. Reflectance (Rank) Distribution, Carbon-Thompson Coal Zone.

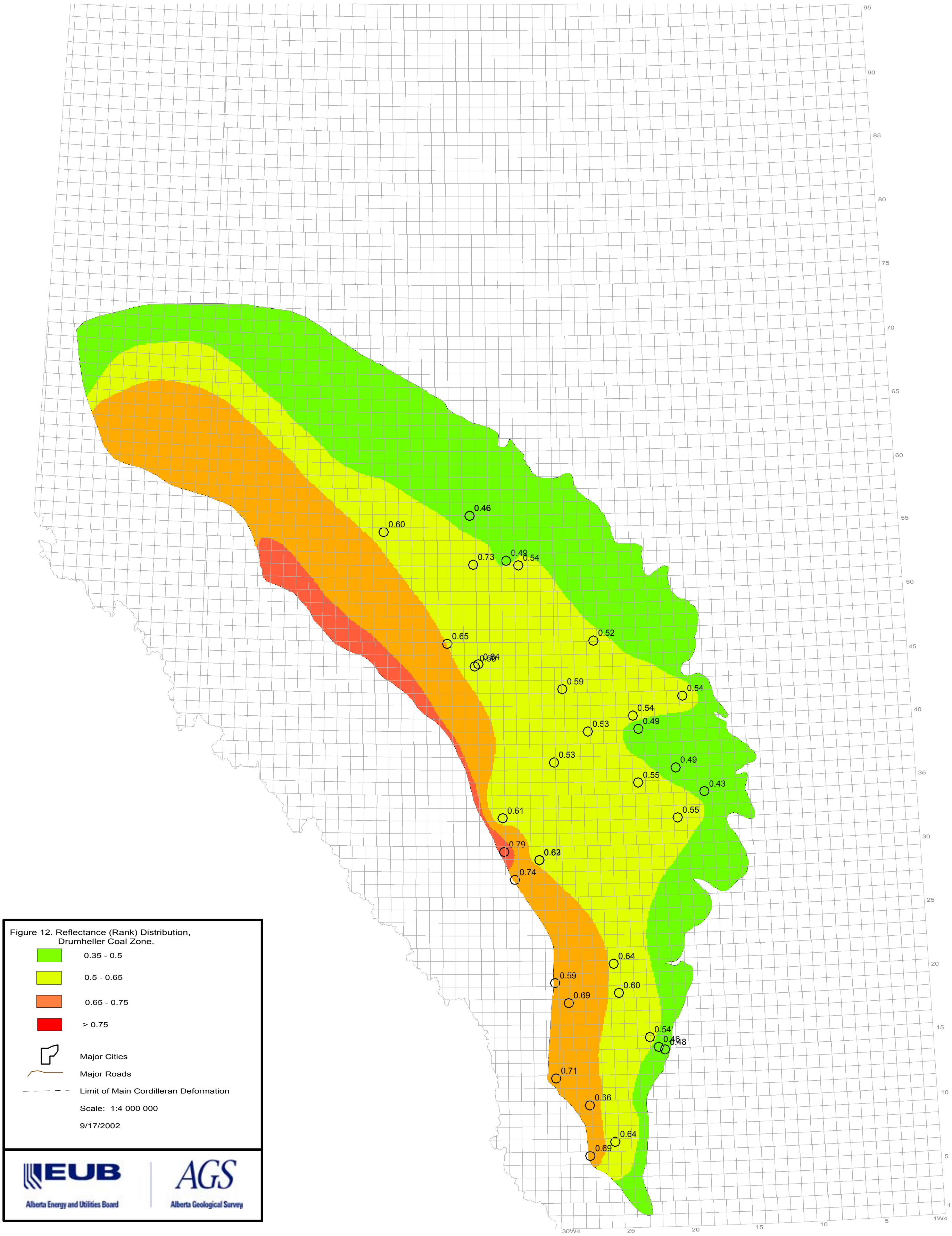


Figure 12. Reflectance (Rank) Distribution, Drumheller Coal Zone.

occurs near the top of the Foremost Formation, and averages 25 m thick with 1 to 3 m of net coal. Thicker coals occur locally (up to 6 m net coal) in northeast-trending bands. Individual seams range from 1 to 2 m thick.

The Lethbridge Coal Zone developed as a result of rising regional water-table levels associated with the advancing Bearpaw seaway. The coals are laterally continuous, and occur near the top of the Oldman Formation. The Lethbridge Coal Zone averages 10 to 15 m thick, with an average of 1 to 3 m net coal that commonly occurs in two seams. The Lethbridge Coal Zone merges with the Drumheller Coal Zone north of Twp. 50, coincident with the distribution limit of the Bearpaw Formation.

The rank of Belly River Group coals is slightly greater than those of the Horseshoe Canyon Formation. Lethbridge Coal Zone rank ranges from subbituminous at shallow depths through high-volatile bituminous C and B westward with increasing depth (Figure 13). Coal rank approaches high-volatile bituminous A in the west-central part of the Plains, suggesting favourable gas-generation potential.

The Taber Coal Zone (Figure 14) is predominantly high-volatile bituminous C in the central Plains and subbituminous C to B in the southeastern Plains. Only in the far western Plains does rank approach high-volatile bituminous B.

The McKay Coal Zone (Figure 15) displays a wide range in coal rank. Shallow coals are typically subbituminous B to A and, in the central Plains, increase to the high-volatile bituminous C range. The McKay Coal Zone includes an area of variable rank data, centred about 47-3W5, where reflectance values range (and overlap) from 0.45% to 0.70% (subbituminous to high-volatile bituminous B). This variability may be due to poor analytical data or incorrect assignment of a sample to a given coal zone. The majority of data within this area indicate a rank range of high-volatile bituminous C to B, within the range associated with the onset of thermal gas generation (Rice, 1993).

4 Coal Evaluation

The CBM potential-resource evaluation for the Upper Cretaceous–Tertiary strata of the Alberta Plains utilized the AGS CBM-coal database (EUB/AGS 2002). The database consists primarily of existing coal and associated stratigraphic data obtained from oil, gas and coal exploration wells, as well as new coal and stratigraphic picks obtained from 392 wells used to construct cross-sections for this study. The database includes 7500 wells, with approximately 32 000 coal picks and 16 000 stratigraphic picks. Understanding the basin architecture underlying the Plains was crucial to understanding coal and coal-zone distribution, and factors conducive to gas potential. Nine new cross-sections were created, identifying lithological trends and distribution and extent of strata for Colorado and younger strata. These cross-sections were used to construct a basin model upon which stratigraphy, coal-seam and coal-zone data from the various datasets were evaluated.

4.1 Picking Protocol

4.1.1 Coal Picks

Coal is best identified by a combination of the gamma, density (bulk or neutron porosity) and resistivity geophysical logs. Coal typically exhibits a low gamma response in conjunction with a low density and a high resistivity response. The low gamma and density responses are a result of high concentrations of organic matter, which have corresponding low amounts of inorganic materials such as clay (resulting in low gamma responses) and low porosity (high resistivity response). In the absence of good density logs,

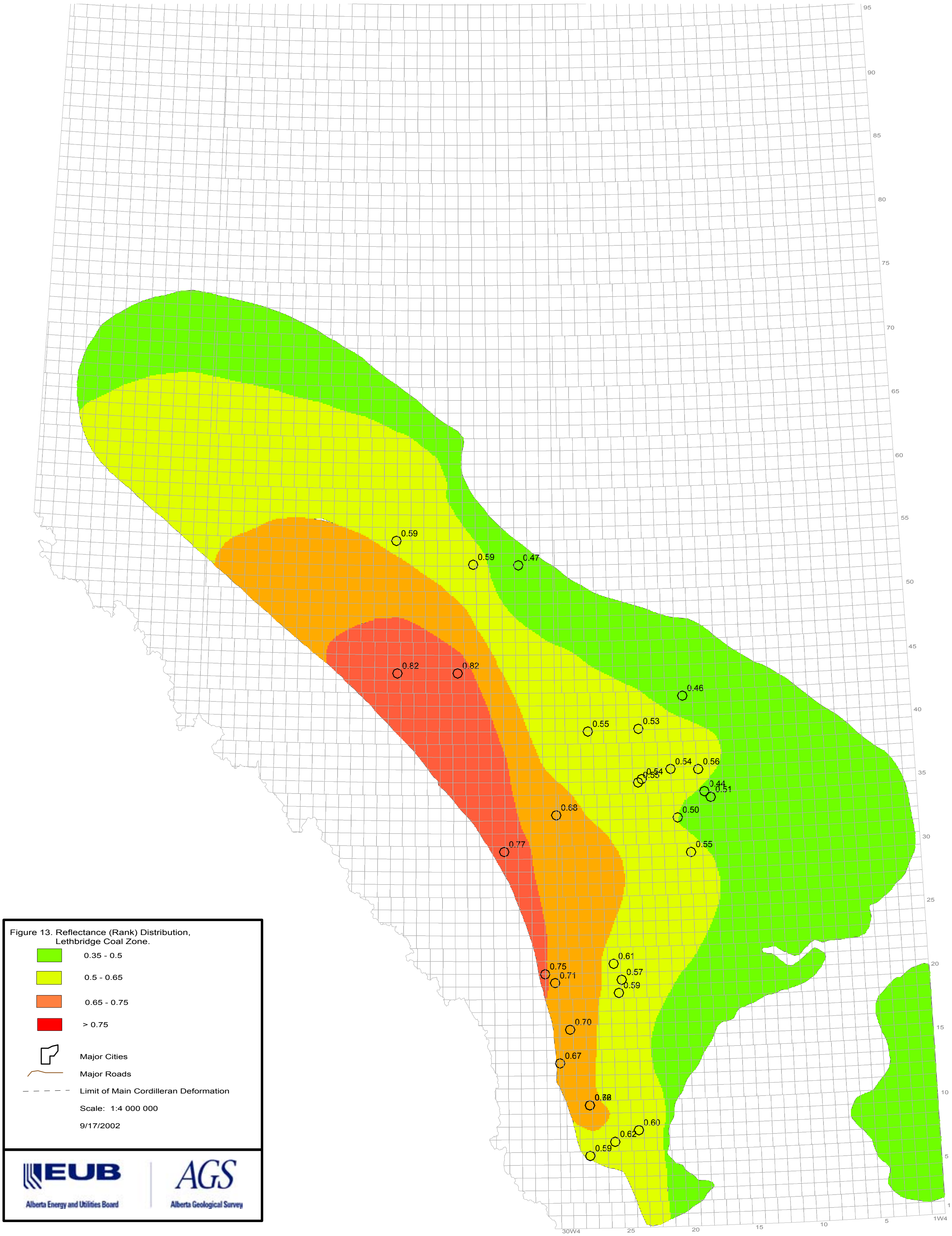


Figure 13. Reflectance (Rank) Distribution, Lethbridge Coal Zone.

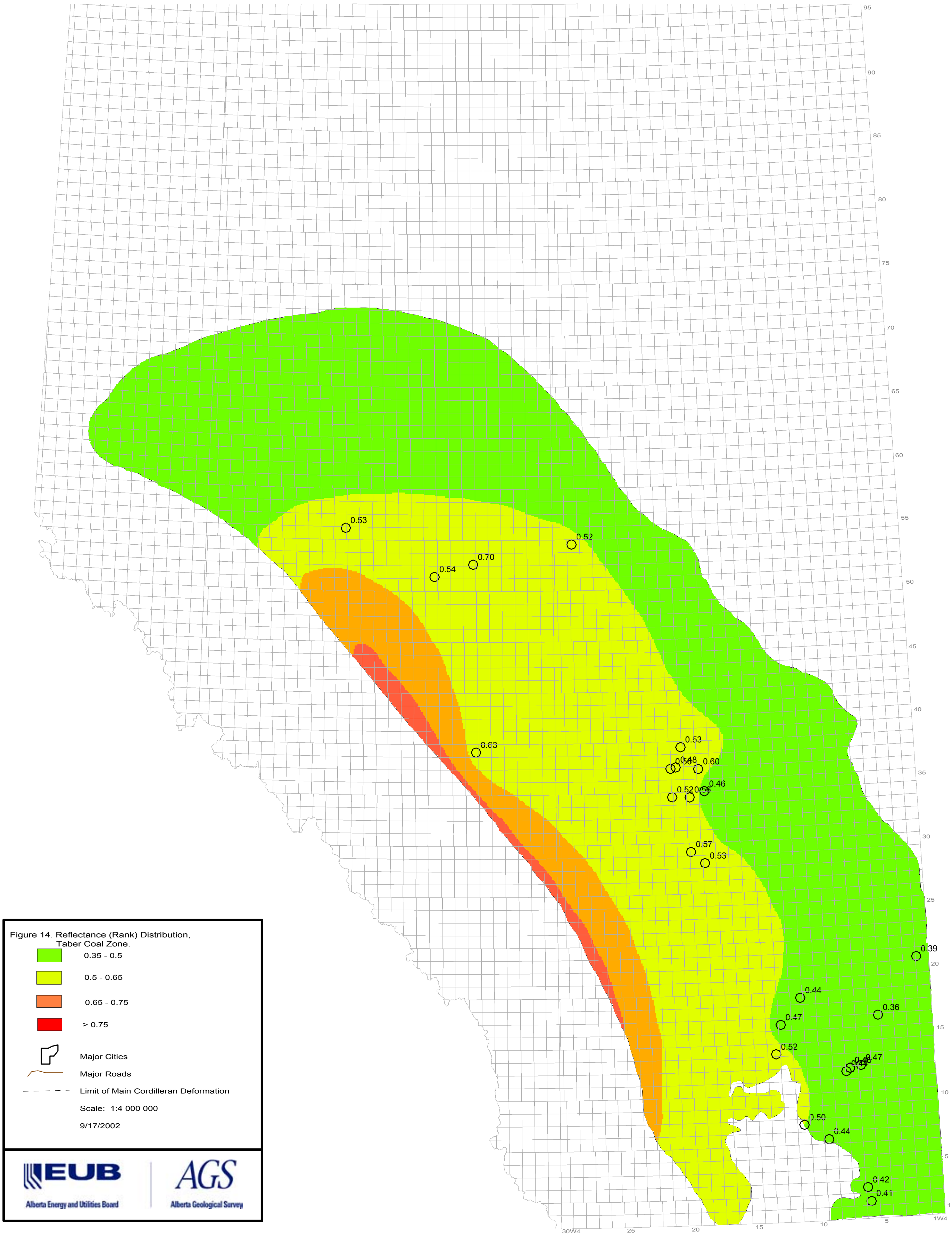


Figure 14. Reflectance (Rank) Distribution, Taber Coal Zone.
0.35 - 0.5
0.5 - 0.65
0.65 - 0.75
> 0.75
Major Cities
Major Roads
Limit of Main Cordilleran Deformation
Scale: 1:4 000 000
9/17/2002
EUB
Alberta Energy and Utilities Board
AGS
Alberta Geological Survey

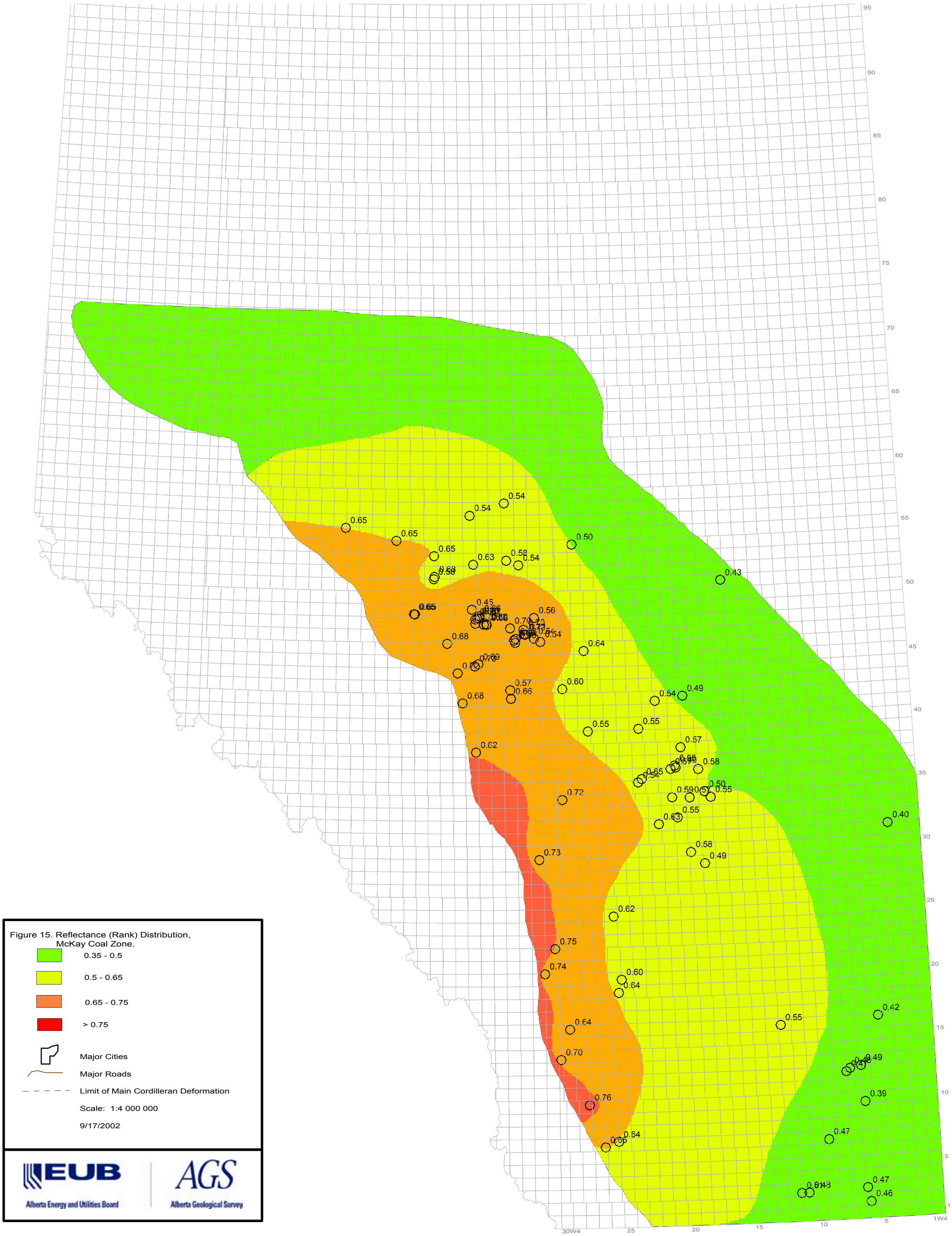


Figure 15. Reflectance (Rank) Distribution, McKay Coal Zone.

sonic logs may be useful, as the sonic log response somewhat mimics the density log, having higher transit times in the organic-rich rock types.

Gamma responses less than 70 API were identified as coal, when coupled with density responses of less than 2 g/cc and resistivity responses exceeding 80 ohm-m. Differentiation between coal and coaly shale can be attempted from the density-log response. Coal has a density of less than 1.7 g/cc, whereas the density of shaly coal ranges between 1.7 and 1.9 g/cc. Coaly shale can be identified by a density response between 1.9 and 2.0 g/cc. Caliper logs often show cavings in coal seams. Cavings may obscure the response from the resistivity and density logs, whereas gamma responses are not as strongly affected by cavings and washouts.

Coal-seam thickness was determined from geophysical logs selected along the new cross-sections, following the protocol of determining the top of the seam along the density trace at one-third of the distance from the low density point on the upper inflection point. The base of the seam was taken at two-thirds of the distance from the low-density point on the lower inflection point. Other methods commonly used (and that may have been used in some of the datasets included in this report) include taking one-third of the distance from the lowest point on the density trace, or the midpoint along the trace between the inflection points. The use of different picking protocols may result in the inclusion or elimination of several centimetres of coal from a seam's calculated thickness.

In the AGS CBM-coal database (constructed from several pre-existing databases), it was often unclear whether the density cutoffs outlined above were used, as protocols were not always defined. Protocols for picking coal varied somewhat between studies compiled from the different data sources (EUB/AGS 2002); however, they followed accepted coal-identification methodology, as described by Hoffman et al. (1982). In an effort to make all datasets compatible and to be consistent within this project, coal and shaly coal were grouped together in the mapping and resource calculations, with corrections for ash and density applied. This approach is warranted, as shaly coal may also have gas potential.

Coal and shaly coal were tentatively identified from 1:600 scale logs, and confirmed on 1:240 scale logs. Seams were assigned to a coal zone (if appropriate) based on their stratigraphic position (as determined by constructing regional cross-sections). Coal seams within the northern and northwestern area of the Plains (Wapiti area) were tentatively correlated to coal seams of the central and southern Plains.

4.1.2 Stratigraphic Picks

Stratigraphic picks for individual formations and intraformational units were based on characteristic geophysical log responses representative of a particular lithology or change in lithology. Table 1 summarizes the typical log responses utilized in picking stratigraphic intervals in the current study. Stratigraphic picks were used to construct a geological model of the Alberta Plains, from which coal zone assignments for different coal picks were made. Stratigraphic picks are included in the CBM/coal database (EUB/AGS 2002).

4.2 Coal Evaluation Methodology

4.2.1 Maps and Modelling Surfaces

Coal and coalbed methane data contained in the CBM-coal database (EUB/AGS, 2002a) were utilized in the CBM resource evaluation for Upper Cretaceous–Tertiary strata of the Alberta Plains. A series of maps was generated for each coal zone using geological-modelling software from ViewLog® Systems

Table 1. Stratigraphic and geophysical characteristics of formations.

Formation	Typical geophysical log response	Formation characteristics
Scollard Fm.	Low gamma ray (Gr) response at the lower part of the formation interval corresponding to sandstone; a higher Gr response at the upper part corresponding to silt and shale. Thick coal interval within the upper silt and shale commonly divided into 4 coal "sub-zones"	2 lithologic intervals: the lower part consists of channel sandstone, and the upper part consist mainly of floodplain silt and shale with thick coal accumulation.
Top of Scollard Fm.		Top of Ardley Coal Zone and/or the base of the compact, thick, overlying Paskapoo sandstone.
Battle Fm.	High Gr response corresponding to fine succession of bentonite beds, which corresponds to low resistivity values. Density response sharply alternates from high to low values over short intervals	Thin formation (<5m to 15m) consisting mainly of silt and bentonitic shale, with lateral variations to coarser lithology.
Top of Battle Fm.	Shale to silty shale, high Gr response	Generally below the consistent disconformable lower sandstone of the overlying Scollard Fm.
Whitemud Fm.	Low Gr response corresponding to fine grained sandstone. Conductivity response gradually increases towards the top of the sandstone	Kaolinitic fine grained sandstone with minor lateral facies changes
Horseshoe Canyon Fm.	Variable gamma ray and density response, moderately high resistivity response.	Continental silty shale, frequent coarsening-upward units in lower part of formation, increasing number of fining-upward units towards top of formation. Includes three coal zones, the upper Carbon / Thompson, the middle Daly / Weaver and the lower Drumheller coal zones.
Top of Horseshoe Canyon Fm.	Conductivity response abruptly changes into overlying Whitemud and Battle formations (if present)	Top of Carbon / Thompson Coal Zone.
Bearpaw Fm.	Moderately high Gr values and high conductivity values corresponding to silt and shale	Marine silt and shale with common coarsening-upward sandstone units
Top of Bearpaw Fm.	Top of a high conductivity response, commonly below the lowermost Horseshoe Canyon coals (Drumheller Coal Zone).	
Upper Belly River Gp. (Oldman Fm.)	Variable Gr and density response to silt and shale, commonly high resistivity response	Series of thin fining-upward, nonmarine units. Lethbridge Coal Zone at top of Formation.
Top of Upper Belly River Gp.	High Gr response, corresponding to thin bentonite layer, may occur when Bearpaw Fm. is absent	Base of marine Bearpaw Fm., and top of Lethbridge Coal Zone
Lower Belly River Gp. (Foremost Fm.)	Lower Gr response and higher resistivity response compared to overlying Oldman Fm., corresponding to overall greater amount of sandstones within the Foremost Fm.	Basal shoreline sandstones overlain by amalgamated fluvial channel sandstone. Includes 2 coal zones, the McKay coal zone near the base and the Taber Coal Zone near the top.
Top of the Lower Belly River Gp.		Top of the most consistent fining-upward unit, commonly 20-30m above the Taber Coal Zone (or facies equivalent)
Lea Park Fm.	High conductivity response with gradually decreasing Gr response from base to top	Marine retrogradational sequence
Milk River Fm.	Gamma ray response typical of coarsening-upward sequences, consistently high resistivity response	Marine silty shale and fine grained sandstone
Top of Milk River Fm.	Equivalent to top of Milk River Shoulder, with sharp reduction in conductivity response, and a corresponding high Gr response compared to the overlying Lea Park Fm	
Top of Colorado Gp.	Very high Gr response and high conductivity response at base of the Milk River Fm. coarsening-upward sequence	

Ltd. Maps showing coal distribution, coal-zone thickness and net coal within a given coal zone were generated on a surface modelling grid (1048 x 800 km grid encompassing the Plains map area, with a 1 km x 1 km grid-cell size). These surfaces were, in turn, used as for generating gas-in-place (cc/g, dry ash free basis, daf) and resource potential-distribution (bcf/section) maps, utilizing the resource equations discussed in section 5.

The maps included with this report present the depth to top, the distribution and the coal-zone thickness for each coal zone (Figures 16–36). Also presented are maps of net coal thickness, indicating areas with greatest total coal potential within a given coal zone.

4.2.2 Net Coal Tonnage

Net coal tonnage for a given coal zone was determined by the equation:

net tonnage (as received basis) = area x net coal thickness x in-place coal density

In-place coal density was derived from EUB Coal Reserves data (Alberta Energy and Utilities Board, 2000), and from selected core-sample intervals (Alberta Geological Survey, 2001a, b). Density values were obtained for the various coal zones, averaged and the following values were applied in the above equation:

In-place coal density, Ardley Coal Zone = 1.44 cc/g
In-place coal density, Horseshoe Canyon Formation coal zones = 1.42 cc/g
In-place coal density, Belly River Group coal zones = 1.41 cc/g

Two tonnage values are presented for each coal zone. The first represents all coal within a coal zone, regardless of depth or net coal thickness. The second, the ‘constrained’ tonnage, includes only coal at depths greater than 200 m and with net coal thickness greater than 1 m, as these constraints more closely reflect current CBM-potential evaluation parameters. Tonnage numbers were subsequently used to calculate gas potential for each coal zone.

4.3 Evaluation Results

4.3.1 Ardley Coal Zone

The Ardley Coal Zone underlies 5.9 x 10^{10} m^2 of the Alberta Plains (Table 2). It outcrops along a northwest-trending belt, extending from 29-23W4 to 65-1W6. The zone dips gently southwestward, attaining an average depth of 800 m in the southwest but only 500 to 600 m in the northwest (Figure 16). Two areas show inconsistencies in the regional depth trend: 1) an eight-township area, centred about 56-19W5, has depths approximately 200 m greater than the regional trend; and 2) a six-township area, centred about 44-14W4, has depths approximately 100 to 200 m shallower than the regional trend.

The Ardley Coal Zone generally thins from west to east, and the also toward the southeast. The coal zone averages 60 to 90 m thick throughout much of the area; however, two regions of increased thickness (up to 25 m) occur 1) along a northeast trend from 50-20W5 to 58-17W5, and 2) in an east-trending band from 49-18W5 to 49-11W5 (Figure 17). Thickness of the coal zone can exceed 150 m in the northeast-trending band and 100 m in the east-trending band.

Net coal distribution (Figure 18) essentially follows coal-zone thickness trends, with an average net coal thickness in the 7 to 10 m range. Net coal decreases toward the east and southeast. The northeast- and east-trending bands containing the greatest thickness of Ardley Coal Zone also contain the thickest net coal, commonly greater than 15 m in the east-trending band and locally up to 23 m in the northeast trending band.

Table 2. Coal resources of Upper Cretaceous-Tertiary strata, Alberta Plains.

Coal Zone	Area m^2	t in place	t constrained
Ardley Coal Zone	5.90E+10	5.96E+11	5.01E+11
Carbon/Thompson Coal Zone	7.55E+10	1.83E+11	1.56E+11
Daly/Weaver Coal Zone	7.55E+10	1.78E+11	1.49E+11
Drumheller Coal Zone	1.28E+11	5.64E+11	4.38E+11
Lethbridge Coal Zone	1.70E+11	2.77E+11	1.13E+11
Taber Coal Zone	1.90E+11	3.35E+11	1.47E+11
McKay Coal Zone	2.12E+11	4.03E+11	2.41E+11
Totals		2.54E+12	1.74E+12

Net coal tonnage is calculated to be 5.96 x 10^{11} t for the Ardley Coal Zone. This calculation includes all coal seams, regardless of thickness and depth. Coalbed methane potential is, in part, dependent on reservoir depths and a minimum thickness of coal for well completions. Assuming net coal for seams greater than 1 m and a minimum depth of 200 m (the paremeters for a 'constrained coal estimate'), tonnage in Ardley Coal Zone, considered within CBM potential parameters, is estimated to be 5.01 x 10^{11} t.

4.3.2 Carbon-Thompson Coal Zone

The Carbon-Thompson Coal Zone underlies 7.55 x 10^{10} m^2 of the Alberta Plains. The zone can be traced from 64-7W6 in the northwest (where it occurs as a Wapiti coal equivalent, the Cutbank Coal Zone) as far south as 15-28W4 (Figure 19). This coal zone outcrops farther east than the Ardley Coal Zone and dips progressively from the outcrop toward the southwest, where depths up to 1100 m are encountered. Two areas that deviate from the regional depth trend are centred around 56-18W5 and 43-14W5. These trends coincide with the depth 'anomalies' present within the Ardley Coal Zone.

The Carbon-Thompson Coal Zone is extremely variable, but zone thickness is generally ranges less than 20 m in the southern Plains, with discontinuous local thick areas (up to 50 m) throughout the central Plains (Figure 20). Several thick 'pods' of occur in the northwestern part of the zone.

Net coal in the Carbon-Thompson is generally coincident with zone thickness (Figure 21). Several local areas contain net coal in the range of 3 to 5 m; these are typically associated with the thickest areas of the zone. Regionally, thickest net coal occurs in a northwest-trending band, at an approximate depth of 700 m, through the center of the area, but coal thickness within the band is variable.

Net coal tonnage in the Carbon-Thompson Coal Zone is calculated at 1.83 x 10^{10} t. Restricting tonnage to seams greater than 1 m and depth greater than 200 m, the resource is calculated at 1.56 x 10^{11} t.

4.3.3 Daly-Weaver Coal Zone

The Daly-Weaver Coal Zone underlies an area comparable to that of the Carbon-Thompson (7.55 x 10^{10} m^2) and can be traced to a depth of greater than 1200 m in the western part of the area (Figure 22).

The southern part of the zone is generally thin (<20 m), although a few pods can exceed 25 m thick

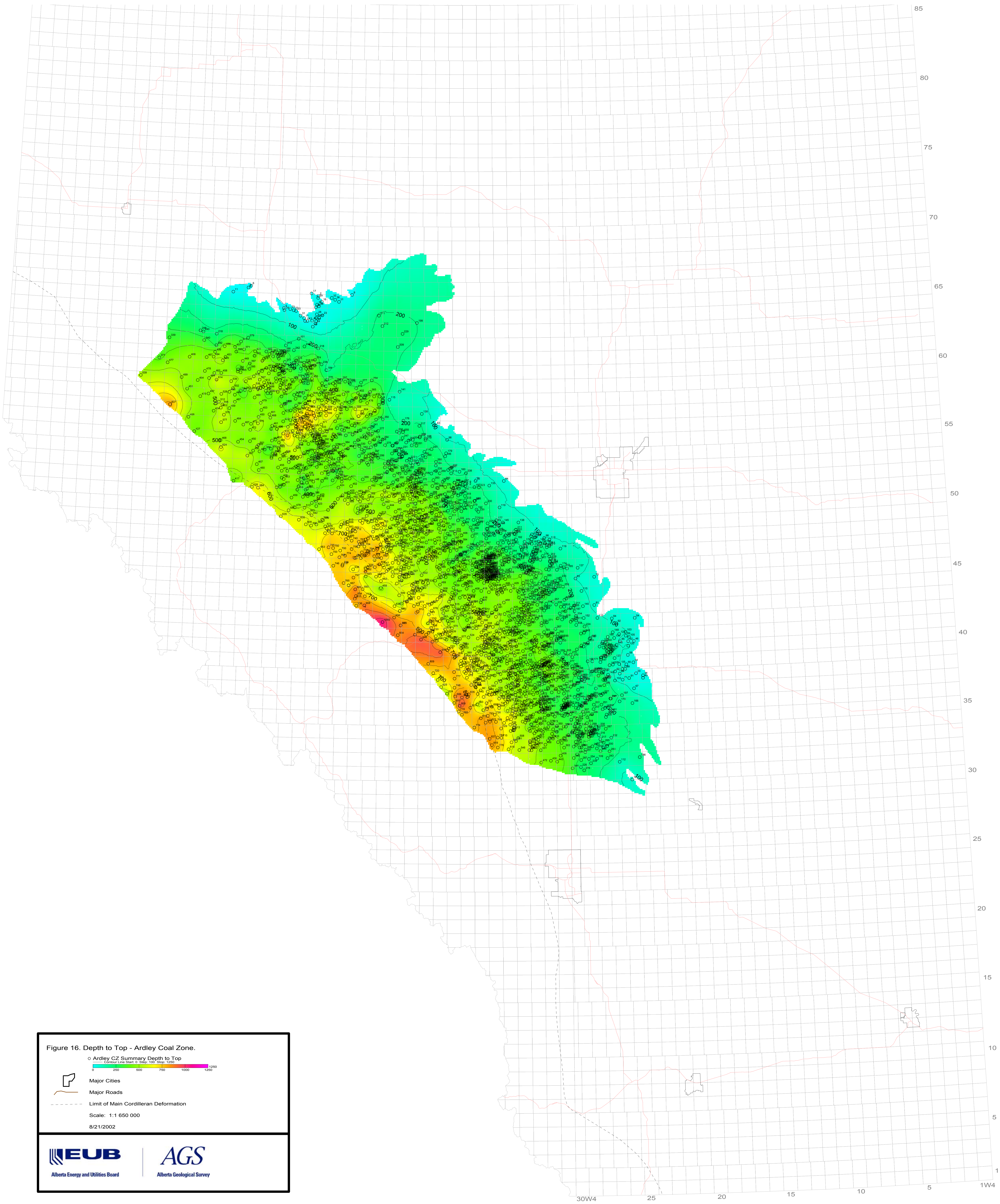


Figure 16. Depth to Top - Ardley Coal Zone.

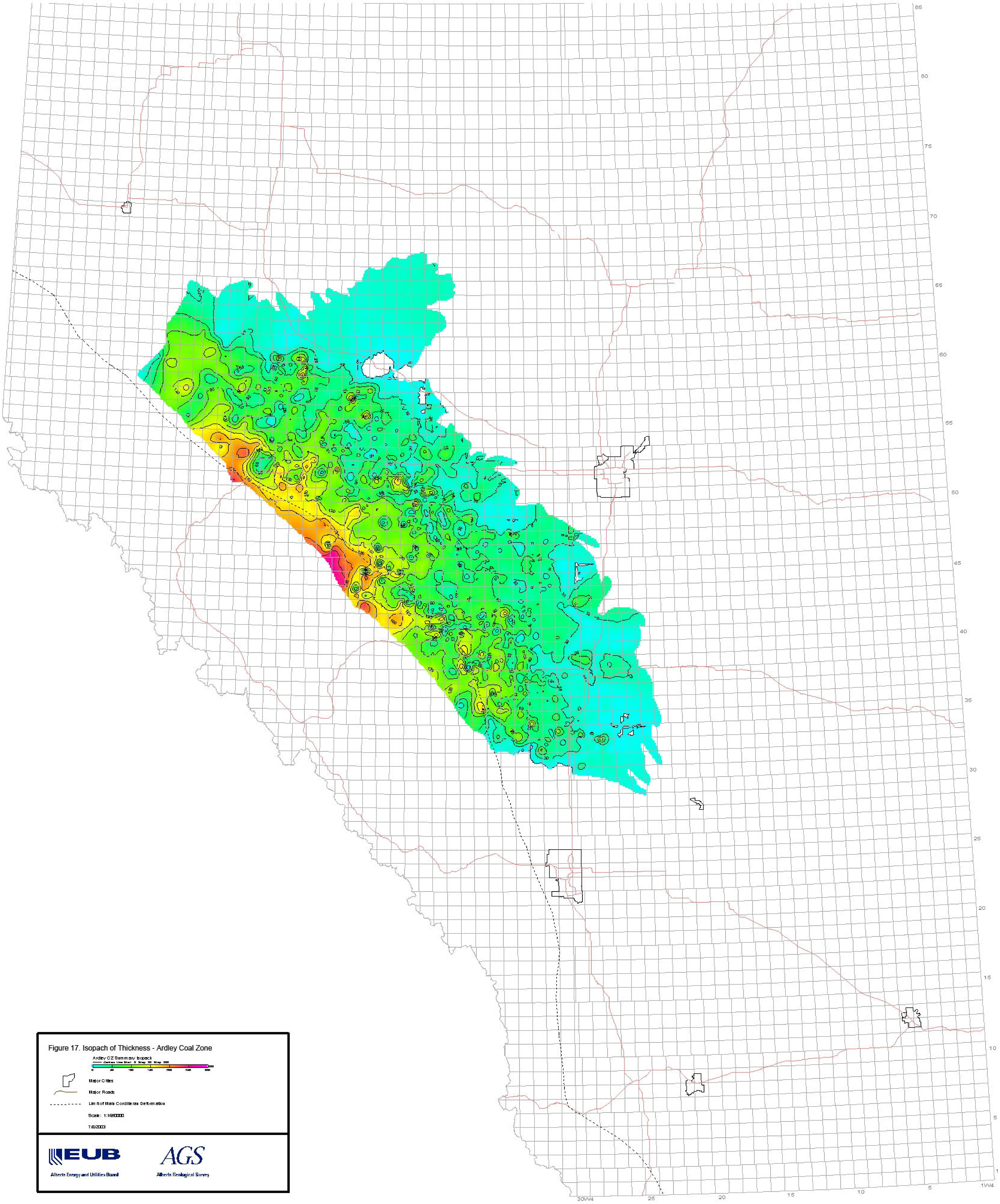


Figure 17. Isopach of Thickness - Ardley Coal Zone

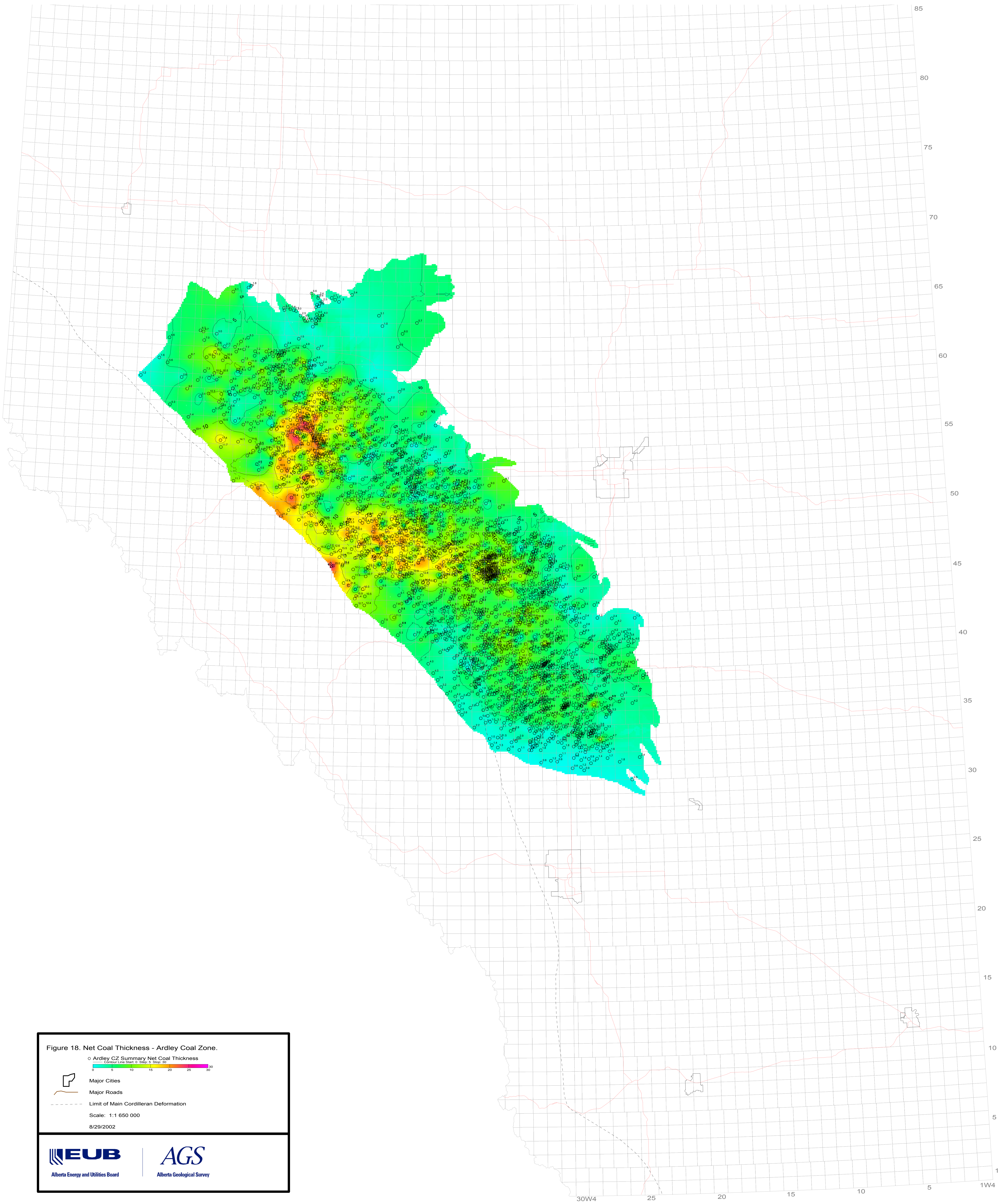


Figure 18. Net Coal Thickness - Ardley Coal Zone.

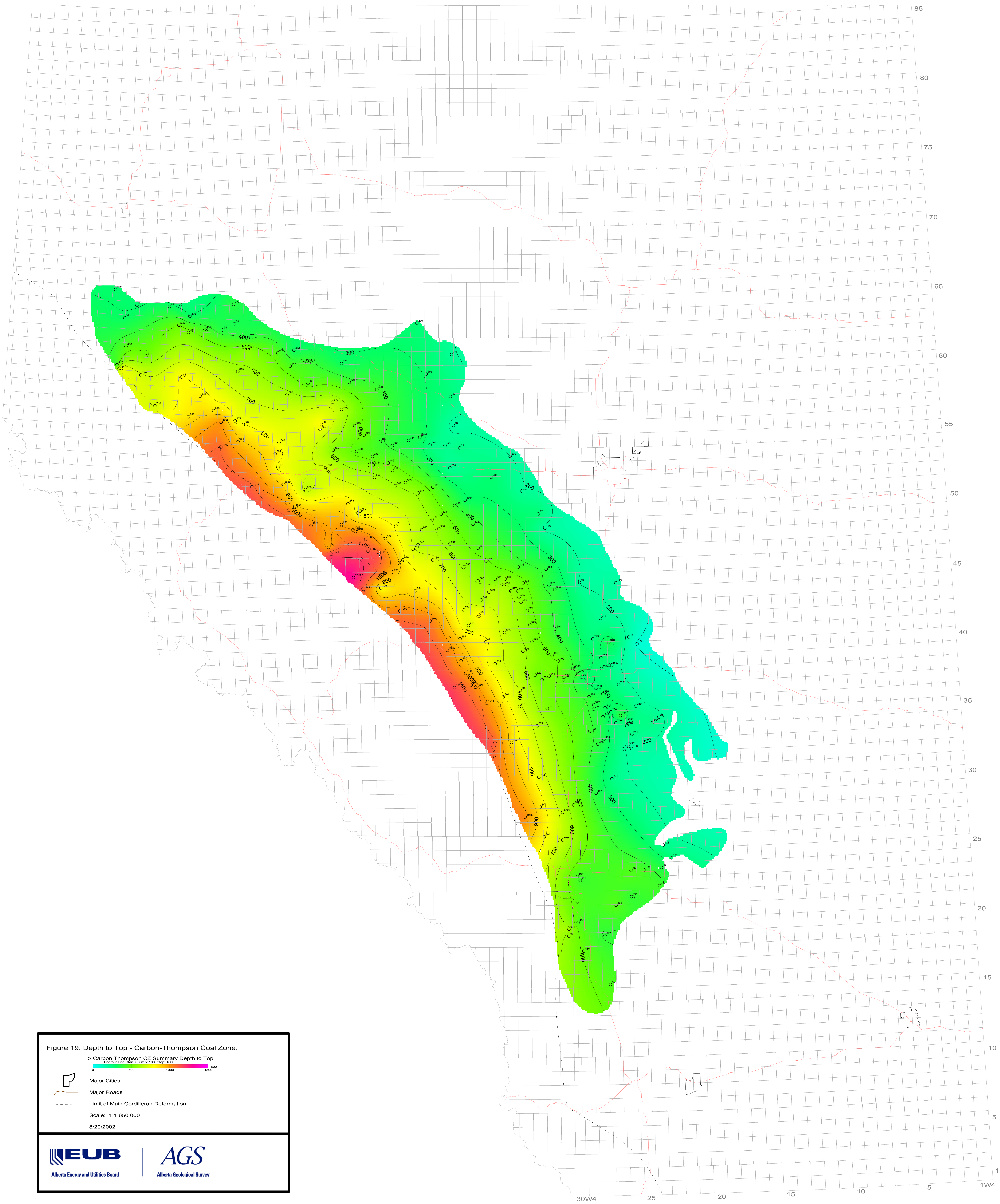


Figure 19. Depth to Top - Carbon-Thompson Coal Zone.

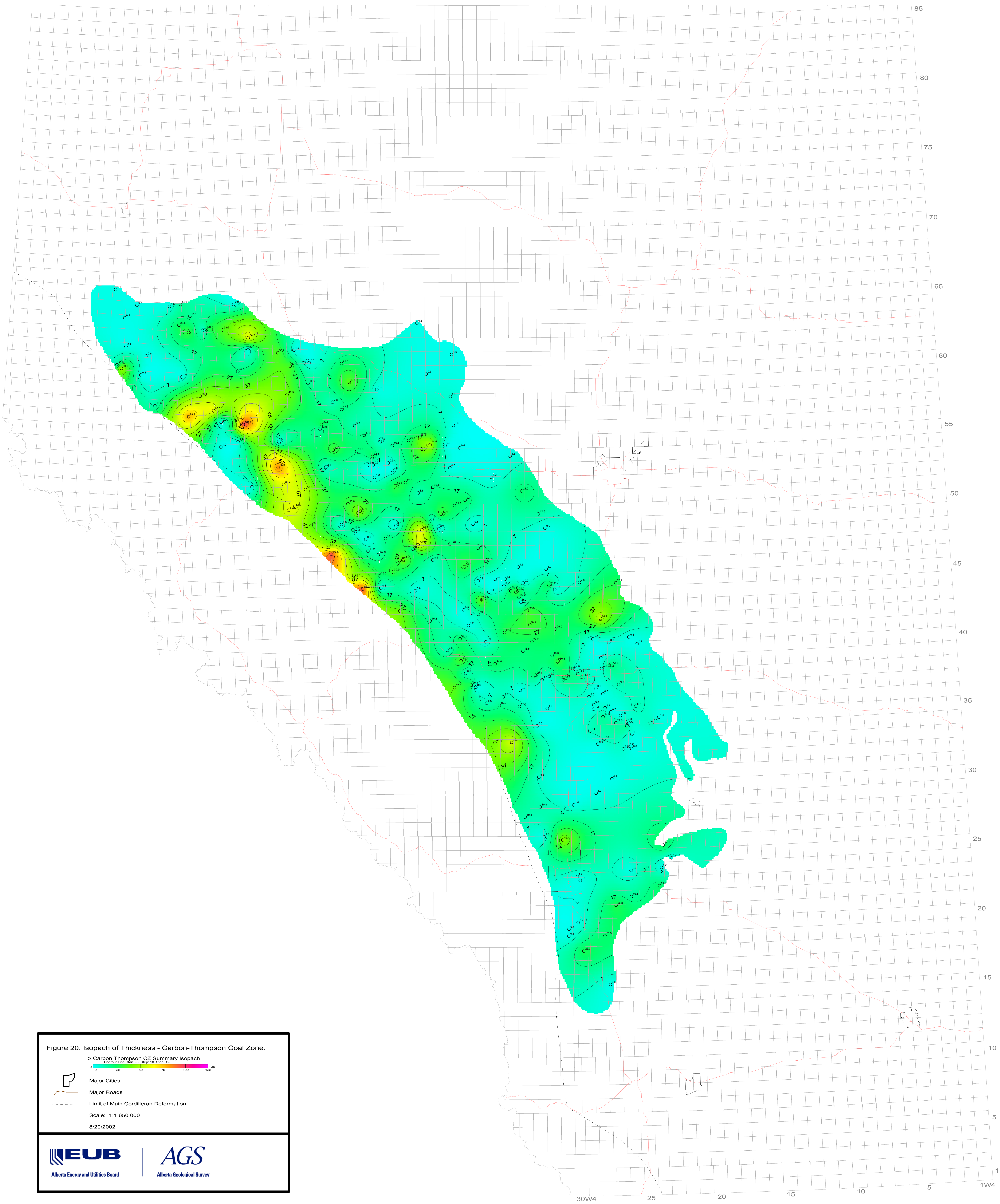


Figure 20. Isopach of Thickness - Carbon-Thompson Coal Zone.

Carbon Thompson CZ Summary Isopach
Contour Line Start: -3 Step: 10 Stop: 125

0 25 50 75 100 125

Major Cities

Major Roads

Limit of Main Cordilleran Deformation

Scale: 1:1 650 000

8/20/2002

EUB Alberta Energy and Utilities Board

AGS Alberta Geological Survey

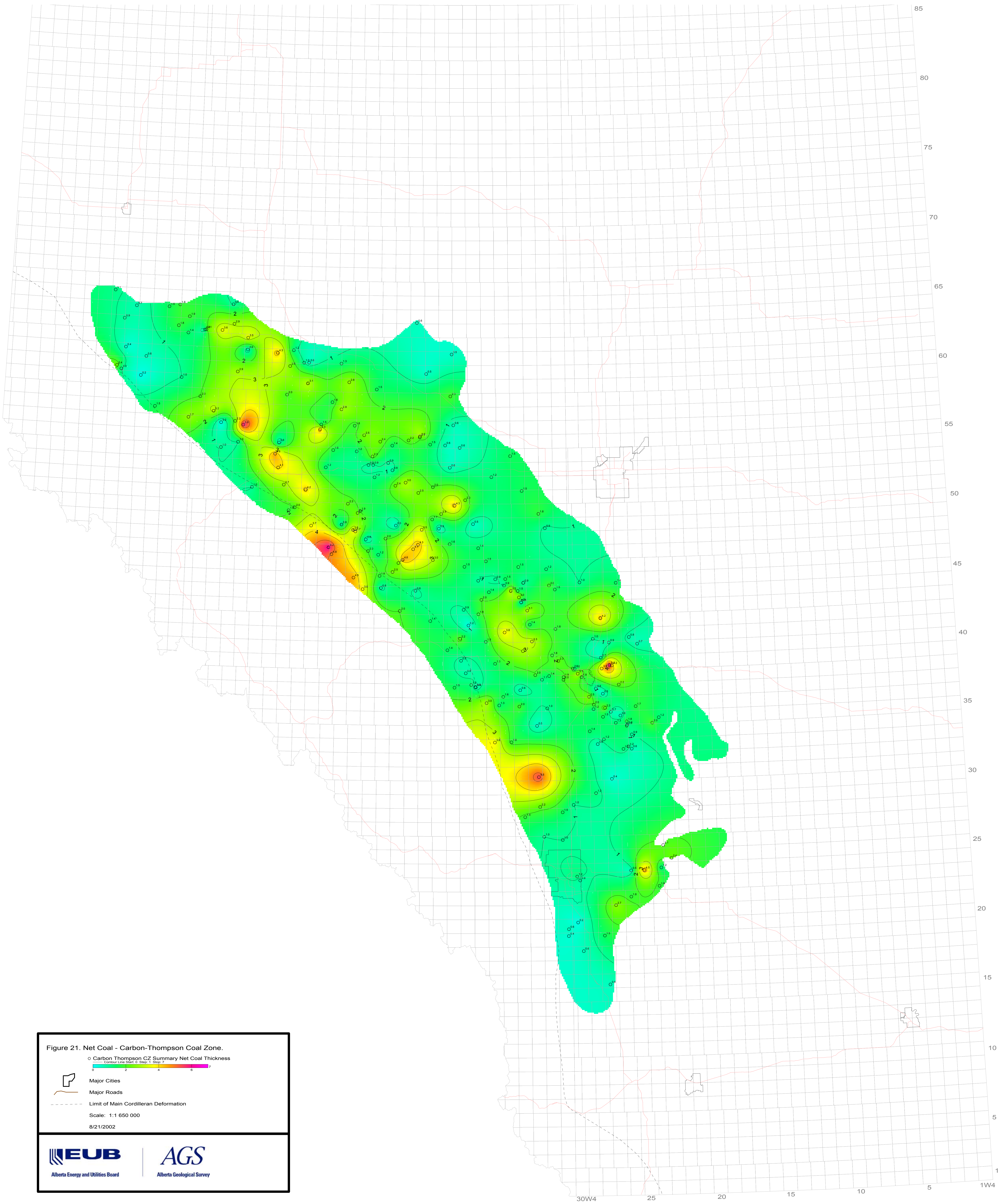


Figure 21. Net Coal - Carbon-Thompson Coal Zone.

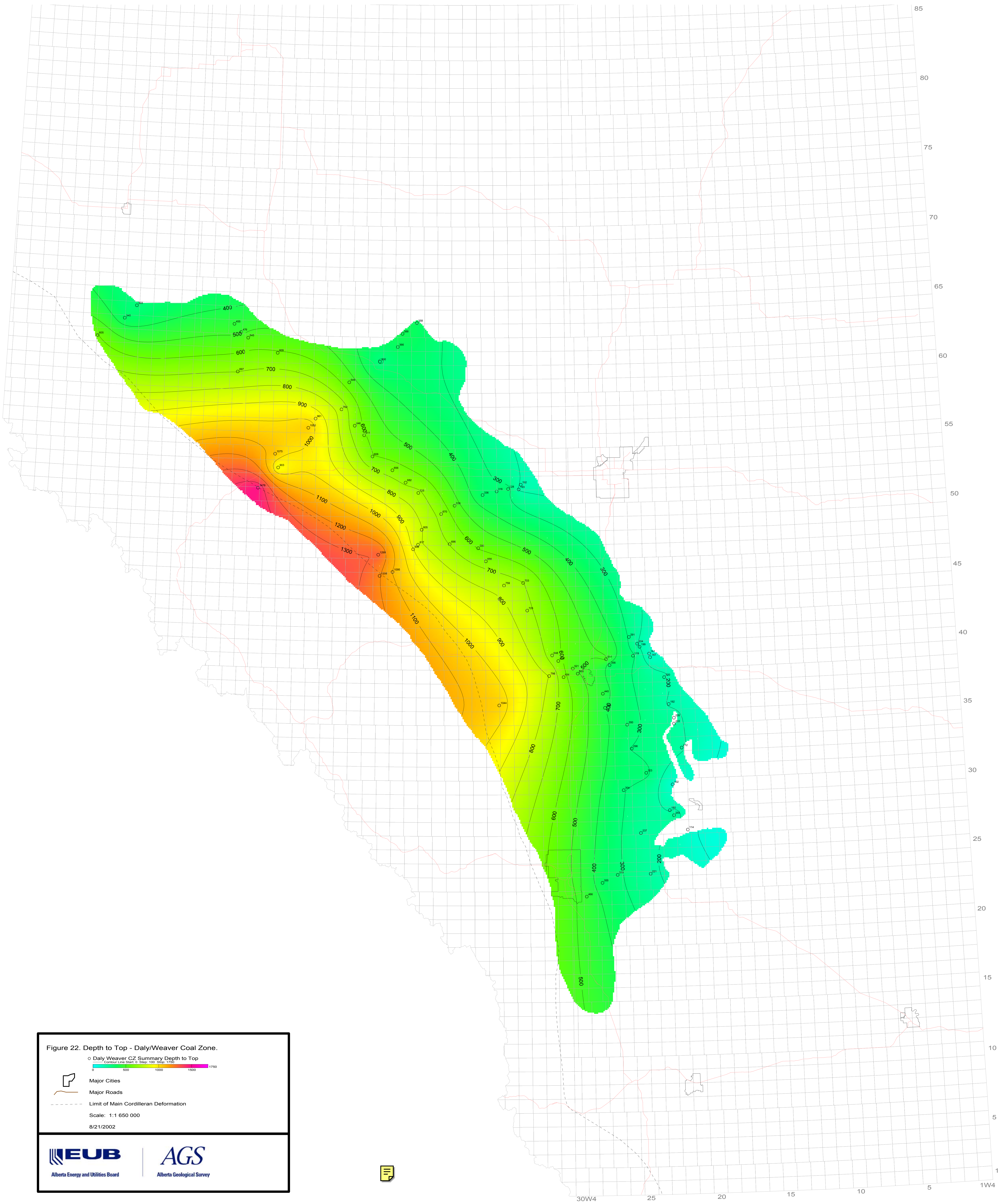


Figure 22. Depth to Top - Daly/Weaver Coal Zone.

(Figure 23). The northern part shows an increase in thickness, ranging from 35 to 65 m.

Net coal in the Daly-Weaver zone is generally thin, rarely exceeding 2 m in the southern area and ranging from 2 to 4 m in the northern area (Figure 24). Greatest net coal thickness is coincident with greatest coal zone thickness.

Net coal tonnage in the Daly-Weaver Coal Zone is estimated at 1.78 x 10^{11} t, and the depth - thickness constrained tonnage is estimated at 1.49 x 10^{11} t.

4.3.4 Drumheller Coal Zone

The Drumheller Coal Zone can be traced from 70-10W6 in the northern part of the Plains (as the equivalent Red Willow Coal Zone of the Wapiti Group) to 2-24W4 at the extreme southern limit of the Plains. This coal zone underlies a large area of the Plains, at 1.28 x 10^{11} m^2.

The Drumheller Coal Zone outcrops east of the Daly-Weaver and Carbon-Thompson zones. Much of the zone lies at depths of less than 400 m (Figure 25), although it reaches maximum depths in the range of 1300 m along the western limit. In the southern Plains, the zone dips toward the west at a much higher gradient than that of the northern Plains, going from 200 m to greater than 1000 m over a distance of nine townships.

The Drumheller Coal Zone is generally thin (<25 m) in its northern and southernmost parts, with a few local thick areas exceeding 100 m. The south-central part of zone, extending from 40-21W4 to 20-27W4, is extremely thick, ranging from 100 m at the periphery to greater than 250 m in the south-central part of this area (Figure 26).

Net coal is generally thin (averaging 2 to 4 m) throughout most of the Drumheller Coal Zone, with the thickest net coal occurring in the south-central area of greatest coal zone thickness (Figure 27). Within this area, net coal thickness commonly average 10 m and can range from 14 to 20 m in the thickest, central part of this area.

Net coal in the Drumheller Coal Zone is comparable to that of the Ardley zone, at 5.64 x 10^{11} t. Constrained coal tonnage is somewhat lower, at 4.38 x 10^{11} t, due to the greater number of thinner seams in the Drumheller compared to the Ardley.

4.3.5 Lethbridge Coal Zone

The Lethbridge Coal Zone underlies 1.70 x 10^{11} m^2 of the Plains and can be correlated with a portion of the Red Willow coal measures in the Wapiti area. A large area underlain by shallow Lethbridge coals (<500 m) occurs in the south-central Plains, extending from 1-1W4 to 45-23W4 (Figure 28). The depth of the coal zone can exceed 1400 m in the northern part and 2000 m in the southwesternmost part. As was noted in the Drumheller Coal Zone, the Lethbridge Coal Zone dips steeply toward the southwest in the southern areas.

Overall thickness of the coal zone (Figure 29) averages less than 1 m in the northern area and less than 2 m for most of the area. North-trending bands with variable thickness, ranging from 10 to 30 m, extend from 47-23W4 to 10-23W4 and from 40-28W4 to 17-30W4.

Net coal thickness, although generally thin (averaging <1 m in the north and <2 m in the south), occurs along the trend of thicker coal zone (Figure 30). Furthermore, thick Lethbridge coals occur west of the

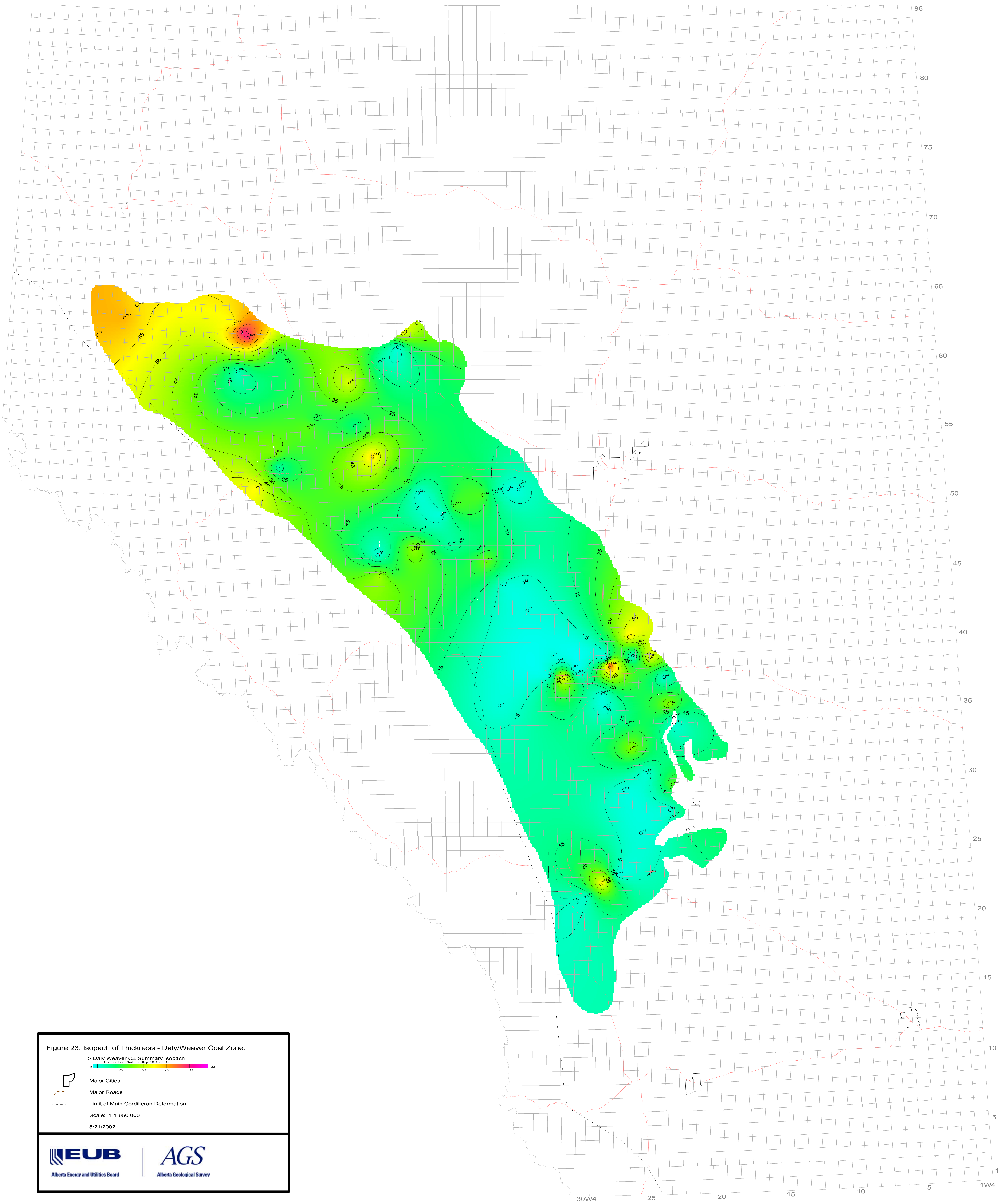


Figure 23. Isopach of Thickness - Daly/Weaver Coal Zone.

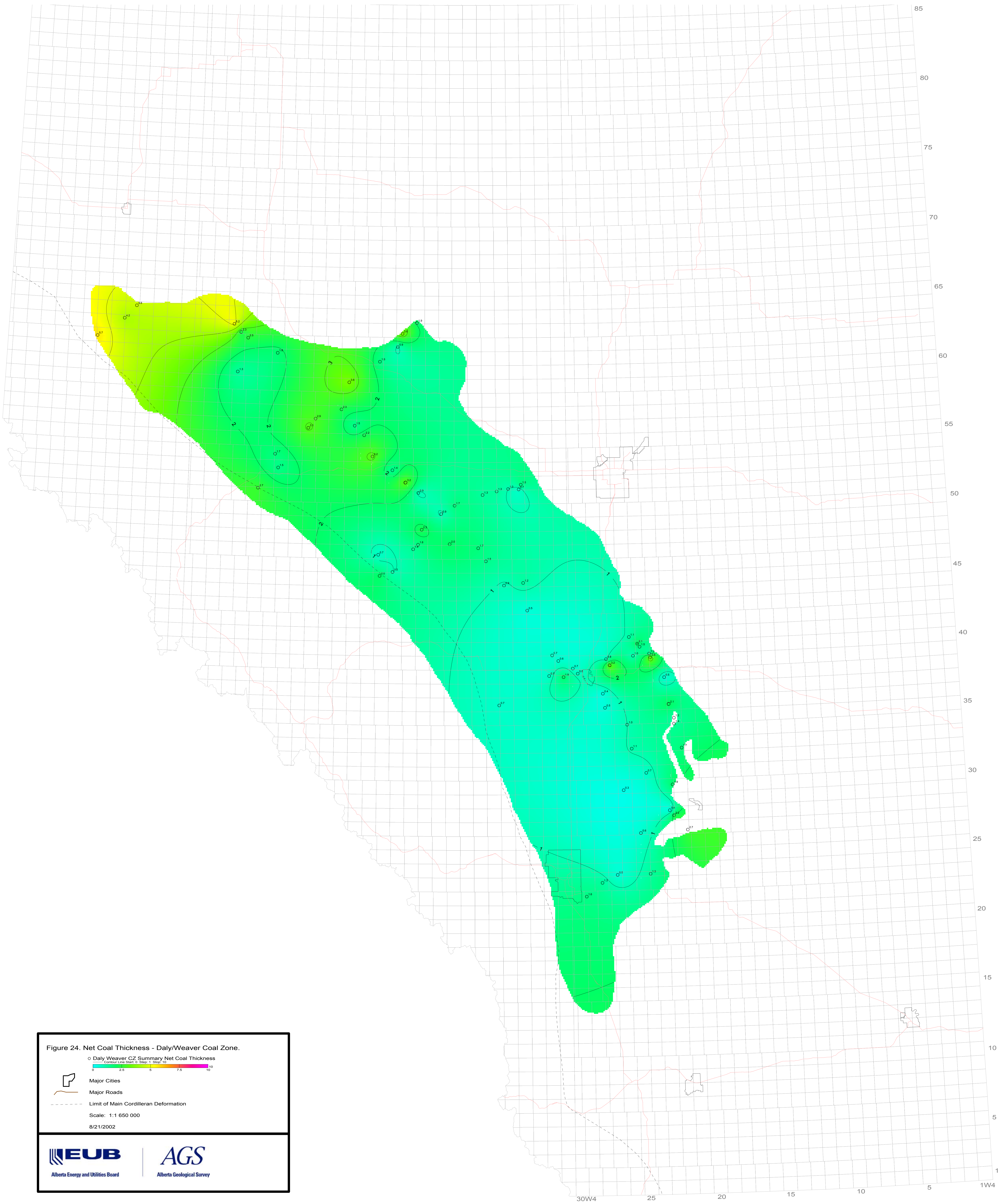


Figure 24. Net Coal Thickness - Daly/Weaver Coal Zone.

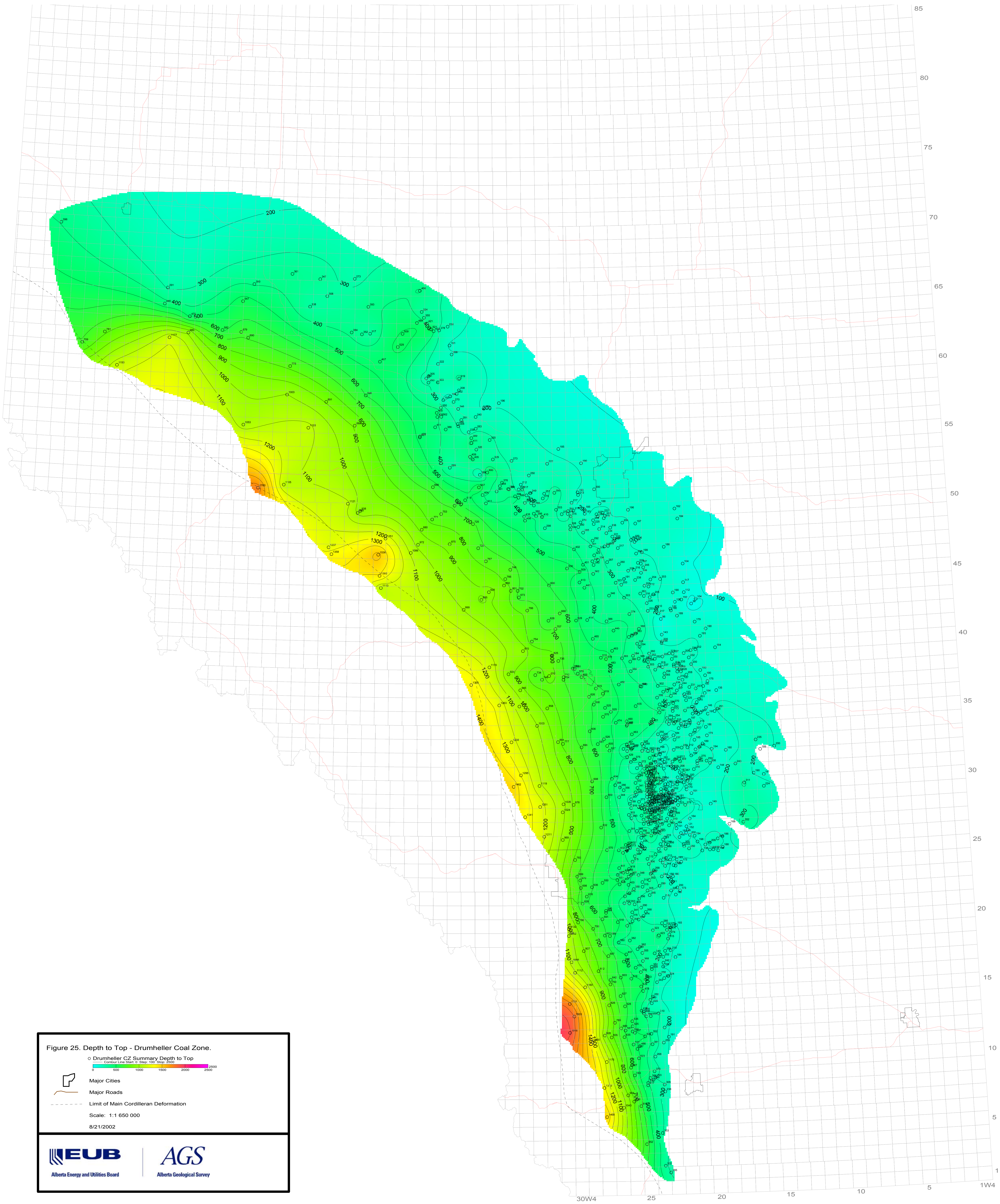


Figure 25. Depth to Top - Drumheller Coal Zone.

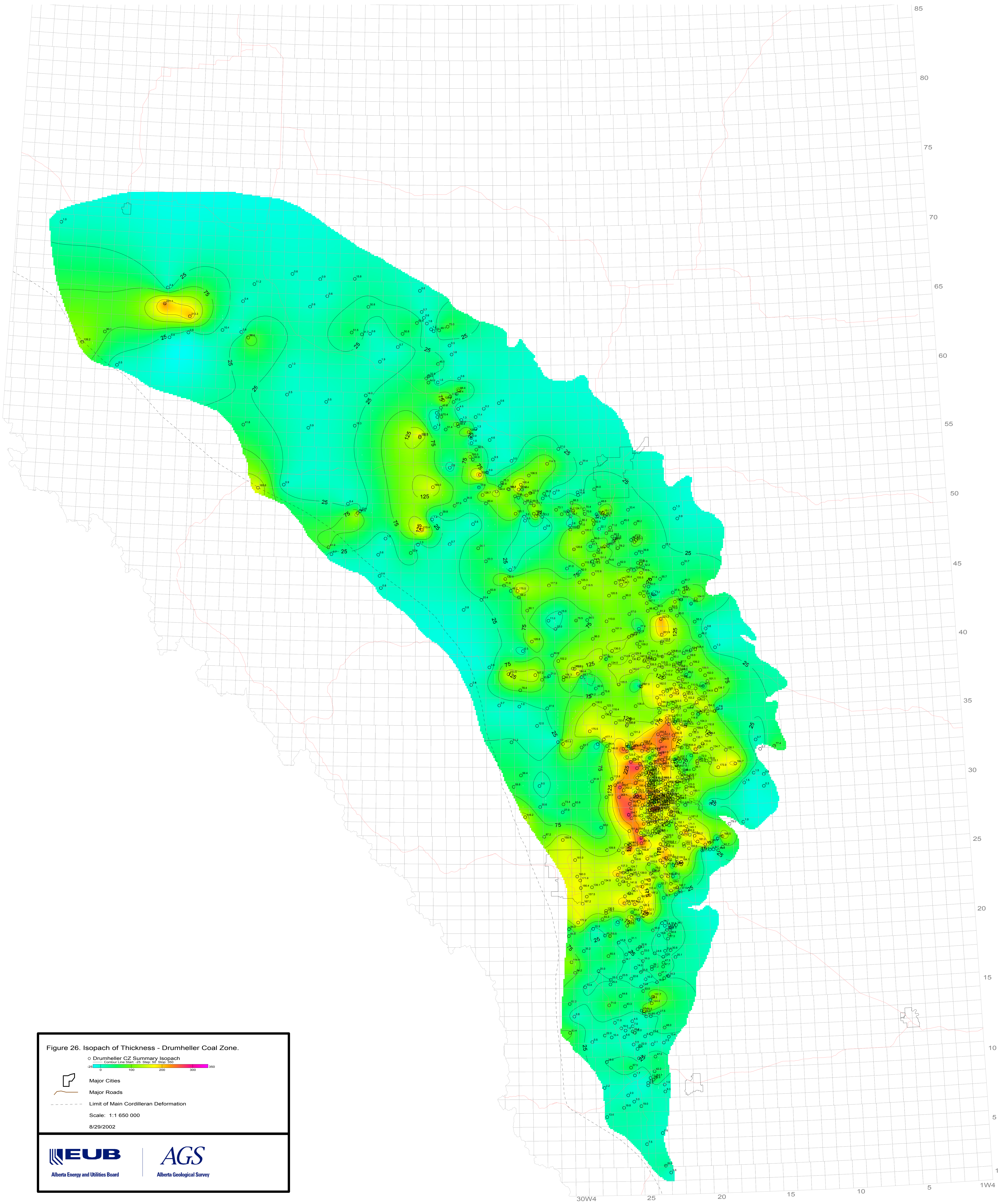


Figure 26. Isopach of Thickness - Drumheller Coal Zone.

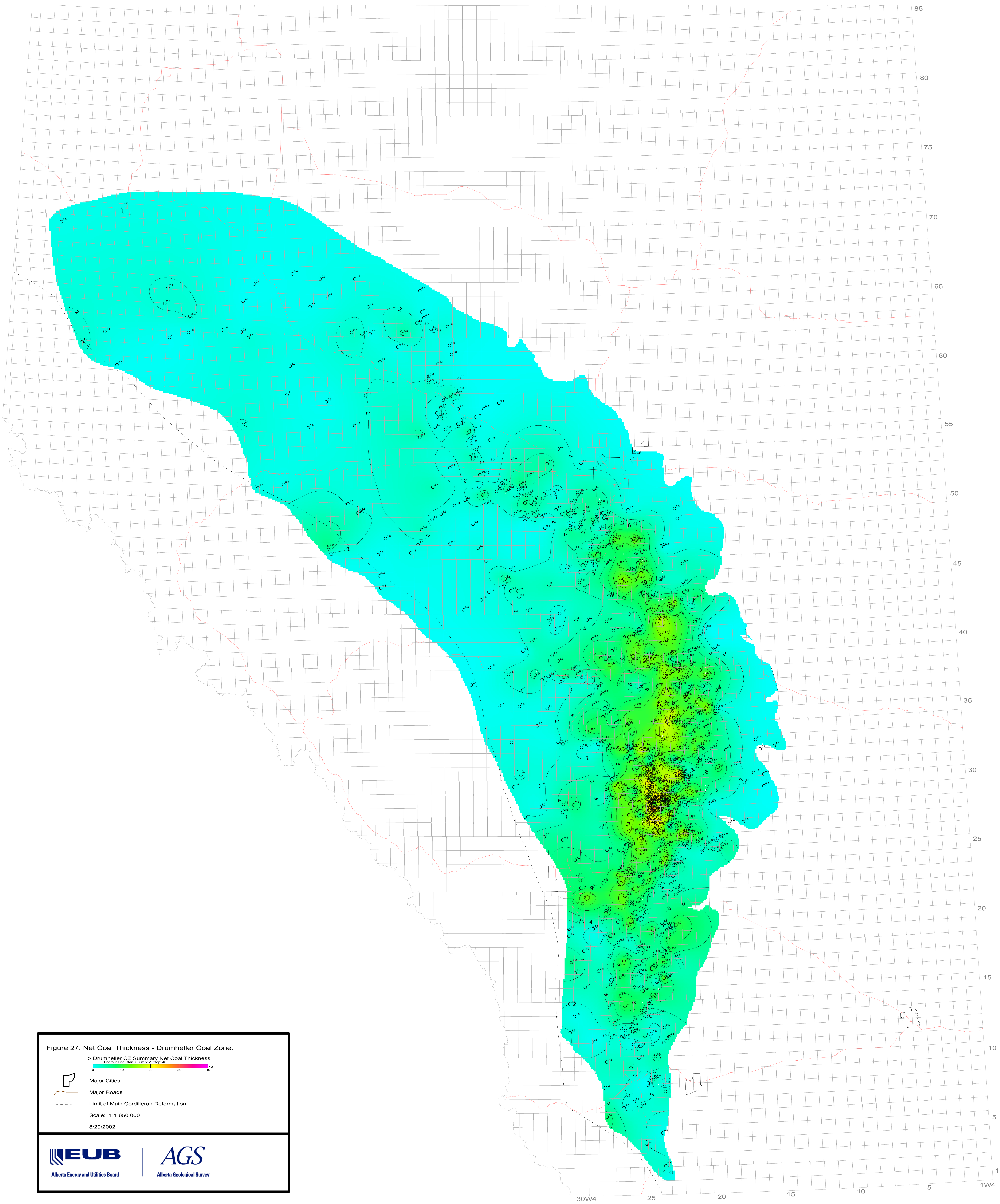


Figure 27. Net Coal Thickness - Drumheller Coal Zone.

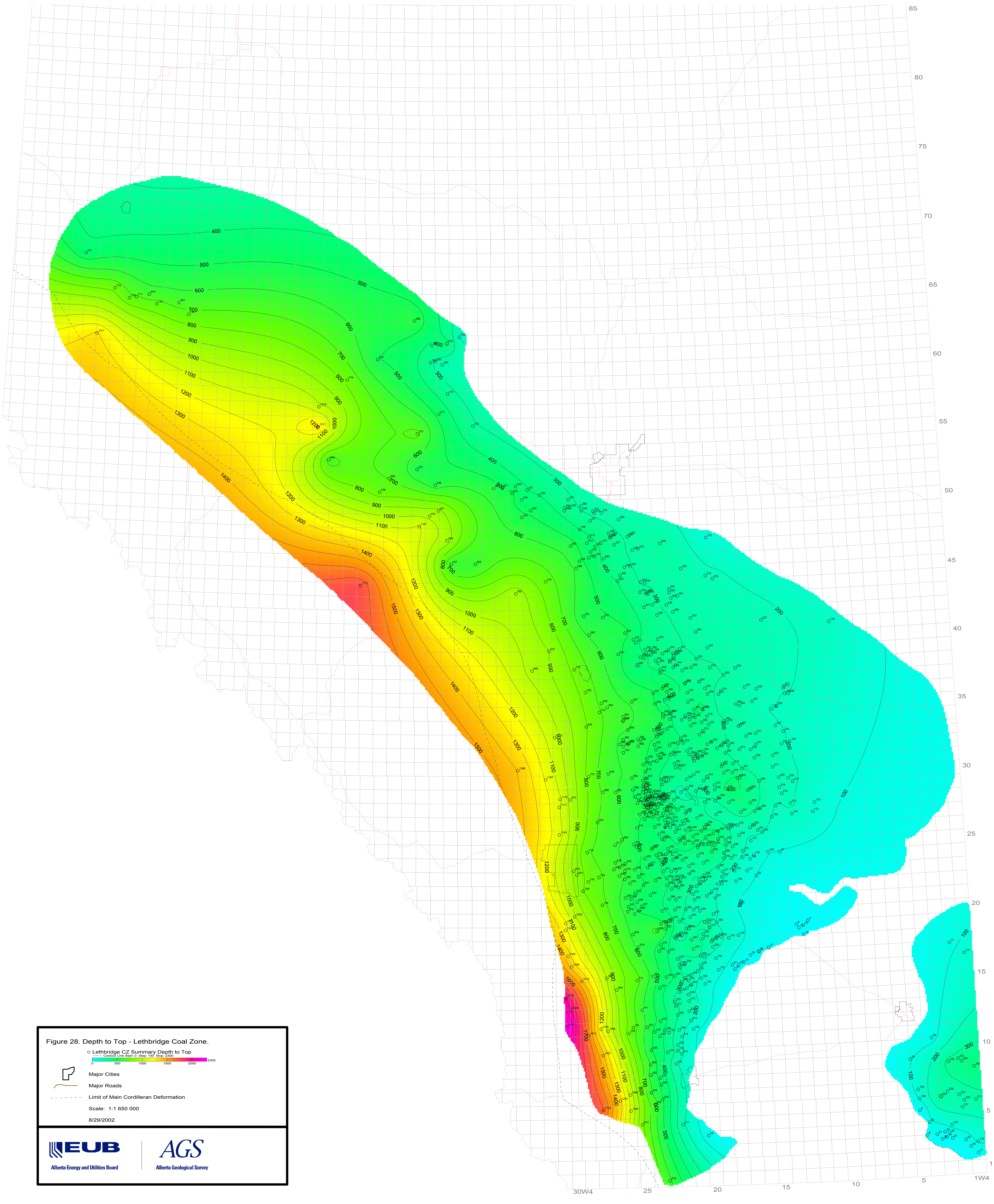


Figure 28. Depth to Top - Lethbridge Coal Zone.

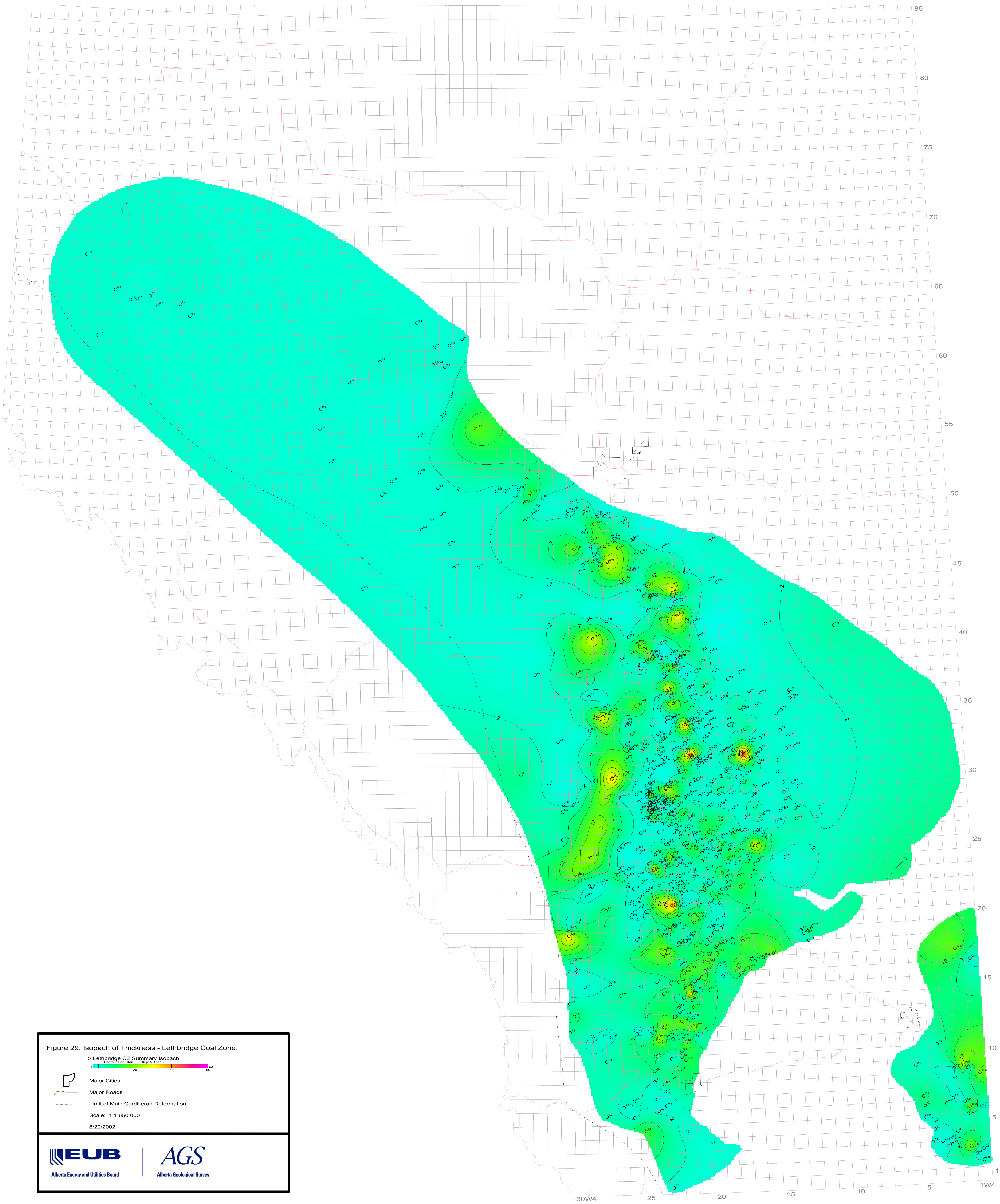


Figure 29. Isopach of Thickness - Lethbridge Coal Zone.

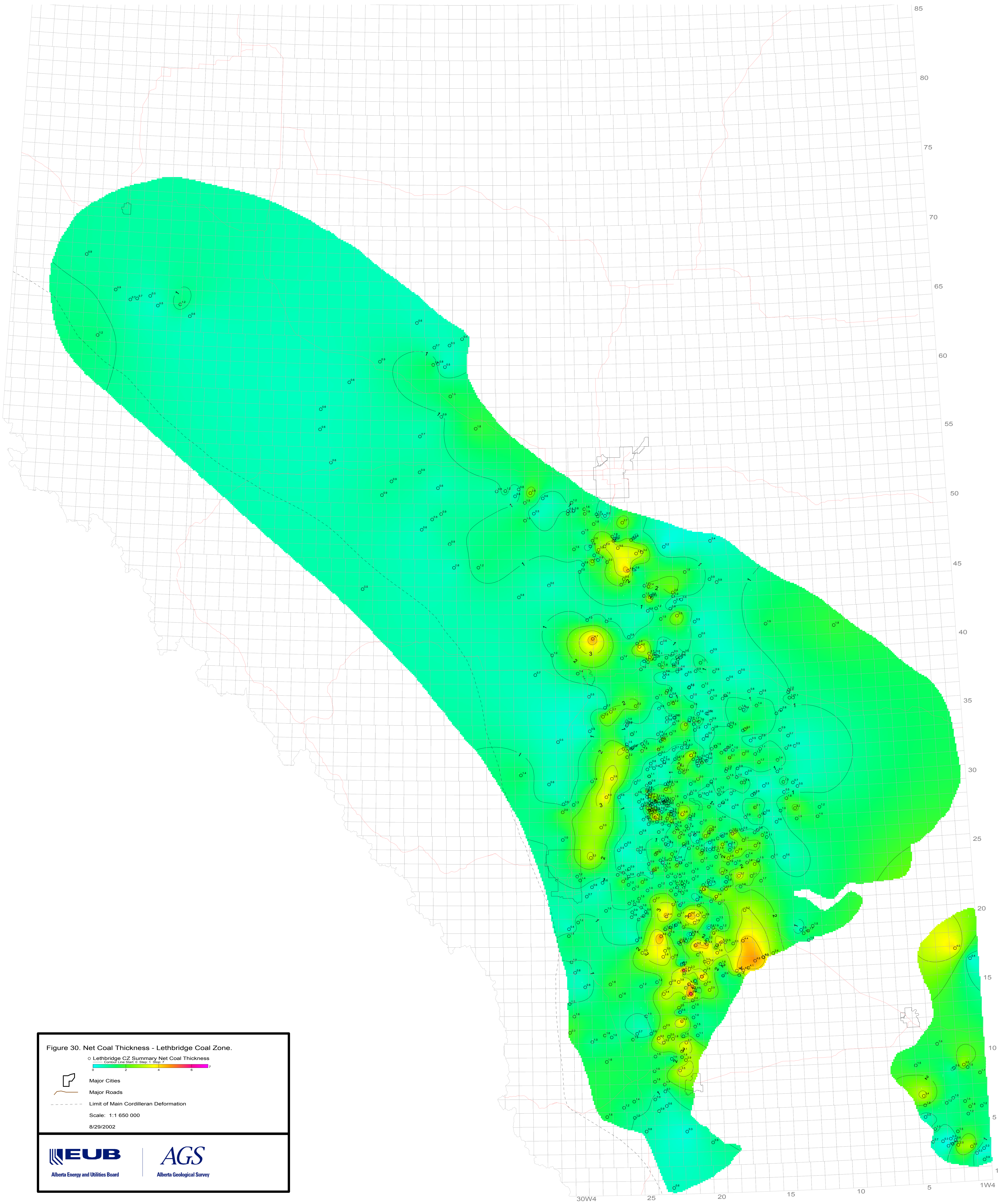


Figure 30. Net Coal Thickness - Lethbridge Coal Zone.

outcrop in the area extending from 22-16W4 to 9-24W4. These coals are not coincident with the thickest total coal zone, and range in net coal thickness from 3 to 5 m. There is some evidence of thick net coal just south of Edmonton (46-23W4 to 44-25W4), where coal net thickness averages 3 m and is associated with a zone thickness of 29 m.

Net coal tonnages for the Lethbridge Coal Zone is 2.77 x 10^{11} t. This tonnage is severely reduced to 1.13 x 10^{11} t when constrained by seam thickness greater than 1 m and depth greater than 200 m., because the depth cutoff eliminates some of the thickest coals in the southern part of the zone, and most of the northern coals are less than 1 m thick.

4.3.6 Taber Coal Zone

The area underlain by the Taber Coal Zone (1.90 x 10^{11} m^2) is well defined in the southern part. Limited data suggest that the zone may be present at depths as great as 1500 m in the northern Plains. Most of the zone is distributed at shallow depths, typically less than 600 m, in the central part (Figure 31). In the southern and southeastern parts, it occurs at depths of less than 500 m and is shallower than 300 m throughout much of the area.

The Taber Coal Zone shows variable thickness, ranging from less than 2 m in the northern part up to 10 to 30 m as locally developed 'pods' scattered throughout the area from 50-23W4 to 1-2W4 (Figure 32).

Net coal in the Taber Coal Zone follows the trend of greatest coal zone thinkness and also occurs just to the east and north of the thickest coal of the Lethbridge Coal Zone. Generally, the thickest coals occur at depths less 300 m, although the area around 28-14W4 has thick coals (5 m net thickness) at depths greater than 300 m (Figure 33). Taber coal net thickness is generally less than 2 m, but may attain net thickness in the range 4 to 5 m where developed in local thick areas.

Net coal tonnage for the Taber is calculated to be 3.35 x 10^{11} t. Much of the coal occurs at shallow depths and has thin net coal, resulting in a constrained tonnage of 1.47 x 10^{11} t.

4.3.7 McKay Coal Zone

The McKay Coal Zone underlies much of the Alberta Plains (2.12 x 10^{11} m^2), extending from as far north as 70-11W6 to 70-25W4, to as far south as 1-1W4 to 1-25W4. The south and central parts of the zone are fairly shallow (<700 m), its dip steepens from the central part of the Plains toward the west, and depths up to 1800 m are encountered (Figure 34). Extensive shallow coal (averaging 400 m and less) occurs in southern and central Alberta, extending from the Alberta-Saskatchewan boundary to approximately Rge. 20, W 4th Mer.

Coal zone thickness is minimal in the northern part (typically <1 m), with a few isolated seams in the west-central part (Figure 35). A north-trending band of thick coal zone extends from 55-23W4 to 15-10W4. The coal zone thickness is erratic, occurring in thin and thick local pods. The greatest thickness occurs the east and southeast of Edmonton, and east and southeast of Calgary.

Most of the area contains thin net coal (<1 m), particularly throughout the northern and western parts. Thickest net coal coincides with the thickest coal zone areas (Figure 36). The thickest and most extensive coals occur east and southeast of Edmonton (46-23W4 to 56-16W4), where net coal exceeds 3 m, and scattered throughout the north-trending thick coal zone band, as locally thick areas with up to 4 m net coal.

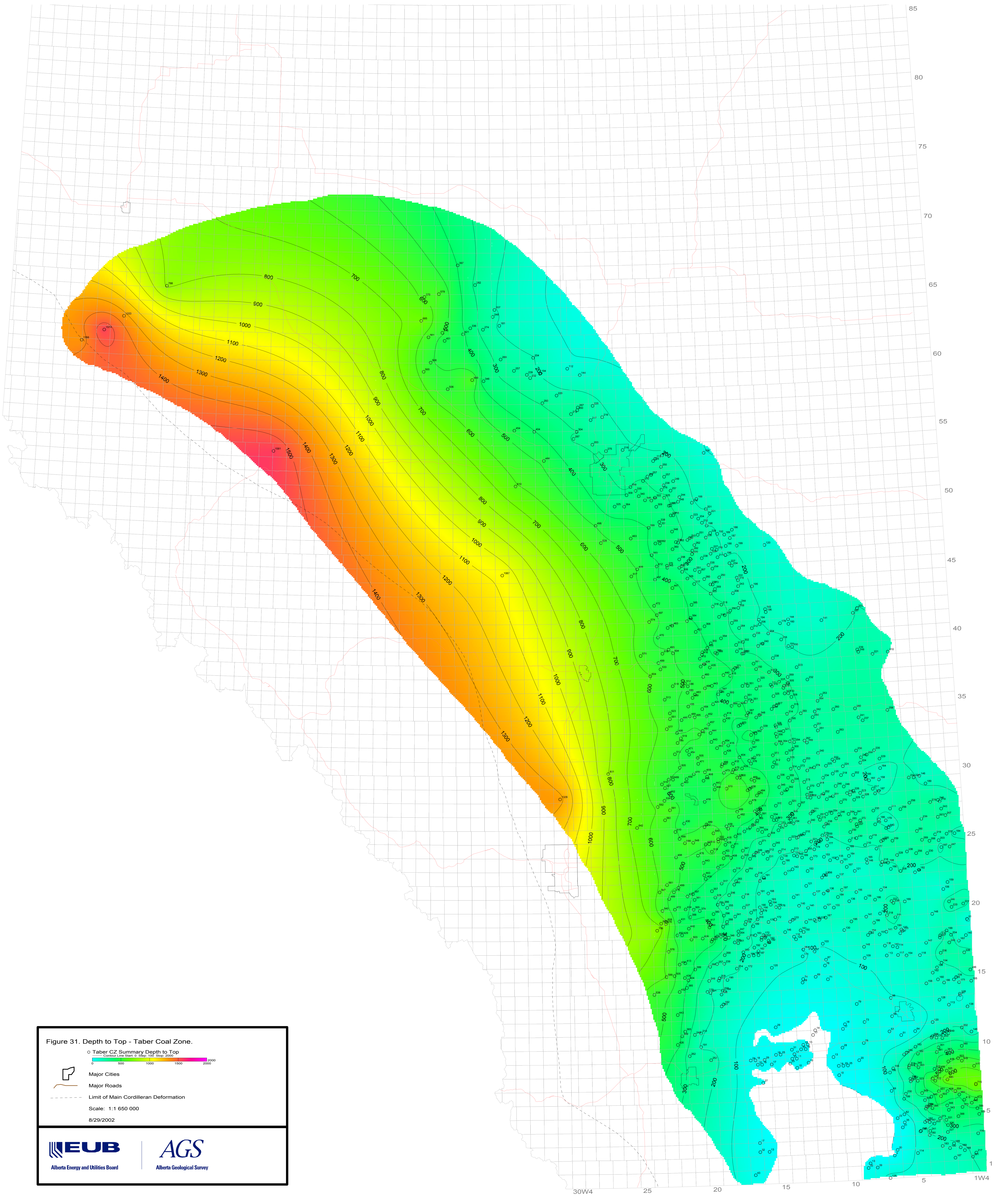


Figure 31. Depth to Top - Taber Coal Zone.

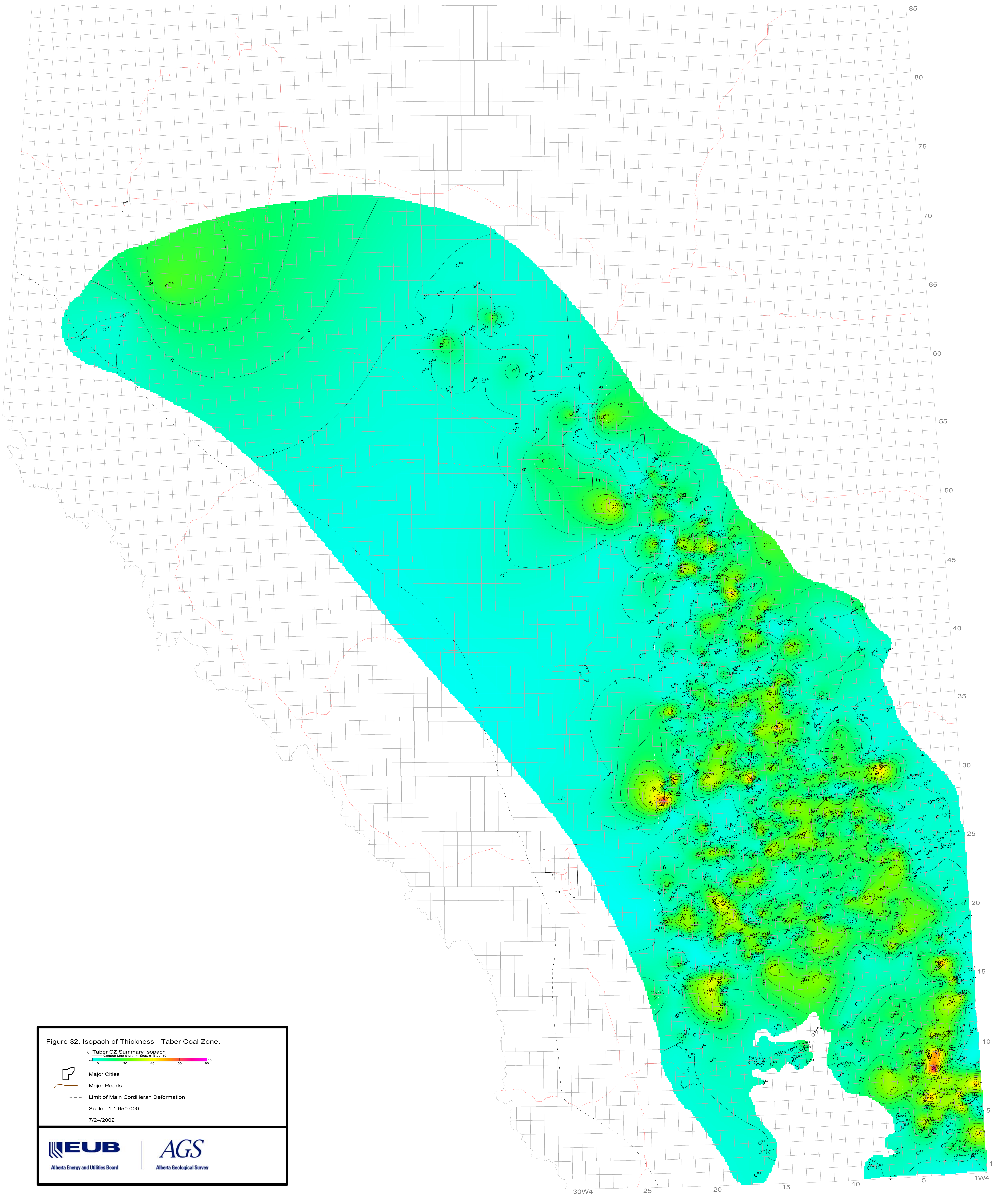


Figure 32. Isopach of Thickness - Taber Coal Zone.

Taber CZ Summary Isopach
Contour Line Start: -4 Step: 5 Stop: 80
-4 0 20 40 60 80 80

Major Cities

Major Roads

Limit of Main Cordilleran Deformation

Scale: 1:1 650 000

7/24/2002

EUB Alberta Energy and Utilities Board

AGS Alberta Geological Survey

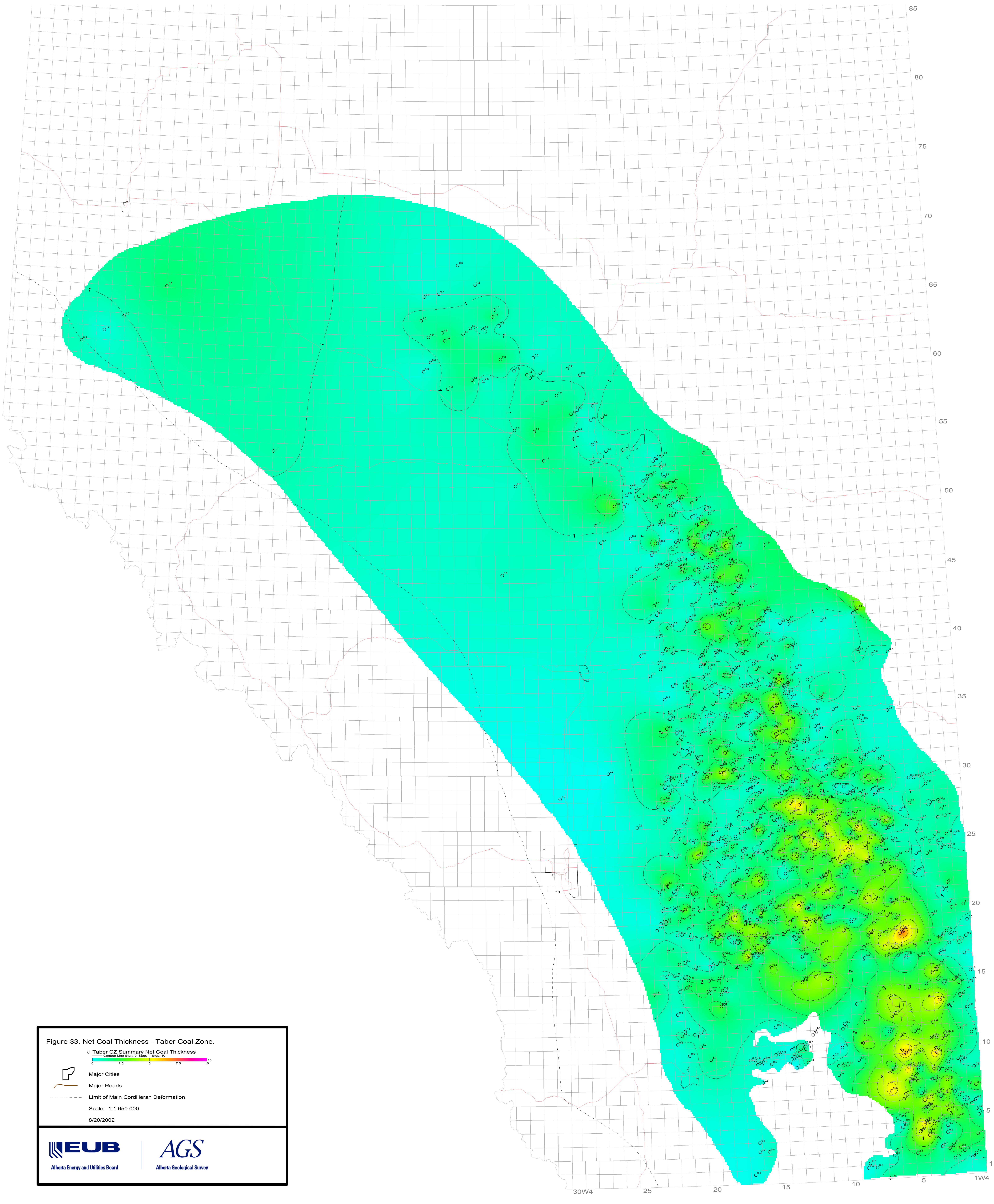


Figure 33. Net Coal Thickness - Taber Coal Zone.

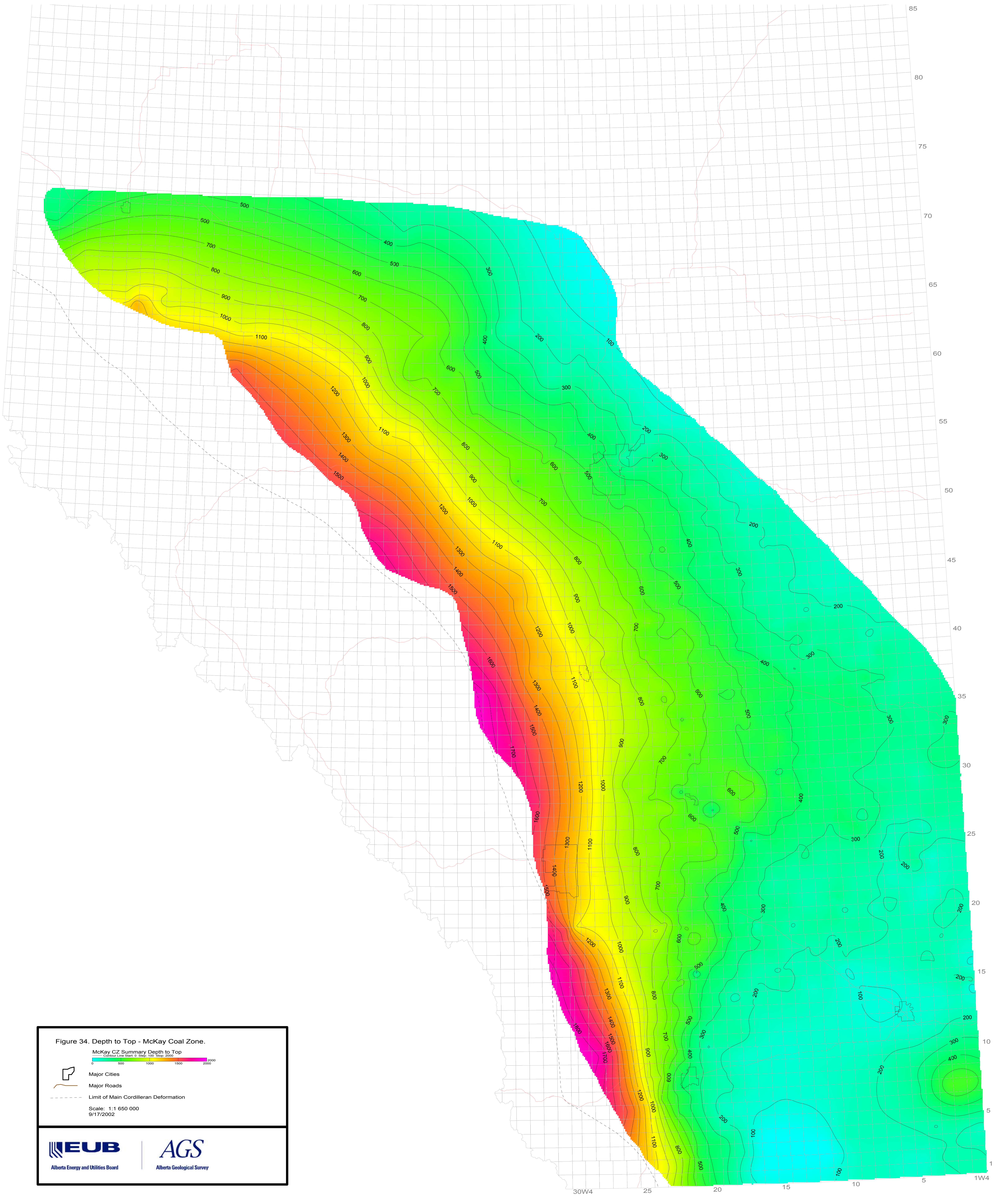


Figure 34. Depth to Top - McKay Coal Zone.

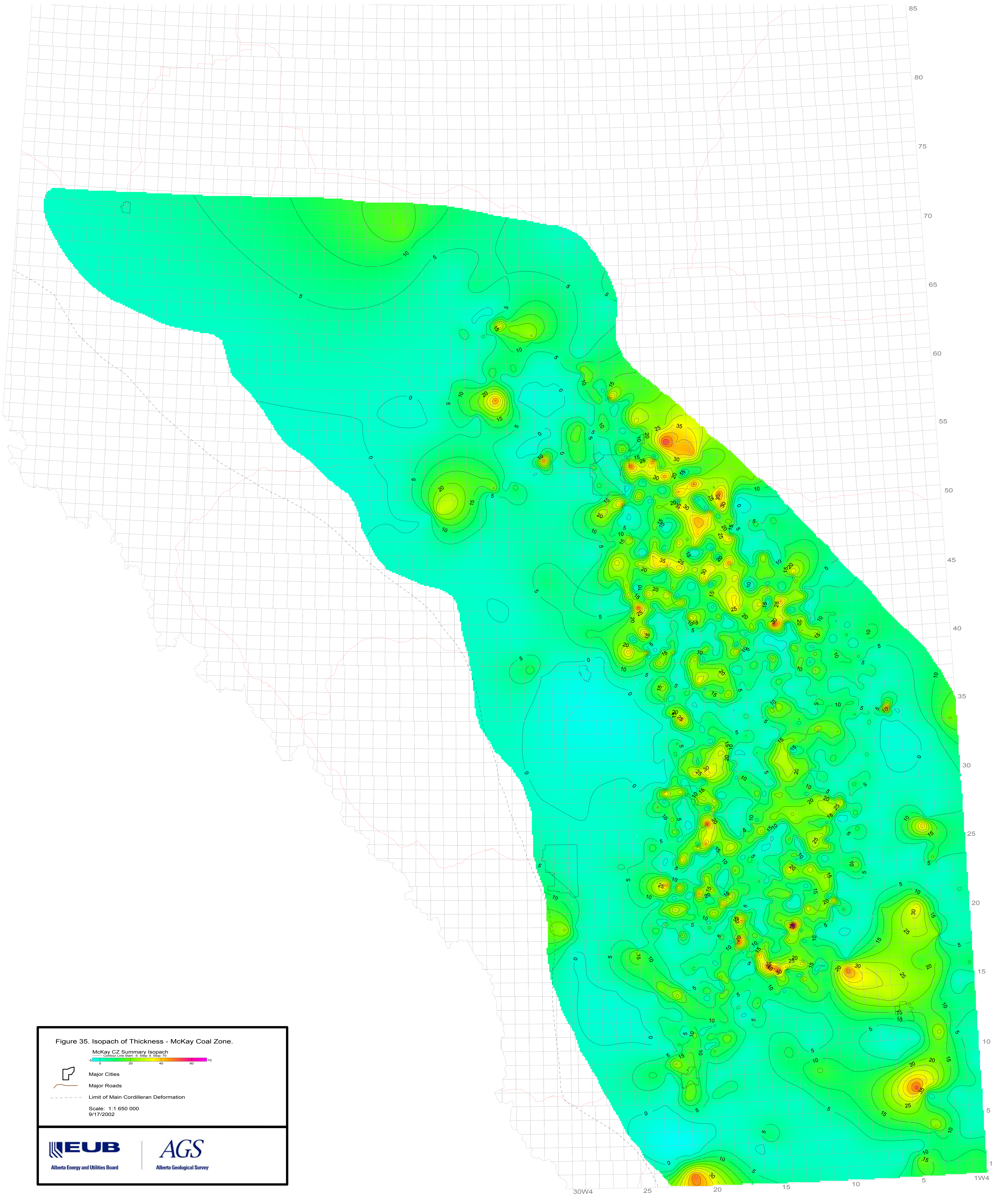


Figure 35. Isopach of Thickness - McKay Coal Zone.

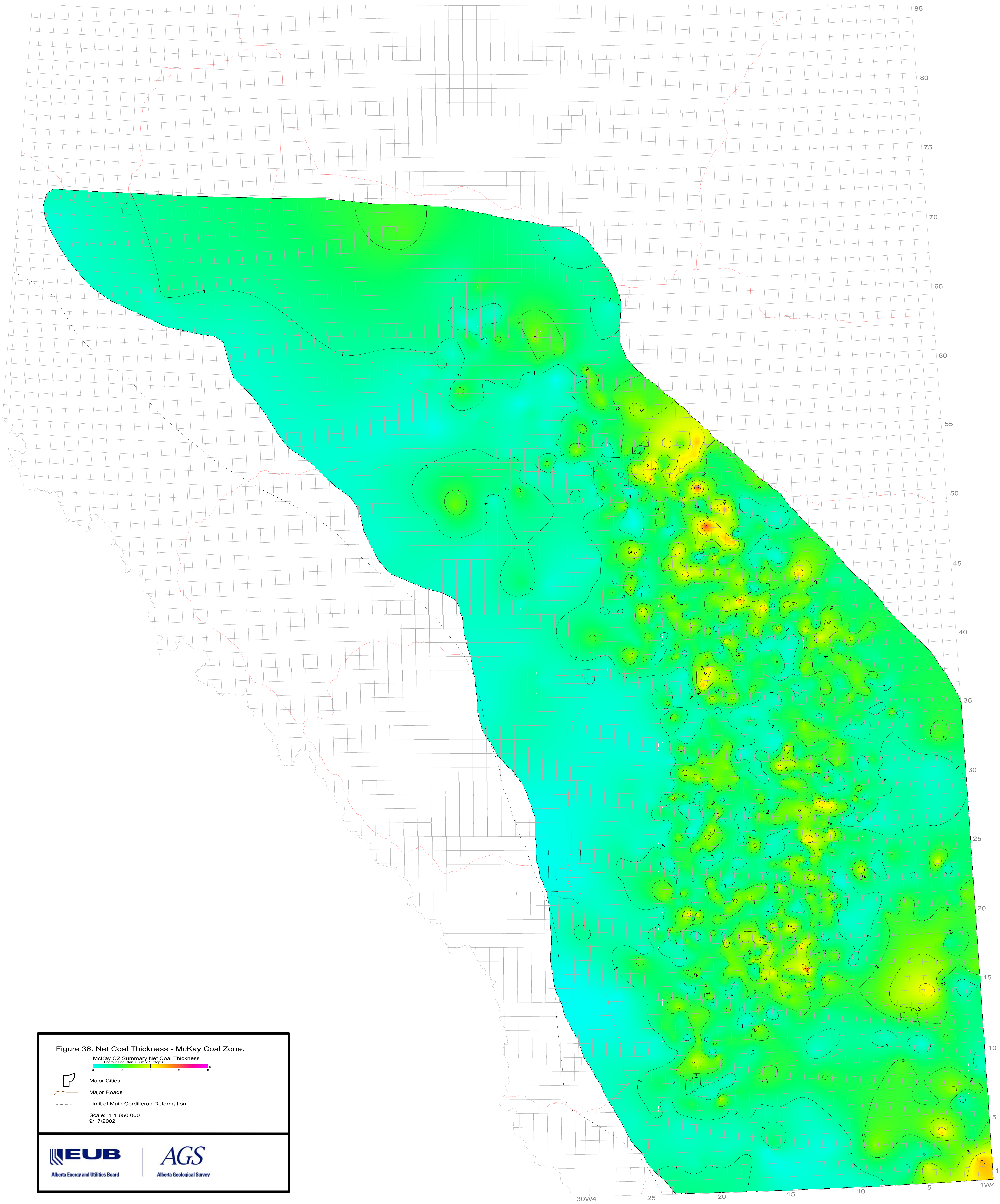


Figure 36. Net Coal Thickness - McKay Coal Zone.

Net coal tonnage for the McKay Coal Zone is calculated to be 4.03 x 10^{11} t. This tonnage is based on good data control in the central and eastern parts, but limited data in the north, west and southeast. Constrained tonnage is calculated at 2.41 x 10^{11} t.

5 Gas Resources Evaluation

5.1 Coal Distribution, Volume and Tonnage

Maps and surfaces of coal-zone depth and net coal thickness were used to generate gas-potential resource maps and total-resource estimates. Grid surfaces of various parameters (net coal, depth, area, tonnage) were generated (*see* section 4), upon which gas resource parameters (such as gas-capacity isotherm data) were applied. From the calculated gas-in-place estimates, gas-resource distribution maps and total gas-resource potential were obtained for each coal zone (Figures 37–48).

5.2 Gas Potential

Gas generation in coal is predominantly a function of rank (maturity) and organic composition, whereas gas retention (or holding capacity) is controlled, to a large extent, by reservoir pressure (a function of depth). In evaluating gas prediction equations applicable to the study area, it was determined that rank distribution observed within the Alberta Plains was insufficient to adequately predict gas concentrations. This is a result of the relatively low rank of the coal (significant gas generation is not attained in coals until a rank of high-volatile A bituminous to medium-volatile bituminous is attained (Levine, 1993; Rice, 1993). Coal zones in the Plains are typically within in the subbituminous B/A to high-volatile C to B rank range. Biogenic-methane generation at shallow depths may contribute to the gas potential of low-rank coals (Rice, 1993).

The actual amount of gas held within a coal may be determined by collecting a sample (core or cuttings) from drilling operations, sealing the sample in a canister and measuring the evolved gas under controlled conditions (Gas Research Institute, 1997). The amount of gas the coal can hold is determined from adsorption-isotherm analysis, where the coal is allowed to adsorb methane to equilibrium under controlled conditions (temperature and equilibrium moisture), and the amount of gas retained at various pressures is measured. Adsorption-isotherm analysis provides the maximum gas holding capacity of the coal at different pressures (which can be equated to depth equivalents from the pressure gradient). From the calculated Langmuir volume and pressure, the maximum gas capacity for similar coal at different depths (pressures) can be determined (Gas Research Institute, 1997). Comparing the maximum (saturated) adsorption-isotherm gas capacity to the amount of coal gas desorbed from the same sample (from desorption analysis), the gas saturation can be calculated and applied in the resource evaluation.

5.3 CBM Data Used in the Gas Potential Evaluation

Adsorption-isotherm (maximum gas capacity) and gas-content (desorption isotherm) data were compiled from publicly available sources and from recent testing, and were plotted to show gas distribution across the basin. Available data were sparse, with only 18 wells reporting results (Dawson et al., 200; Rozak et al., 2002). This dataset contained analyses from seven wells, conducted under the current ASRA-AGS study in conjunction with the Alberta Research Council's ongoing carbon dioxide storage–enhanced coalbed methane (CO_2/ECBM) project. Testing depths ranged from 100 to 600 m. From these well test data, desorption analysis indicated in-place gas concentrations within selected intervals. Adsorption isotherms (gas capacity) were only available for five wells from the above dataset. The dataset almost exclusively reported on the Ardley Coal Zone, with only one well reporting desorption and adsorption analyses for the Horseshoe Canyon Formation. No data were available for Belly River Group coals.

Isotherm results suggest that most coals evaluated in the Upper Cretaceous–Tertiary strata of the Alberta Plains are undersaturated with respect to gas capacity. In addition, in situ gas concentrations do not appear to correlate with rank or depth within the study area; indeed, between seams within a given well, the variability in gas concentration is not fully explained by coal composition (organic components or mineral matter concentrations; EUB/AGS (2001a,b,c). The low rank of coals within the study area (most were at maturity levels below the prime gas generation phase; Figures 10-15), combine with undersaturated conditions to make the application of strict rank versus gas content assumptions invalid in the present study area. Rank has been used in many previous studies as a key parameter in determining CBM potential (Eddy et al., 1982; Ryan, 1992); however, in the Plains area, the rank gradient is relatively low across the shallow parts of the basin (<900 m), thereby not imparting a strong control on gas potential within CBM target depths. Gas saturation and biogenic gas may impart just as much control as rank within the shallow basin.

Adsorption isotherm analysis is a very good indicator of maximum gas capacity, and may best reflect gas potential for any given coal, as coals produce much more gas than they have the capacity to retain (Levine, 1993). Adsorption isotherms from existing well samples were applied basin wide, and an acceptable match to the distribution of available gas concentration data across the Plains was obtained, after adjustment for variation in saturation as indicated by the isotherm analysis. Previous desorption analysis indicated that the basin is generally undersaturated with respect to methane capacity. Deep wells (>200 m) were assigned 70% saturation of maximum isotherm capacity, whereas shallower wells were assigned 40% saturation from isotherm capacity (saturation was based on comparing maximum capacity from adsorption-isotherm analysis to desorption-isotherm measured gas concentrations). Representative isotherm analysis results from Ardley coal were applied to the entire Ardley Coal Zone, as the results matched existing CBM desorption data. Isotherm analyses from the Horseshoe Canyon Formation were applied to coals within both the Horseshoe Canyon Formation and Belly River Group coal zones, as these coals are somewhat comparable in depositional environment, rank and genetic nature (thinner, discontinuous) relative to the Ardley coals.

5.4 Gas Concentrations

Gas concentrations were calculated on a dry, ash-free basis (daf basis), following the method recommended by Scott et al. (1995). This enables a comparison of gas contents on an ash-normalized basis between different coal areas. Furthermore, it reflects only the gas held within the organic matter. As a check, the total resource potential calculated on a dry, ash-free basis and on an as-received gas basis returned comparable results.

Gas concentrations (dry, ash-free basis, daf) were calculated and mapped on the grid area for the Ardley, Horseshoe Canyon and Belly River coal zones using the equations:

for depth>200 m:gas concentration (cc/g, daf)=Lv x (depth x grad)/(depth x grad)+(Lp x 0.70)

and

for depth<200 m:gas concentration (cc/g, daf)=Lv x (depth x grad)/(depth x grad)+(Lp x 0.40)

where Lv is Langmuir volume (cc/g, daf) and Lp is Langmuir pressure (Mpa), both obtained from isotherm analyses; depth is depth to top of coal zone (m); grad is pressure gradient (Mpa); daf is dry, ash free basis; and 0.70 and 0.40 are gas saturation values.

From the above calculations, gas-in-place estimates (cc of gas per g of coal) on a dry, ash-free basis were generated and are presented as maps delineating the gas distribution for each coal zone.

5.5 Gas Resources

Gas-resources (bcf/section) and total gas potential (volume) were calculated and mapped on the basis of gas concentration per section (reported as m^3/section and bcf/section), a measure commonly used by industry for evaluating CBM potential. The following equations were applied to the gas concentration surfaces generated for each coal zone, following the procedure of Scott et al. (1995):

gas resources (daf basis) = gas concentration (cc/g, daf) x 'pure' coal density (g/cc, daf) x net coal thickness (cm) x (9.146 x 10-4)

where 'pure' coal density = $0.905 + (1.593Ro) – 2.886Ro^2 + 2.392Ro^3 – 0.913Ro^4 + 0.133Ro^5$ (Ro is vitrinite reflectance); 9.146×10^{-4} is the constant for conversion from (cm^3/cm^2) to bcf/section (billion cubic feet/section); and daf is 'dry, ash-free basis.'

Almost all the coals studied in this report fall within the high-volatile bituminous range, represented by the reflectance range of 0.50 to 0.65%. 'Pure' coal density was calculated using modified equations of others, as reported by Scott et al. (1995), which produced a pure coal density of 1.23 g/cc for this range of coal ranks.

5.6 Gas-in-Place (GIP) Estimate: Volume/Weight Corrections

Gas-in-place (GIP) estimates can be reported in several ways, most commonly on an'as-received basis' (including ash and moisture within the coal), or on a 'dry, ash-free basis' (corrected for ash and moisture). The dry, ash-free basis is commonly used as a basis for comparing gas contents from coals of differing ash and moisture concentrations, and the gas resources generated from these numbers represent the gas held within only the coal organic matter (Scott et al., 1995).

The approach of utilizing Langmuir parameters on a dry, ash-free basis in the gas concentration equations compensated for the variability of ash distribution within a given coal zone, a variable for which there was limited data available to make proper adjustments. The GIP calculations reflect the dry, ash-free gas concentrations, with corrections for ash yield in coal volume and tonnage calculations (as ash has a greater density than coal organic matter).

The approach of Scott et al. (1995) was utilized in GIP resource calculations, in which a correction factor relating weight percentage ash-free coal and ash yield to the volume of coal (organic matter) was employed as follows:

Fvc = (Fwc x Pa) / ((Fwc + Pa) + (Fwa + Pc))

where $F_{vc}$is the volume correction factor; F_{wc} is weight percentage of coal; P_a is the density of ash; F_{wa} is the weight fraction of ash; and P_c is the density of pure coal.

The density of coal organic matter (pure coal, P_c) is 1.23 (previously derived); and the density of ash is 2.65 (based on predominance of clay minerals in the coal ash). Average ash concentrations, derived from EUB coal-reserve data, are 14% for Ardley coals, 10% for Horseshoe Canyon coals and 12% for Belly

River coals.

Gas-in-place (GIP) calculations were made using the following equation (Scott et al., 1995):

GIP = (net coal thickness x area x Fvc) x Pc x gas content (cc/g, daf)

where GIP is gas-in-place resources; $F_{vc}$is the coal-ash volume correction factor; and P_c is 'pure' coal density.

Gas-in-place estimates were calculated on a cubic metre (m^3) basis and a trillion cubic foot (Tcf) basis.

5.7 Resource Estimates

Two gas-in-place estimates are presented. The first includes all coal at all depths, and therefore represents an 'ultimate' potential for the Upper Cretaceous–Tertiary coal zones. The second estimate is constrained to net coal thickness of 1 metre or greater and a depth of 200 m or greater. This second estimate considers the facts that gas capacity and contents are low for the shallow coals. Biogenic gas potential is not well understood and may not be uniformly distributed, and it is unlikely that net coal of less than 1 m would be a viable production target.

5.8 Gas Potential for the Upper Cretaceous–Tertiary Coals of the Alberta Plains

Gas-in-place estimates were made for each coal zone by applying adsorption-isotherm parameters (derived experimentally) to the depth of coal (pressure constraint) and net coal present. Maps showing resource potential as gas-in-place, cc of gas per g of coal (daf), and as bcf/section for each coal zone are presented in Figures 37 to 48, which indicate areas of maximum resource potential. The resource potential for each coal zone is summarized, and a total resource potential (constrained and unconstrained) is presented for the Upper Cretaceous–Tertiary coal of the Alberta Plains (Table 3).

Table 3. Gas-resource potential of Upper Cretaceous-Tertiary strata, Alberta Plains.

	Gas m^3 in place	Gas m^3 constrained	Gas Tcf in place	Gas Tcf constrained	% of total constrained
Ardley Coal Zone	1.51E+12	1.43E+12	53	51	35
Carbon/Thompson Coal Zone	4.04E+11	3.64E+11	14	13	9
Daly/Weaver Coal Zone	4.06E+11	3.51E+11	14	12	8
Drumheller Coal Zone	1.07E+12	9.36E+11	38	33	23
Lethbridge Coal Zone	5.07E+11	2.47E+11	18	9	6
Taber Coal Zone	5.77E+11	3.12E+11	20	11	8
McKay Coal Zone	8.11E+11	5.29E+11	29	19	13
Totals	5.28E+12	4.17E+12	186	147	

5.8.1 Ardley Coal Zone

The gas-in-place (cc/g, daf basis) for the Ardley Coal Zone ranges from 2.5 cc/g to a maximum of 4.5 cc/g at depth. Shallow Ardley coals (<200 m) are estimated to have in the range 1 to 1.5 cc/g (Figure 37). Gas resource estimates (Figure 38) indicate two very prospective areas for high gas potential; namely, the previously described thick coal trends, where gas potential exceeds 6 bcf/section, to a maximum of 10 bcf/ section in Twp. 48–49, Rge. 14–15, W 5th Mer. and 12 bcf/section in Twp. 55-56, Rge. 19–20, W 5th Mer. These two areas coincide with greatest net coal thickness, and the northeasterly-trending band is further accentuated by elevated gas-in-place due to the 'depth anomaly' that present where the strata are deeper than the regional trend.

Total gas-resource potential for the Ardley Coal Zone is calculated at 53 Tcf. ($1.51*10^{12}m^3$). Constrained gas-resource potential (coals deeper than 200 m and >1 m net coal thickness) is calculated at 51 Tcf. ($1.43*10^{12}m^3$)

5.8.2 Carbon-Thompson Coal Zone

Gas-in-place estimates for the Carbon-Thompson Coal Zone are somewhat lower than the Ardley Coal Zone, based on adsorption-isotherm parameters. Gas-in-place (cc/g, daf basis) ranges from 1.75 to 3.25 cc/g in the deeper, western Plains. Shallow coals (<200 m) are predicted to contain between 0.5 and 1.5 cc/g gas in place (Figure 39).

Gas resources for the Carbon-Thompson Coal Zone are generally low, typically less than 0.5 bcf/section (Figure 40). A narrow band of coal, extending southeast from 57-23W5 to 46-17W5, has variable, enhanced gas content, as does the area encompassing Twp. 29–33, Rge. 2–5, W 5th Mer. These areas show the greatest resource potential within the Carbon-Thompson Coal Zone, ranging from 1 to 1.5 bcf/section.

Total gas-resource potential for the Carbon-Thompson Coal Zone is calculated at 14 Tcf ($3.97*10^{11}m^3$); however, constrained gas-resource potential is reduced slightly to 13 Tcf ($3.68*10^{11}m^3$).

5.8.3 Daly-Weaver Coal Zone

The gas-in-place distribution trends and resource potential for the Daly-Weaver Coal Zone are comparable to those of the Carbon-Thompson Coal Zone. Total gas-resource potential is calculated at 14 Tcf ($3.97*10^{11}m^3$) and constrained gas-resource potential at 12 Tcf ($3.40*10^{11}m^3$).

5.8.4 Drumheller Coal Zone

The Drumheller Coal Zone is calculated to have in-place gas contents ranging from 1.7 cc/g (daf basis) up to 3.5 cc/g at depth in the westernmost Plains. Shallow coals are predicted to have gas contents in the 0.5 to 1 cc/g range (Figure 41).

Resource potential for most of the Drumheller Coal Zone is low (<1 bcf/section); however, a north-trending central belt, extending from 45-20W4 to 20-26W4, has elevated gas in place (2-3 bcf/section). Within this trend, several local areas (including a large area northeast of Calgary, in Twp. 30–27, Rge. 22–24W4) have even greater gas-in-place contents, ranging from 4 to 6 bcf/section (Figure 42).

Total gas-resource potential for the Drumheller Coal Zone is 38 Tcf ($1.08*10^{12}m^3$), second only to that of the Ardley Coal Zone; constrained gas-resource potential is 33 Tcf ($9.35*10^{11}m^3$).

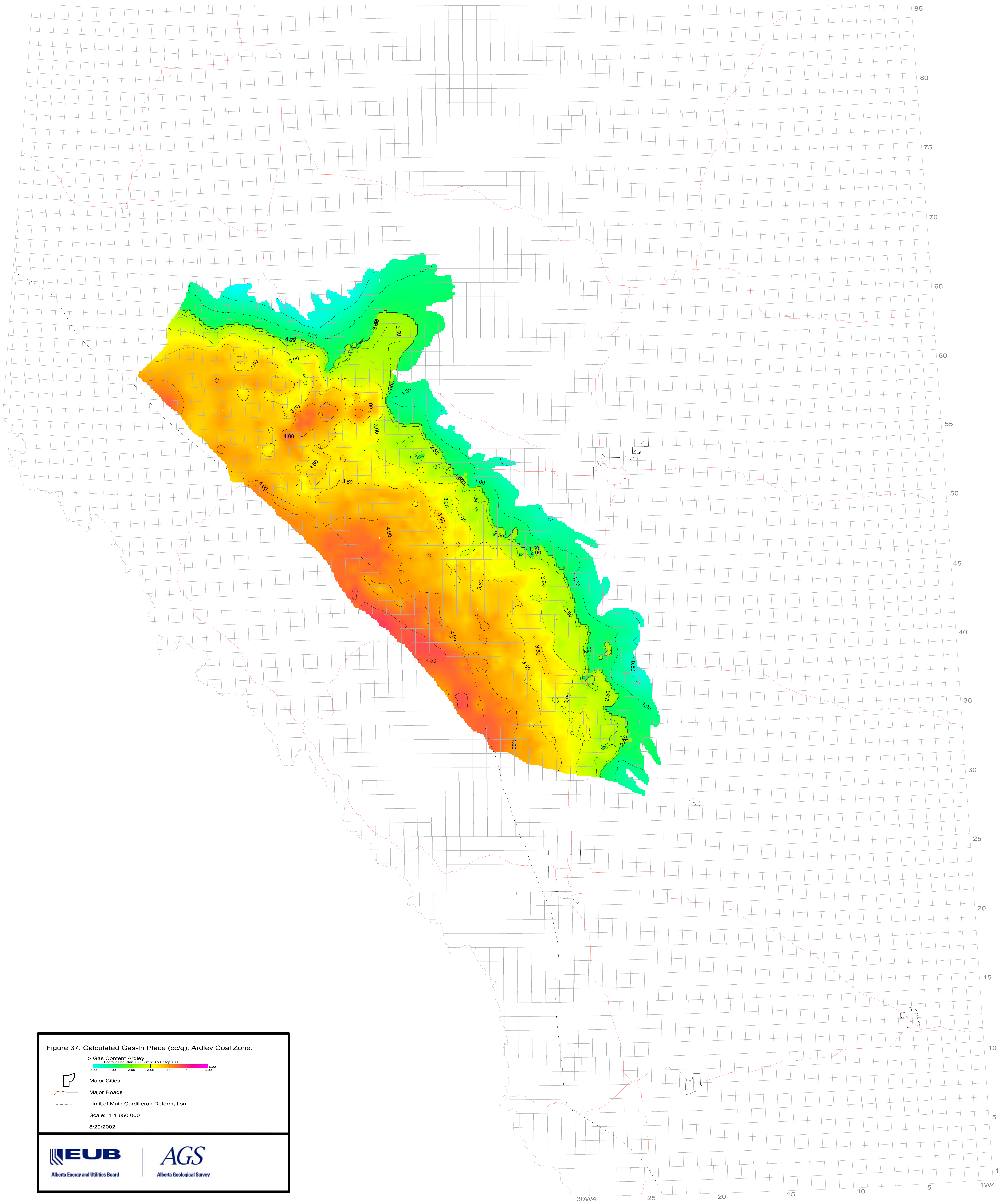


Figure 37. Calculated Gas-In Place (cc/g), Ardley Coal Zone.

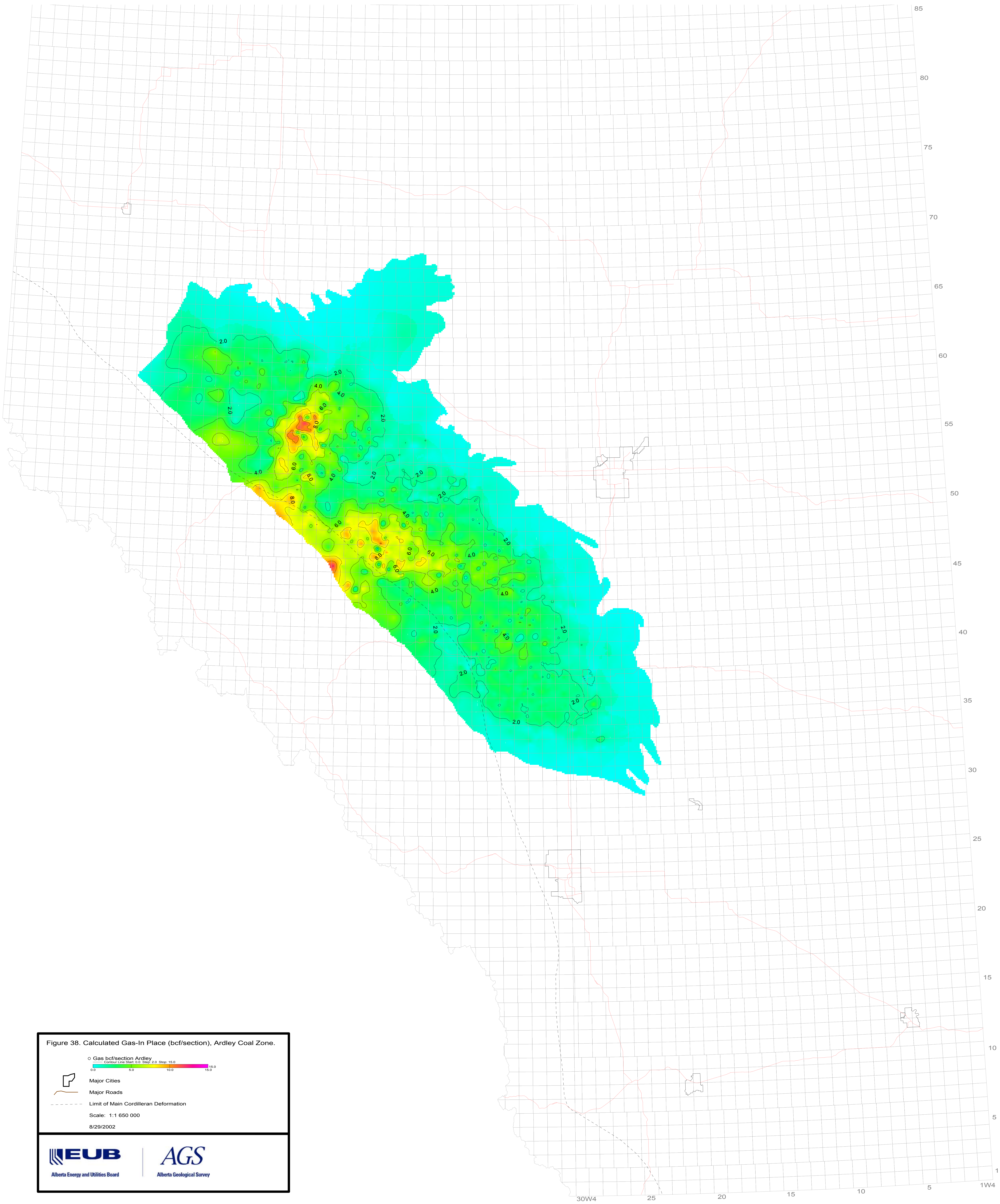


Figure 38. Calculated Gas-In Place (bcf/section), Ardley Coal Zone.

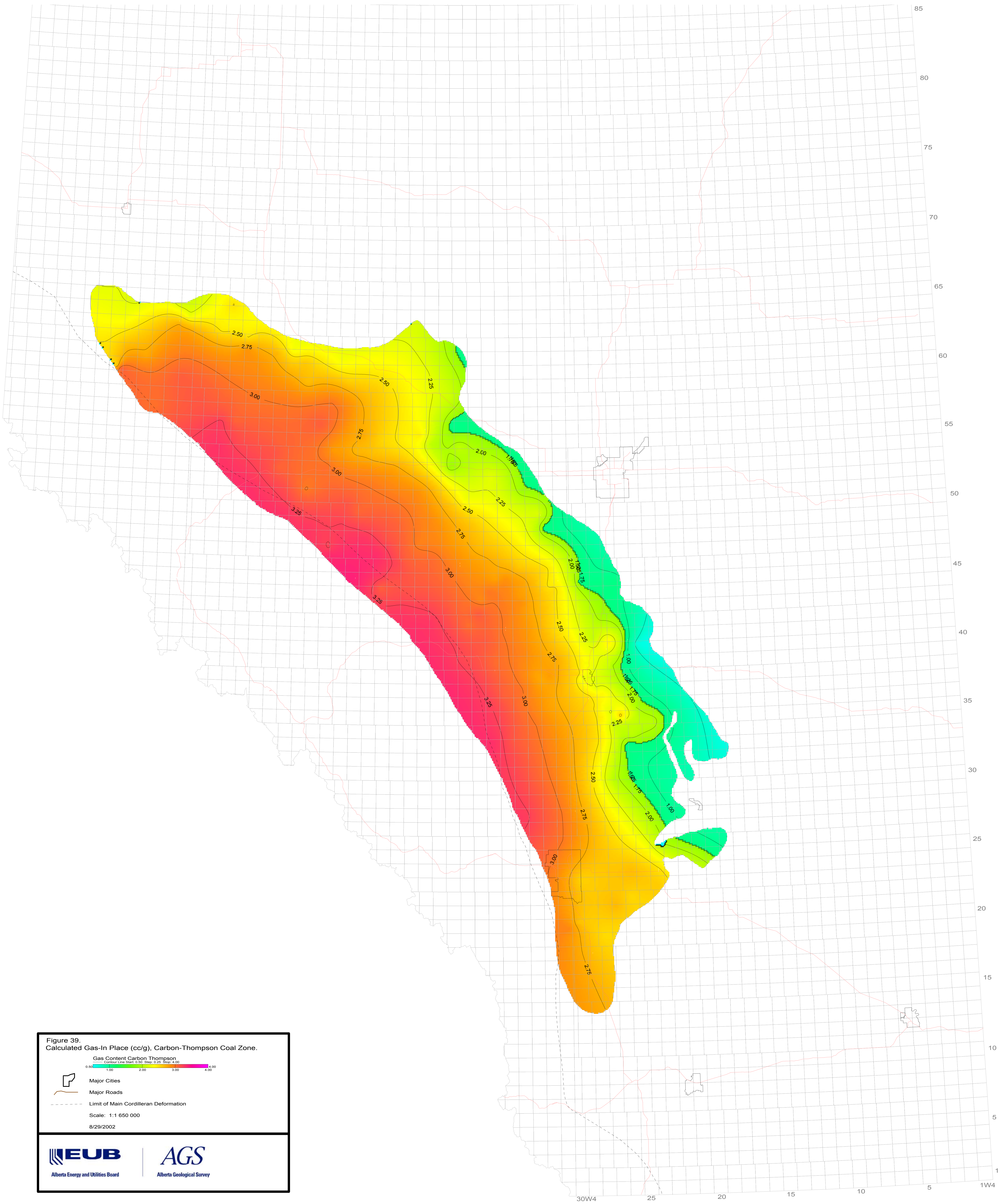


Figure 39.
Calculated Gas-In Place (cc/g), Carbon-Thompson Coal Zone.

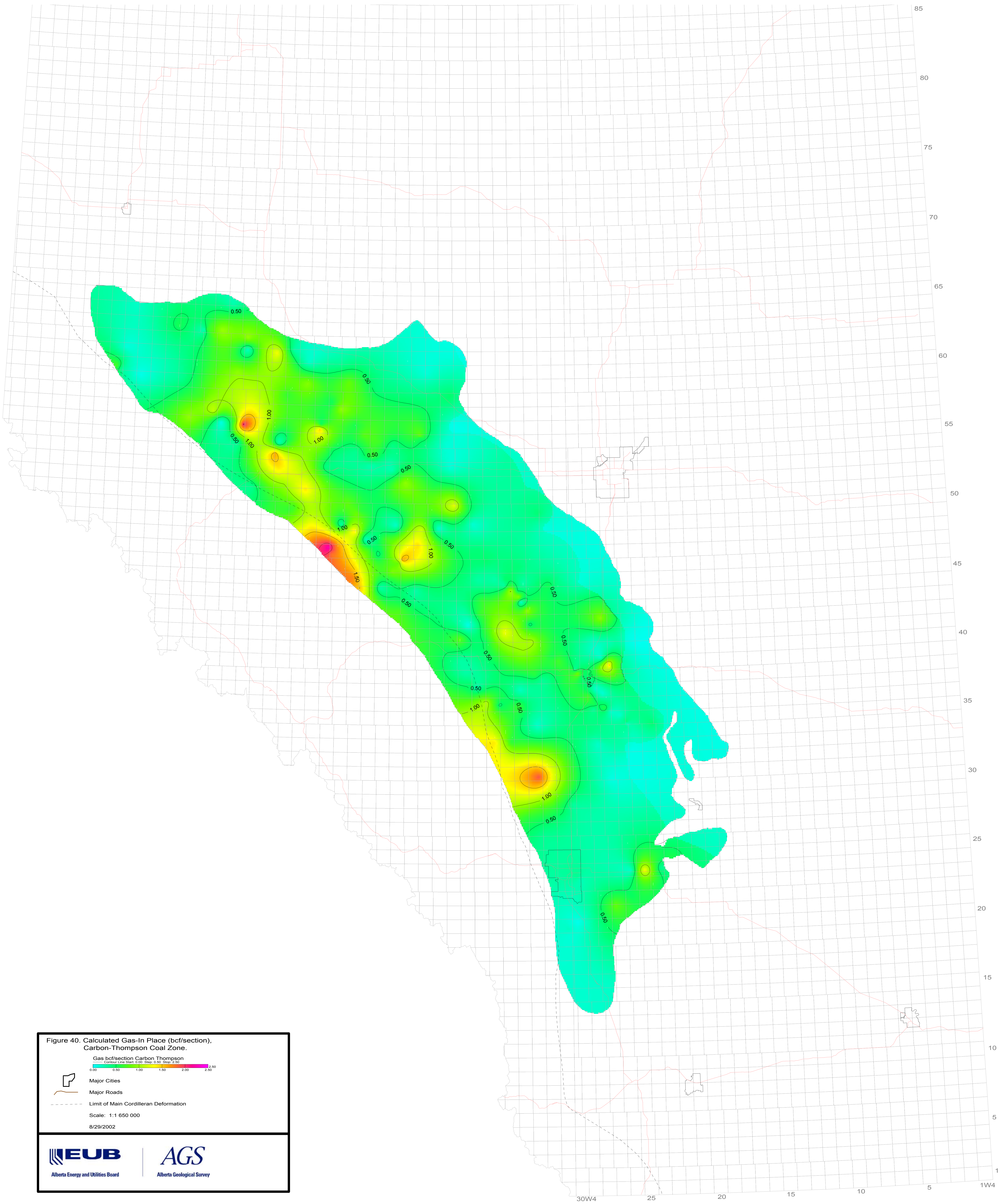


Figure 40. Calculated Gas-In Place (bcf/section), Carbon-Thompson Coal Zone.

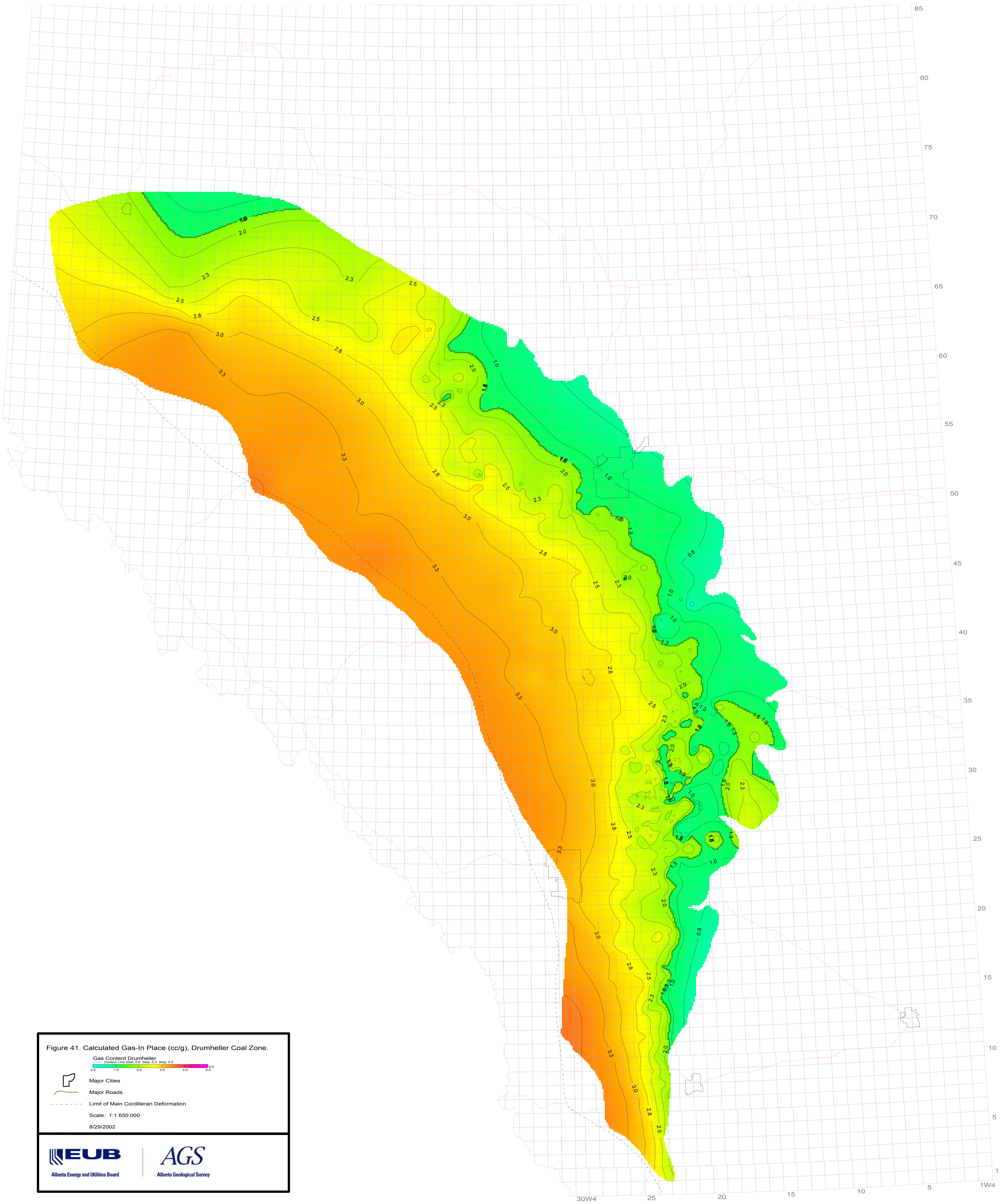


Figure 41. Calculated Gas-In Place (cc/g), Drumheller Coal Zone.

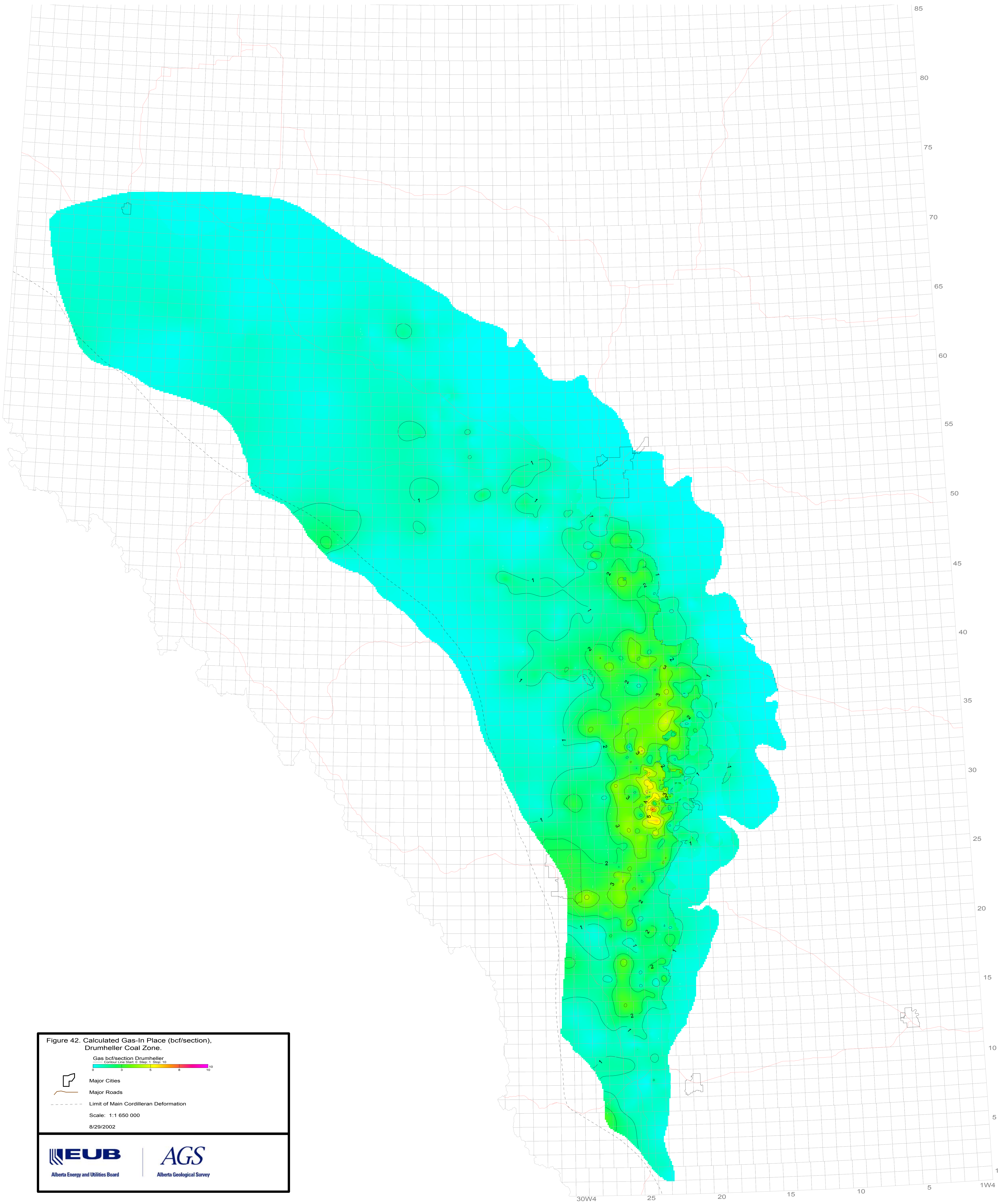


Figure 42. Calculated Gas-In Place (bcf/section), Drumheller Coal Zone.

5.8.5 Lethbridge Coal Zone

The Lethbridge Coal Zone has gas-in-place concentrations ranging from 2 cc/g (daf basis) up to 3.5cc/g at the greatest depths in the western Plains. A large portion of the Lethbridge Coal Zone (extending approx. from Twp. 1 to 23) is shallow, and this large area has overall low gas concentrations (maximum of 2.5 cc/g). Coals within this area at depths less than 200 m average 0.75 cc/g (Figure 43).

A north-trending band in the central area of the Lethbridge Coal Zone (Figure 44) has gas resources ranging from 0.25 bcf/section up to 1.25 bcf/section in local pods. Most notable are an area northeast of Calgary (Twp. 32–25, Rge. 25–28, W 4th Mer.) and one encompassing Twp. 21–11, Rge. 22–24, W 4th Mer., both of which contain more than 0.75 bcf/section.

Total gas-resource potential for the Lethbridge Coal Zone is 18 Tcf ($5.10*10^{11}m^3$) ; however, the large area containing shallow and thin coals reduces the constrained gas-resource potential to 9 Tcf ($2.55*10^{11}m^3$).

5.8.6 Taber Coal Zone

Gas-in-place resources of the Taber Coal Zone range from a low of 2 cc/g (daf basis) at depths of 200 m up to 3.5 cc/g at depth to the west (Figure 45). Much of the zone occurs at depths less than 200 m in the southeastern Plains, where gas contents range from 0.5 to 1.25 cc/g.

Gas-resource potential for the Taber Coal Zone is low throughout the area, typically less than 0.5 bcf/section (Figure 46). The south-central part of the zone contains local elevated gas potential, particularly in Twp. 35–24, Rge. 7–15, W 4th Mer. Pods within this area show elevated gas potential (average >0.75 bcf/section), with some very local areas (2 townships) containing up to 1.5 bcf/section.

The Taber Coal Zone in the southeast corner of the province (Twp. 4–10, Rge. 3–6, W 4th Mer.) has gas contents in the range 0.77 to 1.5 bcf/section. Total gas-resource potential for the Taber Coal Zone is 20 Tcf ($5.67*10^{11}m^3$) and constrained resource potential is 11 Tcf ($3.12*10^{11}m^3$).

5.8.7 McKay Coal Zone

The McKay Coal Zone contains the greatest amount of coal within the Belly River Group coal zones. Gas-in-place concentrations, ranging from 2 cc/g (daf basis) at depths greater than 200 m up to 3.75 cc/g in the deeper, western Plains (Figure 47), reflect the greater depth of these coals compared to the previously mentioned coal zones. A large area of shallow McKay coal underlies Twp. 1–23, Rge. 1–19, W 4th Mer. This region contains low gas concentrations, ranging from 0.25 to 1.25 cc/g.

Gas-resource potential for the McKay (and equivalent) coal zones is low throughout most of the area, typically less than 0.5 bcf/section. The central, north-trending band that underlies Twp. 10–55, Rge. 11–24, W 4th Mer. has the greatest gas potential within the McKay Coal Zone. Within this trend, elevated gas concentrations occur in pods commonly covering 20 or more townships, with gas concentration ranging from 0.75 to 1.25 bcf/section (Figure 48). Two major areas of elevated gas concentrations are present, the first situated east and southeast of Edmonton and the second east-southeast of Calgary. One additional small area with elevated gas underlies Twp. 37–38, Rge. 18–19, W 4th Mer., where potential resources exceeds 1.25 bcf/section.

Total gas-resource potential for the McKay Coal Zone is 29 Tcf ($8.22*10^{11}m^3$), and constrained gas-resource potential is 19 Tcf ($5.38*10^{11}m^3$).

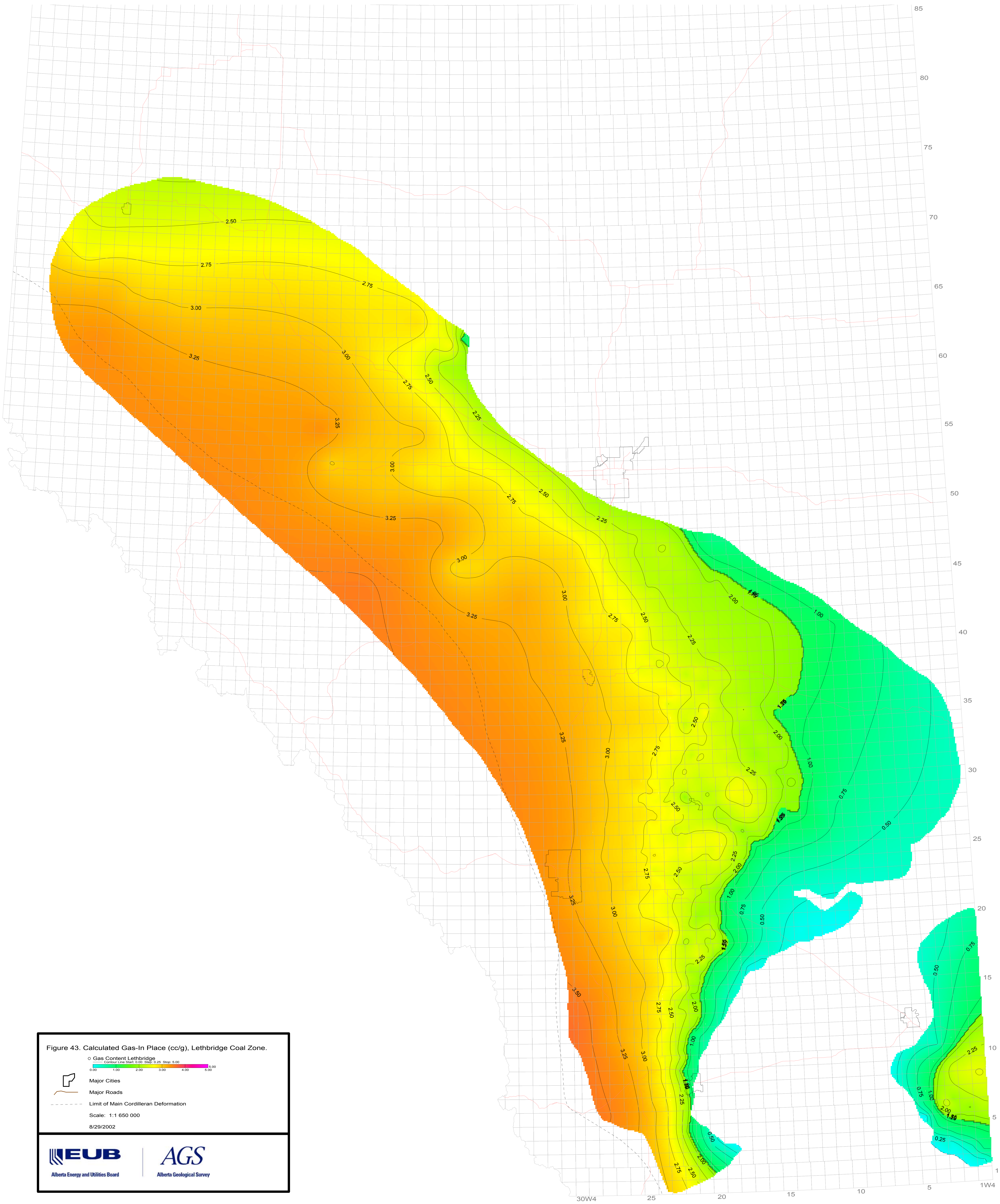


Figure 43. Calculated Gas-In Place (cc/g), Lethbridge Coal Zone.

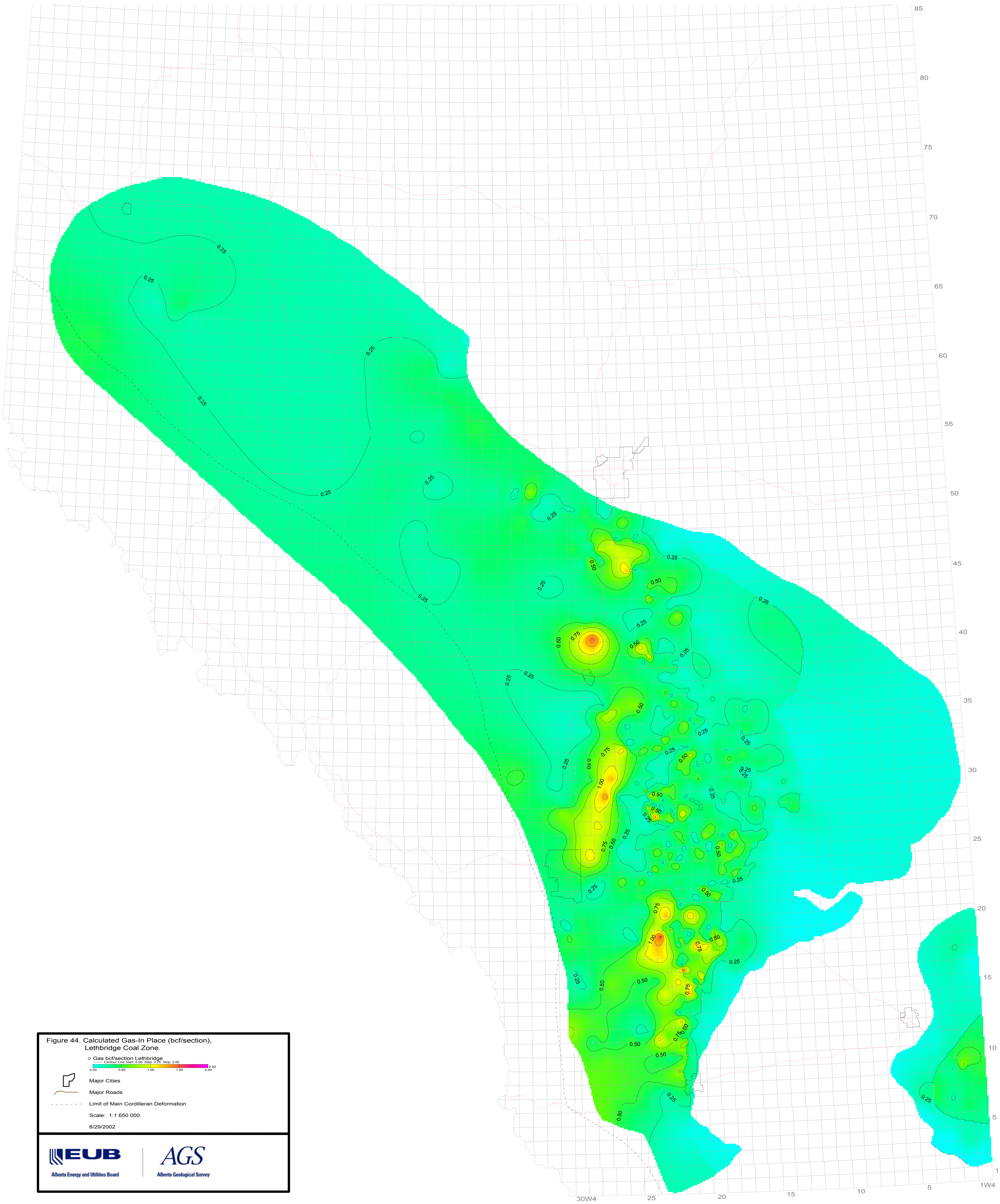


Figure 44. Calculated Gas-In Place (bcf/section), Lethbridge Coal Zone.

Gas bcf/section Lethbridge
Contour Line Start: 0.00 Step: 0.25 Stop: 2.00
0.00 0.50 1.00 1.50 2.00

Major Cities
Major Roads
Limit of Main Cordilleran Deformation
Scale: 1:1 650 000
8/29/2002

Alberta Energy and Utilities Board
Alberta Geological Survey

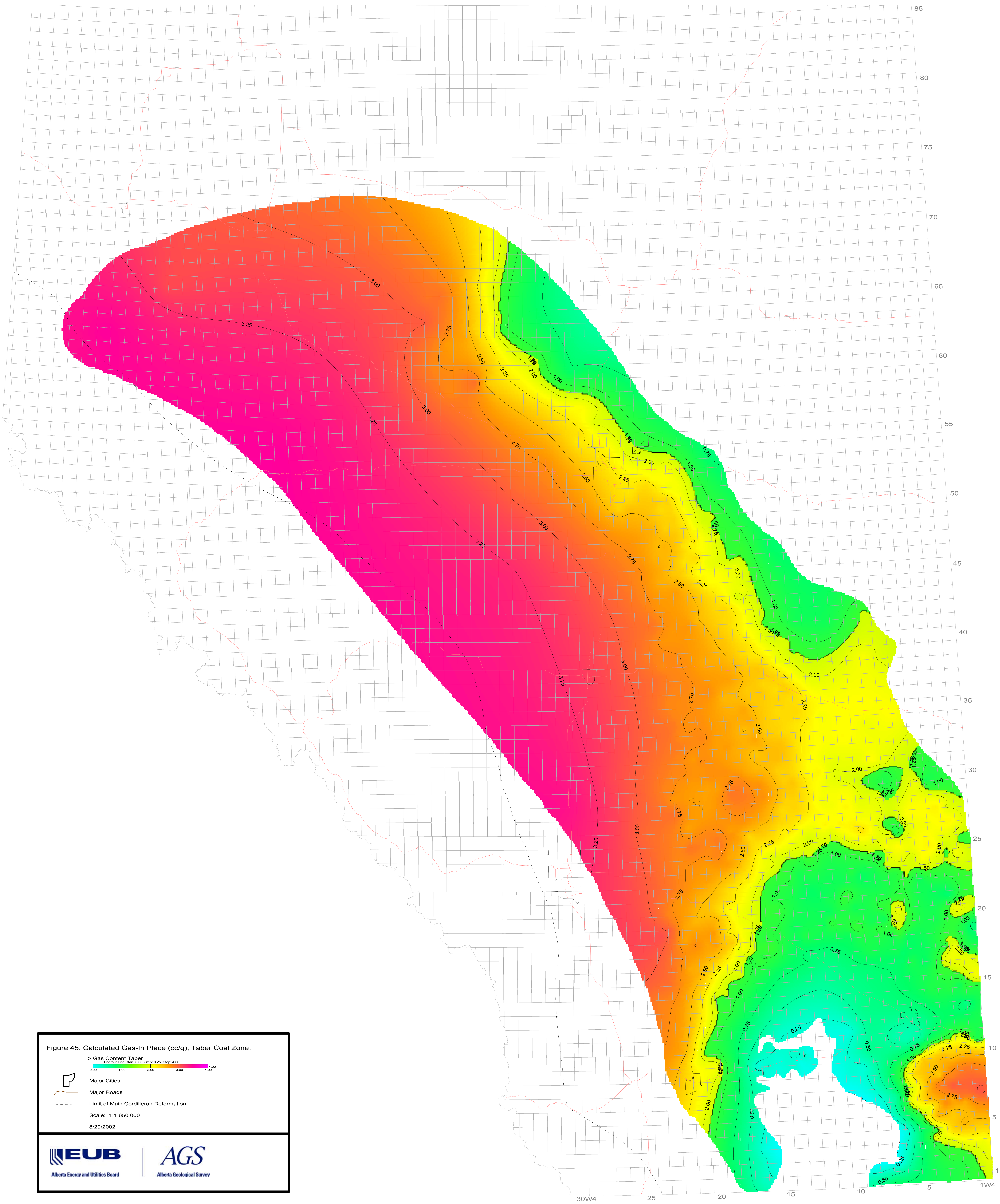


Figure 45. Calculated Gas-In Place (cc/g), Taber Coal Zone.

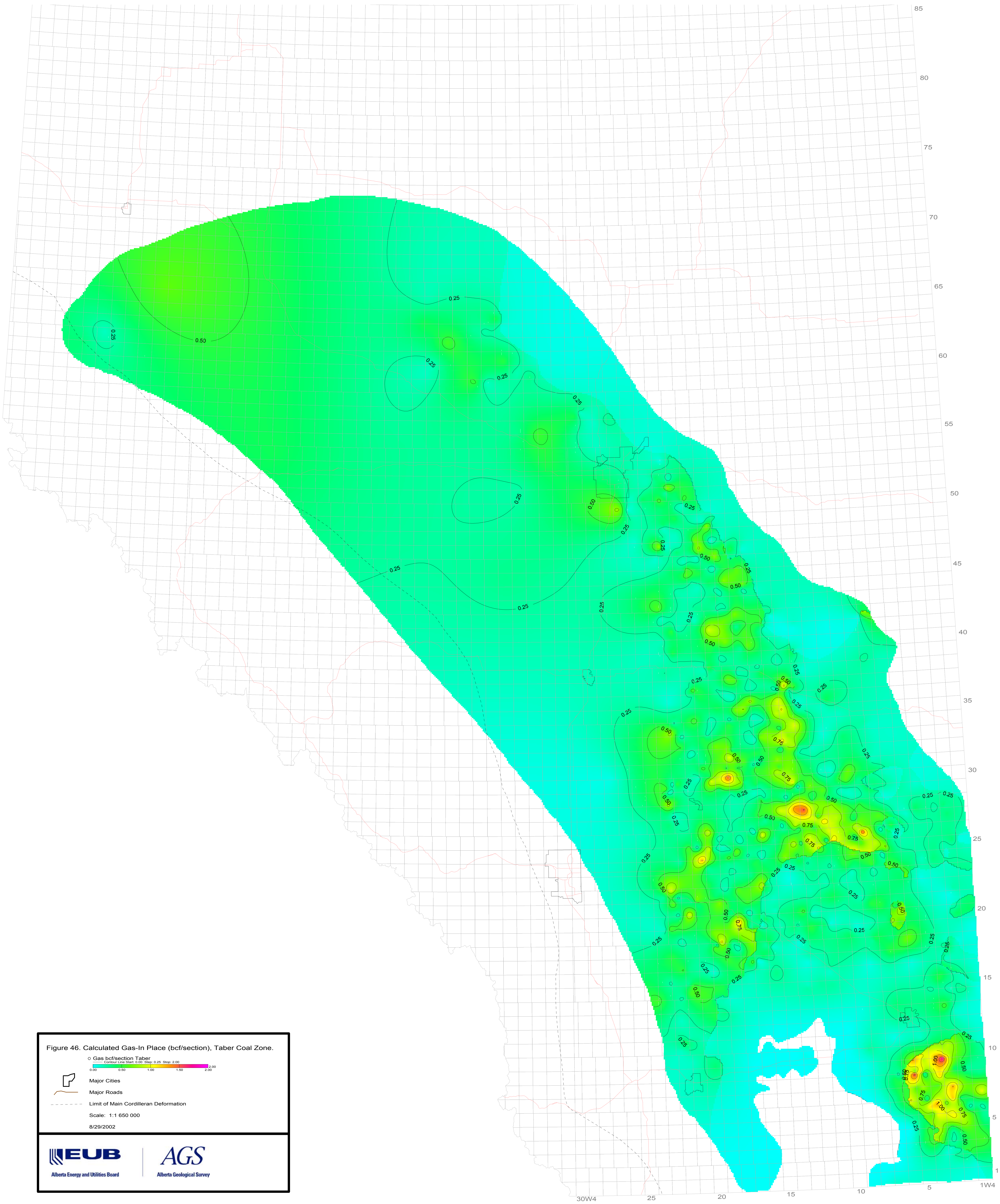


Figure 46. Calculated Gas-In Place (bcf/section), Taber Coal Zone.

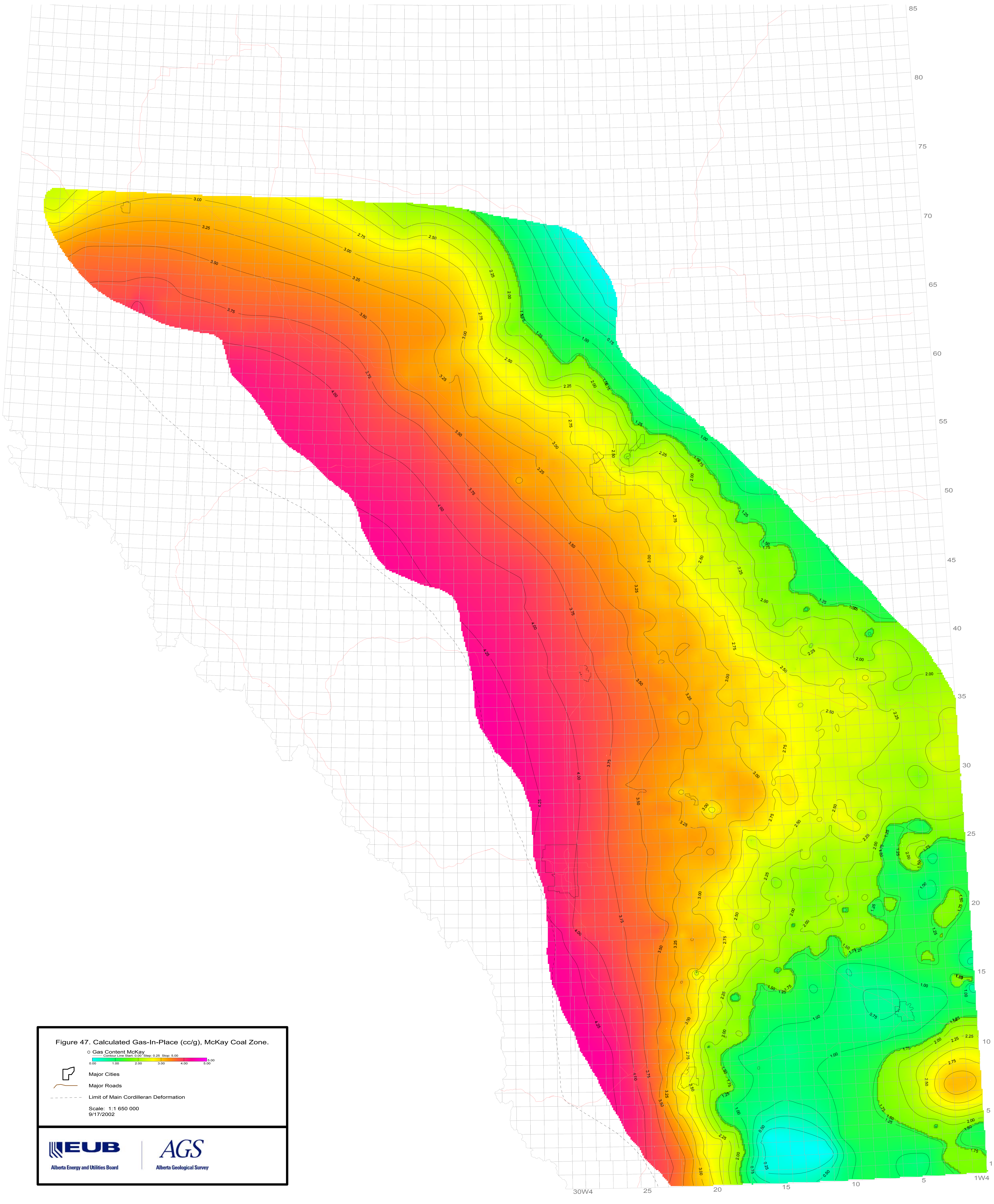


Figure 47. Calculated Gas-In-Place (cc/g), McKay Coal Zone.

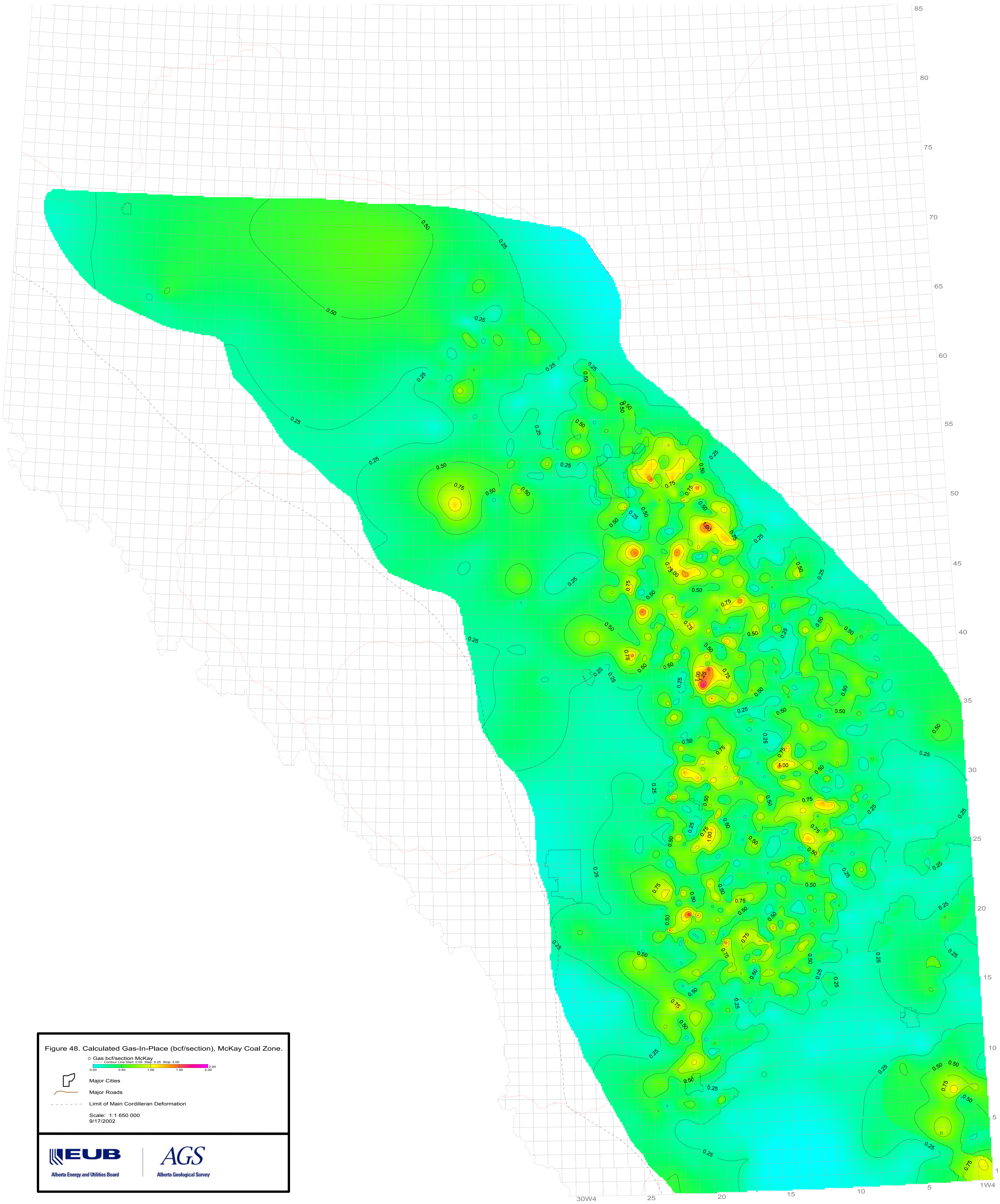


Figure 48. Calculated Gas-In-Place (bcf/section), McKay Coal Zone.

6 Discussion and Conclusions

Significant coal resources have been identified within Upper Cretaceous–Tertiary strata of the Alberta Plains. Limited gas-concentration data for the Plains warrants a cautious approach to estimating coalbed methane (CBM) resource potential. Drawing on the large coal resources present, and recent data obtained through ASRA-AGS investigations, the total CBM gas potential for Upper Cretaceous–Tertiary strata of the Alberta Plains is estimated to be 186 Tcf ($5.27*10^{12}m^3$). Restricting potential coal source beds to depths greater than 200 m, and net coal within a given coal zone to greater than 1 m, a constrained CBM gas potential of 147 Tcf ($4.16*10^{12}m^3$) is obtained (Table 4).

The Ardley Coal Zone, with a constrained gas potential of 51 Tcf ($1.44*10^{12}m^3$), contains a significant portion of this total. The Drumheller Coal Zone also contains significant potential resources of 33 Tcf ($9.35*10^{11}m^3$). The remaining coal zones have lower gas potential.

The Ardley Coal Zone has, to date, been the main target of Upper Cretaceous-Tertiary CBM exploration, based on the presence of thick seams, adequate rank and suitable depths (Scott, 2001; Bustin, 2001). Recent activity in the Alberta Plains has targeted other coal zones, the results from which are still held confidential at the time of this report. Records and anecdotal evidence suggest there is gas present within all coal zones of the Upper Cretaceous–Tertiary strata.

Previous estimates of CBM resources in the Alberta Plains suggest somewhat higher total gas potential than the figures presented in this report. MacLeod et al. (2000) indicated up to 668 Tcf ($1.89*10^{13}m^3$), which included the Lower Cretaceous Mannville coals. Upper Cretaceous–Tertiary strata accounted for 40%, or 267 Tcf ($7.56*10^{12}m^3$) of this estimate. However, by constraining gas potential to depths from 300 to 2200 m and reflectance to greater than 0.6%, a much lower constrained gas potential resource of 100 Tcf ($2.83*10^{12}m^3$) (30% of a total of 215 Tcf ($6.09*10^{12}m^3$)) was calculated for Upper Cretaceous–Tertiary strata. The current study indicates a somewhat higher constrained gas-resource potential, in part explained by the constraints placed on the coal targets. The authors selected a shallower depth interval, as recent wells indicate potential for shallow gas, some of which may be biogenic (Scott, 2001; Scott et al., 1994). Furthermore, coal rank was not used as a constraint in the current study. A large portion of the coals are just within the rank boundary for thermogenic gas generation, and still within the potential biogenic gas regime. Because of this, a decision was made to use isotherm data and gas-saturation data, obtained from coal testing under the current ASRA-AGS study, to determine potential gas resources across the Plains.

Studies of the Ardley Coal Zone in the Alberta Plains (Hughes et al., 1999) indicated total in situ gas-resource potential of 74 Tcf ($2.10*10^{12}m^3$). Deviation of this figure from those of the present study is again explained by the constraints placed on resource calculations. Hughes et al. (1999) assumed saturated conditions for the coal reservoir. Gas contents were calculated from the Ryan equation (Ryan, 1992) using ash and moisture contents of 10% and 18%, respectively, with mean reservoir depth and vitrinite reflectance. A constant gas concentration of 3.4cc/g was used for coal with a reflectance less than 0.65%. The current study applies a depth (pressure) constraint used to calculate gas concentrations, derived from isotherm analysis. Furthermore, the current study did not assume saturated reservoir conditions (recent testing suggests that unsaturated conditions are common).

The coal resources of Alberta are well defined, but very limited data on gas concentrations and reservoir conditions make gas-resource predictions difficult. There is still uncertainty regarding the potential contribution of biogenic gas to CBM resources, particularly within the shallower parts of the Plains. Gas resource estimates commonly evaluate coal only, but the potential exists for gas occurrences within associated coaly shale and adjacent rocks. Coal has the potential to generate more gas than it can retain,

Table 4. Summary of coal and gas potential, Upper Cretaceous-Tertiary strata, Alberta Plains.

	Area m^2	t in place	t constrained	Gas m^3 in place	Gas m^3 constrained	Gas Tcf in place	Gas Tcf constrained
Ardley Coal Zone	5.90E+10	5.96E+11	5.01E+11	1.51E+12	1.43E+12	53.2	50.6
Carbon/Thompson Coal Zone	7.55E+10	1.83E+11	1.56E+11	4.04E+11	3.64E+11	14.3	12.8
Daly/Weaver Coal Zone	7.55E+10	1.78E+11	1.49E+11	4.06E+11	3.51E+11	14.3	12.4
Drumheller Coal Zone	1.28E+11	5.64E+11	4.38E+11	1.07E+12	9.36E+11	37.7	33.0
Lethbridge Coal Zone	1.70E+11	2.77E+11	1.13E+11	5.07E+11	2.47E+11	17.9	8.7
Taber Coal Zone	1.90E+11	3.35E+11	1.47E+11	5.77E+11	3.12E+11	20.4	11.0
McKay Coal Zone	2.12E+11	4.03E+11	2.41E+11	8.11E+11	5.29E+11	28.6	18.7
Total		2.54E+12	1.74E+12	5.28E+12	4.17E+12	186.4	147.3

so adjacent porous strata may act as a trap for potential migrating coal gas. These factors can significantly contribute to total gas resources. Additional research and exploration data are needed in order to evaluate gas potential for these cases.

Even though there are some differences in potential gas resource estimates for the Upper Cretaceous–Tertiary strata of the Alberta Plains, the worst-case scenario still predicts that a large potential resource is present. The amount of recoverable gas remains a great unknown.

Coalbed methane resources and associated recoverable gas resources, compiled for several coal basins in the United States, are presented in Table 5 (*from* Gas Technology Institute, 2001). Recovery estimates vary between basins, ranging from 10% to 62% and averaging 37%. Recovery factors depend on many interrelated parameters, including hydrology, reservoir permeability (cleat, fracture, mineralization), reservoir communication and reservoir pressure. Only limited data are available for most of the above parameters for the Alberta Plains, but industry and government are beginning to collect relevant data in order to evaluate recoverable resources. If an average recovery factor of 35% is applied to the resources calculated in this study, the constrained potential recoverable resource for the Upper Cretaceous–Tertiary strata in the Alberta Plains is 51 Tcf ($1.44*10^{12}m^3$) (Table 4).

Table 5. Total gas-in-place (GIP) resources versus. estimated recoverable resources from selected U.S. coal basins.

Coal Basin	Estimated GIP Resources Tcf	Estimated Recoverable Tcf	% Recoverable
San Juan	84	10.2	12
Black Warrior	20	4.4	22
Central Appalacian	5	2.4	48
Powder River	39	24	62
Uinta	10	5.5	55
Arkoma	4	1.8	45
Raton	10	3.7	37
Cherokee	6	2.8	47
Illinois	21	2.1	10
Average recovery from various US CBM basins			**37%**

Reference: North American Coalbed Methane Resource Map,
GTI E&P Services, GTI-01/0165, 2001.

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