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Regional Stratigraphic Framework of Buffalo Head Hills—Peerless Lake Region, Northern Alberta

Alberta Energy and Utilities Board

Alberta Geological Survey

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Abstract

The Buffalo Head Hills–Peerless Lake (BHH–PL) region in northern Alberta is well known for its prolific oil and gas production. However, the discovery of kimberlites in the Buffalo Head Hills in early 1997 drew exploration attention to this region for diamonds. To date, 38 kimberlites have been discovered, with about 60% being diamond bearing.

This study identifies and correlates 34 stratigraphic horizons from the Precambrian top to the ground surface in the BHH–PL region. Three regional cross-sections, four isopach maps of large sedimentary successions, and two structural maps of the Precambrian top contribute to understanding the stratigraphic framework of the region. As well, 15 lineaments have been inferred; in general, the lineaments trend north, northeast, northwest and east.

The overall Phanerozoic sedimentary cover is a southwest-thickening wedge. The basin-wide sub-Cretaceous unconformity separates the sedimentary bedrocks into two large intervals:

1) the Middle Devonian to Lower Mississippian succession, and
2) the upper Lower to lower Upper Cretaceous succession.

Middle Devonian formations progressively onlap southwest onto the original Peace River Arch (PRA). During the Paleozoic, the BHH–PL region was a shallow shelf to basinal marine setting and dominated by carbonate, shale and evaporite deposits. The uppermost Devonian and Mississippian thicken southwestwardly and were eroded in the uplifted northeast. The Lower Cretaceous strata unconformably overlie Paleozoic formations. During Cretaceous time, the region became part of the Cordilleran foreland basin and was blanketed by marine shales with wedges of sand and silt deposits. Subsequently, the Upper Cretaceous formations were incised and eroded down to the Shaftesbury Formation in the Loon River lowland.

The BHH–PL region is floored by the Early Proterozoic Buffalo Head Domain and traversed by the long-acting PRA. The present PRA consists of a swarm of basement highs and lows with preferred orientations. In places, oil and gas pools are spatially distributed over the trend of some of the basement highs. This indicates that basement discontinuities in the region may have been reactivated, at times, during the Phanerozoic. The PRA and associated basement faults had a profound impact on the deposition and erosion of Phanerozoic sedimentary rocks, the distribution of oil and gas and, possibly, the emplacement of kimberlite pipes in the region.

1 Introduction

1.1 Location, Physiography and Economic Geology

The study area is in the Buffalo Head Hills–Peerless Lake (BHH–PL) region of northern Alberta (Figure 1). It encompasses about 18 275 km^2, which is bounded by Townships 82 and 95 in the north and south and by Ranges 3W5M and 16W5M in the east and west, respectively. The BHH–PL region has been a prolific area for oil and gas production. The discovery of kimberlites in the Buffalo Head Hills in early 1997 drew exploration attention to this region for diamonds.

The BHH–PL region is topographically characterized by three highlands separated by two lowlands. The highlands include the Sawn Lake highland in the northwest, the Peerless Lake highland in the east and the Seal Lake highland in the southwest. The north-trending Loon River lowland occurs between the Sawn Lake highland to the west and the Peerless Lake highland to the east. The Muskwa–Lubicon lakes lowland is between the Sawn Lake and Peerless Lake highlands to the north and the Seal Lake highland to the south.

The remarkable Red Earth oilfield was discovered in 1956. Since then, more than 5690 oil and/or gas wells have been drilled in the BHH–PL region (Figure 1; Alberta Energy and Utilities Board data as of March 2004). Millions of cubic metres (m^3) of oil and billions of m^3 of gas have been produced from the region. The total monthly production from all productive formations in the area is about 51 million m^3 for oil and 12 306 million m^3 for gas. The Devonian is the main oil producer in the area and accounts for 99.7% of the total oil production. In contrast for gas, the Cretaceous is the number one producer and accounts for about 49% of the total gas production. The Devonian and Mississippian account for 27% and 24% of the total gas production, respectively. The Mississippian sequence has the highest average gas production, about 29 million m^3 per well per month.

The distribution of oil and gas pools in the BHH–PL region shows strong impact by the basement lineaments, topography and other structures within the Peace River Arch (PRA) boundaries proposed by O'Connell et al. (1990, as digitally compiled by Pana et al., 2001). Evident phenomena can be observed as follows:

- High oil production occurs mainly within the boundaries of the PRA (Figure 1);
- Oil pools are seemingly preferentially distributed along and around basement highs;
- The oil pools show preferred directions: a) trending north in the east-central, northeast and north areas; b) trending northeast in the west-central area; c) trending east in the south-central area; and d) trending northwest in the southwest and central areas.
- The northeast, east, north and northwest-trending productive belts form a prolific triangle zone that covers a large area in the central part of the BHH–PL region.

1.2 Previous Studies and Objectives of This Study

Stratigraphic studies of the BHH–PL region are rare in the public domain (Eccles et al., 2000), although many publications are available for the PRA in the Peace River region to the west (e.g., de Mille, 1958; Lavoie, 1958; Williams, 1958; Burk, 1962; Cant, 1988; O'Connell et al., 1990; Eaton et al., 1999; Hein, 1999; Chen and Bergman, 1999) and in the Birch Mountains to the east (Cotterill and Berhane, 1996). The regional topographic high or elevated structural surface of the Precambrian top is one of the most important geological features in the BHH–PL region. However, all of the early studies were mainly restricted to west of the town of Peace River, which is outside this study area. Maps had not shown the

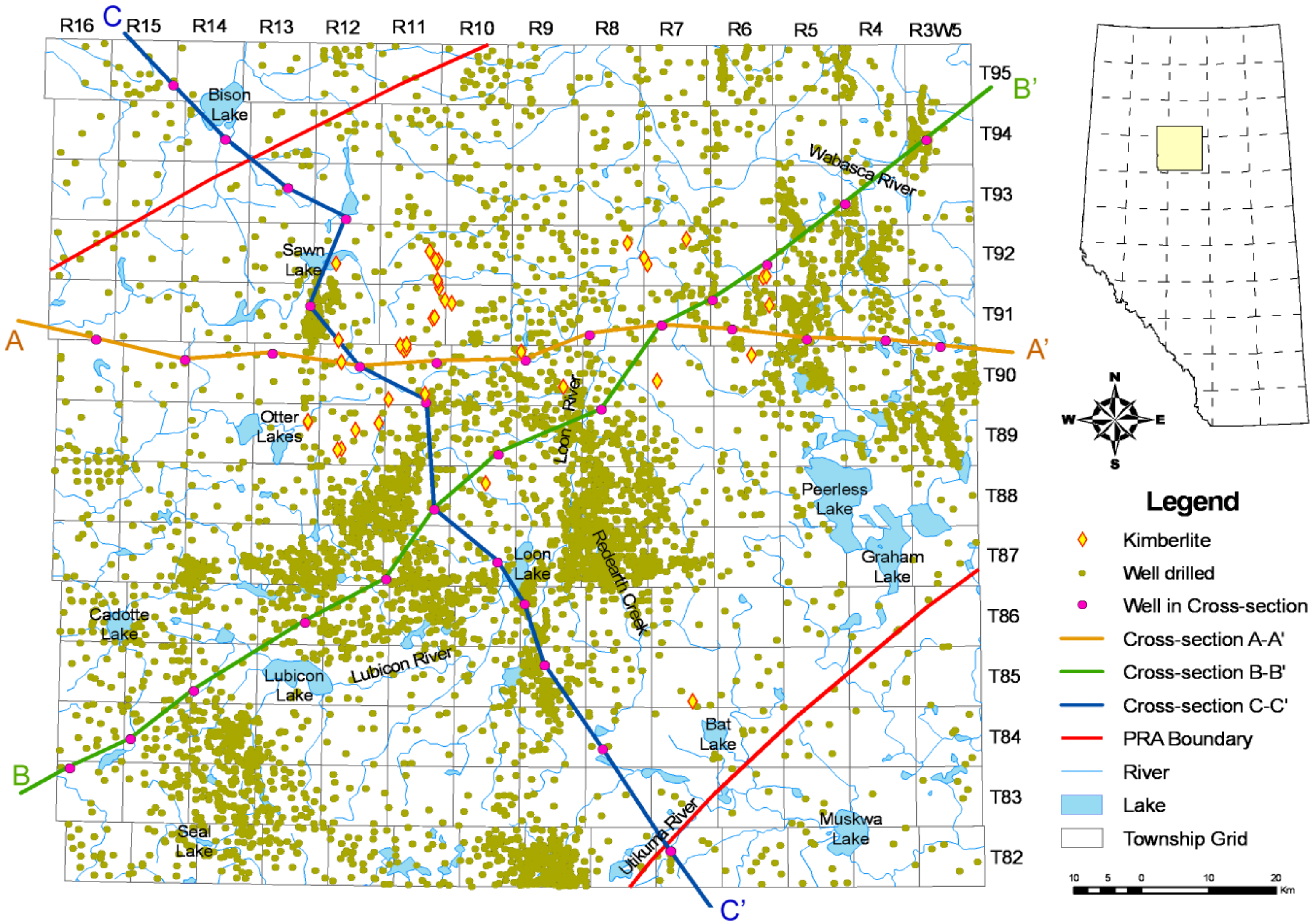

Figure 1. Study area in northern Alberta showing well distribution and location of cross-sections. The buffalo Head Hills—Peerless Lake region has been prolific for oil and gas production. About 5690 oil and gas wells have been drilled in the region. Cross-section A-A' trends east across the Buffalo Head Hills kimberlite field. Cross-section B-B' trends northeast, perpendicular to the regional formational strike. Cross-section C-C' trends northwest, parallel largely to the regional formational strike and across the Peace River Arch (PRA). The PRA boundries are as digitally compiled by Pana et al. (2001) from O'Connell et al. (1990).

BHH–PL potion of the PRA until late 1980s. Although many publications have addressed the various aspects of the PRA, the Arch origin and final uplift still remain largely assumptions. As well, little attention has been given to the BHH–PL region in the early studies.

"*Surprisingly, before the 1990s, diamonds were almost absent from Canadian folklore and mineral history,*" (LeCheminant et al., 1996). In 1996, the Open File Report "Searching for Diamonds in Canada" was published by the Geological Survey of Canada (GSC). Twenty-eight short papers from the GSC, provincial surveys and university-based research provided a snapshot of the spectrum of geoscience information available to assist diamond exploration in Canada. At that time, limited attention was given to diamond exploration in Alberta, although the Alberta Geological Survey (AGS) had recently published two reports on the diamond potential of Alberta (Dufresne et al., 1994, 1996).

During the early 1990s, an ultramafic pipe was discovered northeast of Grande Prairie (Dufresne et al., 1994). Subsequently, kimberlite pipes and bodies were discovered in both the Buffalo Head Hills and Birch Mountain areas, and to date, 48 kimberlitic pipes and bodies have been discovered within Alberta. This includes 38 pipes in the Buffalo Head Hills area, of which about 60% are diamondiferous.

Since the discovery of kimberlites in the Buffalo Head Hills in 1997, AGS has studied the geology, geochemistry and geophysical signature of the currently known Albertan kimberlites, including structure and stratigraphy about the BHH–PL region. Furthermore, AGS has published several reports, including Earth Sciences Report 2001-20, Earth Sciences Report 2001-05, Geo-Note 2002-23 and Geo-Note 2003-37. For all kimberlite-related information, see the AGS publication list at www.ags.gov.ab.ca/publications. Worldwide, there is no single accurate predictor regarding the location of undiscovered kimberlite fields or kimberlites. Many kimberlite/lamproite occurrences have preferred orientations, suggesting pre-existing structures may have played an important role in their emplacement (LeCheminant and Kjarsgaard, 1996). Several faults in the Buffalo Head Hills area have been inferred primarily based on surface data (Eccles et al., 2000; Paganelli et al., 2003). It has been proposed that faults could have provided pathways for at least the relatively near-surface emplacement of kimberlitic pipes because some of the inferred faults appear to be spatially related to known kimberlites in the area (Eccles et al., 2000). Recently, Pana (2002) compiled 'known' and inferred faults from publicly available sources. However, little ground-truthing to confirm such inferred faults has been done; in large part, this is due to the extensive overburden cover in this region.

The kimberlitic rock facies have been studied in central Saskatchewan (Leckie, 1998) and to a lesser extent in the Buffalo Head Hills, Birch Mountains and at Mountain Lake in Alberta. The Buffalo Head Hills kimberlite pipes were emplaced between 86 and 88 million years ago (Carlson et al., 1999). Furthermore, isotope dating has suggested the kimberlite volcanism in Alberta occurred between 91 and 68 million years ago (i.e., during the Cenomanian to Maastrichtian; Eccles et al. 2003).

This study provides regional cross-sections and isopach and structural maps to establish a stratigraphic framework in the BHH–PL region and document major geological features that may have had an impact on kimberlite emplacement. By using geophysical logs from oil and gas wells, as well as other data, this study

- identifies and correlates 34 stratigraphic tops in the BHH–PL region;
- evaluates the horizontal and vertical distribution of selected Phanerozoic units;
- characterizes the features of Upper Cretaceous formations; and
- provides information about the presence or absence of faults in the Buffalo Head Hills area.

2 Regional Geology

2.1 Basement Architecture

The Precambrian rocks in the BHH–PL region, which have been penetrated by oil and gas wells, are dominated by high-grade, metamorphic and/or deep-seated igneous rocks, including gneiss, granulite, amphibolite, other metasedimentary rocks, granite-to-quartz diorite, diabase and gabbro (Burwash et al., 1994). Burwash et al. (1994) suggested a magma cooling and recycling mechanism for the basement beneath the Western Canada Sedimentary Basin (WCSB); i.e., the magma that constitutes the floor of the WCSB cooled in the Early Proterozoic in north-central Alberta, which was earlier than the remainder (1.8–1.7 billion years ago) of the basin floor, and subsequently, the old crustal element underwent recycling by deformation and metasomatism.

In contrast to the magma cooling and recycling mechanism of Burwash et al. (1994), Hoffman (1989) and Ross et al. (1991) suggested a collisional and subduction mechanism, in which the basement in the BHH–PL region is part of the Early Proterozoic Buffalo Head Domain that was accreted between the Rae and Slave Archean Provinces between about 2.4 and 2.0 billion years ago (Ross et al., 1991). Most recently, however, Pana (2002) compiled and reviewed information from aeromagnetic, gravity, electrical conductivity, seismic and cores in northern Alberta, and suggested that the early Proterozoic terrane-accretion model for the northern Alberta basement requires further investigation and testing.

2.2 Basement Faults and Shear Zones

Several faults and shear zones of regional extent have been identified in the exposed western margin of the Canadian Shield and many are inferred to extend beneath the WCSB. Among them, the Great Slave Lake shear zone (GSLsz, Hoffman, 1987) is to the north and the Snowbird Tectonic Zone (STZ, Hoffman, 1989) is south of the Buffalo Head Domain. The GSLsz is a series of northeast-trending brittle faults and ductile high strain zones. Late transcurrent movement along northeast-trending tectonic faults and shear zones has commonly left a clear magnetic signature, especially where these younger structures offset magmatic arcs or older fault and high strain zones.

In northeastern Alberta, a series of north-trending lineaments were cut by later northeast-trending faults (Garland and Bower, 1959). The north-trending Allan fault zone, which formed during the early Hudsonian, has undergone recurrent movement after regional metamorphism. Vertical movements of several hundred metres occurred along these northerly faults in late Paleozoic time (Burwash et al., 1994). Finally, a set of conjugate northeast and northwest-trending faults control the basement topography and sedimentation patterns over the PRA (Cant, 1988).

2.3 Regional Tectonics and the Peace River Arch

The tectonic evolution in the WCSB can be divided into two main stages:

1) Late Proterozoic to Late Jurassic miogeocline-platform; and
2) Late Jurassic to Early Eocene foreland basin (Price, 1994).

The long-acting PRA extends into the BHH–PL region from the southwest to the northeast. In the Peace River region to the west, granitic Precambrian rocks of the PRA are uplifted 1000 metres above the regional elevation of Precambrian basement (Cant, 1988). The evolution of the PRA has three main phases:

> "*a Late Proterozoic to early Paleozoic Arch, a late Paleozoic to earliest Mesozoic Embayment, and as a deep basin component of a Mesozoic foreland basin*" (O'Connell et al., 1990).

According to Chen (2000) and this study, the Peace River region has existed in seven forms:

1) a broad uplift that underwent erosion from the Late Proterozoic to Early Devonian;
2) an island remnant of the former arch, which was subsiding with the surrounding areas from the Middle to Late Devonian;
3) an embayment from the Early Mississippian to Triassic;
4) a foredeep with peripheral erosional zone in the foreland basin from the Jurassic to Earliest Cretaceous;
5) a resumed collapse area during the late Early Cretaceous;
6) an area with shifted foreland basin zones during the early Late Cretaceous; and
7) a locale that subjected to uplift and erosion from the latest Cretaceous to Tertiary.

From the Late Proterozoic to the Early Devonian, the BHH–PL region was exposed and underwent erosion (Kent, 1994). The Arch region began to subside but remained as a highland in the Interior Plains during Middle Devonian time; it became an island during Late Devonian time (Kent, 1994). In early Frasnian time, the BHH–PL region was part of a shale basin. Subsequently, the area was divided into a carbonate shelf in the northeast and a deepwater basin in the southwest (Switzer et al., 1994). The long-standing Arch was last seen as a 'highland' in the Peace River region in early Famennian time when the Whitelaw Member of the Wabamun Group was deposited (Halbertsma, 1994). The BHH–PL region was then in the Smoky River sub-basin, and as a result received outer shelf and basinal carbonate and mudstone deposits (Halbertsma, 1994).

The PRA region in northwest Alberta was downwarped, faulted and became an embayment in Carboniferous through Permian to Triassic time. A thick sequence of sediments accumulated in the embayment, but subaerial erosion during the latest Carboniferous, Permian and subsequent period removed much of the Carboniferous succession (Richards et al., 1994; Gibson and Edwards, 1990; Edwards et al., 1994). In the BHH–PL region, only the Lower Mississippian is preserved in the southwest of the study area.

The tectonic framework of western Canada was completely altered starting in Middle Jurassic time. That is, several allochthonous exotic terranes from the west collided with the North American Craton and created foredeeps inboard along the craton margin. The allochthonous terranes continued to collide periodically and were accreted to the North American cratonic margin from Middle Mesozoic to early Cenozoic time (Coney et al., 1980). As a result, thick packages of marine sandstone and shale accumulated in a narrow foredeep in the Peace River region (Stott, 1963). In contrast, the BHH–PL region was largely off to the east in the setting of east median hinge–eastern platform (Kauffman and Caldwell, 1993) in the earliest Cretaceous.

The PRA region subsided during Cretaceous Albian time, in a manner that was similar to the Carboniferous Peace River Embayment in location, size and shape, and this indicates that there was a resumed collapse of the Arch (Chen, 2000).

From mid-Cretaceous to middle Eocene time, the oblique collision of accreting terranes in the west resulted in the displacement and tectonic loading of supracrustal rocks on the continental margin; this in turn induced subsidence of the foreland basin and provided the source of the sediments for the foreland basin (Price, 1994). In the Peace River area, the interval between the Base of Fish Scale and the Second White Specks thickens westwards with the depo-centre being in the west, whereas the interval between the Second White Specks and the Colorado Group top thickens southwestwards with the depo-centre being parallel to the Rocky Mountain deformation front (Burk, 1962).

Early Tertiary compressional and strike-slip structures overprinted the older rift-related features (Dixon, 1993). In the Eocene, convergence in the northern Rocky Mountains ceased abruptly, and consequently subsidence and filling of the Western Interior Basin ended (Armstrong, 1993). The growth pattern of the foreland thrust and fold belt, and the foreland basin were finally reshaped by an episode of Early and Middle Eocene crustal extension in the central part of the Cordillera (Price, 1994).

3 Stratigraphic Correlation and Nomenclature

3.1 Formations Present in the BHH–PL Region

The stratigraphic table in Figure 2 shows the various formations present in the BHH–PL region. Bedrock strata preserved in the subsurface of the BHH–PL region include, in ascending order: 1) Devonian Elk Point, Beaverhill Lake, Woodbend, Winterburn and Wabamun groups, 2) Mississippian Exshaw and Banff formations, and Rundle Group, and 3) Cretaceous Bluesky/Gething, Spirit River, Peace River, Shaftesbury and Dunvegan formations, and Smoky and Wapiti groups.

Seven major regional unconformities (3 first order, 1 second order and 3 third order) exist in the Phanerozoic of the BHH–PL region (Figure 2). A first order unconformity divides geological erathems; in the BHH–PL region these comprise the

1) sub-Granite Wash unconformity that separates the Devonian from the Precambrian;
2) sub-Cretaceous unconformity that divides the Mesozoic from the Paleozoic; and
3) sub-Quaternary unconformity that separates the Cenozoic from the Mesozoic.

A second order unconformity divides geological systems; in the BHH–PL region, this includes the sub-Exshaw unconformity that separates the Mississippian from the Devonian. Finally, a third order unconformity divides geological groups or formations; these include the three unconformities between the

1) Granite Wash and Chinchaga formations;
2) Muskeg and Watt Mountain formations; and
3) Spirit River and Peace River formations.

Being bounded by the first order unconformities, the Phanerozoic rocks are grouped into three depositional successions:

1) the Paleozoic succession that consists mainly of carbonates, evaporites, and shales with basal coarse-grained clastics;
2) the Mesozoic succession that is dominated by siliciclastics; and
3) the Cenozoic succession that comprises glacial deposits.

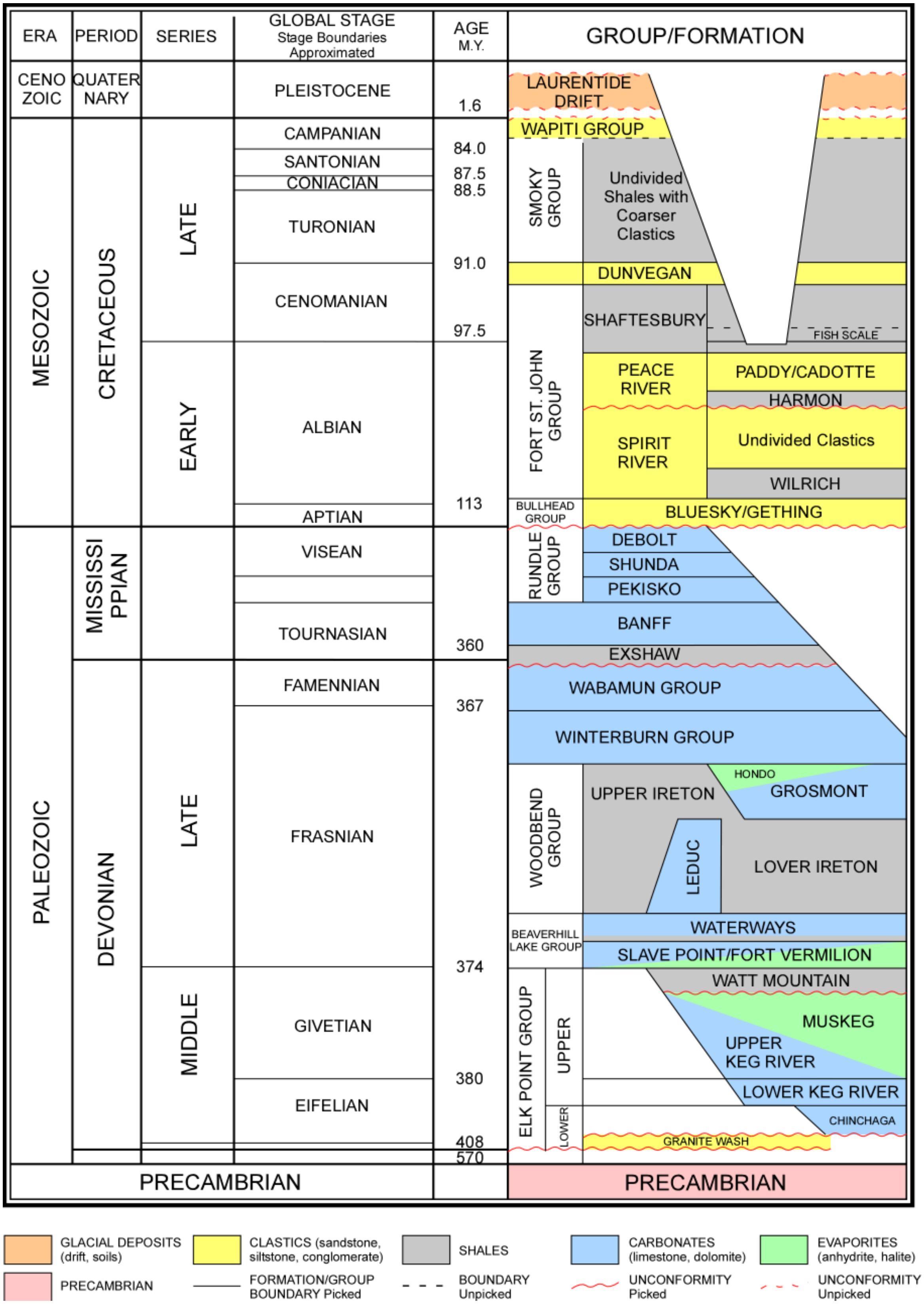

Figure 2. Stratigraphic table of the formations present in the Buffalo Head Hills—Peerless Lake region. The surfaces correlated in this study are indicated in solid black or red lines.

The BHH–PL region covers partially both the northwest and northeast Alberta plains. Several geological boundaries and lateral changes of lithology occur in this region. These include, for example,

- the east edge (northwest-trending) of the PRA fringing reef complex (Beaverhill Lake Group);
- the west edge (northwest-trending) of the Grosmont complex;
- the Hondo evaporite tongue (northwest-trending);
- erosional edges of the Devonian and Mississippian (northwest-trending); and
- erosional limits of Harmon and Cadotte formations (northeast-trending).

According to the formations present in the BHH–PL region, the stratigraphic table in Figure 2 follows the nomenclature typically used for the northwest Alberta Plains; the sole exception is the Grosmont Formation, which is normally thought of as being present only in the northeast Plains.

The stratigraphic table in Figure 2 provides also the information about the relationship between formations. The left part of the "*Group/Formation*" column represents for the west area of the BHH–PL region and the right part of the column represents for the east area of the region. A blank space under the "*Group/Formation*" column indicates non-deposition or erosion of formations. For example, the missing of the sediments in the Middle Devonian was caused by the original uplift of the PRA in the west. As well, the truncation of the Mississippian and Devonian top beneath the Cretaceous resulted mainly from the pre-Cretaceous erosion in the east. Finally, the 'trough' in the Upper Cretaceous indicates post-Cretaceous erosion and removal of Cenozoic and Upper Mesozoic formations in the more recently formed lowland areas within the BHH–PL region.

Each of the unconformities records a period of hiatus and removal of a certain amount of sediments. In terms of geological time, the age gaps or depositional hiatuses in the study area are much longer than that of the preserved sedimentary intervals. For example:

1) the hiatus prior to Granite Wash deposition is about 162 million years;
2) the hiatus between the Mississippian and the Cretaceous is about 214 million years; and
3) the hiatus between the Cretaceous and the Quaternary is about 82 million years.

In contrast, the preserved Devonian deposition lasted only about 23 million years, excluding the hiatus between the deposition of the Granite Wash and Chinchaga formations (which may have been up to 25 million years). Furthermore, Mississippian deposition continued for about 30 million years and Cretaceous deposition took about 32 million years in the BHH–PL region. In short, in the time interval from Cambrian to Recent, which is about 540 million years, sedimentation occupied only about 85 million years, whereas non-depositional hiatuses occupied over 400 million years.

3.2 Correlation Criteria and Stratigraphic Picks

Geophysical logs are extensively employed in the formational correlations carried out by this study. A description of some of the correlation markers/stratigraphic tops (Tables 1, 2 and 3) and picking protocols are as follows:

- Tops of Muskeg and Watt Mountain Formations: on geophysical logs, the shaly Watt Mountain Formation is distinctive from the evaporites and carbonates of the underlying Muskeg and overlying Fort Vermilion formations. The Muskeg top is marked at the base of the shaly interval and the Watt Mountain top is picked at the top of the shaly interval. The markers are traceable across the study

Table 1. Stratigraphic picks for Cross-Section A-A'; pick elevation in metres. Refer to Figure 1 for the section location and Figure 4 for the section illustration.

Site ID	118809	118330	144342	118306	118299	210153	118729	118720	154871	144406	235109	253326
Dunvegan				600.8					562.0	576.2	587.4	569.2
Shaftesbury				587.3					537.1	544.7	560.9	556.7
Base of Fish Scale	485.8	477.5		461.8	456.8	446.4	449.4		418.7	431.2	425.8	437.0
Peace River	393.4	403.3	414.7	391.2	391.3	392.4	384.7		370.7	385.6	381.5	396.4
Harmon	365.0	372.5	391.1	375.5	374.7	379.9	374.8		359.9	380.7	377.4	388.1
Spirit River	356.3	363.8	380.8	364.4	358.2	358.4	351.6		339.2	358.3	354.1	366.6
Wilrich	160.2	157.9	156.3	148.7	149.1	174.0	179.7	190.8	175.5	182.7	182.6	204.1
Bluesky	118.4					154.1	154.8	154.0	155.6	171.1	169.3	184.2
K-Banff	107.3	128.8	147.7	138.4	138.0							
Lower Banff	-3.2	41.2	94.8									
Exshaw	-118.8	-67.3	12.0	65.0								
K-Wabamun						138.4	135.0	138.2	141.5	164.5	160.2	
Wabamun	-130.6	-79.2	4.1	57.1	109.6							
Lower Wabamun	-238.4	-180.9	-126.9	-64.7	-2.8	61.4	115.1					
Winterburn	-385.6	-319.4	-261.0	-219.8	-160.6	-89.8	-33.2	21.0	43.0	104.8	150.2	175.1
Woodbend	-442.4	-421.3		-339.3	-309.9	-224.3	-170.9	-109.8	-68.9	-22.7		
Upper Ireton	-497.7	-477.9	-393.9	-396.1	-408.3	-318.4	-267.8	-271.8				
Leduc Equivalent	-834.7	-756.5	-634.1	-558.2	-577.6	-528.0						
Lower Ireton							-456.8	-373.3	-297.9	-216.6		
Waterways	-859.5	-816.8	-734.4	-686.8	-635.9	-576.9	-503.9	-450.7	-405.6	-345.7		
Beaverhill Lake Surface 2	-925.0	-880.7	-814.8	-779.9	-731.4	-663.9	-609.2	-561.0	-519.9	-457.6		
Slave Point	-948.7	-903.6	-845.6	-821.7	-782.3	-714.4	-653.1	-608.9	-561.3	-491.6		
Watt Mountain	-990.6	-950.6	-889.8	-852.5	-824.9	-750.0	-697.8	-649.5	-619.3	-546.3		
Muskeg	-998.4	-962.4	-899.3	-863.6	-836.7	-761.6	-708.5	-657.0	-644.2	-557.9		
Lower Keg River			-979.7	-953.2	-927.5	-885.0	-846.8	-818.7	-787.3	-720.3		
Chinchaga								-859.6	-827.5			
Granite Wash	-1062.2	-1026.3		-963.2	-953.2	-905.8	-874.8	-882.7		-750.9		
Precambrian	-1072.3	-1030.6	-996.9	-979.7	-983.3	-912.3	-878.4	-896.3	-849.7	-763.3		

Site ID	Unique Well Identifier (UWI)	Site ID	UWI	Site ID	UWI
118809	00/03-02-091-16W5-0	118330	00/02-25-090-15W5-0	144342	00/02-32-090-13W5-0
118306	00/15-22-090-12W5-0	118299	00/07-26-090-11W5-0	210153	00/09-30-090-09W5-0
118729	00/04-08-091-08W5-0	118720	00/02-17-091-07W5-0	154871	00/09-08-091-06W5-0
144406	00/09-04-091-05W5-0	235109	00/09-03-091-04W5-0	253326	00/15-33-090-03W5-0

Table 2. Stratigraphic picks for Cross-Section B-B'; pick elevation in metres. Refer to Figure 1 for the section location and Figure 5 for the section illustration.

Site ID	114599	143642	115624	116264	116776	117469	117938	117923	118720	221419	155018	155067	198300
Dunvegan		626.5											622.5
Shaftesbury		602.3											582.4
Base of Fish Scale	457.1	445.9				453.4	447.8			433.6	436.3		457.4
Peace River	374.3	377.2	381.7	369.5	387.8	397.5	393.5			384.1	389.9	390.3	402.3
Harmon	345.7	360.0	370.6	360.4	372.7	384.4	381.7			369.1	373.4	382.4	395.2
Spirit River	336.6	345.9	354.5	344.3	361.6	369.2	364.4			347.1	348.2	357.1	374.8
Wilrich	94.6	126.0	150.6	159.2	173.1	155.3	164.8	158.0	190.8	191.0	191.8	185.7	223.5
Bluesky	69.4	90.7	106.8			140.2	139.6	149.4	154.0	162.7	165.9	174.6	
K-Debolt	43.2												
Lower Debolt	13.9												
K-Shunda			95.7										
Shunda	-61.8	67.5											
K-Pekisko				134.0									
Pekisko	-162.7	-45.5	38.1										
K-Banff					127.7	133.1	129.4						
Banff	-225.6	-125.2	-47.6	126.9									
Lower Banff	-378.8	-291.1		-10.7	57.0								
Exshaw	-502.9	-406.2		-157.5	-62.3	25.3							
K-Wabamun								132.1	138.2	148.7	152.5		
Wabamun	-516.0	-416.2		-172.6	-81.5	16.3	101.8						
Lower Wabamun	-651.6	-550.9		-305.6	-215.6	-111.3	-28.8	70.8					
K-Winterburn												149.5	193.6
Winterburn	-801.8	-684.1		-449.9	-354.9	-256.0	-178.5	-70.0	21.0	64.5	101.5		
Woodbend					-482.0	-409.8	-301.0	-205.9	-109.8	-59.6	-31.0	63.4	148.9
Upper Ireton	-897.7	-800.1		-586.0	-514.4	-431.4	-371.1	-341.9	-271.8				
Leduc Equivalent				-850.2	-715.0	-581.1	-472.9						
Lower Ireton								-495.1	-373.3	-293.1	-228.3	-132.0	-52.4
Ireton Surface 1												-242.8	-162.5
Waterways	-1130.1	-1026.1		-878.4	-801.7	-712.3	-632.1	-535.2	-450.7	-396.1	-360.7	-274.2	-193.2
Beaverhill Lake Surface 2				-922.8	-876.4	-802.1	-729.5	-653.2	-561.0	-507.4	-477.5	-397.2	-320.8
Beaverhill Lake Surface 1											-512.9	-432.6	-356.2
Slave Point	-1153.3	-1063.4		-941.0	-893.6	-835.8	-767.3	-699.5	-608.9	-547.0	-529.4	-453.9	-380.6
Watt Mountain					-931.9	-866.1	-799.5	-741.2	-649.5	-597.4	-591.1	-490.1	-414.4
Muskeg					-938.0	-875.2	-813.6	-752.2	-657.0	-606.0	-617.0	-500.3	-426.2
Lower Keg River						-939.7		-863.4	-818.7	-780.4	-754.6	-689.6	-639.4
Chinchaga									-859.6	-814.0	-795.0	-737.8	
Granite Wash	-1186.4	-1073.5		-980.3	-964.0		-905.0	-897.6	-882.7				
Precambrian	-1198.3	-1098.7				-970.5	-918.0	-905.2	-896.3	-825.5	-823.7	-761.7	

Site ID	UWI	Site ID	UWI	Site ID	UWI
114599	00/05-32-083-16W5-0	143642	00/07-18-084-15W5-0	115624	00/06-07-085-14W5-0
116264	00/06-14-086-13W5-0	116776	00/11-06-087-11W5-0	117469	00/10-11-088-11W5-0
117938	00/03-11-089-10W5-0	117923	00/10-32-089-08W5-0	118720	00/02-17-091-07W5-0
221419	00/12-30-091-06W5-0	155018	00/04-13-092-06W5-0	155067	00/03-18-093-04W5-0
198300	00/10-17-094-03W5-0				

Table 3. Stratigraphic picks for Cross-Section C-C'; pick elevation in metres. Refer to Figure 1 for the section location and Figure 6 for the section illustration.

Site ID	123668	122387	144799	221569	118797	118306	118294	117469	144011	143856	115583	114914	113929
Dunvegan			612.3	625.4	623.7	600.8							
Shaftesbury			590.3	595.2	596.0	587.3							
Base of Fish Scale			470.9	471.2	470.4	461.8	448.5	453.4		434.9			393.8
Peace River	376.3	373.4	381.2	398.7	396.3	391.2	388.3	397.5		396.0		408.1	341.9
Harmon	363.3	357.1	358.4	361.2	370.2	375.5	375.1	384.4		390.4	366.8	376.0	319.3
Spirit River	349.4	345.7	347.8	347.3	360.4	364.4	360.7	369.2		370.9	356.6	370.6	308.4
Wilrich	137.3	132.9	143.1	159.4	156.5	148.7	145.7	155.3	168.9	171.6	165.3	192.6	169.7
Bluesky	126.7	118.2	131.6	137.3				140.2					145.1
K-Banff					133.7	138.4	135.3	133.1	153.2	151.5	137.3	143.7	116.4
Lower Banff											114.0	97.3	80.9
Exshaw					68.5	65.0	85.6	25.3	39.8	31.5	10.2	0.3	-21.2
K-Wabamun	90.5	70.5	96.6	106.4									
Wabamun					61.9	57.1	80.7	16.3	29.8	19.1	-7.6	-14.8	-33.9
Lower Wabamun	-3.2	-18.4	1.6		-66.9	-64.7	-49.4	-111.3	-98.0	-100.1	-137.0	-141.1	-151.4
Winterburn	-126.4	-138.2	-139.0		-212.8	-219.8	-192.0	-256.0	-245.9	-249.5	-286.0	-300.0	-299.6
Woodbend	-238.1	-232.8	-249.9		-317.4	-339.3	-321.2	-409.8	-388.5			-413.4	-487.9
Upper Ireton	-366.5	-342.8	-326.5		-398.7	-396.1	-364.0	-431.4	-405.5	-399.4	-420.6	-483.8	-555.5
Leduc Equivalent	-557.7	-545.9	-507.5		-555.3	-558.2	-507.1	-581.1	-589.8	-590.6	-616.3		
Lower Ireton											-576.0	-597.9	-602.6
Waterways	-645.7	-645.7	-633.5		-682.4	-686.8	-661.6	-712.3	-707.8	-704.4	-727.3	-724.9	-756.4
Beaverhill Lake Surface 2	-749.7	-746.9	-732.2		-769.7	-779.9	-750.5	-802.1	-801.2	-797.1	-822.3	-818.5	-867.7
Slave Point	-805.1	-807.2	-787.6		-804.0	-821.7	-795.4	-835.8	-832.6	-822.2	-853.7	-855.4	-910.8
Watt Mountain	-852.5	-844.7	-824.3		-851.3	-852.5	-829.6	-866.1	-867.7	-862.9	-883.1	-881.0	-934.7
Muskeg	-868.8	-861.0	-835.7			-863.6	-845.1	-875.2	-871.5	-866.7	-887.9	-889.2	-944.9
Lower Keg River	-1011.4	-1010.6	-973.9			-953.2	-934.0	-939.7		-937.0	-955.7		-1035.8
Granite Wash	-1064.8	-1050.7	-997.3			-963.2	-948.1		-928.1	-945.0	-963.8	-945.0	-1078.5
Precambrian	-1066.8	-1056.8	-1017.3			-979.7	-963.2	-970.5	-937.5	-975.7	-983.9	-951.4	-1095.9

Site ID	UWI	Site ID	UWI	Site ID	UWI
123668	00/10-12-095-15W5-0	122387	00/07-15-094-14W5-0	144799	00/10-22-093-13W5-0
221569	00/09-04-093-12W5-0	118797	00/15-24-091-13W5-0	118306	00/15-22-090-12W5-0
118294	00/07-03-090-11W5-0	117469	00/10-11-088-11W5-0	144011	00/11-14-087-10W5-0
143856	00/06-30-086-09W5-0	115583	00/04-28-085-09W5-0	114914	00/15-08-084-08W5-0
113929	00/11-20-082-07W5-0				

area except in the area west of Cadotte – Seal lakes. The Muskeg Formation is not distinguished from the underlying Keg River Formation because the contact of the two formations is gradational.

- Slave Point Formation Top: The carbonate-dominated Slave Point Formation is distinguishable from the above shale unit. The Slave Point Formation is relatively thin and not distinguished from the underlying Fort Vermillion Formation in this regional-scaled study.
- Waterways Formation Top: the log signature of the calcareous Waterways Formation is very different from that of the overlying massive Ireton shale unit.
- Beaverhill Lake Surfaces 1 and 2: The Beaverhill Lake Surface 1 may represent the top of the Calumet Member of the Waterways Formation and the Beaverhill Lake Surface 2 may represent the top of the Christina Member of the Waterways.
- Leduc Equivalent: instead of Leduc Formation, 'Leduc Equivalent' is used in Tables 1 to 3 because, as yet, no cores have been correlated with the geophysical log signatures.
- Woodbend Group Top: the Woodbend Group top is a lithologically transgressive surface. As a result, this pick represents the top of Upper Ireton Formation shale in the southwest, but represents the top of Grosmont formation carbonate in other areas.
- Tops with Letter 'K': in Tables 1, 2 and 3, the letter 'K' stands for Cretaceous. 'K-Wabamun' means that the pick is the Wabamun Group, but the Wabamun top was eroded and is overlain by the Cretaceous. So does K-Debolt, K-Shunda, K-Pekisko, K-Banff and K-Winterburn. The reason for adding contact information, or in this case only one letter, to a pick name is to record more geological information. The significant sub-Cretaceous unconformity can be recognized immediately in Tables 1, 2 and 3. On geological maps, the data points with letter 'K' indicate the areas that are truncated by Cretaceous strata.
- Wabamun Group and Exshaw Formation Tops: the log signature of Exshaw Formation shale is distinctive from that of the underlying Wabamun Group carbonates. Both tops are terminated under the sub-Cretaceous unconformity and absent in the northeast of the study area.
- Tops of Wilrich and Harmon Members: the BHH–PL region is blanketed by Cretaceous siliciclastics. The Wilrich and Harmon members are two separate correlatable shaly units in the Lower Cretaceous. The Wilrich top is marked at the top of the shaly unit above the Bluesky/Gething clastics. The Harmon top is marked at the top of the shaly unit below Paddy/Cadotte sandstones.
- Base of Fish Scales Marker: the Base of Fish Scales Marker is marked at the base of the distinctive high radioactive shale that is preserved in the highland areas of the BHH–PL region.

In total, 34 stratigraphic surfaces from the ground surface down to the Precambrian basement top were identified and picked for each of the selected wells along cross-sections A-A', B-B' and C-C' in this study. The new stratigraphic pick datasets for each cross-section are contained in Tables 1, 2 and 3, respectively. The order of the data in the tables is the same as that of the position of the corresponding formations in the cross-sections. The unique well identifiers (UWI) of the wells are listed at the bottom of each table.

3.3 Correlation and Nomenclature of Upper Cretaceous

Since the kimberlites in Alberta were emplaced between about 91 and 68 Ma (Eccles et al. 2003), during this study more attention was paid to the Upper Cretaceous formations in the Buffalo Head Hills area. Figure 3 shows the stratigraphic features and associated log signatures, correlation markers and nomenclature of the Upper Cretaceous formations in the area.

In addition to the Base of Fish Scales Marker, five correlation markers or surfaces were identified in the Upper Cretaceous of the Buffalo Head Hills (Figure 3).

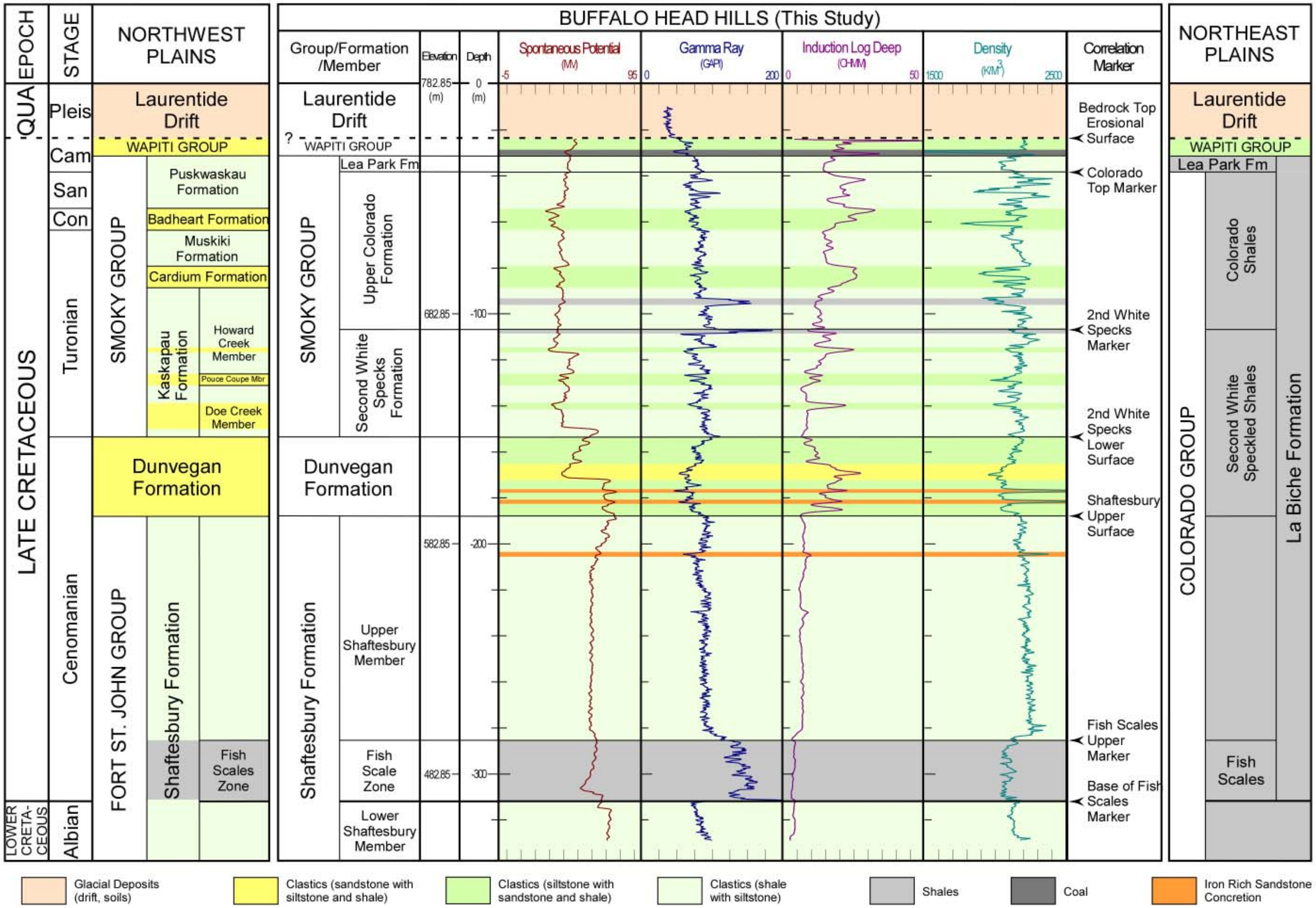

Figure 3. Stratigraphic features and nomenclature of the upper Cretaceous in the Buffalo Head Hills area (this study) and equivalent strata in northern Alberta (modified from Stott, 1982, 1984; Cotterill and Berhane, 1996). The reference logs are from well 9-4-93-12W5, with a kelly bushing (KB) elevation of 782.85 m above sea level. Abbreviations: QUA, Quaternary; Con, Coniacian; San, Santonian; Cam, Campanian; Pleis, Pleistocene; Fm, Formation; Mbr, Member.

- The Fish Scales Upper Marker is defined at the high radioactive shale top of the Fish Scales zone in the Shaftesbury Formation.
- The Shaftesbury Upper Surface is marked at the interface between Shaftesbury shale and Dunvegan sandstone where the gamma-ray curve has a left kick and the resistivity curve has a right kick.
- The Second White Specks Lower Surface is located above the Dunvegan sandstone where a flooding surface is present and the sequence changes from fining-upward to coarsening-upward.
- The high gamma spike of the Second White Specks Marker can be easily recognised in the Smoky Group and is usually associated with another high gamma spike above it.
- The Colorado Top Marker, in general, is characterized by high gamma and low resistivity kicks.

The Upper Cretaceous of the BHH–PL region is transitional from the northwest to the northeast Alberta Plains, being sandier in the northwest Plains and muddier in the northeast Plains (Figure 3). The Upper Cretaceous of the BHH–PL region is dominated by shale and siltstone with some sandstone, bentonite, iron-rich sandstone and coal beds. It can be divided into four parts, which are in ascending order:

1) the shaly Shaftesbury Formation;
2) the sandy Dunvegan Formation;
3) the silty Smoky Group; and
4) the silty and coaly Wapiti Group.

The Shaftesbury Formation can be further divided into the Lower Shaftesbury, Fish Scales and Upper Shaftesbury members. The Smoky Group can be subdivided into the Second White Specks, Upper Colorado and Lea Park formations.

The nomenclature used in Figure 3 for the Upper Cretaceous formations in the Buffalo Head Hills is defined based on the petrophysical log features present in the area, whereas the nomenclature for the northwest and northeast Alberta Plains is modified from Stott (1982, 1984) and Cotterill and Berhane (1996). In contrast, Bloch et al. (1993) proposed naming the Westgate, Fish Scales and Belle Fourche formations for the sedimentary rocks between the Viking and the Second White Specks formations in western Canada. However, both the northwest and northeast Alberta Plains were excluded from the scope of this 'new' definition (Bloch et al., 1993). Furthermore, the 'Westgate' and 'Belle Fourche' members of the Ashville Formation were first applied and defined in Manitoba (McNeil and Caldwell, 1981), which are quite a bit distant from the Buffalo Head Hills area in northern Alberta. Therefore, the naming of the Lower Shaftesbury, Fish Scales and Upper Shaftesbury members is recommended for subdividing the Shaftesbury Formation in the BHH–PL region.

4 Regional Stratigraphic Framework

4.1 Regional Cross-Sections

To provide a correct regional stratigraphic framework with minimal miscorrelations, three cross-sections were constructed from 35 selected wells (shown as red-filled black circles on Figure 1). Cross-section A-A' (orange line on Figure 1), which trends east, crosses through about the middle of the Buffalo Head Hills kimberlite field (Figure 4). Cross-section B-B' (green line on Figure 1), which trends northeast, is perpendicular to the regional formational strike (Figure 5). Cross-section C-C' (blue line on Figure 1), which trends northwest, is parallel to the regional formational strike (Figure 6). The three cross-sections are tied to each other at three wells (10-11-88-11W5, 15-22-90-12W5 and 2-17-91-7W5). The tie wells are marked in each cross-section with a red dot on the top of the tie well.

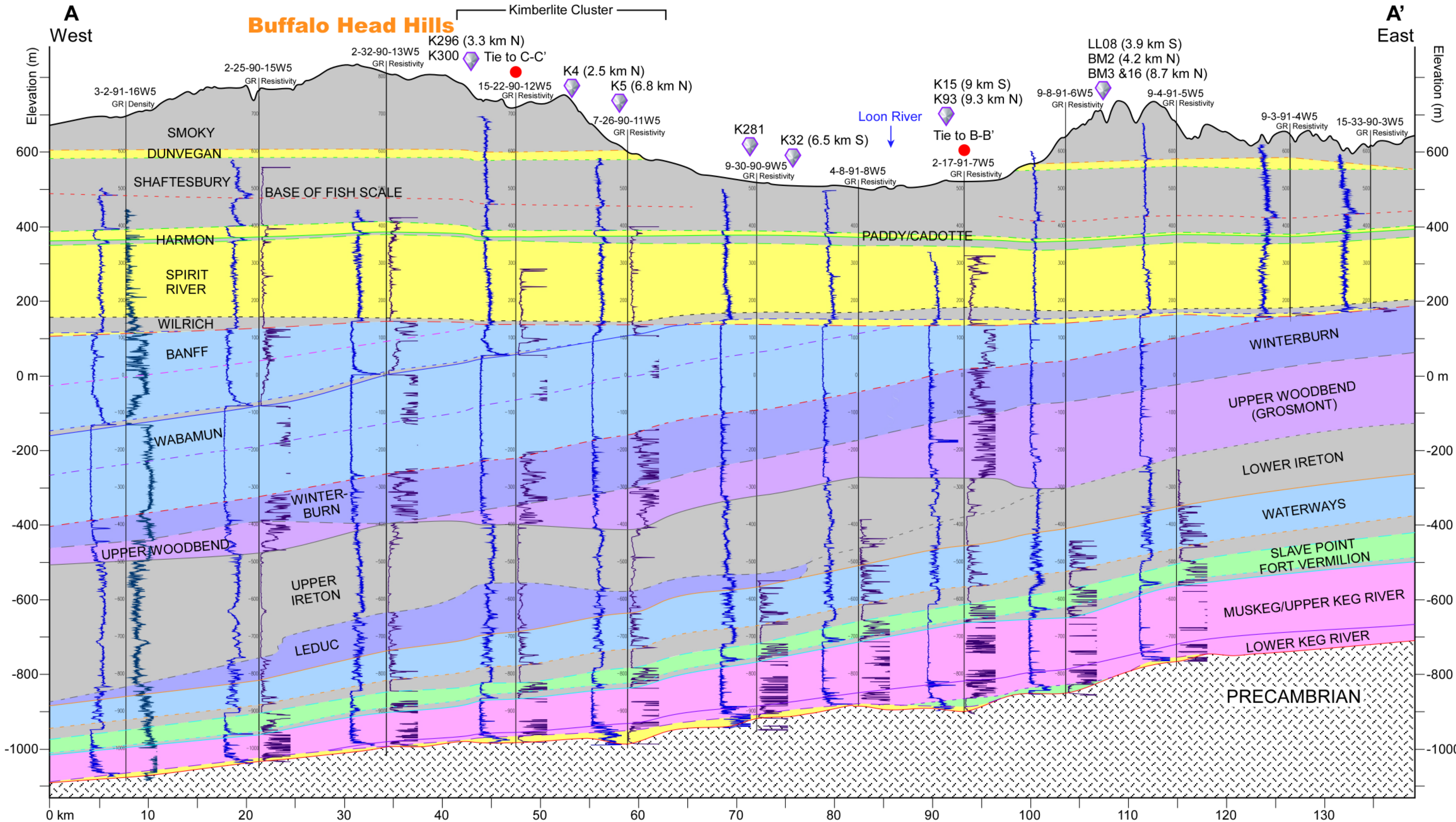

Figure 4. East-trending cross-section A-A'. Vertical scale 1:10,000; horizontal scale 1:380,000 (horizontal versus vertical scale, 1:38). The geophysical logs for selected oil/gas wells are shown. Refer to Figure 1 for the cross-section location and Figure 7 for a legend. Note that glacial deposits are not differentiated from bedrock in this cross-section.

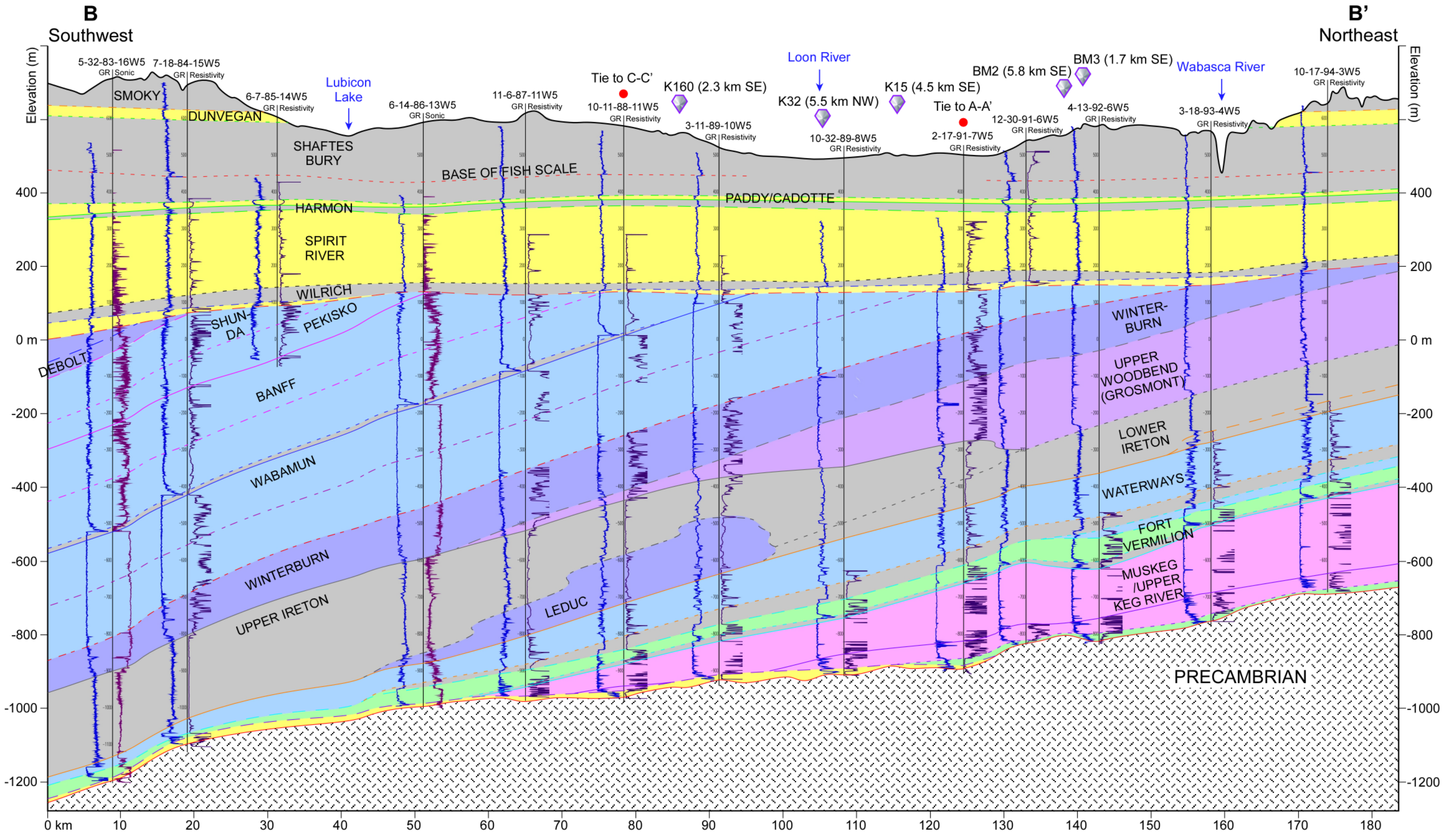

Figure 5. Northeast-trending cross-section B-B'. Vertical scale 1:10,000; horizontal scale 1:500,000 (horizontal versus vertical scale, 1:50). The geophysical logs for selected oil/gas wells are shown. Refer to Figure 1 for the cross-section location and Figure 7 for a legend. Note that glacial deposits are not differentiated from bedrock in this cross-section.

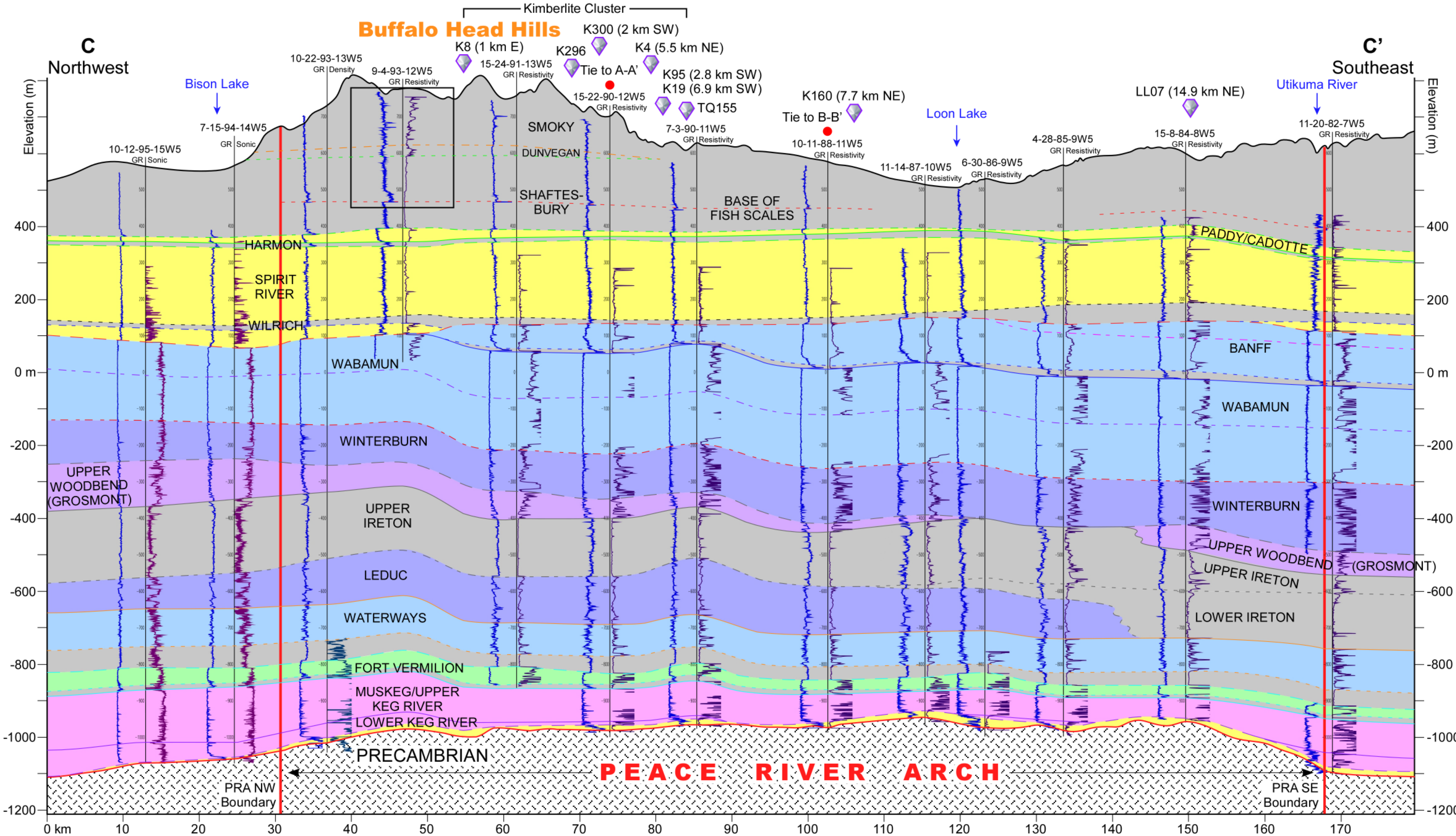

Figure 6. Northwest-trending cross-section C-C'. Vertical scale 1:10,000; horizontal scale 1:480,000 (horizontal versus vertical scale, 1:48). The geophysical logs for selected oil/gas wells are shown. Refer to Figure 1 for the cross-section location and Figure 7 for a legend. Note that glacial deposits are not differentiated from bedrock in this cross-section except for Well 9-4-93-12W5 on the Buffalo Head Hills. See Figure 3 for details of the Upper Cretaceous (black box on Well 9-4-93-12W5). The Peace River Arch (PRA) boundaries are projected from those proposed by O'Connell et al. (1990).

Kimberlite pipes within 10 km of each section (except pipe LL07, which is 14.9 km away) are projected onto the cross-sections. Lateral and vertical scales are present at the bottom and margins of each cross-section. Because of differences in length and high between the three cross-sections, for a better display purpose, each of the three cross-sections (Figures 4, 5 and 6) uses its own lateral versus vertical scales, being 1:38, 1:50 and 1:48 for cross-sections A-A', B-B' and C-C', respectively. The map legend for the cross-sections is provided separately in Figure 7. Note that in cross-section C-C' (Figure 6), Well 9-4-93-12W5, which is up-dip of the average trend of the cross-section, and the immediately next Well 15-24-91-13W5, which is down-dip, act together to falsely 'raise' then 'lower' the stratigraphy, producing a pseudo-fold effect.

Figure 7. Legend for cross-sections A-A' (Figure 4), B-B' (Figure 5), and C-C' (Figure 6).

The northeast-trending cross-section B-B' (Figure 5) is largely sub-parallel to the regional dip; the section thus cuts through most or all of the Phanerozoic formations preserved in the study area and generally shows their maximum thicknesses. In contrast, the northwest-trending cross-section C-C' (Figure 6) is sub-parallel to or along the regional strike; as a result, this cross-section provides the best transect across the PRA.

In general, the overall Phanerozoic sedimentary strata above the Precambrian basement in the BHH–PL region comprise a southwest-thickening wedge (Figures 4, 5 and 6). Within the Paleozoic, the Devonian strata (Granite Wash to Winterburn Group) thicken to the northeast, whereas the Mississippian strata (Exshaw to Debolt formations) thicken to the southwest and are completely eroded in the northeast. In contrast, the overall thickness of Cretaceous strata (Gething/Bluesky formations to Smoky Group) does not change much over the region if the effect from the latest erosion is excluded. The Cretaceous blankets the Paleozoic, but was incised by lowlands/channels during the Cenozoic.

It should be pointed out that in the regional cross-sections, the distance between wells ranges from about 10 to 20 km. Therefore, except for the PRA boundaries with enormous offsets, it is not possible to define a fault that has persistently affected sedimentation using the regional cross-sections from this study.

4.2 Isopach Maps and Digital Elevation Model

The Phanerozoic sedimentary cover in the BHH–PL region is more than 1 200 m thick in the northeast and less than 2 000 m thick in the southwest. This study splits the Phanerozoic cover into four layers and provides preliminary isopach maps (Figures 8, 9, 10 and 11) with a digital elevation model (Figure 12). The purpose of mapping out the sedimentary successions is to view the spatial distribution of the preserved sedimentary successions, observe possible depositional and erosional trends of the successions, and identify locations that may have been affected by faults. The isopach maps of Devonian (Figure 8), Mississippian (Figure 9), Lower Cretaceous (Figure 10), and Upper Cretaceous and Cenozoic (Figure 11) are constructed of 2 870, 3 297, 365 and 400 data points, respectively. Devonian and Mississippian isopachs have very good coverage controls, especially for the Mississippian that has such a large amount of data points contained in half of the mapping area (Figure 9).

The Devonian succession ranges from about 640 to 1 180 m thick (Figure 8) and represents the interval from the base of the Granite Wash to the top of the Wabamun Group. The Devonian strata are characterized by:

- thinning to the southwest on the original PRA;
- thickening outside of the PRA boundaries to the northwest and southeast; and
- being eroded and truncated in the northeast by the overlying Cretaceous strata.

The pattern of the Devonian isopach reflects the combined result from pre-, syn-, and post-depositional tectonic affects; that is:

- uplift of the PRA prior Middle Devonian time and gradual subsidence of the Arch during Middle and Late Devonian time;
- syn-depositional, basin-wide subsidence; and
- post-depositional deformation and erosion prior to deposition of the unconformably overlying Cretaceous in the region.

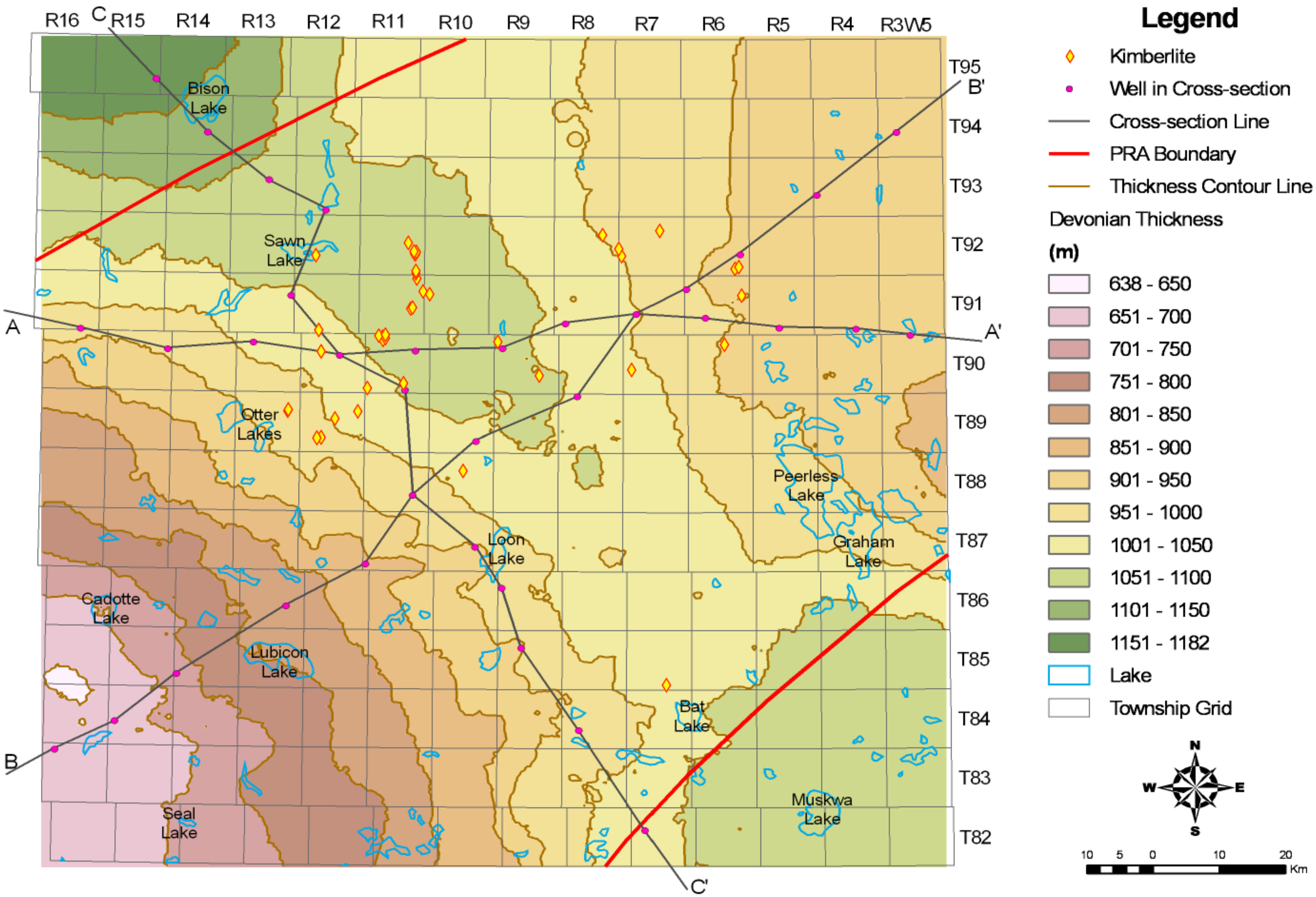

Figure 8. Isopach map of Devonian formations in the Buffalo Head Hills—Peerless Lake region, representing the thickness of the strata from the Granite Wash litho-zone base to the Wabamun Group top. Note that the Wabamun top is truncated by Cretaceous formations in the northeast of the area. The Peace River Arch (PRA) boundaries were digitally compiled by Pana et al. (2001) from O'Connell et al. (1990).

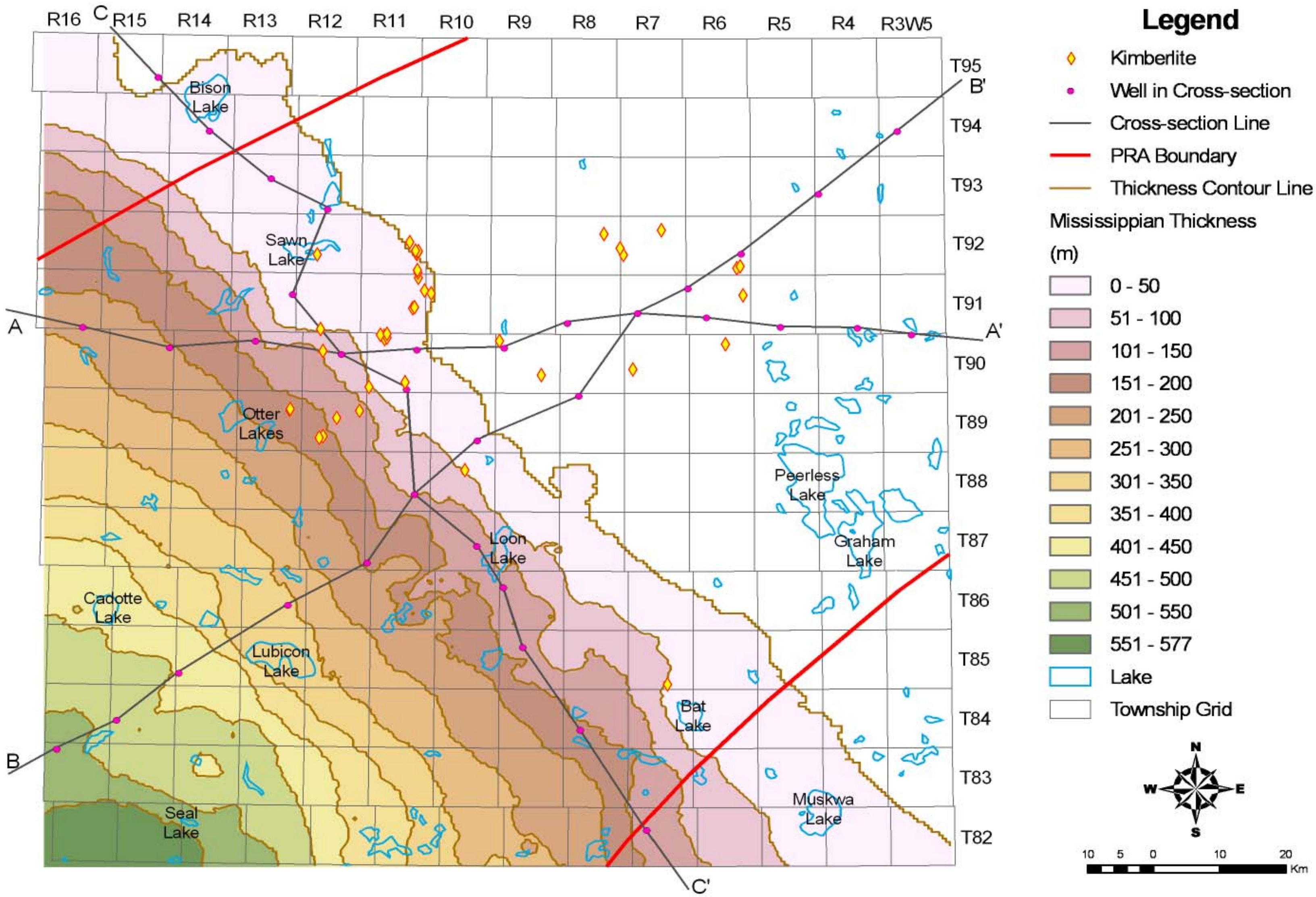

Figure 9. Isopach map of Mississippian formations for the Buffalo Head Hills—Peerless Lake region, representing the thickness of the strata from the Exshaw Formation base to the Rundle Group top erosional surface. The Mississippian strata were truncated to the northeast and is overlain by the Lower Cretaceous units. The Peace River Arch (PRA) boundaries were digitally compiled by Pana et al. (2001) from O'Connell et al. (1990).

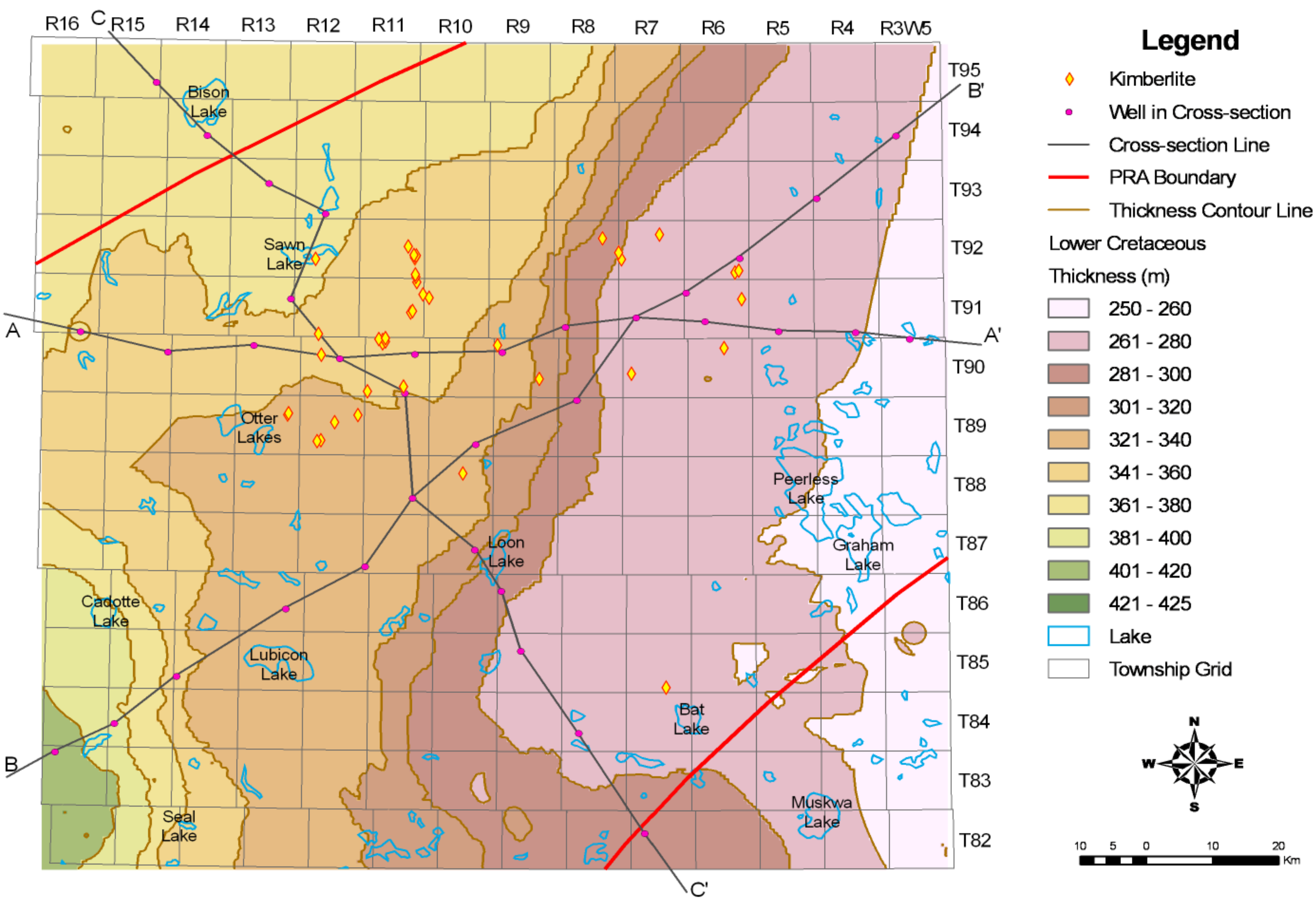

Figure 10. Isopach map of Lower Cretaceous formations for the Buffalo Head Hills—Peerless Lake region, representing the thickness of the strata from the base of the Gething and/or Bluesky Formation to the base of the Fish Scales Formation. The Peace River Arch (PRA) boundaries were digitally compiled by Pana et al. (2001) from O'Connell et al. (1990).

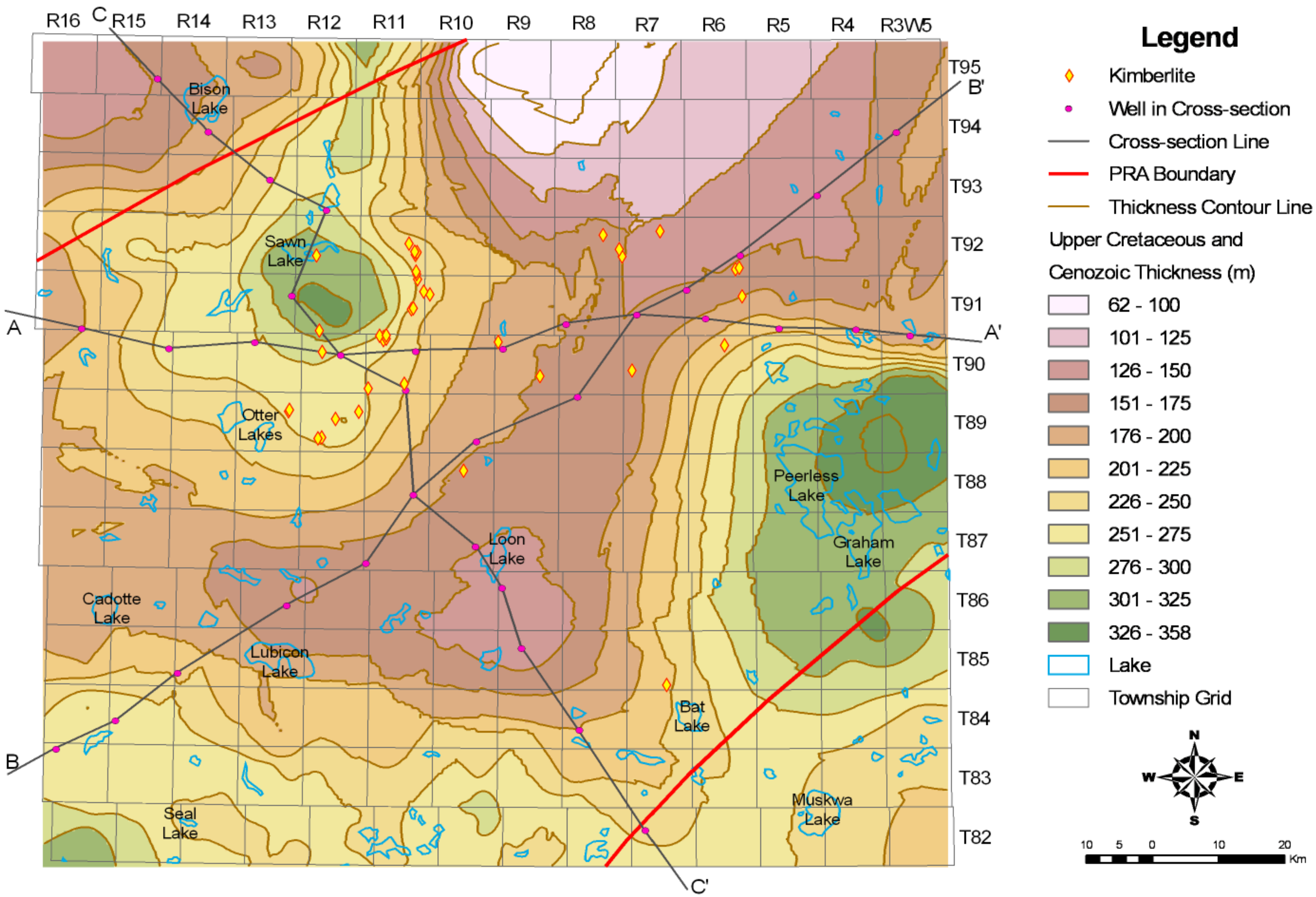

Figure 11. Isopach map of Upper Cretaceous and Cenozoic formations for the Buffalo Head Hills—Peerless Lake region, representing the thickness of the strata from the base of the Fish Scales Formation to the ground surface. Note that the pattern of this isopach map is very similar to that of the ground surface topography in Figure 12. The Peace River Arch (PRA) boundaries were digitally compiled by Pana et al. (2001) from O'Connell et al. (1990).

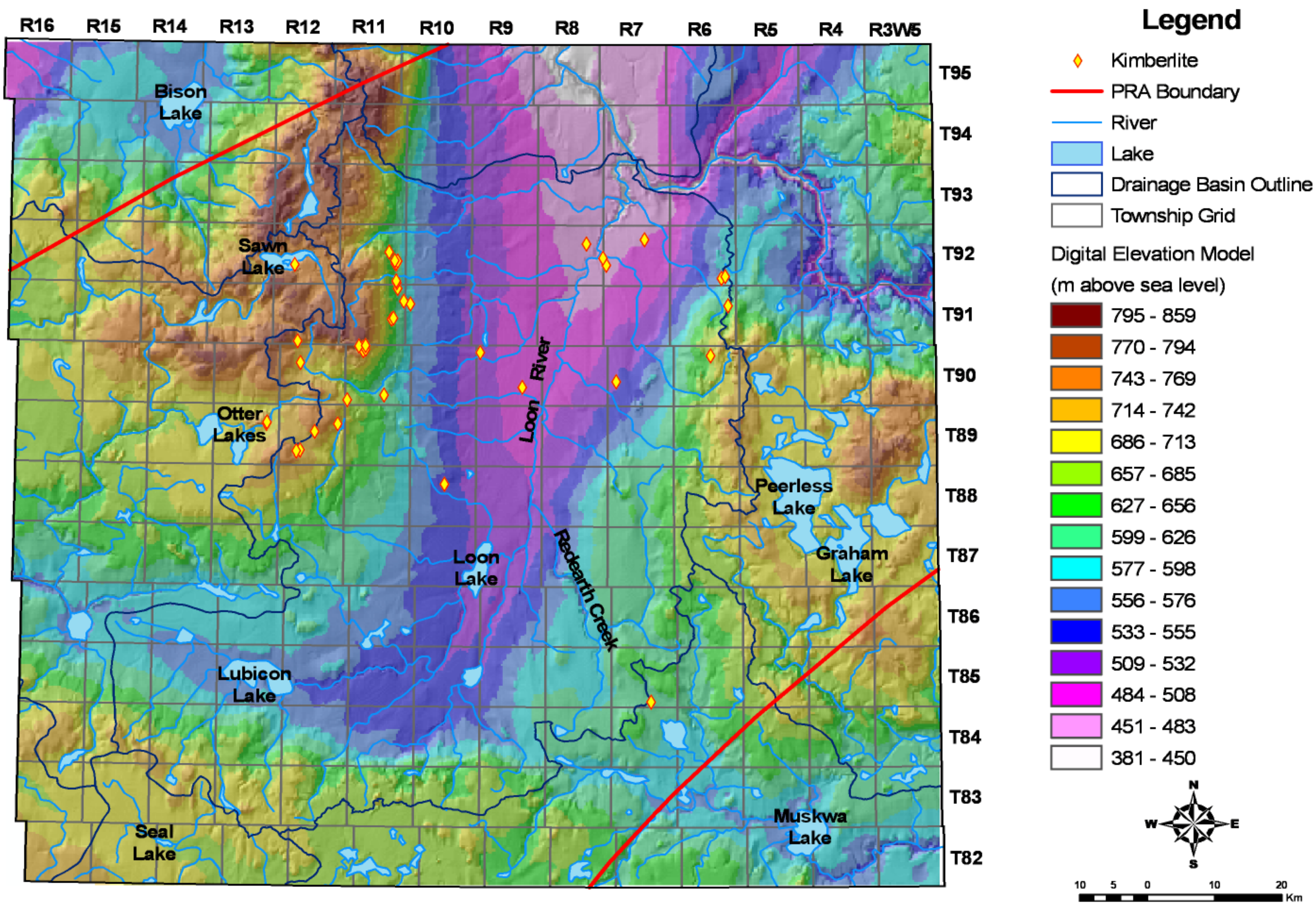

Figure 12. Digital elevation model of the ground surface for the Buffalo Head Hills—Peerless Lake region. Note that the east half of the Buffalo Head Hills relatively steeply descends into the Loon River Valley; this may have resulted from tectonism related to the Peace River Arch uplift post Late Cretaceous deposition and to subsequent syn-glacial/post-glacial erosion. The Peace River Arch (PRA) boundaries were digitally compiled by Pana et al. (2001) from O'Connell et al. (1990).

The Mississippian isopach ranges from zero thickness up to a maximum of about 580 m thick in the southwest and represents the interval from the base of the Exshaw Formation to the erosional top of the Rundle Group (Figure 9). The Mississippian succession 1) is truncated by the Cretaceous in the northeast (almost half of the study area), and 2) possibly slightly thins outside of the PRA boundaries proposed by O'Connell et al. (1990).

The Lower Cretaceous thickness ranges from about 250 to 430 m (Figure 10) and represents the interval from the base of the Bluesky/Gething formations to the Base of Fish Scales Marker. The Lower Cretaceous succession slightly thickens to the west and northwest with separate depo-centres in the northwest and southwest. These depo-centres may result from the influences by 1) the resumed collapse of the PRA to the southwest and 2) the convergence event along the continental margin to the northwest.

The preserved Upper Cretaceous and Cenozoic strata from the Base of Fish Scales Marker to ground surface in the study area range about 60 to 360 m in thickness (Figure 11). The isopach thickens in the Sawn Lake, Peerless Lake and Seal Lake areas (present highlands), and thins in the Loon River and Muskwa – Lubicon lakes areas (present lowlands). Although the interval includes glacial deposits, generally, glacial deposits are thinner in highland areas and thicker in lowland areas of the BHH–PL region. This means that the drift does not contribute to the thickness on the present highlands. The pattern of the isopach in Figure 11 is very similar to that of the digital elevation model in Figure 12. Figure 11 does not show much impact from the underlying PRA structure except perhaps for the PRA northwest boundary that may have affected the bedrock top erosion.

On the digital elevation model (Figure 12), the east half of the Buffalo Head Hills (Sawn Lake highland) descends relatively steeply into the Loon River Valley. This may have resulted from reactivation of north-trending basement faults (refer to Section 5) related to the basement uplift post Cretaceous deposition and to subsequent syn-glacial/post-glacial erosion. In conclusion, the present bedrock top pattern results from the combination of deposition and erosion of the bedrocks, which was controlled by foreland basin tectonics, basement fault reactivation and surficial processes during syn- and post-Late Cretaceous time. The bedrock top was mainly shaped during post Cretaceous time.

4.3 Characteristics of Formations within the BHH–PL Region

4.3.1 Devonian

The BHH–PL region is on the northeast flank of the ancestral PRA, which was a large structural and topographic high that affected the Paleozoic deposition as a positive feature before being completely inundated. Beginning in Middle Devonian time, deposition of sedimentary rocks in the BHH–PL region consistently onlapped onto the ancestral PRA to the southwest along with subsidence of the Arch (Figure 5). The earliest deposition was identified as the Granite Wash and the Elk Point Group.

The basal siliciclastic unit, the Granite Wash, which was derived from the erosion of PRA, unconformably overlies and onlaps uplifted faulted blocks of Precambrian igneous and metamorphic rocks along the flanks of the Arch at various stratigraphic levels (Trotter and Hein, 1988). The Granite Wash mainly consists of poorly sorted arkosic sandstone and conglomerate that form coalescing alluvial fans. In the subsurface, the early Middle Devonian Granite Wash cannot be differentiated from the late Middle Devonian Gilwood Member in the Watt Mountain Formation to the southwest (i.e., southwest of Well 11-6-87-11W5, Figure 5).

Crickmay (1954) defined nine formations in the Elk Point Group. Four of them are deposited or preserved in the study area. These are, in ascending order, the Chichaga, Lower Keg River, Muskeg/Upper Keg River and Watt Mountain formations. In the BHH–PL region, there was a coastal plain developed to the southwest during Elk Point deposition, whereas there was a shallow shelf setting to the northeast. Shallow water carbonate and evaporites of the Elk Point Group were accumulated in a shallow shelf setting. Meijer Drees (1994) showed a more detailed cross-section of the Elk Point strata in the BHH–PL region. In their cross-section, the Elk Point Group onlaps the Peace River highland and the facies changes from redbeds and marginal clastics in the west and southwest, to carbonate and evaporite to the east and northeast.

By the time of Beaverhill Lake Group deposition (Figure 2), subsidence had changed the BHH–PL region into a transitional belt whereby the shallow-shelf setting in the southwest was suitable for the build-up of shallow water carbonate and reef complexes, whereas the basinal marine setting in the northeast was more favourable for deep-water shale and carbonate accumulation. The Beaverhill Lake Group in the BHH–PL region consists of three formations, which in ascending order, are Fort Vermilion, Slave Point and Waterways formations (Figure 5). The Waterways can be further divided into a lower silicate clay member (equivalent to the Christina or Firebag units in the northeast Alberta Plains) and an upper carbonate member (equivalent to the Calumet, Moberly and Mildred units in the northeast Plains). The shallow, restricted carbonate-evaporite sediments of the Fort Vermilion and Slave Point formations onlapped a stable PRA.

When the PRA shrank to an island in middle Frasnian time, the BHH–PL region became part of a shale basin; afterwards the region evolved into a carbonate shelf in the northeast and a deepwater basin in the southwest. The Woodbend Group can be divided into three units, which in ascending order, are Leduc, Ireton, and Grosmont formations. Typical deposits of the Leduc Formation comprise stacked carbonate platform deposits that occurred in three major stages: a basal transgressive ramp, a locally rimmed shelf and a distally steepened muddy carbonate ramp (Dix, 1990). In late Frasnian time, on the Grosmont platform margin, the northwest-trending Hondo evaporite tongue was developed across the central area of the BHH–PL region. By the end of the overlying Winterburn Group deposition, however, the basin topography became relatively flat (Switzer et al., 1994).

The PRA was completely submerged in latest Devonian time and the BHH–PL region became part of the Smoky River sub-basin. The uniform deposition of the Wabamun Group was developed in a stable environment of outer-shelf to basin and is characterized by dolomitic limestone and calcareous dolomite (Halbertsma, 1994).

4.3.2 Mississippian

Although an anomalously thick sedimentary succession of Carboniferous age is preserved in the Peace River region of north-central Alberta and northeastern British Columbia (O’Connell, 1990), less than 600 m of only Mississippian formations is preserved in the southwest part of the BHH–PL region. The preserved Mississippian formations exist as a carbonate wedge with a northwest-trending erosional edge running diagonally across the area between Bison and Muskwa lakes (Figures 5 and 9). In the subsurface of the BHH–PL region, three Lower Mississippian units remain; these are the Exshaw and Banff formations and the Rundle Group. The Lower Mississippian strata are primarily composed of carbonate with minor siliciclastic units.

The diachronous Exshaw Formation is of latest Devonian to earliest Carboniferous age. Typically, the Exshaw consists of fine siliciclastics, with the lithology gradationally changing from more shaly in the lower part to more silty in the upper part. The fine-grained siliciclastics of the Exshaw Formation were deposited in euxinic-basin to shallow-neritic environments during late Famennian and earliest

Tournaisian time, and the black shale in the lower member records the culmination of a regional transgression (Richards et al., 1994). The Exshaw shale is only present in the southwest of the BHH–PL region, and the unit gradually tapers out to the northeast.

The Banff Formation is primarily a heterogeneous assembly of carbonate ramp and siliciclastic sedimentary rocks (Richards et al., 1994) and appears to be a shallowing-upward sequence. The Banff Formation can be divided into the lower and the upper successions (Warren, 1927). 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 (Richards et al., 1994).

The Rundle Group is an overall shallowing-upward succession, can be divided into the Pekisko, Shunda and Debolt formations, but is only preserved in the Seal–Lubicon lakes area (Figures 4, 5 and 6). In the subsurface, the Pekisko Formation consists predominantly of light coloured, coarsely crinoidal and fragmental, to fine-grained, sparsely crinoidal, in part dense limestone (Douglas, 1953), and formed on a shallow shelf setting that passes westerly into the slope and basin. The Shunda Formation consists of interbedded limestone and dolomite, argillaceous limestone, silty and argillaceous dolomite, siltstone, sandstone, shale and breccia (Stearn, 1956). The unit is characterized by its lithological heterogeneity and by the predominance of argillaceous carbonates and shale. The Debolt Formation consists mainly of shallow and restricted shelf carbonate, with anhydrite and carbonate predominating in the upper Debolt (O'Connell, 1990).

The entire interval between the Mississippian Debolt Formation and the Lower Cretaceous Gething Formation is missing from the BHH–PL region, which may have resulted from truncation beneath several sub-Triassic to sub-Cretaceous subaerial unconformities.

4.3.3 Lower Cretaceous

By Middle Mesozoic time, however, the BHH–PL region had turned into a foreland basin environment; as a result siliciclastic sediments derived from the west, including from the early- and later-forming Rocky Mountains, were shed into the region. After a lengthy time hiatus (about 210 million years), the BHH–PL region began receiving deposits of the Lower Cretaceous Gething and Bluesky formations in late Aptian time. The Gething and Bluesky formations comprise sand-rich units that were deposited at the base of a marine succession, are very thin and are discontinuously distributed in the topographically low areas on the sub-Cretaceous unconformity (Figures 4, 5 and 6).

The Spirit River Formation was deposited when collapse of the PRA occurred during Albian time. The westerly thickening of this unit and the depo-centre in the southwest (Figure 10) may have resulted from this effect. In the study area, the Spirit River Formation consists essentially of coarsening-upward clastics with the fine-grained Wilrich member at the base.

The Peace River Formation (late middle to late Albian) is characterized by stacked progradational shoreline sequences, incised valleys and subsequent valley-fills, unconformable surfaces, condensed sections of marine shelf deposits, erosional shoreface notches and paleosols (Leckie and Reinson, 1993). The shaly lower part of the Peace River Formation is named the Harmon Member, and the sandy upper part is named the Paddy and Cadotte members. The Joli Fou Formation, which exists to the east in northeastern Alberta and Saskatchewan and to the south in the central Alberta Plains, is equivalent to the Harmon Member. The Viking Formation, which also exists to the east and to the south, is equivalent to Paddy and Cadotte members (Tizzard and Lerbekmo, 1975; Caldwell et al., 1978; Simpson and O'Connell, 1979). In the BHH–PL region, the Peace River Formation is relatively thin, but its upper sandy part slightly thickens in the Sawn Lake area (Figure 6), west of Sawn and Otter lakes (Figure 4), and south and southwest of Muskwa–Lubicon–Cadotte lakes area (Figures 5 and 6).

4.3.4 Upper Cretaceous and Quaternary

The preserved Upper Cretaceous succession in the BHH–PL includes the Shaftesbury and Dunvegan formations, and Smoky and Wapiti groups (Figure 3). The Shaftesbury Formation comprises fine siliciclastics and is commonly divided into three members (in ascending order):

1) Lower Shaftesbury
2) Fish Scale Zone
3) Upper Shaftesbury (Figure 3)

The Base of Fish Scales is usually used as the boundary between the Upper and Lower Cretaceous. Typically, the Lower Shaftesbury Member below the Base of Fish Scales consists of dark mudstone with minor amounts of bioturbated silty shale and bentonite (Leckie et al., 1994). The Fish Scales Zone, which is the Shaftesbury Formation between the Base of Fish Scales Marker and the Fish Scales Upper Marker, is highly radioactive (Figure 3) and may contain abundant fish remains (scales and skeletal material) within finely laminated, generally non-bioturbated sandstone and siltstone (Leckie et al., 1994). The Shaftesbury Formation above the Fish Scales Upper Marker comprises mainly shale and siltstone, and may contain iron rich sandstone in its upper part (Figure 3).

The Cenomanian Dunvegan Formation represents a fluvio-deltaic wedge and is composed of sand-rich progradational cycles. Concretional layers of iron rich sandstone present in places in the formation (Figure 3). Laterally, the formation thins and fines southeastward and changes from a prograding deltaic facies in the northwest to a shale-dominated shallow shelf facies in the southeast (Smith, 1994). The sand-rich unit pinched out in the southeast portion of the study area (Figure 6) and was eroded along the Loon River–Lubicon Lake lowland and near Bison Lake (Figures 4, 5 and 6).

The Smoky Group consists of marine, thinly bedded, dark silty shale with occasional ironstone and claystone nodules, and thin bentonite streaks. In the BHH–PL region, the Smoky Group can be divided into three formations by the Second White Specks and Colorado Top markers (Figure 3). They are, in ascending order, the Second White Specks, Upper Colorado and Lea Park formations. The Smoky Group in the BHH–PL region underwent severe post-Cretaceous erosion and is best preserved on the Buffalo Head Hills (Figures 4, 5 and 6).

The Wapiti Group, which consists of medium- to coarse-grained, feldspathic, calcareous, buff weathering sandstone (Stott, 1960), also is preserved on the Buffalo Head Hills (Figure 3). However, most of the Wapiti Group and the entire overlying Scollard and Paskapoo formations were either not deposited or are completely eroded from the BHH–PL region. Lastly, of possible economic interest is the fact that a coal bed, about 3 m thick, was identified in the base of the Wapiti Group based on its geophysical features (Figure 3).

The bedrock topography map (Fenton et al., 1994) shows that the sub-surficial sediment erosional pattern of the BHH–PL region is similar to the present topography of the region. The similarity of the Upper Cretaceous–Cenozoic isopach pattern (Figure 11) to the present topography pattern (Figure 12) indicates that the region was mainly shaped prior to or syn-basal Quaternary deposition. The stripping away of the bedrock units from the eastern margin of the Buffalo Head Hills had not occurred until latest Cretaceous time and may have resulted from one or more of the following processes:

- basement uplift and reactivation of north-trending basement faults (refer to the next chapter of this report) syn- and post-Late Cretaceous time;
- accelerated erosion to the east across the crest of the uplifted basement, perhaps beginning in Eocene time;
- syn-glacial/post-glacial scouring along the eroded lowland, especially toward the south and southwest during early Quaternary; and
- subsequently, recent erosion by rivers and streams that are draining the highland regions.

5 Present Peace River Arch and Precambrian Basement Top

The basement in the BHH–PL region was 1) the northeast flank of the ancestral PRA in Devonian time (Figures 5 and 8), 2) a distal-ramp to slope environment in Mississippian time (Figure 9), and 3) a hinge-platform setting of the foreland basin in Early Cretaceous time (Figure 10). The original Arch uplift left a weak zone in the basement floor, which could have provided pathways for kimberlitic pipes.

Experiencing multi-episodes of uplift and subsidence, the present Precambrian basement in the BHH–PL region appears to be a positive feature (Figure 13), which is about 100 m higher than the regional basement elevation of the foreland basin within the PRA boundaries as digitally compiled by Pana et al. (2001) from O'Connell et al. (1990). In Figure 13, in which the regional slope has not been removed, the present Precambrian basement forms an uplifted region trending northeasterly within O'Connell's (1990) PRA boundaries. The Precambrian top sits about 700 to 1 280 m below the present sea level in the BHH–PL region.

More than 3 230 wells have reached the Precambrian in the BHH–PL region to date (Figure 14). The data set from these wells was used to generate a structural contour map of the Precambrian top (Figure 13) and a residual map of the top (Figure 15) with the interpolation method being 'Inverse Distance Weighted' of ArcGIS®.

Fifteen lineaments have been inferred in the present study, which include five north-trending lineaments, L_{N1} to L_{N5} (navy-blue dashed lines in Figures 13 and 15); six northeast-trending lineaments, L_{NE1} to L_{NE6} (red and purple dashed lines in Figures 13 and 15); three northwest-trending lineaments, L_{NW1} to L_{NW3} (brown dashed lines in Figures 13 and 15); and one east-trending lineament, L_E (black dashed line in Figures 13 and 15). The lineament inference is based on

- changes of contour line strike and pattern of the Precambrian basement top (Figure 13);
- the residual pattern of the Precambrian basement top (Figure 15); and
- the distribution of oil and gas pools and production (Figure 16).

Evidence that some or all of these basement lineaments are faults are that structural contours are bent and shifted in direction across the inferred lineaments (Figure 13). As well, it can be discerned that the structural contours change significantly across the lineaments L_E, L_{NE1} and L_{NE6} (Figure 14). That is, the contours strike largely northwest in the South-central Block, north/north-northwest in the North-central Block, east and northwest in the Southeast Flank Block, and north/north-northeast in the Northwest Flank Block.

The residual map of the Precambrian top (Figure 15) was generated in order to remove the muffling effect of the regional slope and improve the visibility of any anomalies on the Precambrian basement. On

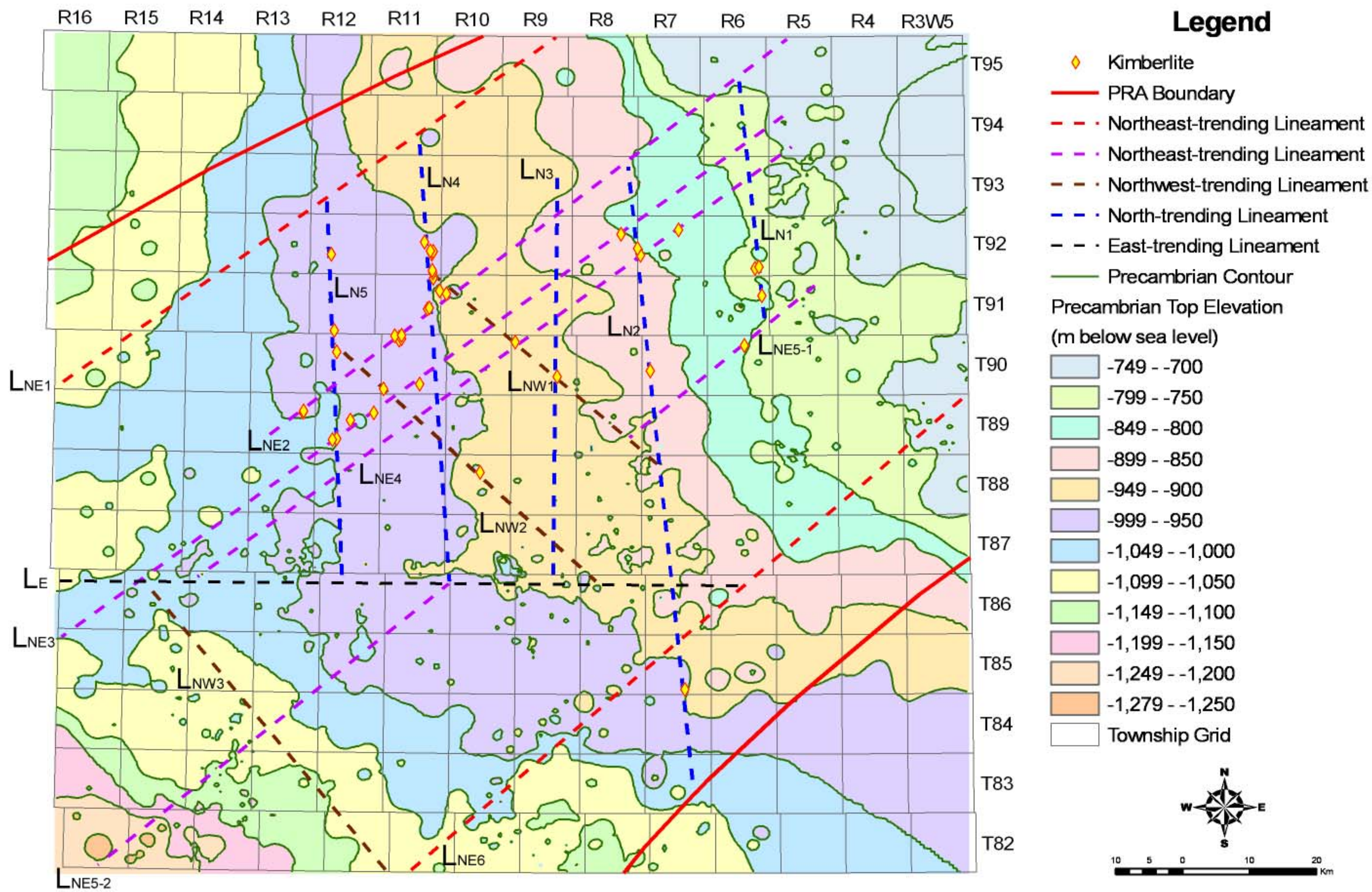

Figure 13. Structural contour map of the Precambrian basement top with inferred lineaments in the Buffalo Head Hills—Peerless Lake region. Fifteen lineaments are inferred by this study, which may reflect possible basement faults. They are north-trending L_{N1} to L_{N5}, northwest-trending L_{NW1} to L_{NW3}, northeast-trending L_{NE1} to L_{NE6}, and east-trending L_E. Contour lines are bent and shifted in direction across the lineaments. The Peace River Arch (PRA) boundaries were digitally compiled by Pana et al. (2001) from O'Connell et al. (1990). see Figure 14 for mapping control points.

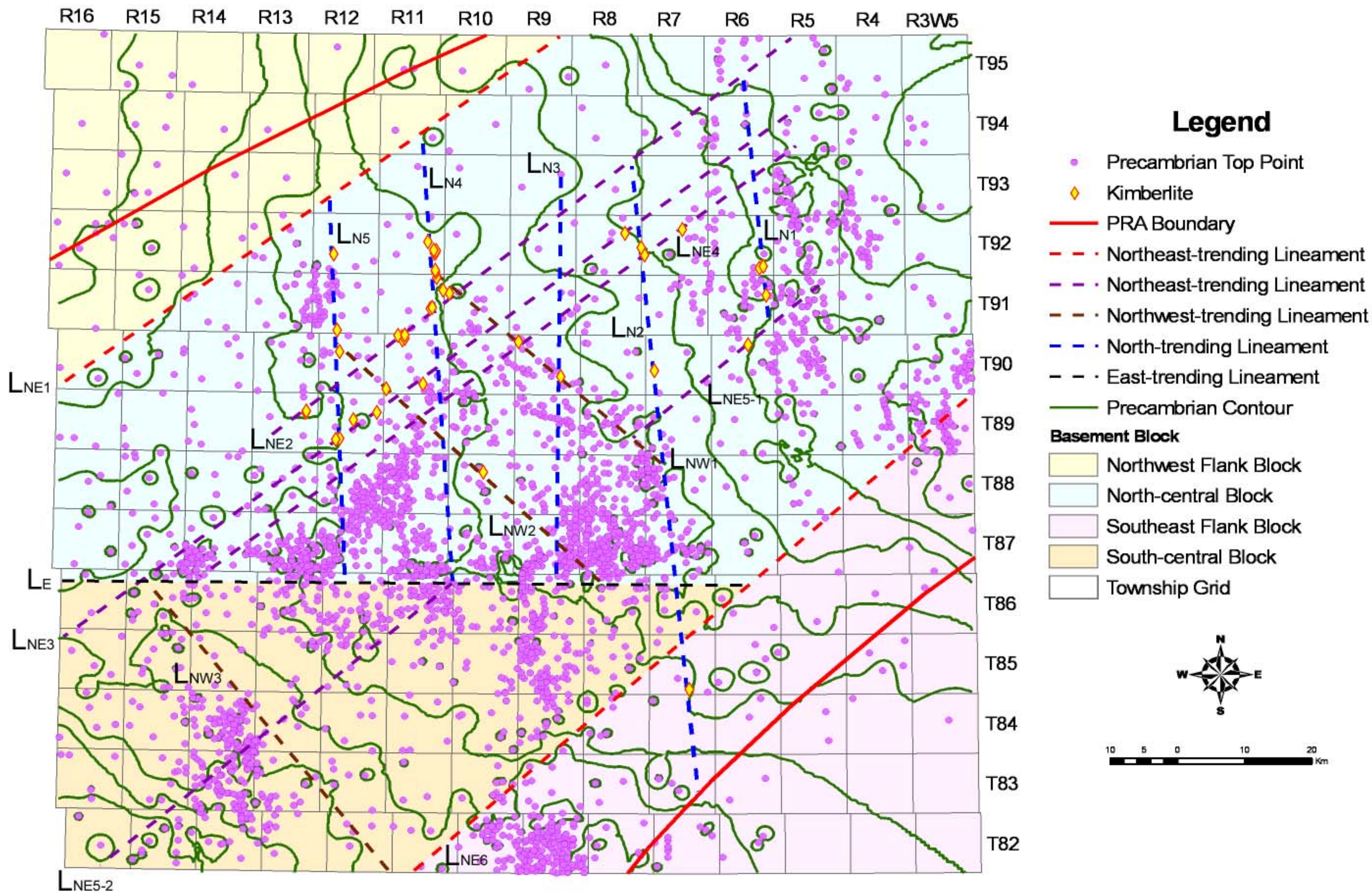

Figure 14. Basement subdivisions and locations of the wells with the Precambrian basement top identified in the Buffalo Head HIlls—Peerless Lake region. There are 3230 mapping control points (pink-filled purple circles) for the maps in Figures 13 and 15. The region can be divided into four large blocks based on the change of the overall contour line strikes and patterns. The Peace River Arch (PRA) boundaries were digitally compiled by Pana et al. (2001) from O’Connell et al. (1990).

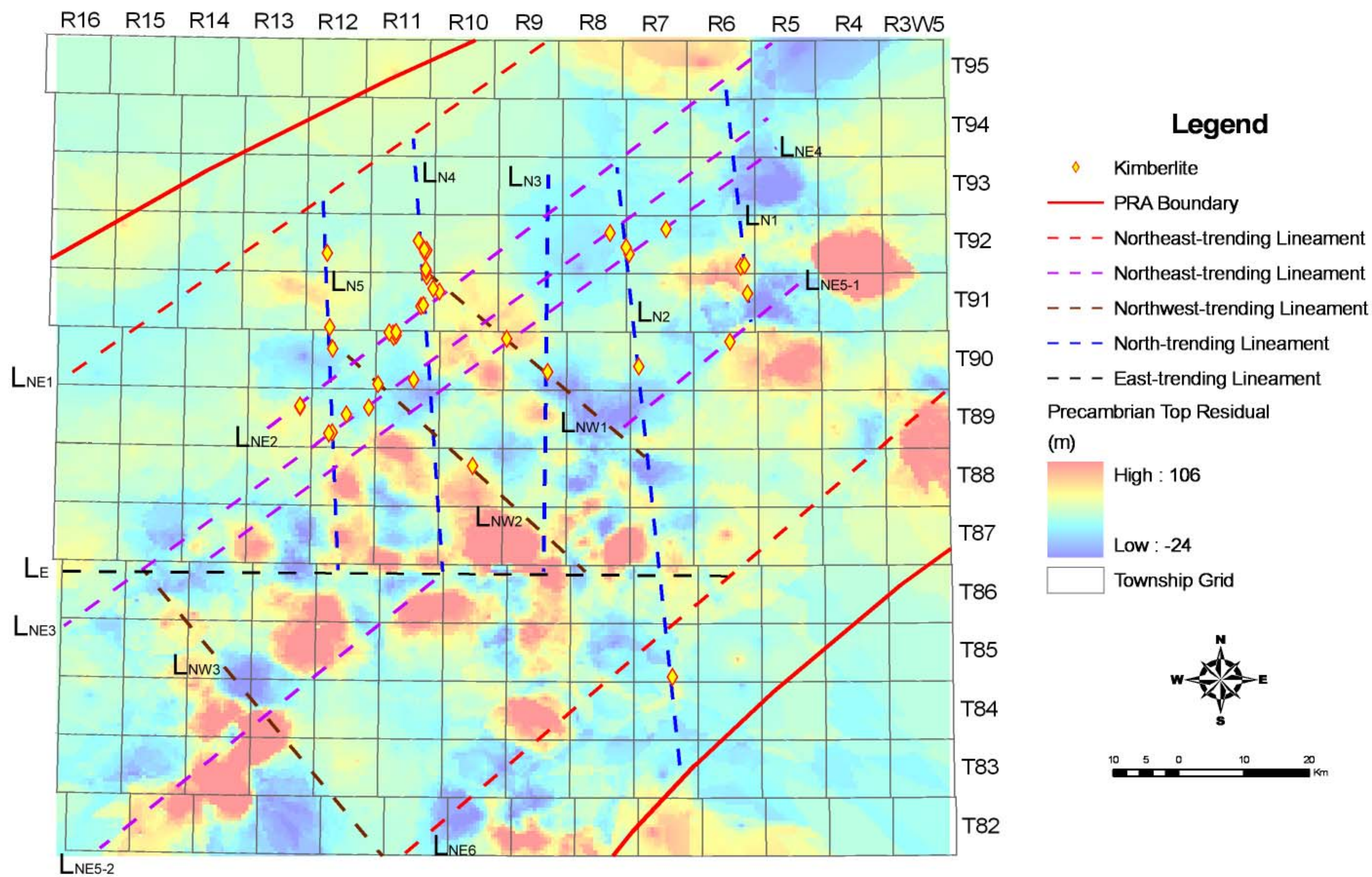

Figure 15. Residual map of the Precambrian basement top with inferred lineaments in the Buffalo Head Hills—Peerless Lake region. On this map, the regional slope has been removed. The present Precambrian basement is uplifted within the boundaries of the Peace River Arch (PRA, as digitally compiled by Pana et al. (2001) from O'Connell et al. (1990) and is composed of a swarm of topographic highs and lows. Fifteen lineaments are inferred by this study, which may reflect possible basement faults. See Figure 14 for mapping control points.

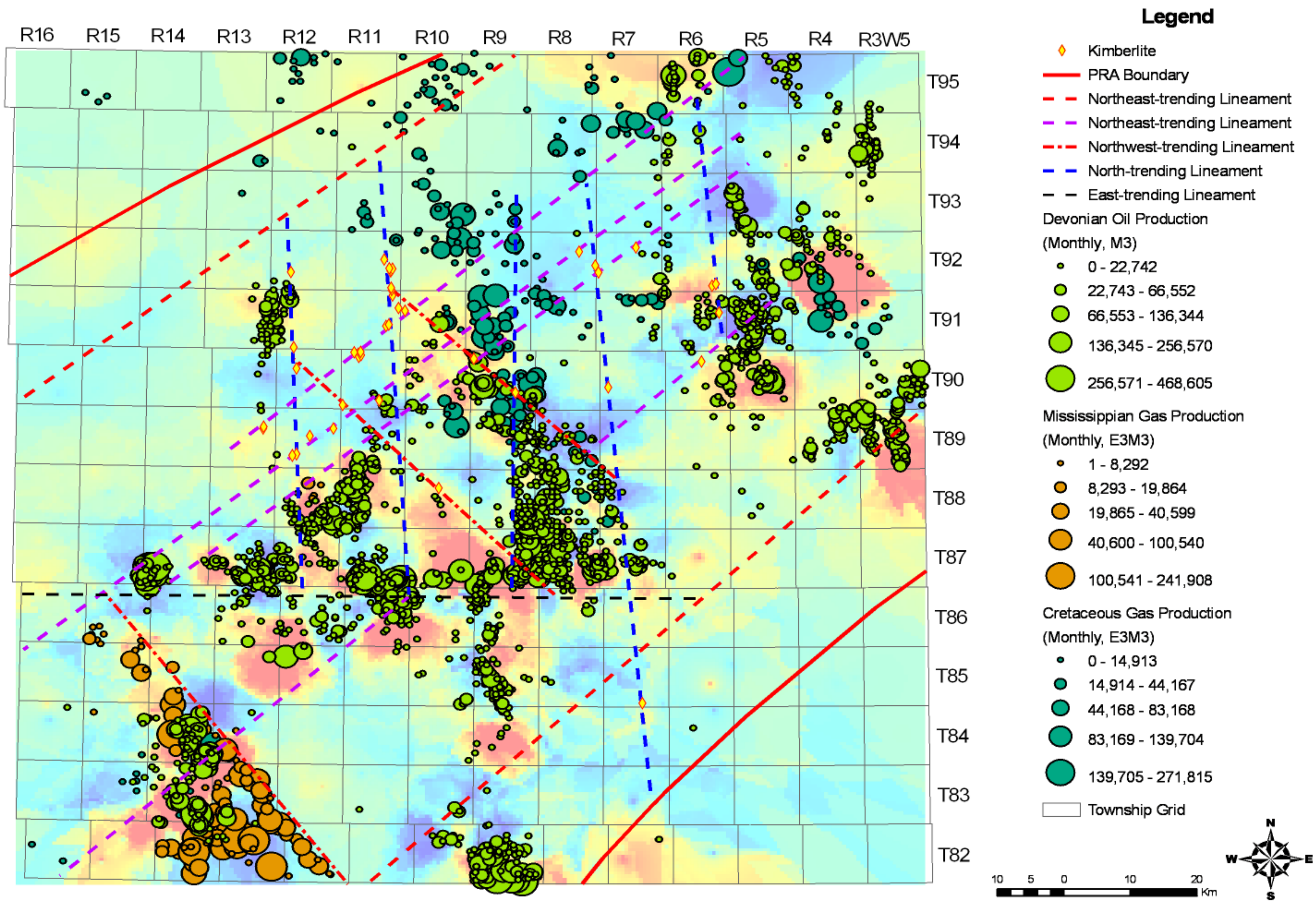

Figure 16. Distribution of oil and gas pools and production in the Buffalo Head Hills—Peerless Lake region, showing strong impact by the basement topography and lineaments. The pools are seemingly preferentially distributed along and around basement highs and confined by the lineaments inferred by this study. The Peace River Arch (PRA) boundaries were digitally compiled by Pana et al. (2001) from O'Connell et al. (1990). Figure 15 for lineament names and Precambrian top residuals.

the residual map, the regional slope has been removed, but otherwise the anomalies are not exaggerated. Points above the regional slope are positive topographic features, which are displayed in pink to yellow, whereas points below the regional slope are negative topographic lows, which are displayed in violet to light green. That is, all the pink areas represent true topographic highs on the present Precambrian basement top. In Figure 15, the present PRA appear to comprise a swarm of topographic highs and lows that in several places line-up to some degree in preferred directions. The basement lineaments in this study are inferred to occur along the edges of or in the 'troughs' between Precambrian topographic highs. This situation is, in effect, similar to that in the exposed Precambrian in northeastern Alberta where Godfrey (1958a, 1958b, 1961, 1963), based on his geological mapping, aerial photograph and topographic map interpretations, found that many linear to curvi-linear topographic lows (draws and valleys) are underlain by relatively late brittle-ductile and brittle faults. Therefore, the alignment of Precambrian basement topographic highs and lows in Figure 15 may in some way reflect pre-Devonian lithological and/or structural controlled differential erosion.

The distribution of oil and gas pools and production in Figure 16 shows strong impact by the basement topography and lineaments in the BHH–PL region. The pools are seemingly preferentially distributed along and around basement highs and confined by the lineaments inferred in the current study. Furthermore, the kimberlite pipes in the Buffalo Head Hills area are coincidently along the inferred lineaments. These lineaments may reflect possible brittle or brittle-ductile basement faults. Such basement faults, if active or re-activated during the Phanerozoic, may have influenced the Phanerozoic sedimentation (e.g., Figures 8 to 12), the location of oil and gas pools (Figure 16), and perhaps kimberlite emplacement during the Latest Cretaceous (Figure 15).

6 Summary

Three regional cross-sections were constructed and 34 stratigraphic surfaces from the ground surface down to the Precambrian basement top were identified and picked for each of the selected wells in the cross-sections. Correlation markers and picking protocols of formation tops are described in the report. The Upper Cretaceous formations are defined and characterized with the geophysical logs for the Buffalo Head Hills area.

The BHH–PL region was situated on the northeast flank of the ancestral PRA in Devonian time. A distal-ramp to slope environment was developed in Mississippian time. By Cretaceous time, the region was along or near the east median hinge to eastern platform of the foreland basin. The original PRA uplift left a weak zone in the basement, and this could have provided or led to later fault pathways that facilitated kimberlite intrusive emplacement in latest Cretaceous time.

The Phanerozoic sedimentary cover in the BHH–PL region is a southwest-thickening wedge, ranging about 1 200 to 2 000 m in thickness. Two major regional unconformities exist in the Phanerozoic bedrocks in the BHH–PL region: sub-Granite Wash and sub-Cretaceous unconformities. The Phanerozoic bedrocks are divided into two large depositional successions: 1) the Middle Devonian to Lower Mississippian succession, and 2) the upper Lower to lower Upper Cretaceous succession.

The Devonian succession range from about 640 to 1 180 m thick, thins to the southwest, is truncated in the northeast, and thickens outside of the PRA boundaries in the northwest and southeast. The Mississippian is less than 580 m thick, thickens to the southwest, is truncated by the Cretaceous in the northeast, and slightly thins outside of the PRA boundaries. The Lower Cretaceous ranges from about 250 to 430 m thick, thickens to the west and northwest with separated depo-centers in the northwest and southwest at different times. The interval from the Base of Fish Scales Marker to ground surface ranges from about 60 to 360 m thick, thickens in the present highland areas, and thins in the present lowland areas.

The east half of the Buffalo Head Hills relatively steeply descends into the Loon River Valley; this may have resulted from may have resulted from reactivation of north-trending basement faults related to the basement uplift post Cretaceous deposition and to subsequent syn-glacial/post-glacial erosion. The present bedrock top pattern mainly results from the accelerated erosion to the east across the crest of the uplifted basement, glacial scouring along the eroded lowland, and subsequent erosion by rivers and streams. Finally, the bedrock top was mainly shaped in post latest Cretaceous time.

At present the Precambrian basement shows as an uplifted region of about 100 m on the structural contour map of the Precambrian floor of the foreland basin. On the residual map obtained by computer removal of the regional slope, the Precambrian basement within the study area appears as a swarm of topographic highs and lows (Figure 15). In some cases the basement highs and lows appear preferentially aligned, which may indicate basement faults. Fifteen lineaments have been inferred in this study based on changes of contour line strike and pattern of the Precambrian basement top, the residual pattern of the Precambrian basement top, and the distribution of oil and gas pools and production. In general, the main lineaments trend north, northeast, northwest and east. The kimberlite pipes in the Buffalo Head Hills area are coincidently along the inferred lineaments. Finally, it is suggested that in places all or some of the inferred basement faults may have influenced the Phanerozoic sedimentation, the location of oil and gas pools and perhaps kimberlite intrusive emplacement.

7 References

Armstrong, R.L. (1993): Late Triassic to Earliest Eocene magmatism in the North American Cordillera: implications for the Western Interior Basin; *in* Evolution of the Western Interior Basin, W.G.E. Caldwell and E.G. Kauffman (ed.), Geological Association of Canada, Special Paper 39, p. 49-72.

Bloch, J., Schroder-Adams, C., Leckie, D.A., McIntyre, D.J., Craig, J. and Staniland, M. (1993): Revised stratigraphy of the lower Colorado Group (Albian to Turonian), Western Canada; Bulletin of Canadian Petroleum Geology, v. 41, no. 3, p. 325-348.

Burk, C.F. Jr. (1962): Upper Cretaceous structural development of the southern flank of the Peace River Arch; Journal of Alberta Society of Petroleum Geologists, v. 10, no. 5, p. 223-227.

Burwash, R.A, McGregor, C.R. and Wilson, J. (1994): Precambrian basement beneath the Western Canada Sedimentary Basin; *in* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, chap. 5, p. 49-56.

Caldwell, W.G.E., North, B.R., Stelck, C.R. and Wall, J.H. (1978): A foraminiferal zonal scheme for the Cretaceous System in the Interior Plains of Canada; *in* Western and Arctic Canadian Biostratigraphy; C.R. Stelck and B.D.E. Chatterton (ed.), Geological Association of Canada, Special Paper 18, p. 495-575.

Cant, D.J. (1988): Regional structure and development of the Peace River Arch, Alberta: a Paleozoic failed-rift system?; Bulletin of Canadian Petroleum Geology, v. 36, no. 3, p. 284-295.

Carlson, J.A., Kirkley, M.B., Thomas, E.M. and Hillier, W.D. (1999): Recent Canadian kimberlite discoveries; *in* 7th International Kimberlite Conference, J.J. Gurney, J.L. Gurney, M.D. Pascoe and S.H. Richardson (ed.), Red Roof Publishers, Cape Town, South Africa, v. 1, p. 81-89.

Chen, D. (2000): Cretaceous Stratigraphy and Basement Influences in Peace River Arch region, Western Canada Sedimentary Basin; Ph.D. thesis, University of Regina, 146 p.

Chen, D. and Bergman, K.M. (1999): Stratal reorientation, depositional processes, and sequence evolution of the Cretaceous in the Peace River Arch region of the Western Canada Sedimentary Basin; Bulletin of Canadian Petroleum Geology, v. 47, no. 4, p. 594-620.

Coney, P.J., Jones, D.L. and Monger, J.W.H. (1980): Cordilleran suspect terranes; Nature, v. 288, no. 27, p. 329-333.

Cotterill, D. and Berhane, H. (1996): Preliminary mapping and field reconnaissance of the Lower to Upper Cretaceous (Middle to Lower Turonian) stratigraphy – northeastern Alberta; Alberta Energy and Utilities Board, EUB/AGS Open File Report 1996-05, 48 p.

Crickmay, C.H. (1954): Paleontological correlation of Elk Point and equivalents; *in* Western Canada Sedimentary Basin, Ralph Leslie Rutherford Memorial volume, L.M. Clark (ed.), AAPG Bulletin, p. 143-158.

de Mille, G. (1958): Pre-Mississippian history of the Peace River Arch; Journal of Alberta Society of Petroleum Geologists, v. 6, no. 3, p. 61-69.

Dix, G.R. (1990): Stages of platform development in the Upper Devonian (Frasnian) Leduc Formation, Peace River Arch, Alberta; Bulletin of Canadian Petroleum Geology, v. 38A, p. 66-92.

Dixon, J. (1993): Cretaceous tectonics and sedimentation in northwest Canada; *in* Evolution of the Western Interior Basin: Geological Association of Canada, W.G.E. Caldwell and E.G. Kauffman (ed.), Special Paper 39, p. 119-129.

Douglas, R.J.W. (1953): Carboniferous stratigraphy in the southern Foothills of Alberta; *in* 3rd Annual Field Conference Guidebook, Alberta Society of Petroleum Geologists, p. 66-88.

Dufresne, M.B., Olson, R.A., Schmitt, D.R., McKinstry, B., Eccles, D.R., Fenton, M.M., Pawlowicz, J.G., Edwards, W.A.D. and Richardson, R.J.H. (1994): The diamond potential of Alberta: a regional synthesis of the structural and stratigraphic setting, and other preliminary indicators of diamond potential; Alberta Research Council, Alberta Geological Survey, Open File Report 1994-10, 349 p.

Dufresne, M.B., Eccles, D.R., McKinstry, B., Schmitt, D.R., Fenton, M.M., Pawlowicz, J.G. and Edwards, W.A.D. (1996): The diamond potential of Alberta; Alberta Research Council, Alberta Geological Survey, Bulletin 63, 158 p.

Eaton, D.W., Ross, G.M. and Hope, J. (1999): The rise and fall of a cratonic arch: a regional seismic perspective on the Peace River Arch; Bulletin of Canadian Petroleum Geology, v. 47, no. 4, p. 346-361.

Eccles, D.R., Grunsky, E.C., Grobe, M. and Weiss, J. (2000): Structural-emplacement model for kimberlitic diatremes in northern Alberta; Alberta Energy and Utilities Board, EUB/AGS Earth Sciences Report 2000-01, 106 p.

Eccles, D.R., Heaman, L.M. and Creaser, R.A. (2003): Radiogenic isotope geochemistry of kimberlitic rocks in northern Alberta: constraints for source of magmatism and emplacement age; Alberta Energy and Utilities Board, EUB/AGS Geo-Note 2003-37, 21 p.

Edwards, D.E., Barckay, J.E., Gibson, D.W., Kvill, G.E. and Halton, E. (1994): Triassic strata of the Western Canada Sedimentary Basin; *in* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop, and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, chap. 16, p. 259-276.

Fenton, M.M., Schreiner, B.T., Nielsen, E. and Pawlowicz, J.G. (1994): Quaternary geology of the Western Plains; *in* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop, and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, chap. 26, p. 413-420.

Garland, G.D. and Bower, M.E. (1959): Interpretation of aeromagnetic anomalies in northeastern Alberta; *in* Fifth World Petroleum Congress, Proceedings, Geology and Geophysics, section 1, p. 787-800.

Gibson, D.W. and Edwards, D.E. (1990): An overview of Triassic stratigraphy and depositional environments in the Rocky Mountain Foothills and Western Interior Plains, Peace River Arch area, northwestern British Columbia; Bulletin of Canadian Petroleum Geology, v. 38A, p. 146-158.

Godfrey J.D. (1958a): Mineralization in the Andrew, Waugh and Johnson Lakes Area, Northeastern Alberta; Alberta Research Council, Alberta Geological Survey, Earth Sciences Report 1958-04, 17 p.

Godfrey J.D. (1958b): Aerial photographic interpretation of Precambrian structures north of Lake Athabasca; Alberta Research Council, Alberta Geological Survey, Bulletin 1, 19 p.

Godfrey J.D. (1961): Geology of the Andrew Lake, north district; Alberta Research Council, Alberta Geological Survey, Earth Sciences Report 1958-03, 32 p.

Godfrey J.D. (1963): Geology of the Andrew Lake, south district, Alberta; Alberta Research Council, Alberta Geological Survey, Earth Sciences Report 1961-02, 30 p.

Halbertsma, H.L. (1994): Devonian Wabamun Group of the Western Canada Sedimentary Basin; *in* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop, and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, chap. 13, p. 203-220.

Hein, F.J. (1999): Mixed ("multi") fractal analysis of Granite Wash fields/pools and structural lineaments, Peace River Arch area, northwestern Alberta, Canada: a potential approach for use in hydrocarbon exploration; Bulletin of Canadian Petroleum Geology, v. 47, no. 4, p. 556-572.

Hoffman, P.F. (1987): Continental transform tectonics: Great Slave Lake Shear Zone (1.9 Ga), northwest Canada; Geology, v. 15, p. 785-788.

Hoffman, P.F. (1989): Precambrian geology and tectonic history of North America; *in* The Geology of North America, A.W. Bally and A.R. Palmer (ed.), Geological Society of America, p. 447-512.

Kauffman, E.G. and Caldwell, W.G.E. (1993): The Western Interior Basin in space and time; *in* Evolution of the Western Interior Basin, W.G.E. Caldwell and E.G. Kauffman, (ed.), Geological Association of Canada, Special Paper 39, p. 1-30.

Kent, D.M. (1994): Paleogeographic evolution of the cratonic platform – Cambrian to Triassic; *in* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop, and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, chap. 7, p. 69-86.

Lavoie, D.H. (1958): The Peace River Arch during Mississippian and Permo-Pennsylvanian time; Journal of Alberta, Society of Petroleum Geologists, vol. 6, no. 3, p. 69-74.

LeCheminant, A.N., Richardson, D.G., DiLabio, R.N.W. and Richardson, K.A. (1996): Searching for diamonds in Canada; *in* Searching for Diamonds in Canada, A.N. LeCheminant, D.G. Richardson, R.N.W. DiLabio and K.A. Richardson (ed.), Geological Survey of Canada, Open File 3228, p. 1-3.

LeCheminant, A.N. and Kjarsgaard, B.A. (1996): Part 1: geology, petrology, and geotectonic controls – introduction; *in* Searching for Diamonds in Canada, A.N. LeCheminant, D.G. Richardson, R.N.W. DiLabio and K.A. Richardson (ed.), Geological Survey of Canada, Open File 3228, p. 5-9.

Leckie, D.A. (1998): Cretaceous diamond-bearing kimberlites in the Mannville, Colorado, and Wapiti groups of western Canada – not only is there gas and oil, there are diamonds as well!; Canadian Society of Petroleum Geologists, Reservoir, v. 25, issue 8, p. 7.

Leckie, D.A. and Reinson, G.E. (1993): Effects of middle to late Albian sea-level fluctuations in the Cretaceous Interior Seaway, western Canada; *in* Evolution of the Western Interior Basin, W.G.E. Caldwell and E.G. Kauffman (ed.), Geological Association of Canada, Special Paper 39, p. 151-175.

Leckie, D.A., Bhattacharya, J.P., Bloch, J., Gilboy, C.F. and Norris, B. (1994): Cretaceous Colorado/Alberta Group of the Western Canada Sedimentary Basin; *in* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop, and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, chap. 20, p. 335-352.

McNeil, D.H. and Caldwell, W.G.E. (1981): Cretaceous rocks and their foraminifera in the Manitoba escarpment; Geological Association of Canada, Special Paper 21, 439 p.

Meijer Drees, N.C. (1994): Devonian Elk Point Group of the Western Canada Sedimentary Basin; *in* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop, and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, chap. 10, p. 129-148.

O'Connell, S.C. (1990): The development of the Lower Carboniferous Peace River embayment as determined from Banff and Pekisko formation depositional patterns; Bulletin of Canadian Petroleum Geology, v. 38A, p. 93-114.

O'Connell, S.C., Dix, G.R. and Barclay, J.E. (1990): The origin, history, and regional structural development of the Peace River Arch, Western Canada; Bulletin of Canadian Petroleum Geology, v. 38A, p. 4-24.

Paganelli, F., Grunsky, E.C. and Richards, J.P. (2003): Structural interpretation of RADARSAT-1 principal components imagery and its potential application to kimberlite exploration in the Buffalo Head Hills Area, north central Alberta; Alberta Energy and Utilities Board, EUB/AGS Special Report 21, 52 p.

Pana, D. (2002): Precambrian basement of the Western Canada Sedimentary Basin in northern Alberta; Alberta Energy and Utilities Board, EUB/AGS Earth Sciences Report 2002-02, 32 p.

Pana, D., Waters, J. and Grobe, M. (2001): GIS compilation of structural elements in northern Alberta; Alberta Energy and Utilities Board, EUB/AGS Earth Sciences Report 2001-01, 53 p.

Price, R.A. (1994): Cordilleran tectonics and the evolution of the Western Canada Sedimentary Basin; *in* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop, and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, chap. 2, p. 13-24.

Richards, B.C., Barclay, J.E., Bryan, D., Hartling, A., Henderson, C.M. and Hinds, R.C. (1994): Carboniferous strata of the Western Canada Sedimentary Basin; *in* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop, and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, chap. 14, p. 221-250.

Ross, G.M., Parrish, R.R., Villeneuve, M.E. and Bowring, S.A. (1991): Geophysics and geochronology of the crystalline basement of the Alberta Basin, western Canada; Canadian Journal of Earth Sciences, v. 28, p. 512-522.

Simpson, F. and O'Connell, S. (1979): Low-permeability gas reservoirs in marine, Cretaceous sandstones of Saskatchewan, 2. Lower Colorado (middle Albian to Cenomanian) strata of southern Saskatchewan; *in* Saskatchewan Geological Survey, Summary of Investigations, J.E. Christopher and R. Macdonald (ed.), Saskatchewan Mineral Resources, Miscellaneous Report 79-10, p. 181-185.

Smith, D.G. (1994): Paleogeographic evolution of the Western Canada Foreland Basin. *in* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop, and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, chap. 17, p. 277-296.

Stearn, C.W. (1956): Type section of the Shunda Formation; Journal of Alberta Society of Petroleum Geologists, v. 4, p. 237-239.

Stott, D.F. (1960): Cretaceous rocks between Smoky and Pine Rivers, Rocky Mountain Foothills, Alberta and British Columbia; Geological Survey of Canada, Paper 60-16, 52 p.

Stott, D.F. (1963): The Cretaceous Alberta Group and equivalent rocks, Rocky Mountain Foothills, Alberta; Geological Survey of Canada, Memoir 317, 306 p.

Stott, D.F. (1982): Lower Cretaceous Fort St. John Group and Upper Cretaceous Dunvegan Formation of the Foothills and Plains of Alberta, British Columbia, District of Mackenzie and Yukon Territory; Geological Survey of Canada, Bulletin 328, 124 p.

Stott, D.F. (1984): Cretaceous sequences of the foothills of the Canadian Rocky Mountains; *in* The Mesozoic of North America, D.F. Stott and D.J. Glass (ed.), Canadian Society of Petroleum Geologists, Memoir 9, p. 85-108.

Switzer, S.B., Holland, W.G., Christie, D.S., Graf, G.C., Hedinger, A.S., McAuley, R.J., Wierzbicki, R.A. and Packard, J.J. (1994): Devonian Woodbend – Winterburn strata of the Western Canada Sedimentary Basin; *in* Geological Atlas of the Western Canada Sedimentary Basin, G.D. Mossop, and I. Shetsen (comp.), Canadian Society of Petroleum Geologists and Alberta Research Council, chap. 12, p. 165-202.

Tizzard, P.C. and Lerbekmo, J.F. (1975): Depositional history of the Viking Formation, Suffield area, Alberta, Canada; Bulletin of Canadian Petroleum Geology, v. 23, p. 715-752.

Trotter, R. and Hein, F.J. (1988): Sedimentology and depositional setting of the Granite Wash, northwestern Alberta; *in* Sequences, Stratigraphy, Sedimentology: Surface and Subsurface, D.P. James and D.A. Leckie (ed.), Canadian Society of Petroleum Geologists, Memoir 15, p. 475-484.

Warren, P.S. (1927): Banff area, Alberta; Geological Survey of Canada, Memoir 153, 54 p.

Williams, G.K. (1958): Influence of the Peace River Arch on Mesozoic strata; Journal of Alberta Society of Petroleum Geologists, v. 6, no. 3, p. 74-81.