EUB/AGS Earth Sciences Report 2005-02

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D. Chen, K. Parks, W. Langenberg, M. Berhane, and S. Stewart

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Alberta Energy and Utilities Board
Alberta Geological Survey
4th Floor, Twin Atria Building
4999 – 98th Avenue
Edmonton, Alberta
T6B 2X3
Canada

Tel: (780) 422-3767 (Information Sales)
Fax: (780) 422-1918
E-mail: EUB.AGS-Infosales@gov.ab.ca

Website: www.ags.gov.ab.ca

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## Abstract

The Red Deer–Buck Lake area of west-central Alberta has been a prolific producer of conventional oil and gas. In recent years, the focus of exploration has shifted from conventional oil and gas toward drilling for shallow unconventional gas, including coalbed methane. Studies show that deep structures in this area vary greatly, act differently and have a profound impact on sedimentation. Gas production from the Devonian, Mississippian, Jurassic and Cretaceous has a certain relationship with these deep structures. To some degree, the deep structures that influence the formation of coalbed hostrocks may control the distribution of unconventional gas.

Geophysical logs were intensively employed during this study. The picking protocol of the 41 correlation markers is briefly described, and 12 600 new, internally consistent stratigraphic picks, 15 structural cross-sections (elevation as datum) and more than 80 structural and isopach contour maps are provided. The stratigraphic correlation, database management, and geological analysis were greatly assisted by advanced software.

The Medicine River area is floored by three northeast-trending Precambrian basement domains. Five large blocks appear to have had slightly different motions during Phanerozoic time. Seven basement lineaments appear to have affected the sedimentary strata. The characteristics of the successions from the Devonian Wabamun top to the Lower Tertiary are described, and the zero edges and subcrop areas of the Mississippian and Jurassic formations are defined.

Huge volumes of natural gas have been produced from Devonian, Mississippian, Jurassic and Cretaceous reservoirs in this area, particularly along the Rimbey Arc, downdip of the Mississippian and Jurassic zero edges, and along intensively fractured belts. The Drumheller, Carbon-Thompson, Ardley and Upper Manville are relatively well developed in the Medicine River area. Prospective areas have been identified for each of the coal zones based on the structure analysis and study of production history.

# 1 Introduction

The Medicine River area is located in west-central Alberta (Figure 1), covering the rectangle formed by 120 townships, extending from townships 35 to 46 and from ranges 26W4 to 7W5. The area has been a prolific producer of oil and gas. In addition to the petroleum resources, the Medicine River area hosts abundant coal, minerals, groundwater and resort areas, which are important to the development of the Alberta economy and local lifestyles. In recent years, the focus of exploration has shifted from conventional oil and gas toward drilling for shallow unconventional gas, including coalbed methane (CBM).


**Figure 1. Study area in west-central Alberta.**

It is postulated that the same deep structural controls that made the Medicine River area rich in multilevel conventional targets will, to some degree, control the distribution of unconventional gas. In 2004, the Alberta Geological Survey launched a study to 1) investigate the deep structures, 2) examine the relationship between the deep structures and the discovered hydrocarbon reservoirs, and 3) provide insights on the CBM exploration in the area.

The Medicine River area extends from the east edge of the Rocky Mountain Foothills into the Alberta Plains (Figure 2). The elevation of the area ranges from 780 to 1240 m. The ground surface is elevated in the southwest toward the Rocky Mountains Foothills. A topographic high in the west is separated from the Rocky Mountain Foothills in the southwest by the Rocky Mountain House low. The central area is dominated by northwest-trending belts incised by the Medicine and Blindman rivers. The areas along the Battle River in the northeast and the cities of Red Deer and Lacombe in the east are topographic lows. The area east of the Battle River is a lowland.

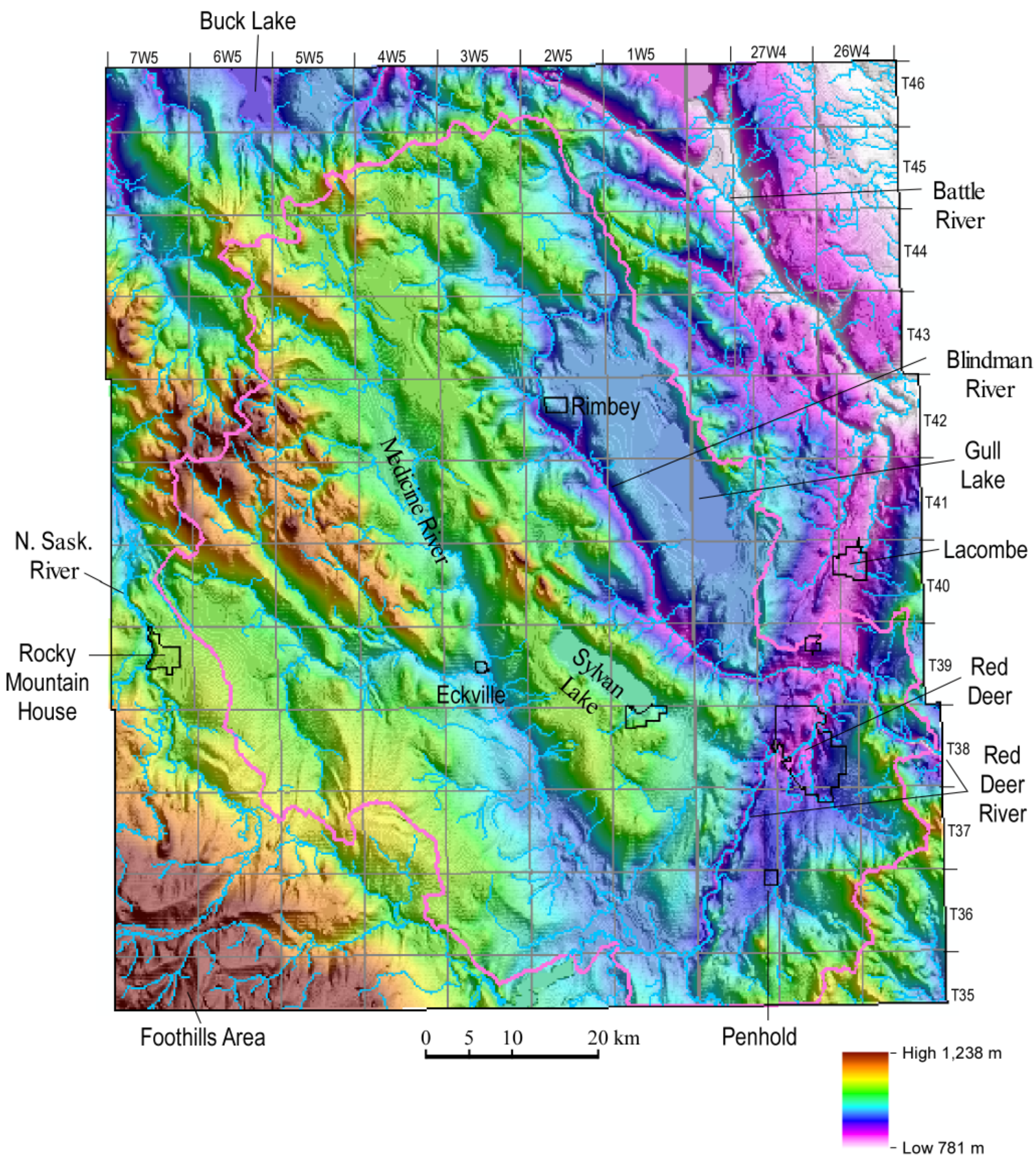


**Figure 2. Digital elevation model of the Medicine River area.**

The pink curve in Figure 2 and subsequent figures outlines the Medicine River drainage basin. This outline is included for information because groundwater flow is known to have regional control on methane content in shallow gas deposits (Bachu and Michael, 2002; Ridgley, 1998). Although this report does not analyze the groundwater-flow regime in the study area, the reader may want to consider that downward-directed meteoric recharge will be prevalent on the edges of the drainage basin, whereas upward-directed groundwater discharge will be present in the centre of the drainage basin. Ridgley (1998) postulated that enriched methane levels in the shallow gas in southern Alberta may be associated with higher geothermal gradients in areas of groundwater discharge near rivers.

About 9400 oil and gas wells have been drilled and a large number of oilfields have been found in the study area, in addition to a large amount of groundwater and CBM resources, which are related to subtle structures and sedimentary assemblages. Nevertheless, previous regional studies/databases do not provide continuous and detailed structural and isopach maps. Serious problems exist with the available databases. A number of detailed studies on individual formations/members suggested mechanisms of basement control without providing strong evidence and were unable to document both tectonic and sedimentary processes in the area.

This report provides an overview of the structural framework and natural-gas distribution in the area of the Medicine and Blindman rivers in central Alberta, and has generated 12 600 new, internally consistent stratigraphic picks, 15 structural cross-sections (elevation as datum), and more than 80 structural and isopach contour maps. Using geophysical log cross-sections and contour maps, distinct geological relations, such as variations in thickness, are highlighted as they relate to the boundaries of individual structural blocks. In addition, thoughts on possible correlation between conventional gas production and CBM potential are given.

This stratigraphic framework review suggests five areas for future work

- identify and pick the correlation markers in more wells to increase the control points in the existing mapping units
- correlate the formations below the Mississippian
- analyze aeromagnetic and gravity data for the basement, and integrate the results from all available sources to get a better understanding of the structures in the study area
- investigate the gradient of the piezometric surface, the rate of groundwater movement, the areas of natural replenishment and discharge, and the route of groundwater movement
- analyze the relationship between methane content and the pattern of groundwater recharge and geothermal gradients in the Medicine River area.

# 2 Previous Studies and Objectives of This Study

## 2.1 Previous Studies

For half a century, the Medicine River area has drawn the attention of the petroleum industry, academia, and governments due to its abundant oil and gas production. Many classical outcrops are found along the Red Deer River valley, which incises the Upper Cretaceous Bearpaw, Horseshoe Canyon, Whitemud, Battle, Scollard, and Paskapoo formations. A huge amount of hydrocarbon has been produced from 1) the Rimbey-Homeglen Reef Belt, a north-northeast-trending belt across the central and northern parts of the area; 2) the Gilby and Medicine River fields in the central part; 3) the Joffre Field in the east; 4) the Pembina Field in the north; 5) the Willesden Green and Ferrier fields in the west; and 6) 27 other fields in the area.

The Rimbey-Homeglen Reef Belt is a part of the famous Rimbey-Leduc-Meadowbrook Reef Complex (Switzer et al., 1994) and has been studied since early 1950s (McPherson, 1954). Efforts have been focused on the configuration of the reef belt (Webb and White, 1968; Anderson et al., 1989), the dolomitization and reservoir formation of the reef belt (Machel and Mountjoy, 1987; Marquez and Mountjoy, 1996; Mountjoy et al., 1999), and the influence of Precambrian crystalline basement (Edwards and Brown, 1999).

The Pekisko Formation hosts the majority of Mississippian pools in the south-central part of the area and was studied by Hopkins (1999) in the Medicine River field. The Lower Jurassic in the Gilby and Medicine River fields was examined by Rall (1980). Hopkins et al. (1998) investigated the Jurassic pools in the Medicine River Field. Strobl et al. (1993) correlated Jurassic and lowest Cretaceous formations in the south-central part of this study area.

The Lower Mannville and associated units in the Medicine River area were studied by Hopkins (1981). Lower Glauconitic sandstone in the Medicine River area was researched by Reichenbach (1981) and Strobl (1988). Downing and Walker (1988) studied the Viking sandbodies in the Joffre Field. Mannville coal and CBM have been analyzed by Langenberg et al. (1997) and Wadsworth et al. (2002).

The Upper Cretaceous to Quaternary strata in the Red Deer and Rosebud area were studied by Allan and Sanderson (1945). Eyles and Walker (1988) examined the Upper Cretaceous Cardium reservoirs in the Willesden Green Field. Upper Cretaceous to Lower Tertiary coal-bearing formations in the Medicine River area have been investigated by Nurkowski and Rahmani (1984), Lerbekmo and Coulter (1985), Demchuk (1990), Langenberg et al. (2000), and Hamblin (2004). Langenberg et al. (2000) were more focused on the Ardley coal resources in the Buck Lake area.

Previous individual studies in the Medicine River and surrounding areas have provided invaluable information for understanding particular formations, structures, and associated resources in the area. Detailed and continuous structural and stratigraphic data, however, will enable examination of the relationship between the structures and formations, and their possible impact on the distribution of resources in the area. Although there are more than a hundred thousand picks in existing public databases, problems exist with the databases due to miscorrelations and data-entry errors.

## 2.2 Objectives of This Study

The purpose of this study is to identify deep structures, the interaction between the deep structures and existing reservoirs, and possible controls on the distribution of unconventional gas in the Medicine River area. In order to identify deep structures and their impact, it is necessary to characterize the structural and stratigraphic features through detailed formational correlations and mapping throughout the area.

The objectives of this study are to

- establish a stratigraphic framework, via detailed well-log correlation and map generation;
- define basement blocks and lineaments through analysis of the cross-sections and maps; and
- document major structural features that may have impacted depositional processes and hydrocarbon accumulation.

# 3 Methodology

## 3.1 Features and Procedures of the Study

Geophysical logs were intensively employed by this study. The stratigraphic correlations, database management and geological analysis were greatly assisted by advanced software, such as ViewLog®, Microsoft® Access®, ArcGIS® and Canvas®. In addition to the 12 600 new stratigraphic picks created by this study, data were also collected from internal AGS databases and commercial data services, such as GeoOffice and AccuMap.

Stratigraphic tops in this study were picked directly on the computer screen. Data points were modified on-screen and recontoured immediately, so the result of modification could be viewed without a delay. The methodology employed by this study was characterized by all processes being automated and time efficient.

The major steps of the study included

- construction of digital log database;
- collection of stratigraphic and production data, plus AGS metadata;
- digital log selection and operation;
- evaluation and clean-up of stratigraphic data;
- identification and picking of new stratigraphic tops;
- generation of structural and isopach grids;
- calculation of parameters;
- generation of cross-sections;
- analysis of gas-production and coal-distribution data;
- identification and highlighting of basement and surficial lineaments; and
- overlaying lineaments on structural and isopach maps.

## 3.2 Database Construction and Digital Log Operation

Figure 3 shows the distribution of the 9400 oil and gas wells that have been drilled in the Medicine River area. Logs of about 4630 wells have been digitized. Digital logs of 1774 wells were ultimately selected from the available gamma ray (GR), resistivity, sonic and density logs. Well logs were selected (Figure 4) based on

- one well per section (1/36 township),
- longest logs in the section, and
- shallow start of logging depth (less than 200 m).

Other major operations on the digital logs include

- selection of log pairs, since not every well has the same types of logs and it is impossible to show all log types on the screen;
- slicing logs into three intervals because the Medicine River area is close to the axis of the Alberta

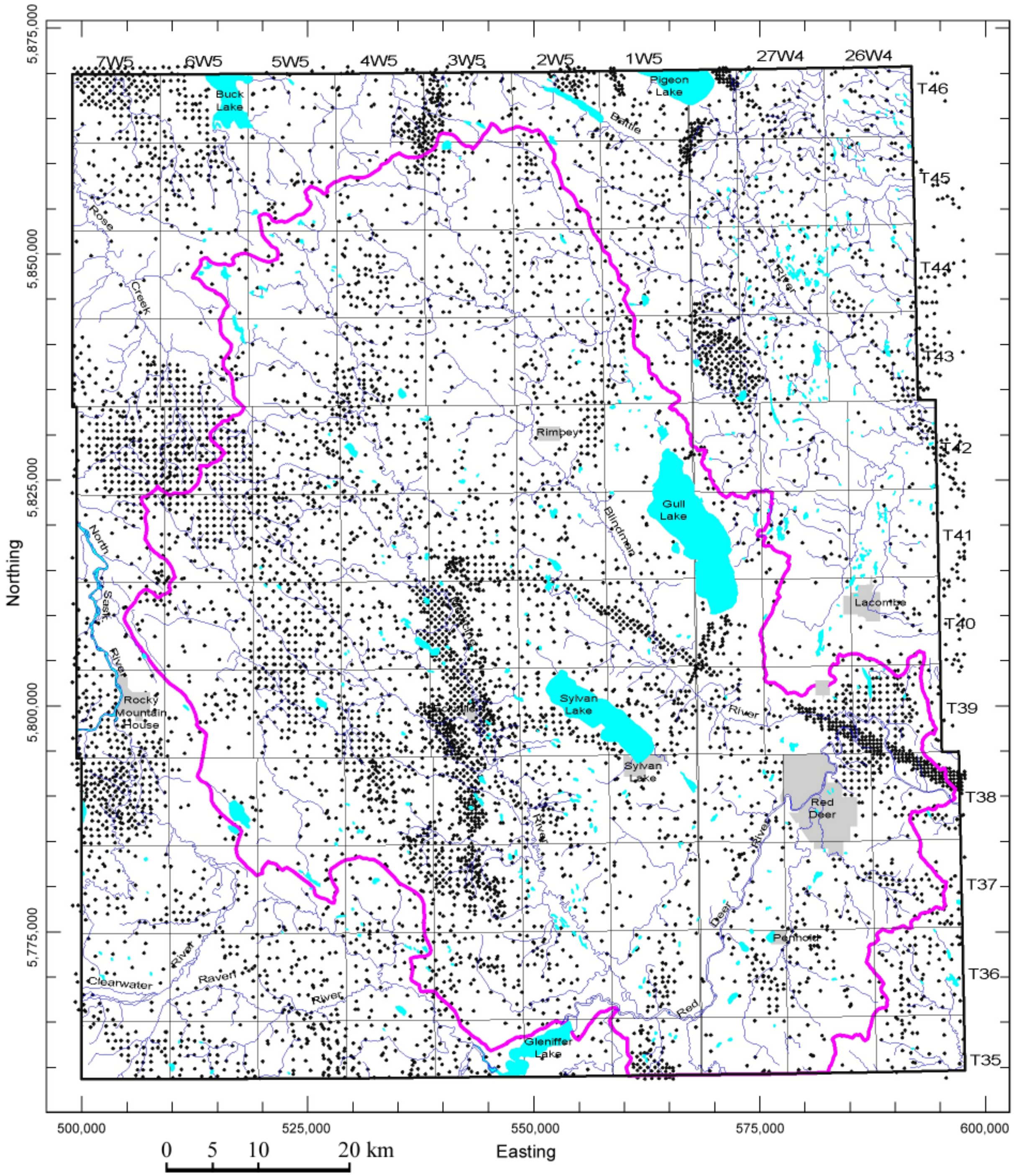


**Figure 3. Wells drilled in the study area.**

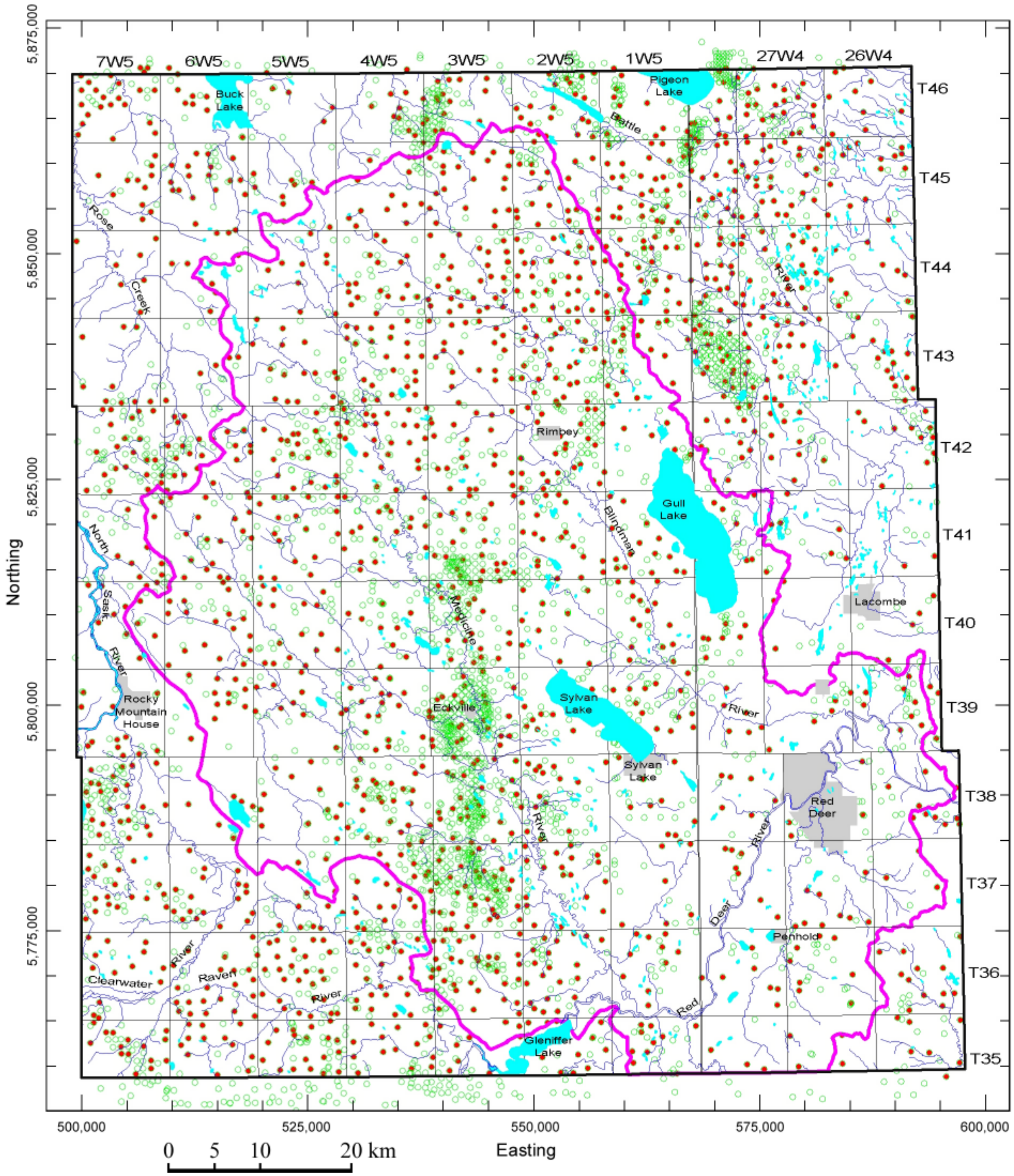


**Figure 4. Wells with digital logs.**

Syncline, with a fairly thick deposition in the area, and it is slow and time consuming to work on the entire log interval. During the log-slicing operation, the Mark Database Field function was used to write data back into the database at selected borehole locations.

## 3.3 Evaluation and Operations on AGS Internal Data

In the internal AGS database, there are about 108 000 picks of 176 tops for the Medicine River area. Among the 176 tops, 34 tops above the Wabamun have more than 200 picks (Table 1). The datasets were examined to evaluate the following three types of problems:

- **Lack of control points in most of the formations:** Among the 115 layers, 9 formations (Belly River, Lea Park, Colorado, Cardium, Cardium Sandstone, Second White Specks, Base of Fish Scales, Viking Sandstone and Mannville) have more than 5600 picks, whereas 79 layers (70%) have less than 78 picks.
- **Inconsistency on interfingered formations**, such as the Lea Park top–Belly River base, Belly River top–Bearpaw base and Bearpaw top–Horseshoe Canyon base.
- **Miscorrelation or data entry errors:** A stratigraphic pick error generates a 'bull's-eye' on one map sheet, but a kelly bushing (KB) error generates a 'bull's-eye' on each of the map sheets. Three incorrect KBs were detected in the mapping area, in wells F1/08-10-039-02W5/0, F2/08-10-039-02W5/0 and 00/08-10-039-02W5/0. Hundreds of bad data points were marked in the datasets.

**Table 1. Summary of available AGS internal stratigraphic picks.**

| Stratigraphic Top ID | Stratigraphic Top Name | Stratigraphic Type | Stratigraphic Top Abbreviation | Picks in Area |
|---|---|---|---|---|
| 1060 | Edmonton | Group | EDM | 970 |
| 1180 | Kneehills Tuff Zone | | KHL TF | 1001 |
| 1240 | Bearpaw | Formation | BEPW | 369 |
| 1260 | Belly River | Group | BR | 7836 |
| 1340 | Basal Belly River Sand | | BSL BR | 1658 |
| 1400 | Lea Park | Formation | LP | 8702 |
| 1600 | Colorado | Group | COLO | 8097 |
| 1700 | Cardium | Formation | CARD | 5922 |
| 1760 | Cardium Sand | | CARD SD | 6036 |
| 1860 | Second White Specks | | 2WS | 6881 |
| 2060 | Base of Fish Scales | | BFSC | 7156 |
| 2140 | Viking | Formation | VIK | 3717 |
| 2180 | Viking Sand | | VIK SS | 6416 |
| 2360 | Joli Fou | Formation | JOLI | 3994 |
| 2440 | Blairmore | Group | BL | 459 |
| 2480 | Mannville | Group | MANN | 5643 |
| 3000 | Glauconitic Sandstone | | GLC SS | 4630 |
| 3100 | Lower Mannville | Formation | L MANN | 2763 |
| 3120 | Ostracod Zone | | OST | 1881 |

| Stratigraphic Top ID | Stratigraphic Top Name | Stratigraphic Type | Stratigraphic Top Abbreviation | Picks in Area |
|---|---|---|---|---|
| 3160 | Ostracod Sandstone | | OST SS | 265 |
| 3340 | Basal Quartz Sand | | BSL QTZ | 261 |
| 3360 | Ellerslie Member | Member | ELRS | 3252 |
| 4000 | Jurassic System | | JUR SYS | 215 |
| 4140 | Fernie | Group | FERN | 626 |
| 4320 | Rock Creek | Member | RK CK | 914 |
| 4400 | Poker Chip Shale | | PK C SH | 920 |
| 4440 | Nordegg | Member | NORD | 1458 |
| 4460 | Jurassic Sandstone | | JUR SS | 230 |
| 6380 | Elkton Member | Member | ELTN | 339 |
| 6400 | Shunda | Formation | SHUN | 1501 |
| 6420 | Pekisko | Formation | PEK | 2394 |
| 6440 | Banff | Formation | BNFF | 3960 |
| 6480 | Exshaw | Formation | EX | 965 |
| 6580 | Wabamun | Group | WAB | 861 |

Cleaning bad data points was done by adding a status field to the dataset, showing symbols on a contour map, finding the site ID of the bad point, and changing the status of the bad point. Other data operations included checking deviated wells, wells that intersect thrust faults, duplicates with the same ID, and different records with the same pick name.

### 3.4 Selection of Stratigraphic Markers and Verification of Digital Picks

Through examination of changes in geophysical log signatures throughout the region, 44 interfaces are selected as picking markers (Table 2). The twenty-four shaded rows are new markers defined by this study. The codes and names of the other 20 stratigraphic tops were adopted from the Alberta Energy and Utilities Board (EUB) codes and names, but the picking protocol of this study may be slightly different from that of the EUB.

**Table 2. Stratigraphic markers identified and picked by this study.**

| Serial Number | Stratigraphic Top ID | Stratigraphic Top Name | Stratigraphic Type | Stratigraphic Top Abbreviation |
|---|---|---|---|---|
| 1 | 1060 | Edmonton Top | Group | EDM |
| 2 | 1185 | Battle Top | Formation | BATL |
| 3 | 1188 | Battle Base | | BATL_B |
| 4 | 1230 | Bearpaw Marker 2 | | BP2 |
| 5 | 1240 | Bearpaw Marker 1 | | BP1 |
| 6 | 1260 | Belly River Top | Group | BR |
| 7 | 1340 | Basal Belly River Sandstone Top | | BSL_BR |
| 8 | 1350 | Basal Belly River Sandstone Base | | BSL_BR_B |

| Serial Number | Stratigraphic Top ID | Stratigraphic Top Name | Stratigraphic Type | Stratigraphic Top Abbreviation |
|---|---|---|---|---|
| 9 | 1400 | Lea Park Top | Formation | LP |
| 10 | 1410 | Lea Park Marker 1 | | LP1 |
| 11 | 1600 | Colorado Top | Group | COLO |
| 12 | 1622 | Colorado Marker 2 | | COLO2 |
| 13 | 1628 | Colorado Marker 1 | | COLO1 |
| 14 | 1632 | Wapiabi Marker 4 | | WPBI4 |
| 15 | 1652 | Wapiabi Marker 3 | | WPBI3 |
| 16 | 1658 | Wapiabi Marker 2 | | WPBI2 |
| 17 | 1672 | Wapiabi Marker 1 | | WPBI1 |
| 18 | 1700 | Cardium Top | Formation | CARD |
| 19 | 1760 | Cardium Sandstone Top | | CARD_SD |
| 20 | 1799 | Cardium Sandstone Base | | CARD_B |
| 21 | 1812 | Blackstone Marker 3 | | BKST3 |
| 22 | 1832 | Blackstone Marker 2 | | BKST2 |
| 23 | 1834 | Blackstone Marker 1 | | BKST1 |
| 24 | 1860 | 2nd White Specks Top | Formation | 2WS |
| 25 | 1918 | 2nd White Specks Marker 5 | | 2WS5 |
| 26 | 1952 | 2nd White Specks Marker 4 | | 2WS4 |
| 27 | 1962 | 2nd White Specks Marker 3 | | 2WS3 |
| 28 | 1964 | 2nd White Specks Marker 2 | | 2WS2 |
| 29 | 1966 | 2nd White Specks Marker 1 | | 2WS1 |
| 30 | 2010 | Fish Scales Marker 1 | | FSC1 |
| 31 | 2060 | Base of Fish Scales | | BFSC |
| 32 | 2180 | Viking Sandstone Top | | VIK_SS |
| 33 | 2357 | Viking Sandstone Base | | VIK_B |
| 34 | 2480 | Mannville Top | Group | MANN |
| 35 | 2970 | Mannville Marker 1 | | U_MANN1 |
| 36 | 3100 | Lower Mannville Top | Group | L_MANN |
| 37 | 3485 | Jurassic-Cretaceous Sandstone | | J-K_SS |
| 38 | 4000 | Jurassic Top | | JUR |
| 39 | 4440 | Nordegg Top | Member | NORD |
| 40 | 6390 | Elkton-Shunda Top | | ELTN-SHUN |
| 41 | 6420 | Pekisko Top | Formation | PEK |
| 42 | 6440 | Banff Top | Formation | BNFF |
| 43 | 6480 | Exshaw Top | Formation | EX |
| 44 | 6580 | Wabamun Top | Group | WAB |

Log signatures, which correspond to changes in lithology, vary across the study area. Three type-logs are shown in Figures 5–7. Twelve markers are defined for the deep interval, from the Wabamun Group top to the Base of Fish Scales (Figure 5). Twenty markers are defined for the middle interval, from the Base of Fish Scales to the Colorado Group top (Figure 6). Nine markers are defined for the shallow interval, from the Colorado Group top to the Edmonton Group top (Figure 7).

# 4 Basement Architecture and Phanerozoic Tectonics

## 4.1 Basement Architecture

The Medicine River area is floored by three northeast-trending Precambrian basement domains known as the Thorsby, Rimbey, and Lacombe domains (Figure 8). According to Ross et al. (1989), the Thorsby is an accreted terrane, the Rimbey is a continental-margin magmatic arc, and the Lacombe is a zone along the front of the Hearne Archean Province.

Metasedimentary-volcanic rocks of unknown age are found in the Lacombe Domain (Hoffman, 1989). Ross et al. (1990) indicated that the Lacombe Domain "…appears to consist chiefly of undated, supracrustal rocks (metatuff, phyllite, rhyolite) and a single granite that produced a very discordant Early Proterozoic age (ca. 2.2 Ga)."

The Rimbey Domain, in the central part of the area, was dated at 1.85–1.78 Ga (Ross et al., 1990) and is characterized with moderate-amplitude anomalies and/or magnetizations, suggesting the presence of ferrimagnetic basic and granitoid rocks (Pilkington et al., 2000).

Zircon from sheared gneiss and gabbro in the Thorsby Domain yields ages of 2.29–2.4 Ga (Ross et al., 1990). The Thorsby domain is weakly magnetic and characterized by magnetic sources that are paramagnetic, interpreted to be the result of low-susceptibility silicate minerals or demagnetization effects accompanying collision (Pilkington et al., 2000).

## 4.2 Phanerozoic Tectonics

In addition to the Precambrian basement background, Figure 9 shows the Phanerozoic tectonic features in the Medicine River area including

- the Rimbey Arc in the Rimbey Domain, which is northeast to east-northeast trending;
- the Caroline Arch (Haman and Jurgens, 1976) in the south, which is east trending and crosscuts the Lacombe and Rimbey domains;
- the axis of the Alberta Syncline in the southwest, which is largely northwest trending and crosscuts all three Precambrian domains; and
- the east front of the Rocky Mountain Foothills in the southwest corner.

All of these features appear to have affected the sedimentary cover in certain ways at different times. Phanerozoic tectonic events sliced the Medicine River area into five large blocks that have been named the Buck Lake, Rimbey, Sylvan Lake, Penhold and Foothills blocks to emphasize the Phanerozoic tectonic activity in the area (Figure 10). These blocks appear to have had slightly different motions during Phanerozoic time. The Buck Lake Block is developed in the Thorsby Domain. The Rimbey and Foothills blocks reside in the Rimbey Domain. The Sylvan Lake and Penhold blocks occur in the Lacombe Domain.

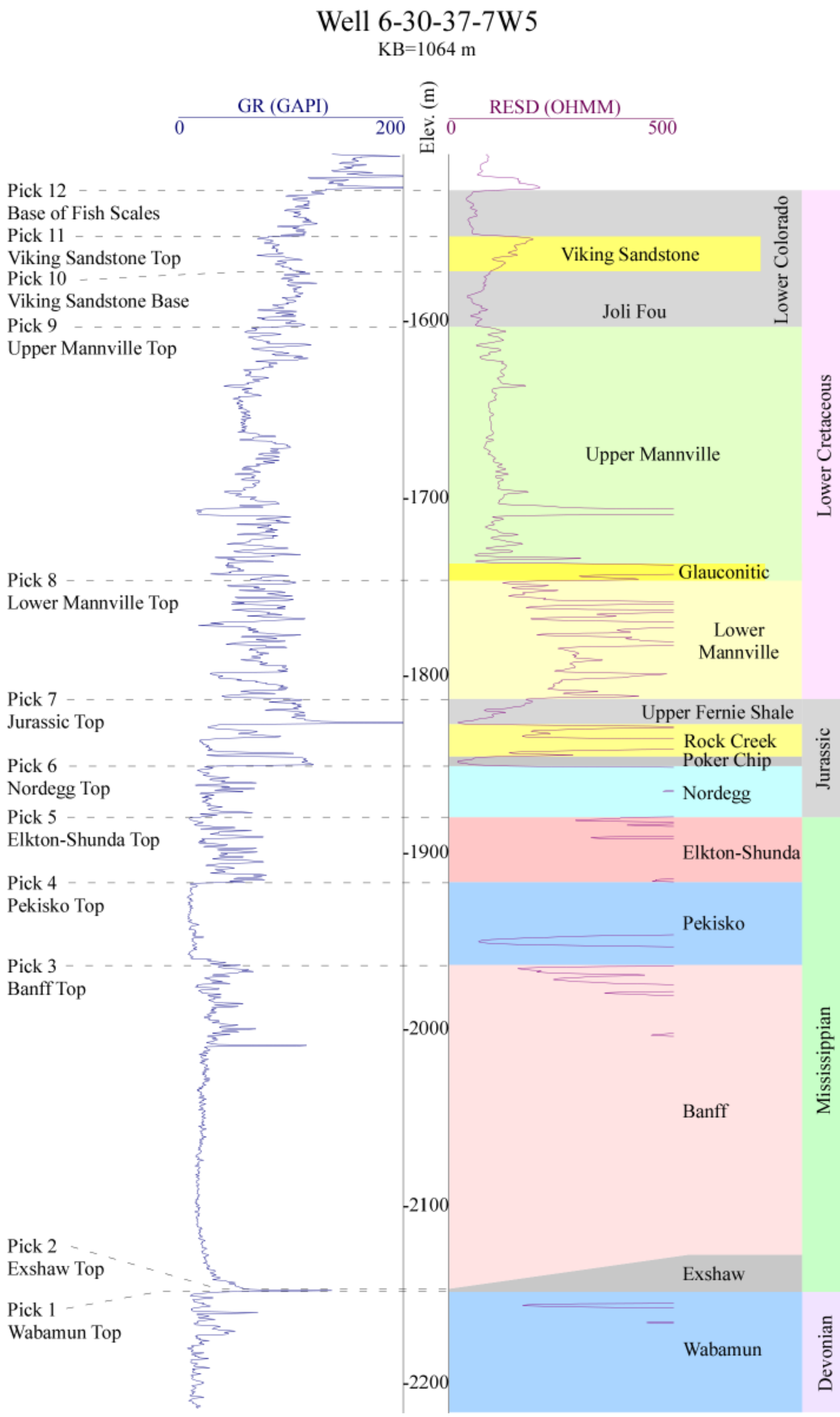


**Figure 5. Stratigraphic picks in the deep interval.**

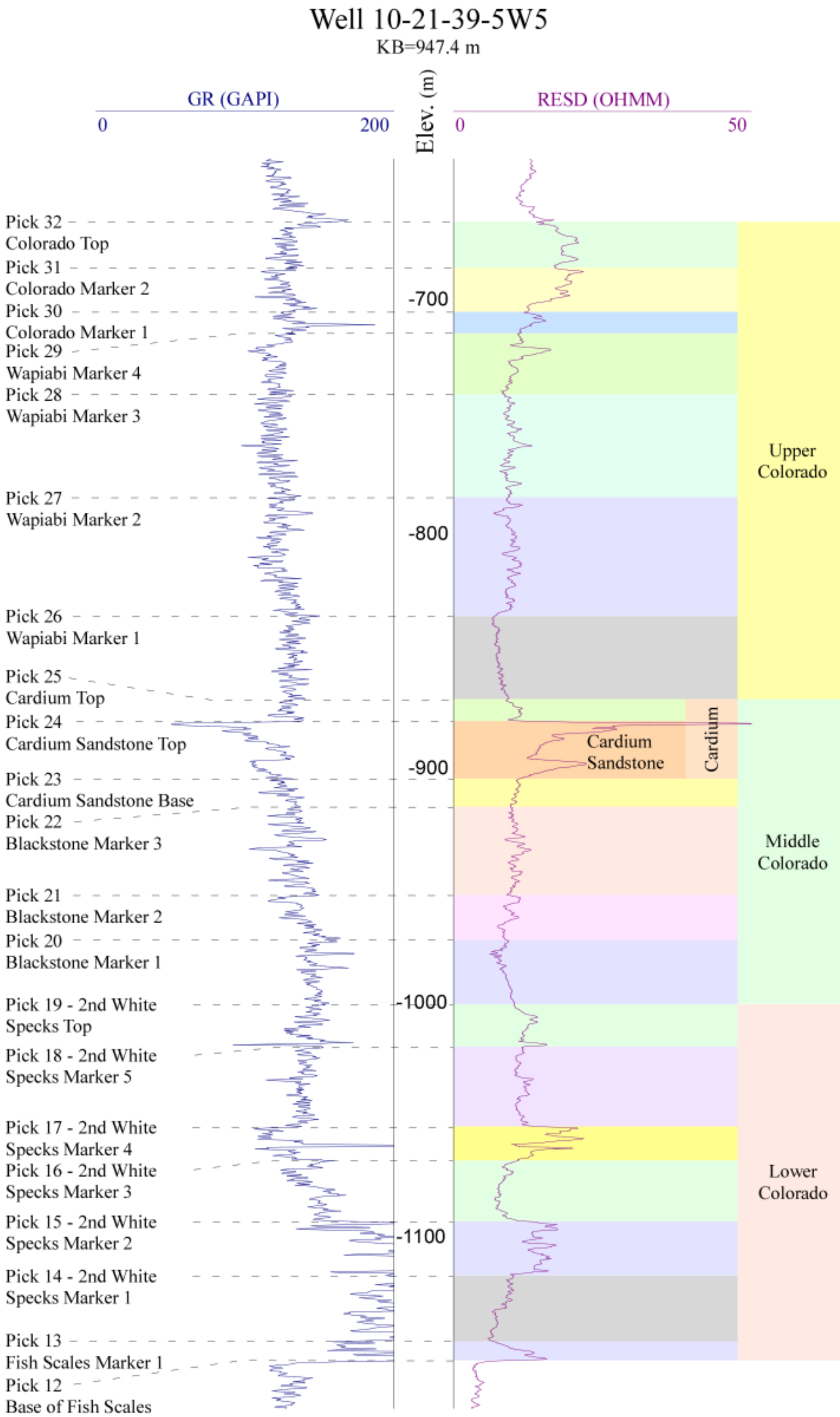


**Figure 6. Stratigraphic picks in the middle interval.**

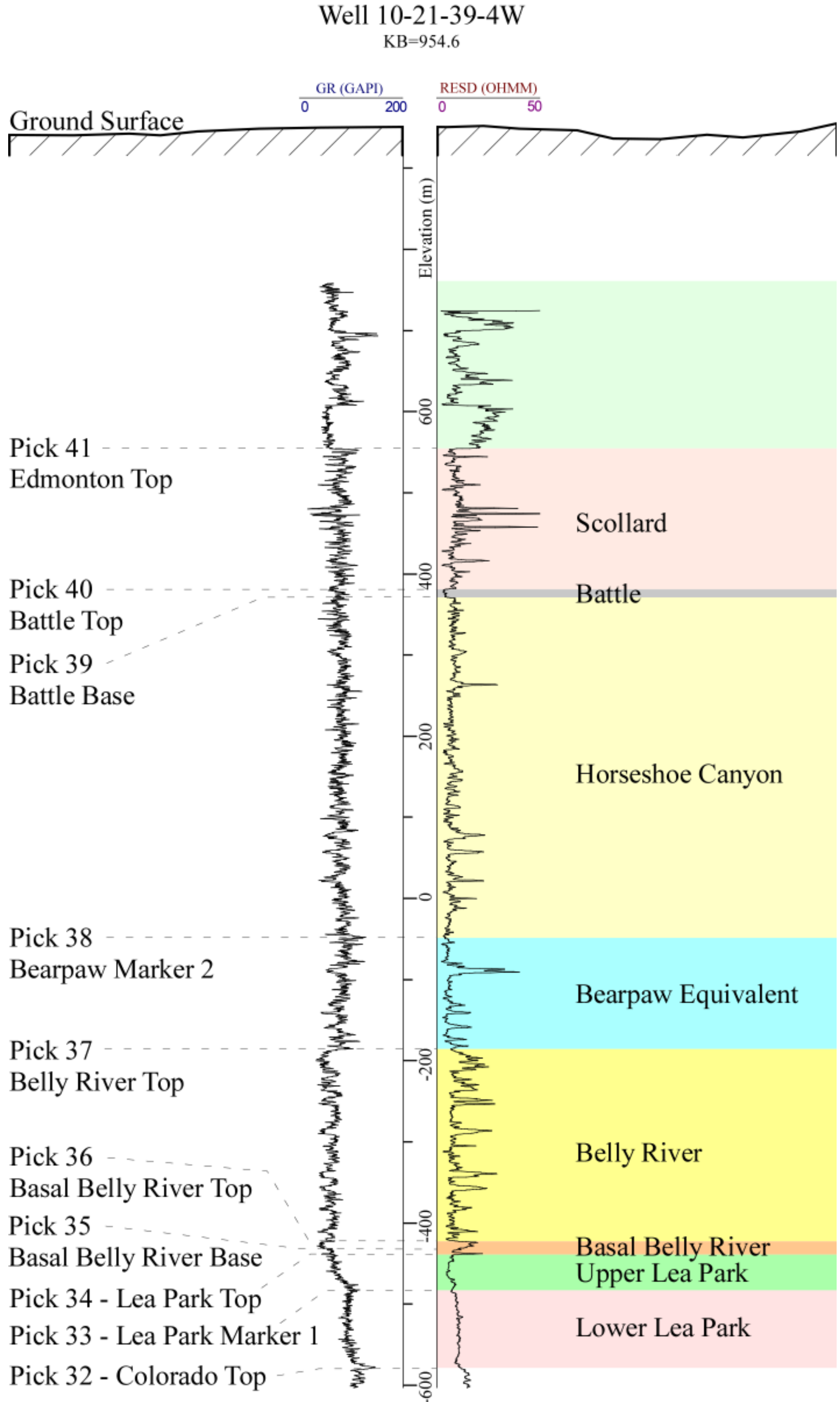


**Figure 7. Stratigraphic picks in the shallow interval.**

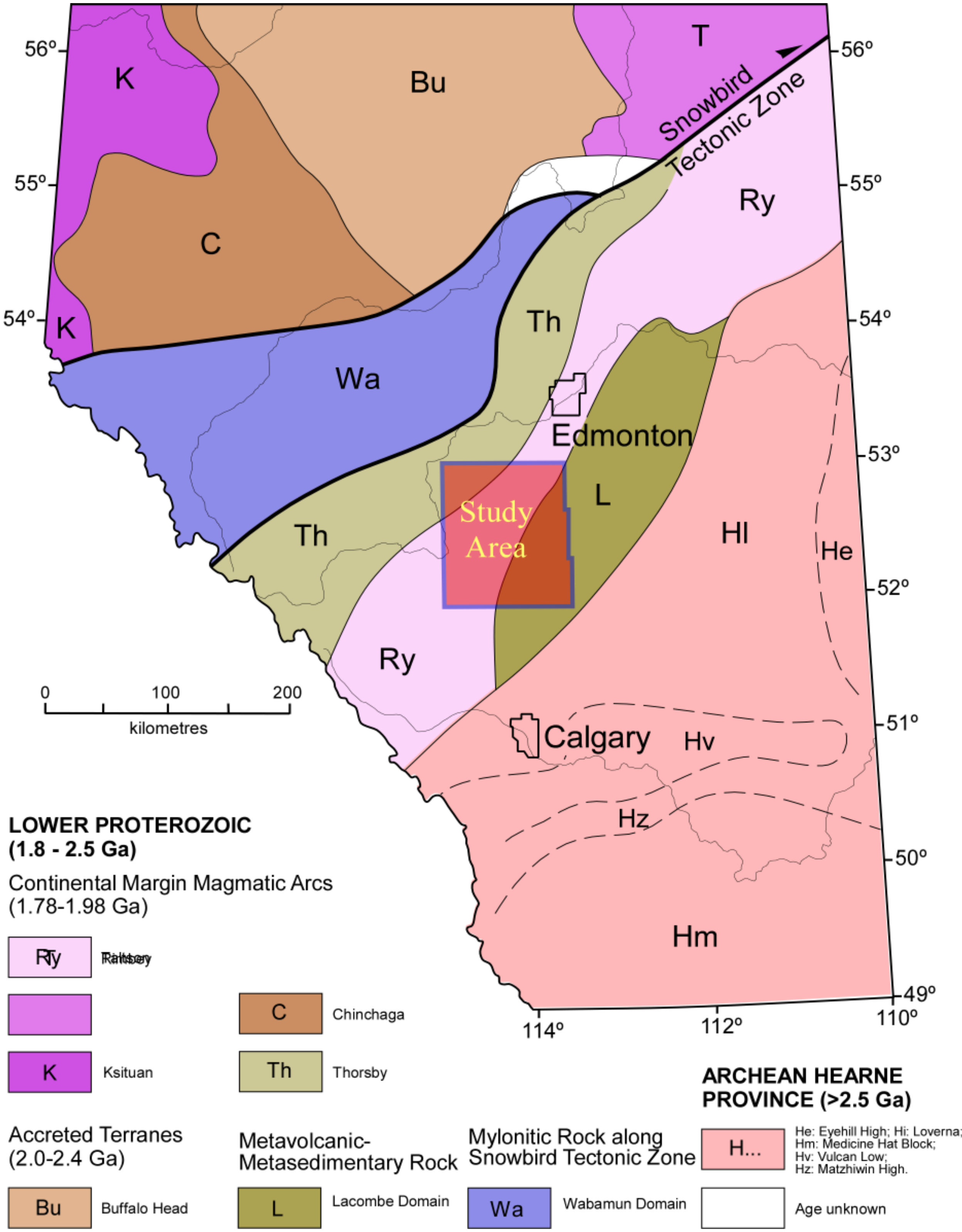


**Figure 8. Regional Precambrian basement features.**

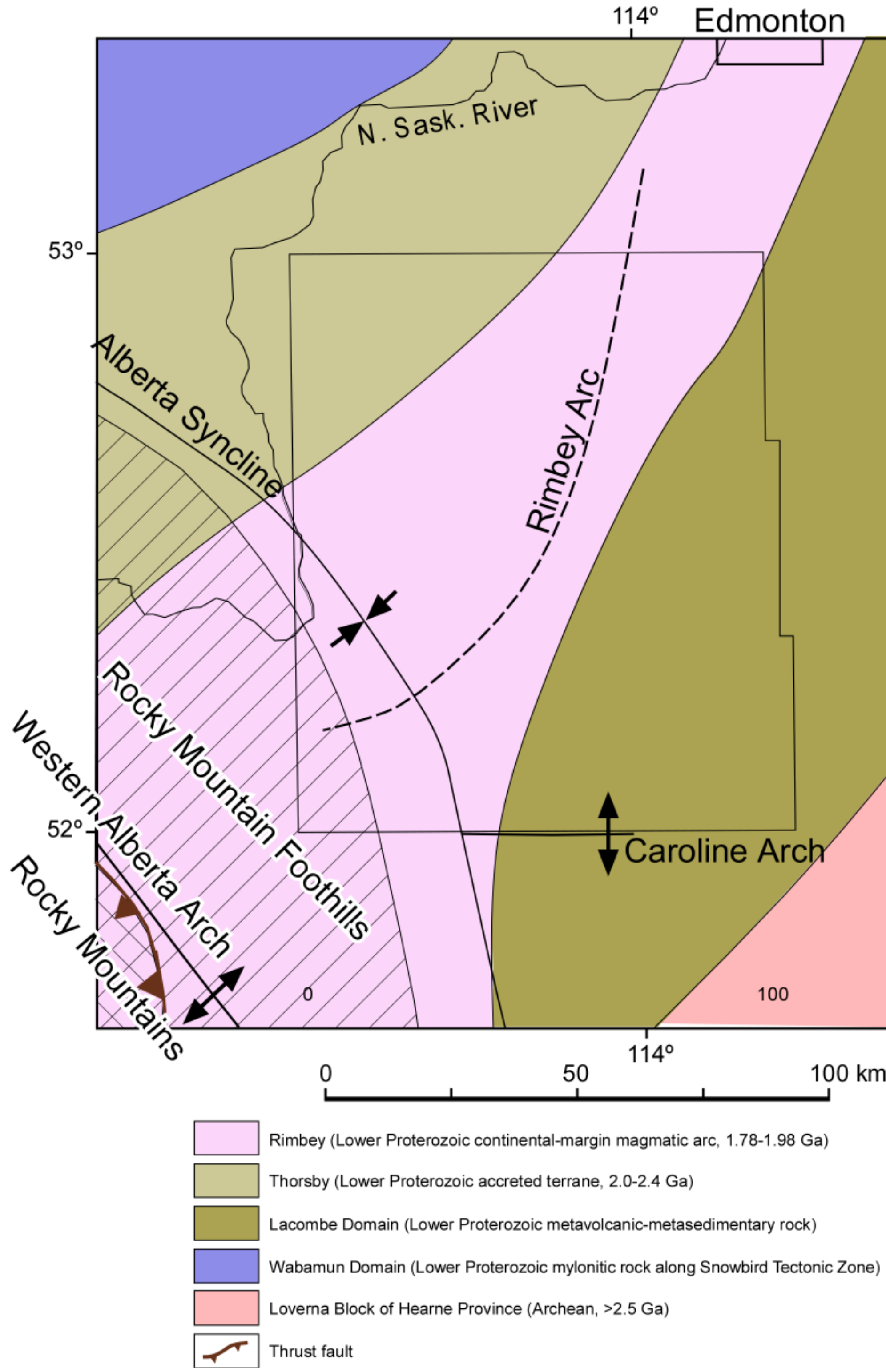


**Figure 9. Precambrian basement and Phanerozoic tectonic features in the study area.**

Seven basement lineaments are shown in Figure 10: 1) Thorsby-Rimbey Boundary, 2) Rimbey Arc, 3) Rimbey-Lacombe Boundary, 4) Sylvan Lake Lineament, 5) Penhold Lineament, 6) Battle River Lineament, and 7) east edge of the Rocky Mountain Foothills. Note that the Precambrian domain and Phanerozoic tectonic boundaries and lineaments defined by this study (Figure 10) are slightly different than those defined previously (Figure 9). Instead of a smooth arc, the Rimbey Arc consists of two lineaments. The main part of the arc trends north-northeast and the southwestern part of the Arc trends east-northeast.

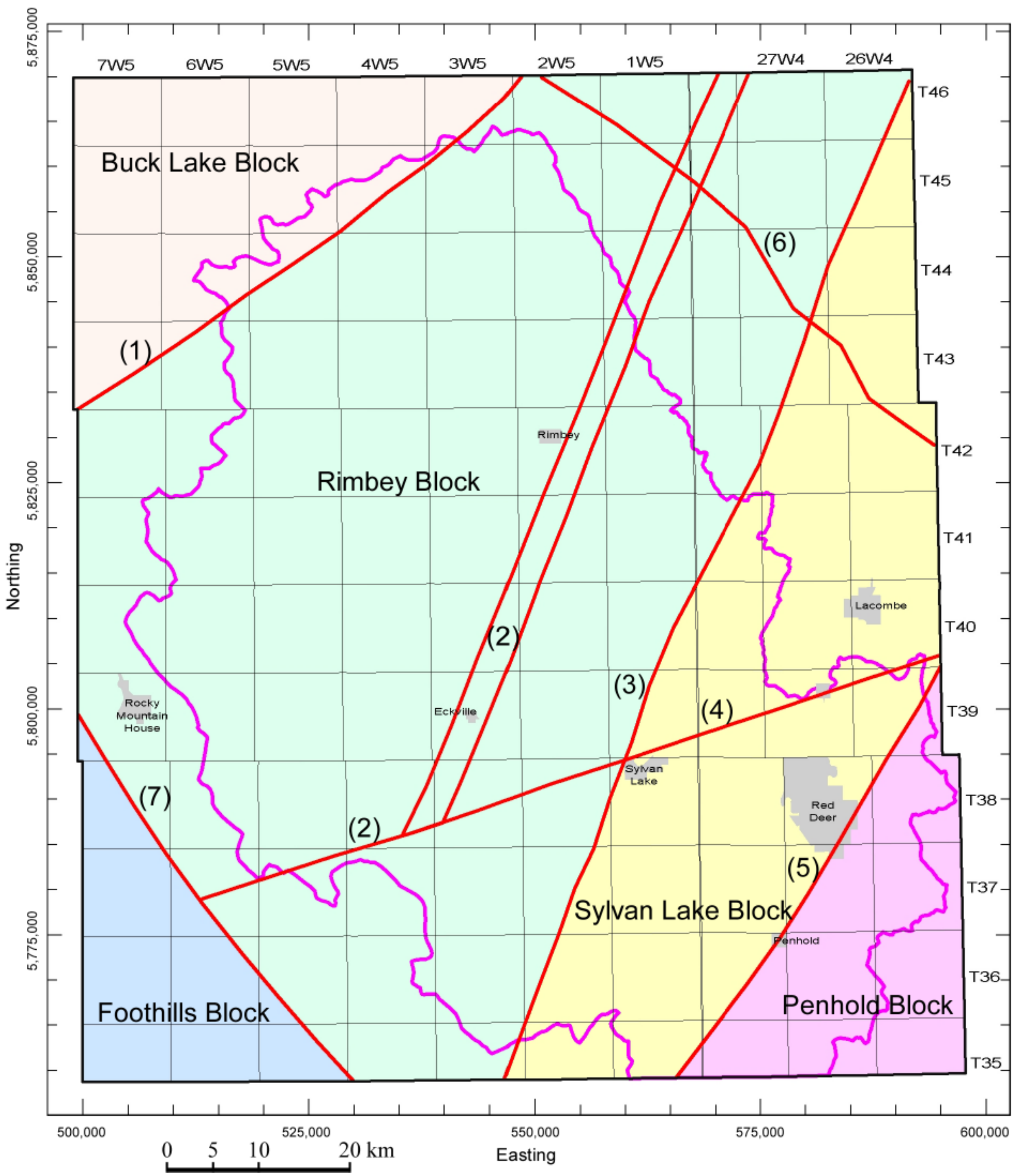


**Figure 10. Basement blocks and lineaments.**

The Rimbey Block can be subdivided to the west, east and south Rimbey blocks by the Rimbey Arc and the Sylvan Lake Lineament. The Sylvan Lake Block can be subdivided to the north and south Sylvan Lake blocks. The area northeast of the Battle River Lineament has slightly different features and motions from those of the Rimbey and Sylvan Lake blocks.

Along the Rimbey Arc, the Rimbey-Homeglen Reef Belt, part of the well-known Rimbey-Leduc-Meadowbrook Reef Complex, is developed. When viewed on seismic profiles, the basement surface beneath the Rimbey-Homeglen reef is relatively featureless; the Rimbey Arc does not correlate with any significant basement structure according to Edwards and Brown (1999), although they did not exclude the possibility of seismically irresolvable undulations existing on pre-Leduc reflectors. A Bouguer gravity anomaly, interpreted as an extension of the Snowbird Tectonic Zone, coincides with a significant part of the Rimbey-Leduc-Meadowbrook Reef Complex.

The undeformed portion of the Phanerozoic in west-central Alberta can be viewed as a simple wedge above Precambrian crystalline basement. The wedge tapers from a thickness of about 5000 m in the axis of the Alberta Syncline to about 3000 m in the northeast (Wright et al., 1994). The Phanerozoic cover can be divided into two distinct parts. The lower part is from the Paleozoic to the Lower Jurassic, dominated by carbonate rocks deposited on the passive continental margin. The upper part, from the Middle Jurassic to the Lower Tertiary, is dominated by clastic rocks formed in the foreland basin at the same time as Canadian Cordilleran Orogeny.

During Paleozoic and earliest Mesozoic time, west-central Alberta was dominated by extensional tectonics, and cratonic platform depositional sequences were built up in an open ocean to the west. For most of the platform succession, sedimentation and erosion were strongly influenced by episodically differentiated intracratonic uplifts (Wright et al., 1994). Beginning in the mid-Jurassic, the study area was developed in the foredeep and forebulge settings of the foreland basin. The episodic collisional events on the western margin resulted in thrusting and folding of the rocks in the west, downwarping of the foredeep and migration of the foredeep and the forebulge across the area. The foreland clastic wedge is characterized by overall coarsening-upward progradational and aggradational cycles capped by extensive nonmarine deposits (Mossop and Shetsen, 1994). After the Paleocene culmination of the Laramide Orogeny, erosion and sediment bypass resulted in the subcrop of Tertiary Paskapoo classic rocks as the youngest bedrocks throughout the study area.

# 5 Stratigraphic Framework and Structures

## 5.1 Stratigraphic Table and Cross-Sections

The stratigraphic table in Figure 11 was constructed from three type logs in the study area. The interval below the Base of Fish Scales was constructed using the log data from well 6-30-37-7W5. The interval from the Base of Fish Scales to the top of the Colorado was constructed using the log data from well 10-21-39-5W5. The interval above the top of the Colorado was constructed using the log data from well 10-21-39-4W5. In the stratigraphic table, the blue colour indicates carbonate rocks, the yellow colour represents coarse siliciclastic rocks and the grey colour represents shale deposits.

In the Medicine River area, the overall dip of the formations is toward the southwest. From the Wabamun top to the ground surface, the thickness is about 3200 m in the southwest and 1600 m in the northeast. The Upper Cretaceous to Lower Tertiary succession occupies about 60% of the sedimentation wedge. For correlation purposes, the formations from the Devonian top to the ground surface were grouped into three intervals: deep, middle, and shallow.

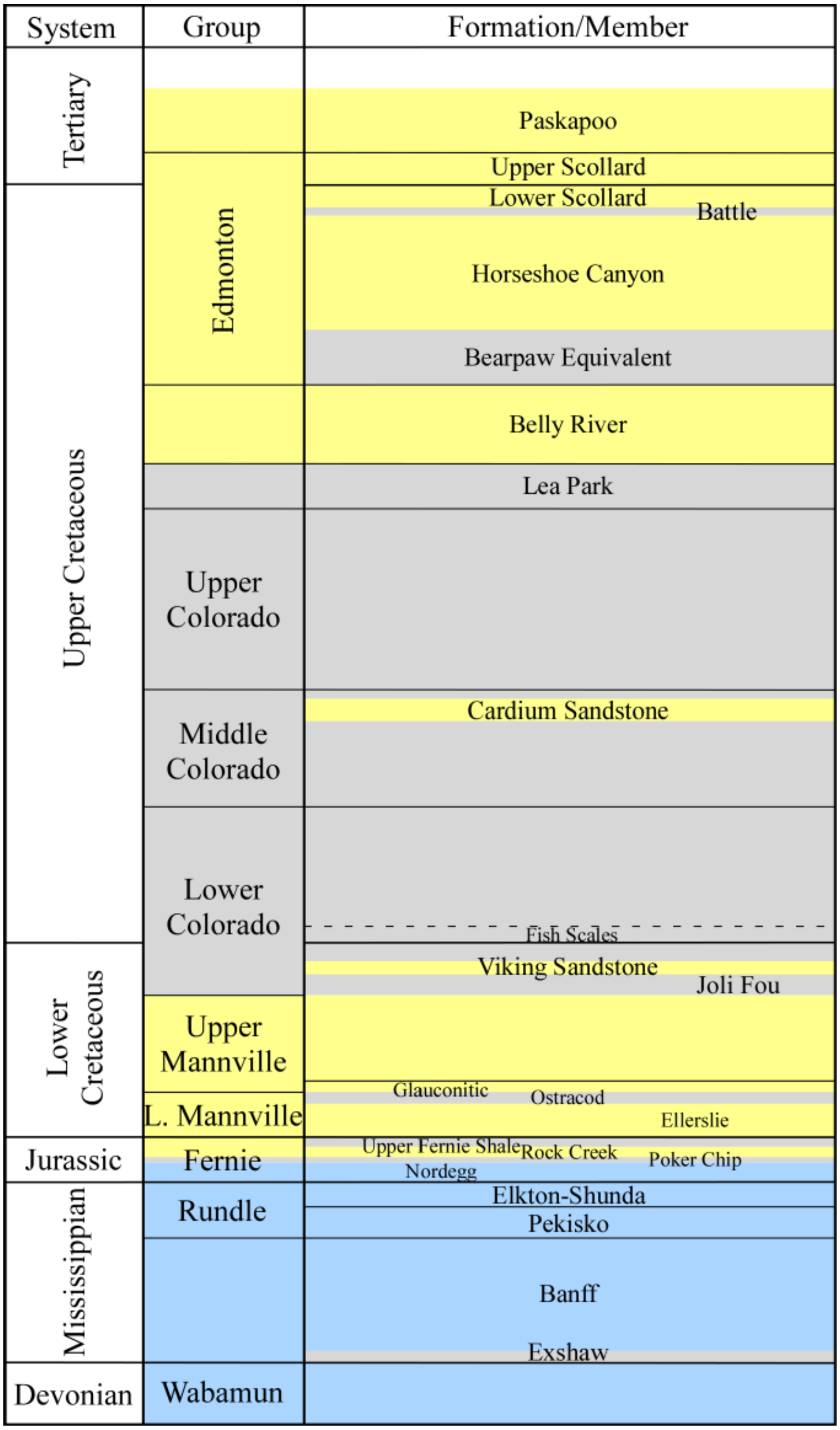


**Figure 11. Stratigraphic table of the Medicine River area.**

Figure 12 shows the locations of the five cross-sections in the deep interval: A-A' to E-E' (Figures 15–19). Figure 13 shows the locations of the six cross-sections in the middle interval: F-F' to K-K' (Figures 20–25). Figure 14 shows the locations of five cross-sections in the shallow interval: L-L' to O-O' (Figures 26–29).

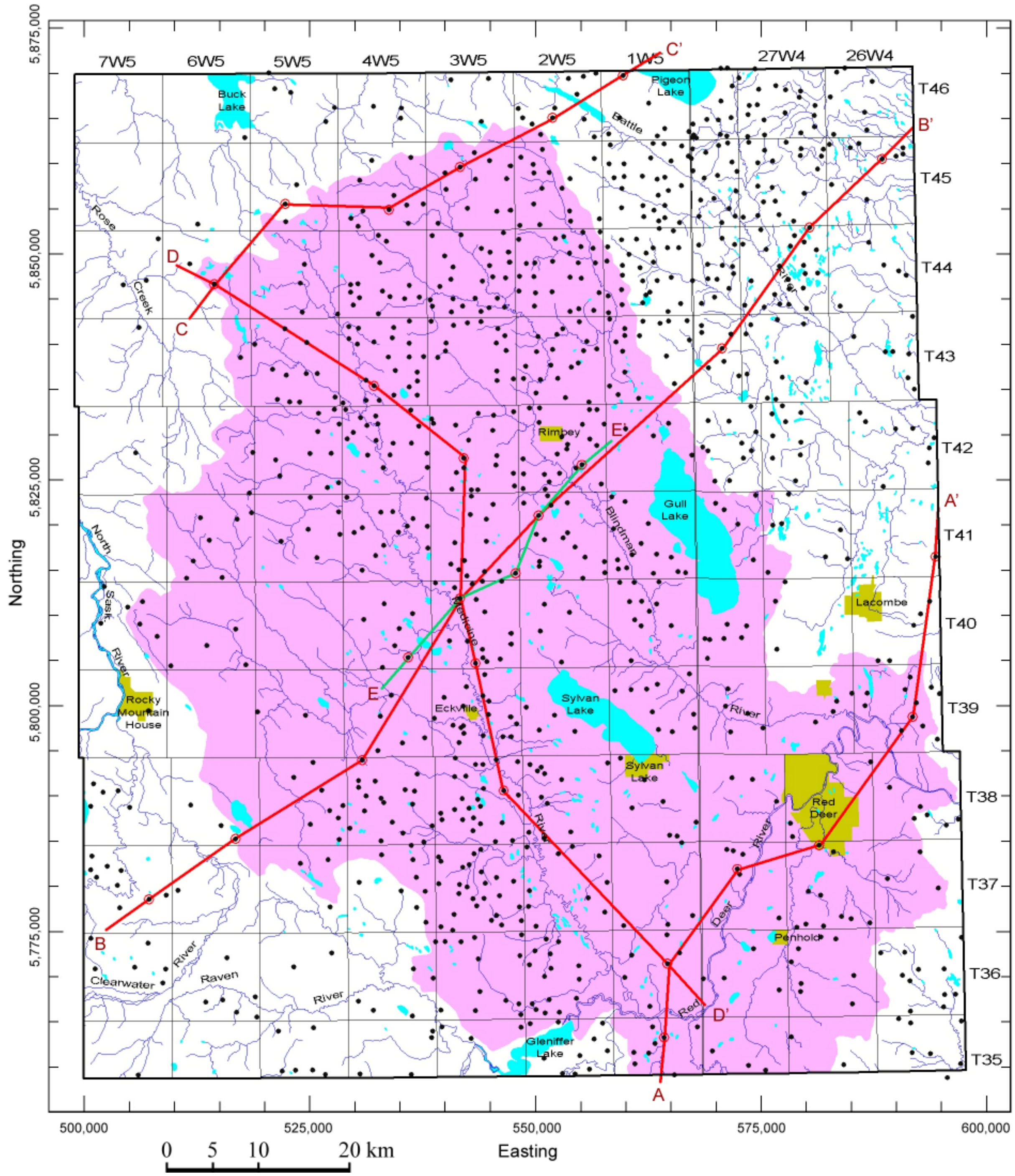


**Figure 12. Location of cross-sections in the deep interval.**

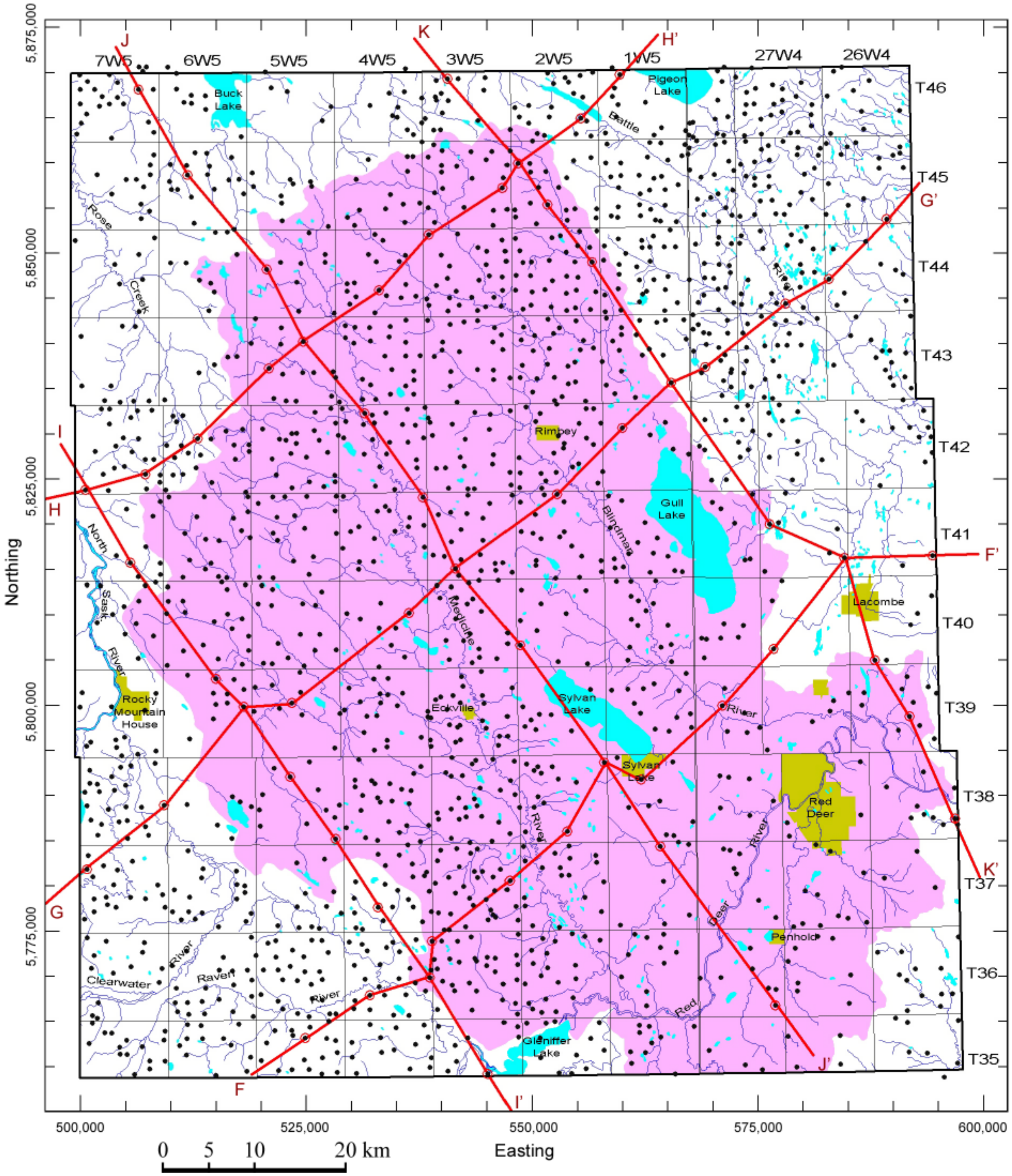


**Figure 13. Structural cross-section A-A'.**

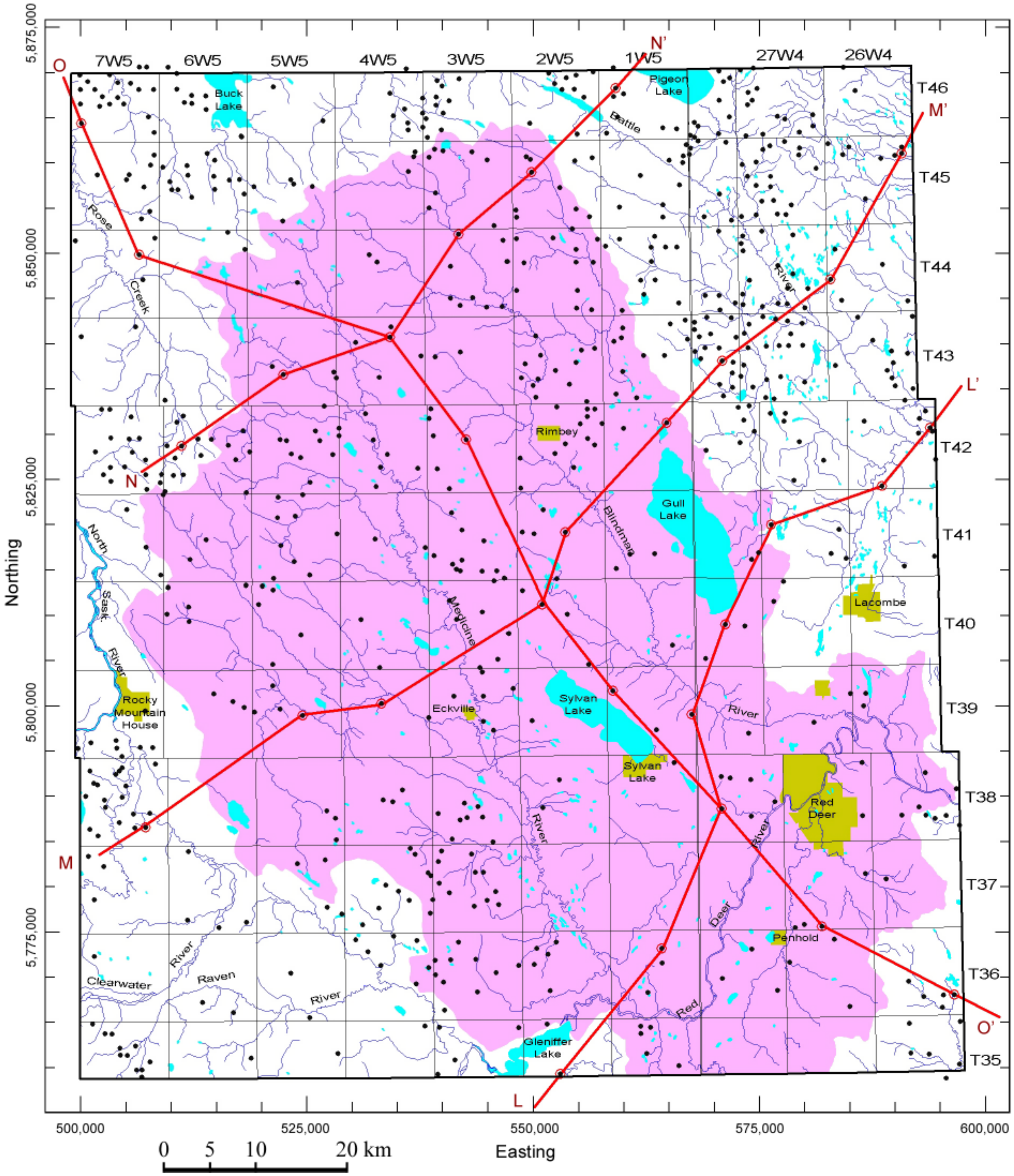


**Figure 14. Structural cross-section B-B'.**

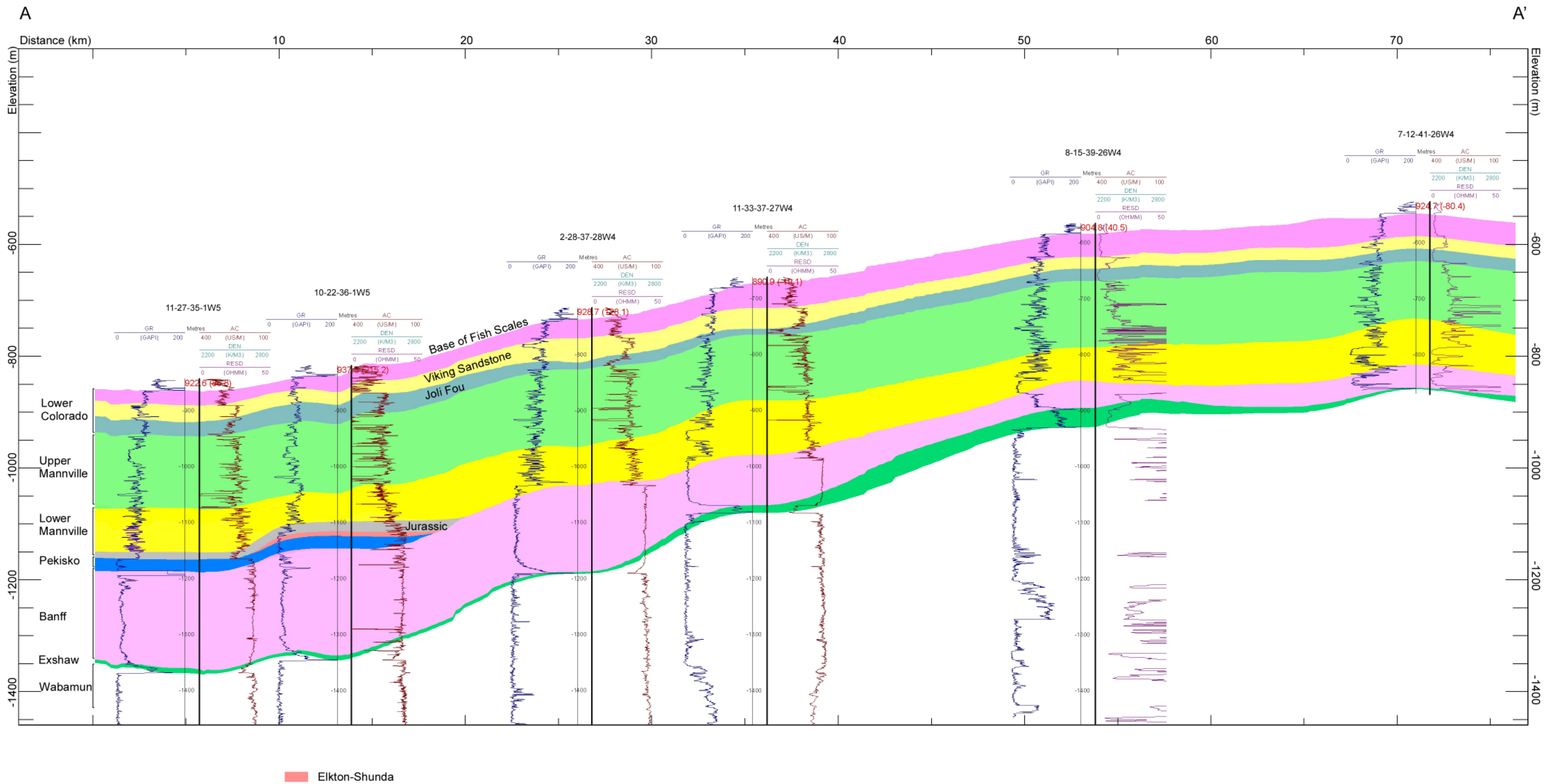


**Figure 15. Structural cross-section C-C'.**

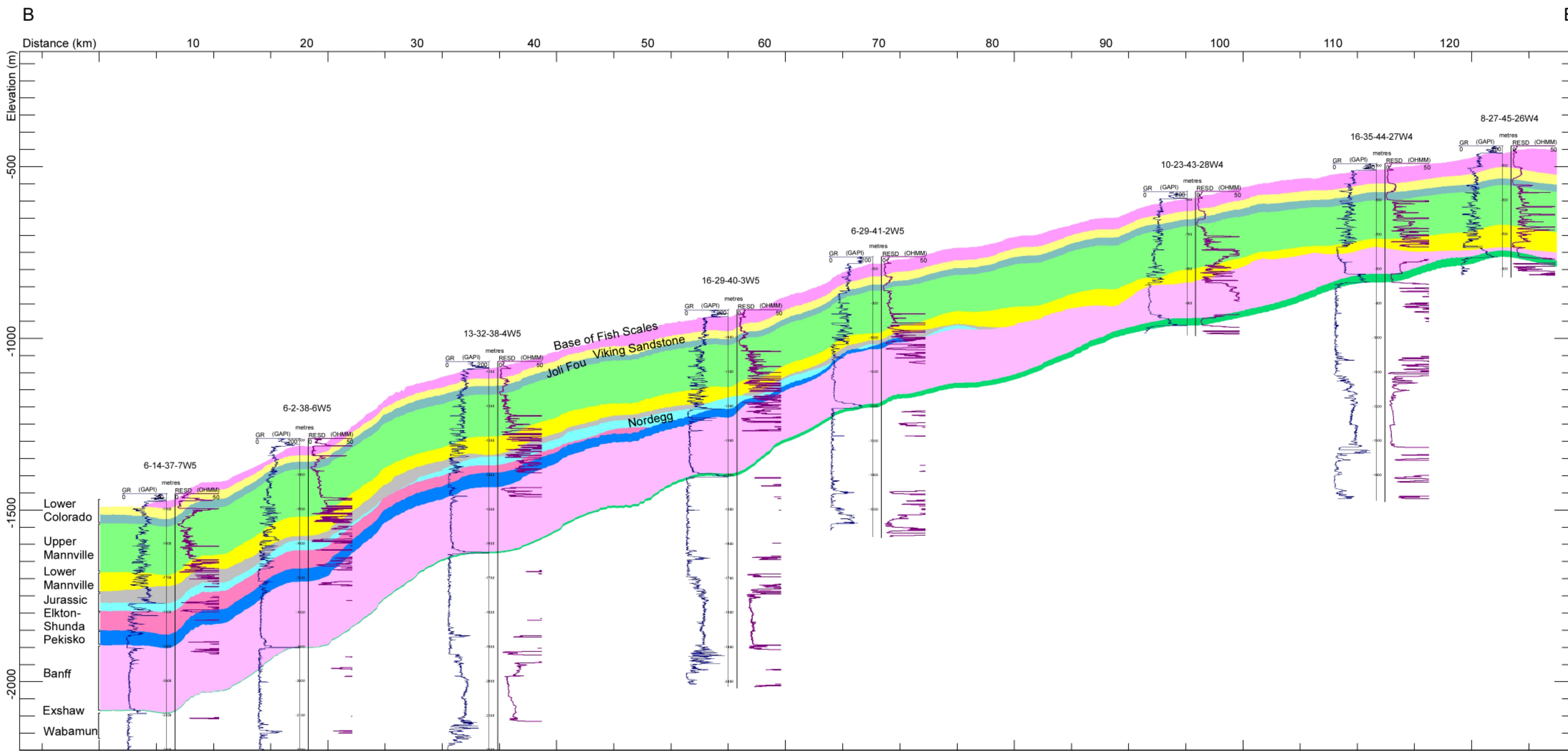


**Figure 16. Structural cross-section D-D'.**

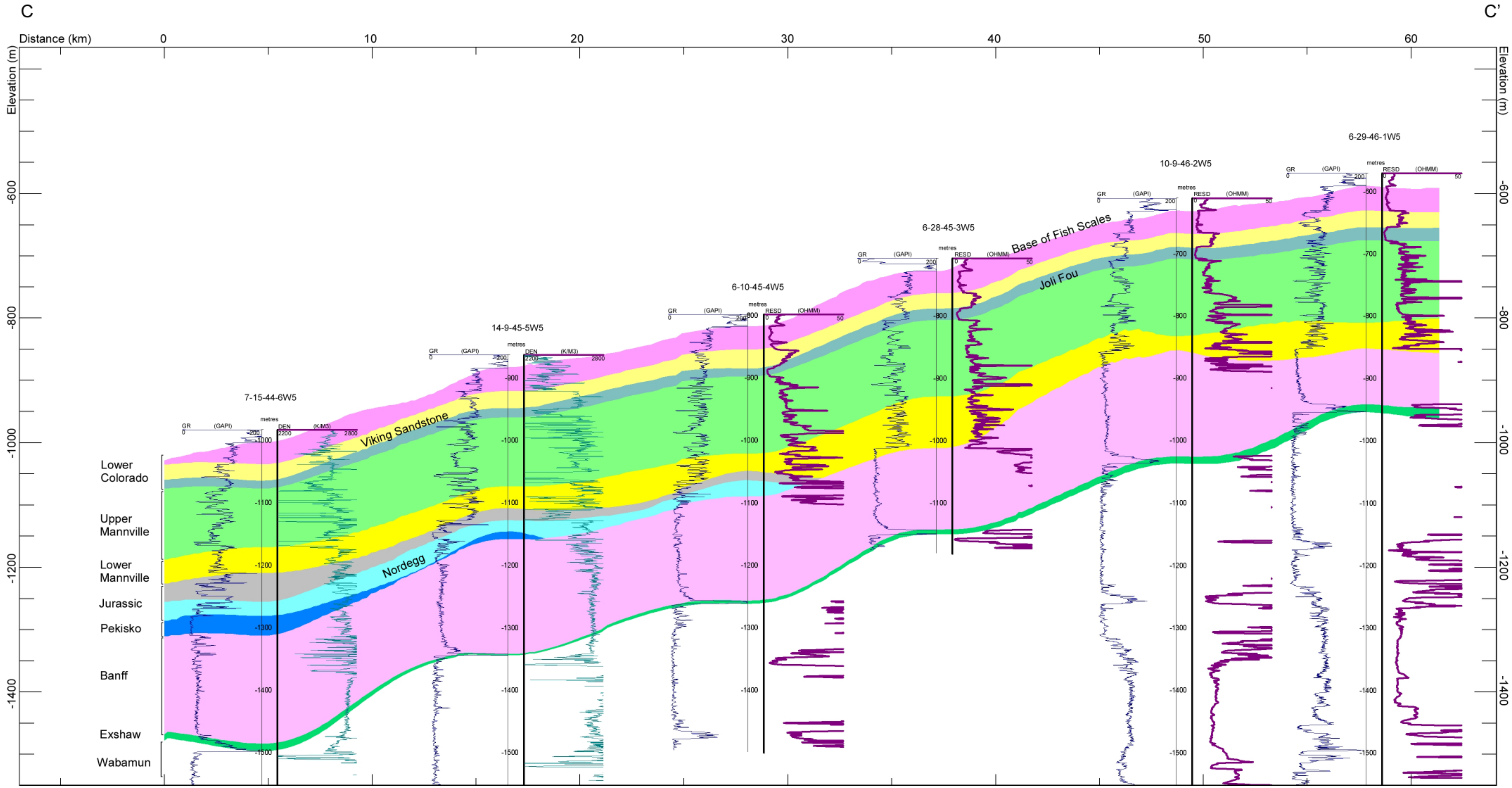


**Figure 17. Structural cross-section E-E'.**

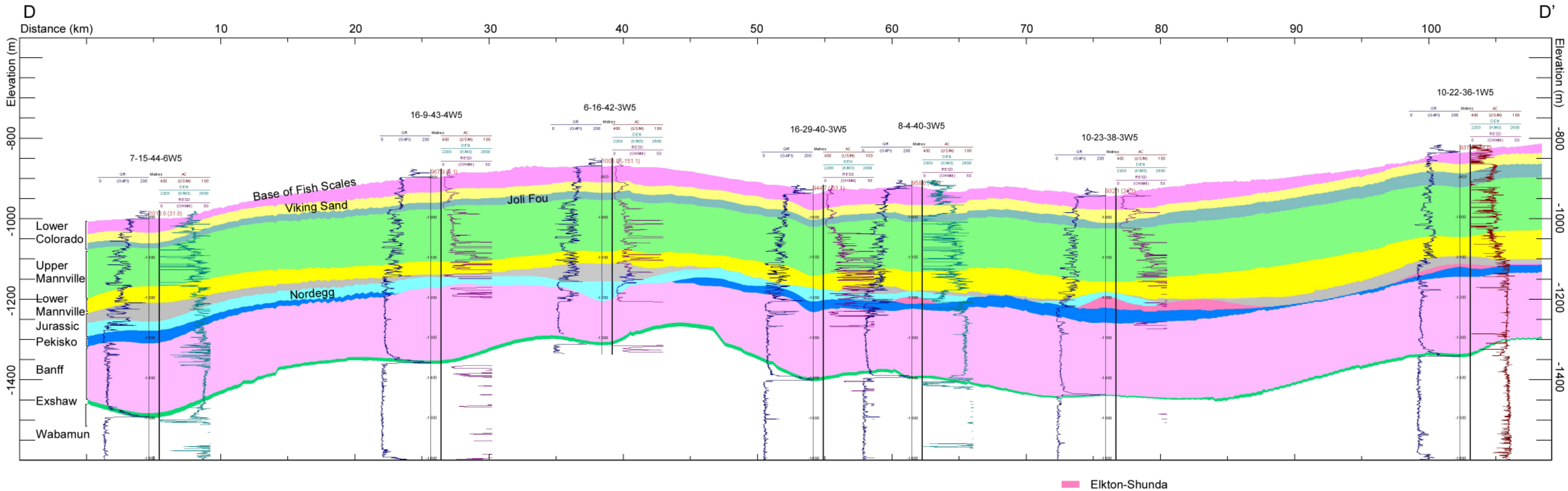


**Figure 18. Location of cross-sections in the middle interval.**

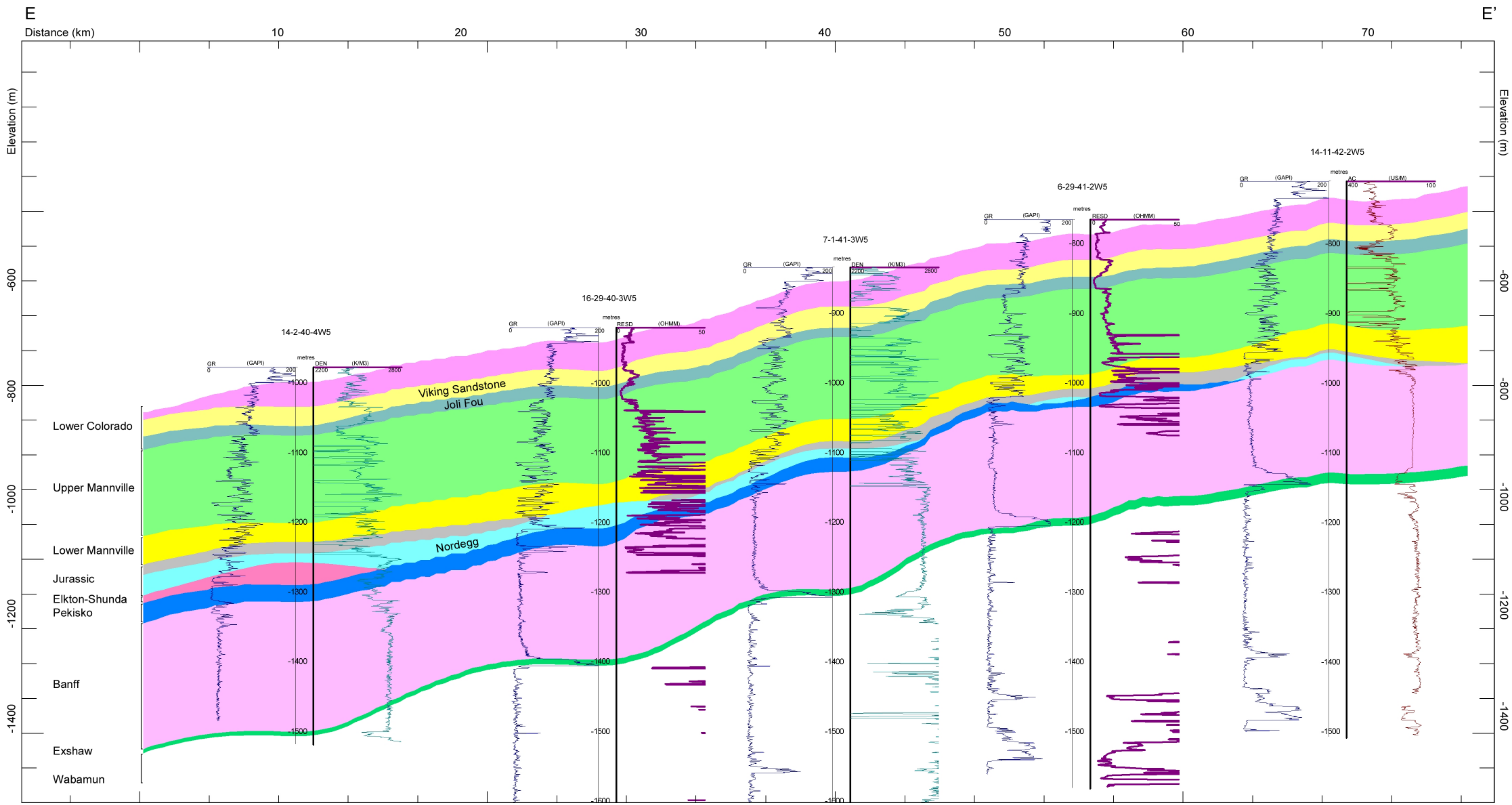


Figure 19. Structural cross-section F-F'.

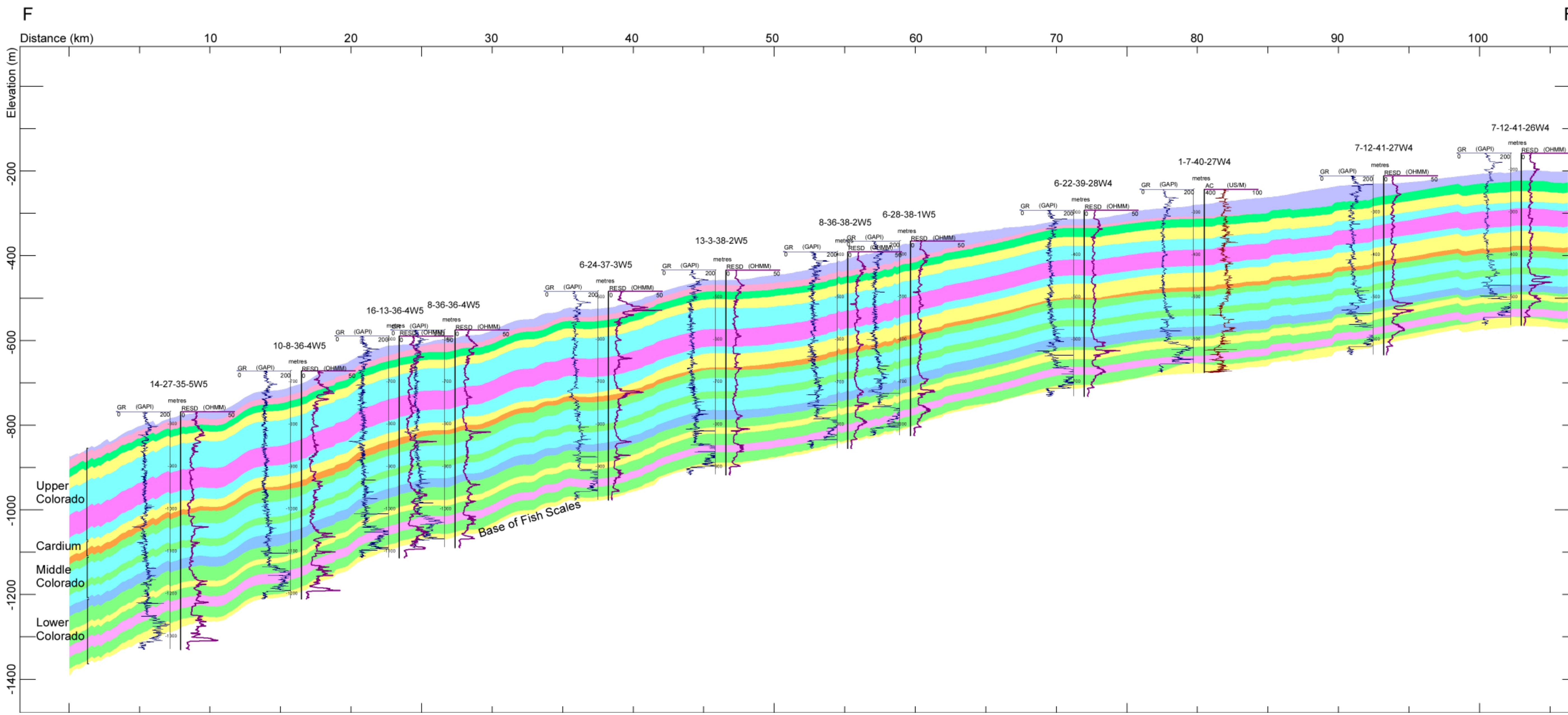


**Figure 20. Structural cross-section G-G'.**

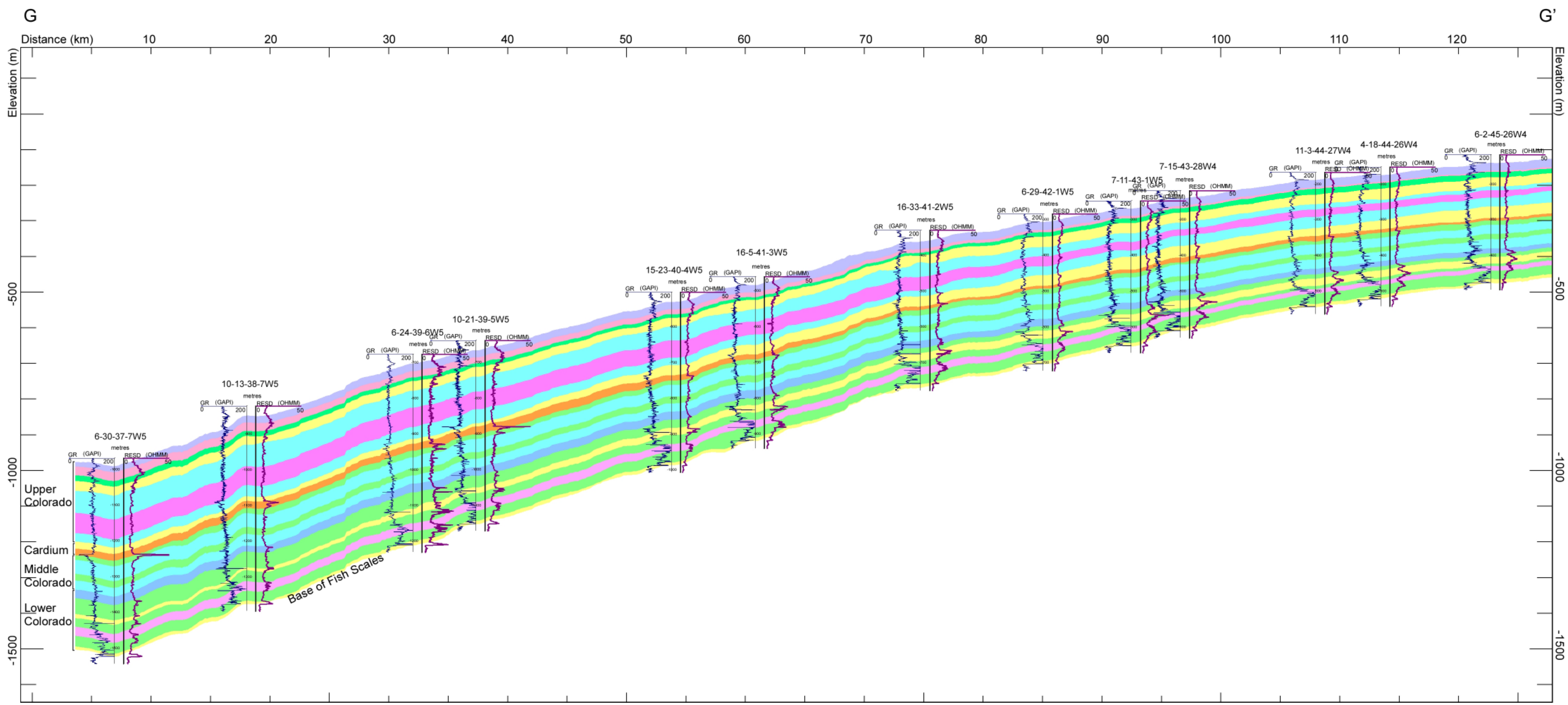


**Figure 21. Structural cross-section H-H'.**

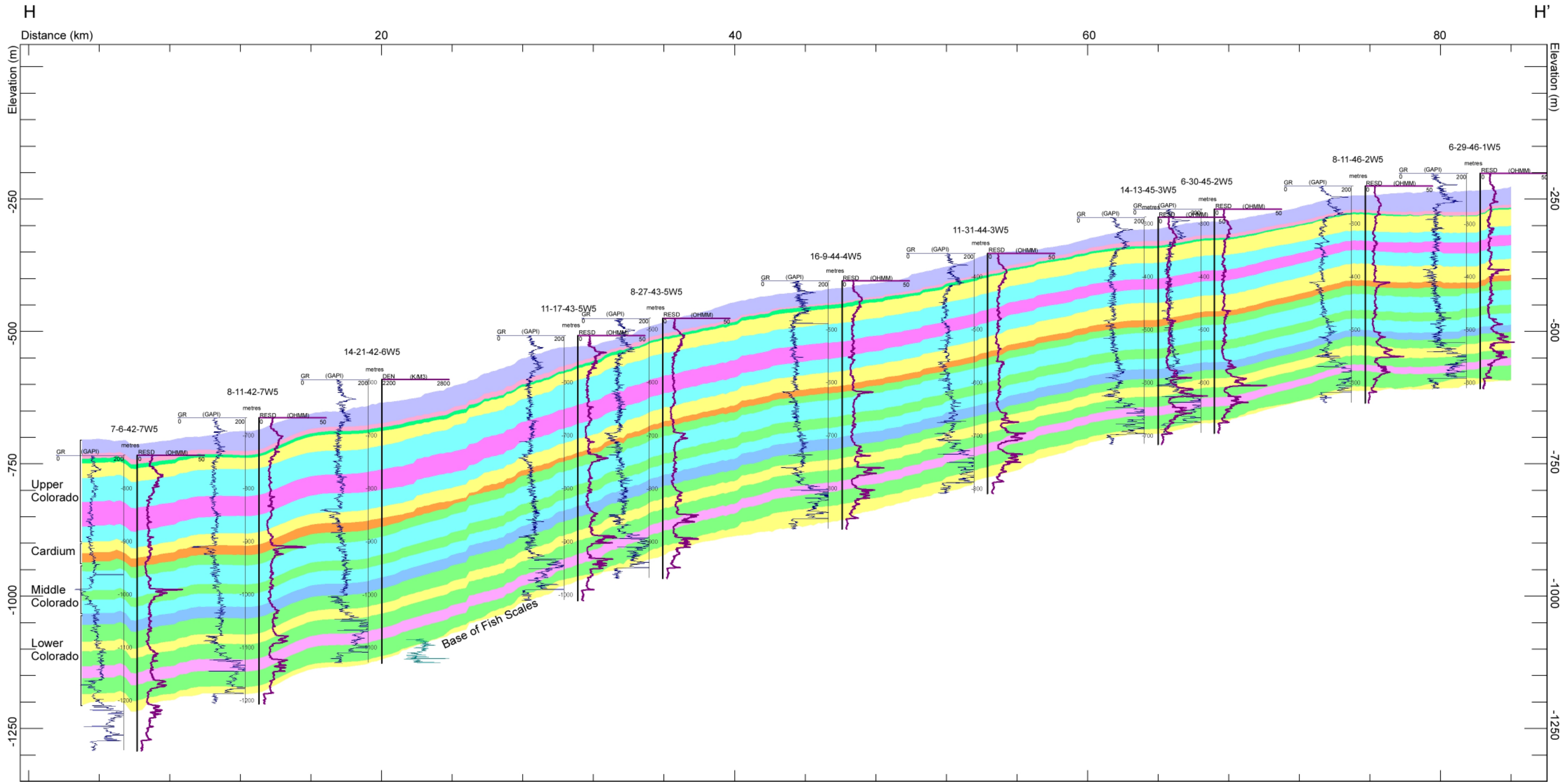


**Figure 22. Structural cross-section I-I'.**

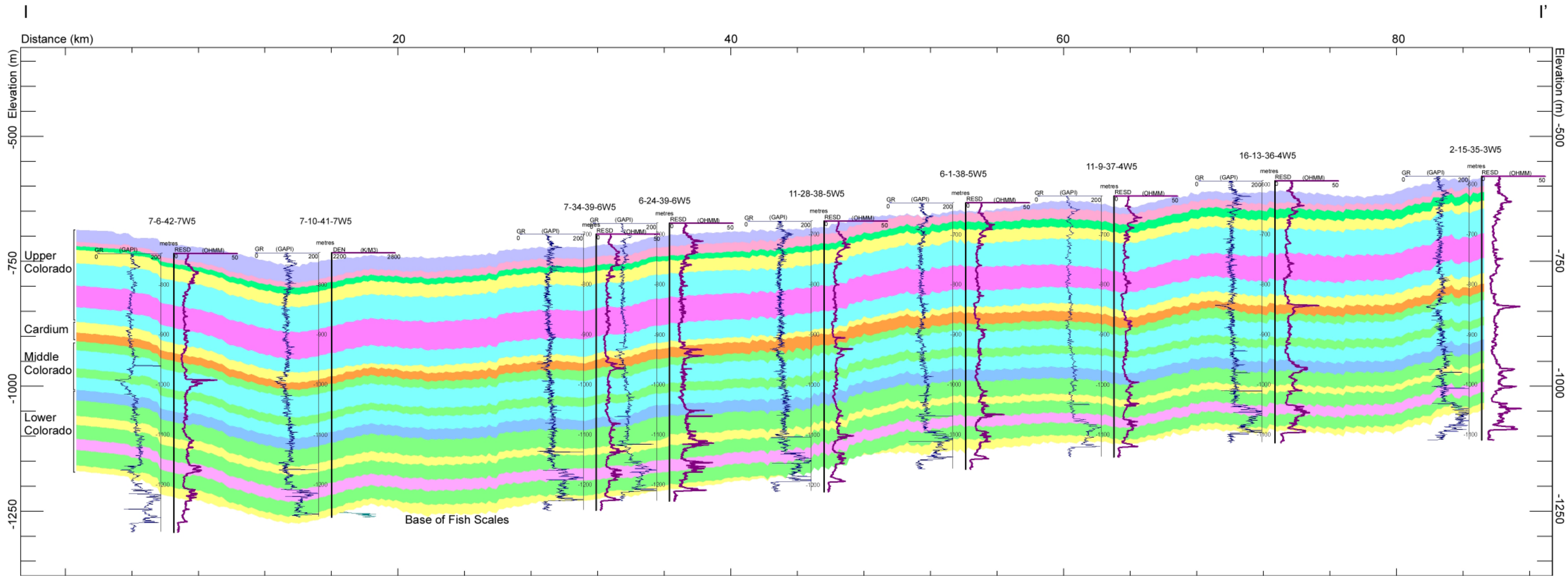


**Figure 23. Structural cross-section J-J'.**

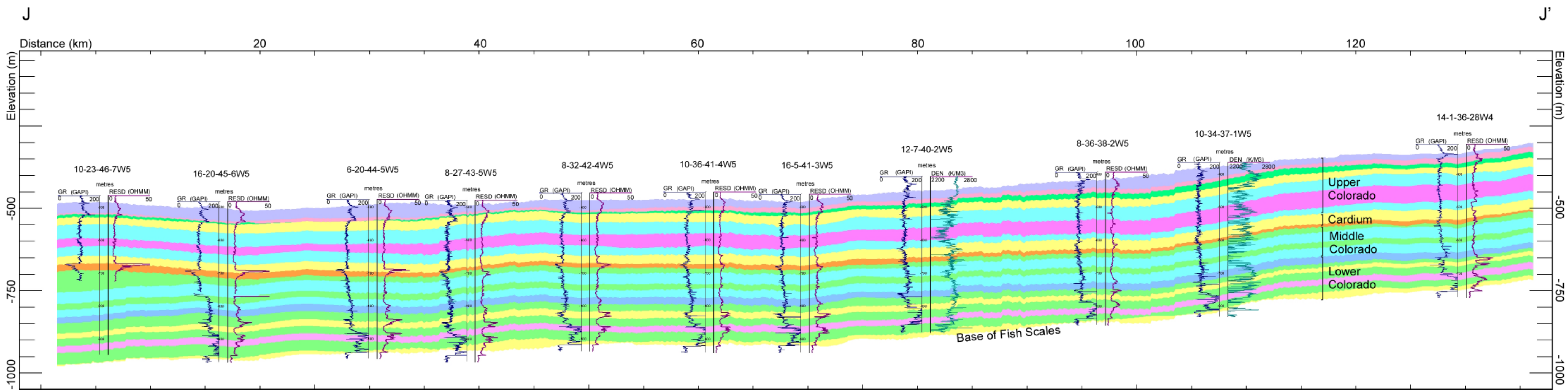


**Figure 24. Structural cross-section K-K'.**

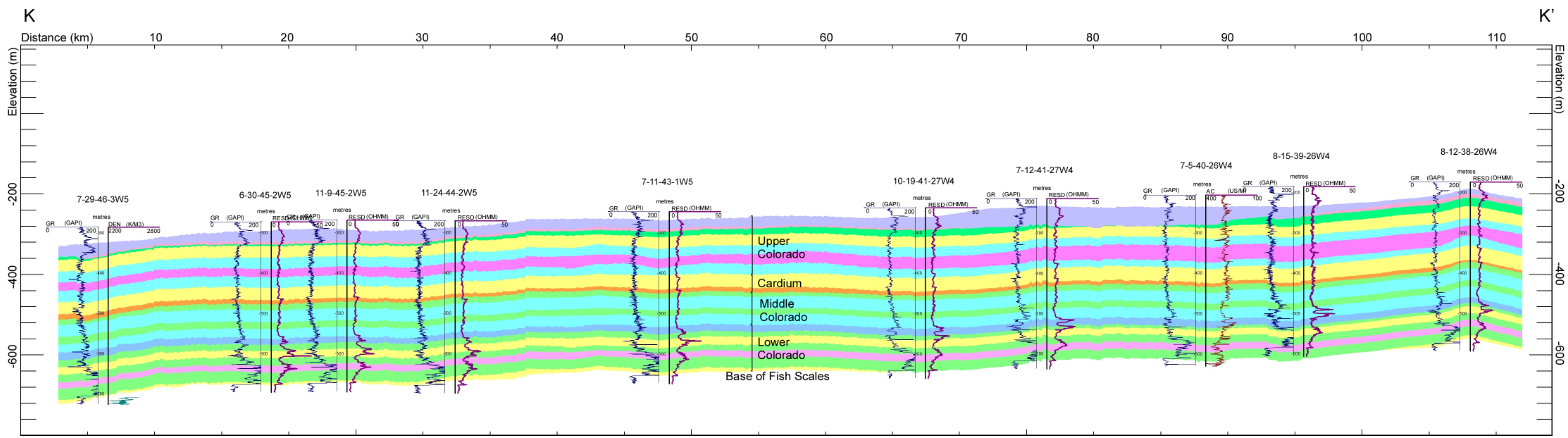


**Figure 25. Location of cross-sections in the shallow interval.**

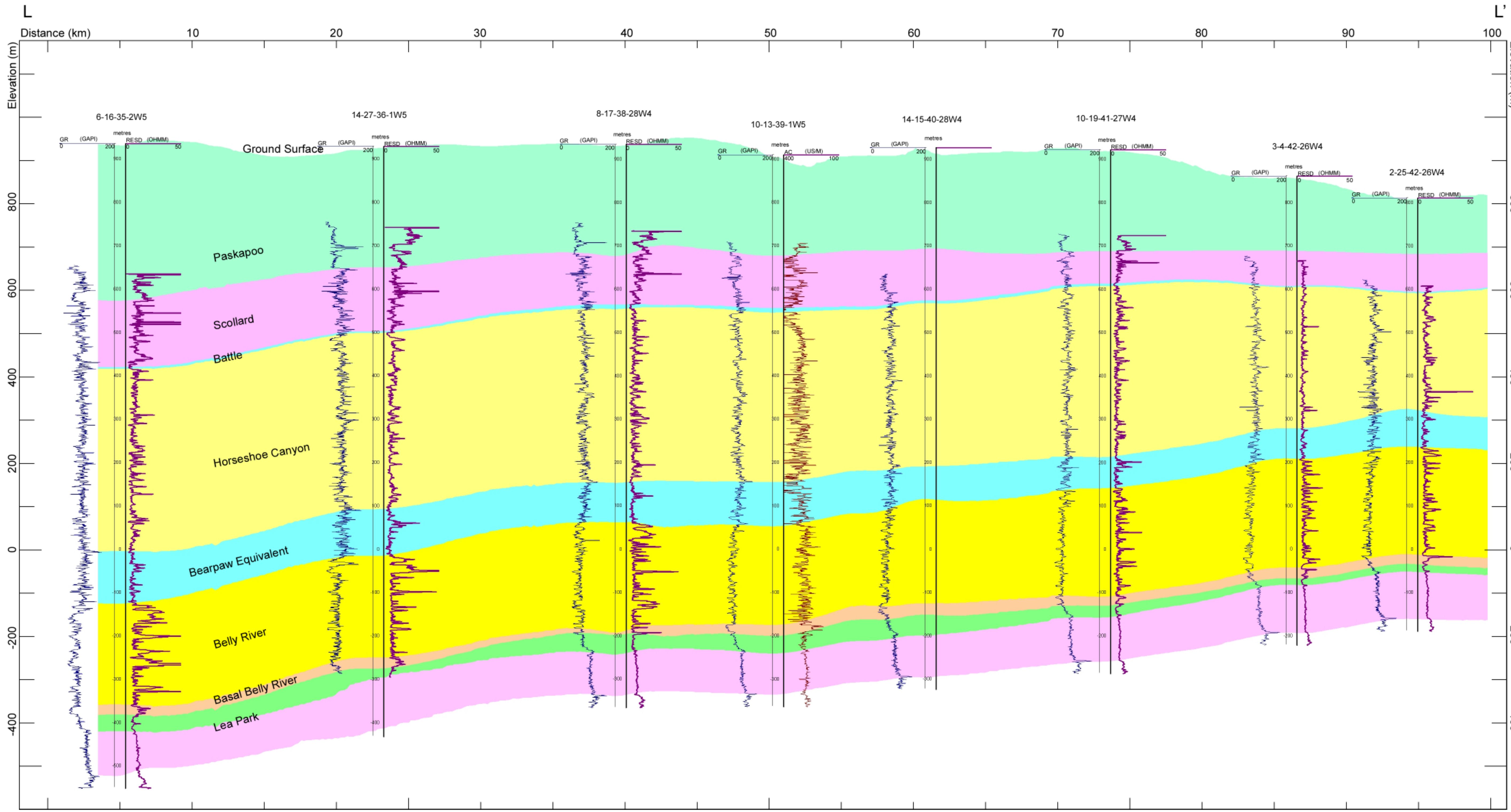


Figure 26. Structural cross-section L-L'.

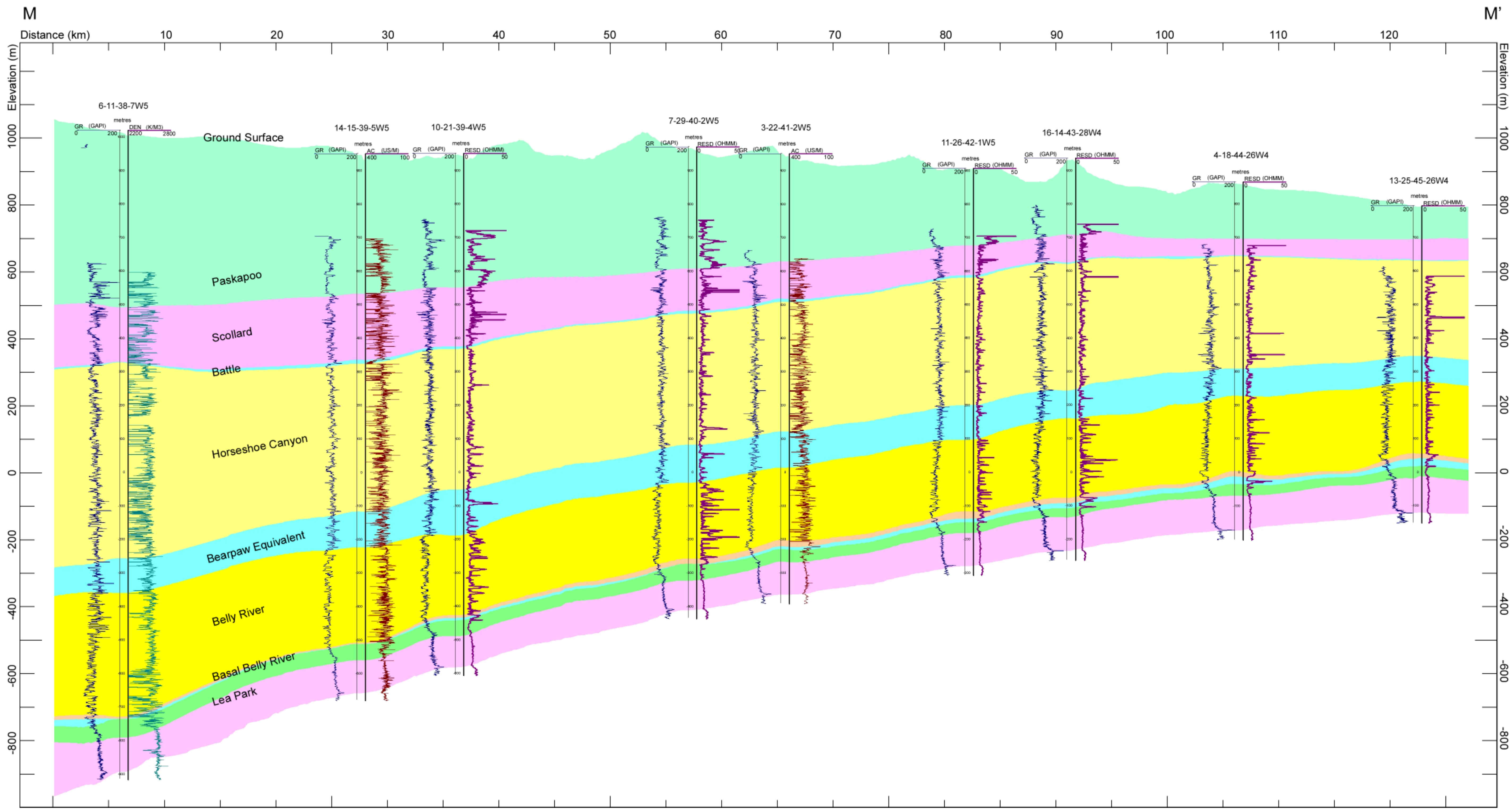


**Figure 27. Structural cross-section M-M'.**

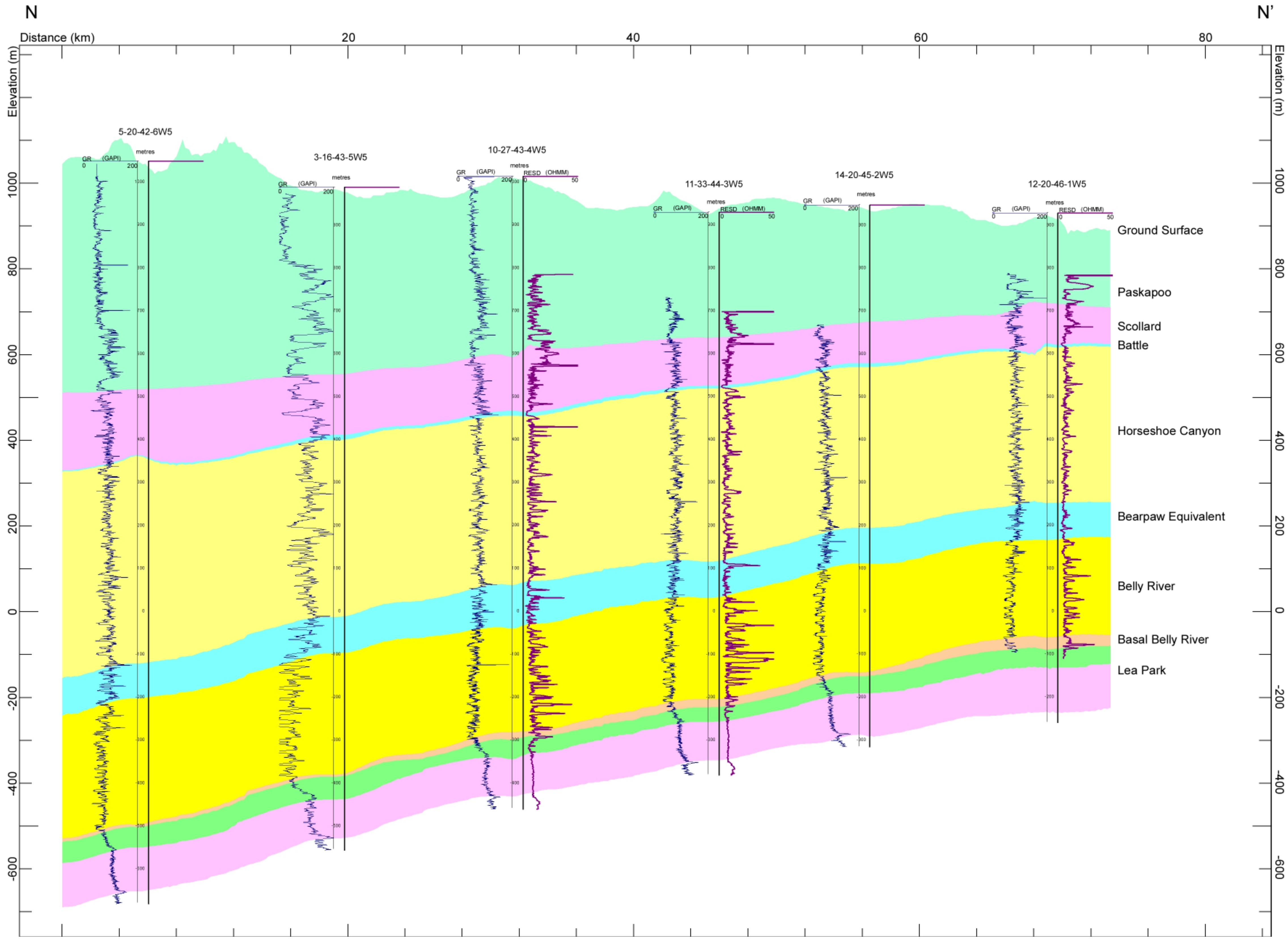


Figure 28. Structural cross-section N-N'.

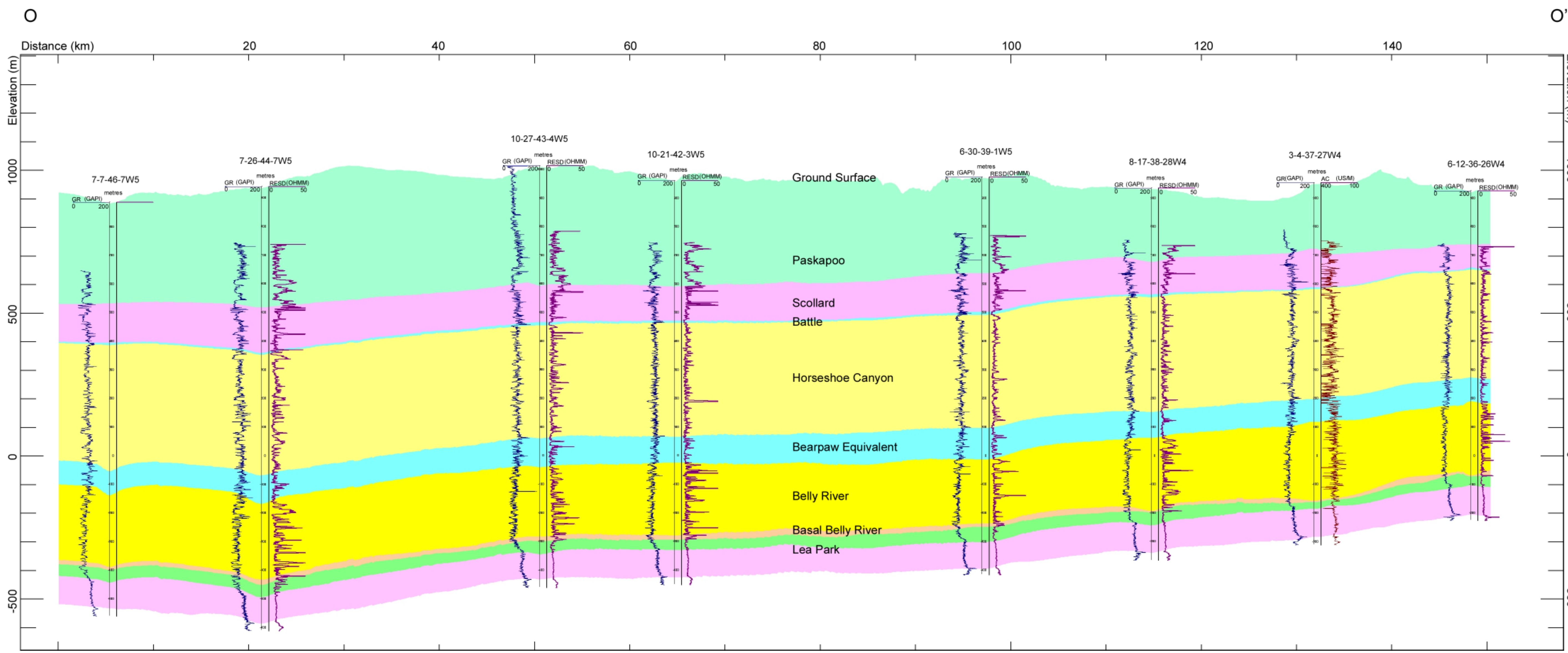


**Figure 29. Structural cross-section O-O'.**

The deep interval is about 300–620 m thick and consists of Mississippian carbonate and shale, Jurassic carbonate and clastic rocks, and Lower Cretaceous clastic rocks. Twelve correlated horizons bound eleven successions: Exshaw, Banff, Pekisko, Shunda-Elkton, Nordegg, Jurassic clastics, Lower Mannville, Upper Mannville, Joli Fou, Viking and Lower Colorado Shale (below Base of Fish Scales). The characteristics of major log signatures and key correlation points for this interval are as follows (Figure 5):

- The log signature of Banff carbonate, except the slightly shaly uppermost part, is characterized by block-shaped, very low GR and very high resistivity responses.
- Exshaw shale is marked by high GR and low resistivity kicks between the blocky responses of the Banff and Wabamun carbonates.
- The GR signature of Pekisko carbonate is chunky and the readings are lower than those of the underlying Banff carbonate.
- The Shunda-Elkton formations have slightly higher (than the underlying Pekisko) but oscillatory GR responses.
- In the study area, the log signatures of Nordegg carbonate are difficult to differentiate from those of the Pekisko where the Sunday-Elkton formations do not exist. Generally, the GR readings of the Nordegg are slightly higher than those of the Pekisko.
- On the logs, the interface between the Fernie shale and overlying basal Cretaceous sand is discernable.
- The Lower Mannville top is marked at the Glauconitic sandstone base and the top of the fining-upward sequence of the Lower Mannville.
- The log curves of the shaly Joli Fou sediments form a neck between underlying Upper Mannville and overlying Viking sandstone.
- The Base of Fish Scales Marker is picked at the bottom of the extremely high GR and the base of the wide resistivity spike, which serves as a regional correlation marker between the Upper and Lower Cretaceous.

The middle interval is about 325–550 m thick and composed of the upper Lower and the Middle Colorado shale and siltstone with some sandstone beds. This interval includes the strata of the Fish Scales, Second White Speckled Shale and Blackstone equivalents, Cardium sandstone, Cardium zone, and Wapiabi equivalent. Twenty-one correlation markers separate the strata into twenty correlative units, each of which has distinctive log signatures. The characteristics of major log signatures and key correlation points for this interval are as follows (Figure 6):

- The Fish Scales Formation has high GR responses and a unique wide spike of high resistivity.
- The unit between Fish Scales Marker 1 and 2$^{nd}$ White Specks Marker 1 has high (increasing-upward) GR responses and low resistivity (slightly increasing-upward).
- The GR response of the unit between 2$^{nd}$ White Specks markers 1 and 2 is extremely high, with a few low GR spikes. The resistivity of the unit is relatively high.
- The GR response of the unit between 2$^{nd}$ White Specks markers 2 and 3 is medium low (deceasing upward). The resistivity of the unit is low.
- The unit between 2$^{nd}$ White Specks markers 3 and 4 has low GR readings with high splits. The resistivity of the unit is high (increasing upward).

- The GR is medium low and the resistivity is medium for the unit between 2nd White Specks markers 4 and 5.
- The unit between 2nd White Specks Marker 5 and 2nd White Specks top has medium-low and increasing-upward GR response, forming a bell-shaped pattern. The resistivity is medium.
- The unit between 2nd White Specks top and Blackstone Marker 1 has medium GR and medium-low (deceasing-upward) resistivity responses.
- The unit between Blackstone markers 1 and 2 has funnel-shaped curves, with GR decreasing upward and resistivity increasing upward. Its top contact is sharp.
- The GR of the unit between Blackstone markers 2 and 3 consists of decreasing-upward responses. Average resistivity is medium, slightly increasing in the lower part and decreasing in the upper part.
- There are two coarsening-upward sequences between Blackstone Marker 3 and the Cardium Sandstone Top Marker. Log responses show a stacking of two outstanding funnel-shaped combinations characterized with low GR and high resistivity. The Cardium Sandstone Base Marker is picked at the bottom of the distinctive low GR and high resistivity curves.
- The interval from the Cardium Sandstone top to Wapiabi Marker 1 is a combined fining-upward sequence. The Cardium top is defined at the top of the first fining-upward subsequence (top of the bell-shaped GR pattern), at which the typical resistivity changes from medium low to low. The unit between Cardium top and Wapiabi Marker 1 has medium GR and low resistivity responses.
- The strata between Wapiabi markers 1 and 2 are a combination of a fining-upward sequence on top of a coarsening-upward sequence. The GR responses are medium low, decreasing upward followed by slightly decreasing upward. The resistivity is medium low.
- The log signatures between Wapiabi markers 2 and 3 are almost identical to that of the underlying unit. Wapiabi markers 2 and 3 are picked at the boundary between the coarsening-upward and fining-upward sequences.
- The unit between Wapiabi markers 3 and 4 is bounded by relatively finer beds and contains patterned curves of low GR and medium resistivity.
- The high GR response at the Colorado top is typical. On the top, the resistivity changes from high to lower values. The strata between Wapiabi Marker 4 and Colorado top have medium GR and high resistivity responses. Colorado markers 1 and 2 are drawn at the splits in the log curves that indicate flooding surfaces.

The shallow interval consists of the uppermost Cretaceous to Lower Tertiary. Nine markers bound the Lea Park, Basal Belly River, Belly River, Bearpaw equivalent, Horseshoe Canyon, Battle, Scollard and Paskapoo formations/units. The interval is about 800–1600 m thick from the Colorado Group top to the Edmonton Group top, and about 100–700 m thick from the Edmonton Group top to the ground surface. The bedrock top is an erosional surface and composed mainly of the Lower Tertiary Paskapoo Formation throughout most of the area. The shallow interval was deposited in a paleo-environment that changed from marine through coastal plain to fluvial-dominated settings. Each of the formations has unique log signatures. The characteristics of major log signatures and key correlation points for this interval are as follows (Figure 7):

- The low Lea Park has medium GR and medium-low resistivity responses. The log curves are relatively smooth.
- The upper Lea Park is a coarsening-upward sequence and has funnel-shaped log signatures. Lea Park Marker 1 was picked at the base of the funnel.

- The basal Belly River sandstone units are imbricate on top of one another. A younger sandbody was deposited progressively on top of the tapered older sandbody. The boundary between the Lea Park Formation and the overlying Belly River Group is transitional and picked empirically and arbitrarily. The basal Belly River sandstone has low GR and high resistivity responses.
- The Belly River Group is dominated by low GR responses. Numerous high resistivity spikes are interbedded with low resistivity responses.
- The Bearpaw equivalent sequence has slightly higher GR responses than those of the underlying Belly River Group and overlying Horseshoe Canyon Formation. Bearpaw Marker 2 is picked at the flooding surface on top of the sequence. The resistivity of the unit is low with some high spikes.
- The very low resistivity gap between the Horseshoe Canyon and Scollard formations is unique and marks the location of the Battle Formation. Usually, the GR responses of the Battle are medium to relatively high.
- The Scollard Formation is characterized by numerous long narrow resistivity spikes in its upper part, corresponding to coal seams. The top of the Scollard Formation is marked at the base of the massive Paskapoo sandstone.

## 5.2 Zero Edges, Surficial Lineaments, and Selected Structural Contour Maps

There are two significant regional unconformities in the Mississippian to Cretaceous interval in the Medicine River area: the Mississippian-Jurassic unconformity and the Jurassic-Cretaceous unconformity. The entire Triassic is missing from the study area. The Jurassic Nordegg Formation unconformably overlies the Mississippian Elkton, Shunda, Pekisko and Banff formations. The Lower Cretaceous unconformably overlies the Mississippian and Jurassic formations.

Figure 30 shows the zero edges inclusive of discontinuous outliers and subcrop areas of the Mississippian and Jurassic formations. These formation-zero edges may have been fault related and resulted from a combination of structural uplift and subaerial erosion. The Pekisko zero edge, trending largely northwest, is subparallel to the east edge of the Rocky Mountain Foothills and the Battle River Lineament (Figure 10). The bend in the Pekisko zero edge in the Red Deer–Penhold area may have resulted from uplift and erosion along the Penhold Lineament (Figure 10). The Elkton-Shunda zero edge also trends largely northwest and bends across the Penhold Lineament. The Nordegg and Jurassic zero edges trend roughly north-northwest to northwest in the northern part of the area and largely north in the southern part. The orientation change of the Jurassic zero edges may have been from the combined effects of 1) the southwest tilting of the basin floor, and 2) the slightly different motions of the Rimbey and Sylvan Lake–Penhold blocks.

Figure 31 is a hill-shaded digital elevation model (DEM). Surficial lineaments are highlighted with yellow bars on the image. Figure 32 shows the basement blocks and lineaments (red lines; cf. Figure 10) overlain by the surficial lineaments (blue lines). The basement lineaments have three major preferred orientations: N30ºE and N15ºE (major), and N75º (minor). The surficial lineaments can be grouped into nine sets. The Buck Lake set (set 1) shows a convergent orientation of N135ºE. Set 2 has two preferred orientations: N150ºE and N120ºE. The remaining sets of surficial lineaments in the Rimbey Block have two preferred directions: N135ºE and N120ºE. Set 6 in the Foothills Block shows a major orientation of N135ºE and a minor orientation of N30ºE. The surficial lineaments in the Sylvan Lake Block are divergent, the majority being oriented in N15ºE except north of Red Deer, where most are oriented N90ºE. The predominant orientation of set 9 is N45ºE in the Penhold Block.

Thickness changes across the basement domain boundaries and other lineaments were observed during this study. In general, thickness changes may be caused by 1) a predepositional impact, such as a

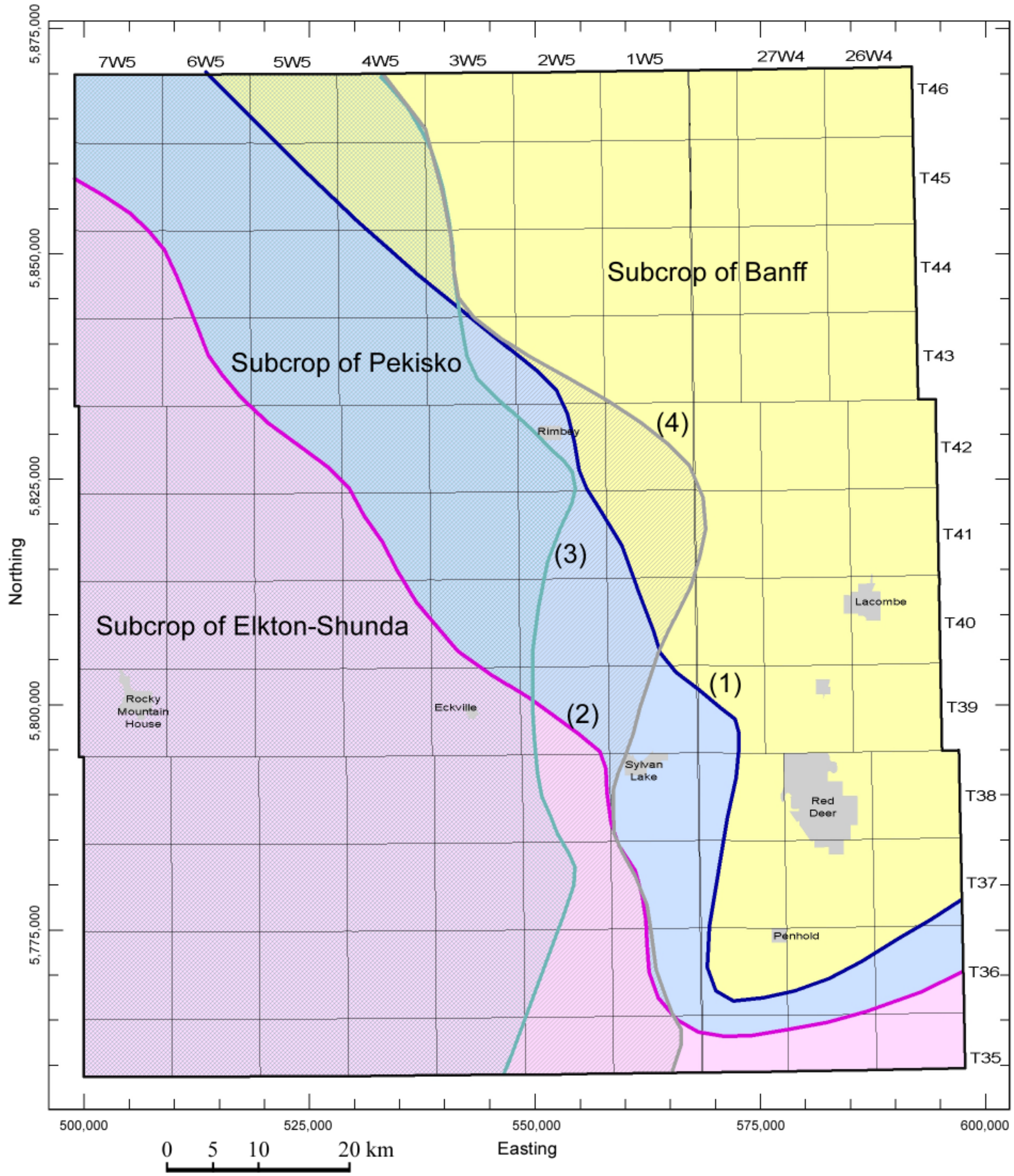


**Figure 30. Zero edges of Mississippian and Jurassic formations**

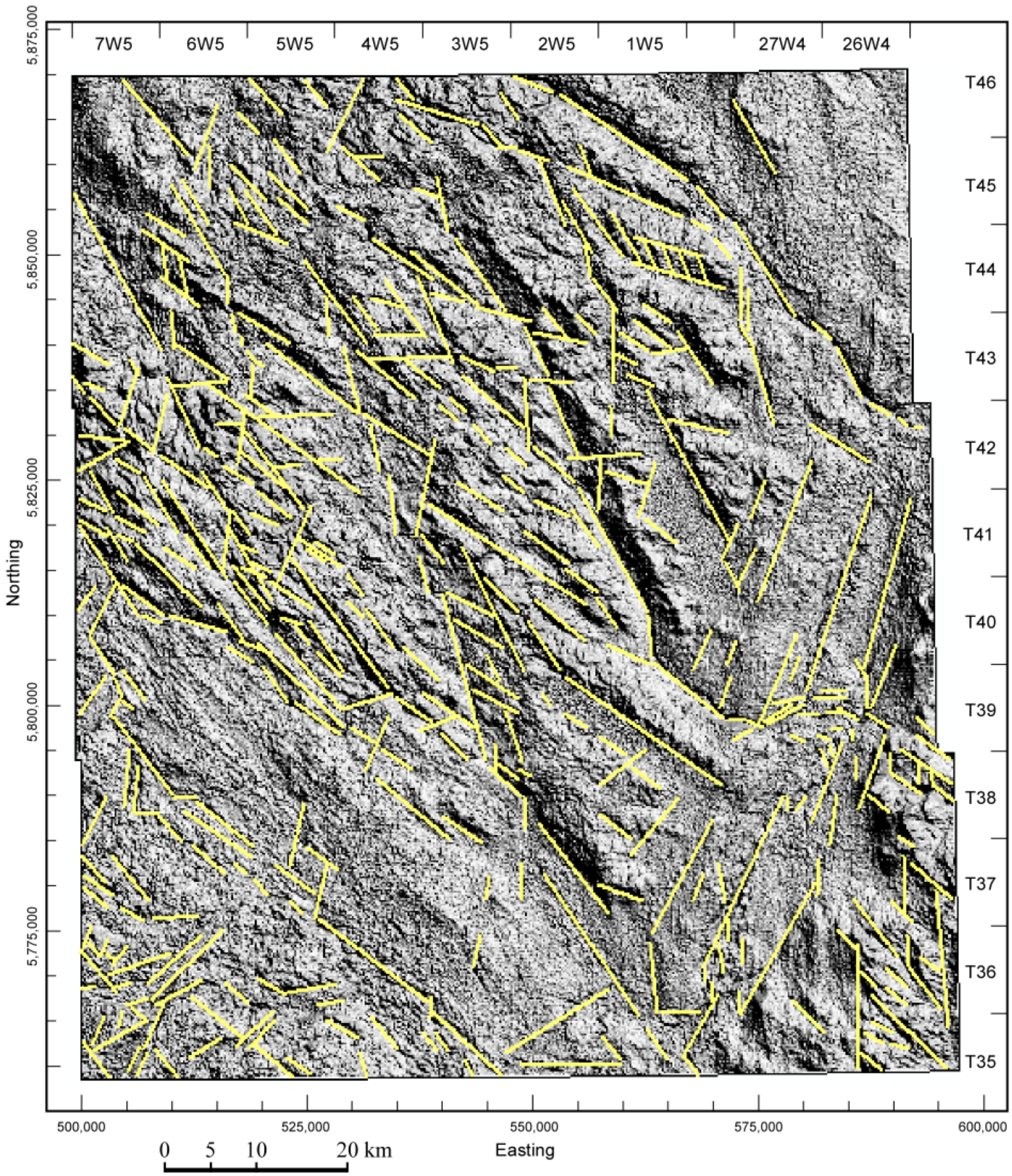


**Figure 31. Surficial lineaments defined from digital elevation model.**

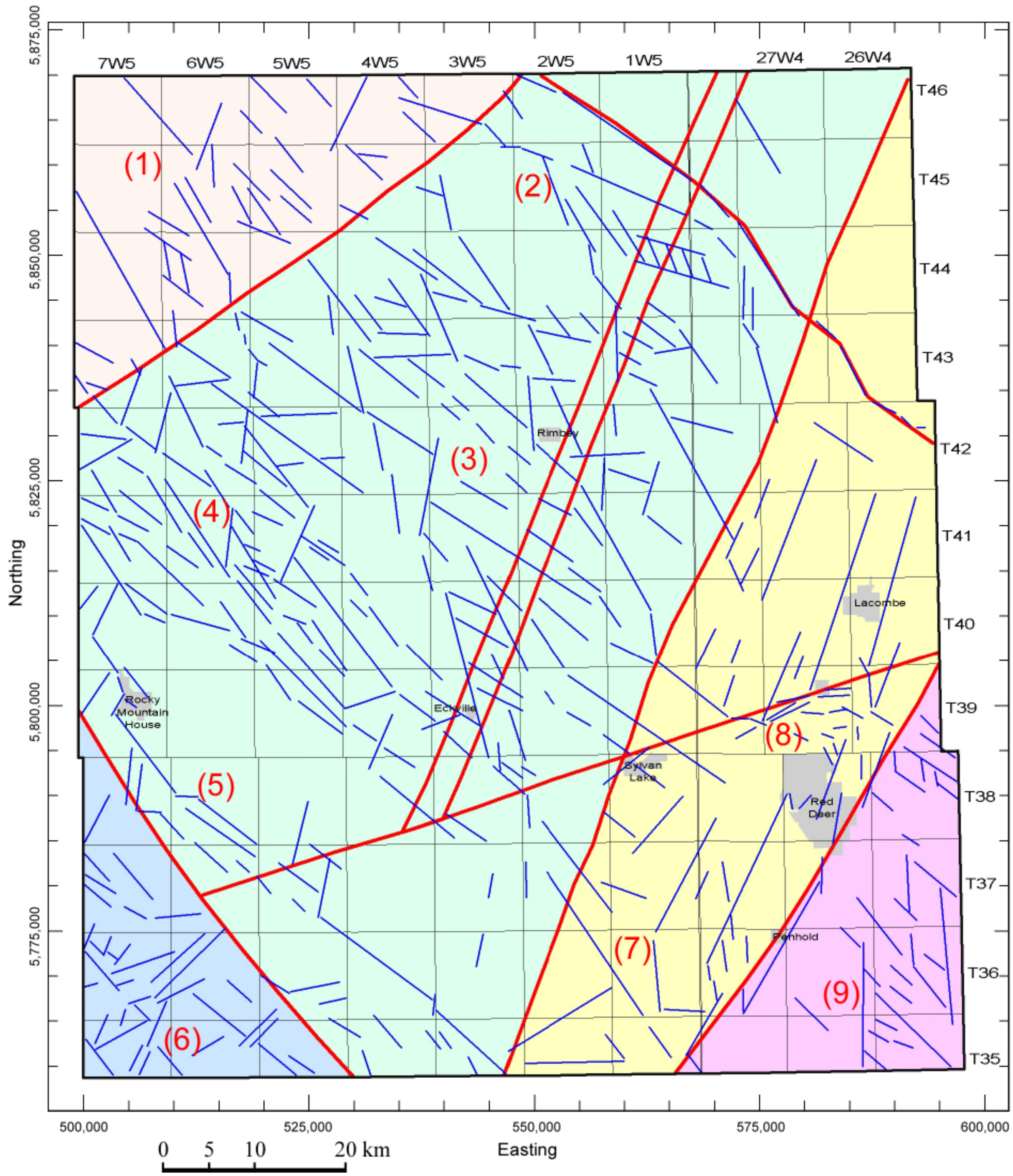


**Figure 32. Basement and surficial lineaments.**

basement structure; 2) a syndepositional process, including syndepositional faulting, change in sediment supply, and the distribution of a depositional system; and (3) a postdepositional process, including the differential compaction between different rock types and thrust faulting. Except in the foothills area in the southwest, thrust faulting is not a significant factor contributing to thickness change in the study area. The majority of the formations under investigation are marine-dominated strata. Therefore, repeat thickness changes across basement lineaments may indicate differential subsidence across the lineaments in most of the study area. The observations of differential subsidence are as follows:

- The Thorsby-Rimbey Boundary appears to affect the deposits of the Upper Mannville (Figure 51), Joli Fou (Figure 52), Viking (Figure 53) and Cardium sandstone (Figure 60).
- The Rimbey Arc appears to have impacts on the structures of the Wabamun (Figure 33), Banff (Figure 34), Lower Mannville (Figure 36), Viking (Figure 37), Cardium (Figure 39) and Edmonton (Figure 43).
- The Rimbey-Lacombe Boundary appears to have influenced the structures of the Banff (Figure 34), Lower Mannville (Figure 36) and Edmonton (Figure 43), and the deposits of the Banff (Figure 46).
- The Sylvan Lake Lineament appears to have an effect on the structures of the Banff (Figure 34) and the deposits of the Upper Mannville (Figure 51), Joli Fou (Figure 52), Viking (Figure 53) and Cardium sandstone (Figure 60).
- The Penhold Lineament appears to influence the structures of the Wabamun (Figure 33) and the Banff (Figure 34), and the deposits of the Banff (Figure 46).
- The Battle River Lineament appears to have an impact the deposition of lower Colorado shale (from the Viking sandstone top to the Base of Fish Scales, Figure 54).
- The east edge of the Rocky Mountain Foothills appears to have affected the deposition of the Elkton-Shunda (Figure 48), and Cardium (Figure 61).

# 6 Characteristics of Stratigraphic Units

## 6.1 Mississippian Succession

In the Medicine River area, the Mississippian is about 20–320 m thick and thickens toward the southwest (Figure 44). It is divided into four mappable units: Exshaw, Banff, Pekisko and Elkton-Shunda. Contour lines bend across the Rimbey-Lacombe Boundary, the Penhold Lineament, and the western part of the Sylvan Lake Lineament. A slight influence from the Rimbey Arc and Thorsby-Rimbey Boundary can be discerned on the Mississippian isopach map.

Conformably/disconformably overlying the Wabamun Group, the Exshaw Formation consists of a lower shale-dominated member gradationally overlain by an upper member comprising siltstone and silty limestone (Warren, 1937). The fine-grained siliciclastic sediments deposited in euxinic-basin to shallow-neritic environments during late Famennian and earliest Tournaisian time, and the black shale in the lower member, record the culmination of a regional transgression (Richards et al., 1994). In the study area, the Exshaw is between 0.5 and 35 m in thickness, generally thinning to the west and thickening to the east (Figure 45). The upper member of the Exshaw becomes sandier to the east and northeast (Figures 15 and 16).

The Banff Formation disconformably/unconformably overlies the Exshaw Formation. In general, the formation comprises a lower succession of shale and marlstone grading upward and eastward into spiculite, bedded chert and carbonate that pass into interbedded sandstone, siltstone and shale (Warren, 1927). The Banff Formation is primarily a heterogeneous assembly of carbonate ramp and siliciclastic

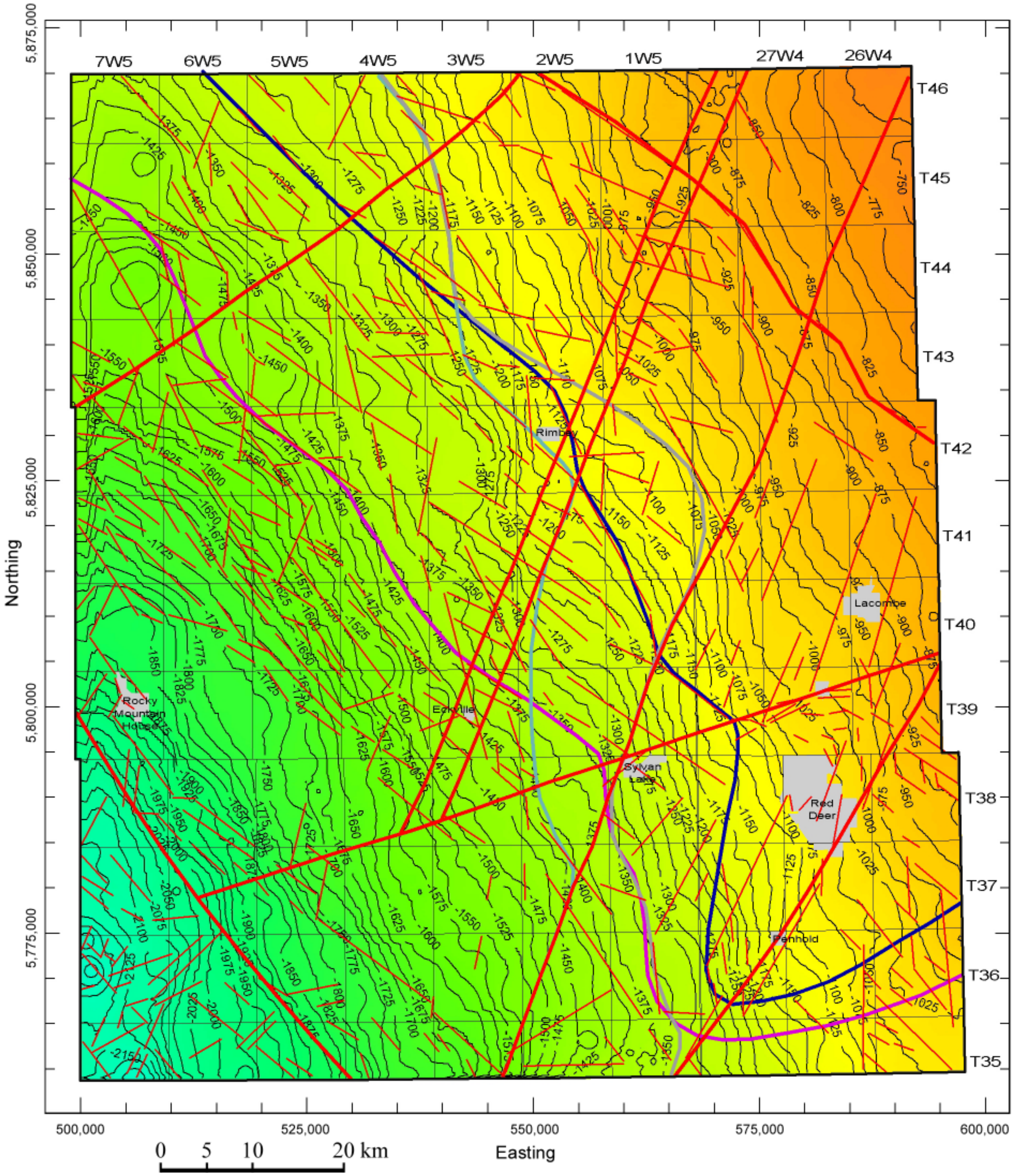


Figure 33. Structure contour map of the Wabamun Formation top.

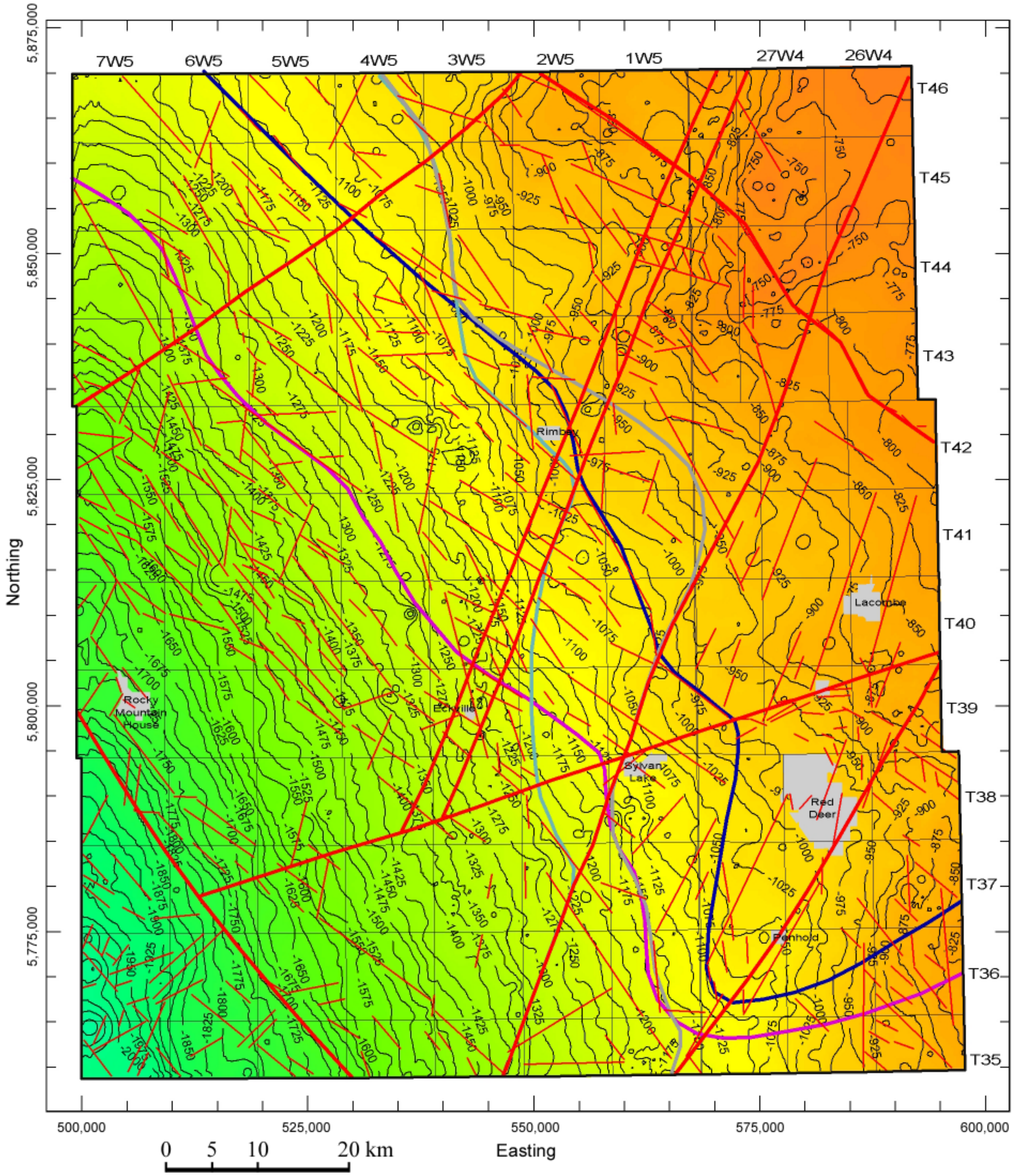


**Figure 34. Structure contour map of the Banff Formation top.**

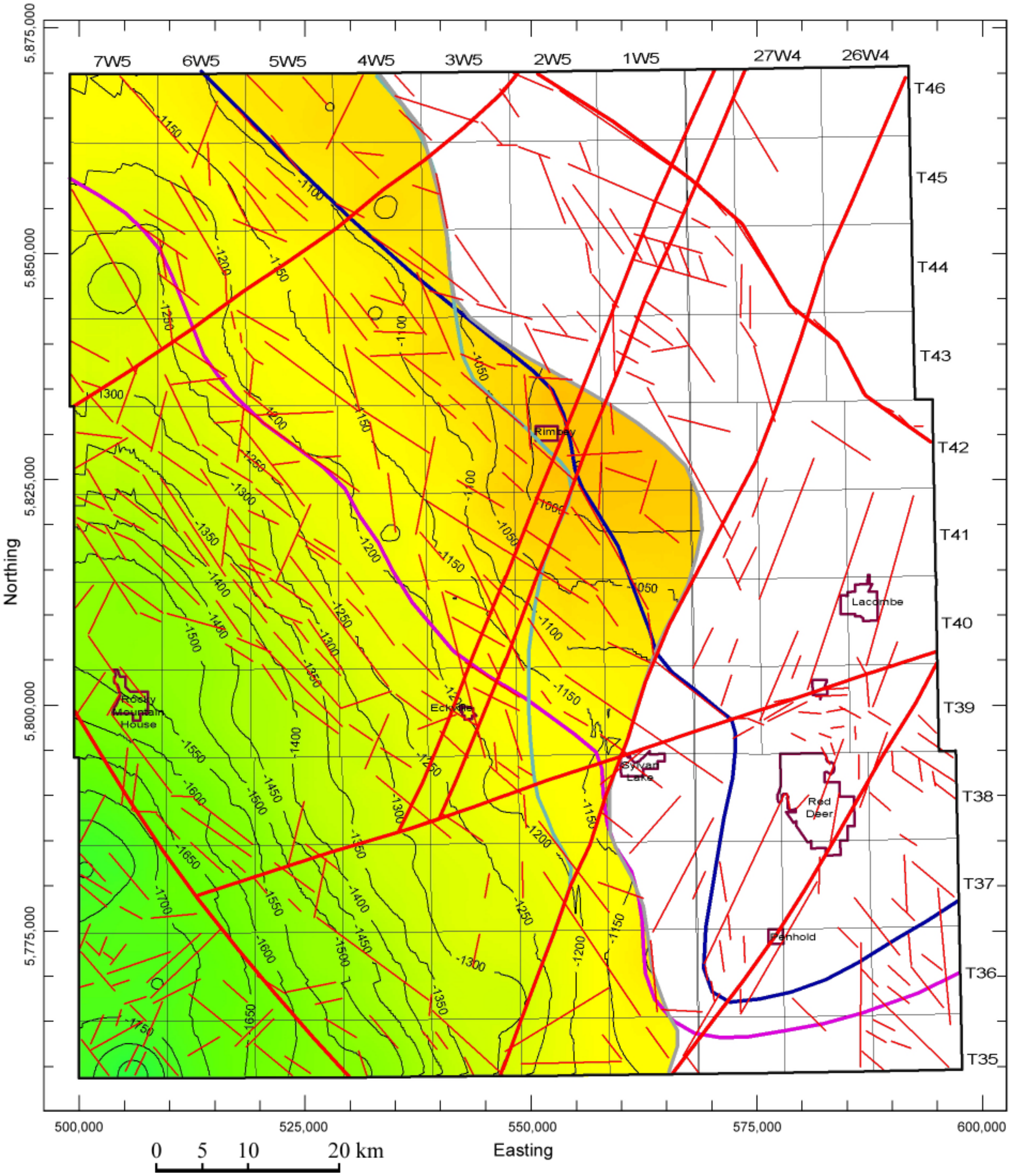


**Figure 35. Structure contour map of the Jurassic top.**

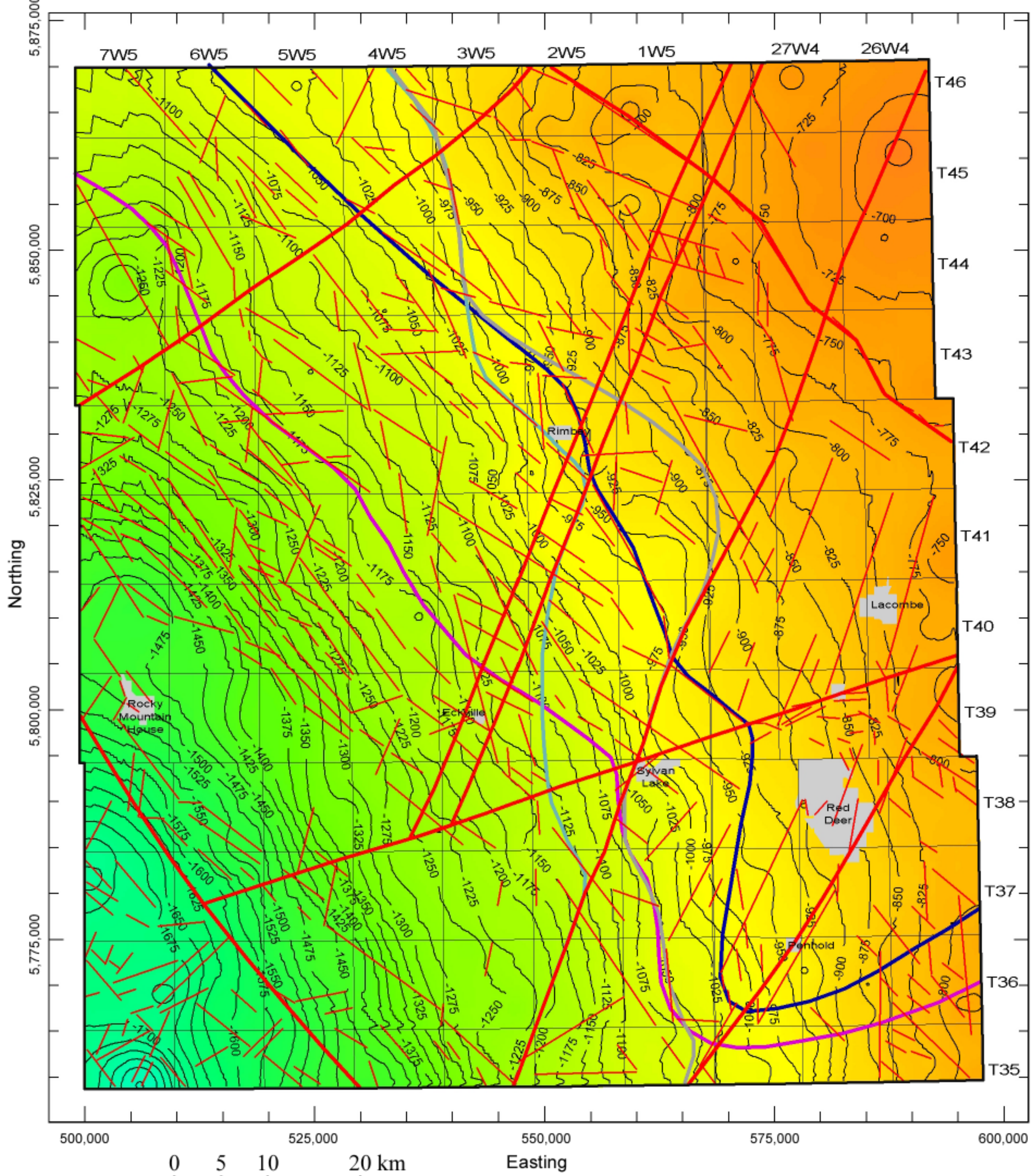


Figure 36. Structure contour map of the Lower Mannville Group top.

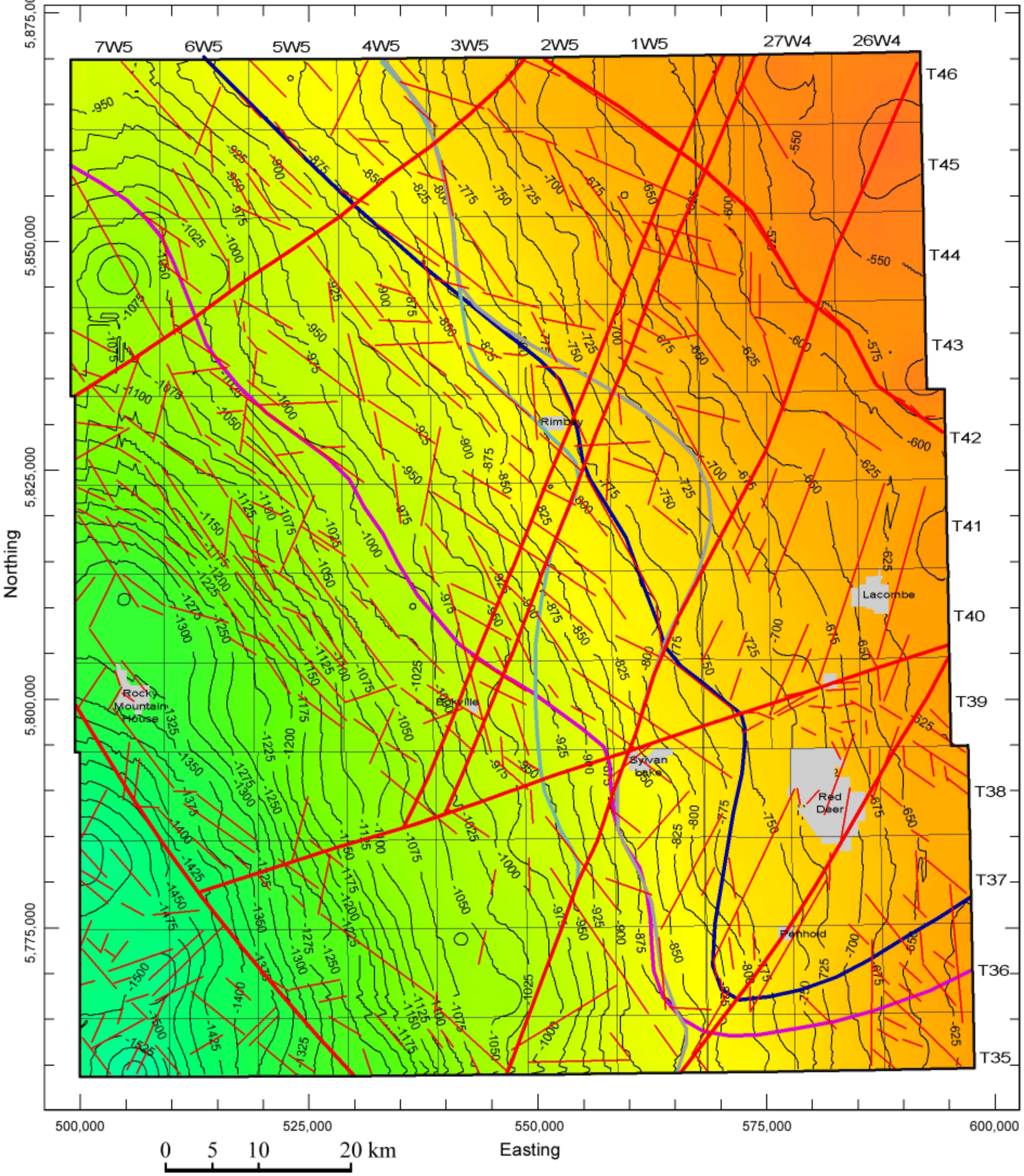


**Figure 37. Structure contour map of the Viking Sandstone top.**

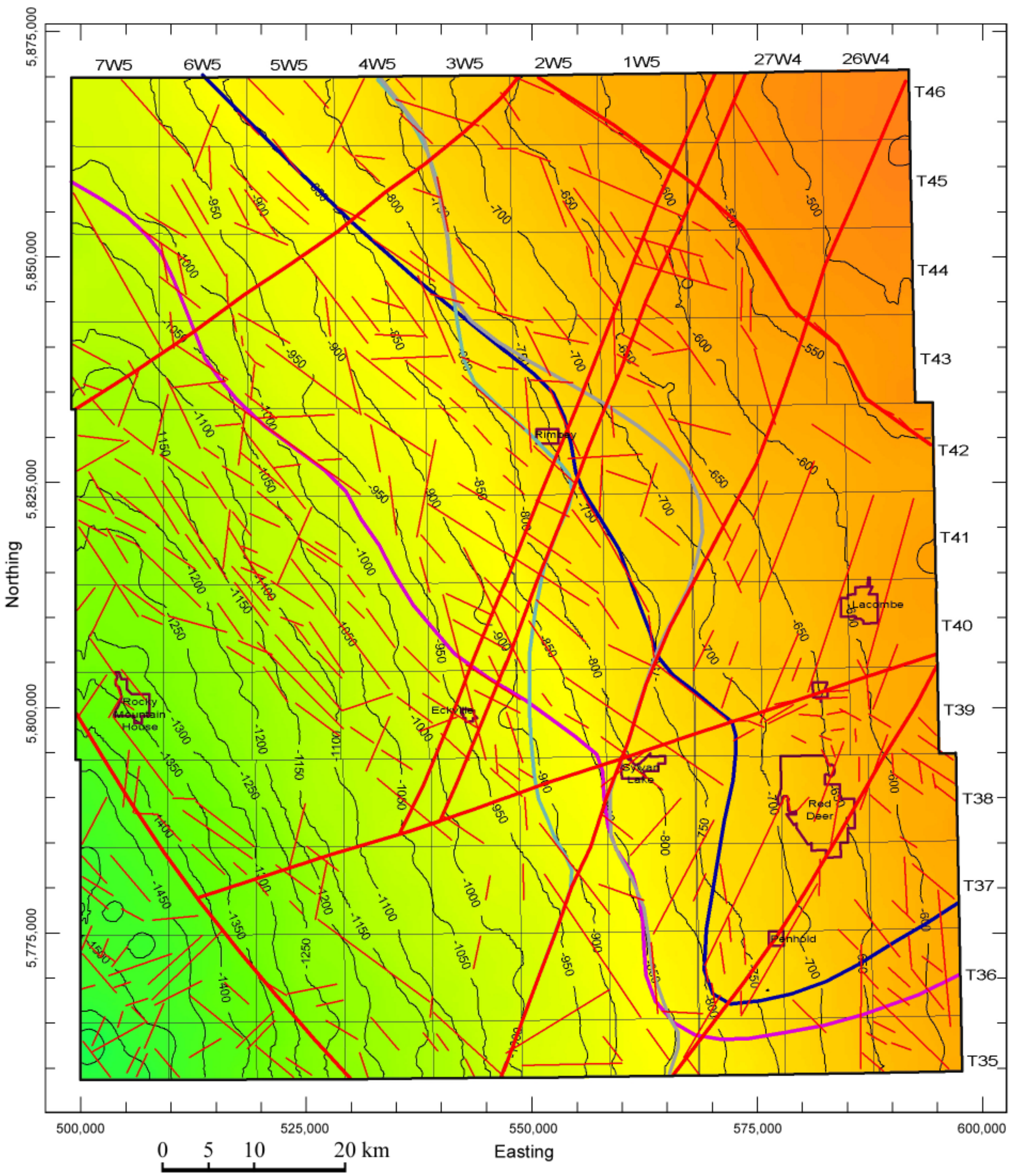


**Figure 38. Structure contour map of the Base of Fish Scales.**

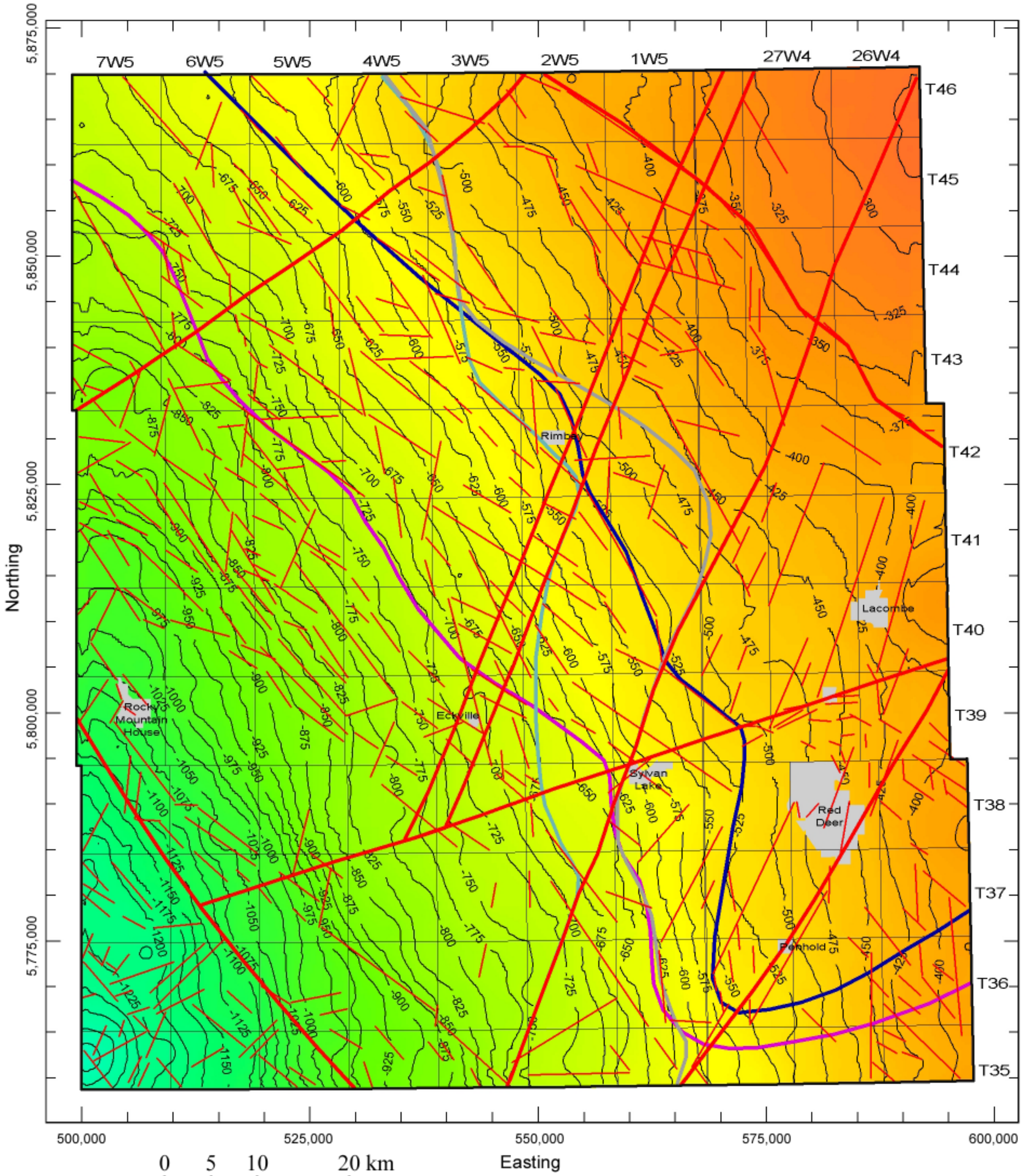


**Figure 39. Structure contour map of the Cardium Sandstone top.**

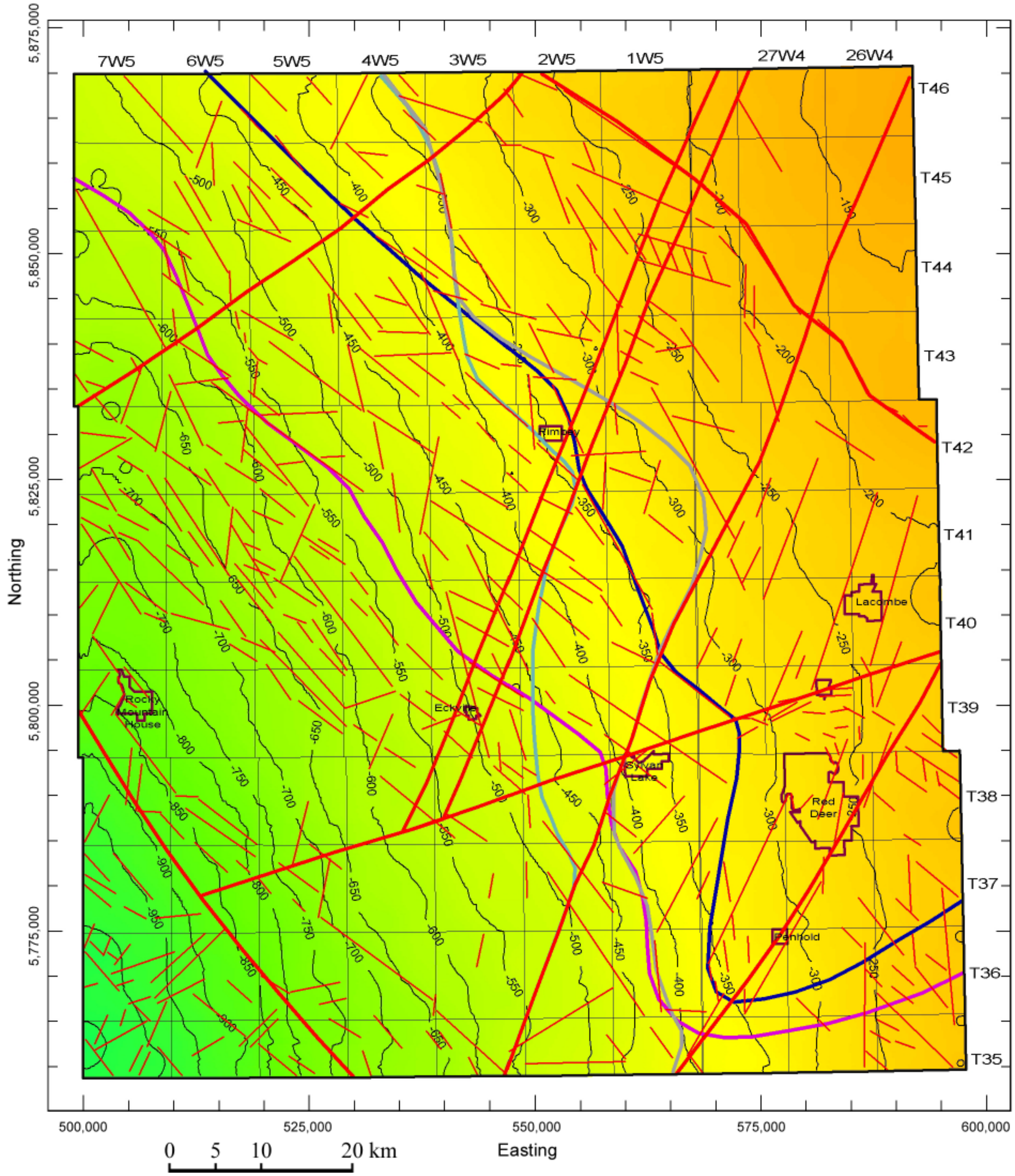


**Figure 40. Structure contour map of the Colorado Group top.**

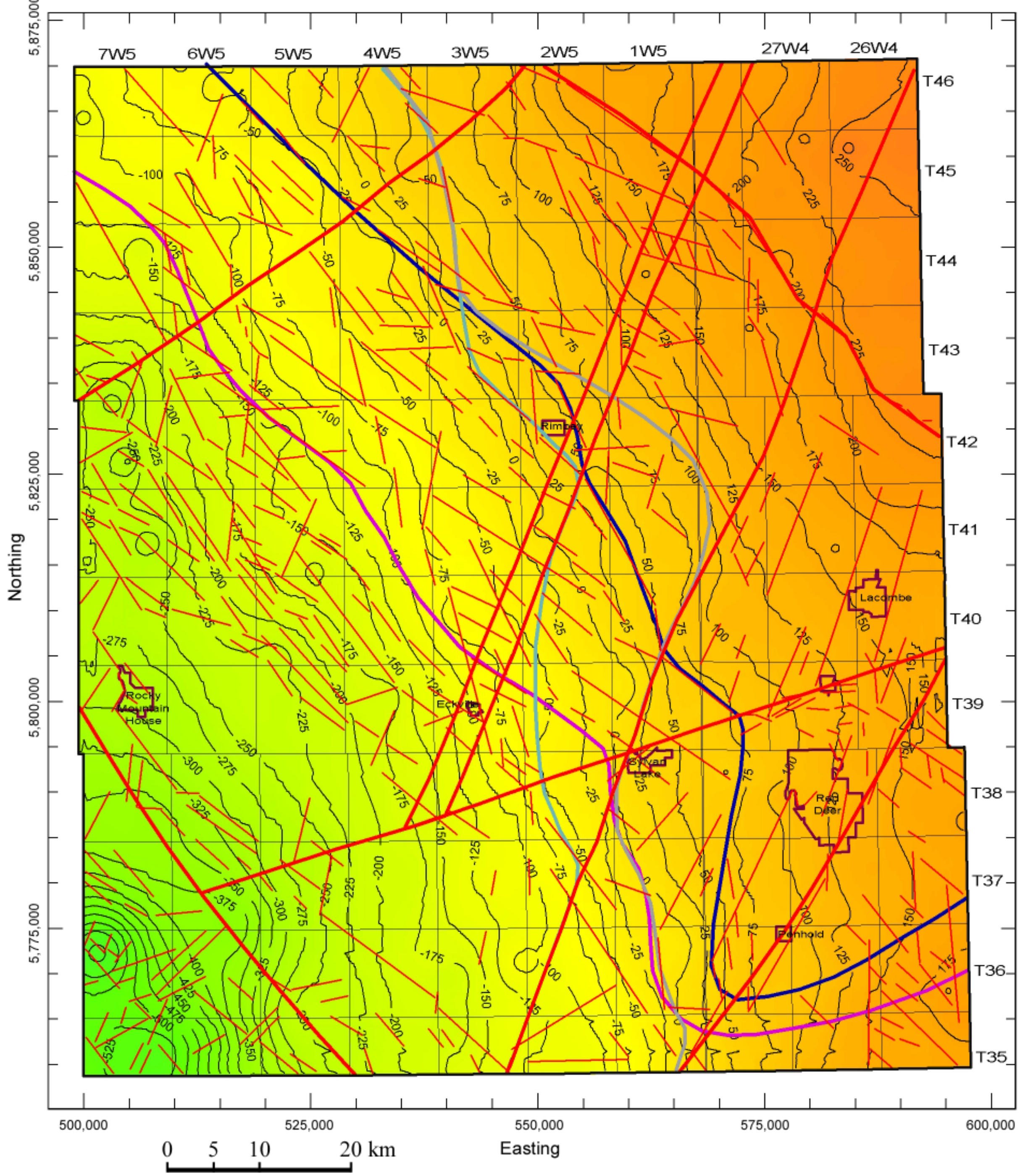


**Figure 41. Structure contour map of the Belly River Group top.**

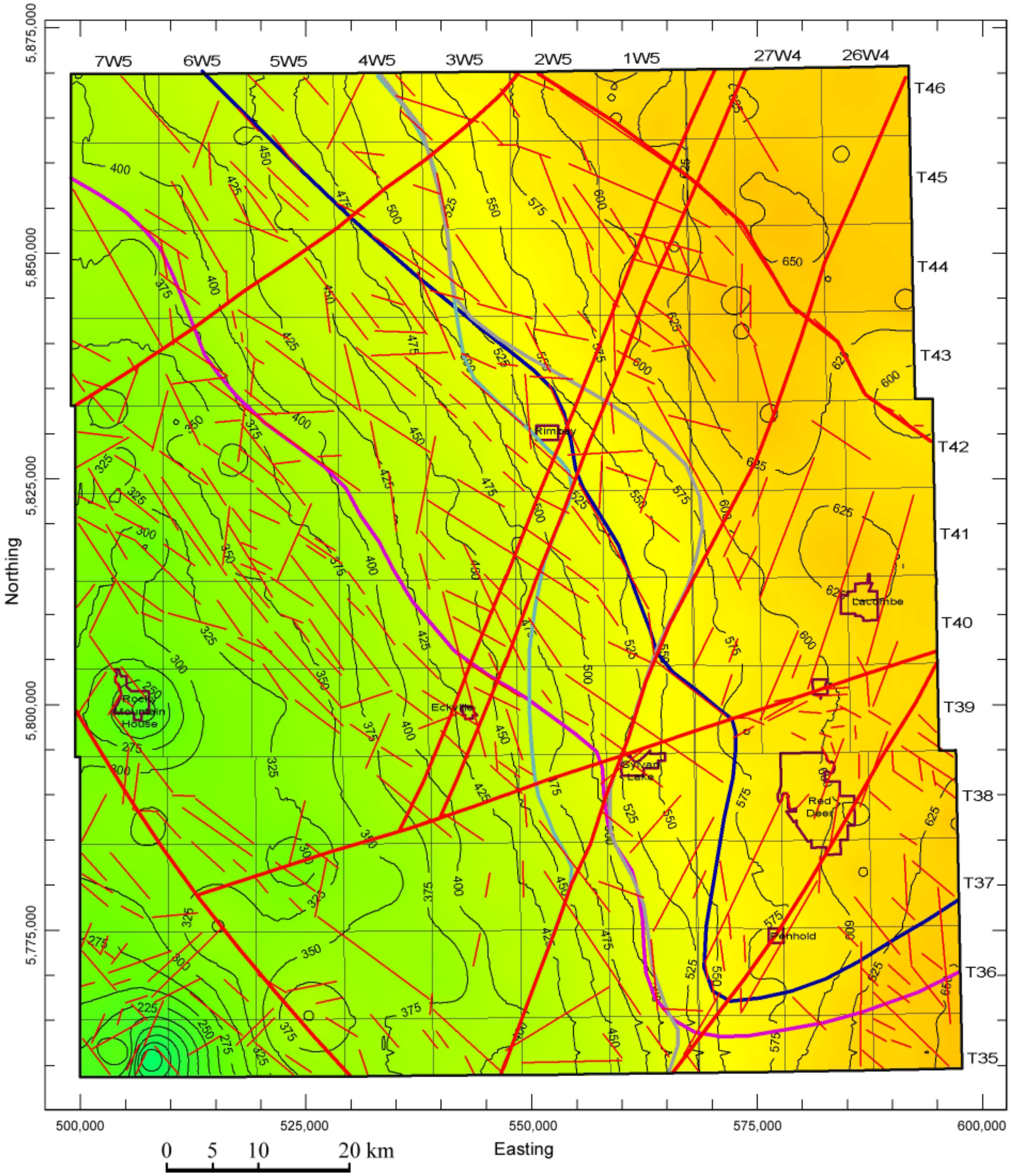


**Figure 42. Structure contour map of the Battle Formation top.**

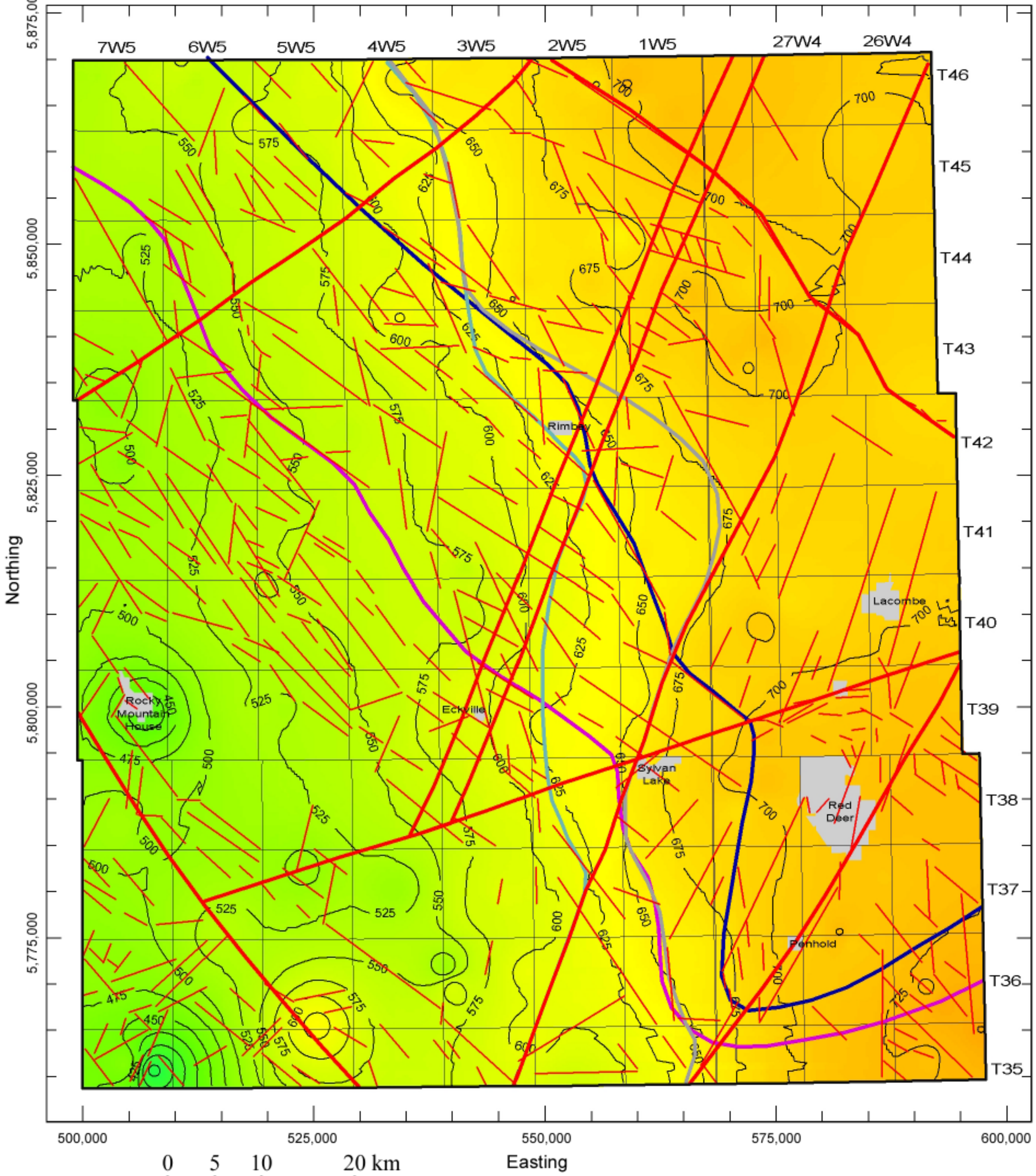


**Figure 43. Structure contour map of the Edmonton Group top.**

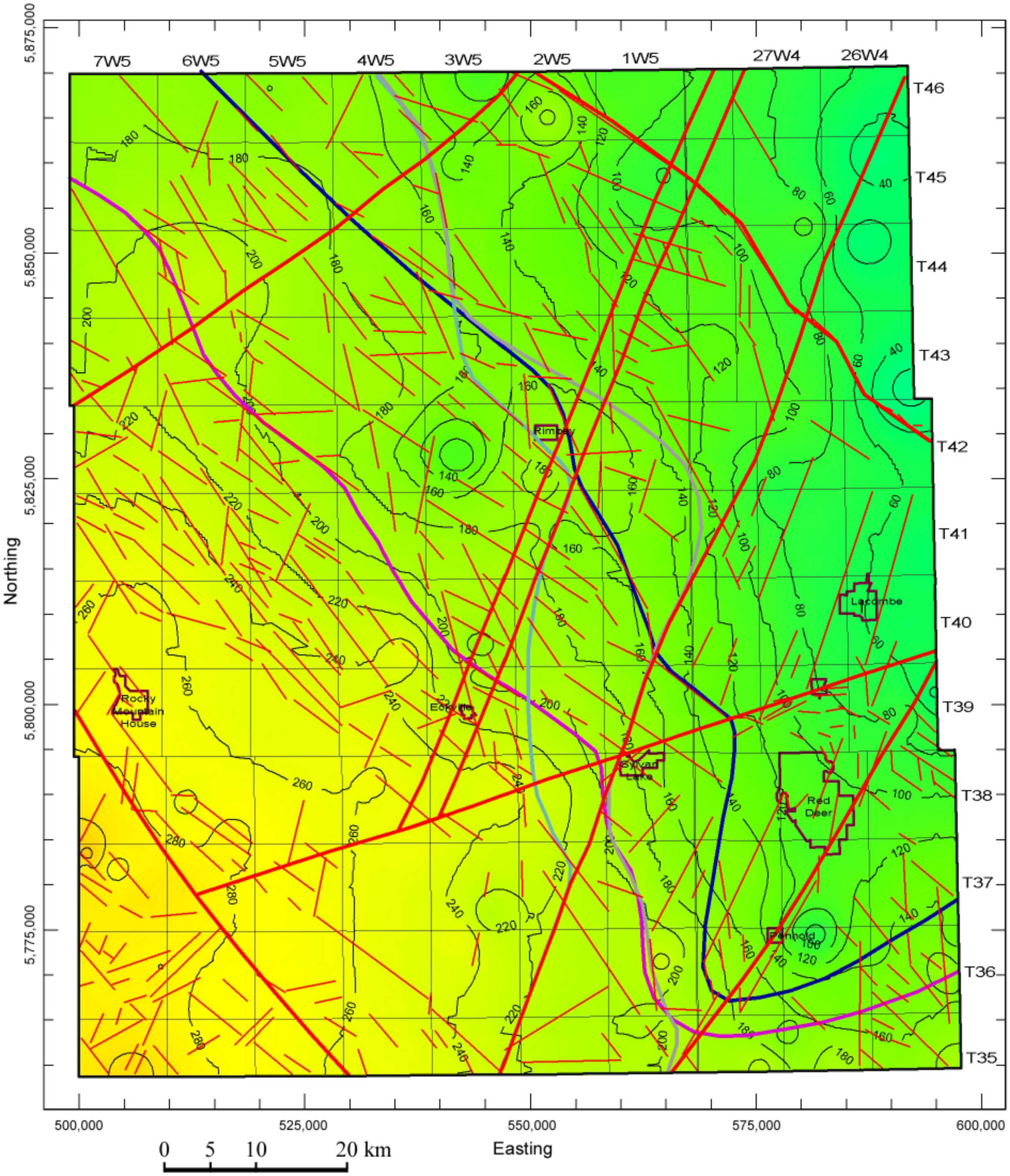


**Figure 44. Isopach map of the Mississippian.**

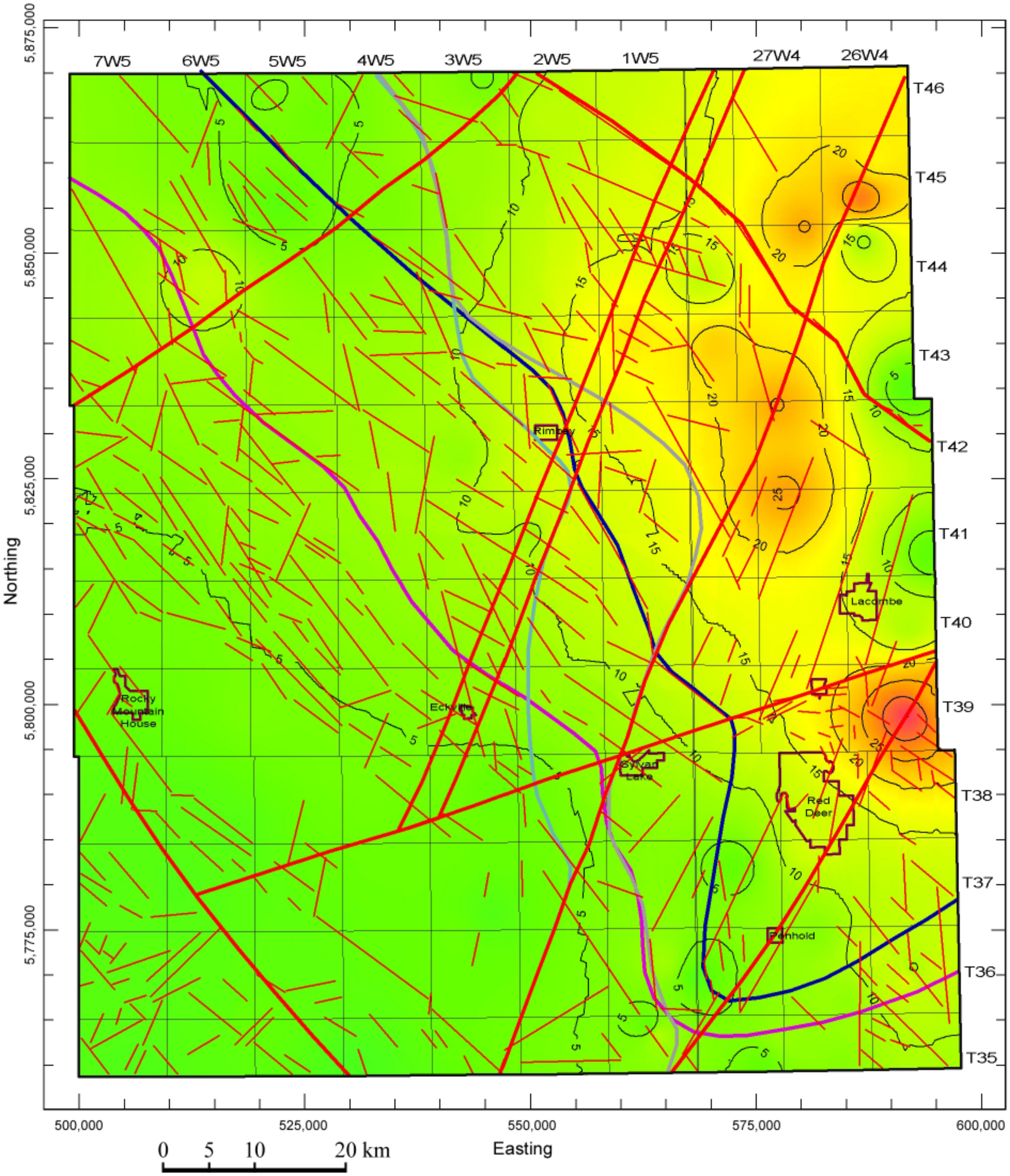


**Figure 45. Isopach map of the Exshaw Formation.**

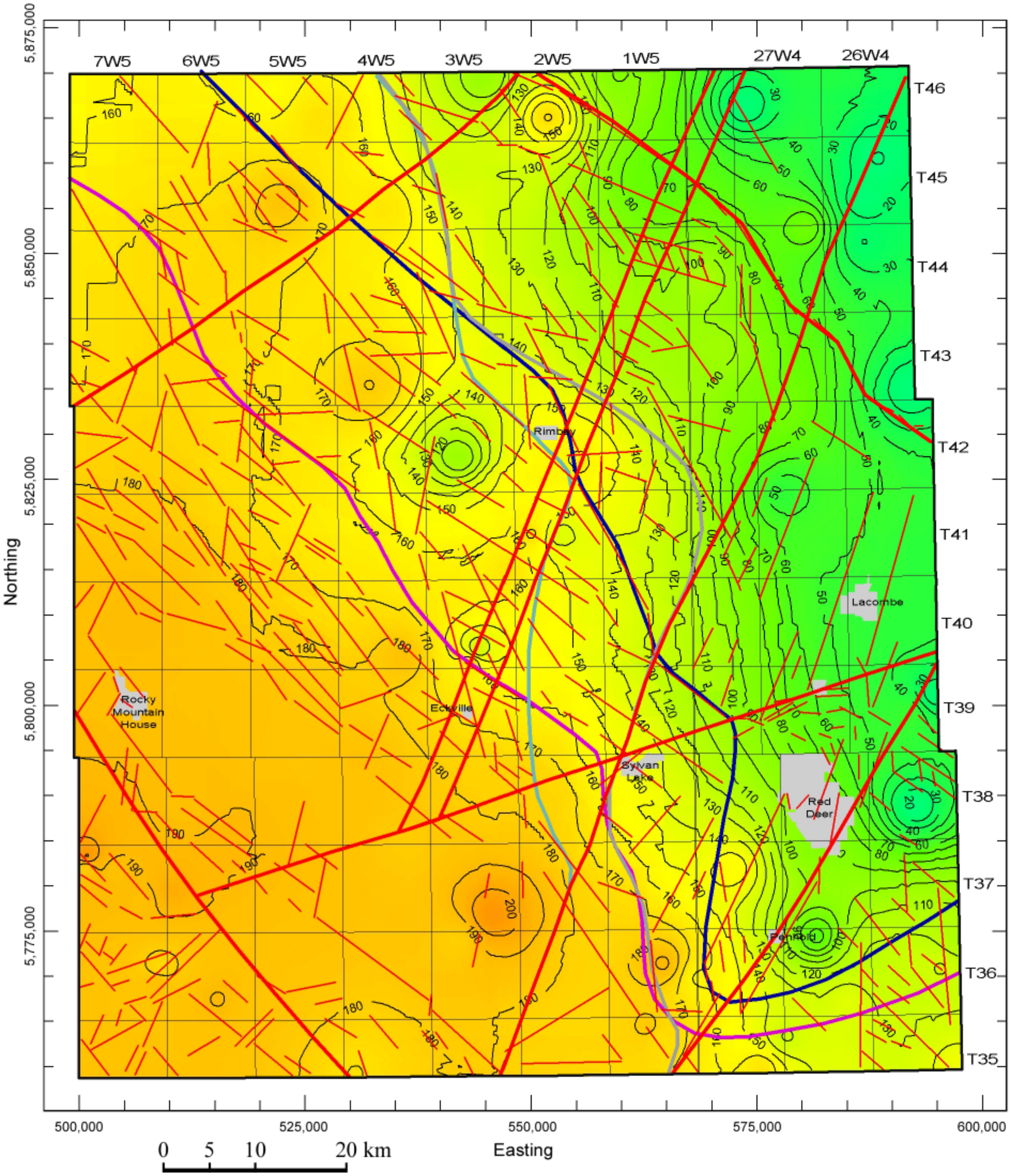


**Figure 46. Isopach map of the Banff Formation.**

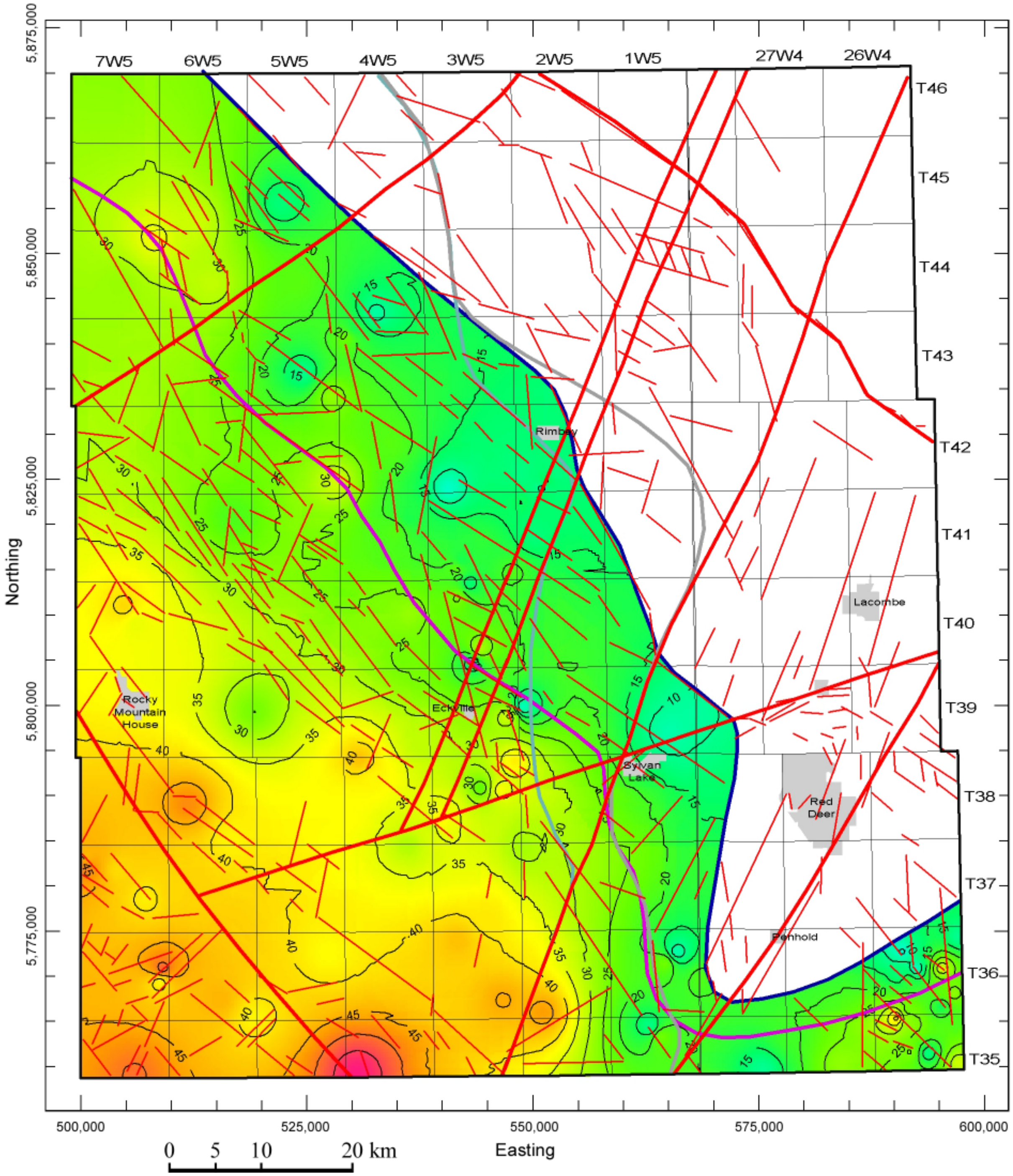


**Figure 47. Isopach map of the Pekisko Formation.**

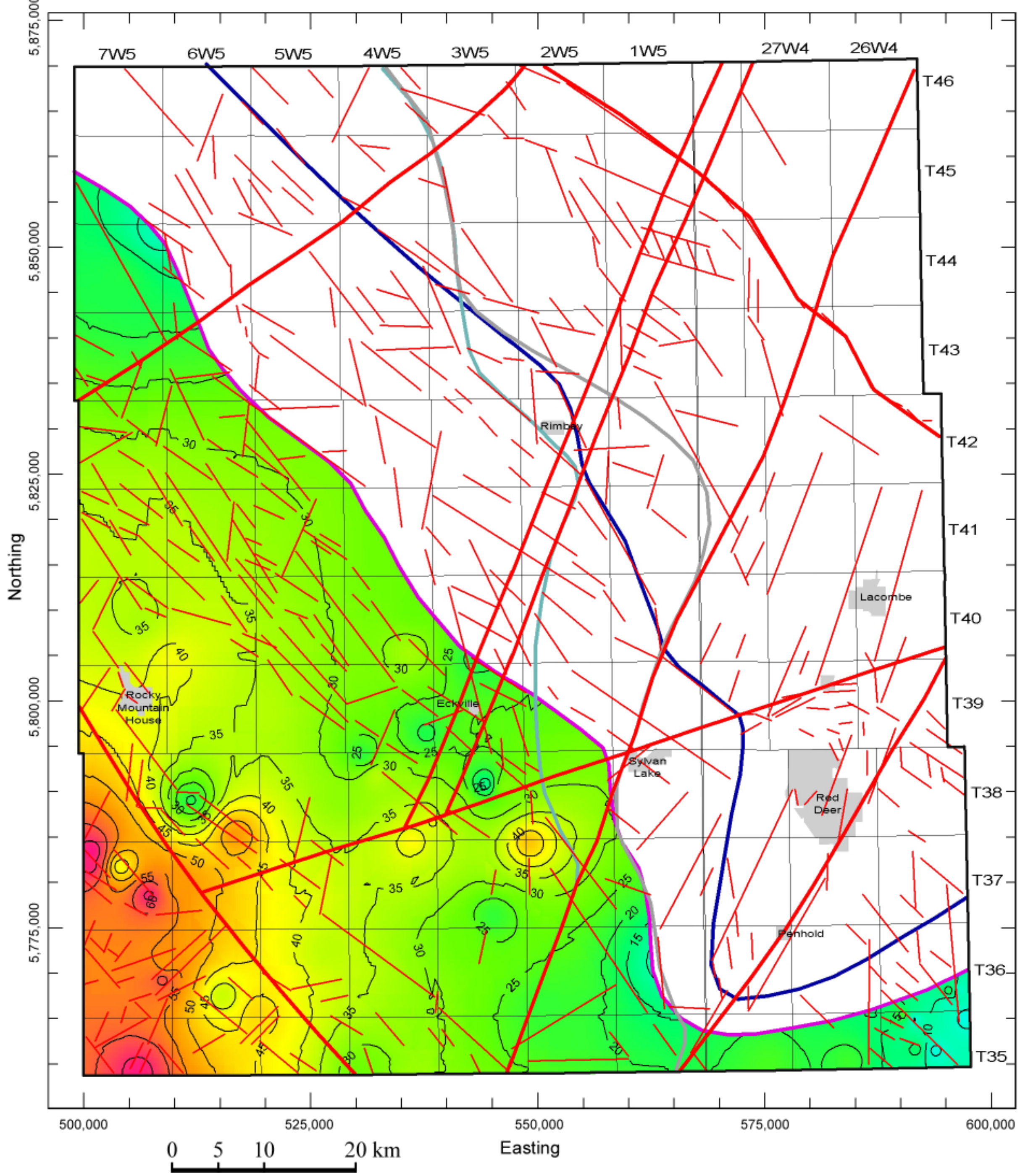


**Figure 48. Isopach map of the Elkton-Shunda formations.**

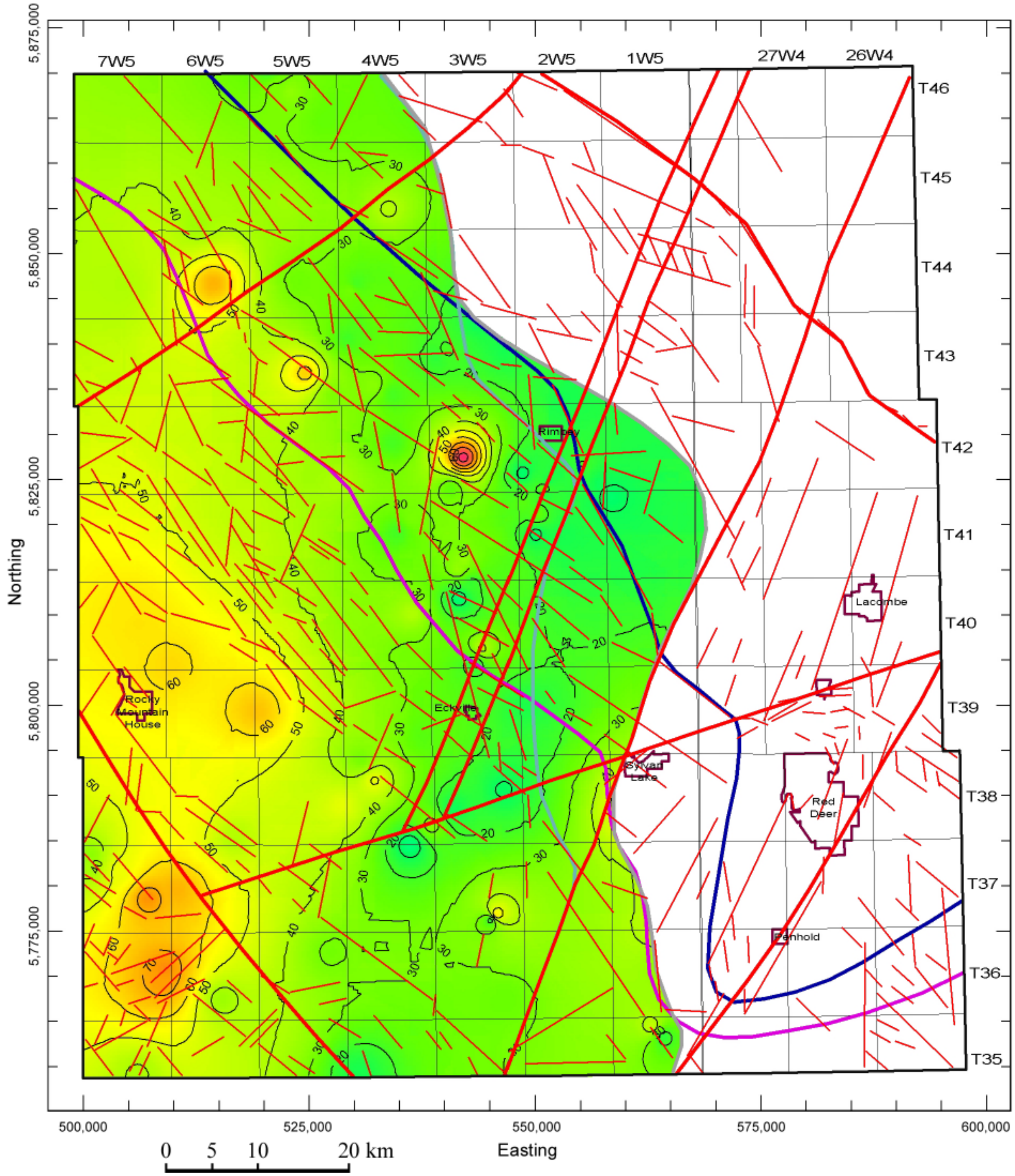


**Figure 49. Isopach map of the Jurassic.**

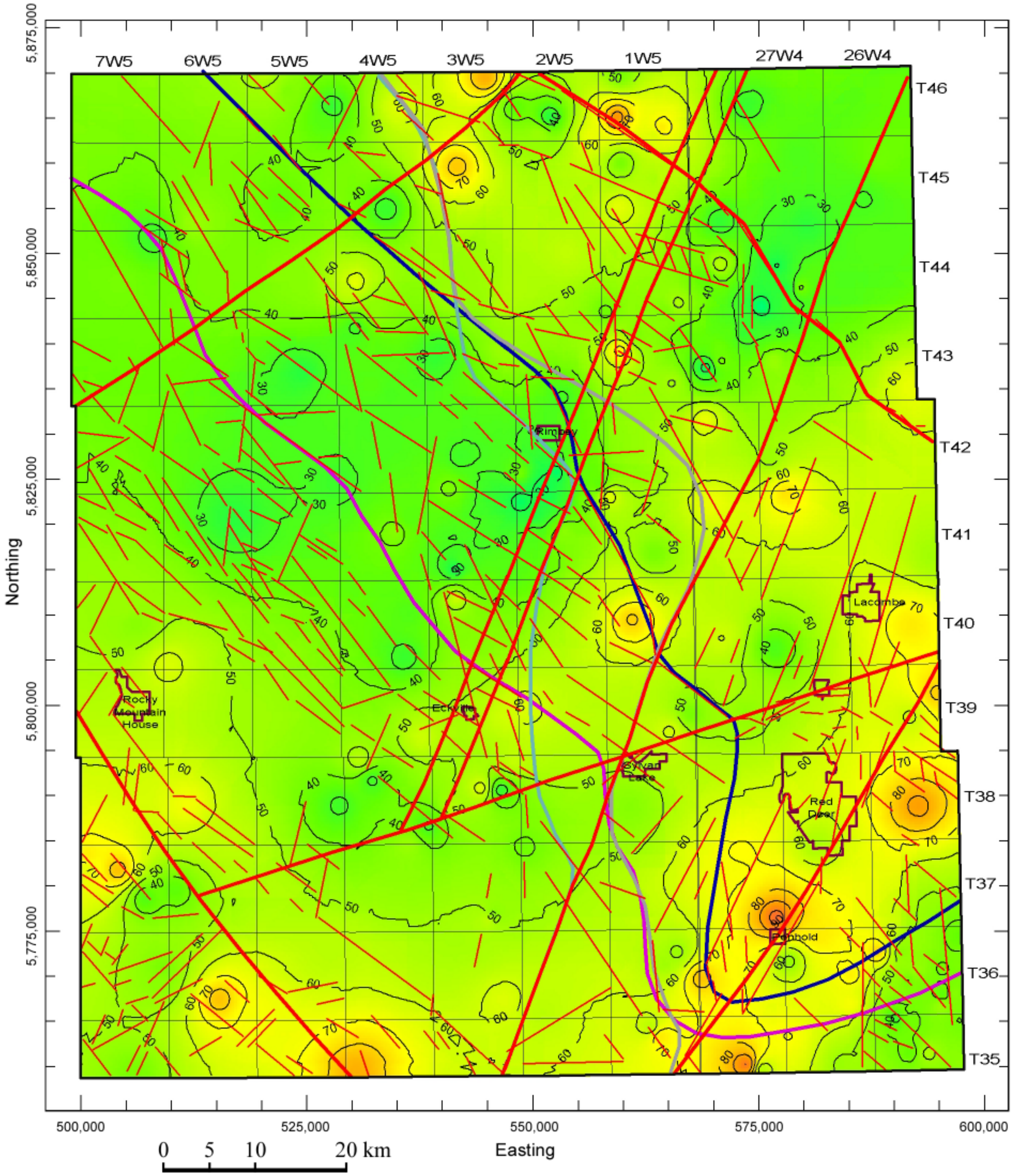


**Figure 50. Isopach map of the Lower Mannville Group.**

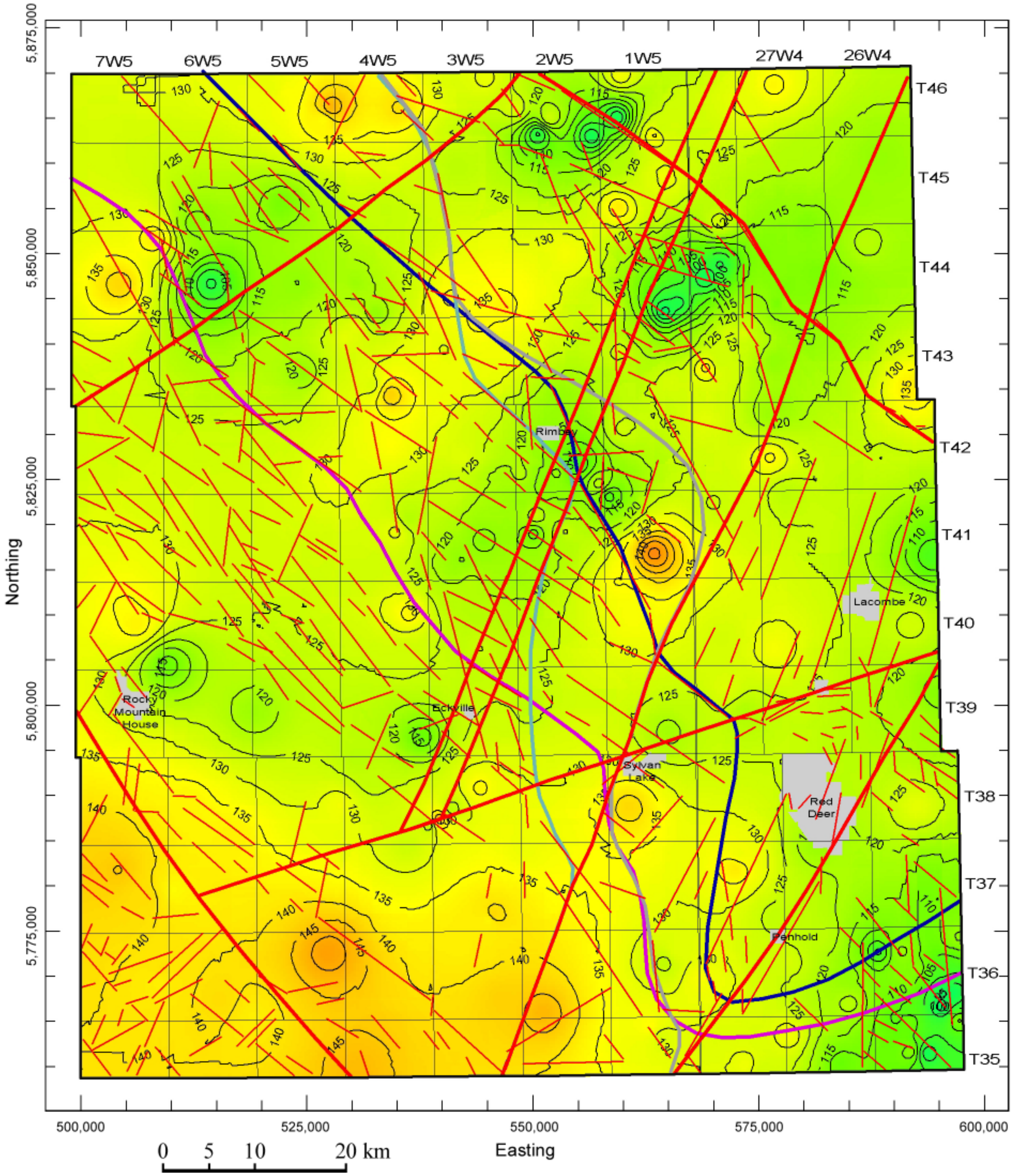


Figure 51. Isopach map of the Upper Mannville Group.

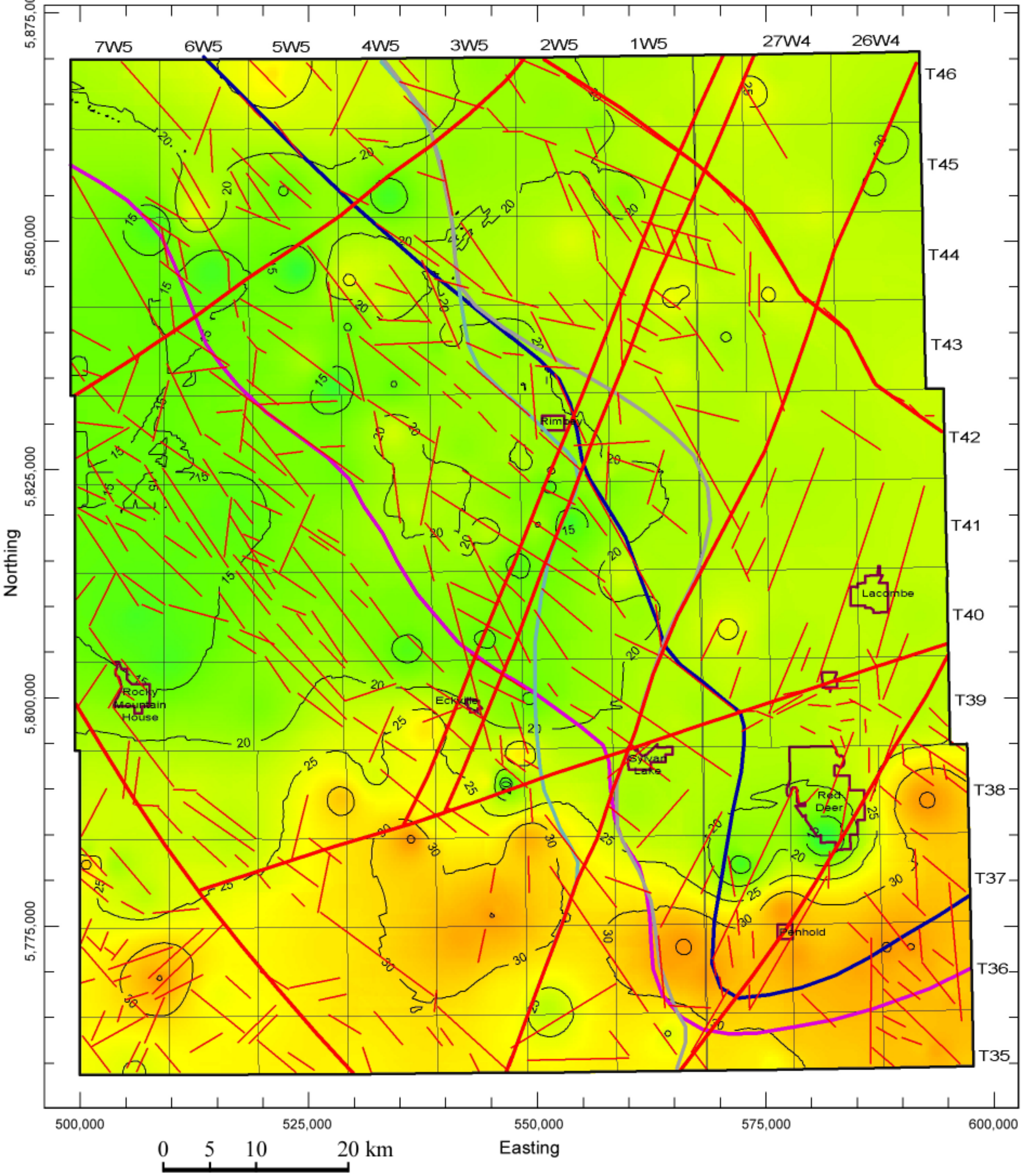


**Figure 52. Isopach map of the Joli Fou Formation and overlying fine clastic rocks.**

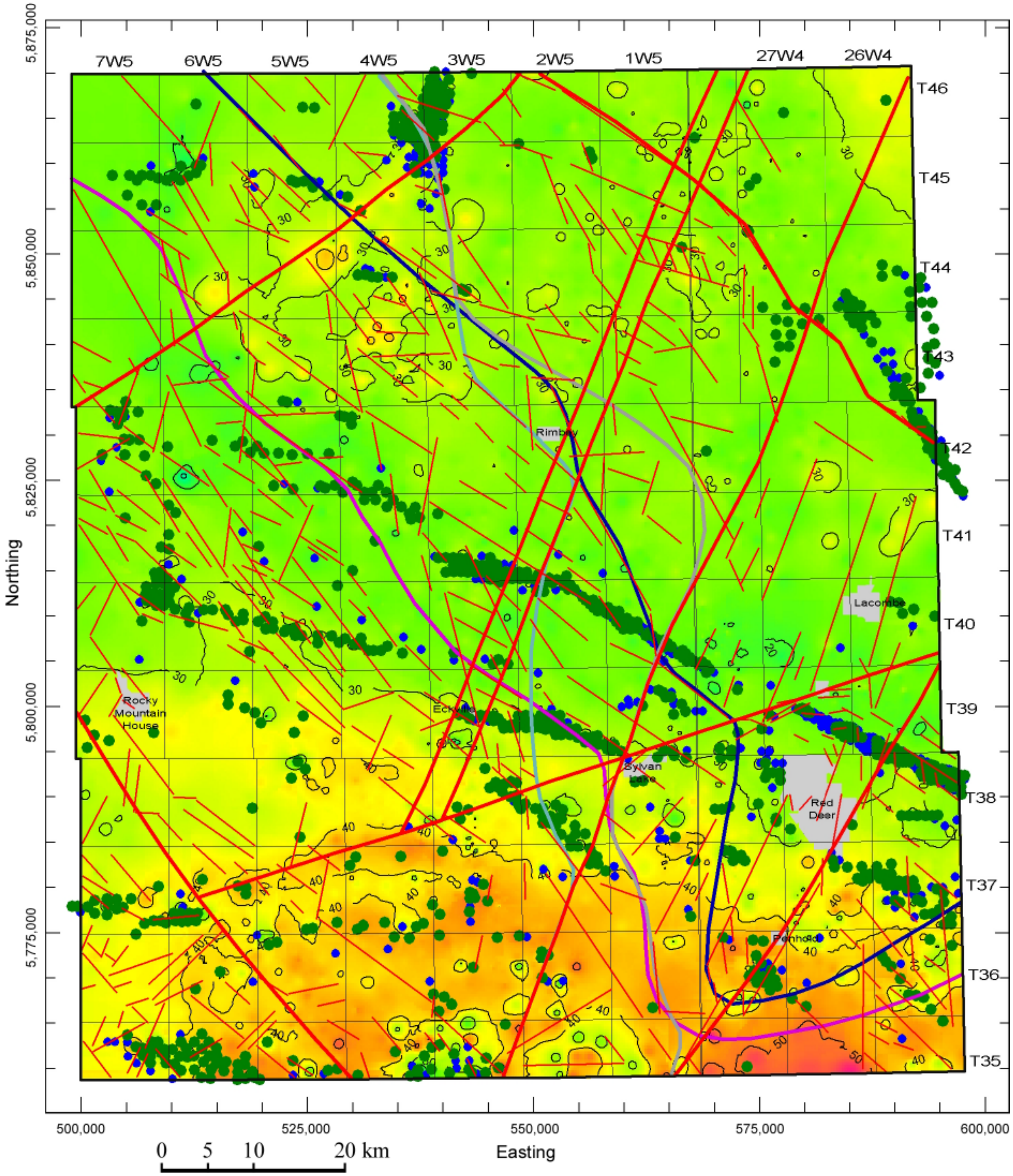


Figure 53. Isopach map of the Viking Sandstone.

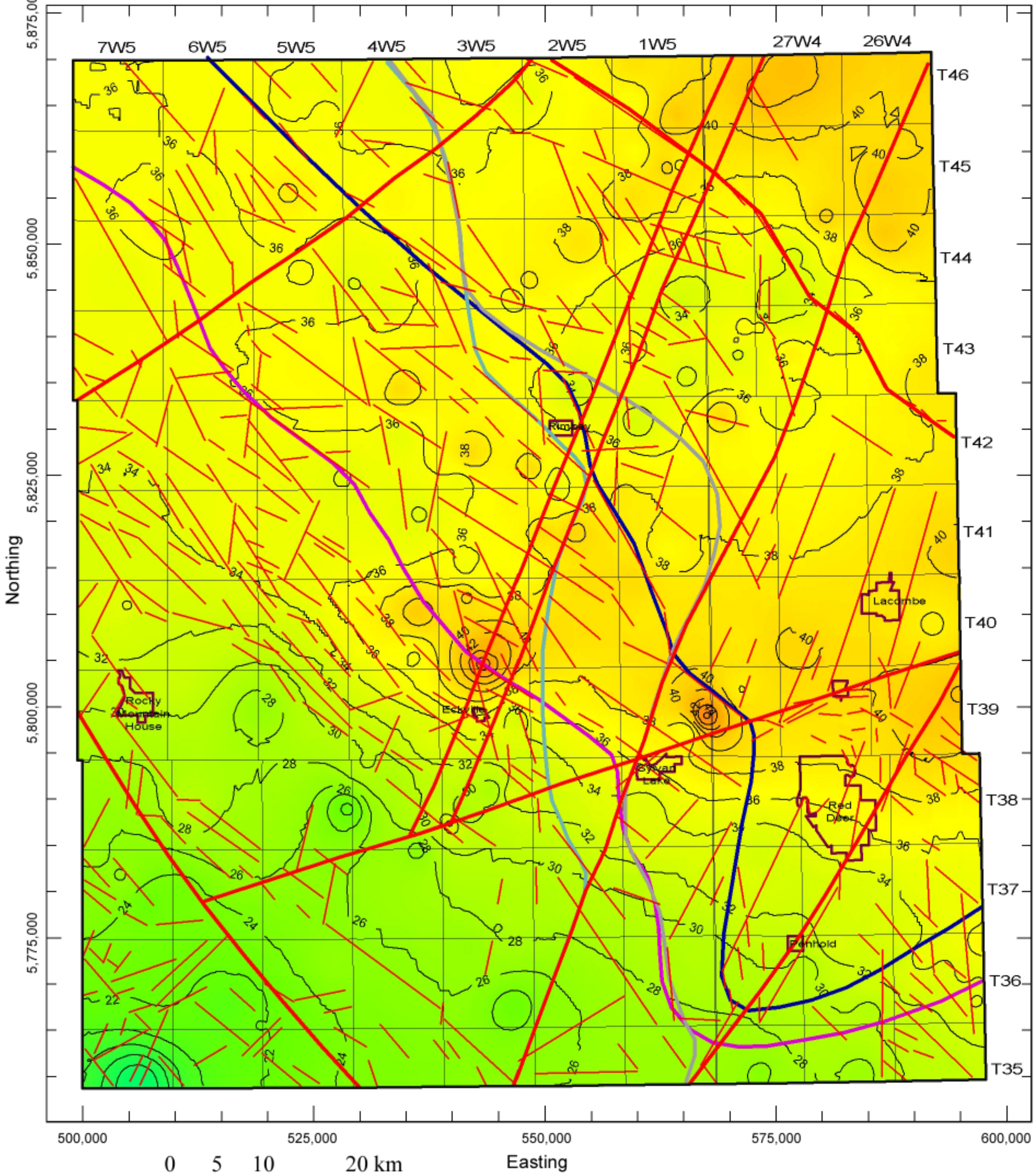


Figure 54. Isopach map of the Westgate shale unit.

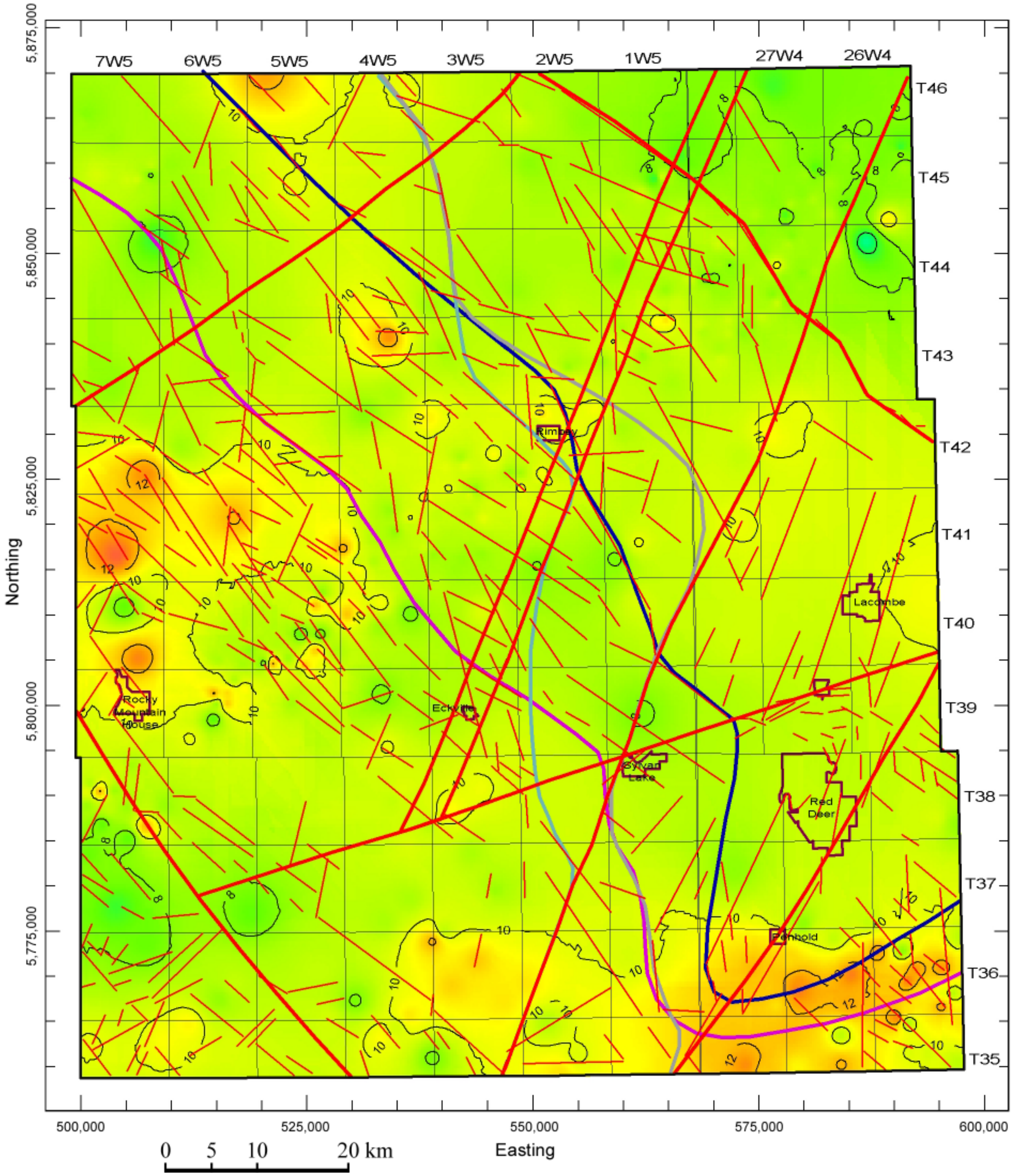


**Figure 55. Isopach map of the Base of Fish Scales.**

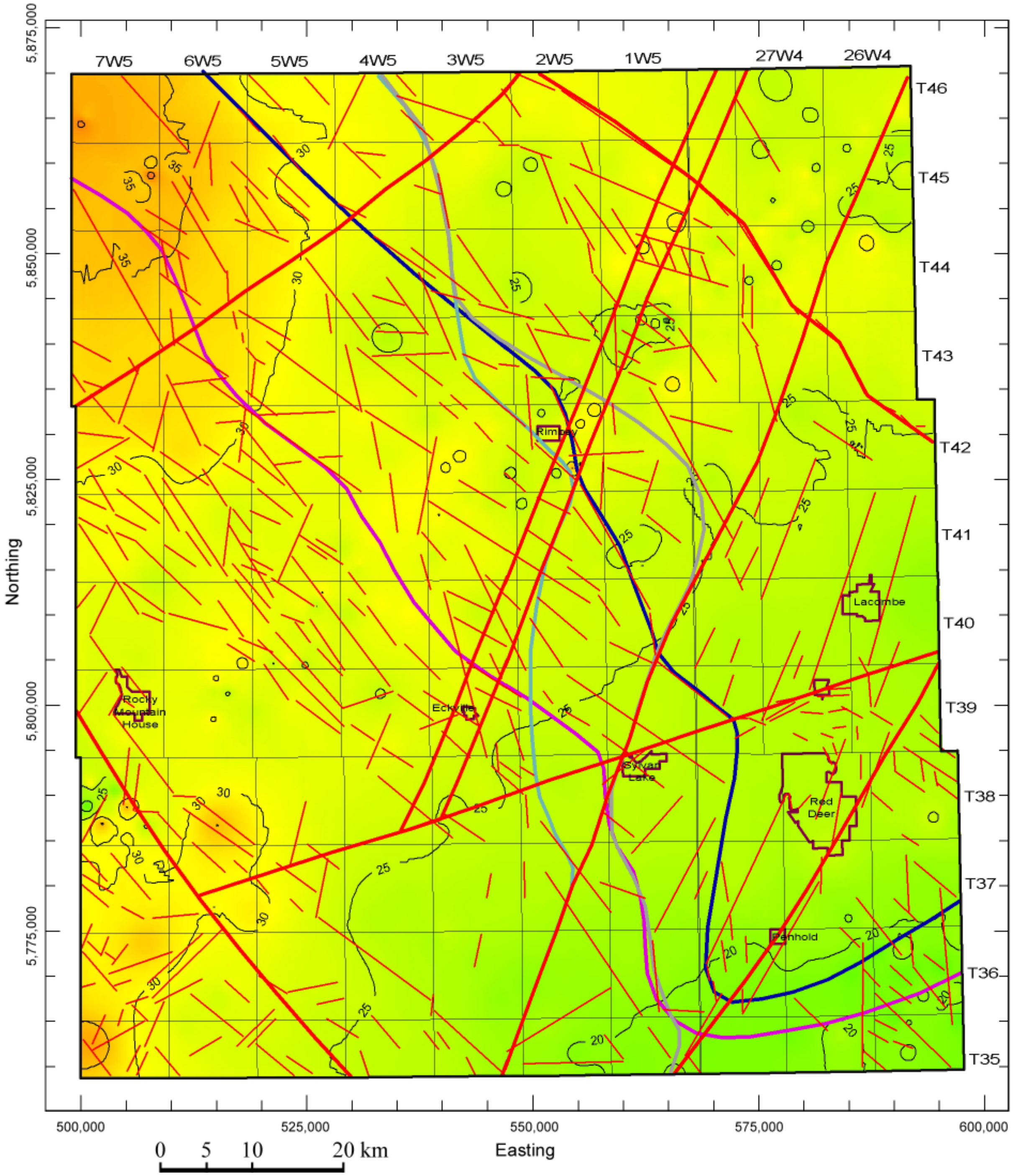


**Figure 56. Isopach map from Fish Scales Marker 1 to 2nd White Specks Marker 1.**

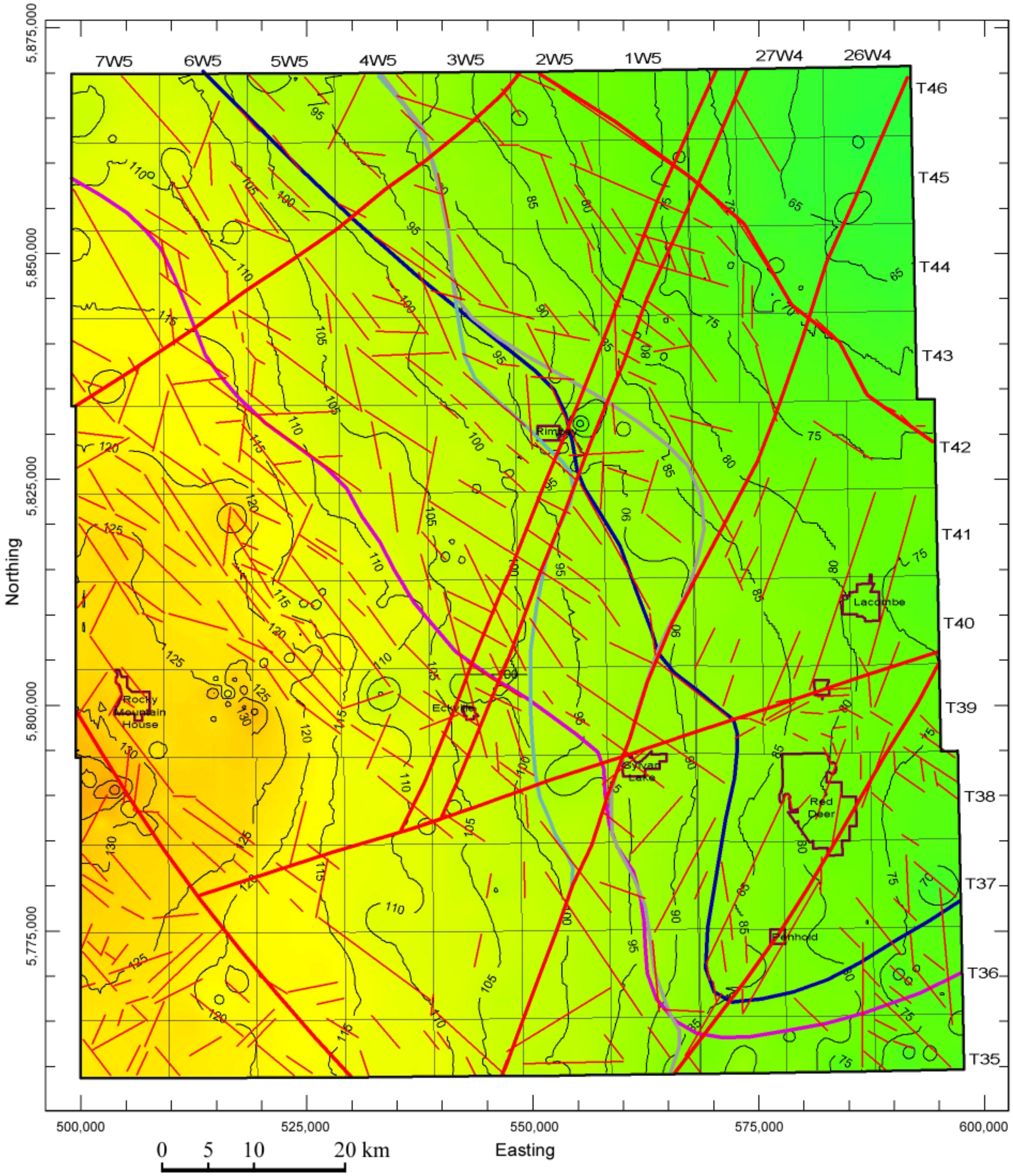

Figure 57. Isopach map from 2nd White Specks Marker 1 to 2nd White Specks top.

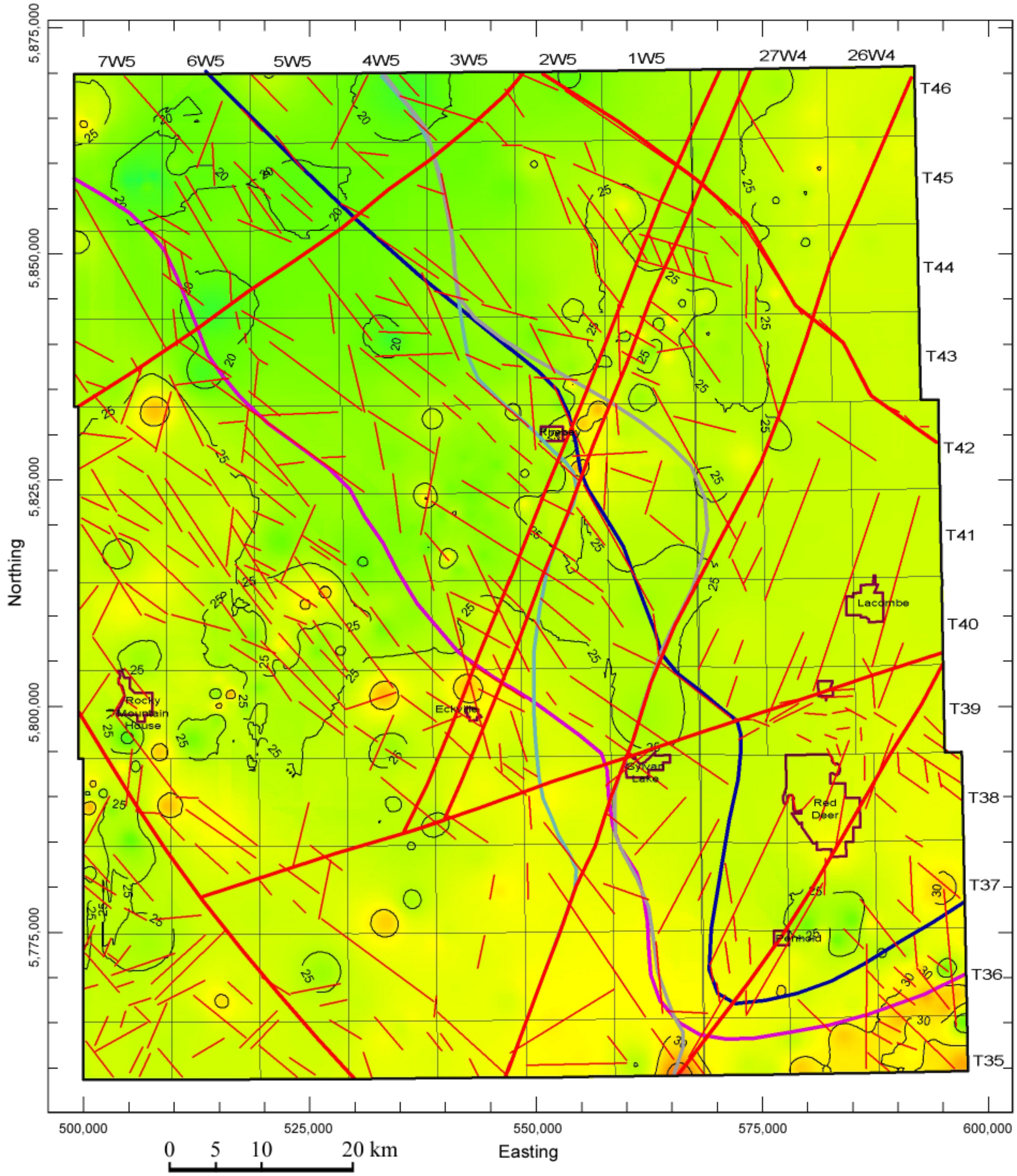


**Figure 58. Isopach map from 2nd White Specks top to Blackstone Marker 1.**

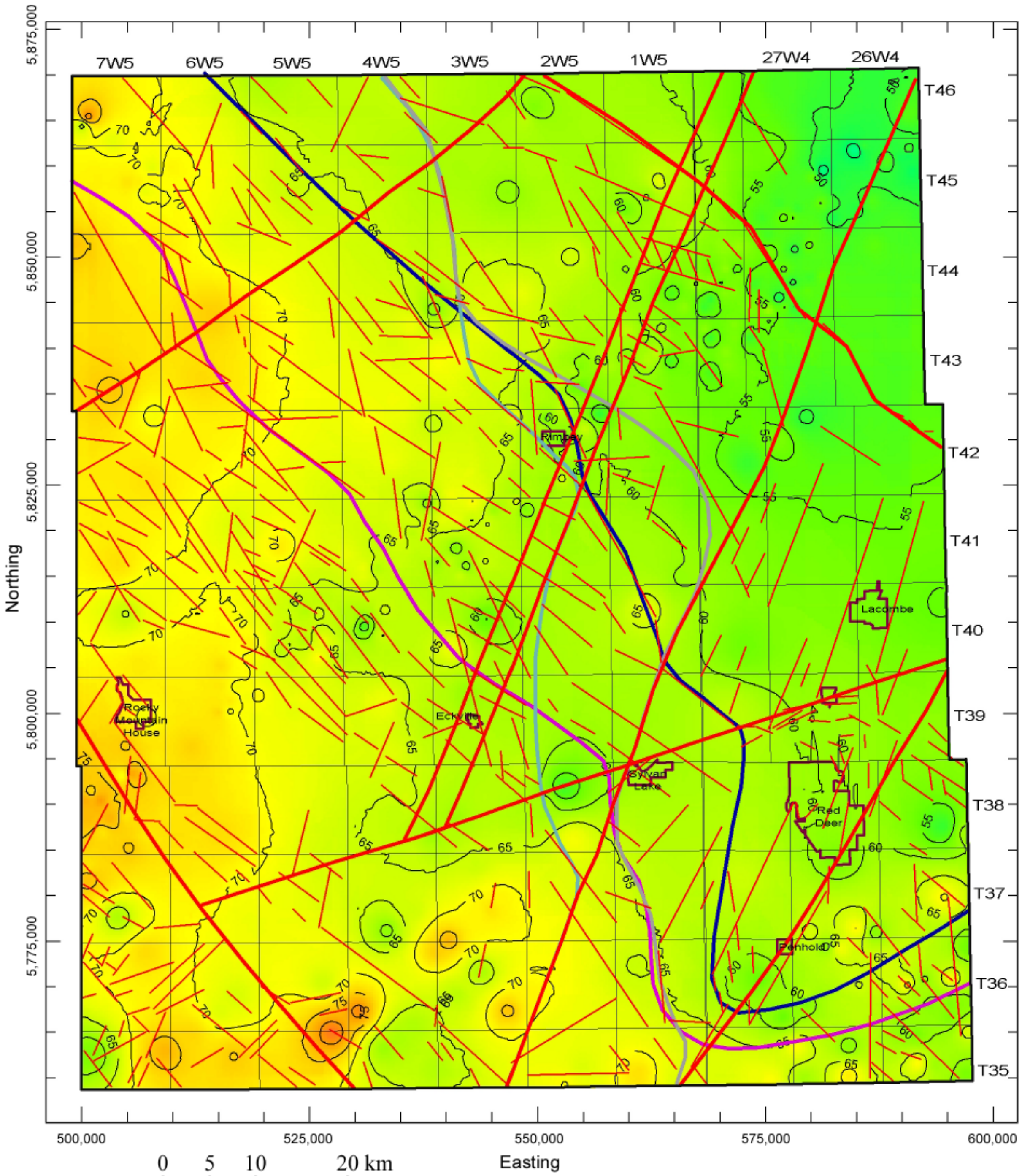


**Figure 59. Isopach map from Blackstone Marker 1 to Cardium Sandstone base.**

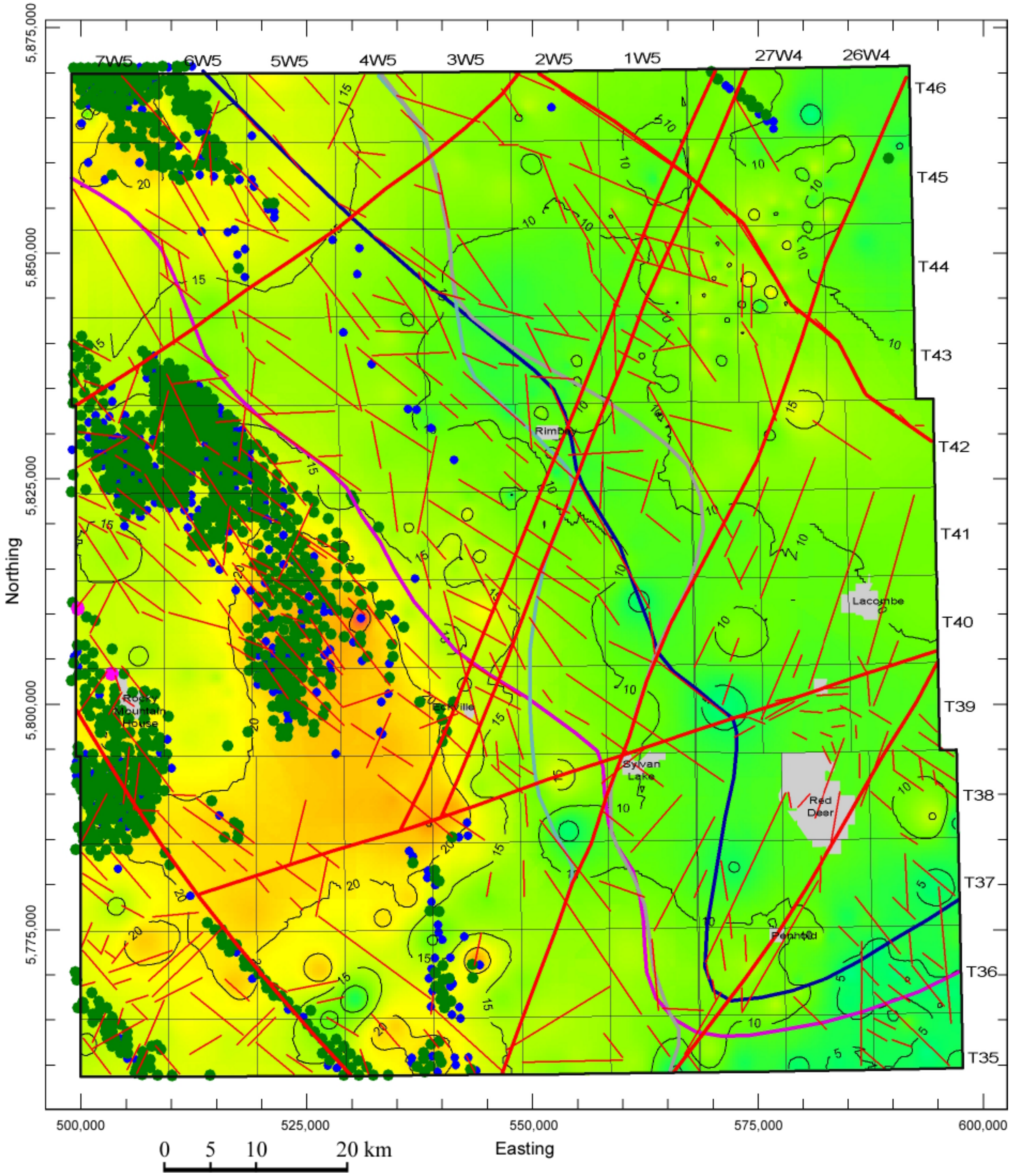


Figure 60. Isopach map of the Cardium Sandstone.

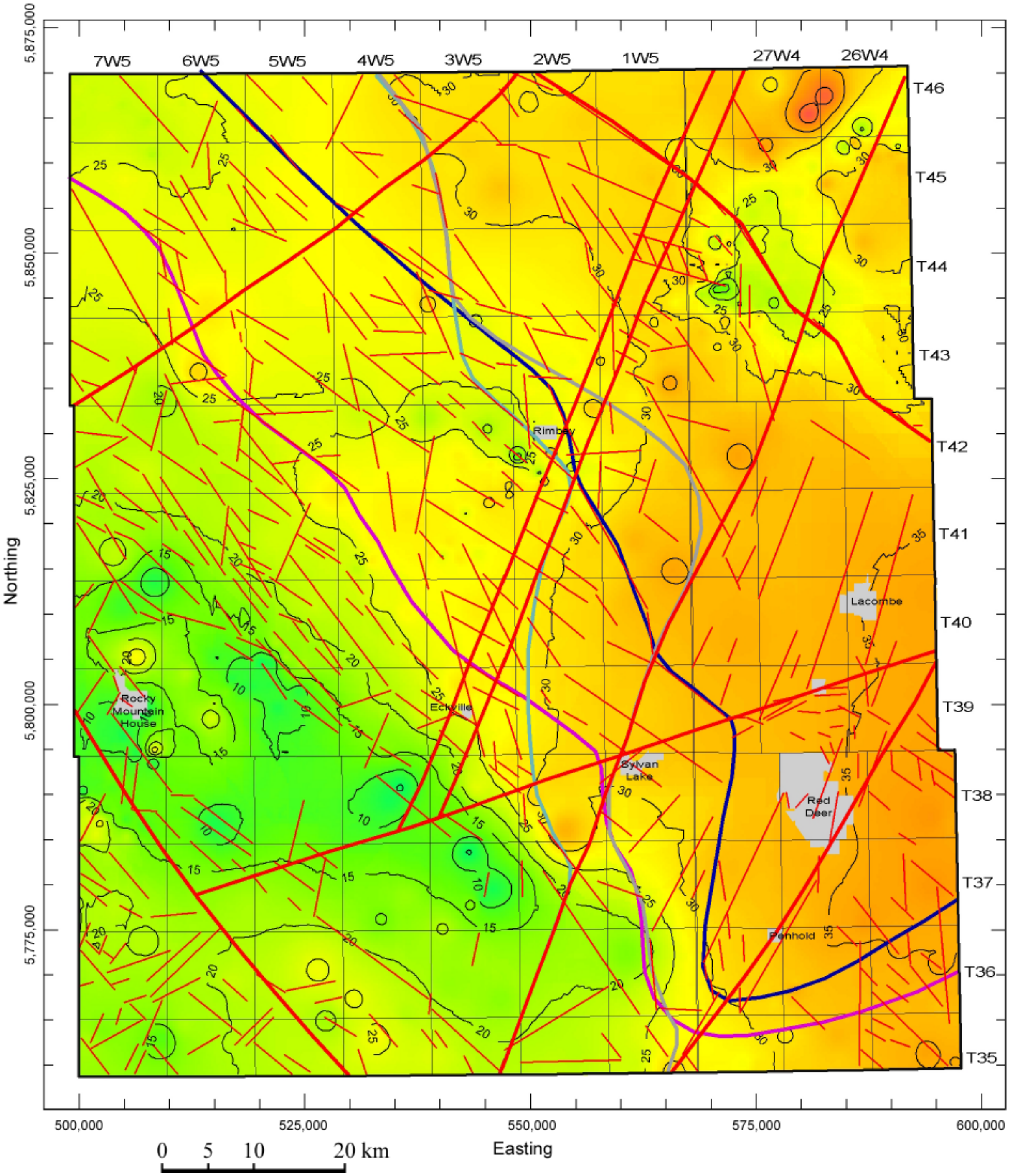


**Figure 61. Isopach map from Cardium Sandstone top to Cardium Formation top.**

rocks; the shale, spiculite and fine-grained carbonate in the lower part of the suite record the continuation of the early Tournaisian transgression and the establishment of widespread, moderately deep-water basin, distal-ramp, and slope environments; these were followed by shallowing and basinward progradation of slope and distal-ramp to supratidal carbonate and siliciclastic rocks; and this trend culminated with deposition of the restricted-shelf lithofacies of the uppermost Banff Formation during the late early Tournaisian (Richards et al., 1994). In the study area, the Banff Formation is about 10–210 m thick and thickens to the southwest (Figure 46). The Banff Formation is elevated toward the northeast and truncated beneath Mesozoic strata (Figures 15–17). The Rimbey-Lacombe Boundary, the Penhold Lineament and the Rimbey Arc appear to influence the thickness of the Banff Formation (Figure 46).

The Pekisko Formation conformably overlies the argillaceous Banff Formation. The clean carbonate unit of the type Pekisko records a regional transgression (Richards et al., 1994). In the subsurface, the Pekisko consists predominantly of light-coloured, coarsely crinoidal and fragmental to fine-grained and sparsely crinoidal, in part dense limestone (Douglas, 1953). In the study area, the Pekisko thickness ranges from 0 to 60 m (Figure 47). The Pekisko is erosionally truncated to the east below Jurassic and Cretaceous strata (Figures 15–17). The Pekisko zero edge trends largely northwest and bends across the major basement lineaments. A complicated subcrop belt was formed along the unconformity edge and trapped oil in discrete pools close to the unconformity edge (Hopkins, 1999).

The Shunda Formation conformably overlies the Pekisko Formation. The Shunda consists of interbedded limestone and dolomite, argillaceous limestone, silty and argillaceous dolomite, siltstone, sandstone, shale and breccia (Stearn, 1956). Shunda deposits are dominated by open-marine skeletal limestone and characterized by their lithological heterogeneity and by the predominance of argillaceous carbonate and shale; the widespread restricted-marine carbonate and anhydrite in the Shunda Formation recorded the first major regression, which subsequent to the Pekisko transgression, occurred during the late Tournaisian (Richards et al., 1994).

The Elkton Member consists of fine to coarsely crystalline dolomite and lesser limestone. Its upper and lower contacts are both conformable. In the study area, the Elkton-Shunda unit is between 0 and 70 m thick, occurring in the southwestern part of the study area (Figure 48). The unit is truncated beneath the Mesozoic to the northeast (Figures 15–17). The Elkton-Shunda zero edge trends essentially northwest but bends across the Rimbey-Lacombe Boundary and Penhold Lineament. The east edge of the Rocky Mountain Foothills appears to affect the erosional extent of the unit (Figure 48).

## 6.2 Jurassic Succession

The successions from the uppermost Mississippian to the Triassic are missing from the study area, and the Jurassic Nordegg Member unconformably overlies the Mississippian formations (Figures 15–17). The superposition of unconformities and shallower sandstone facies toward the east causes particular difficulties in accurately identifying and correlating rock units in central Alberta (Poulton, 1984; Poulton et al., 1994).

Jurassic strata are thin and truncated by unconformities within the Jurassic and below the Lower Cretaceous. The preserved Jurassic is about 0–90 m thick and distributed in the west and central parts of the area (Figure 49). The interval can be divided into two mappable units: the Nordegg Member and the Jurassic clastics.

The Nordegg Member consists of dark grey to black, hard, platy to medium-bedded, cherty and phosphatic limestone; where present, the Nordegg represents the base of the Fernie Group and rests directly on Paleozoic units, indicating a significant hiatus with erosion prior to deposition of the first

Jurassic sediments (Spivak, 1949). In the study area, the Nordegg Member is about 0–50 m thick and thins to the east.

The Jurassic Clastics unit is dominated by brownish, medium to dark grey and black shale (Hamblin and Walker, 1979; Hall, 1984; Poulton, 1984; Stronach, 1984). Rock Creek sandstone is restricted to the western part of the area. Thick Jurassic sandstone occurs locally in the Red Deer and Rimbey areas. The Jurassic Clastics unit is about 0–60 m thick and generally thins toward the east.

In addition to the regionally syndepositional and postdepositional tilting of the basin floor, the deposition/preservation of Jurassic strata appears to be affected by all of the basement lineaments, especially the Rimbey-Lacombe Boundary and the east edge of the Rocky Mountain Foothills.

## 6.3 Cretaceous to Tertiary Succession

The Cretaceous to Tertiary succession is dominated by thick siliciclastic rocks in the Medicine River area. The base of the succession is close to 1600 m deep in the northeast and about 2850 m deep in the southwest. The Lower Cretaceous is relatively thin, comparing with the Upper Cretaceous in the area. The Cretaceous to Tertiary succession can be divided into the Mannville and Colorado groups, Lea Park Formation and Belly River Group, Edmonton Group and Paskapoo Formation (Figure 11). With the exception of the Mannville Group in the Lower Cretaceous, coal-bearing formations of the Belly River, Horseshoe Canyon and upper Scollard are all concentrated in the uppermost Cretaceous to Lower Tertiary section.

The uppermost Cretaceous to Paleocene strata of the Alberta Basin were divided by Jerzykiewicz (1997) into the Belly River–Edmonton sequence and the Entrance-Paskapoo sequence using the 68 Ma boundary that is marked by the Kneehills Tuff Zone and strongly related to basin tectonics. The Belly River–Edmonton sequence consists of marginal marine and nonmarine strata, and the Entrance-Paskapoo sequence consists of exclusively terrestrial strata. Within the lower sequence, the 83 Ma, 80 Ma and 71 Ma boundaries are related to the Wapiabi, Pakowki-Nomad and Bearpaw transgressions, respectively. Within the upper sequence, the 63 Ma and 60 Ma boundaries are marked by basin-wide erosional surfaces. Unconformities and/or subaerially exposed surfaces at these boundaries are related to tectonic activities.

### 6.3.1 Mannville Group

Lying above the sub-Cretaceous unconformity, the Mannville Group consists of interbedded nonmarine sand and shale overlain by a thin, nonmarine calcareous member that is, in turn, overlain by marine shale, glauconitic sand and nonmarine salt-and-pepper sand in southern and central Alberta (Nauss, 1945). In central Alberta, the group can be divided into a transgressive sequence, containing the Ellerslie and Ostracod beds, and a regressive sequence, containing the Glauconitic and the Upper Mannville sandstone. The Medicine River and Glauconitic coals formed in the Upper Mannville.

In the study area, the thickness of the Lower Mannville Group is about 10–105 m (Figure 50). Sediments appear to thicken mainly along the Penhold Lineament and the east edge of the Rocky Mountain Foothills. Northeast and northwest are the dominant orientations of the strata in the Lower Mannville.

The thickness of the Upper Mannville Group is about 85–160 m (Figure 51). The depocentre of the Upper Mannville is in the southwest. The group thins along the Rimbey Arc and the Thorsby-Rimbey Boundary. The strata appear to trend northeast, parallel to the paleoshoreline at that time.

### 6.3.2 Colorado Group

A widespread disconformity separates the Colorado Group from the underlying the Mannville Group. The Colorado Group is dominated by marine shale with a few sandier units of marginal marine origin. The group is divided into the following eight units, in ascending order: Joli Fou, Viking, Westgate, Fish Scales, Second White Specks equivalent, Blackstone equivalent, Cardium and Wapiabi equivalent. The Viking and Cardium are the major sand units in the group.

The Joli Fou Formation comprises dark grey, noncalcareous shale with minor interbedded fine- and medium-grained sandstone (Caldwell et al., 1978; Simpson and O'Connell, 1979). The Joli Fou, including the shaly deposits below the Viking sandstone, is about 10–35 m thick in the study area (Figure 52). The formation thickens on the south side of the Sylvan Lake Lineament, which may be related to the Caroline Arch activity during deposition.

The Viking Formation unconformably overlies the Joli Fou and consists of relatively well-washed and variably fine- to coarse-grained sandstone, with subordinate conglomerate and pebbly sandstone (Tizzard and Lerbekmo, 1975; Simpson and O'Connell, 1979). The Viking in the Caroline and Garrington fields consists of a two-part stratigraphy: the lower unit contains a northeast-prograding coastal succession of offshore and shoreface storm deposits capped by nonmarine facies, and the upper unit contains marine black shale with five tongues of coarse sandstone and conglomerate (Davies and Walker, 1993). The thickness of Viking sandstone is about 10–45 m in the study area (Figure 53). Similar to the Joli Fou (Figure 6-9), the Viking Formation thickens in the south along the Caroline Arch. Productive sandbodies (reservoirs), trending west-northwest or west, are subparallel to the axis of the subsiding centre in the south during Viking deposition.

The shale unit of the Westgate Formation below the Fish Scales Formation is about 10–50 m thick in the study area (Figure 54). In contrast to the Viking and Joli Fou formations, the Westgate shale thins in the south and southwest, suggesting 1) lack of fine sediments in the Foothills and the Caroline Arch areas, or 2) uplift of the Foothills and the Caroline Arch areas during that time.

The Fish Scales Formation consists of fine and very fine grained sandstone and coarse-grained siltstone, with medium to dark grey calcareous shale and mudstone (Caldwell et al., 1978). In the study area, the thickness of the Fish Scales Formation is about 5–15 m (Figure 55). The base of the Fish Scales is used as the boundary between the Lower and Upper Cretaceous, and as a stratigraphic marker in subsurface correlation. The Albian-Cenomanian boundary may be a regional paraconformity (North and Caldwell, 1975).

The contact between the Second White Specks equivalent unit and the underlying Fish Scales is gradational. The Second White Specks unit is composed mainly of calcareous shale and mudstone, with intercalated shaly chalk and skeletal calcarenite, as well as subordinate bentonite, accumulations of fish-skeletal debris, concretionary layers of calcite and siderite, nodular phosphorite and localized occurrences of sandstone and siltstone (Caldwell et al., 1978). In the study area, it is about 20–40 m thick from the Fish Scales top to the Second White Specks Marker 1 (Figure 56), and about 60–150 m thick from the Second White Specks Marker 1 to the Second White Specks top (Figure 57). The depocentre shifted from the northwest (Figure 56) to the west (Figure 57).

The Blackstone Formation equivalent unit disconformably/unconformably overlies the Second White Specks equivalent unit. The Blackstone Formation comprises primarily dark grey to black marine mudstone and siltstone with minor beds of argillaceous limestone, sandstone, bentonite and some sideritic concretions (Wall and Germundson, 1963). The formation contains more silt in the westernmost exposures along the foothills and decreases in thickness from west to east across the foothills. In the study area, it is about 20–30 m thick from the Second White Specks top to the Blackstone Marker 1 (Figure 58), and about 40–85 m thick from the Blackstone Marker 1 to the Cardium Sandstone base (Figure 59). Sediments were shed to the west (Figure 59). The Rimbey Arc and the Penhold Lineament appear to influence the thickness of the Blackstone equivalent unit.

Disconformably overlying the Blackstone equivalent unit, the Cardium Formation is characterized by its fine-grained marine sandstone. The formation can be divided into lower (Pembina River) and upper members (Cardium zone) by an abrupt change in lithology from conglomerate below to shaly siltstone above. The Cardium Zone consists of black, finely laminated and bioturbated shale and shaly siltstone with infrequent stringers of coarse sand and chert-pebble conglomerate. A transition zone is almost always present from shale through interbedded shale and thinly bedded sandstone to massive sandstone (Krause and Nelson, 1984; Walker, 1985; Plint et al., 1986; Bergman and Walker, 1988). In the study area, the Cardium Formation extends from the foothills belt into the plains and grades laterally eastward into shale. Cardium sandstone is about 0–30 m thick and concentrated in the west (Figure 60). Thickness from the Cardium sandstone top to the Cardium top is about 5–45 m (Figure 61). This upper Cardium unit thickens in the east and northeast. It appears that the northwest-trending zones of the foreland basin were more active during Cardium sedimentation.

The contact between the Wapiabi Formation equivalent unit and the underlying Cardium Formation is mainly conformable. The unit consists of dark grey to black marine shale, which locally contains abundant sideritic concretions, minor siltstone, sandstone and limestone (Wall and Germundson, 1963). In the study area, thickness from the Cardium top to the Wapiabi Marker 1 is about 10–40 m (Figure 62), and from the Wapiabi Marker 1 to Marker 4 is about 40–160 m (Figure 63). Differential subsidence along elongate, northwest-trending structural zones was prevalent during the time of Cardium and Wapiabi deposition (Figures 60–62). As was the case for the underlying interval between Wapiabi markers 1 and 4 (Figure 63), the depocentre of the interval between Wapiabi Marker 4 and the Colorado top remained in the southwest (Figure 64). Thickness of the latter interval is about 30–60 m.

### 6.3.3 Lea Park Formation and Belly River Group

The Lea Park Formation consists of medium to dark grey shale with minor amounts of silt. Very fine grained sand seams, numerous layers of calcite-veined clay-ironstone concretions and scattered thin bentonite seams occur throughout the formation (Meijer Drees and Myhr, 1981). In the Medicine River area, the Lea Park Formation can be divided into lower and the upper members by the Lea Park Marker 1, which is equivalent to the Milk River Shoulder correlation marker. Thickness is about 65–115 m for the lower member (Figure 65) and 10–60 m for the upper member (Figure 66).

The Belly River Group overlies the Lea Park Formation gradationally. The marine shale of the Lea Park interfingers with the basal Belly River sandstone (Bergman and Eberth, 1998; Chen and Bergman, 1999).

The Belly River Group is composed mainly of grey and green interbedded mudstone to very fine grained sandstone with coarser grained sandstone beds. Bentonite, coal and concretionary beds are present (McLean, 1977). A fine- to medium-grained sandstone unit is often present in the basal Belly River and is about 2–35 m thick when present in the Medicine River area. The lower part of the Belly River comprises thick to massive, fine to very coarse grained sandstone beds with abrupt bases and upward decrease in grain size. In the study area, the thickness of the Belly River Group is about 210–430 m and generally thins to the northeast (Figure 67).

Bergman and Eberth (1998) did regional correlations of the Belly River Group in Alberta and Saskatchewan and recognized three formations, in ascending order, the Foremost (regressive paralic),

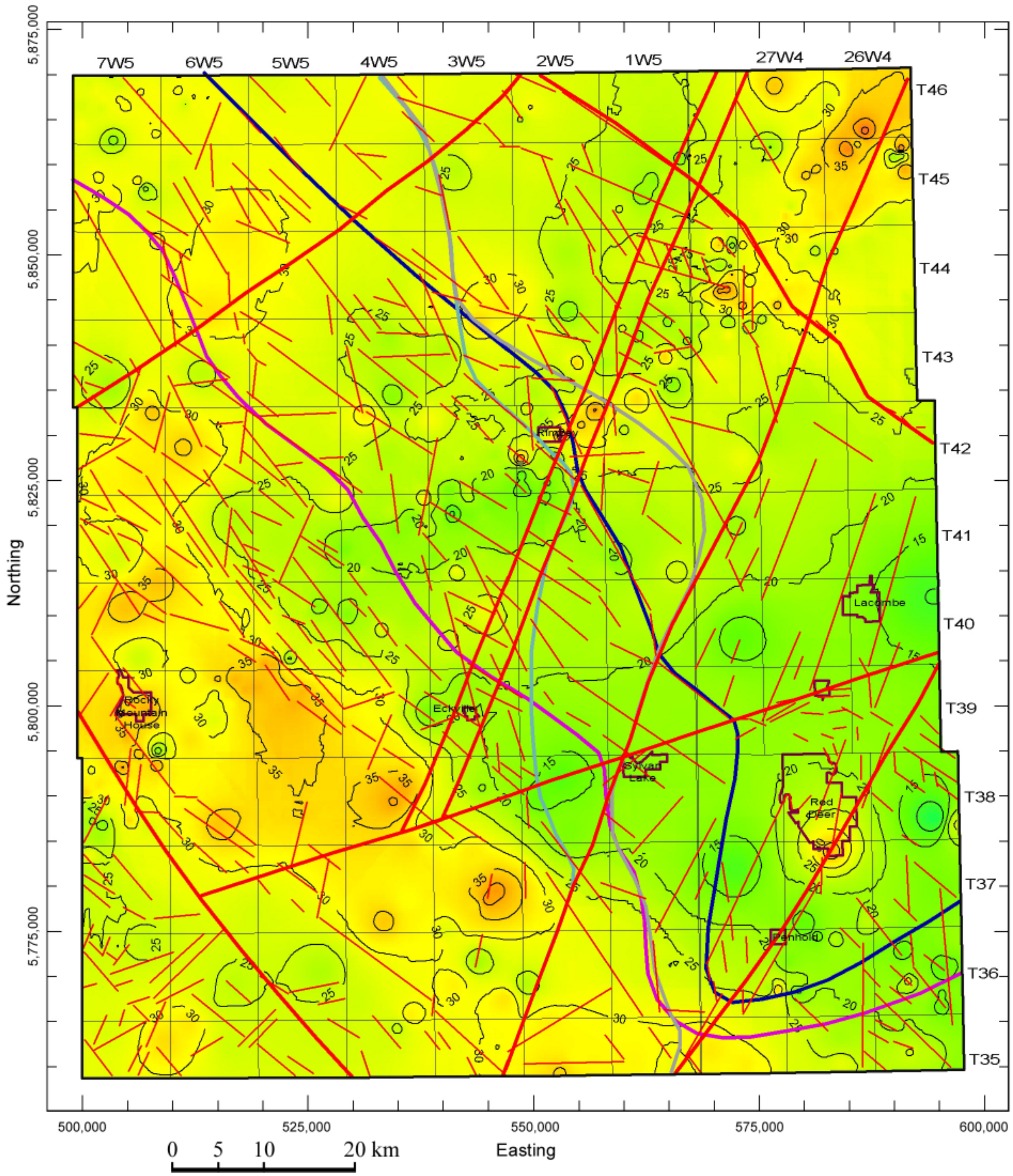


**Figure 62. Isopach map from Cardium Formation top to Wapiabi Marker 1.**

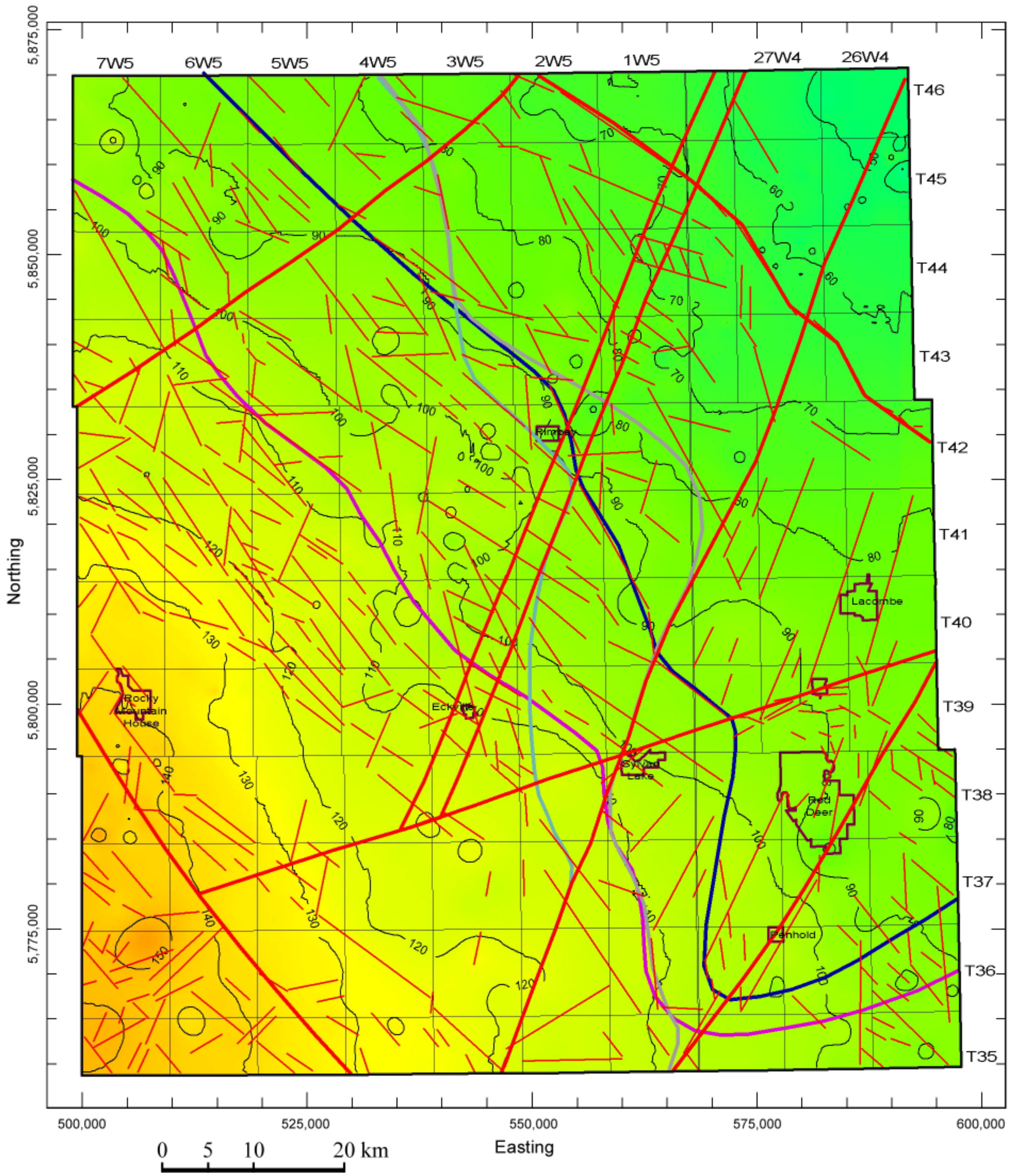


**Figure 63. Isopach map from Wapiabi markers 1 to 4.**

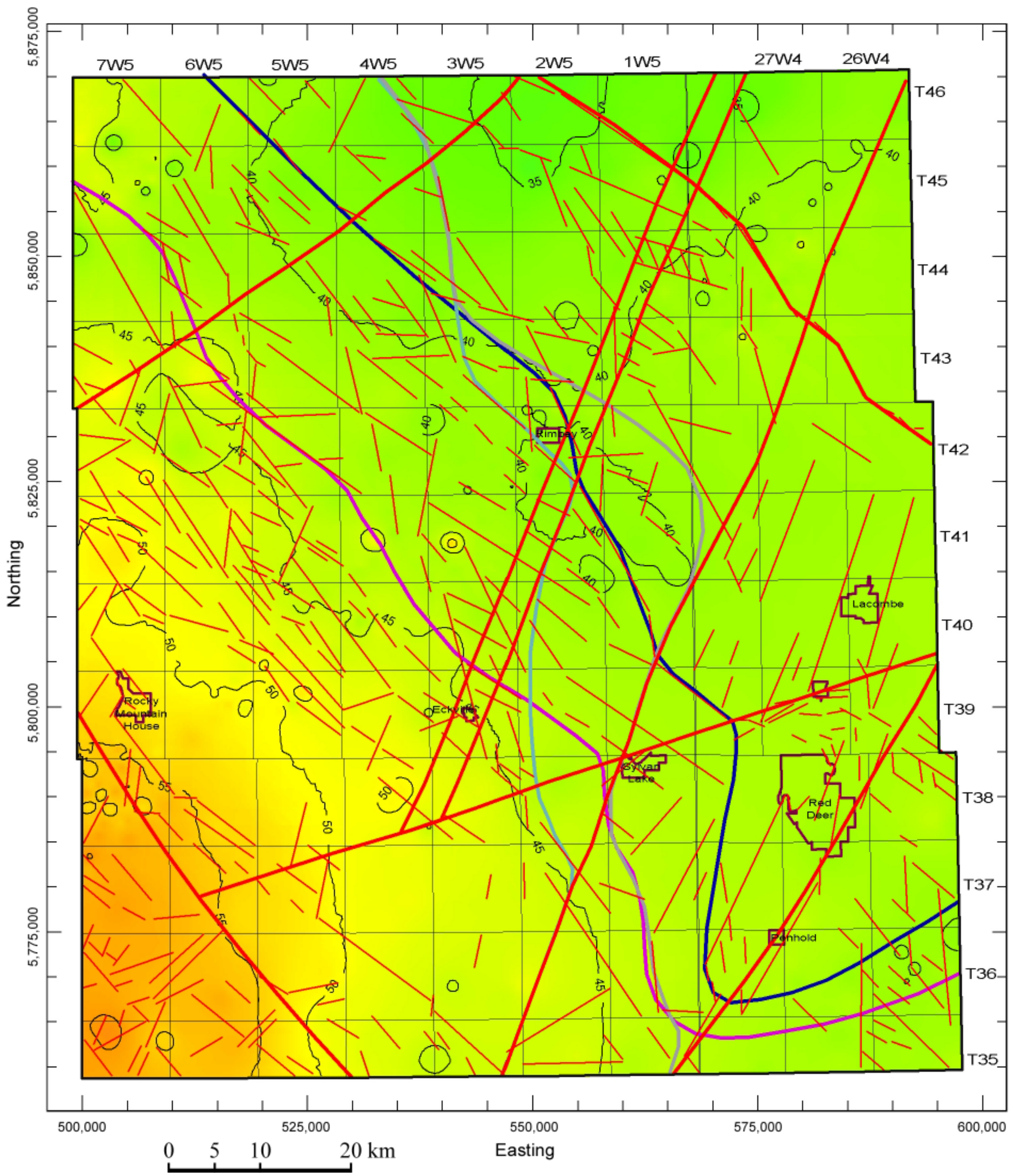


**Figure 64. Isopach map from Wapiabi Marker 4 to Colorado Group top.**

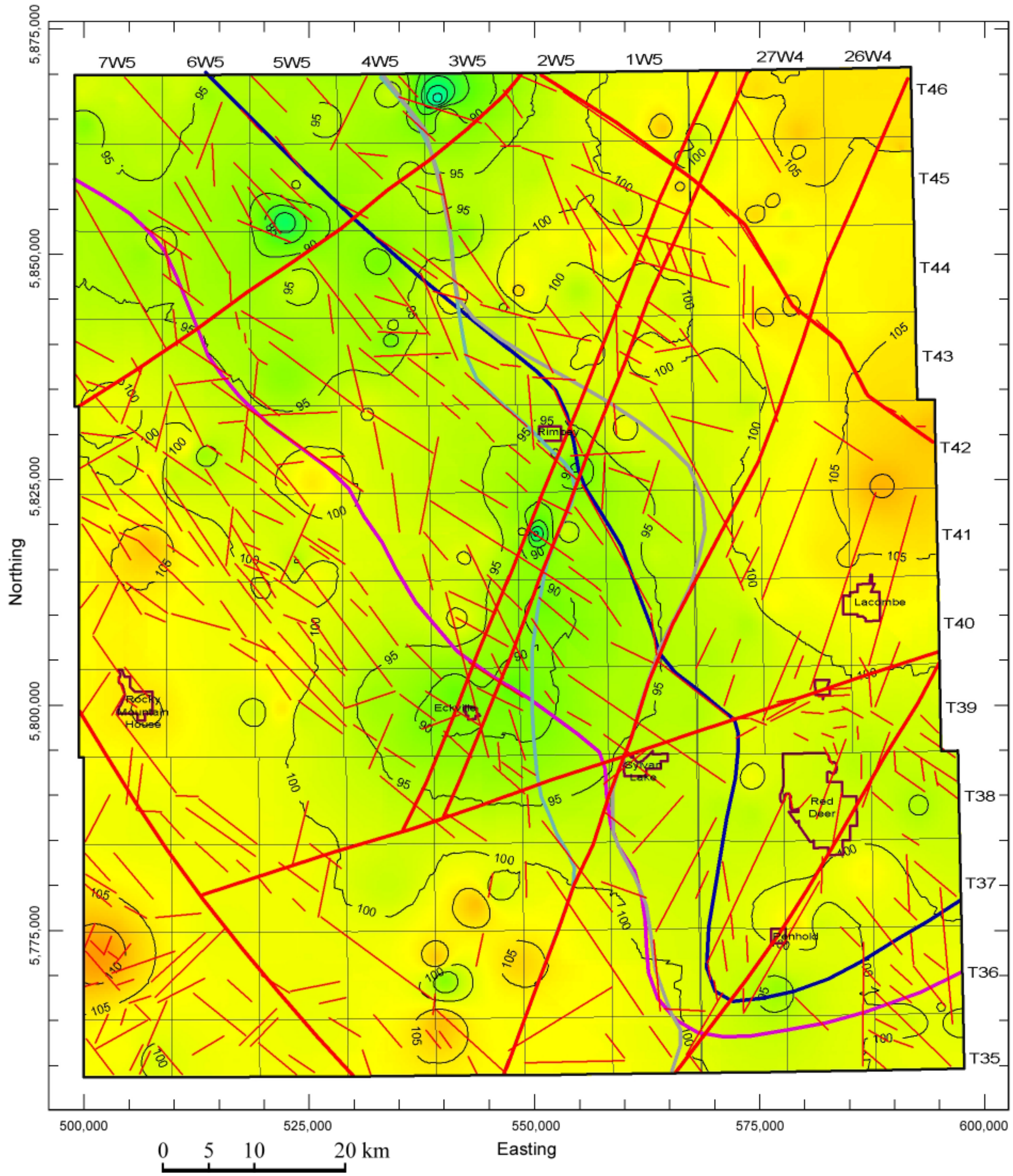


**Figure 65. Isopach map of the Lower Lea Park Formation.**

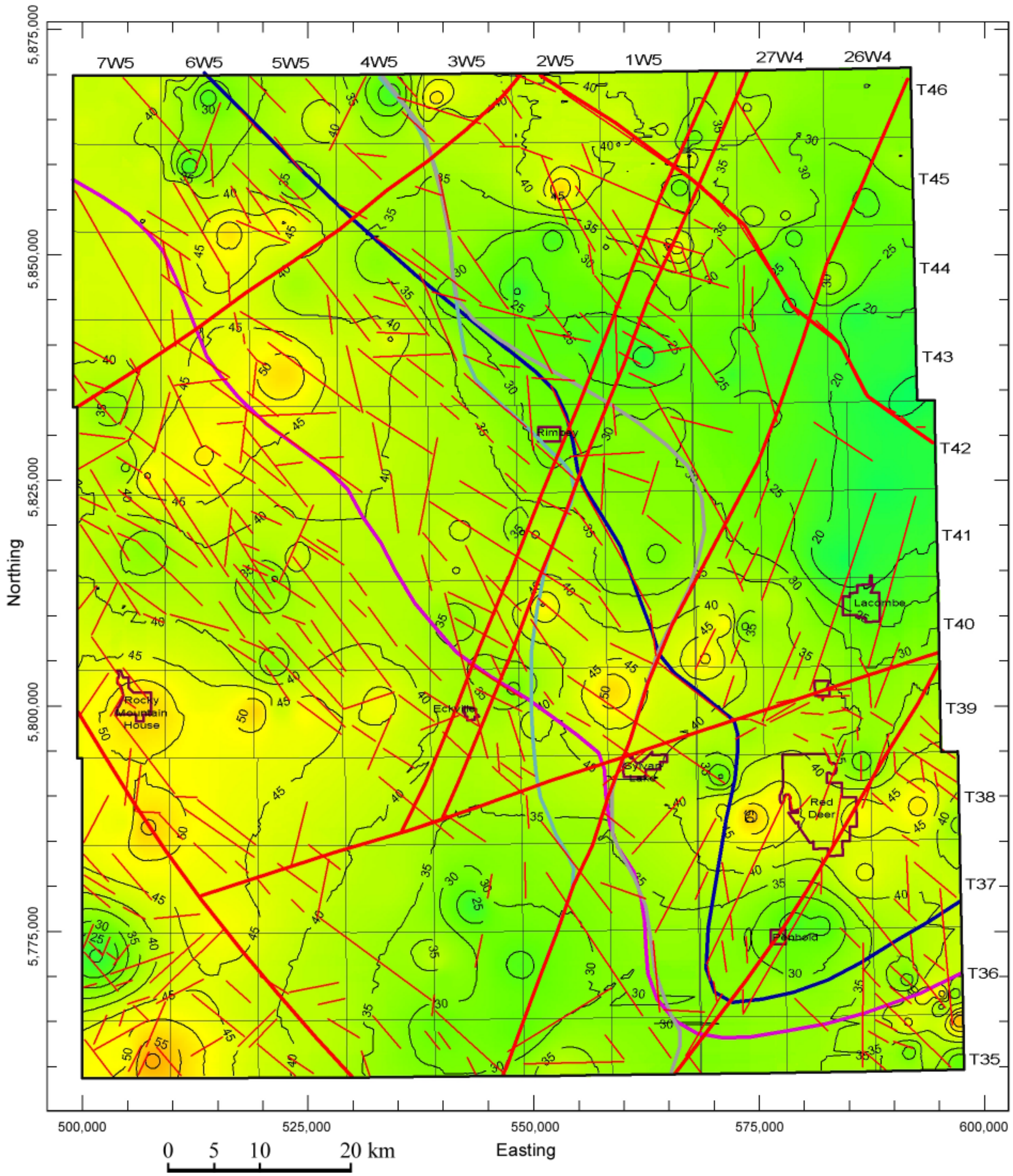


**Figure 66. Isopach map of the Upper Lea Park Formation.**

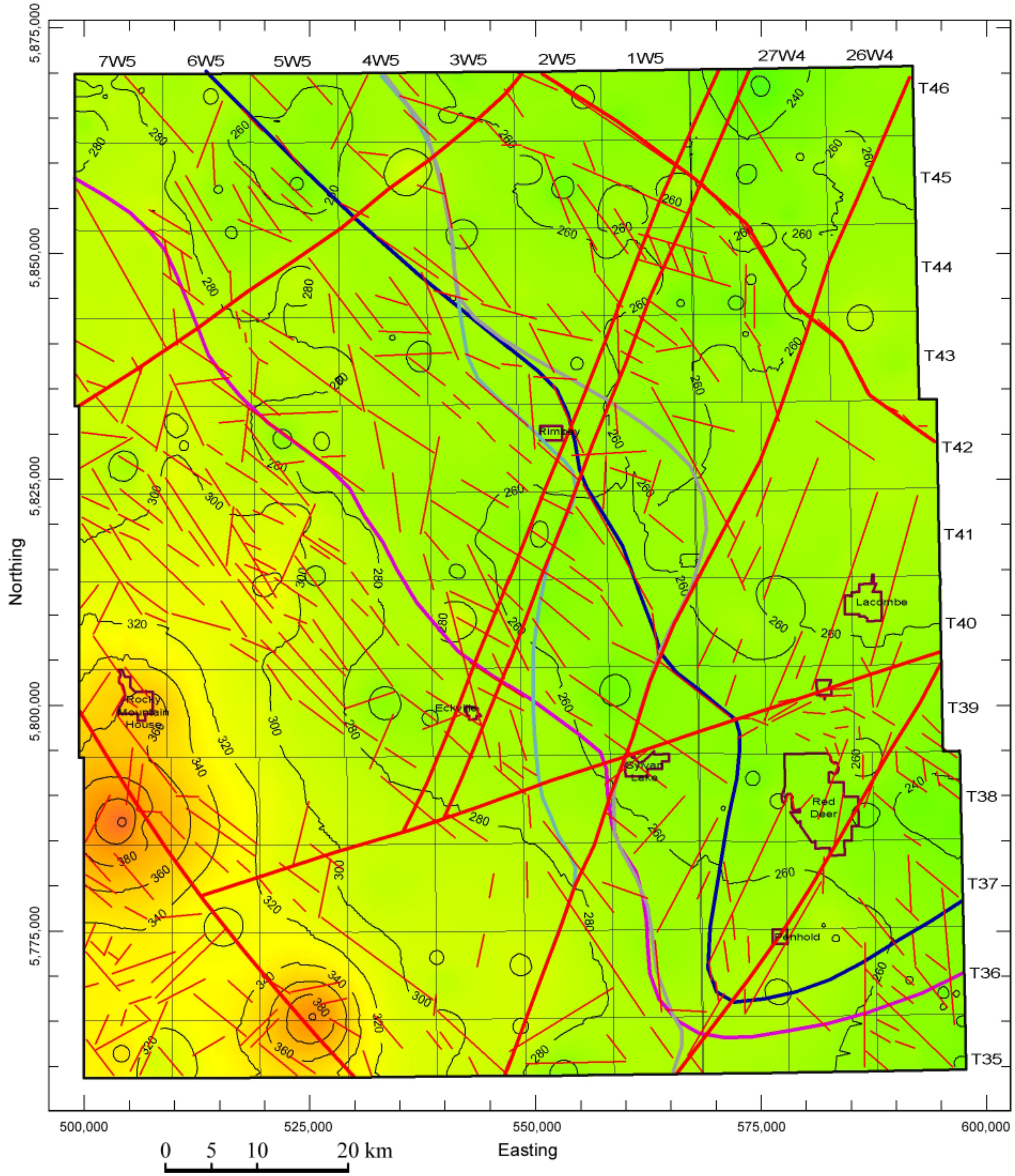


Figure 67. Isopach map of the Belly River Group.

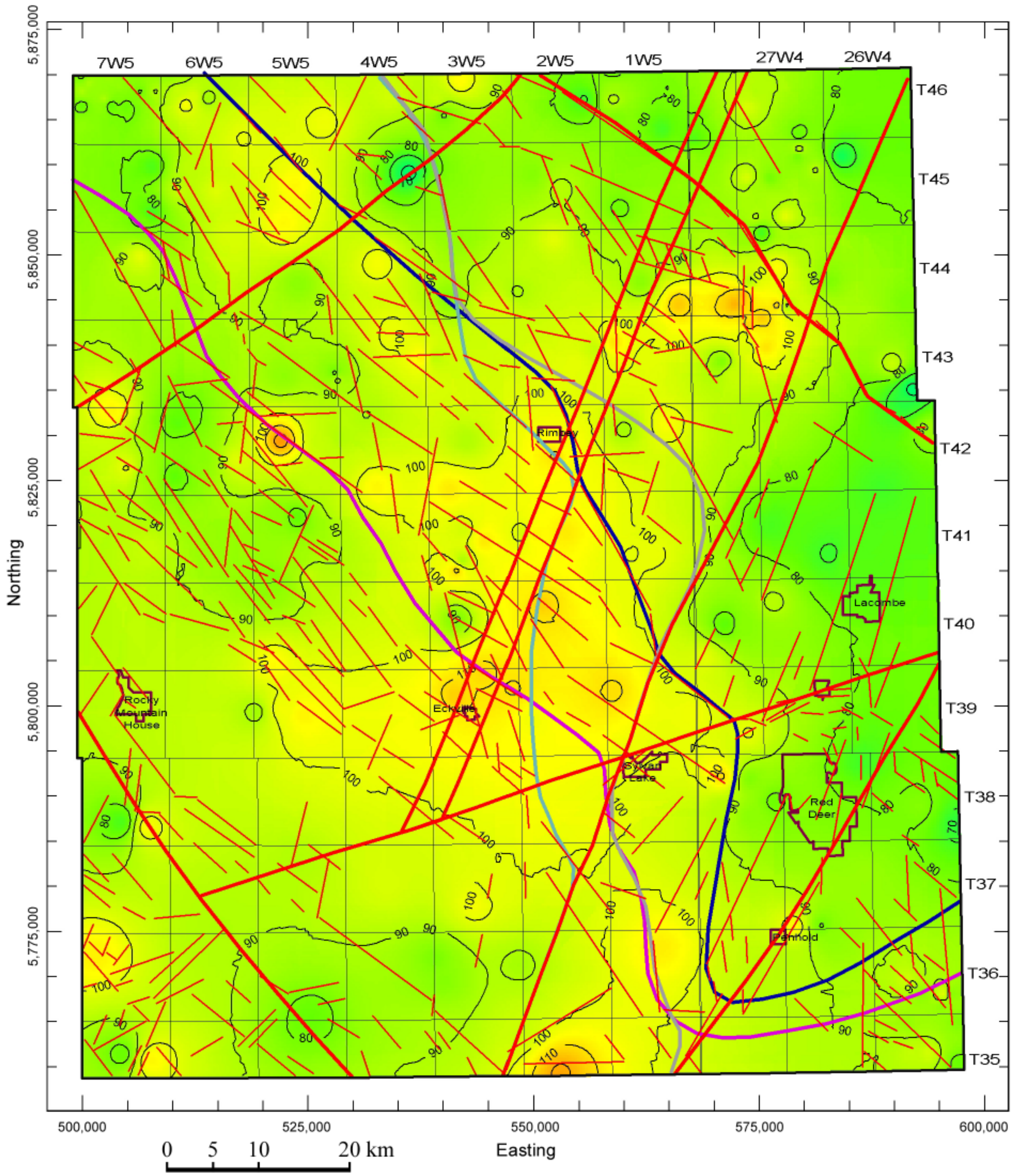


**Figure 68. Isopach map of the Bearpaw Formation equivalent.**

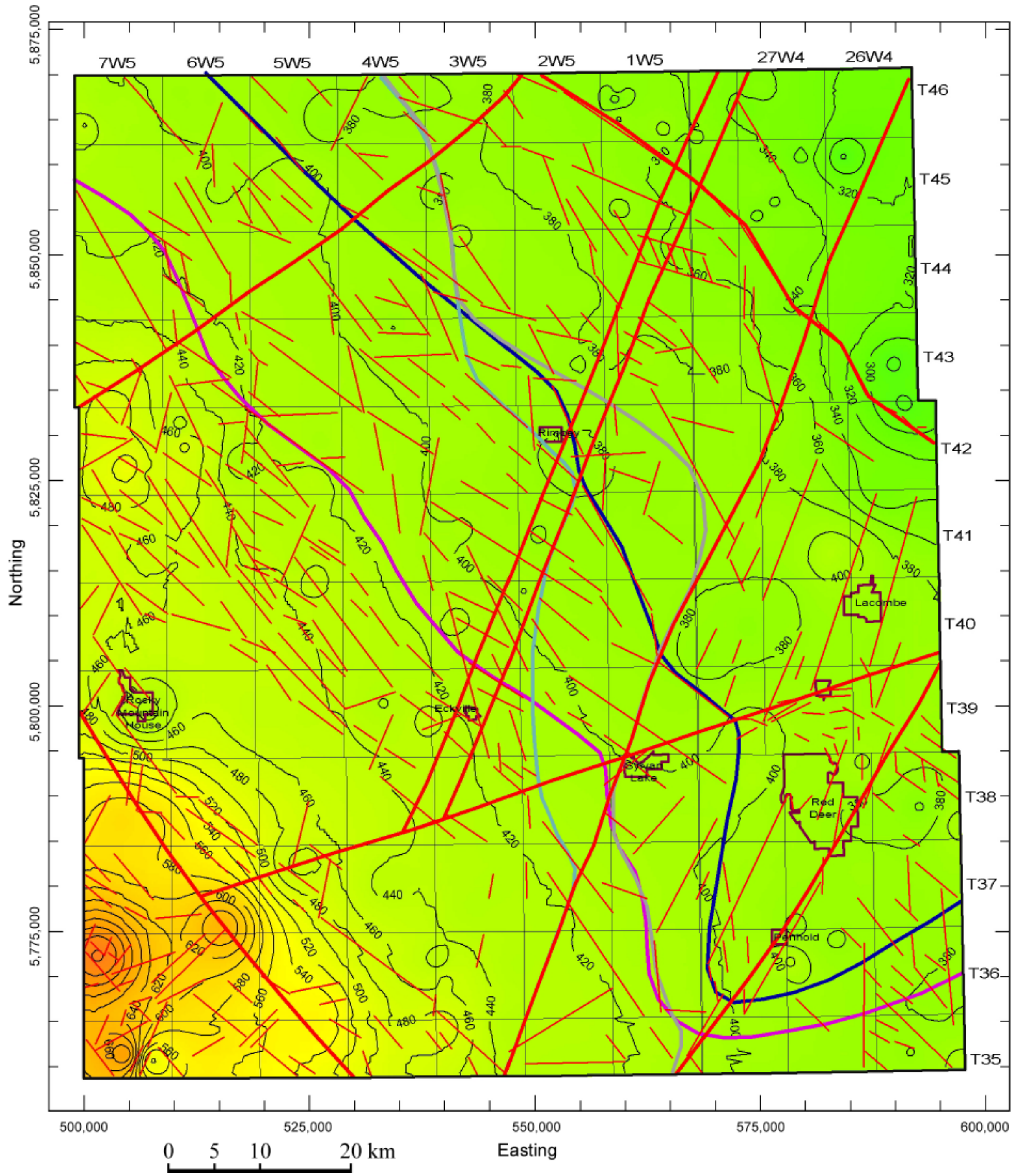


**Figure 69. Isopach map of the Horseshoe Canyon Formation.**

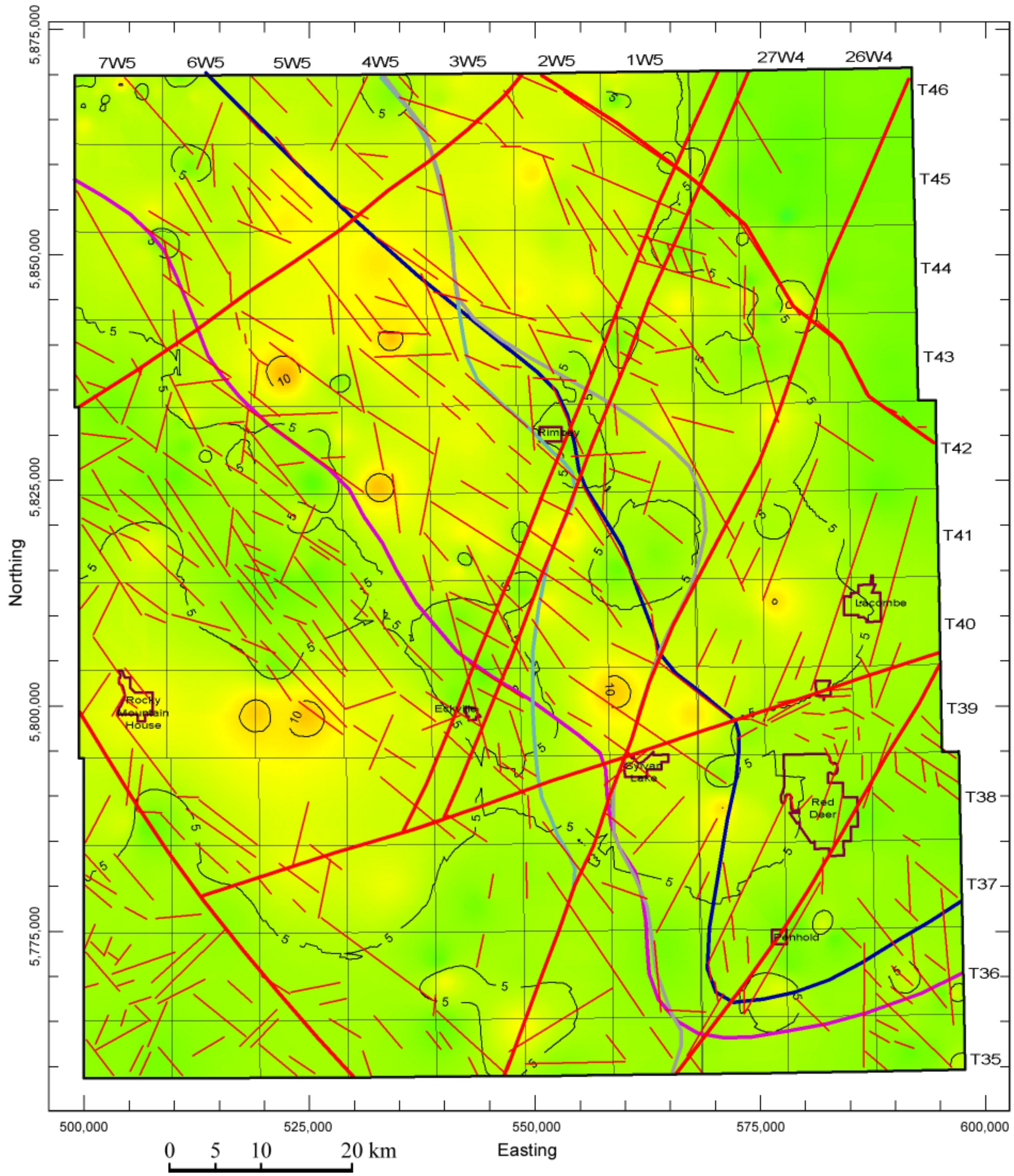


**Figure 70. Isopach map of the Battle Formation.**

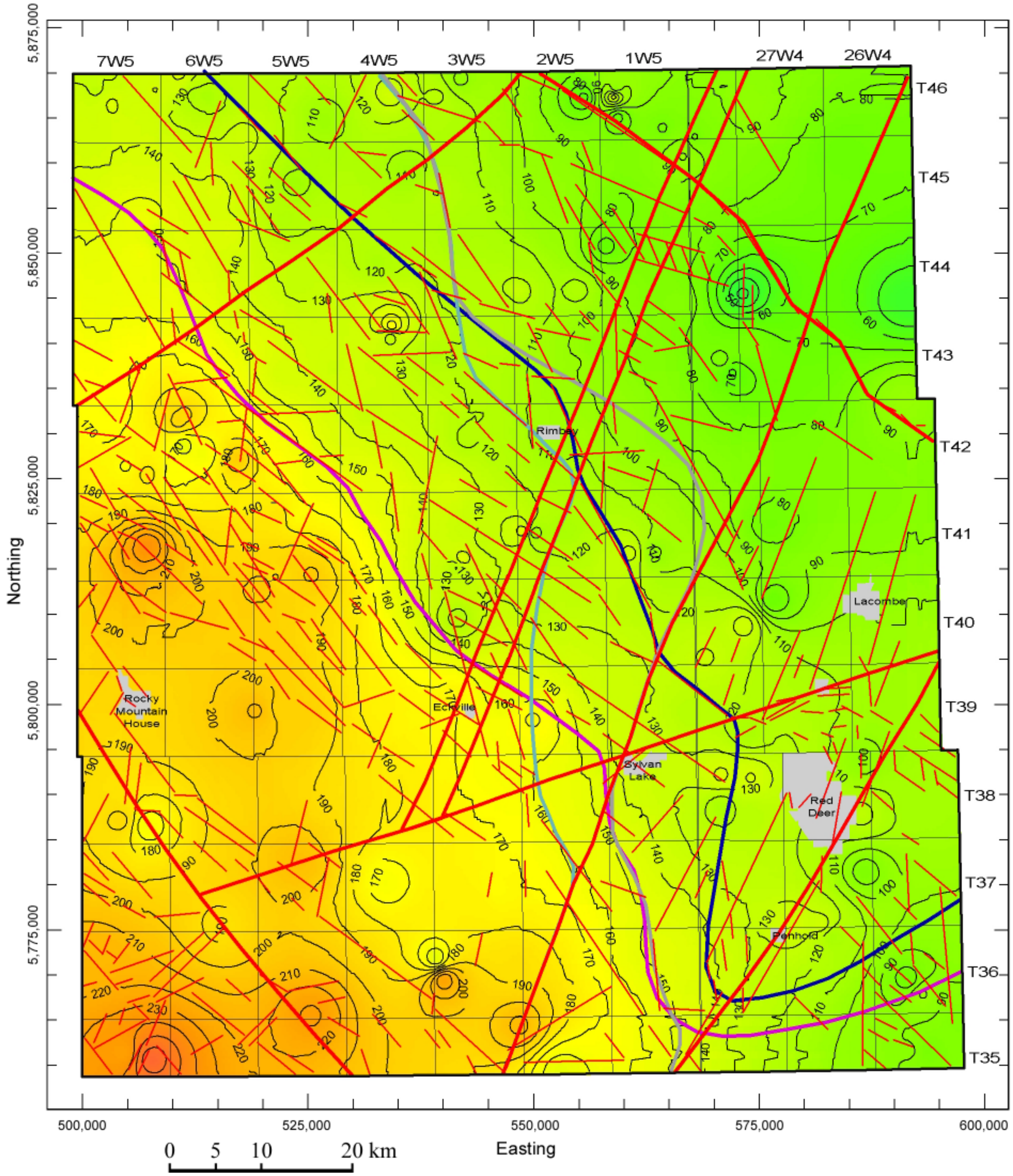


Figure 71. Isopach map of the Scollard Formation.

Oldman (regressive-transgressive alluvial to paralic) and Dinosaur Park (transgressive paralic), which are bounded by disconformities controlled by tectonics.

### 6.3.4 Edmonton Group

Four units of the Edmonton Group were recognized in the Medicine River area during this study: Bearpaw Formation equivalent unit, Horseshoe Canyon Formation, Battle Formation and Scollard Formation (Figures 26–29).

The abundant coal and CBM resources in the Horseshoe Canyon Formation and its close relationship with the Bearpaw marine transgressions/regressions have attracted the attention of industry and academia for more than half a century. Knowledge of the Bearpaw and Horseshoe Canyon formations has been well established through studies on the outcrops and subsurface geophysical logs along the Red Deer River and around the town of Drumheller (Allan and Sanderson, 1945; Lines, 1963; Ainsworth, 1994; Eberth and Straight, 1998; Pană and Beaton, 2002). There are at least three Bearpaw marine tongues that are interfingered with the lower and middle Horseshoe Canyon Formation (Hamblin, 2004). Using stratigraphic criteria, Catuneanu (2002) and Chen et al. (2002) carried out correlations of the Bearpaw and lower Horseshoe Canyon formations from the southern Plains to the northwest-central Plains.

The Bearpaw Formation equivalent unit overlies the Belly River Group abruptly but conformably. The Bearpaw Formation consists of dark grey clay, claystone, shale, silt and siltstone, with minor brownish grey sand and sandstone. It contains numerous concretionary beds and thin beds of bentonite (Allan and Sanderson, 1945; Caldwell et al., 1978). The argillaceous units (open-sea conditions) and the arenaceous units (regression conditions) form a series of coarsening-upward sequences resulting from the marine transgressions and regressions. Up to 11 third-order T-R sequences have been delineated within the Bearpaw Formation (Catuneanu et al., 1997). The thicknesses of the Bearpaw tongues decrease northward and westward. Typical Bearpaw marine shale is not present in the foothills. The thickness of the Bearpaw equivalent unit is about 55–125 m (Figure 68).

The continental deposits of the lower and middle Horseshoe Canyon Formation are interfingered with Bearpaw marine tongues. The Horseshoe Canyon consists of deltaic and fluvial deposits of interbedded and interlensed fresh- and brackish-water sandstone, siltstone and shale, with seams of coal and bentonite and minor concretions and thin nodular beds of ironstone (Jerzykiewicz, 1997). The Drumheller marine tongue occurred in the upper Horseshoe Canyon. Rahmani (1981) interpreted the depositional environment for the transitional zone between the Bearpaw and Horseshoe Canyon formations to be a tidally dominated delta. In the study area, the unit from the Bearpaw Marker 2 to the Battle base is about 270–745 m in thickness (Figure 69). The thickening to the southwest is mostly gradual, but abrupt in the Foothills.

The Horseshoe Canyon beds are bounded by the overlying Battle, Scollard and Paskapoo formations. In the Foothills area, it becomes difficult to separate the Horseshoe Canyon beds from overlying and underlying nonmarine strata.

In the Red Deer River–Oldman River area of Alberta, the Whitemud Formation consists of white-weathering, light grey argillaceous sand with crossbedding, interbedded with white- to cream-weathering, silty and sandy clay (Broughton, 1981). In the Drumheller region, the lower contact of the Whitemud with the underlying Horseshoe Canyon Formation is conformable and gradational. In the study area, the base of the Whitemud is not picked. The Whitemud is overlain abruptly, but presumably conformably, by the Battle Formation. The Battle Formation is composed of dark, bentonitic, silty shale with porous popcorn-like weathered crust (Russell, 1970). In the study area, the Battle Formation is very thin, about 5–15 m (Figure 70).

The contact between the Scollard Formation and the underlying Battle Formation is abrupt and disconformable. The Scollard Formation consists mainly of interbedded argillaceous sandstone, siltstone, mudstone and shale. The Scollard Formation was divided into lower and the upper members. The upper part of the unit contains thick coal seams associated with carbonaceous to coaly shale and laterally persistent bentonite beds (Holter et al., 1975; Russell and Singh, 1978; Lerbekmo et al., 1979; Jerzykiewicz, 1997). In the study area, the Scollard Formation ranges from 50–270 m in thickness (Figure 71). The thickness of the formation increases gradually to the southwest, and significantly on the southwest side of the Elkton-Shunda zero edge. The Scollard Formation is truncated by the massive sandstone of the Paskapoo Formation.

The Cretaceous-Tertiary boundary was suggested at the base of the Ardley coal seam no. 14 by Russell and Singh (1978), and at the top of the Nevis coal seam (no. 13) by Lerbekmo et al. (1979).

### 6.3.5 Paskapoo Formation

Allan and Sanderson (1945) stated, "The name 'Paskapoo' is the Indian word for Blindman. The formation was so named by J.B. Tyrrell because the strata in this series are well exposed along the Blindman River which enters the Red Deer river about six miles north of the town of Red Deer. The Paskapoo Formation consists chiefly of soft, grey, clayey sandstone, soft shale and clay slightly indurated." Jerzykiewicz (1997) described the Paskapoo Formation as an assemblage of interbedded mudstone, siltstone and sandstone, with minor limestone, coal, pebble conglomerate and bentonite. The sandstone beds are thick, abrupt based, massive to crossbedded, and medium to coarse grained. Farther up in the sequence, the sandstone beds are finer and thinner, and well indurated to unconsolidated, with soft mudstone and siltstone becoming more abundant. The thickness of the formation increases westward, perhaps up to 600 m or much greater in certain areas. The upper surface of the Paskapoo is usually the present erosional surface; the formation is overlain abruptly and disconformably in a few localities by later Tertiary gravel and Quaternary drift sediments.

# 7 Gas Production and Suggestion for CBM Exploration

## 7.1 Oil and Gas Fields and Gas Production

Thirty-three oil and gas fields have been found in the study area (Figure 72). Strikingly, boundaries of the oil and gas fields show some correlations to the basement lineaments and the zero edges of the Mississippian and Jurassic formations. For instance,

- the Sylvan Lake Lineament runs largely along the borders of the Medicine River, Sylvan Lake, Lacombe, Willesden Green and Garrington fields;
- the Elkton-Shunda zero edge goes essentially along the borders of the Willesden Green, Medicine River, Gilby, Wilson Creek, Gosling, Buck Lake and Penhold fields; and
- the Medicine River and Gilby fields are located where the extensional zone along the Rimbey Arc intersects Mississippian and Jurassic zero edges.

Figure 73 shows the distribution of gas production from all producing formations in the study area. The blue dots are wells from which the monthly gas production (all years) is below 1 million $m^3$. The green dots are wells from which the monthly gas production is 1–500 million $m^3$. The pink dots are wells from

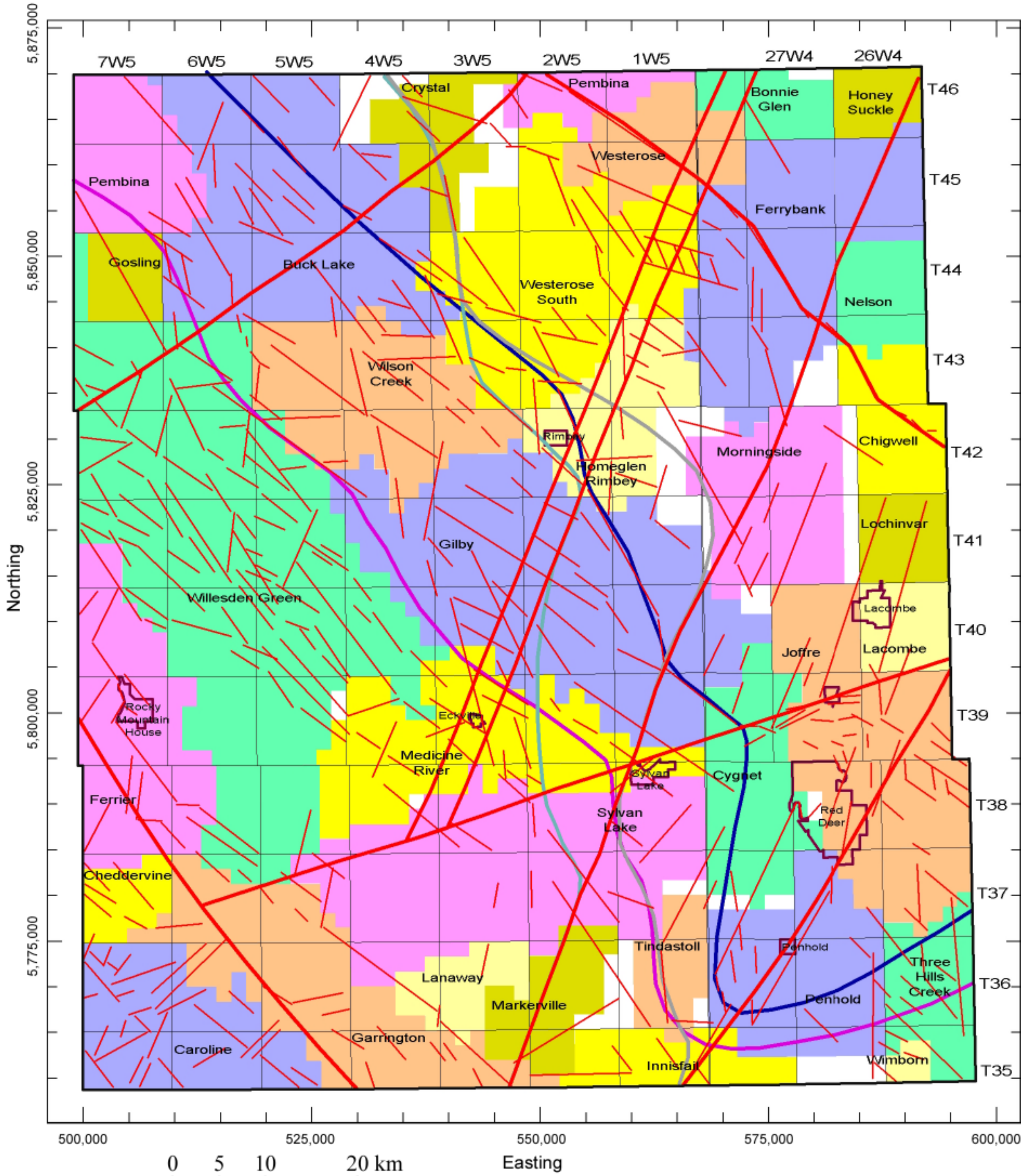


**Figure 72. Distribution of oil and gas fields in the Medicine River area.**

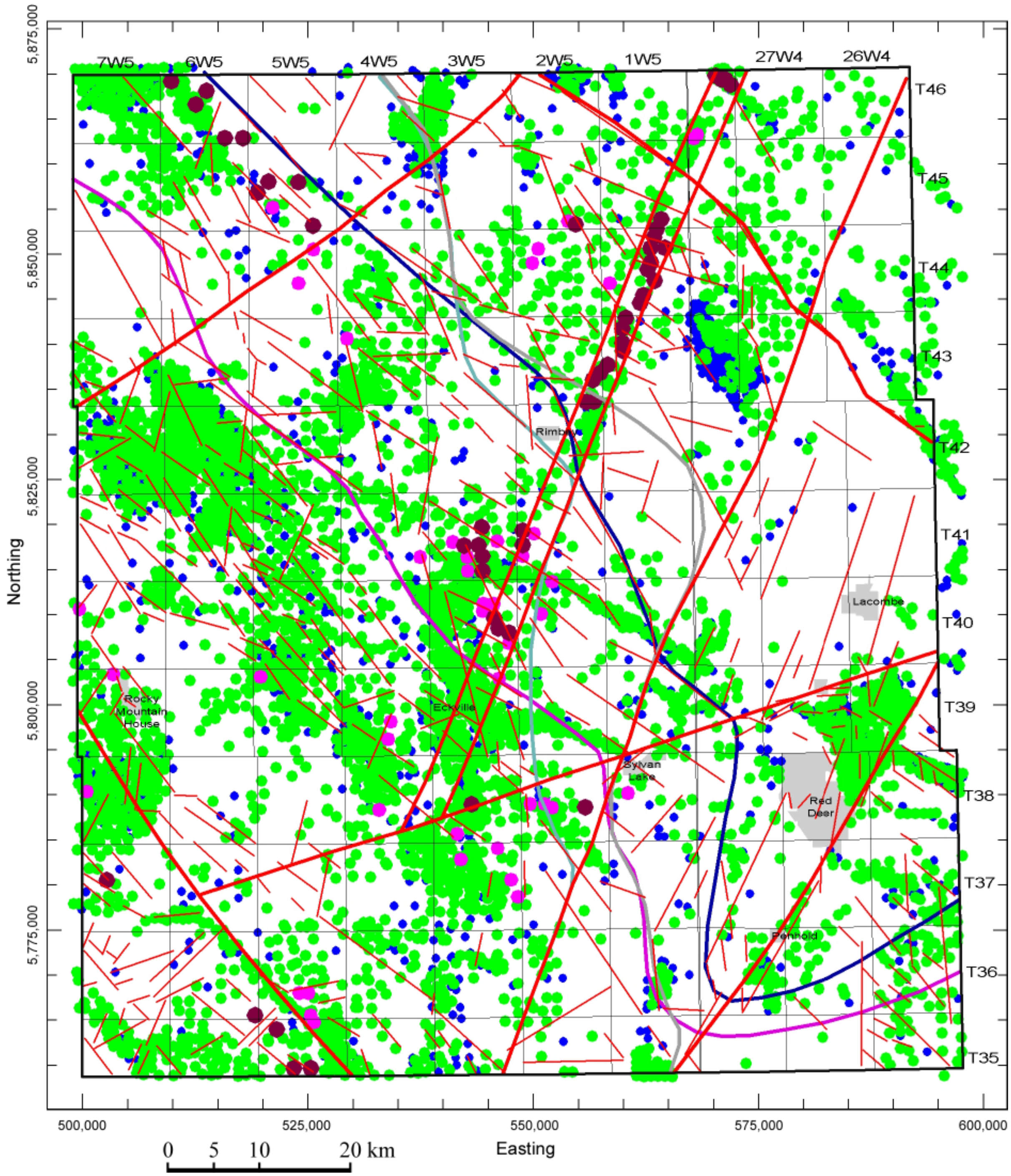


Figure 73. Distribution of gas production from all formations.

which the monthly gas production is 500 million to 1 billion m$^3$. The purple dots are wells from which the monthly gas production is above 1 billion m$^3$. Note that green dots overlie blue, pink dots overlie green and purple dots overlie pink.

The distribution of gas production shows a good correlation to the basement discontinuities. The wells that have a monthly gas production of more than 500 million m$^3$ are distributed

1) along the Rimbey Arc,

2) around the intersection of the Rimbey-Lacombe Boundary and the Sylvan Lake Lineament,

3) along the east edge of the Rocky Mountain Foothills, and

4) along the Pekisko zero edge in the Buck Lake Block.

The gas production data summarized in Table 3 indicate that the maximum monthly gas production per well generally decreases upward from the Devonian through the Mississippian to the Lower Cretaceous. In the Upper Cretaceous, the Cardium Formation is the most important producer and the Belly River Group is the second most important producer.

**Table 3. Monthly gas production (all years) in the Medicine River area.**

| System/Formation (Including Equivalents) | Maximum Monthly Gas Production/Well (million m$^3$) | Wells Producing ≥ 1 billion m$^3$ | Wells Producing < 1 billion but ≥ 500 million m$^3$ | Wells Producing < 500 but ≥ 1 million m$^3$ | Wells Producing < 1 million m$^3$ |
|---|---|---|---|---|---|
| Paskapoo | 3.3778 | | | 2 | |
| Horseshoe Canyon | 16.6880 | | | 9 | 9 |
| Belly River | 239.2531 | | | 400 | 326 |
| Lea Park | 61.4321 | | | 8 | 3 |
| Wapiabi Equivalent | 95.5824 | | | 17 | 5 |
| Cardium | 836.5127 | | 2 | 1037 | 289 |
| Second White Specks Equivalent | 115.4883 | | | 47 | 36 |
| Fish Scales | 1.7017 | | | 2 | |
| Viking | 382.5296 | | | 936 | 357 |
| Upper Mannville | 1622.7749 | 3 | 8 | 692 | 127 |
| Lower Mannville | 2310.9255 | 7 | 13 | 998 | 233 |
| Jurassic | 2532.1248 | 3 | 11 | 436 | 108 |
| Mississippian | 2532.1248 | 15 | 21 | 479 | 169 |
| Devonian | 8928.8712 | 28 | 2 | 325 | 46 |

The total monthly gas production of 1024 billion m$^3$ was obtained from 7209 wells (Table 4). The percentage of gas production attributed to each group/formation, and the percentage of producing wells possessed by each, are:

- 40% gas from Devonian wells (6% of the total)
- 18% gas from Mississippian wells (9% of the total)
- 12% gas from Lower Mannville wells (17% of the total)
- 10% gas from Cardium wells (18% of the total)

- 9% gas from Upper Mannville wells (12% of the total)
- 4% gas from Viking wells (18% of the total)
- 4% gas from Jurassic wells (8% of the total)
- 3% gas from Belly River wells (10% of the total)

**Table 4. Producing wells and total monthly gas production in the Medicine River area.**

| System/Formation (Including Equivalents) | Total Producing Wells | | Total Monthly Gas Production | |
|---|---|---|---|---|
| | Number | % | Million $m^3$ | % |
| Paskapoo | 2 | 0.03 | 259.7331 | 0.03 |
| Horseshoe Canyon | 18 | 0.25 | 2 217.0423 | 0.22 |
| Belly River | 726 | 10.07 | 31 825.2285 | 3.11 |
| Lea Park | 11 | 0.15 | 168.7240 | 0.02 |
| Wapiabi Equivalent | 22 | 0.31 | 344.0610 | 0.03 |
| Cardium | 1 328 | 18.42 | 103 463.1743 | 10.10 |
| Second White Specks Equivalent | 83 | 1.15 | 1 742.6756 | 0.17 |
| Fish Scales | 2 | 0.03 | 3.0411 | 0.00 |
| Viking | 1 293 | 17.94 | 43 078.9847 | 4.21 |
| Upper Mannville | 830 | 11.51 | 94 076.1936 | 9.18 |
| Lower Mannville | 1 251 | 17.35 | 121 782.9957 | 11.89 |
| Jurassic | 558 | 7.74 | 40 367.1894 | 3.94 |
| Mississippian | 684 | 9.49 | 179 370.2409 | 17.51 |
| Devonian | 401 | 5.56 | 405 641.3055 | 39.60 |
| Total | 7 209 | 100.00 | 1 024 340.5897 | 100.00 |

## 7.2 Distribution of Gas Pools

Huge volumes of natural gas have been produced from Mississippian, Jurassic and Cretaceous reservoirs in the Medicine River area, particularly where the extensional zone along the Rimbey Arc intersects Mississippian and Jurassic zero edges. Unconformably overlying on the Jurassic and Mississippian formations, the Lower Mannville Group has a widespread gas production between the deep faults in addition to in the central productive zone. Upper Mannville gas pools appear to be controlled by the northeast-trending, nearshore sandbodies, which were controlled by basin development. Gas production from the Viking Formation appears to be confined by the linear sandbodies, which were controlled by shoreline migrations that were, in turn, controlled by subsidence of the basin floor. Cardium gas production is largely confined to the places where thick Cardium sandstone is present, whose distribution appears to be influenced by structural trends, assumed to be fault related. Gas production in the Belly River Group may have been controlled by both structures and distribution of fluvial sandbodies. In addition to structural and stratigraphic trends, the edges of some reservoirs are associated with rivers or watersheds.

### 7.2.1 Devonian

Gas pools in the Devonian are primarily distributed 1) along the Rimbey Arc, 2) close to the east edge of the Rocky Mountain Foothills, 3) at the corner confined by the Sylvan Lake and Penhold lineaments, and 4) at the southwest end of the Penhold Lineament (Figure 74). Some producing wells are scattered throughout the southern Rimbey Block and the Penhold Block. Enormous gas production along the Rimbey Arc is from the Rimbey-Homeglen reef belt.

Seismic lines 4, 5 and 6 of the Central Alberta Transects (CAT of the LITHOPROBE Alberta Basement Transects) traverse the northeastern part of the study area, where a seismic anomaly in the Paleozoic was observed and interpreted as a composite occurrence from intra-Stephen sandstone and Cathedral carbonate, and from westward termination of upper Deadwood reflection (Dietrich, 1999). Line 5 intersects the Rimbey Arc, along which Upper Devonian reefs are developed. Velocity pull-up was observed below the reefs (Dietrich, 1999; Edwards and Brown, 1999). The Rimbey Arc may have been reactivated by compression from the west, related to collisional events since Mesozoic time.

The cross-section in Figure 75 shows the correlation of Devonian strata and the log feature across the Rimbey Arc. A schematic diagram of the Rimbey Arc fault zone and the relationship between the fault zone and the Rimbey reef belt is proposed in Figure 76, which is based on the geophysical log and gas-production data of this study, the physical model by Withjack et al. (1990), and the models from seismic data by Hope et al. (1999) and Lemieux (1999). Movement along a brittle basement fault may result in a Y-shaped fault zone associated with an upward-widening deformation/fracture zone.

Some locations in the Medicine River area, such as the Rimbey Arc and the east edge of the Foothills, are prolific gas producers for many systems/formations.

### 7.2.2 Mississippian

Truncation of the Pekisko Formation along an unconformity edge prior to the Jurassic and several periods of incision from Early Jurassic to Early Cretaceous have formed an intricately sculptured subcrop belt; oil is trapped in discrete pools close to the unconformity edge (Hopkins, 1999).

The distribution of Mississippian gas production is shown in Figure 77. Gas pools are mainly concentrated 1) around the intersection of the Rimbey Arc and the Sylvan Lake Lineament, 2) along the south part of the Rimbey Arc, 3) along the Pekisko zero edge in the Buck Lake Block, and 4) around the southeast end of the east edge of the Foothills. Other producing wells seem to be related to the zero edges and local structures, which may have influenced the deposition or enhanced the diagnosis of carbonate reservoirs.

### 7.2.3 Jurassic

Jurassic sedimentary rocks form significant oil and gas reservoirs in the Medicine River area (Rall, 1980; Poulton et al., 1994; Hopkins et al., 1998). Figure 78 provides the distribution of the Jurassic pools in the study area. The gas production is mainly concentrated in the central part of the area, inside the Nordegg zero edge and around the Rimbey Arc, and around the intersection of the Rimbey Arc and the Sylvan Lake Lineament. Other scattered pools in the northwest may be related to local lithology and fracture development.

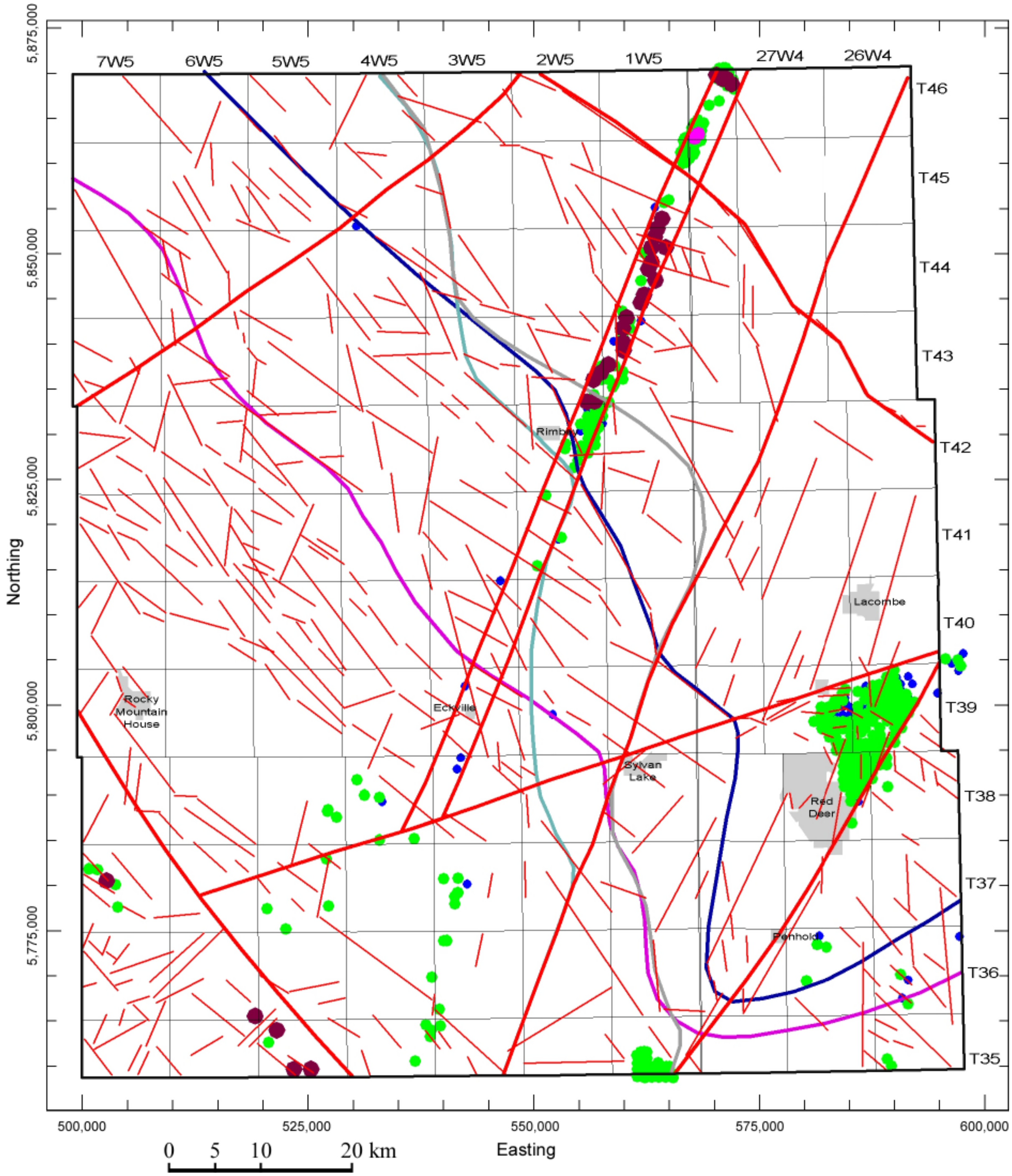


**Figure 74. Distribution of gas production from the Devonian System.**

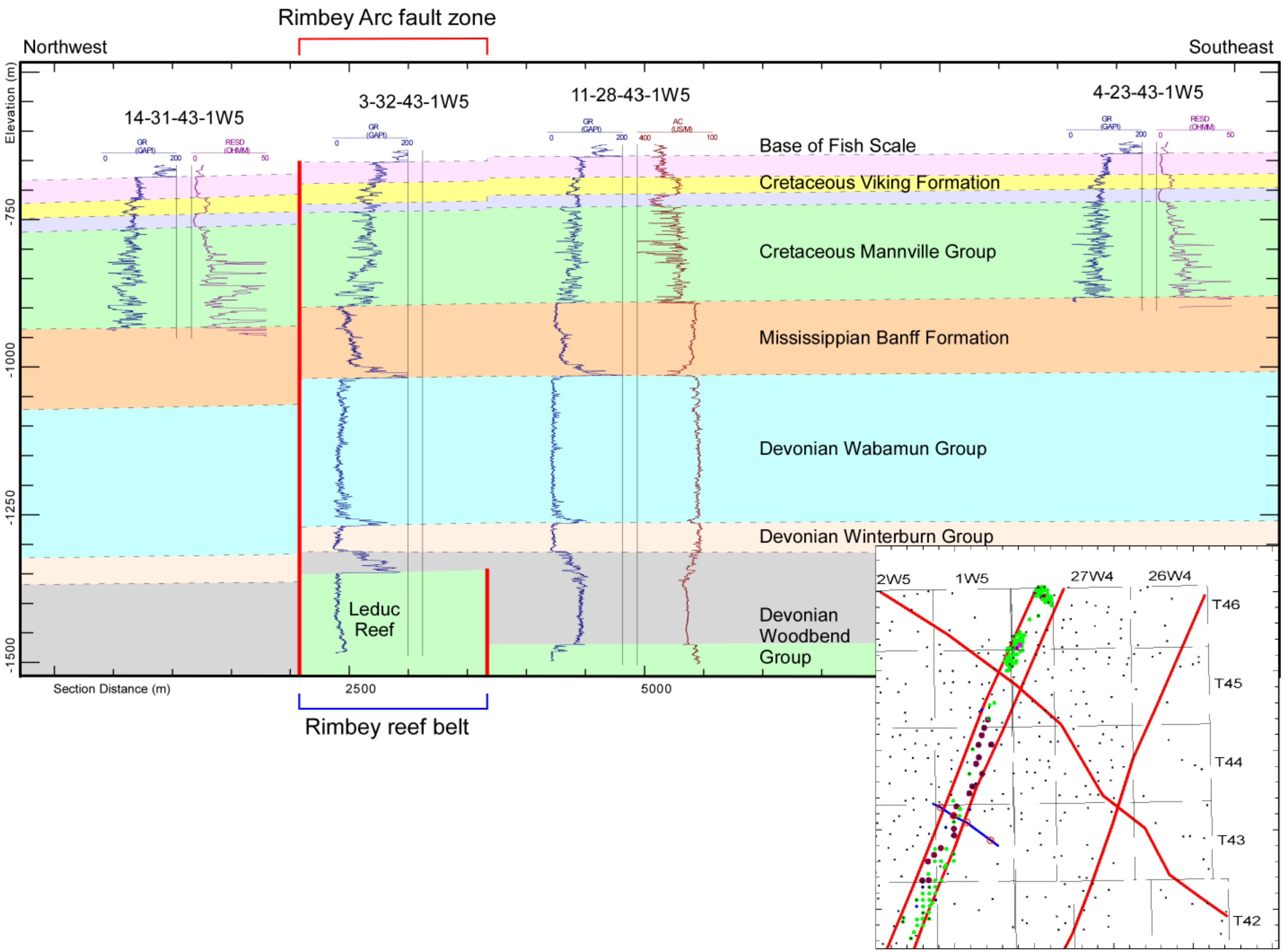


**Figure 75. Formational changes across the Rimbey Arc fault zone.**

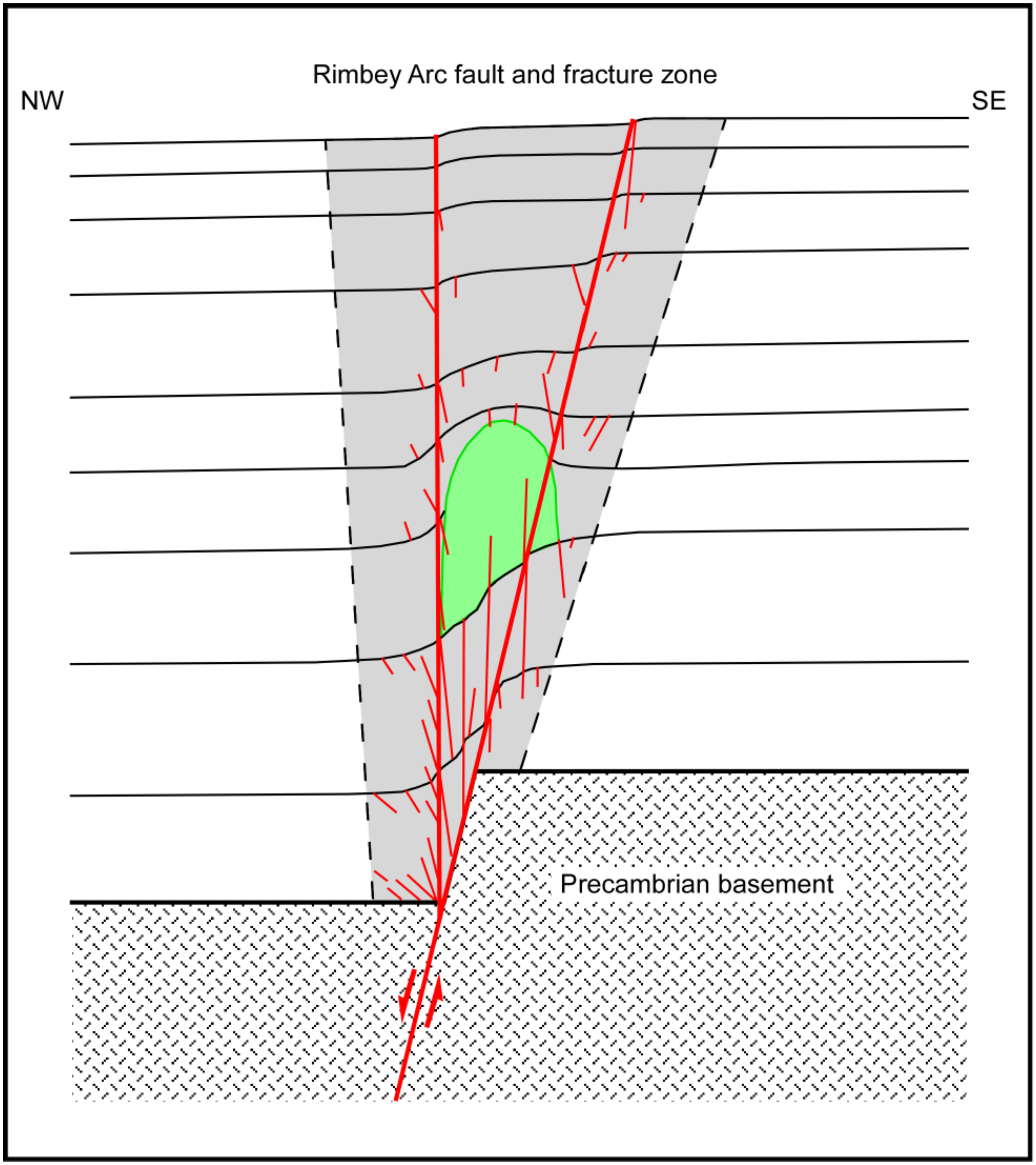


**Figure 76. Schematic diagram of the Rimbey Arc fault and fracture zone.**

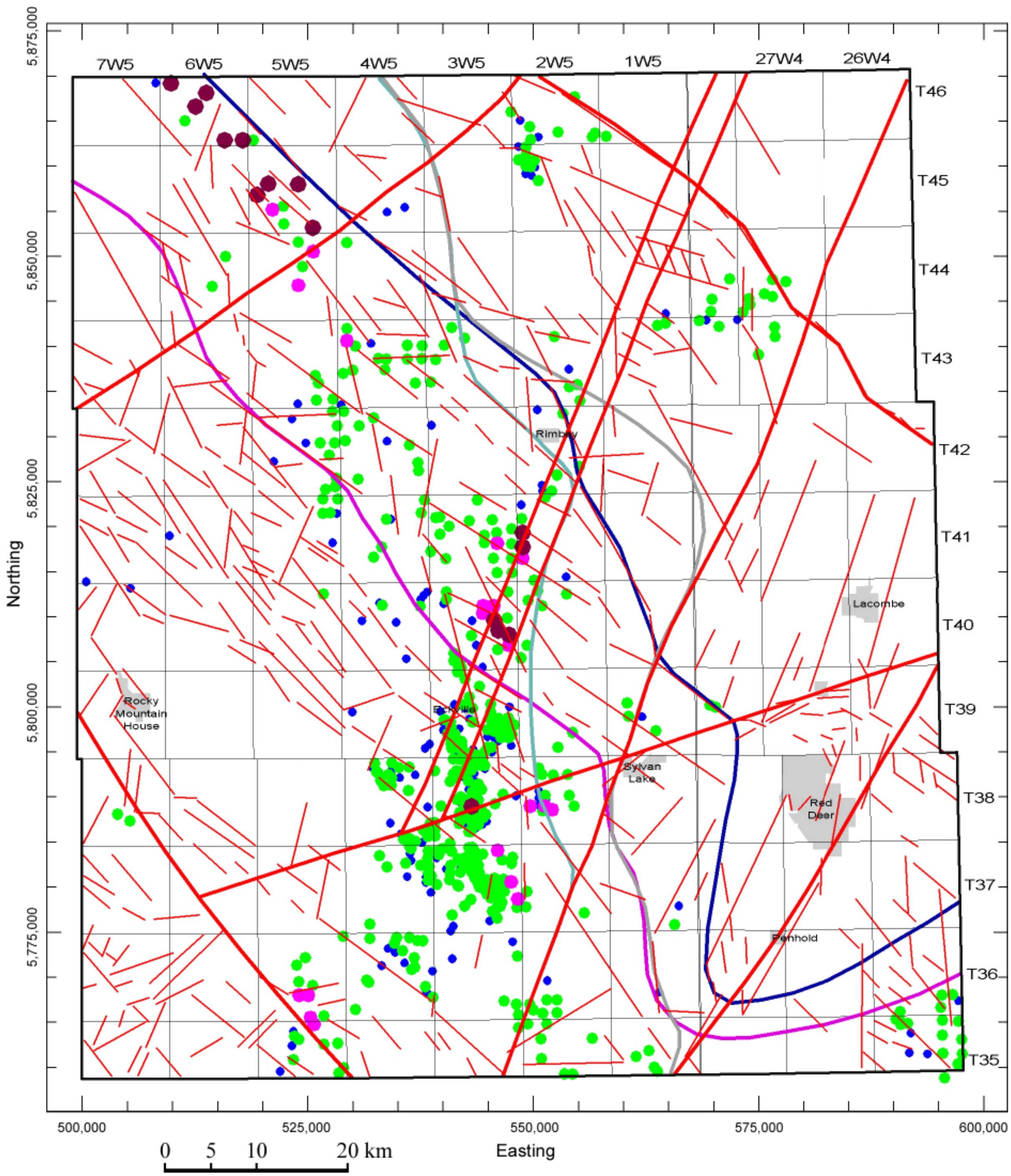


**Figure 77. Distribution of gas production from the Mississippian System.**

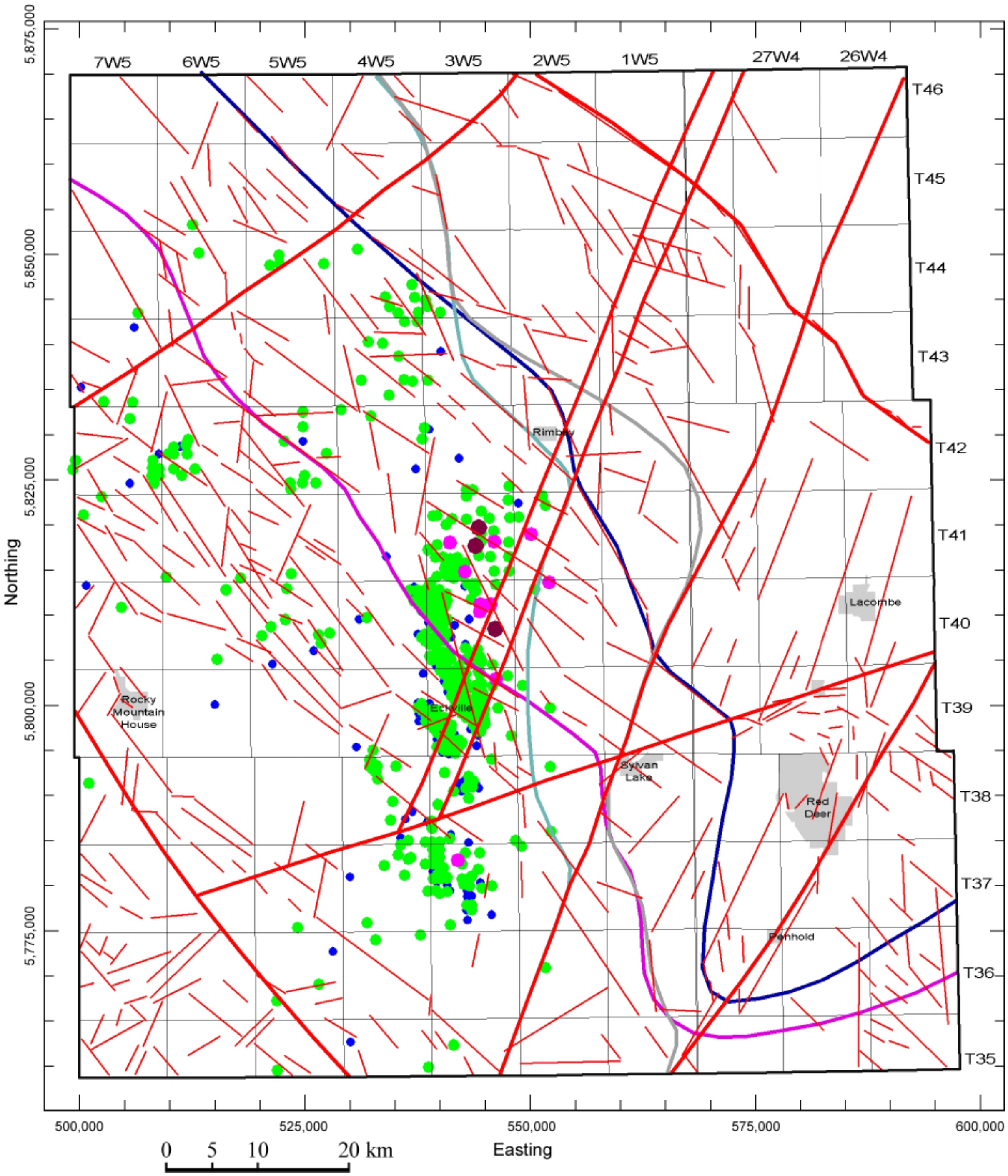


**Figure 78. Distribution of gas production from the Jurassic System.**

### 7.2.4 Lower Cretaceous

Gas production in the Lower Mannville Group (Figure 79) is concentrated 1) in the central productive zone where the Rimbey Arc meets the Nordegg zero edge, 2) around the intersection of the Rimbey Arc and the Sylvan Lake Lineament, and 3) around the southeast end of the east edge of the Foothills. Except within the Buck Lake Block, the Lower Mannville pools spread out widely between the basement lineaments. This may have been partially the result of topography on the sub-Cretaceous unconformity, which overlies the Mississippian and Jurassic formations. Hydrocarbons generated from the older systems may have migrated along the sub-Cretaceous unconformity and been trapped in the Lower Mannville reservoirs.

The Upper Mannville gas pools (Figure 80) are primarily developed 1) along the northeast-trending belt, 2) west of the town Eckville, 3) around the southeast end of the east edge of the Foothills, 4) around the junction of the Rimbey Arc and Sylvan Lake Lineament, and 5) northeast of the town Sylvan Lake. During Albian time, the deep basin was developed in the northwest. The gas production belt in the north is related to the northeast-trending, nearshore sandbodies that were controlled by basin development.

Gas production from the Viking Formation (Figure 81) is restricted to the linear sandbodies. During Viking deposition, the Caroline Arch (Figure 9) along the south border of the study area became a depocentre (Figure 53). The linear sandbodies are subparallel to the depocentre. Downing and Walker (1988) studied the long, narrow Viking sand bodies at the Joffre oilfield (Figure 72) and suggested that the linear nature of the field is due to its formation along the shoreface, and relative sea level fluctuations and consequent shifts in the position of the shoreface control the location of reservoir sand.

### 7.2.5 Upper Cretaceous

Gas pools are scattered throughout the Fish Scales Formation and the Second White Specks equivalent in the study area (Figure 82).

Gas production from the Cardium Formation is much concentrated in the west (Figure 83), where thick Cardium sandbodies are present, the distribution of which appears to be controlled by structural trends (Figure 60). In the southwest, gas production follows the east edge of the Foothills and a parallel lineament in the Foothills. In the west, gas is trapped in the sandbodies above the Elkton-Shunda zero edge. In the northwest (Buck Lake Block), gas is produced from the thick sandbodies between the Pekisko and Elkton-Shunda zero edges. Eyles and Walker (1988) studied the reservoir characteristics of the Willesden Green oilfield and concluded that the Cardium reservoirs are largely determined by the “geometry” and stacking of the sandstone sequences, and that the long, narrow “geometry” of the field is not controlled by the primary deposition of sand as an offshore bar, but by subsequent erosional dissection of a sheet-like stack of sandstone bodies.

A few gas pools occur in the Wapiabi equivalent and the Lea Park Formation (Figure 84). These wells are mostly located in the Foothills Block and north of the Rocky Mountain House area.

To date, the Belly River is the shallowest unit that produces significant amounts of gas (Figure 85). Gas produced from the Belly River Group is basically from the north and southeast of the study area. Belly River gas pools may have been controlled by the distribution of fluvial sandbodies and structures. Most of the locations of Belly River production are prolific for many other formations.

There are not many producing gas wells in the Horseshoe Canyon and Paskapoo formations (Figure 86). The producing wells are mainly distributed in the southern part of the Rimbey Block and the Buck Lake area.

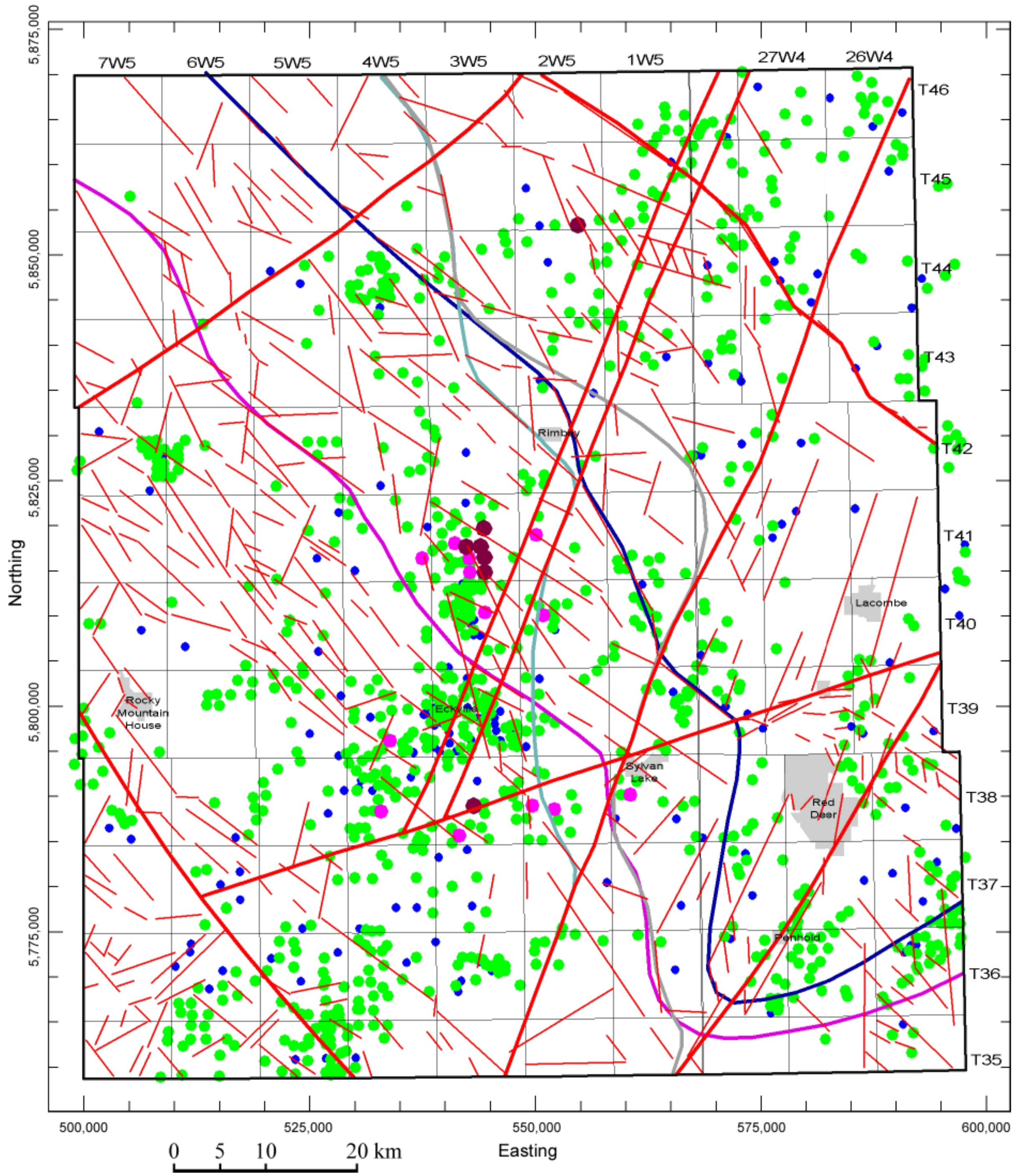


Figure 79. Distribution of gas production from the Lower Mannville Group.

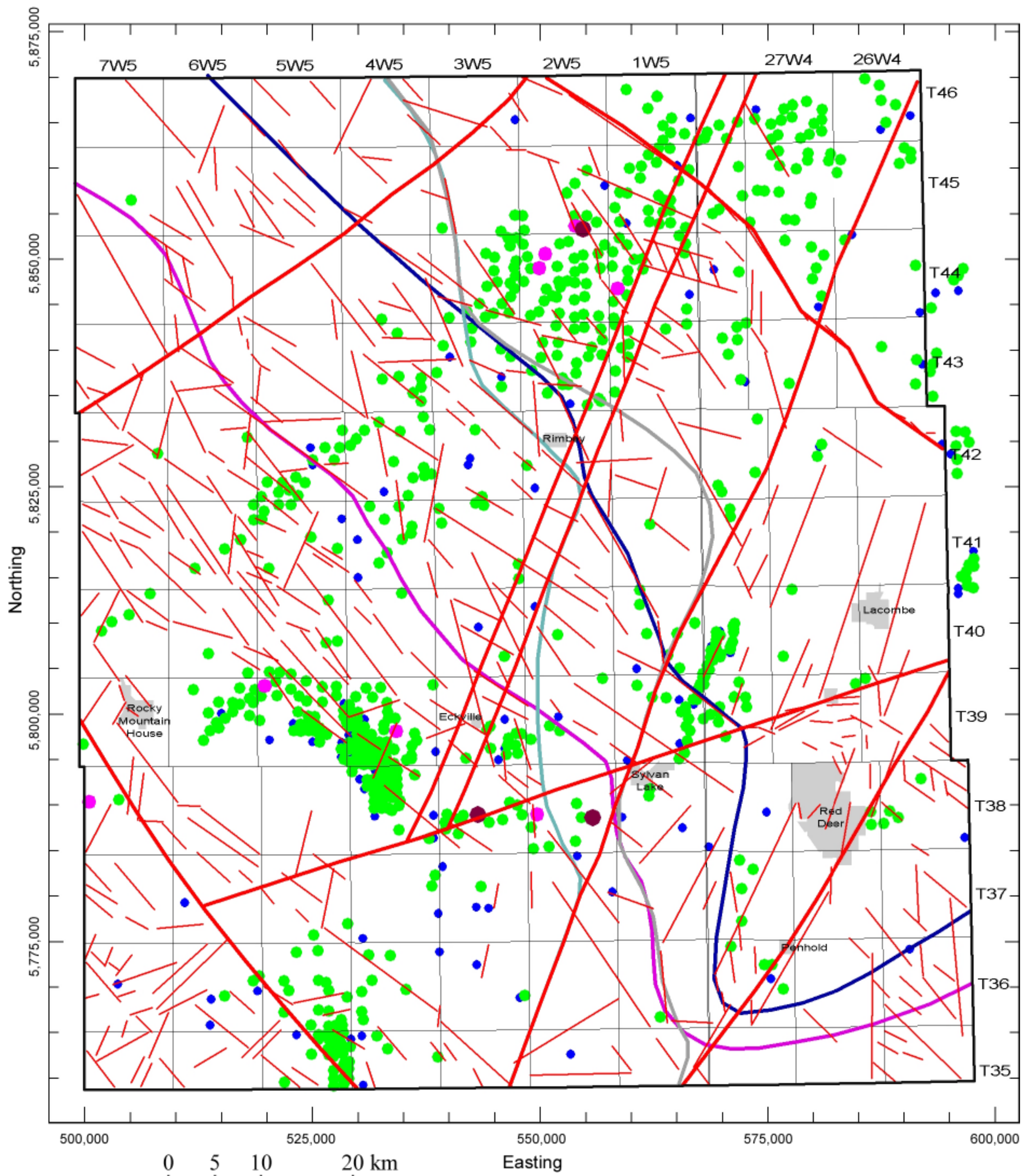


**Figure 80. Distribution of gas production from the Upper Mannville Group.**

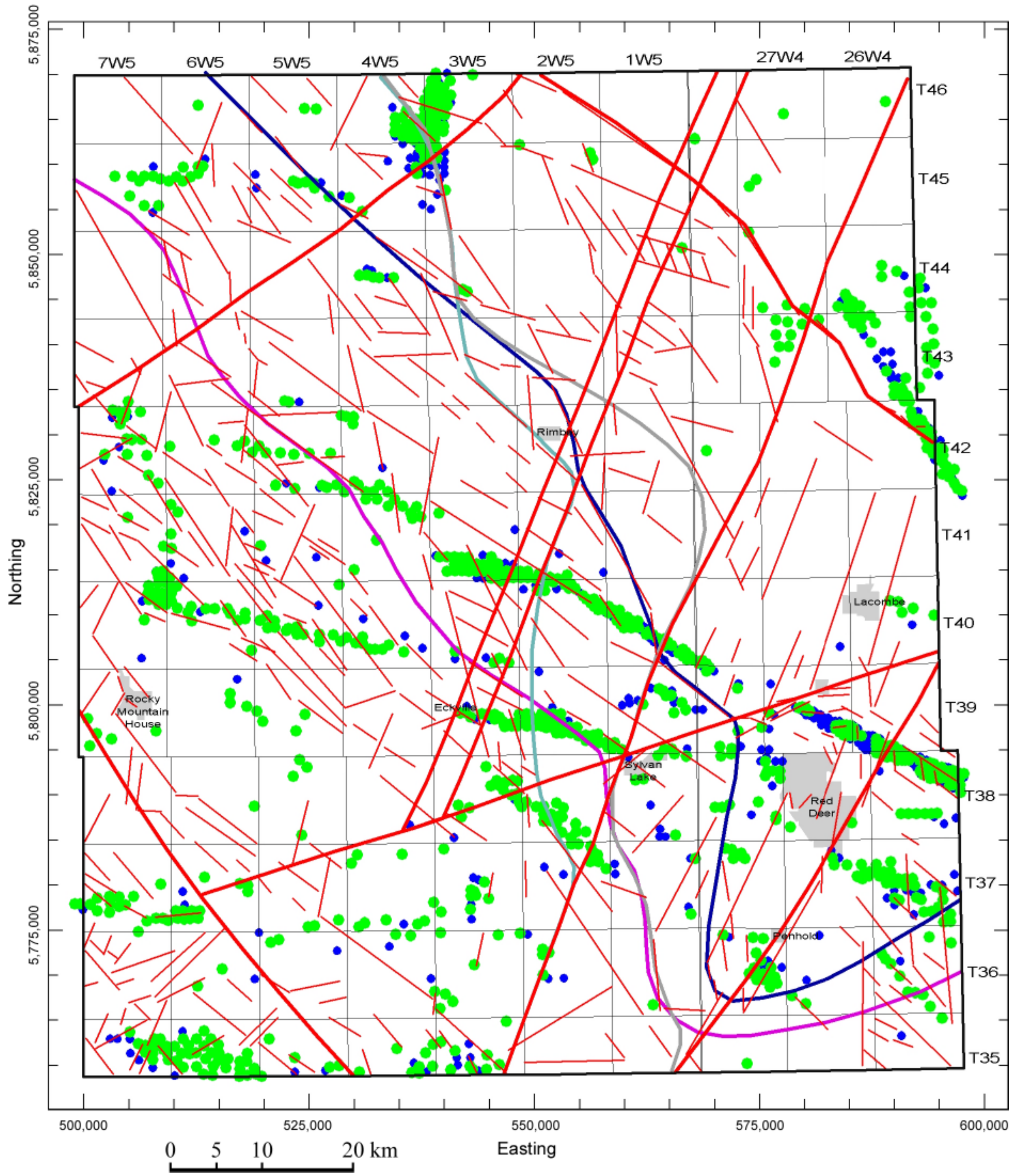


Figure 81. Distribution of gas production from the Viking Formation.

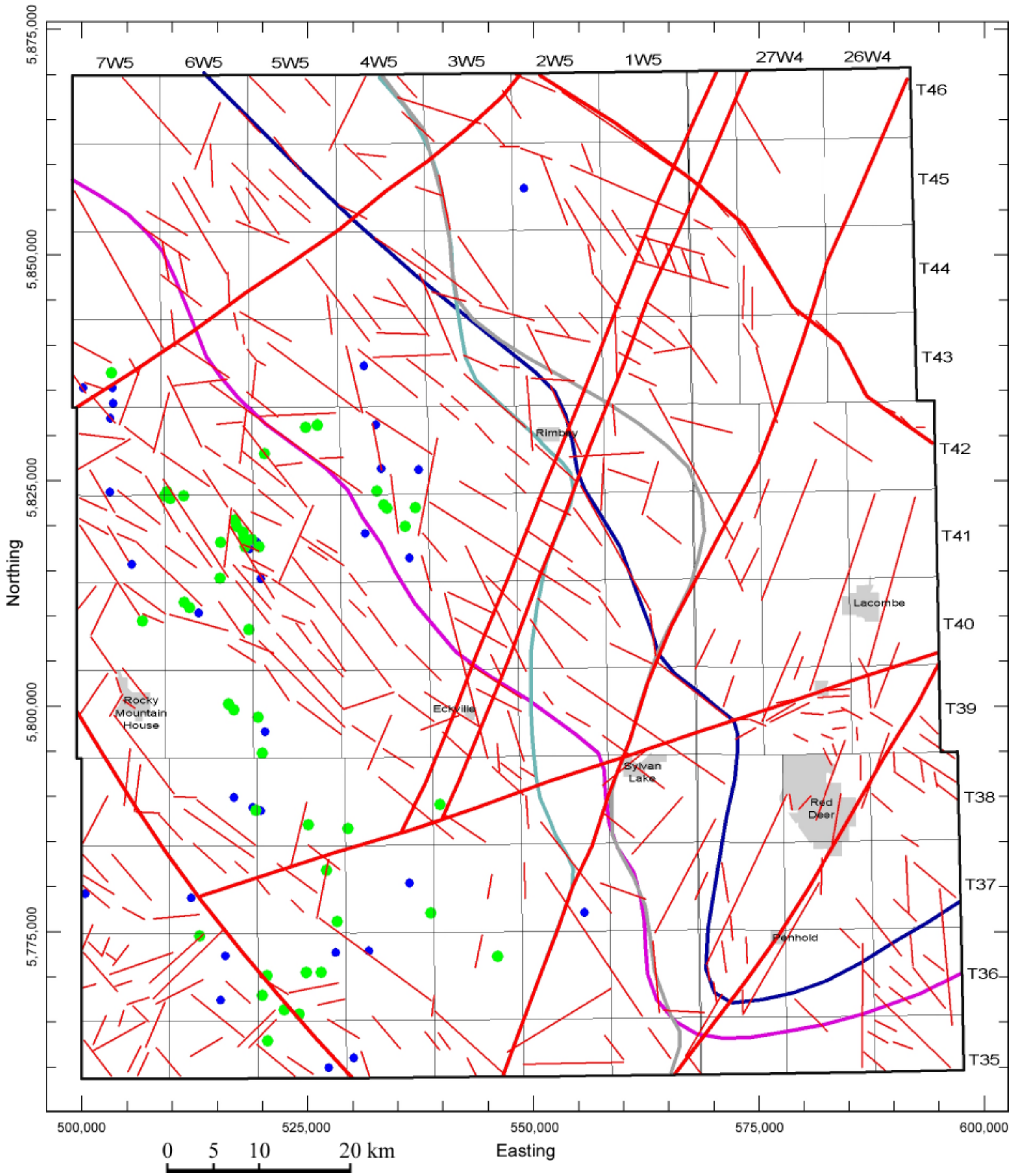


**Figure 82. Distribution of gas production from the Fish Scales Formation and Second White Specks equivalent.**

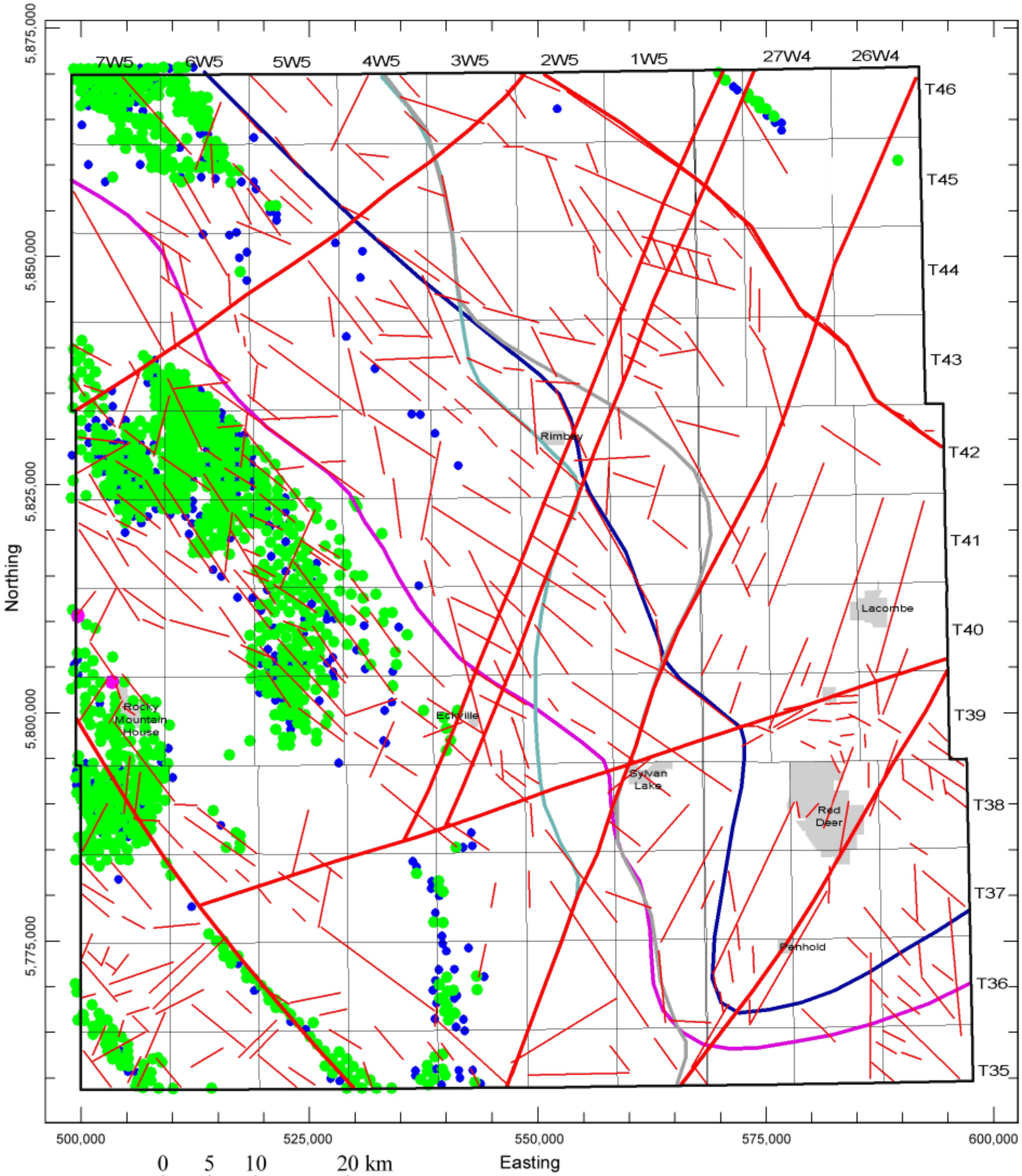


**Figure 83. Distribution of gas production from the Cardium Formation.**

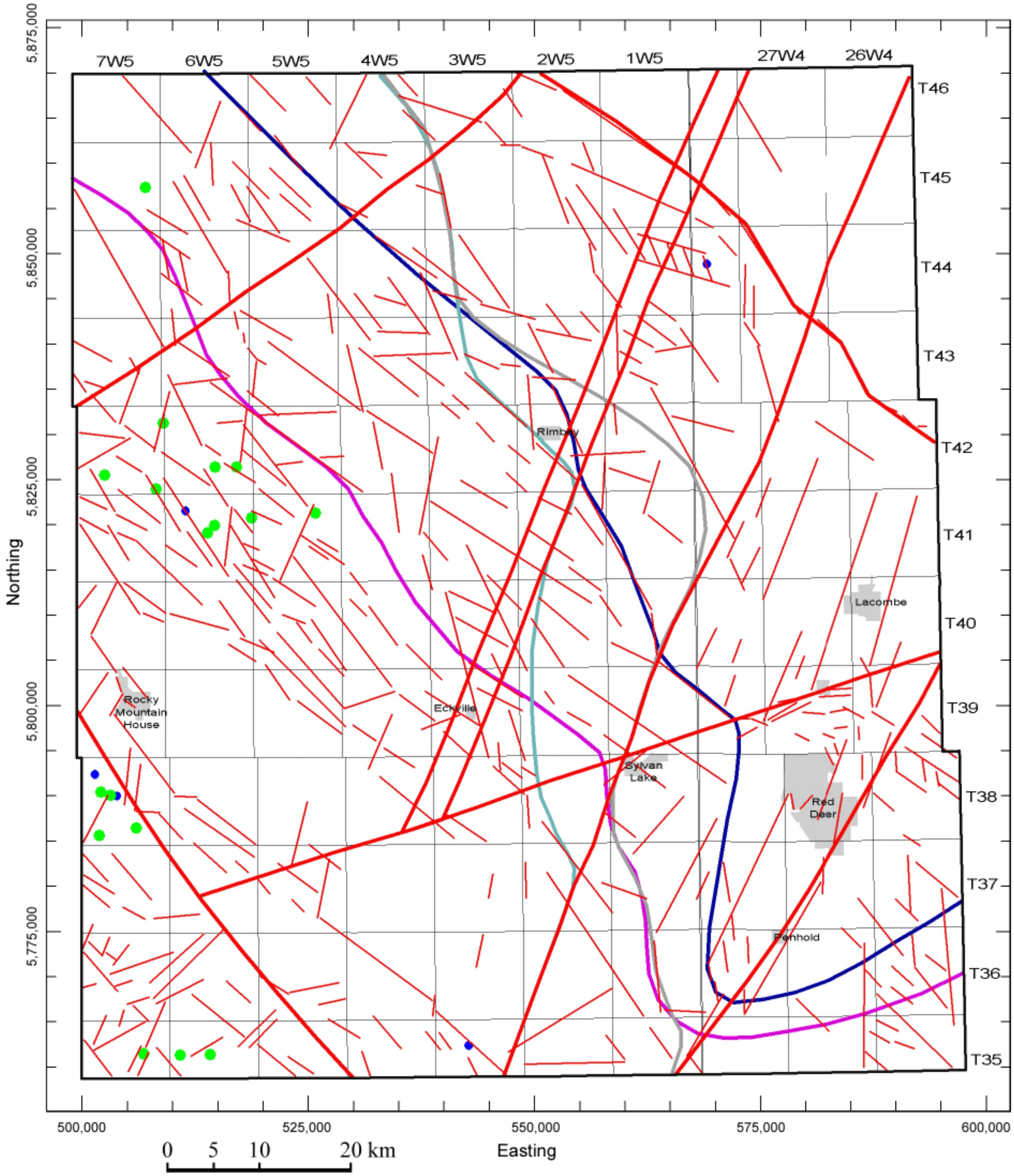


**Figure 84. Distribution of gas production from the Wapiabi equivalent and Lea Park Formation.**

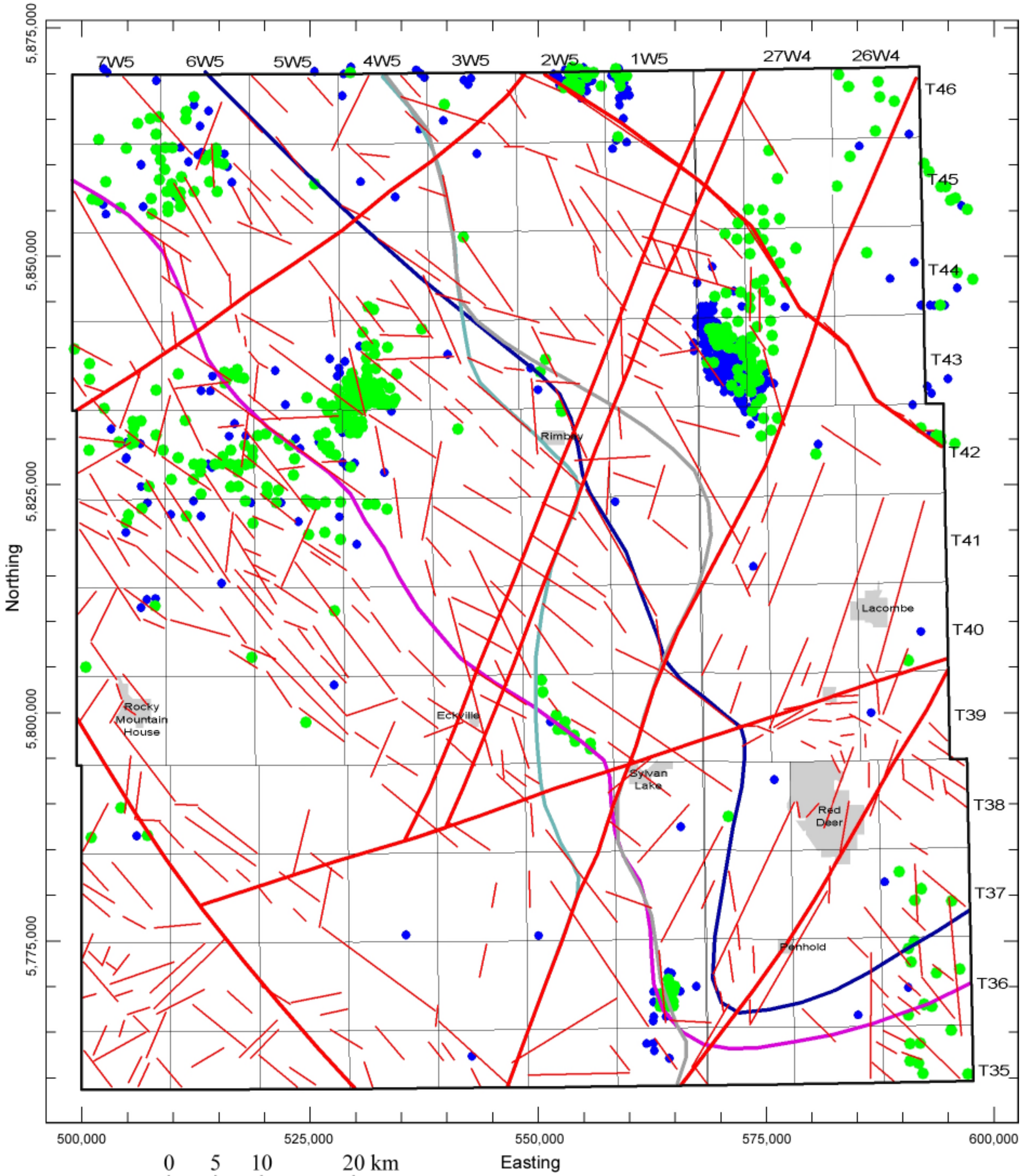


**Figure 85. Distribution of gas production from the Belly River Group.**

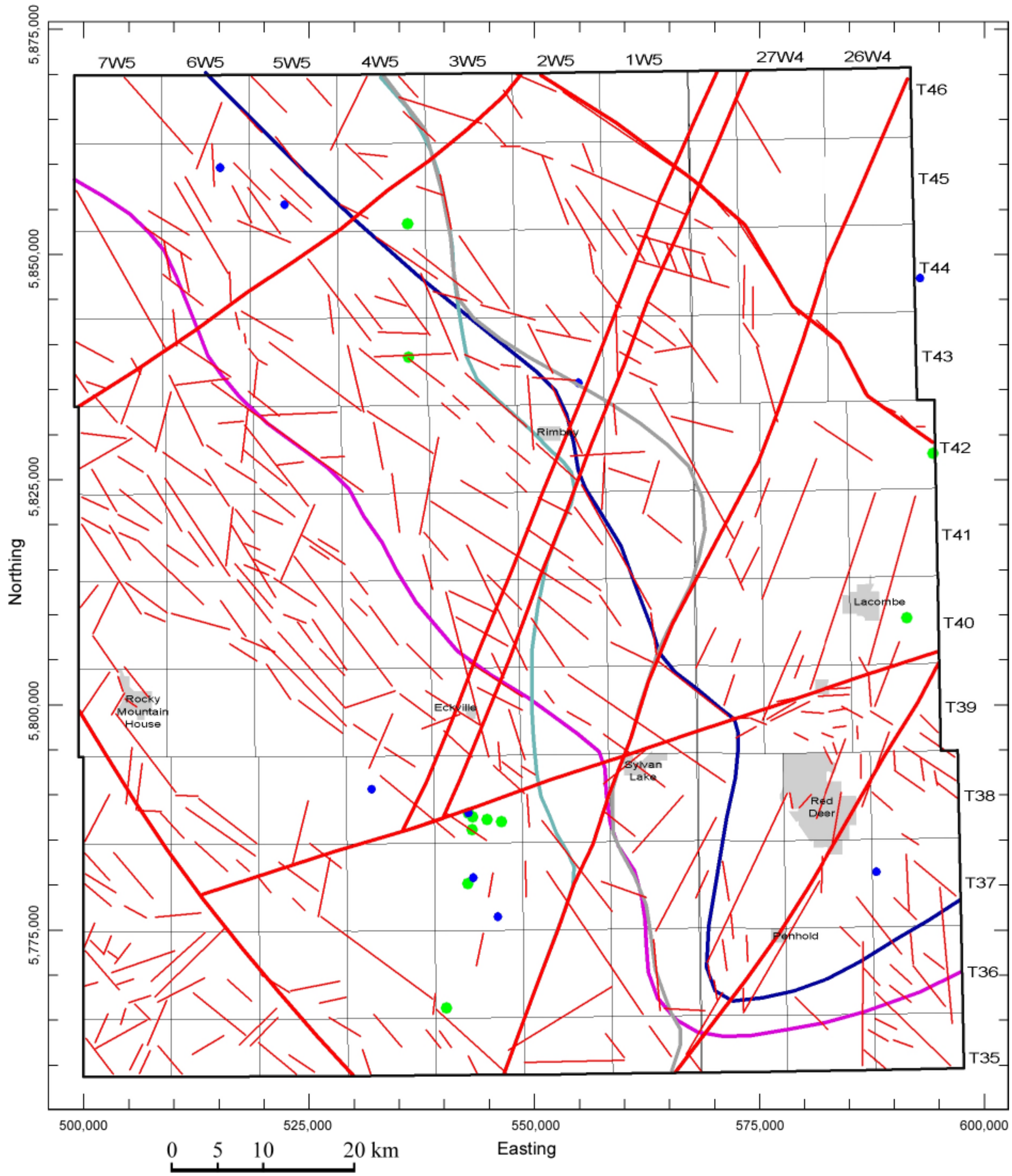


**Figure 86. Distribution of gas production from the Horseshoe Canyon and Paskapoo formations.**

## 7.3 Major Coal Zones and Suggestions for CBM Exploration

Except for the Lower Cretaceous Mannville Group, the uppermost Cretaceous–Lower Tertiary interval accommodates three coal-bearing strata: the Belly River, Horseshoe Canyon, and upper Scollard formations. Four coal zones (i.e., Drumheller, Carbon-Thompson, Ardley and Mannville) are relatively well developed in the study area. If productivity and prospectivity trends in these coal zones can be linked to deeper structural trends, operators might be able to use deep structural elements mappable by dense conventional drilling data to find new productive zones for unconventional gas resources.

### 7.3.1 Drumheller and Carbon-Thompson Coal Zones

The Horseshoe Canyon Formation contains three coal zones. They are, in ascending order, the Drumheller, Weaver-Daly and Carbon-Thompson. Very little Weaver-Daly coal is present in the study area. Amounts of CBM have been produced from the Horseshoe Canyon Formation in the area of the Drumheller coal fairway. The net thickness of the Drumheller coals is about 0–10 m, with the greatest thickness occurring along the east border of the area (Figure 87). The prospective areas for CBM exploration are suggested to be 1) the corner confined by the Sylvan Lake and the Penhold lineaments (Twp. 39, Rge. 26W4), and 2) the southeast corner of the Penhold Block (Twp. 35, Rge. 26W4). Other prospects include the intersection of the Rimbey Arc and the Sylvan Lake Lineament (Twp. 38, Rge. 3W5), and southwest of the Pekisko zero edge in the Buck Lake Block (Twp. 45, Rge. 5W5).

The net coal thickness of the Carbon-Thompson varies from 0–5 m (Figure 88). There are four potential areas for CBM exploration: 1) the northeast end of the Penhold Lineament (Twp. 39, Rge. 26W4), 2) Twp. 41, Rge. 5W5 (west of the Elkton-Shunda zero edge), 3) Twp. 42, Rge. 26W4 (south side of the Battle River Lineament), and 4) Twp. 36, Rge. 6–7W5 (west of the Foothills east edge).

### 7.3.2 Ardley Coal Zone

The Ardley coal zone is hosted by the upper Scollard Formation of the lowest Tertiary and is the most prominently developed coal unit in the south-central and west-central Alberta Plains. Richardson et al. (1988) evaluated the Ardley coal resources in the Alberta Plains. Langenberg et al. (2000) focused more on the Ardley coal resources in the Buck Lake area.

The Ardley coal zone is about 5–7 m thick in the subsurface south of Red Deer, Lacombe and west of Beaverhills Lake, and reaches a maximum thickness of 9–13 m in the Wabamun Lake area (Holter et al., 1975; Richardson et al., 1988). The unit consists of interbedded coal, carbonaceous shale and laterally persistent bentonite beds. The coal quality and thickness increase from the bottom to the top of Ardley coal zone (Langenberg et al., 2000).

The Ardley coal zone was deposited in an alluvial plain environment, and generally, the coal seams become thicker with increasing depth (Richardson et al., 1986). In the study area, the Ardley coal has a net thickness of about 2–15 m, with the thickest net coals (10–15 m) occurring in the Buck Lake Block (Figure 89). According to Langenberg et al. (2000), the Buck Lake Block, with the thickest net coal, has the potentially highest gas content. The Ardley coal belt trends northwest and tapers away to the southeast.

Based on the gas-production history in the Buck Lake Block, the area between the Elkton-Shunda and the Pekisko zero edges has the highest potential for gas production (Figure 89, Twp. 45, Rge. 5–7W5 and Twp. 46, Rge. 6–7W5). The area southwest of the Pekisko zero edge and northwest of the Rimbey Arc could be a second potential area of production (Twp. 42, Rge. 4W5). The area southwest of the

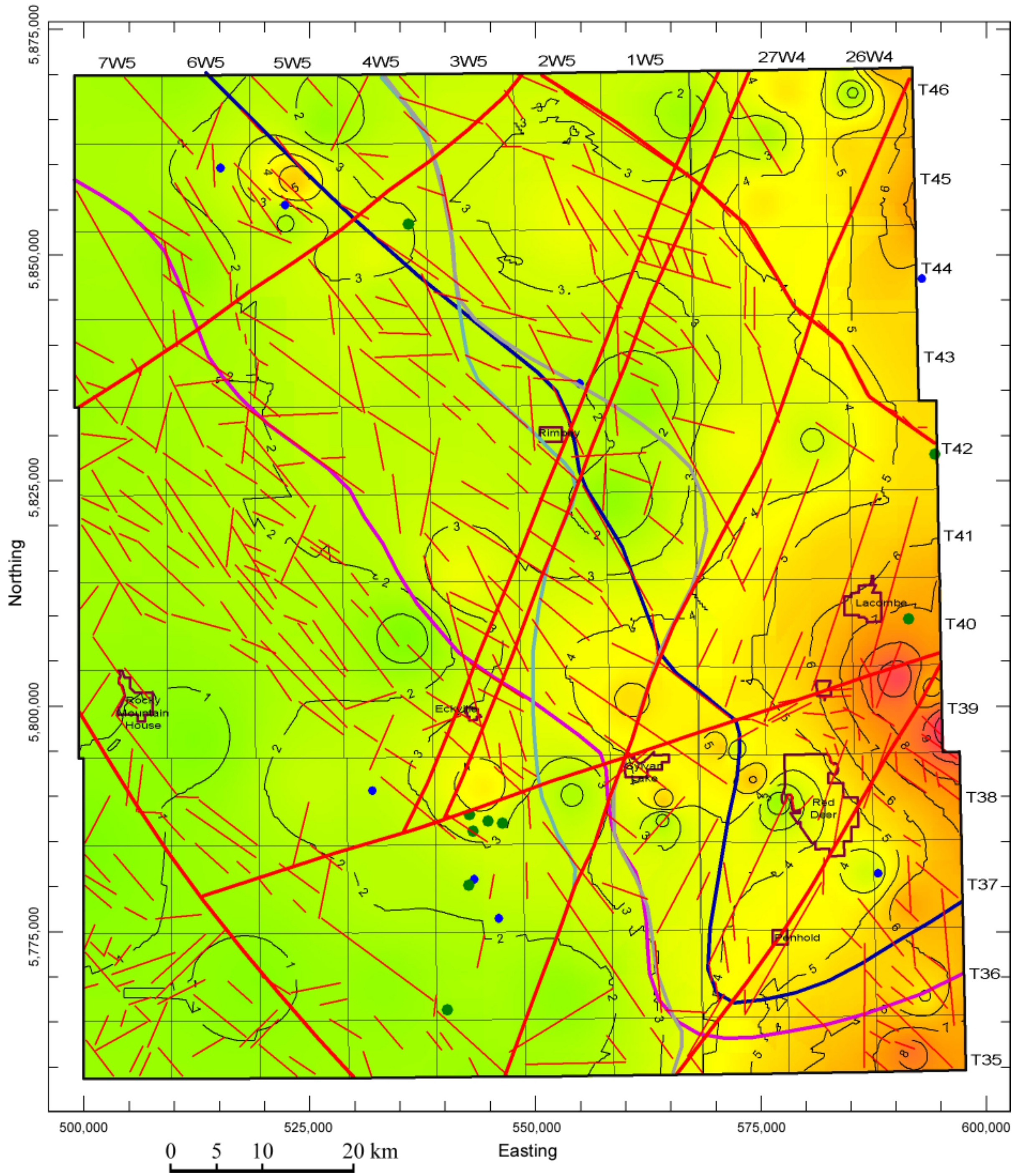


**Figure 87. Thickness of Drumheller net coal.**

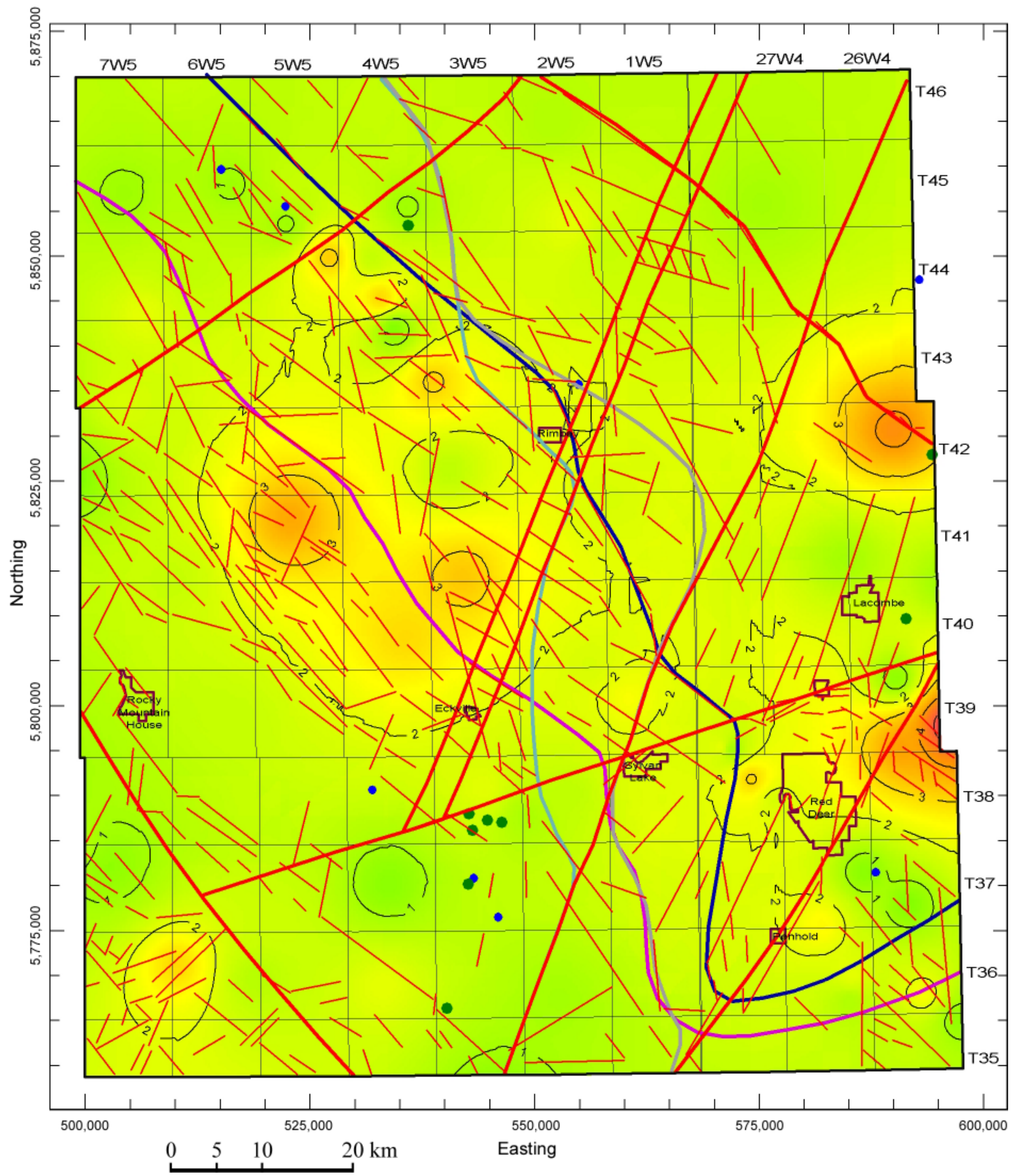


**Figure 88. Thickness of Carbon-Thompson net coal.**

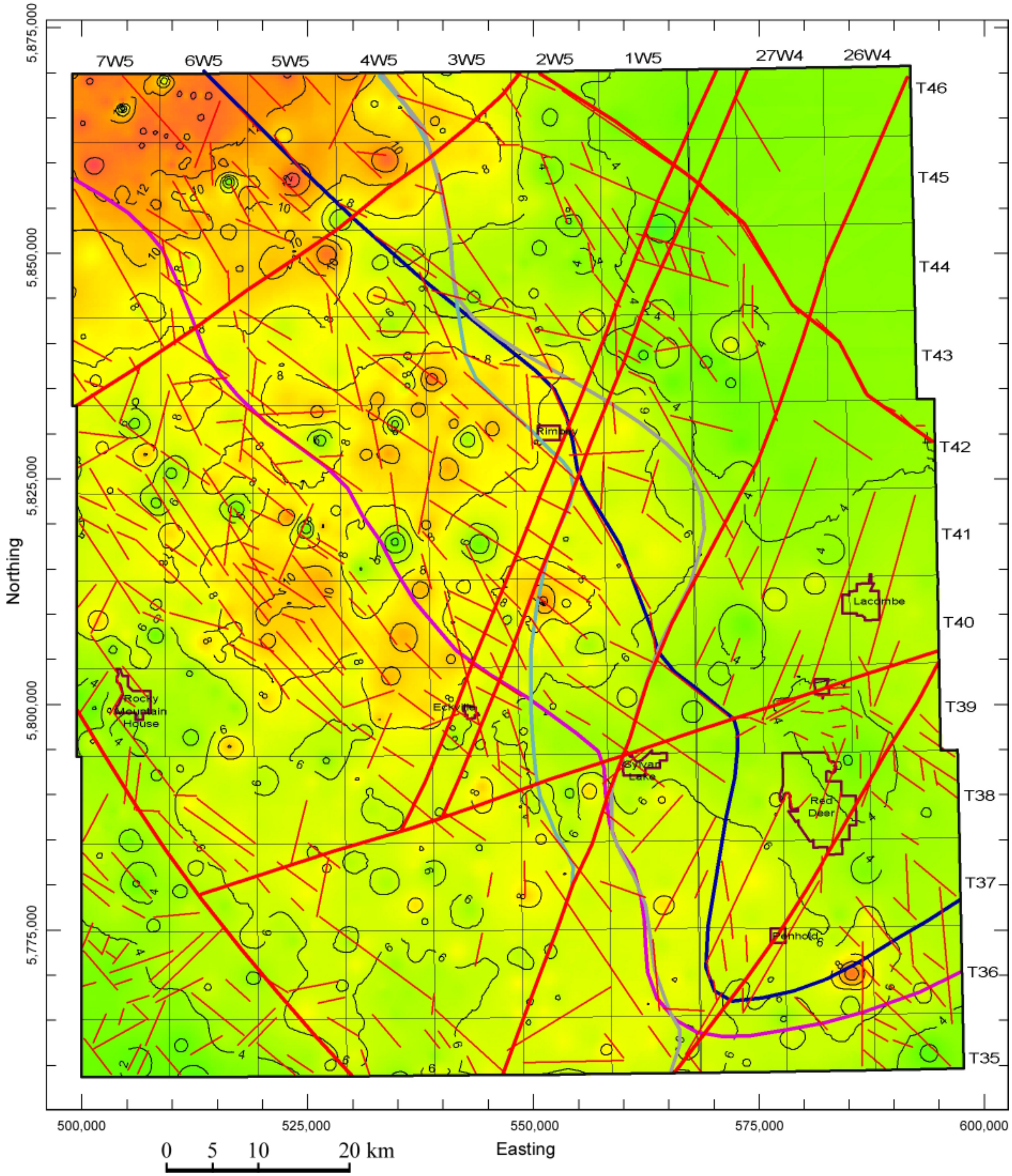


**Figure 89. Thickness of Ardley net coal.**

Elkton-Shunda zero edge and northwest of the Rimbey Arc could be a third potential area of production (northwest of Twp. 39, Rge. 3W5).

### 7.3.3 Medicine River and Glauconitic Coal Zones

The Mannville Group contains almost one-quarter of the total discovered gas resources of the Western Canada Sedimentary Basin, and an additional 957 billion $m^3$ gas-in-place exists within the Mannville Group (Warters et al., 1997). Total gas resource in the Upper Mannville was estimated to be more than 4,500 billion $m^3$ (more than 160 TCF; Langenberg et al., 1997). The Upper Mannville Group coals are thick and widespread, about 6–12 m thick in the Red Deer area (Langenberg et al., 1997). Identified coal seams in the Upper Mannville include the Medicine River and the Glauconitic coals (Figure 90; Strobl et al., 1993).

The advantage of exploring for gas in the Mannville is that the group contains multiple types of gas resources (conventional and unconventional), both sandstone and coal-bed reservoirs, and is below the thick Colorado shale (cap rock). The Mannville Group needs further testing to establish CBM production potential.

## 8 Summary and Future Work

The Red Deer–Buck Lake area of west-central Alberta has been a prolific producer of conventional oil and gas. In recent years, the focus of exploration has shifted from conventional oil and gas toward drilling for shallow unconventional gas, including coalbed methane (CBM).

Studies show that deep structures in this area vary greatly, act differently and have a profound impact on sedimentation. Gas production from the Devonian, Mississippian, Jurassic and Cretaceous has a certain relationship with these deep structures. The deep structures that influence the formation of coalbed hostrocks may control the distribution of unconventional gas to some degree.

Geophysical logs were intensively employed by this study. The picking protocol of the 41 correlation markers is provided, as are 12 600 new, internally consistent stratigraphic picks; 15 structural cross-sections (elevation as datum); and more than 80 structural and isopach contour maps. The stratigraphic correlation, database management and geological analysis were greatly assisted by advanced software.

The Medicine River area is floored by three northeast-trending Precambrian basement domains, known as the Thorsby, Rimbey and Lacombe domains. Five large blocks proposed by this study, the Buck Lake, Rimbey, Sylvan Lake, Penhold and Foothills, appear to have had slightly different motions during Phanerozoic time.

Previously defined Phanerozoic tectonic features include the Rimbey Arc, the Caroline Arch, the axis of the Alberta Syncline and the east front of the Rocky Mountain Foothills, all of which appear to have affected the sedimentary cover in certain ways at certain times.

This study modified or identified seven basement lineaments: Thorsby-Rimbey Boundary, Rimbey Arc, Rimbey-Lacombe Boundary, Sylvan Lake Lineament, Penhold Lineament, Battle River Lineament, and east edge of the Rocky Mountain Foothills. Differential subsidence across the basement lineaments was identified.

The characteristics of the strata from the Devonian Wabamun top to the Lower Tertiary are described in the report. The zero edges and subcrop areas of the Mississippian and Jurassic formations are defined.

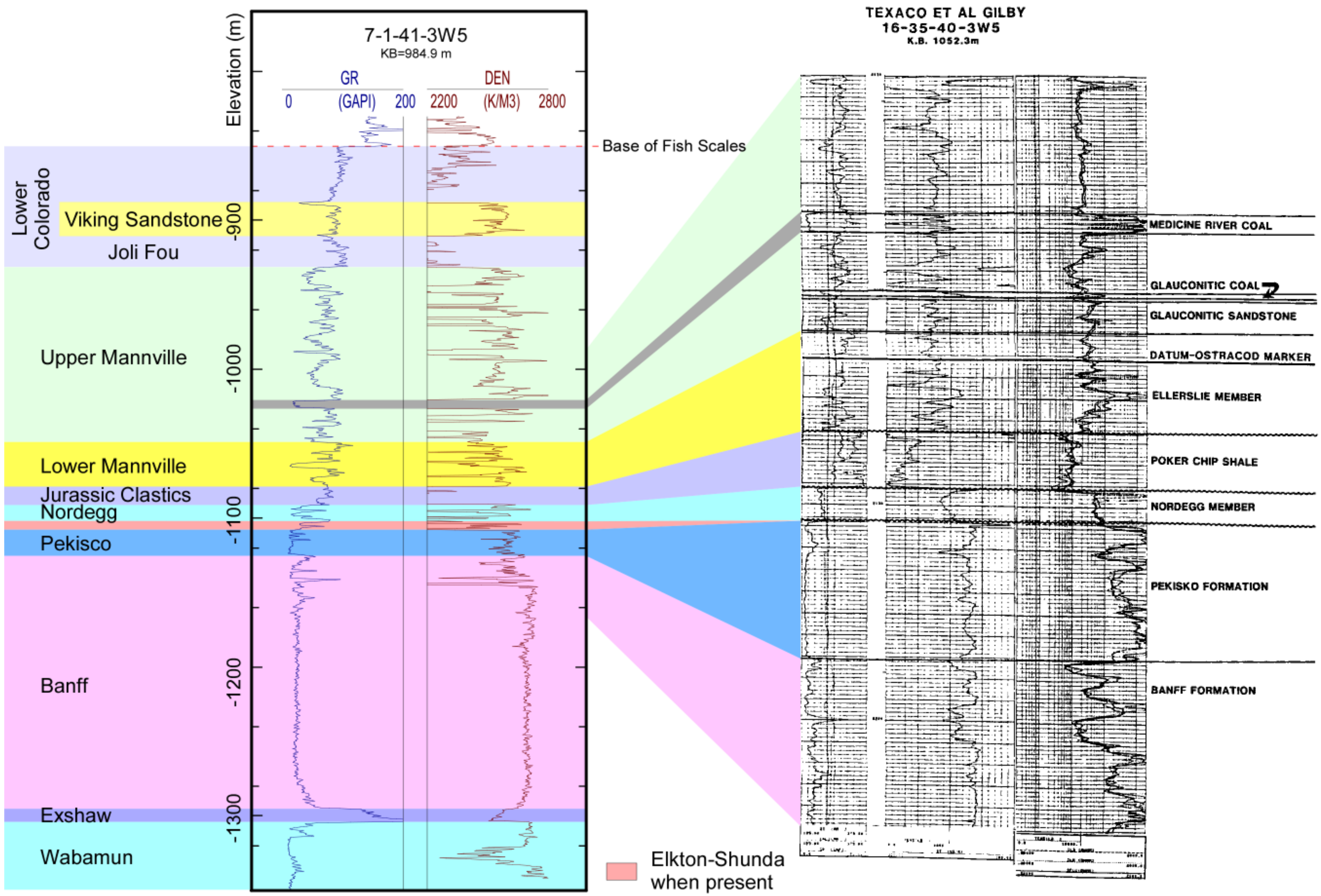


**Figure 90. Succession of the Mississippian to Lower Cretaceous formations, showing the Mannville coal seams.**

These zero edges may have been fault related and resulted from a combination of structural uplift and subaerial erosion.

Thirty-three oil and gas fields have been found in the study area. The boundaries of the oil and gas fields show some correlations to the basement lineaments and the zero edges of the Mississippian and Jurassic formations.

Huge volumes of natural gas have been produced from Mississippian, Jurassic and Cretaceous reservoirs in the Medicine River area, particularly where the extensional zone along the Rimbey Arc intersects Mississippian and Jurassic zero edges. The Lower Mannville Group unconformably overlies the Jurassic and Mississippian formations; gas pools from this group spread out widely between the deep faults in addition to the central productive zone. Upper Mannville gas pools appear to be controlled by the northeast-trending, nearshore sandbodies, which were controlled by basin development. Gas production from the Viking Formation appears to be confined by the linear sandbodies, which were controlled by shoreline migrations that were, in turn, controlled by subsidence of the basin floor. Cardium gas production is largely confined to the places where thick Cardium sandstone is present, the distribution of which appears to be influenced by structural trends, assumed to be fault related. Gas production in the Belly River Group may have been controlled by both structures and distribution of fluvial sandbodies. In addition to structural and stratigraphic trends, the edges of some reservoirs are associated with rivers or watersheds.

The Drumheller, Carbon-Thompson, Ardley and Upper Mannville coal zones are relatively well developed in the Medicine River area.

The prospective areas for CBM exploration in the Drumheller coal zone include 1) the corner confined by the Sylvan Lake and Penhold lineaments (Twp. 39, Rge. 26W4), and 2) the southeast corner of the Penhold Block (Twp. 35, Rge. 26W4). Other prospects include the intersection of the Rimbey Arc and the Sylvan Lake Lineament (Twp. 38, Rge. 3W5), and southwest of the Pekisko zero edge in the Buck Lake Block (Twp. 45, Rge. 5W5).

Three potential areas for CBM exploration in the Carbon-Thompson coal zone include 1) the northeast end of the Penhold Lineament (Twp. 39, Rge. 26W4, west side of the lineament may be better), 2) Twp. 41, Rge. 5W5 (west of the Elkton-Shunda zero edge), 3) Twp. 42, Rge. 26W4 (south side of the Battle River Lineament), and 4) Twp. 36, Rge. 6–7W5 (west of the Foothills east edge).

For the Ardley coal zone, the area between the Elkton-Shunda and Pekisko zero edges has the highest potential of gas production (Figure 89, Twp. 45, Rge. 5–7W5 and Twp. 46, Rge. 6–7W5). The area southwest of the Pekisko zero edge and northwest of the Rimbey Arc could be the second potential area of production (Twp, 42, Rge. 4W5). The area southwest of the Elkton-Shunda zero edge and northwest of the Rimbey Arc could be the third potential area of production (northwest of Twp. 39, Rge. 3W5).

The Upper Mannville Group coals are thick and widespread and have great potential for CBM production.

Although a large number of digital logs have been collected in the project database, this stratigraphic framework review did not identify and correlate the stratigraphic markers in all wells. Also, due to time constraints, the correlation interval was cut off at the Mississippian base. As well, the available public-domain aeromagnetic and gravity data were not analyzed and integrated into this study. Therefore, future work may focus on 1) identifying and picking the correlation markers in more wells to increase the control points in the existing mapping units; 2) correlating the formations below the Mississippian; and 3) analyzing aeromagnetic and gravity data for the basement, and integrating the results from all available sources to get a better understanding of the structures in the study area.

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