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Alberta Energy and Utilities Board

Alberta Geological Survey

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Abstract

The Clear Hills–Smoky River region is known as a prolific area of oil and gas production; for example, about 14 trillion cubic feet (~400 billion cubic metres) of gas and 652 million barrels (~104 million cubic metres) of oil have been produced from various formations in the region. As well, the Clear Hills iron deposits in the Bad Heart Formation have attracted considerable exploration interest, particularly during the 1950s and 1960s and, more recently, from 2004 onwards. Total iron resources have been estimated by some prior workers at over 1 billion tonnes grading about 34% iron.

Although many regional or targeted stratigraphic studies have been published on individual sedimentary intervals in the region, well log cross-sections showing the complete Phanerozoic are rare. A complicating factor for most of the Upper Cretaceous stratigraphic studies is that they are constrained along the southeast flank of the Peace River Arch (PRA) due to the following reasons: 1) severe erosion of the Upper Cretaceous along the Peace River valley, and 2) the unavailability of shallow geophysical logs in the region. In addition, there are few Upper Cretaceous stratigraphic picks for the Clear Hills area. Finally, and partly as a result of the relative scarcity of accurate and detailed data for the Upper Cretaceous, miscorrelations and wrong data entry exist in both the Alberta Geological Survey and IHS Inc. AccuMap well databases.

This study constructed nine digital log and stratigraphic pick databases for an area encompassing nine 1:250 000 map areas (NTS 83M, N, O, and 84B, C, D, E, F, G), compiled major structural lineaments and formational edges in the region, constructed four regional and two local cross-sections, identified forty-seven stratigraphic horizons, correlated subsurface formations along the cross-sections, evaluated bedrock top formation boundaries with cross-sections and digital elevation model data, and characterized Upper Cretaceous formations on selected logs and the local cross-section.

The depositional centre in the Clear Hills–Smoky River region has shifted through time. The PRA and the 'forebulge' zone have been favourite locales for developing faults. However, there is not a good correlation between the younger faults and the older faults, and between ground surface topography and the subsurface fault structures. Oil and gas fields show northwest dominant trends. The Laramide age 'foredeep,' 'forebulge' and paleo-highlands, along with the Dunvegan, Tangent and Rycroft faults, likely played an important role in hydrocarbon accumulation.

Eight Upper Cretaceous strata are identified with log responses and are correlated with the Base of Fish Scale Marker, flooding surfaces, litho-contact, and log trends and patterns. The results from this study contribute to the understanding of the stratigraphic framework of the Smoky River–Clear Hills region, and will benefit (1) ongoing studies and exploration of the ooidal ironstones in the Clear Hills to Smoky River region, and (2) hydrocarbon exploration in this region.

1 Introduction

1.1 Study Area

The Clear Hills to Smoky River region in northwestern Alberta, which encompasses, particularly in the south, the long-acting Peace River Arch (PRA), has been a prolific oil and gas producer. This region holds the Clear Hills iron deposits in Late Cretaceous (Coniacian) Bad Heart Formation that in the past has attracted considerable exploration interest, as it does currently. Although there have been many previous stratigraphic studies in this region, these studies have mainly focused on individual sedimentary intervals; whereas, well log cross-sections that show the complete Phanerozoic sedimentary successions are rare. As well, stratigraphic studies focused specifically on Upper Cretaceous formations have been mostly done along the southeast flank of the PRA in the Peace River to Smoky River area.

This project was initiated in 2004 to better understand Upper Cretaceous formations across the entire PRA area and to support the exploration of natural resources (i.e., iron, diamondiferous kimberlites, coalbed methane, shallow gas, etc.) in northern Alberta. Specifically, the study area was selected to include the 1) ooidal ironstones in Bad Heart Formation in the Clear Hills–Smoky River region, 2) diamondiferous kimberlites in the Buffalo Hills–Peerless Lake region (Chen and Olson, 2005), and 3) oil, gas and coal exploration along both the southeast and northwest flanks of the PRA.

The Clear Hills–Smoky River region (Figure 1) is bounded by latitudes 55^o and 58^o in the south and north, and longitudes 116^o and 120^o in the east and west, respectively. The study area covers about 77 700 km^2 (30 000 mi^2) and encompasses six 1: 250 000 map areas, including NTS 83M, 83N, 84C, 84D, 84E and 84F. Digital log databases were constructed for these six map areas, as well as for NTS 83O, 84B and 84G that encompass the Buffalo Hills–Peerless Lake region. Approximately 750 townships are enclosed in the Clear Hills–Smoky River study area, ranging from Township 69 to 103 and from Range 13W5 to 13W6.

Studies of Upper Cretaceous strata along the northwest flank of the PRA (from the Peace River to the northern Clear Hills) are hampered by several factors, including the following: 1) extensive overburden and concomitantly very few outcrops in the Clear Hills, 2) removal of considerable amount of Late Cretaceous to Tertiary bedrock from the region, and 3) the lack of 'near-surface' geophysical logs in oil/gas wells in this region. For example, although more than 23 000 oil/gas wells have been drilled in the study area, only a small fraction of the wells in the Clear Hills area have geophysical log information for the formations above Upper Cretaceous Dunvegan Formation. Finally, correlations between Upper Cretaceous strata in the Clear Hills versus that at Smoky River are difficult because much of the Upper Cretaceous has been severely eroded, especially along the extensive Peace River and Chinchaga River lowlands.

The digital elevation model (DEM) for the Clear Hills–Smoky River region is shown in Figure 1. Relief in the Clear Hills–Smoky River region ranges from about 250–1210 m above present sea level (asl), and is greatest in the northwest, west and south where the Milligan Hills, Halverson Ridge, Clear Hills sensu stricto and Saddle Hills exist (Figure 1). Major rivers developed between these uplands, including the Peace River, Smoky River, Whitemud River, Notikewin River and Chinchaga River. The Peace River is by far the largest drainage in the region; it flows from west to east, then turns north near the town of Peace River. Figure 1 also shows the locations of the following: 1) outcrops of ooidal ironstone in the region after Kidd (1959), 2) the only two wells in the Clear Hills area that were identified by prior studies to have Bad Heart Formation stratigraphic picks, 3) a cross-section showing the Bad Heart Formation and its westerly equivalent, Marshybank Formation, drawn by Plint et al. (1990), and 4) the inferred outcrop or subcrop trace for the Bad Heart Formation from Green (1972) and Hamilton et al. (1999).

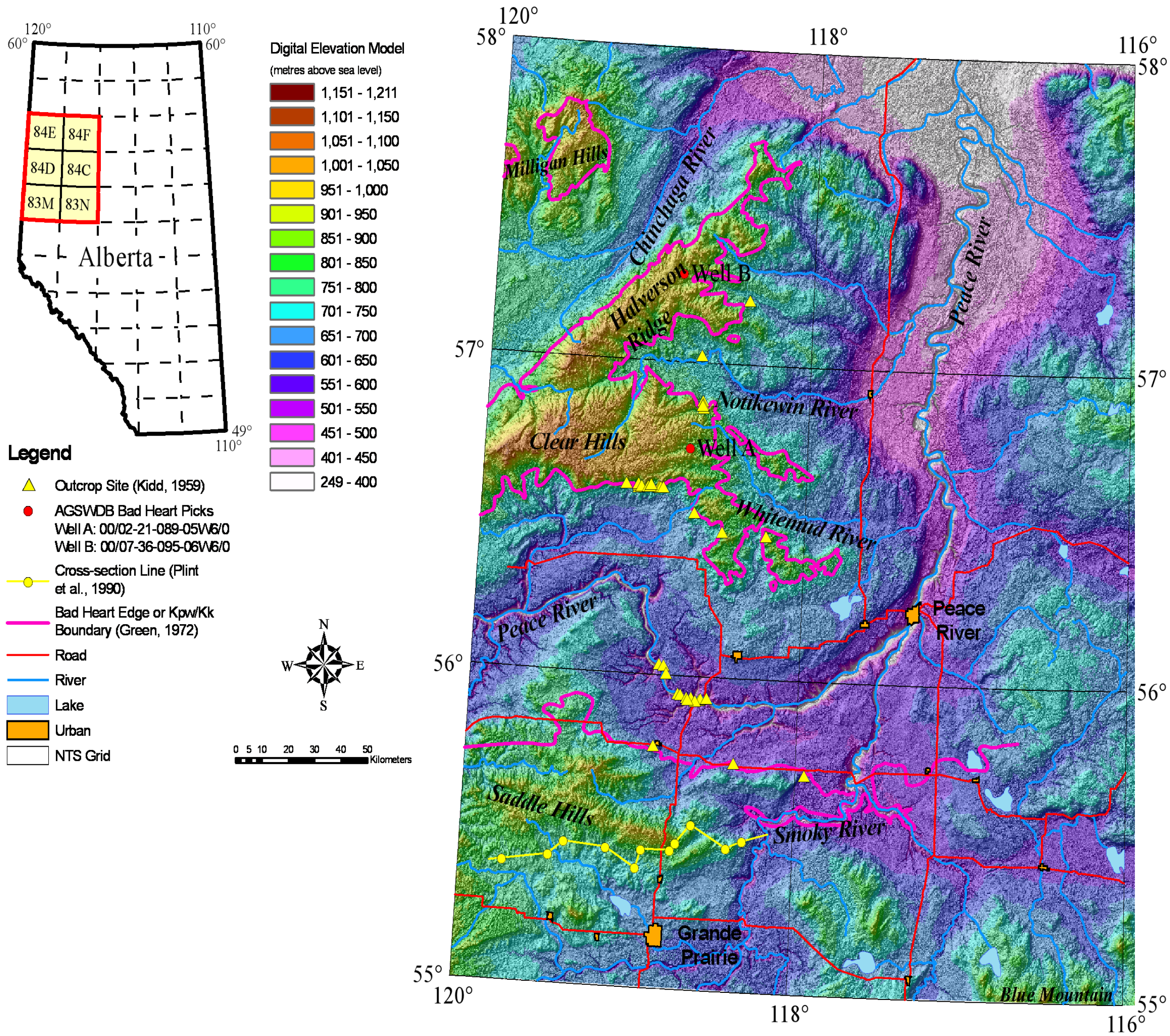

Figure 1. Study area: Clear Hills–Smoky River region in northwestern Alberta. Approximate Bad Heart Edge and selected outcrop sites are shown. Kpw/Kk: Cretaceous Puskwaskau/Kaskapau formations; AGSWDB: Alberta Geological Survey Well Database; NTS: National Topographic System.

1.2 Regional Tectonic Setting and Structural Lineaments

Tectonically, the Phanerozoic sedimentary cover in the Clear Hills–Smoky River region is underlain by Precambrian basement, which is divided into three Early Proterozoic domains (Ross, 1990): Buffalo Head Domain in the east, the Chinchaga Domain in the middle and the Ksituan Domain in the west (Figure 2). Ross (1990) suggested that the Buffalo Head and Chinchaga domains are accreted terranes, whereas the Ksituan Domain is a continental margin magmatic arc.

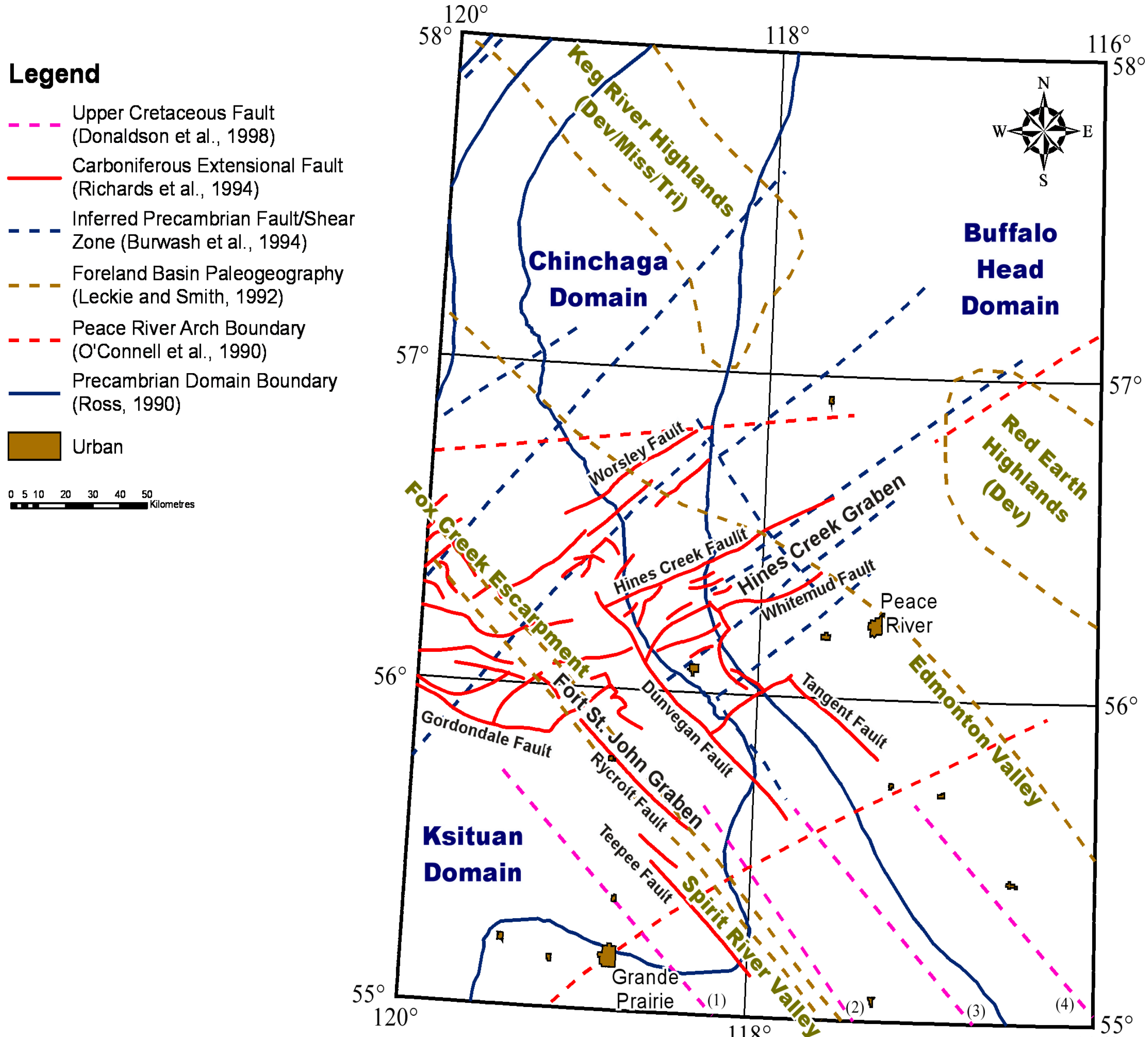

Figure 2. Tectonic setting of the Clear Hills–Smoky River region and some major structures in the region. Kpw/Kk: Cretaceous Puskwaskau/Kaskapau formations; Dev: Devonian; Miss: Mississippian; Tri: Triassic.

The PRA is a major structural feature in northern Alberta. The Arch extends from northeastern British Columbia into Alberta in an east-northeast direction and extends from the Peace River area to at least the Buffalo Head Hills area. The PRA boundaries that were proposed by O'Connell et al. (1990) are shown as dashed red lines in Figure 2, and the authors suggested the evolution of the PRA comprised 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*." Finally, in the PRA region in northwest Alberta the present Precambrian basement is about 1000 m higher than the regional basement elevation (Cant, 1988).

Since being welded together in the Early Proterozoic (Ross, 1990), the Precambrian domains in the Clear Hills–Smoky River region have subsequently been subjected to periodic faulting or other structural deformation, especially within the PRA boundaries. The faults/shear zones inferred by various workers are shown in Figure 2, and, in general, they appear to form a set of conjugate lineaments that trend northeast–southwest and northwest–southeast within the Arch boundaries. Richards et al. (1994) suggested the Carboniferous extensional faults formed syndepositionally during the collapse of the ancestral PRA in late Paleozoic time. Lastly, the evolution of the PRA and reactivation of basement faults had a profound influence on the development of sediments, accumulation of hydrocarbons and, possibly, the enrichment of minerals in the Arch area.

By Late Jurassic time the Clear Hills–Smoky River region changed from a miogeocline-platform to foreland basin setting (Price, 1994). The foreland basin paleo-geographic features proposed by Leckie and Smith (1992) are shown in Figure 2. The inferred paleo-geographic lineaments and highlands of Leckie and Smith (1992) largely trend northwest–southeast (parallel to the Rocky Mountains deformation front). This report suggests that in Early Cretaceous (Aptian) time the area west of the Spirit River Valley resembles the 'western foredeep;' the area between the Spirit River Valley and the Edmonton Valley resembles the 'forebulge;' and the area northeast of the Edmonton Valley resembles the 'west-median trough' in terms of megatectonics discussed by Kauffman and Caldwell (1993). Superimposed on the PRA's largely vertical movements, the evolution of the foreland basin zones and the migration of the 'forebulge' had a strong impact on the deposition and facies distribution in the foreland basin in this region.

With specific respect to possible faulting during Bad Heart Formation deposition, Donaldson et al. (1998) suggested four Late Cretaceous faults were active (shown as dashed pick lines in Figure 2). These four faults all trend northwest–southeast and exist along the southeast flank of the PRA. Fault 1 is located in the 'Foredeep,' and faults 2, 3 and 4 are in the 'forebulge.' Faults 3 and 4 may extend northwest and, thus, be connected to the Dunvegan and Tangent faults of Richards et al. (1994). Faults 1 and 2 (Donaldson et al., 1998) are not clearly associated with any other faults, although Fault 1 trends towards a portion of the Gordondale Fault and Fault 2 exists near and subparallel to the Rycroft Fault.

Figure 2 shows all of the major structural lineaments of various ages posted on the same diagram, and, as a result, it indicates there were preferred structural trends where faults formed. For example, Figure 2 indicates that the PRA and the 'forebulge' were preferred zones for fault development. Having said this, in most cases there is no convincing evidence to demonstrate that the younger faults are derived from older faults.

Figure 3 shows the major structural elements from Figure 2 overlying the regional digital elevation model from Figure 1. In general, there are only a few places where subsurface faults and other structural elements appear to have had an affect on the overlying surface topography. In many cases, the subsurface lineaments of different ages (Ross, 1990; Burwash et al., 1994; O'Connell et al., 1990; Richards et al., 1994; Leckie and Smith, 1992; Donaldson et al., 1998) cut across both topographic highs and lows with no or little effect. In short, there is not a good correlation between the ground surface and the subsurface structures.

1.3 Economic Geology

Huge volumes of oil and gas have been produced from the Clear Hills–Smoky River region, as shown by the distribution of cumulate oil production in Figure 4 and the distribution of cumulate gas production in Figure 5. In total, about 14 trillion cubic feet (~400 billion cubic metres) of gas and 652 million barrels (~104 million cubic metres) of oil have been produced from various formations in this region (Divestco Inc. data, January 2006). These two figures show that drilling for hydrocarbons in the PRA area has been a great success. For example, a 97% success rate was obtained by Canex Energy Inc. in 2005 (in Daily Oil Bulletin, January 27, 2006, obtained as online web article). The subsurface lineaments from Figure

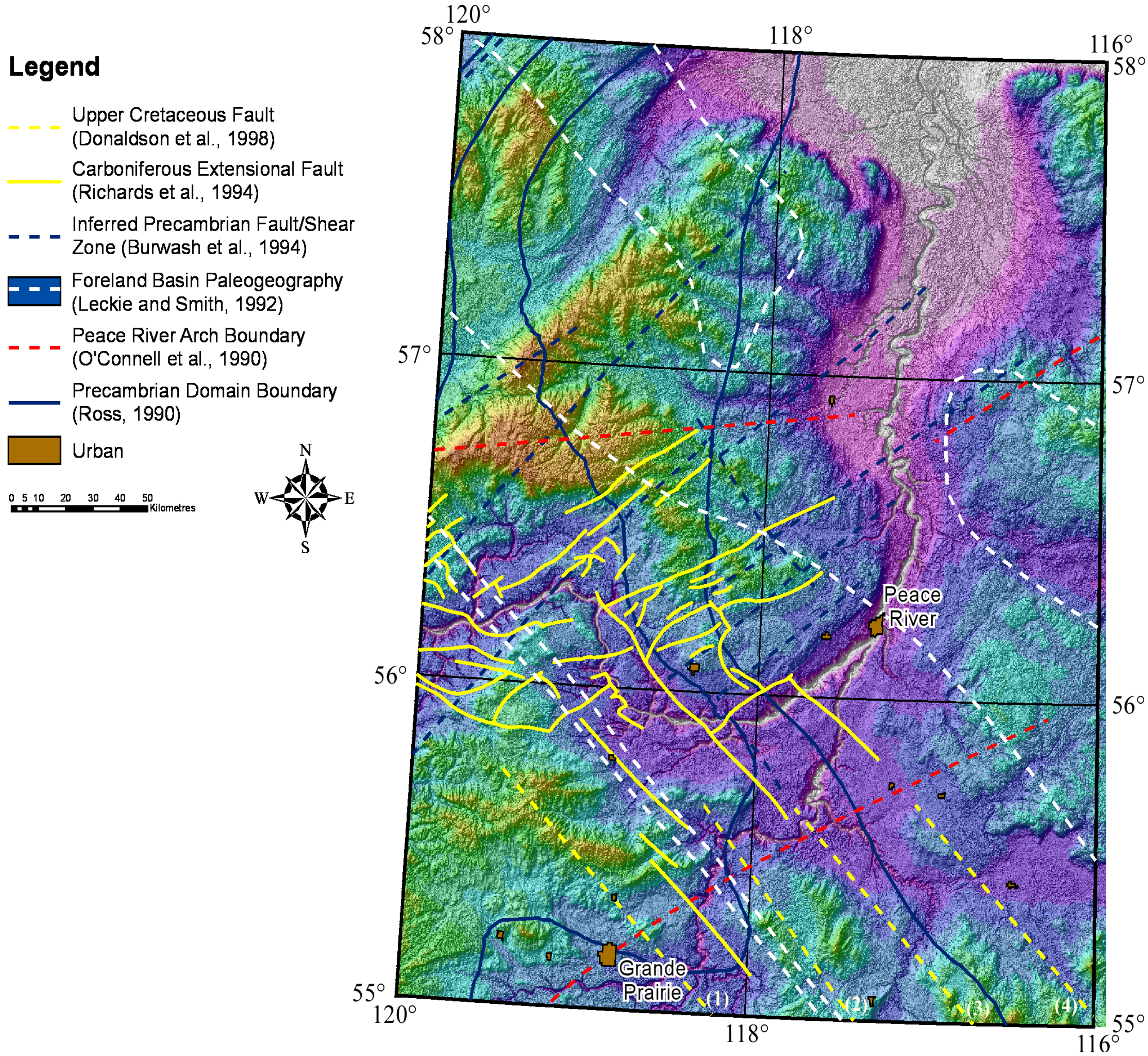

Figure 3. Comparison of major basement and bedrock structures with topographic features in the Clear Hills–Smoky River region. See Figure 1 for ground surface elevation and Figure 2 for structure names. Kpw/Kk: Cretaceous Puskwaskau/Kaskapau formations.

2 are also overlain on Figures 4 and 5 in order to detect possible structural controls on hydrocarbon production. In many places, both cumulate oil and gas production show preferential orientations and a spatial association with some of the subsurface lineaments. In general, the oil and gas producing fields show a dominant northwest–southeast trend in the region. More specifically:

Oil producing fields (Figure 4) appear to be concentrated

- in the up-dip of the ‘foredeep,’ southwest of the Fox Creek Escarpment;
- between the Dunvegan Fault (Richards et al., 1994) and its southeast extension Fault 3 (Donaldson et al., 1998), and the Tangent Fault (Richards et al., 1994) and its southeast extension Fault 4 (Donaldson et al., 1998); and
- within the overall southeast and northwest boundaries of the PRA of O’Connell et al. (1990).

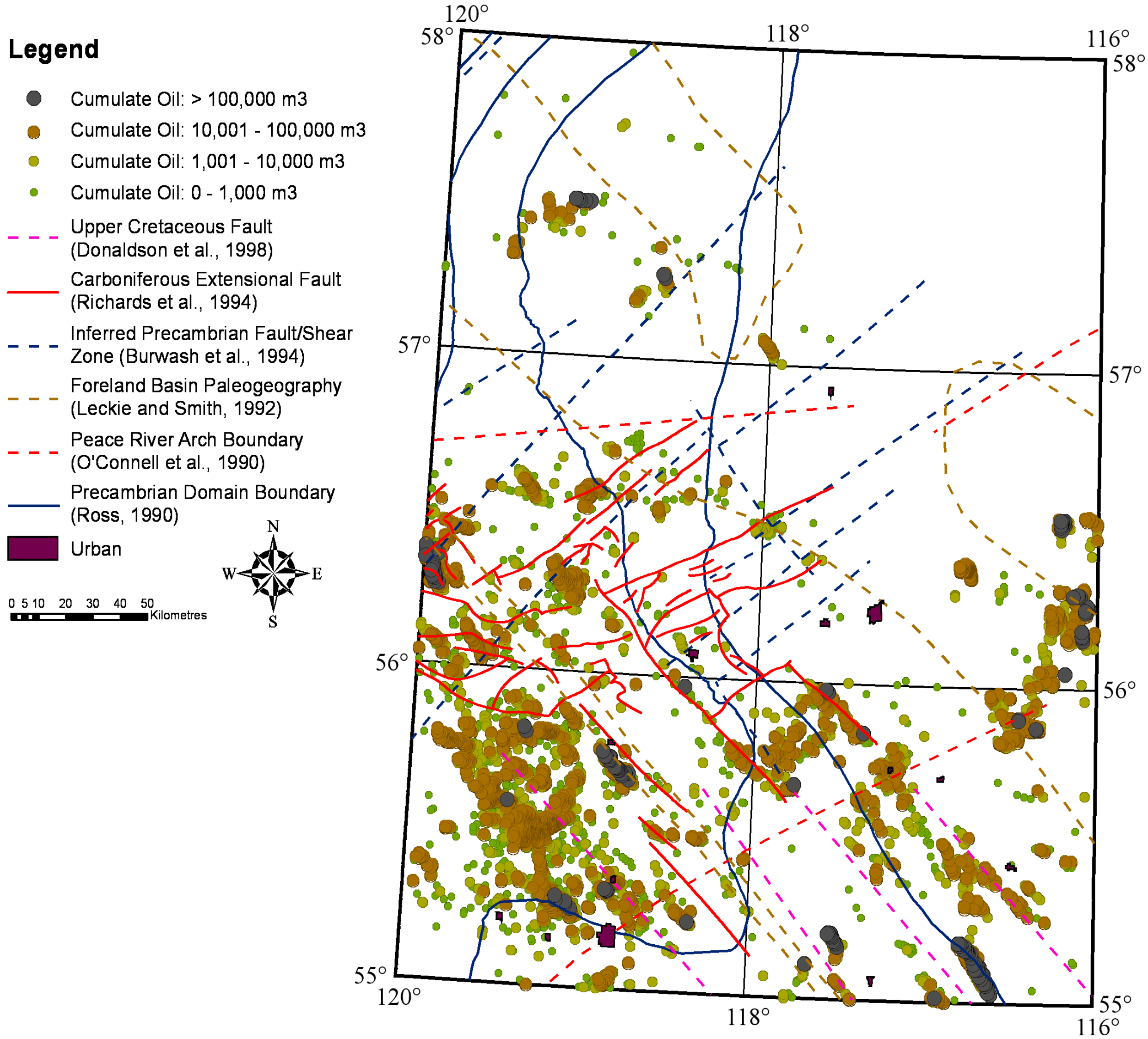

Figure 4. Cumulate oil production and distribution in the Clear Hills–Smoky River region. About 652 million barrels (~104 million cubic metres) of oil have been produced from this area (data from Divestco Inc., January 2006). See Figure 2 for names of the faults and structural boundaries.

In general, the gas producing fields (Figure 5) have a broader distribution than that of oil production in the Clear Hills–Smoky River region. Gas production appears to be concentrated

- in the 'foredeep' southwest of the Fox Creek Escarpment;
- in the zone between and, especially, along the Dunvegan Fault/Fault 3 and Tangent Fault/Fault 4;
- within the southeast and northwest boundaries of the PRA; and
- around the Keg River Highlands (Leckie and Smith, 1992).

Evidently, foreland zones and paleogeography ('foredeep,' 'forebulge,' Keg River and Red Earth highlands) and subsurface lineaments (Dunvegan Fault/Fault 3, Tangent Fault/Fault 4, and Rycroft Fault) played an important role in hydrocarbon accumulation in the Clear Hills–Smoky River region.

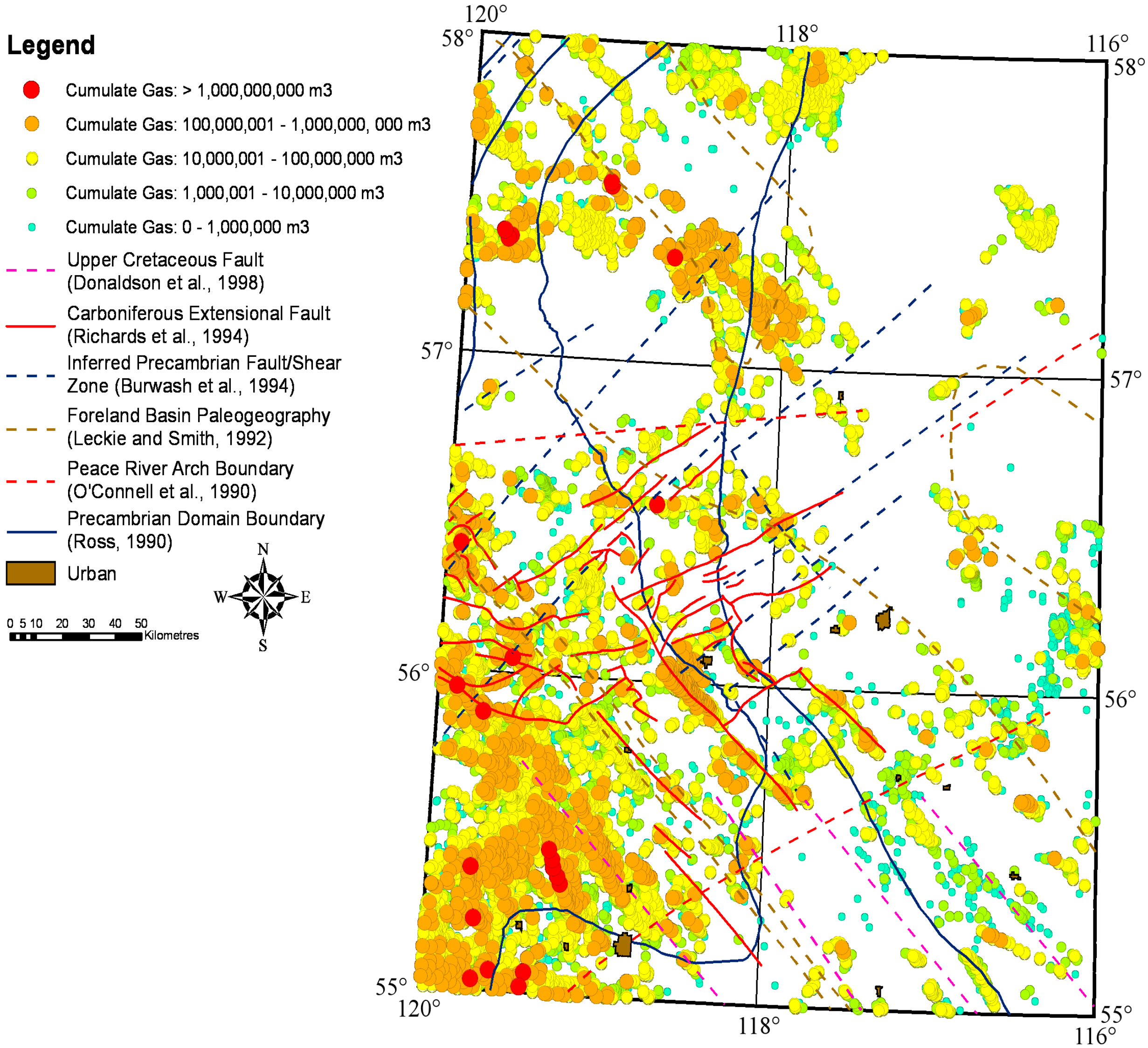

Figure 5. Cumulate gas production and distribution in the Clear Hills–Smoky River region. About 14 trillion cubic feet (~400 billion cubic metres) of gas have been produced from this area (data from Divestco Inc., January 2006). See Figure 2 for names of the faults and boundaries.

Turning to minerals, the Bad Heart Formation in the Clear Hills and along the Smoky River is iron bearing, with the iron deposits comprising interbedded zones of ooidal ironstone. The iron deposits were initially discovered in 1924 and, periodically, have attracted considerable exploration interest since that time, particularly during the 1950s and 1960s (Olson et al., 1999). Total iron resources have been estimated at over 1 billion t grading about 34% iron (Hamilton, 1980).

2 Previous Studies and Existing Stratigraphic Picks

2.1 Previous Studies

The great success of oil and gas exploration and production in the Peace River region, the enigmatic uplift and subsidence of the PRA, and interest in the Clear Hills iron deposits have all attracted industries and academia to this region for many decades. Numerous papers have been published since the first symposium on the PRA (for example, deMille, 1958; Lavoie, 1958; Williams, 1958). The Canadian Society of Petroleum Geologists published a special volume (Bulletin of Canadian Petroleum Geology, Volume 38A), which collected 17 papers on PRA geology, including those by O'Connell et al. (1990), Ross (1990), McMechan (1990), Norford (1990), Keith (1990), Dix (1990), Barclay et al. (1990), Gibson and Edwards (1990), Poulton et al. (1990), Leckie et al. (1990), Hart and Plint (1990) and others. The geology of the PRA region was also discussed in the Geological Atlas of the Western Canada Sedimentary Basin (Mossop and Shetson, compilers., 1994). Other articles dealing with the PRA issue include Burk (1962), Cant (1988), Ross and Eaton (1997), Eaton et al. (1999), Hein (1999), and Chen and Bergman (1999).

Most of these previous studies in the Clear Hills–Smoky River region have targeted individual sedimentary intervals. With respect to regional stratigraphic correlation of the Upper Cretaceous, most are restricted to the region south and west of the Peace River (e.g., Stott, 1960; Hart and Plint, 1990; Plint et al., 1990; Bhattacharya, 1994; Krause et al., 1994; Dawson et al., 1994; Donaldson, 1997; Donaldson et al., 1998; Chen and Bergman, 1999; Plint 2000; Collom, 2001). However, there are very few well log cross-sections that show the complete Phanerozoic and the Upper Cretaceous, especially along the northwest flank of the PRA. The reasons that most of the Upper Cretaceous stratigraphic studies are constrained to the southeast flank of the PRA include the following: 1) severe erosion of the Upper Cretaceous in the region, especially along the Peace River lowlands, 2) the scarcity of outcrops in the Clear Hills – Halverson Ridge area, and 3) the fact that there are very few shallow geophysical logs that record information above Shaftesbury strata in the region north of the Peace River. Partly as a result of the scarcity of accurate and detailed data for the Upper Cretaceous in the Clear Hills–Smoky River region, miscorrelations and in some cases wrong data entries exist in both the Alberta Geological Survey (AGS) and IHS Inc. AccuMap well databases.

In the AGS oil/gas well database (AGSWDB) prior to this study, there were only two stratigraphic picks of the Bad Heart top for the entire Clear Hills area (Figure 1). Since the mid-1980s, D.G. Plint and some of his graduate students at the University of Western Ontario have been studying Upper Cretaceous strata in the Peace River to Smoky River region. A few selected papers pertaining to the Kaskapau to Puskwaskau formations by these workers include those by Plint (1990, 2000), Plint et al. (1987, 1990, 1991, 1993), Donaldson (1997), Donaldson et al. (1998, 1999), and Varban and Plint (2005). In addition, Collom (2001) completed doctoral studies of the systematic palaeontology, biostratigraphy and paleoenvironment of the Upper Cretaceous Wapiabi Formation, which included studying the Bad Heart Formation along the Smoky River. However, although there have been regional correlations of Upper Cretaceous strata along the southern part of the PRA, such as the cross-section by Plint et al. (1990), the location of which is shown in Figure 1, only Donaldson et al. (1999) showed a schematic diagram that correlated the Bad Heart Formation on the Smoky River to outcrops along Rambling River (also known as Swift Creek) that exists between the Whitemud and Notikewin Rivers in the southeastern Clear Hills. Donaldson et al. (1999) figure suggested that there exists a regional unconformity at the base of the Bad Heart Formation and that the upper parts of the Kaskapau Formation and overlying units (e.g., Muskiki Formation and underlying Cardium Formation along the Smoky River) are truncated to the north.

The Clear Hills ooidal ironstone deposits have been studied and reported on by a number of geologists. Some of the AGS publications include those by Kidd (1959), Green and Mellon (1962), Hamilton (1980) and Olson et al. (1999). In the late 1950s, Kidd (1959) documented ooidal ironstone exposures in the Clear Hills to Smoky River region (yellow-filled triangles in Figure 1), although it is now known that all the ooidal ironstones along the Peace River are in lower Kaskapau Formation rather than in Bad Heart Formation (Varban and Plint, 2005). Figure 1 shows the inferred subcrop edge of the Bad Heart

Formation or the boundary between the Puskwaskau and Kaskapau formations where the Bad Heart Formation is missing (Green and Mellon, 1962; Green, 1972; compiled by Hamilton et al., 1999). Olson et al. (1999) provides a summary of the history of exploration and prior geological studies about the Bad Heart Formation, and Olson et al. (2006) provides a summary of the digital data compiled for ooidal ironstone and coal in the Clear Hills to Smoky River region. Lastly, Chen and Olson (2005) provide a suite of selected cross-sections across the Buffalo Head Hills to Peerless Lake region that correlate with the cross-sections and other information provided by this current study in the Clear Hills–Smoky River region.

2.2 Evaluation of Geophysical Logs and Existing Stratigraphic Picks

In the Clear Hills–Smoky River region about 23 460 oil/gas wells have been drilled according to the AGSWDB records in 2004. In the diagram to the right in Figure 6, the green and yellow dots represent the wells drilled in the Clear Hills–Smoky River region. Logs for about 8 439 wells have been digitized (green dots); whereas, for the other approximately 15 020 wells the logs have not been digitized, but are available as raster images (yellow dots).

The regional dip of the Bad Heart Formation is a few degrees to the south at Smoky River, but in the Clear Hills the formation is flat-lying to possibly very gently east-dipping to the east. In the Clear Hills most of the known outcrops exist at or above an elevation of about 775 m above sea level. As a result, for the area bounded by latitudes 56º 6’ and 58º in the south and north, and by longitudes 117º 42’ and 120º in the east and west, respectively, all the wells with Ground Surface elevations above 775 m were identified (Figure 6). In total, there are 1626 wells where Ground Surface elevations are equal to or higher than 775 m, and, hence, in these wells information about the Bad Heart information may exist. Table 1 summarizes the log status for the 1626 selected wells in the Clear Hills area; these same wells are also shown on the left diagram in Figure 6.

Table 1. Well log status for the Clear Hills area

WELLS	GROUND SURFACE ELEVATION	DIGITAL LOGS	LOG START ELEVATION
109	> 775 m	Yes	> 775 m
548	> 775 m	Yes	< 775 m
969	> 775 m	No	Above and below 775 m
1626	Total wells within latitude 56º 6’—58º and longitude 117º 42’—120º		

In the AGSWDB for wells drilled to 2004, there are 218 427 stratigraphic picks for 168 horizons in the 23 460 wells that have been drilled in the Clear Hills–Smoky River region. Among the 168 horizons, five horizons have more than 10 000 picks each. They are the Base of Fish Scales Zone, and the tops of the Harmon, Spirit River, Bluesky and Gething formations; these five picks are highlighted with **bold** font in Table 2. Ten horizons, each of which has 5000 to 10 000 picks, are highlighted with ***bold italic*** font in Table 2. The remaining 29 horizons in Table 2 have from 1000 to 5000 picks each.

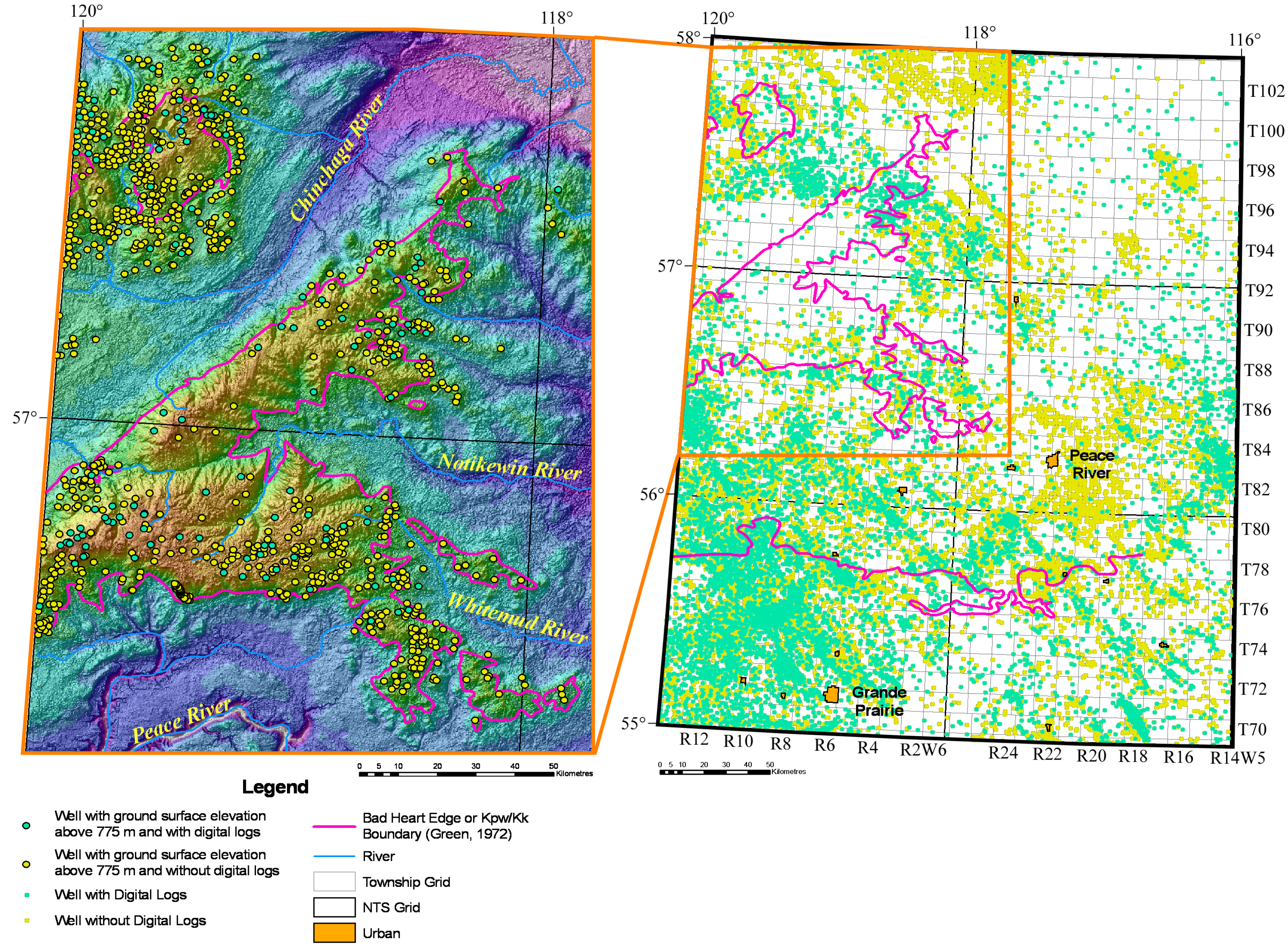

Figure 6. Distribution of oil and/or gas wells and availability of digital logs in the study area. About 23 460 wells were drilled in the study area (AGSWDB data in 2004), among which, logs of 8439 wells have been digitized. In the Clear Hills area, the Bad Heart Formation is distributed higher than 775 m above present sea level. At the sites of about 1626 wells, ground surface elevations are higher than 775 m. Among the wells, 109 wells have digital logs. Kpw/Kk: Puskwaskau/Kaskapau formations.

Table 2. Horizons that have more than 1000 stratigraphic picks in the AGSWDB for the Clear Hills–Smoky River region

HORIZON CODE	HORIZON NAME	CLASS	ABBREVIATION	AMOUNT OF PICKS
1660	BAD HEART	FM	BADH	1794
1700	CARDIUM	FM	CARD	3018
1760	CARDIUM SAND		CARD SD	2869
1820	KASKAPAU	FM	KPAU	2585
1900	DOE CREEK	MBR	DOE CK	4424
1920	DUNVEGAN	FM	DUNV	4986
1960	***SHAFTESBURY***	***FM***	***SHFT***	***5877***
2060	**BASE OF FISH SCALES ZONE**		**BFSC**	**11054**
2280	***PEACE RIVER***	***FM***	***PR***	***6158***
2300	***PADDY***	***MBR***	***PADY***	***6249***
2320	***CADOTTE***	***MBR***	***CDOT***	***6296***
2380	**HARMON**	**MBR**	**HARM**	**10622**
2640	**SPIRIT RIVER**	**FM**	**SPRT R**	**11672**
3040	**BLUESKY**	**FM**	**BLSK**	**10884**
3260	**GETHING**	**FM**	**GETH**	**10942**
3480	***CADOMIN***	***FM***	***CADM***	***5664***
4080	NIKANASSIN	FM	NIKA	2742
4140	***FERNIE***	***GRP***	***FERN***	***8411***
4320	ROCK CREEK	MBR	RK CK	3074
4400	POKER CHIP SHALE		PK C SH	2540
4440	***NORDEGG***	***MBR***	***NORD***	***9478***
5000	TRIASSIC	SYSTEM	TRIA SYS	2184
5060	BALDONNEL	FM	BALD	1766
5080	***CHARLIE LAKE***	***FM***	***CH LK***	***5954***
5160	HALFWAY	FM	HFWY	3732
5200	DOIG	FM	DOIG	4377
5240	***MONTNEY***	***FM***	***MONT***	***5211***
5560	BELLOY	FM	BELL	4873
6050	TAYLOR FLAT	FM	TALR FLAT	1003
6060	KISKATINAW	FM	KISK	1428
6080	GOLATA	FM	GOLA	2261
6120	***DEBOLT***	***FM***	***DBLT***	***5439***
6380	ELKTON	MBR	ELTN	1199
6400	SHUNDA	FM	SHUN	4031
6420	PEKISKO	FM	PEK	3189
6440	BANFF	FM	BNFF	4051

HORIZON CODE	HORIZON NAME	CLASS	ABBREVIATION	AMOUNT OF PICKS
6480	EXSHAW	FM	EX	2691
6580	WABAMUN	GRP	WAB	4045
6700	WINTERBURN	GRP	WINT	2527
7100	IRETON	FM	IRE	2188
7440	BEAVERHILL LAKE	GRP	BH LK	2231
7580	SLAVE POINT	FM	SL PT	2016
9760	GRANITE WASH		GRWH	1605
9800	PRECAMBRIAN	SYSTEM	PRECAM SY	1761

GRP: Group; FM: Formation; MBR: Member.

Stratigraphic picks are not evenly distributed in the Clear Hills–Smoky River region. For example, most of the picked tops for the Upper Cretaceous formations are in the south of the region. In contrast, stratigraphic picks above the Base of Fish Scales are less common and spatially scattered in the Clear Hills area. Table 3 shows that there are only nine Upper Cretaceous stratigraphic units with picked tops in the AGSWDB for the Clear Hills area. Furthermore, six horizons have only one to four picks over an area of some 25 900 km^2 (10 000 mi^2), with Bad Heart Formation having only two picks.

Table 3. Upper Cretaceous stratigraphic picks in the AGSWDB for the Clear Hills area

HORIZON CODE	HORIZON NAME	CLASS	ABBREVIATION	AMOUNT OF PICKS
10	BASE OF DRIFT		BS DRIFT	2
1460	SMOKY RIVER	GRP	SMKY R	2
1660	BAD HEART	FM	BADH	2
1860	SECOND WHITE SPECKS		2WS	4
1880	POUCE COUPE	MBR	PC CP	1
1900	DOE CREEK	MBR	DOE CK	19
1920	DUNVEGAN	FM	DUNV	71
1940	FORT ST JOHN	GRP	FT ST JN	2
1960	SHAFTESBURY	FM	SHFT	677
2060	BASE OF FISH SCALES ZONE		BFSC	3010

GRP: Group; FM: Formation; MBR: Member.

In addition to the unavailability of stratigraphic picks for Upper Cretaceous and younger strata in the Clear Hills, errors caused by miscorrelation, inconsistency and wrong data entry exist in the AGSWDB and AccuMap databases, especially in structurally active areas, along unconformities, across litho-changes and between interfingered formations. For example, one of the two Bad Heart top picks is four m above the Base of Fish Scales in the AGSWDB in the Clear Hills area, whereas the Bad Heart top should be more than 300 m above the Base of Fish Scales.

In summary,

- Well log cross-sections showing complete Phanerozoic successions over the entire Clear Hills–Smoky River region are rare.
- Stratigraphic studies linking Upper Cretaceous formations between the Clear Hills and Smoky River areas (i.e., linking both flanks of the PRA) are rare.
- There are relatively few stratigraphic picks of Upper Cretaceous formations for the Clear Hills area currently in the AGSWDB.
- Lastly, for the existing picks in the AGSWDB and AccuMap databases, there are, in places, miscorrelation, inconsistency and wrong data entry.

2.3 Objectives of This Study

The purpose of this study is the preparation of a series of bedrock cross-sections that support the development of resources (i.e., iron, diamond, coalbed methane, shallow gas, etc.) in northern Alberta. The objectives of this study are to fill in some of the gaps between previous stratigraphic studies, especially in the largely un-investigated Clear Hills area, by providing well log cross-sections showing the complete Phanerozoic successions and to correlate selected subsurface formations over the entire region. The approach includes establishing the regional stratigraphic framework, as well as investigating selected formational details, especially for Upper Cretaceous strata. The study methodology included the following steps:

- constructing nine MS Access databases that contain digital logs and stratigraphic picks for oil/gas wells within NTS map areas 83M, 83N and 84C to 84F
- constructing four regional cross-sections (A-A' to D-D' in Figure 7) that show all Phanerozoic successions and two local cross-sections (E-E' and F-F') that are specific to Upper Cretaceous formations
- collecting and evaluating geological data of stratigraphic picks, structural lineaments, formation edges, formation boundaries of bedrock top, DEM, and oil and gas production within the Clear Hills–Smoky River region
- characterizing type logs and downhole models for formation identification
- identifying and correlating subsurface formations along the regional cross-sections
- analyzing well logs and correlating Upper Cretaceous formations in the Clear Hills area
- evaluating formation boundaries using bedrock tops with DEM and log information

3 Project Databases and Picking Protocol of Horizons

3.1 Project Databases and Tools

This study heavily relied on geophysical logs, especially digital logs. Nine digital log databases (for each of NTS map areas 83M to 83O, and 84B to 84G were constructed in order to cover both the Bad Heart formation ooidal ironstones in the Clear Hills–Smoky River region and known kimberlite pipes in the Buffalo Head Hills–Peerless Lake region. The nine MS Access databases are named: NTS83M_Grande-Prairie.mdb, NTS83N_Winagami.mdb, NTS83O_Lesser-Slave-Lake.mdb, NTS84B_Peerless-Lake.mdb, NTS84C_Peace-River.mdb, NTS84D_Clear-Hills.mdb, NTS84E_Chinchaga-River.mdb, NTS84F_Bison-Lake.mdb and NTS84G_Wadlin-Lake.mdb. These files are on file at the AGS for ongoing internal use.

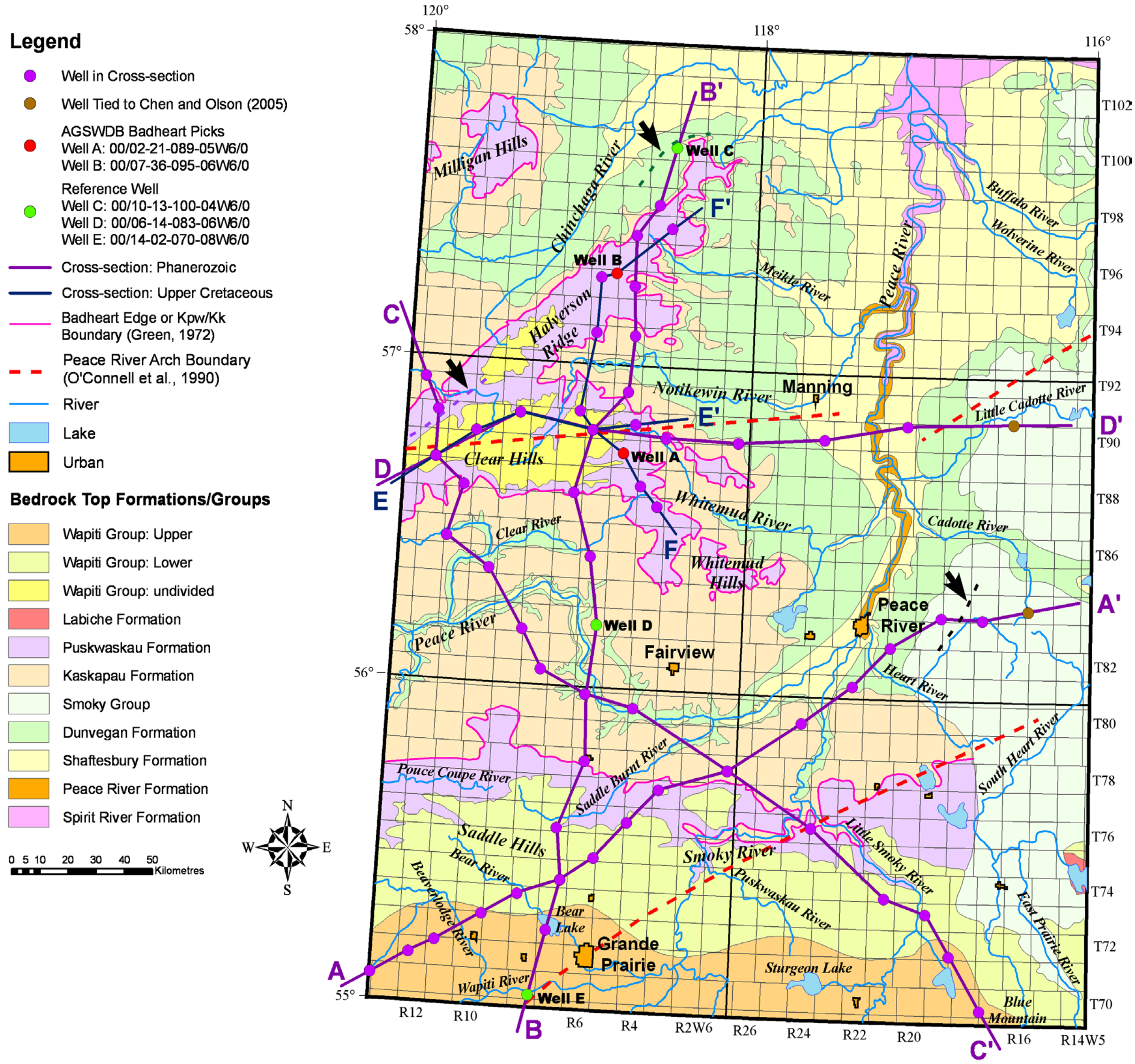

Figure 7. Cross-sections, reference wells and bedrock top formations/groups in the Clear Hills–Smoky River region. The geological boundaries of the bedrock tops are clipped from Map 236 of the Alberta Geological Survey. As indicated by black arrows, the dashed green (northern Clear Hills), purple (western Clear Hills) and black (east of the town of Peace River) lines show where boundaries need further work.

In these nine NTS map areas, more than 33 300 oil/gas wells have been drilled (based on the AGSWDB data as of 2004), among which, logs for over 13 900 wells (~42%) have been digitized. From this subset of wells with digital logs, more than 129 400 digital log traces have been imported to the project databases (Table 4).

A variety of datasets have been collected from a few selected sources in this study, and these have been manipulated and evaluated using a number of software applications. Main data sources for the project databases/datasets included iDc GeoOffice, HIS AccuMap, AGSWDB, AGS Infostore, AGS data share and Divestco GeoCarta. The 13 912 LAS files were downloaded partially from the GeoOffice and partially from the collection of EUB/AGS colleague Andre Lytviak on the AGS data share. The picks of stratigraphic horizons and associated data were collected from the AGSWDB. The major subsurface lineaments were selected from the compilation by Pana et al. (2001). The DEM data were clipped and converted by EUB/AGS colleague Dennis Chao from the Alberta DEM dataset. The geological formation boundaries were gathered from the database for the Geological Atlas of the Western Canada Sedimentary Basin. The geographic base features were collected from the AGS Infostore. The oil and gas production data were extracted from GeoCarta and AccuMap. Finally, the major software used in the study included Viewlog®, MS Access®, ArcGIS® and Canvas®.

Table 4. Wells drilled and logs digitized in the nine NTS map sheets in northern Alberta

NTS MAP AREA	NAME	WELLS DRILLED	WELLS WITH DIGITAL LOGS	DIGITAL LOG TRACES IN DATABASE
NTS83M	GRANDE PRAIRIE	9084	3678	36 571
NTS 83N	WINAGAMI	3711	1209	9365
NTS 83O	LESSER SLAVE LAKE	4243	2256	20 402
NTS 84B	BUFFALO HEAD HILLS	4518	2592	25 846
NTS 84C	PEACE RIVER	3175	867	7817
NTS 84D	CLEAR HILLS	4216	1518	12 048
NTS 84E	CHINCHAGA RIVER	2237	917	9481
NTS 84F	BISON LAKE	1037	325	1780
NTS 84G	WADLIN LAKE	1094	668	6104
TOTAL		**33 315**	**13 912**	**129 414**

A variety of datasets have been collected from a few selected sources in this study, and these have been manipulated and evaluated using a number of software applications. Main data sources for the project databases/datasets included iDc GeoOffice, HIS AccuMap, AGSWDB, AGS Infostore, AGS data share and Divestco GeoCarta. The 13 912 LAS files were downloaded partially from GeoOffice and partially from an internal collection. The picks of stratigraphic horizons and associated data were collected from the AGSWDB. The major subsurface lineaments were selected from the compilation by Pana et al. (2001). The DEM data were clipped and converted by EUB/AGS colleague Dennis Chao from the Alberta DEM dataset. The geological formation boundaries were gathered from the database for the Geological Atlas of the Western Canada Sedimentary Basin. The geographic base features were collected from the AGS Infostore. The oil and gas production data were extracted from GeoCarta and AccuMap. Finally, the major software used in the study included Veiwlog®, MS Access®, ArcGIS® and Canvas®.

3.2 Log Signatures and Picking Protocol of Stratigraphic Horizons

The location of three reference wells used to prepare 'type-logs' are shown as green dots in Figure 7. Well C (10-13-100-4W6), well D (6-14-83-6W6) and well E (14-2-70-8W6) all fall along cross-section B—B' and are located in the northwest, central PRA and southwest, respectively. The reason for selecting these three reference wells is that the shape of the basin floor changed through time and, as a result the depositional centre shifted, resulted in an uneven development of formations over the region. For example, most of the Devonian is missing from the centre of the PRA; whereas the Jurassic, Triassic, Permian and part of the Carboniferous are missing from the northeast; and the uppermost Cretaceous is missing from the central and most of the northern parts of the region. Thus, the selected type-logs ensure that most of the formations present in the Clear Hills–Smoky River region are included.

Signatures of gamma ray and resistivity logs are characterized in Figures 8 and 9. For each well, the gamma ray log in the left column ranges from 0 to 125 American Petroleum Institute (API) and the resistivity log in the right column ranges from 0 to 50 ohm metres (OHMM). The API standard was set by the primary calibration test pit at the University of Houston where a radioactive cement calibrator is assigned a value of 200 API units. The scale was chosen so that a value of zero would mean no radioactivity and a value of 100 would match a typical mid-continent shale. The 'normal' API range for sediments in the Clear Hills─Smoky River region is about 0 to 125 API, with sandstones (including conglomerates and concretions) typically producing 5 to 50 API, shales/mudstones producing 90 to 125 API, and carbonates 0 to 30 API. The API levels for some of the more radioactive lithologies, such as those in the First or Second White Specks or in bentonite layers, range from about 120 to 500 API or higher. In general, carbonates show high levels of radioactivity only when they contain disseminated shale or have been mineralized by uranium-bearing solutions.

In the Clear Hills–Smoky River region, the Devonian comprises mainly carbonate (limestone and dolomite), shale and evaporite (anhydrite and halite); the Carboniferous consists largely of carbonate and shale with minor siltstone and sandstone; and the formations above the Carboniferous are dominated by shale and other clastics (sandstone, siltstone and conglomerate) with minor carbonate. In Figure 8, well C (10-13-100-4W6) shows the typical Gamma Ray (GR) and Resistivity-deep (RESD) signatures for Devonian formations, and well D (6-14-83-6W6) shows those for Mississippian, Pennsylvanian, Permian, Triassic and Jurassic formations. Well E (14-2-70-8W6) in Figure 9 shows the 'typical' GR and RESD signatures for Cretaceous formations.

In general, a formation boundary is usually associated with one or more of the following: a flooding surface, an erosional surface or a lithological change. These changes across formation and lithological boundaries result in varying GR and RESD signatures, and hence, the trend and pattern of log responses were used to characterize and differentiate formations and their internal lithologies. A total of 47 stratigraphic horizons were identified on the three type logs, including the following: 13 in the Devonian, 7 in the Mississippian, 1 in the Pennsylvanian, 1 in the Permian, 2 in the Triassic, 4 in the Jurassic, 10 in the Lower Cretaceous and 9 in the Upper Cretaceous (Figures 8 and 9). The horizon names and identification features are summarized in Table 5.

4 Regional Cross-sections and Bedrock Top Boundaries

The four regional cross-sections, A─A', B─B', C─C' and D─D', that were constructed are shown in Figures 10 to 13, inclusive. The cross-sections contain the entire successions across the Clear Hills–Smoky River region. Figure 7 shows the locations of the cross-sections that are tied with each other. Purple-filled circles represent correlated wells; brown-filled circles represent the wells tied to those at cross-section ends in Chen and Olson (2005); green-filled circles indicate the sites of the three reference wells in Figures 8 and 9, and red-filled circles indicate the wells that have Bad Heart top picked in the AGSWDB for the Clear Hills area.

Cross-section A─A' (Figure 10), which trends northeast, is largely along the regional dip of most formations and links to a prior cross-section at the Buffalo Head Hills area (i.e., cross-section B─B' of Chen and Olson, 2005). Cross-section B─B' (Figure 11), which trends north, traverses across the Clear Hills to Halverson Ridge area and both flanks of the PRA. Cross-section C─C' (Figure 12), which trends northwest, is largely along the regional strike of most formations and crosses both flanks of the PRA. Cross-section D─D' (Figure 13), which trends east, crosses the Clear Hills ooidal ironstones near the headwaters of the Whitemud River, and also extends to the east across the Peace River lowlands and is linked to the Buffalo Head Hills area (i.e., cross-section A─A' of Chen and Olson, 2005).

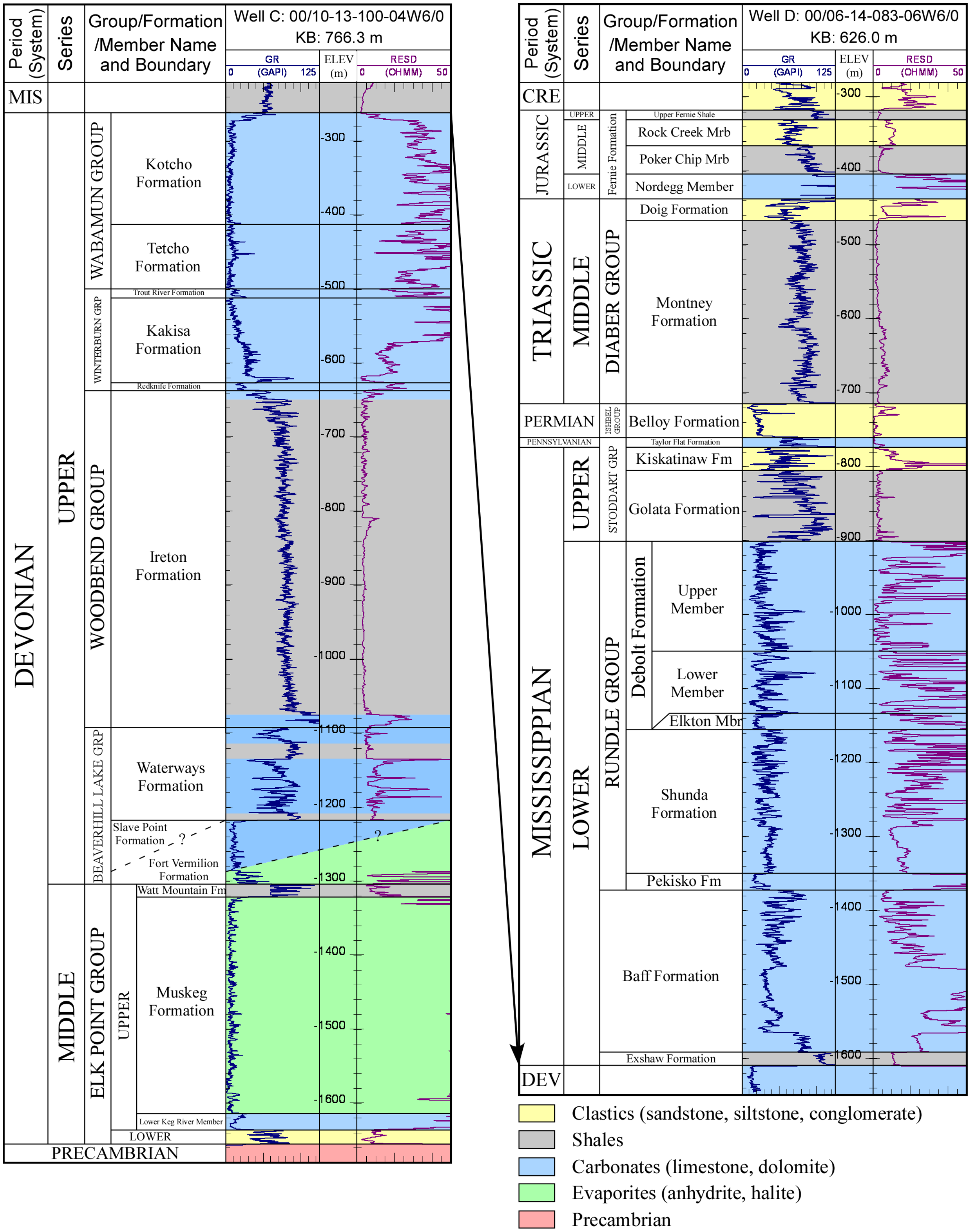

Figure 8. Paleozoic and lower Mesozoic formations in the Clear Hills–Smoky River region. Reference logs with dominant lithology are shown. KB: Kelly Bushing; ELEV: Elevation; GR: Gamma Ray; RESD: Resistivity - deep; CRE: Cretaceous; MIS: Mississippian; DEV: Devonian; GRP: Group; Fm: Formation; Mbr: Member; L.: Lower. See Figure 7 for well locations of the reference logs.

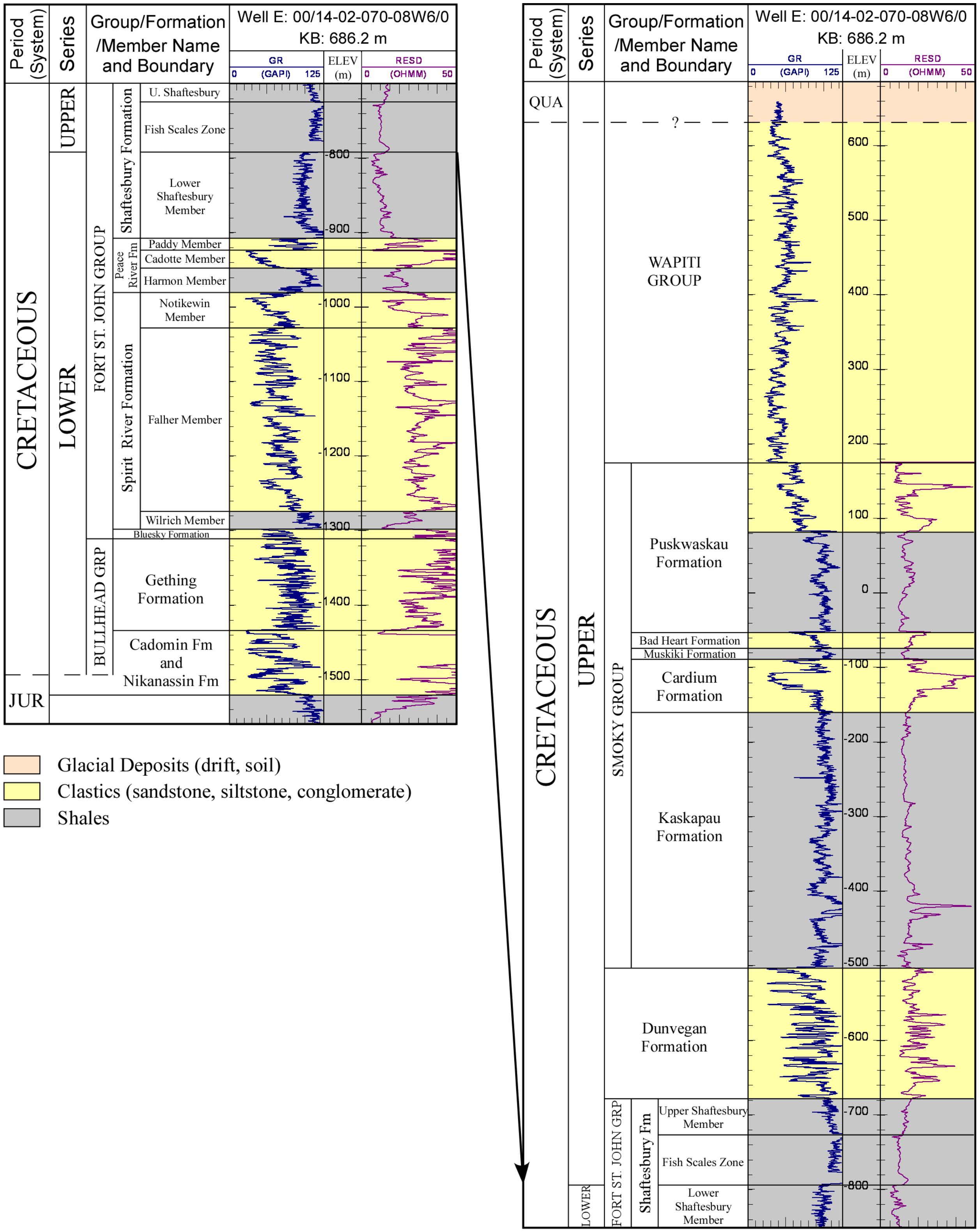

Figure 9. Cretaceous formations in the Clear Hills–Smoky River region. Reference logs with dominant lithology are shown. KB: Kelly Bushing; ELEV: Elevation; GR: Gamma Ray; RESD: Resistivity; QUA: Quaternary; JUR: Jurassic; GRP: Group; Fm: Formation; Mbr: Member; U.: Upper. See Figure 7 for well location of the reference logs.

Table 5. Summary of stratigraphic horizons identified in reference wells; listed from stratigraphic base to top

HORIZON NAME	UNDERLYING LITHOLOGY	OVERLYING LITHOLOGY	GAMMA RAY	RESISTIVITY
Devonian Base	Precambrian igneous and metamorphic rocks	Red beds, granite wash	Above sharp left kick	Above sharp right kick
Lower Elk Point Top	Red beds	Carbonate	On top of neck-shaped package	On top of neck-shaped package
Lower Keg River Top	Carbonate	Evaporite, carbonate	At small left kick	High
Muskeg Top	Evaporite	Shale, fine clastics	On shoulder of chunk low gamma	On shoulder of chunk extremely high resistivity
Watt Mountain Top	Shale	Evaporite, carbonate	On top of neck-shaped package	On top of neck-shaped package
Slave Point Top	Carbonate	Shale	On top of chunk low gamma	On top of chunk extremely high resistivity
Waterways Top	Argillaceous limestone, shale	High gamma argillaceous limestone	At base of high gamma	Below right kick
Ireton Top	Thick shale, argillaceous limestone	Carbonate	Below low gamma package	Below high resistivity package
Redknife Top	Carbonate	Thin shale layer	At left kick	At right kick
Kakisa Top	Carbonate with shale partings	Quartzose carbonate with shale partings	At small left kick	Break above very high resistivity
Trout River Top	Quartzose carbonate with shale partings	Limestone with shale partings	At small left kick	At major break
Tetcho Top	Limestone with shale partings	Limestone	Small kick below very low gamma	Break in very high resistivity
Wabamun Top	Limestone	Shale	On shoulder of very low gamma	On shoulder of very high resistivity
Exshaw Top	Shale	Siltstone, silty limestone	On top of neck-shaped responses	On top of neck-shaped responses
Banff Top	Shale, argillaceous limestone	Massive dense limestone	At base of pan-shaped responses	At base of pan-shaped responses
Pekisko Top	Massive dense limestone	Argillaceous limestone with clastics	On top of pan-shaped responses	On top of pan-shaped responses
Shunda Top	Interbedded limestone and shale	Massive bioclastic limestone	At base of bulky low gamma	Below high resistivity package
Lower Debolt Top	Bioclastic limestone	Micritic carbonate	At major break	Above bunch of major spikes
Upper Debolt Top	Micritic carbonate	Limestone, shale	At major left kick	At sharp right kick

HORIZON NAME	UNDERLYING LITHOLOGY	OVERLYING LITHOLOGY	GAMMA RAY	RESISTIVITY
Golata Top	Argillaceous limestone, fine clastics	Quartz sandstone	Below major package of low gamma	Below high resistivity spike
Kiskatinaw Top	Calcareous clastics	Calcareous shale, argillaceous limestone	Above package of low gamma	Above package of high-medium response
Taylor Flat Top	Calcareous shale	Sandstone, sandy dolostone	At base of chunky low gamma	Above very low response
Belloy Top	Sandstone, sandy dolostone	Siltstone, shale	On top of chunky low gamma	Above small right kick
Montney Top	Siltstone, shale	Argillaceous siltstone, calcareous shale	At base of low gamma package	Below high resistivity package
Doig Top	Siltstone	Cherty and phosphate limestone	Split between above extremely high and below medium-low gamma	Below very high resistivity package
Nordegg Top	Cherty and phosphate limestone	Calcarious shale	Above extremely high gamma package	On top of very high resistivity package
Poker Chip Top	Shale with thin Calcarious-cemented beds	Quartzose siltstone and sandstone	At base of pan-shaped package	At base of pan-shaped package
Rock Creek Top	Quartzose siltstone and sandstone	Shale	At base of neck-shaped response	At base of neck-shaped response
Fernie Top	Shale	Sandstone	On top of neck-shaped package	On top of neck-shaped package
Cadomin Top	Conglomerate with interbedded sandstone, siltstone and mudstone	Sandstone, conglomerate	On top of medium-low package	On top of very high resistivity package
Gething Top	Sandstone, conglomerate	Sandstone, usually glauconitic, containing fair porosity	At base of uppermost coarsening-up sandy sequence	At uppermost major split in high resistivity package
Bluesky Top	Shallow marine sandstone	Shale	Separates high gamma from underlying medium-low gamma	On top of high resistivity package
Wilrich Top	Shale with thin interbeds of silt and sand	Siltstone	At base of lowing-up response	At base of high resistivity package
Falher Top	Greywacke, shale and siltstone	Argillaceous sandstone with shale	At base of uppermost sandy sequence	At base of uppermost sandy sequence
Notikewin Top	Argillaceous sandstone with shale and ironstone concretions	Marine shale with thin beds of sandstone and siltstone	At base of neck-shaped package	At base of neck-shaped package

HORIZON NAME	UNDERLYING LITHOLOGY	OVERLYING LITHOLOGY	GAMMA RAY	RESISTIVITY
Harmon Top	Marine shale with thin beds of sandstone and siltstone	Shallow marine sandstone	At base of pan-shaped package	At base of pan-shaped package
Cadotte Top	Shallow marine sandstone	Sandstone with thin shale and coal beds	At top of pan-shaped package	At top of pan-shaped package
Paddy Top	Sandstone with thin shale and coal beds	Shale	Separate above high gamma from below medium gamma	On top of high resistivity
Base of Fish Scales	Siltstone, shale	High radioactive siltstone and fine sandstone	At base of extremely high gamma	At base of medium-low knob
Fish Scales Top	Shale	Shale	High gamma flooding surface	Low resistivity split
Shaftesbury Top	Shale, siltstone	Sandstone with thin beds of shale, shelly limestone and coal	At base of low gamma spike	At base of medium resistivity spike
Dunvegan Top	Sandstone	Carbonaceous shale	On top of package of low gamma spikes	On top of package of medium resistivity spikes
Kaskapau Top	Shale	Coarsening-up sandy unit	At base of coarsening-up sequence	At base of funnel-shaped package
Cardium Top	Thick sandstone separated by shale	Shale	On top of left kick	On top of right kick
Muskiki Top	Shale	Sandstone, ironstone, some interbedded sandy shale	At base of funnel-shaped package	At base of funnel-shaped package
Bad Heart Top	Sandstone, ironstone, some interbedded sandy shale	Shale	On top of funnel-shaped package	On top of funnel-shaped package
Puskwaskau Top	Silty beds	Thin bedded to thick, feldspathic, calcareous sandstone	At base of thick package of low to medium response	At base of package of medium to high response

Confined by cross-section scales and paper size, only seven selected horizons are shown in the regional cross-sections among the 47 horizons that were identified and shown on Figures 8 and 9. These seven horizons are, in ascending order: the Precambrian, Devonian, Carboniferous, Jurassic, Lower Cretaceous, Dunvegan and Marshybank/Bad Heart tops. The ground surface in cross-sections A—A’ to D—D’ (Figures 10 to 13) was drawn based on digital elevation model data. Glacial deposits are, at present, not well differentiated from bedrock in these regional cross-sections. Hence, the dashed line beneath the ground surface is schematic and, thus, only uniformly approximates the bedrock top; whereas, in reality, the overburden thickness probably ranges from a few up to perhaps a 100 m or more across the Clear Hills–Smoky River region.

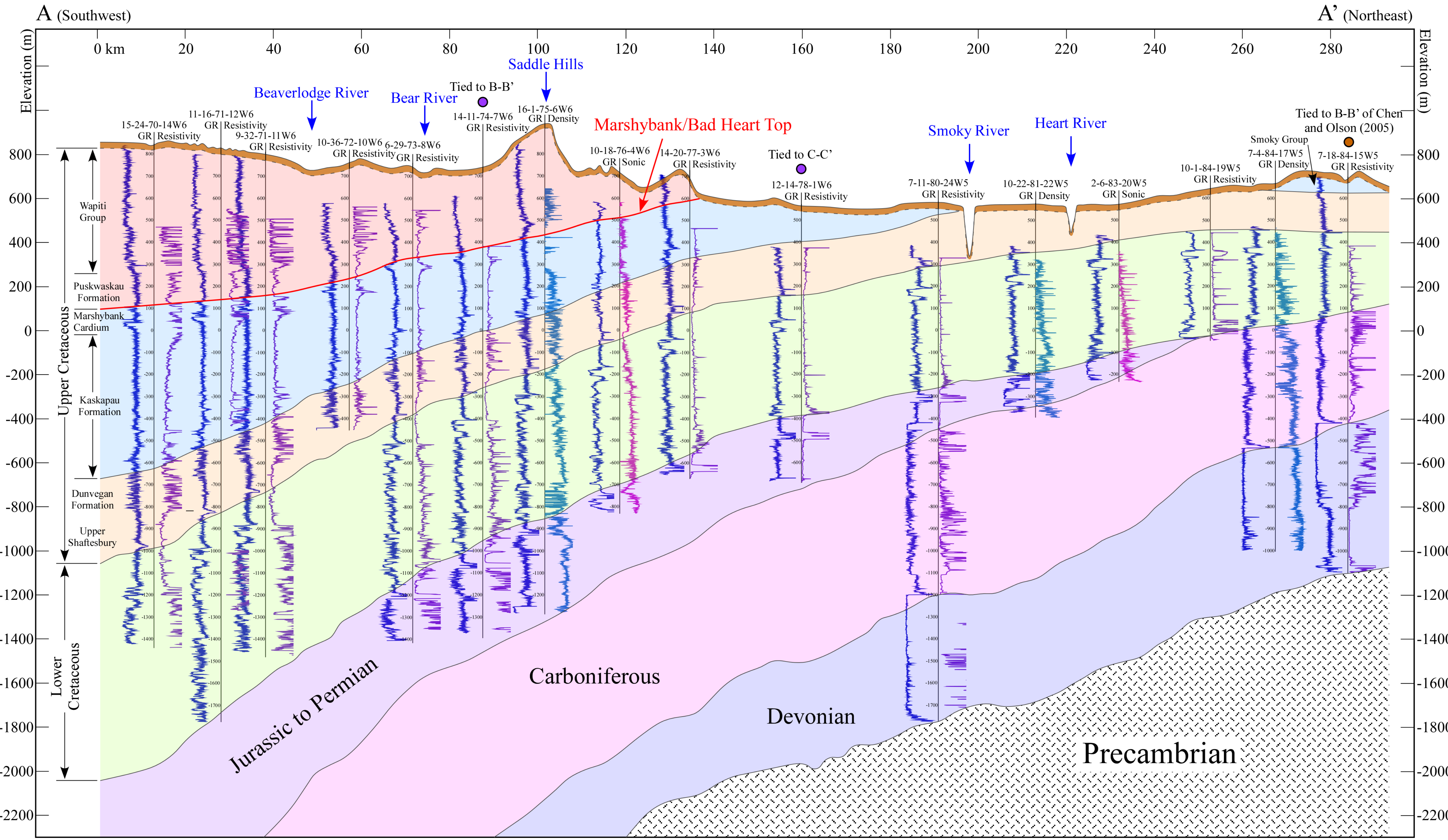

Figure 10. Northeast-trending cross-section A–A'. Lateral versus vertical scale, 1:50. The solid red line represents the approximate top of the Marshybank Formation and the laterally equivalent Bad Heart Formation. See Figure 7 for cross-section location. GR: gamma ray; RES: resistivity; DEN: density; AC: acoustic.

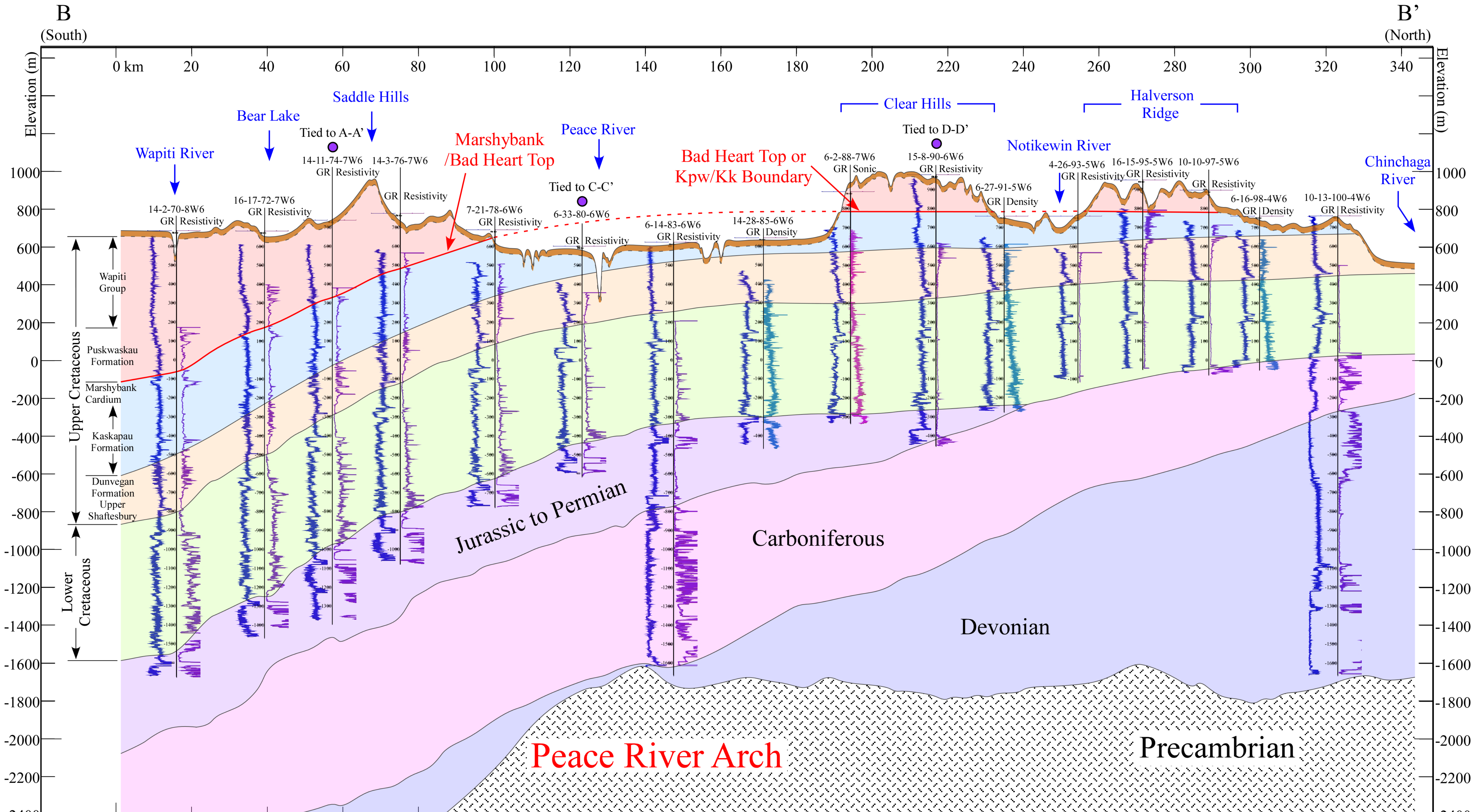

Figure 11. North-trending cross-section B–B'. Lateral versus vertical scale, 1:50. The solid red line represents the approximate top of the Marshybank Formation (from south of Wapiti River, north to about the Saddle Hills) and the laterally equivalent Bad Heart Formation (from north of the Saddle Hills, north to the Clear Hills) or the boundary of the Puskwaskau/Kaskapau (Kpw/Kk) formations. See Figure 7 for cross-section location. GR: gamma ray; RES: resistivity; DEN: density; AC: acoustic.

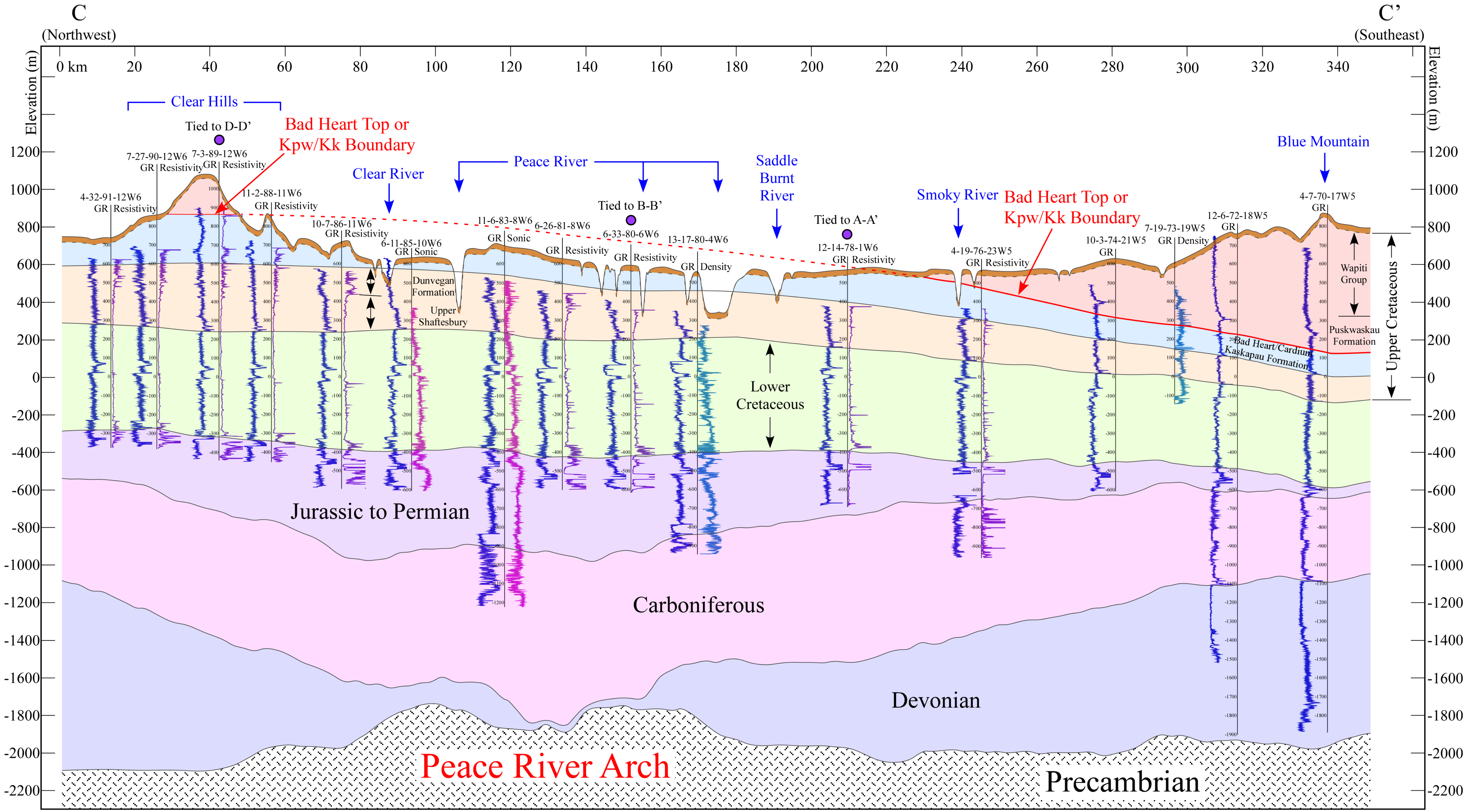

Figure 12. Northwest-trending cross-section C–C'. Lateral versus vertical scale, 1:50. The solid red line represents the approximate top of the Bad Heart Formation or the boundary of the Puskwaskau/Kaskapau (Kpw/Kk) formations. See Figure 7 for cross-section location. GR: gamma ray; RES: resistivity; AC: acoustic; DEN: density.

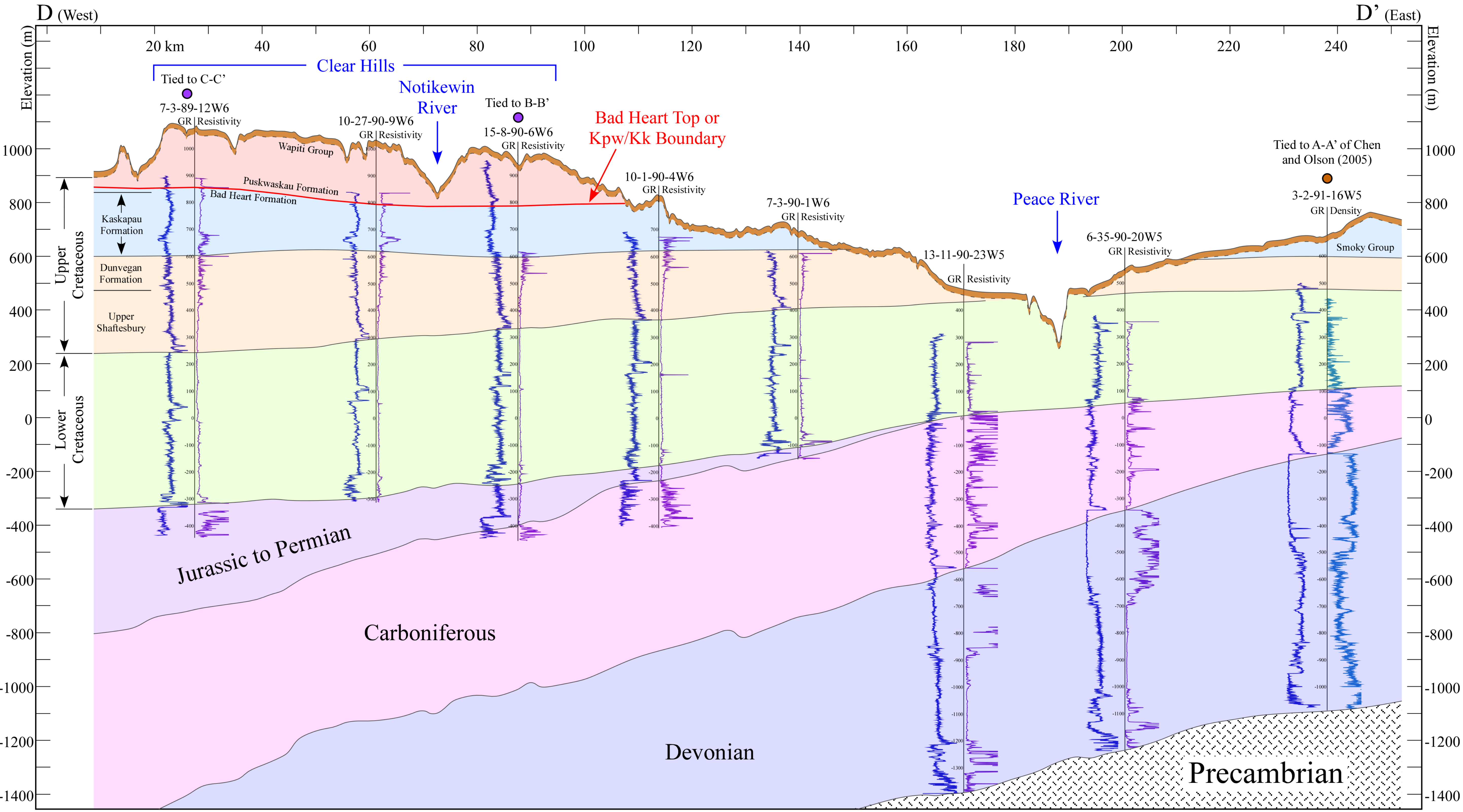

Figure 13. East-trending cross-section D–D'. Lateral versus vertical scale, 1:50. The solid red line represents the approximate top of the Bad Heart Formation or the boundary of the Puskwaskau/Kaskapau (Kpw/Kk) formations. See Figure 7 for cross-section location. GR: gamma ray; RES: resistivity; DEN: density.

The Precambrian basement–Phanerozoic contact generally dips westerly from northeast to southeast and is at an elevation approximately 1100 m above the present sea level in the east end of cross-sections A─A' and D─D' (Figures 10 and 13). However, from northwest to southeast the Precambrian basement is uplifted across the PRA (e.g., up to about 350 m as shown on Figure 12). The Devonian thins toward the PRA, but the Carboniferous and Permian thicken in the Arch (Figure 12). The sub-Cretaceous unconformity truncates all of the underlying systems, including the Jurassic, Triassic, Permian, Pennsylvanian and Mississippian.

Upper Cretaceous formations have been significantly eroded in most of the Clear Hills–Smoky River region, especially across the Peace River valley (Figure 7). The boundaries of the bedrock formations shown in Figure 7 were clipped from the Geological Map of Alberta (AGS Map 236, Hamilton et al., 1999), but the extensive overburden and lack of large-scale geological mapping mean that there is probably much imprecision in the formation boundaries detail. The bedrock units that have a relatively large subcrop area include the Shaftesbury Formation in the northeast, the Dunvegan Formation in the northwest and central-east, the Smoky Group in the east, the Kaskapau Formation in the west and central-south, the Puskwaskau Formation in the central-south and Clear Hills area, and the Wapiti Group in the south and central Clear Hills. In general, the formations become older to the north and northeast, whereas the youngest units exist to the west and south, and in the uplands, such as the Clear Hills. The bedrock formations are also deeply incised by rivers. For example, the Peace River incises down to the Shaftesbury Formation from Peace River town to the west (Figures 7 and 12), to the Peace River Formation between Peace River town and latitude 57º (Figures 7 and 13), and to the Spirit River Formation north of latitude 57º (Figure 7).

In the regional cross-sections (Figures 10 to 13), the up-dip boundaries of subcropping formations can be estimated using the projected formation tops with the DEM data. The estimated boundaries in the cross-sections have been compared with those geological boundaries from AGS Map 236 (Hamilton et al., 1999). In general, there is a good correlation between the bedrock formation boundaries in the cross-sections and those from AGS Map 236. Having said this, three locations that need further work to better define the formation extent have been identified; these are indicated by the dashed lines in black (east end of section A─A'), green (north end of section B─B') and purple (northwest end of section C─C') on Figure 7. The dashed black line east of Peace River town indicates that the boundary between the Dunvegan Formation and Smoky Group may be further to the east (i.e., east of the east end of Figure 10) than is currently shown on AGS Map 236. The dashed green line near the north end of section B─B' indicates that the boundary between the Dunvegan and Kaskapau formations may actually be somewhat to the north of well C (Figure 11). Finally, the dashed purple line at the northwest end of section C─C' in the Clear Hills indicates that the boundary between the Kaskapau and Puskwaskau formations may actually be a little more southeast (Figure 12) than shown on AGS Map 236.

The Peace River Arch area (Figure 2), which initially was an arch or topographic high prior to becoming an embayment, had a significant impact on the depositional patterns of Phanerozoic strata from the mid-Devonian to at least the mid to late Mesozoic and perhaps even into the Tertiary. Figure 14 shows major PRA outlines over time and selected sedimentary unit zero edges in the study area. These are discussed at more length below.

As a result of the EUB/AGS ongoing study of the ooidal ironstones in the Upper Cretaceous in the Clear Hills–Smoky River region and particularly within the Clear Hills, two more detailed sections for the Upper Cretaceous were prepared; one runs east-west across the southern part of the Clear Hills and the other runs northerly from the southeastern part of the Clear Hills to the northeastern part of Halverson Ridge (Figures 15 to 17). Finally, details for two selected wells (labelled Wells A and B on Figures 7 and 15) are shown on Figure 18.

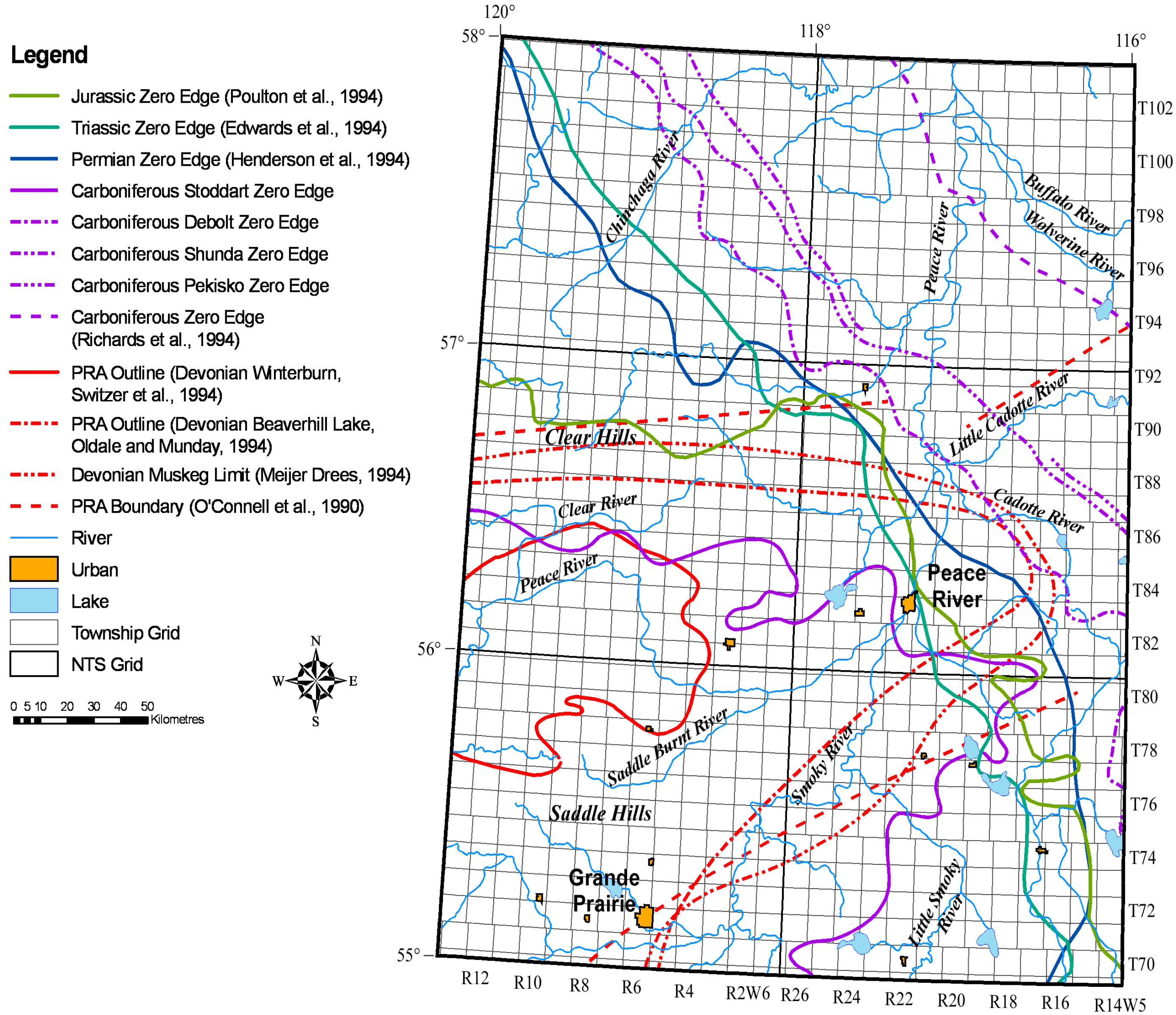

Figure 14. Peace River Arch (PRA) outline over time and selected zero edges of major formations in the Clear Hills–Smoky River region.

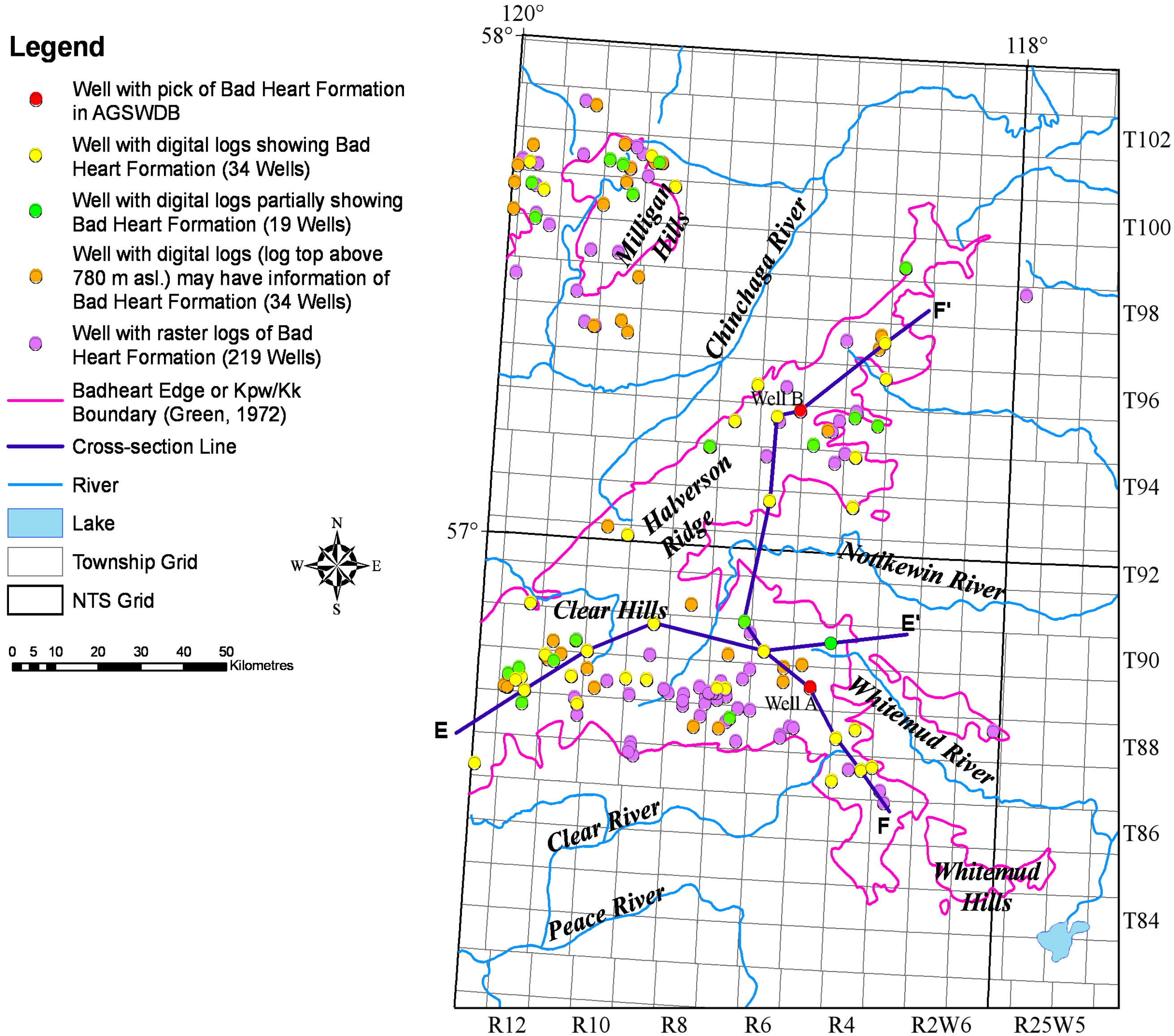

Figure 15. Locations of cross-sections E–E' and F–F' (Figures 16 and 17) and well logs showing Upper Cretaceous formations in the Clear Hills area. See Figure 18 for details of wells A and B. See tables in Appendices A and B for well information. Kpw/Kk: Puskwaskau/Kaskapau.

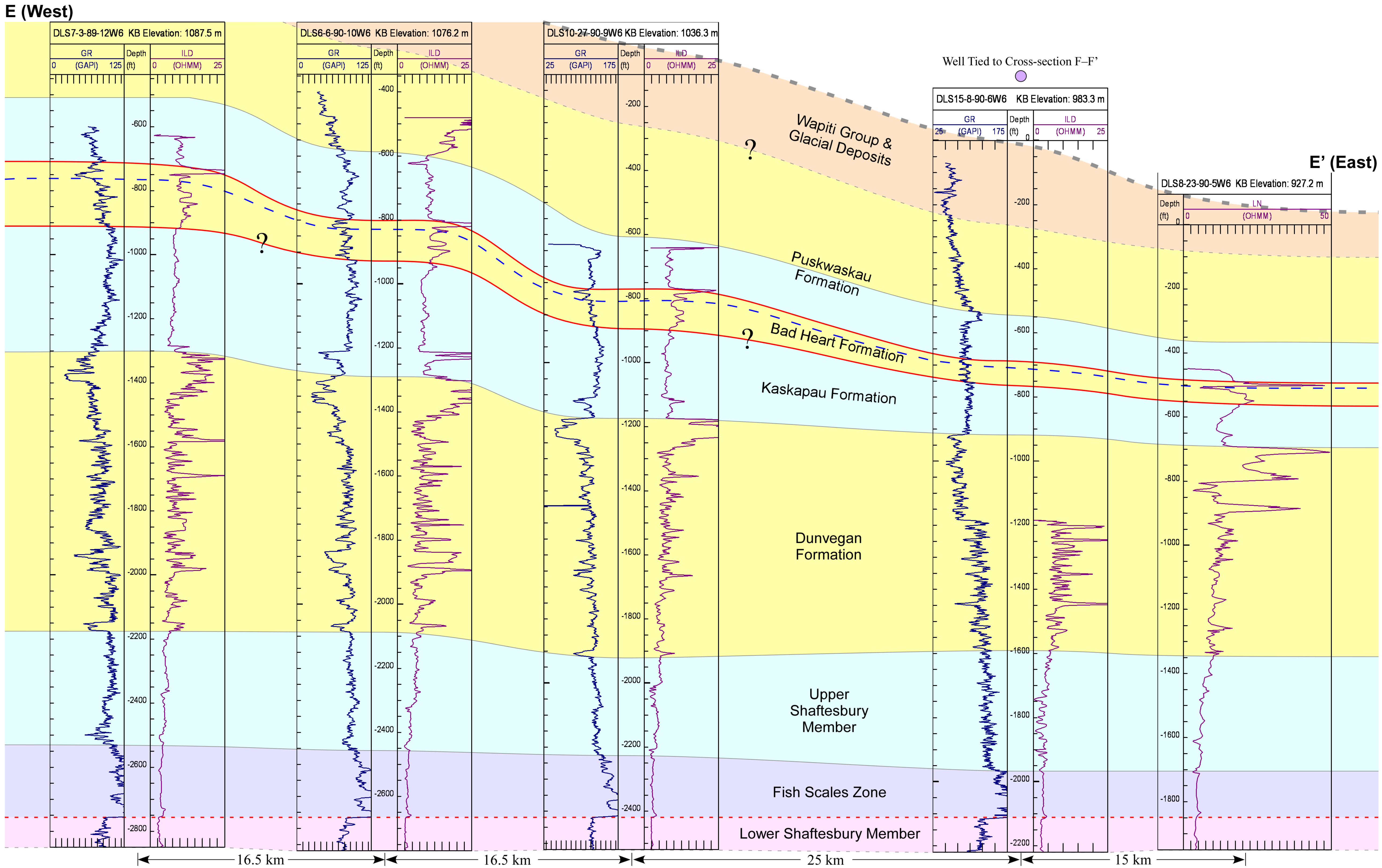

Figure 16. East-trending cross-section E–E', showing Upper Cretaceous formations in the Clear Hills. Cross-section datum: Base of Fish Scales (dashed red line). See Figure 15 for locations of the cross-section and wells. GR: Gamma Ray; ILD: Deep Induction Log; LN: Long Normal. Note that glacial deposits are not differentiated from bedrocks in this cross-section.

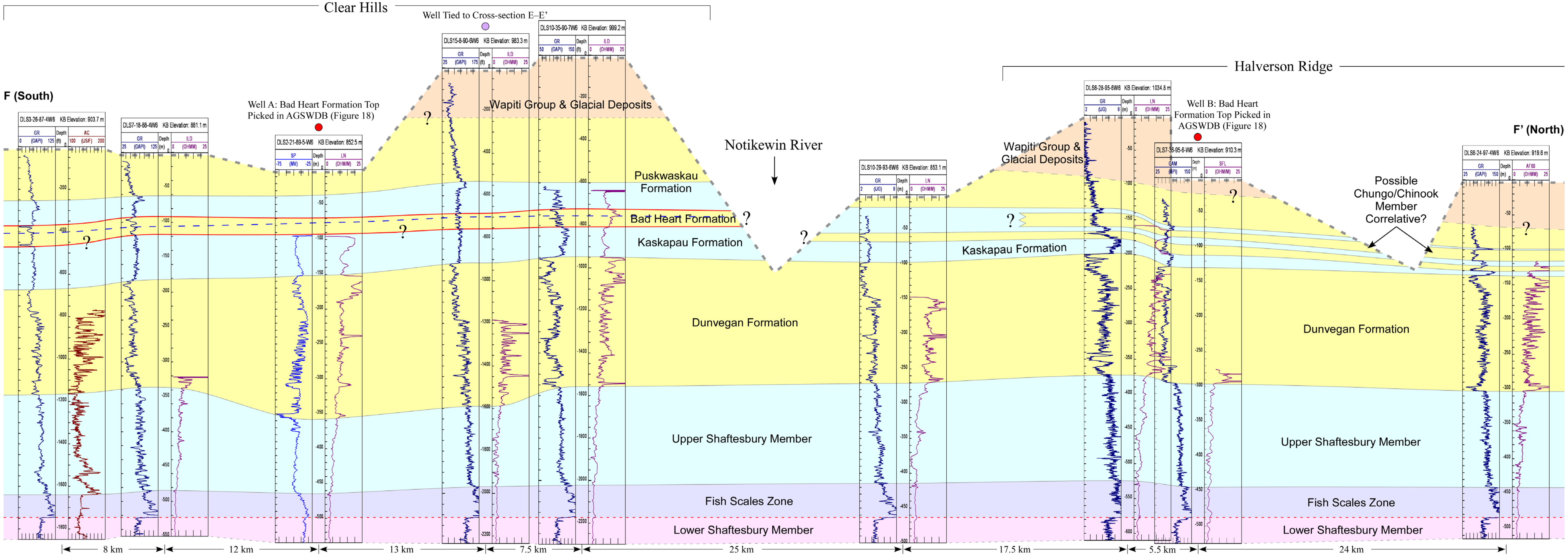

Figure 17. North-trending cross-section F–F', showing Upper Cretaceous formations from the southeast of the Clear Hills to the northeast of the Halverson Ridge. Cross-section datum: Base of Fish Scales (dashed red line). See Figure 15 for locations of the cross-section and wells. The Bad Heart Formation (solid red line) and equivalent vary in thickness and features. AC: acoustic; GR and GAM: gamma ray; ILD and AF60: deep induction resistivity; LN: long normal; SFL: spherically focused log; SP: spontaneous potential. Note that glacial deposits are not differentiated from the bedrock in this cross-section.

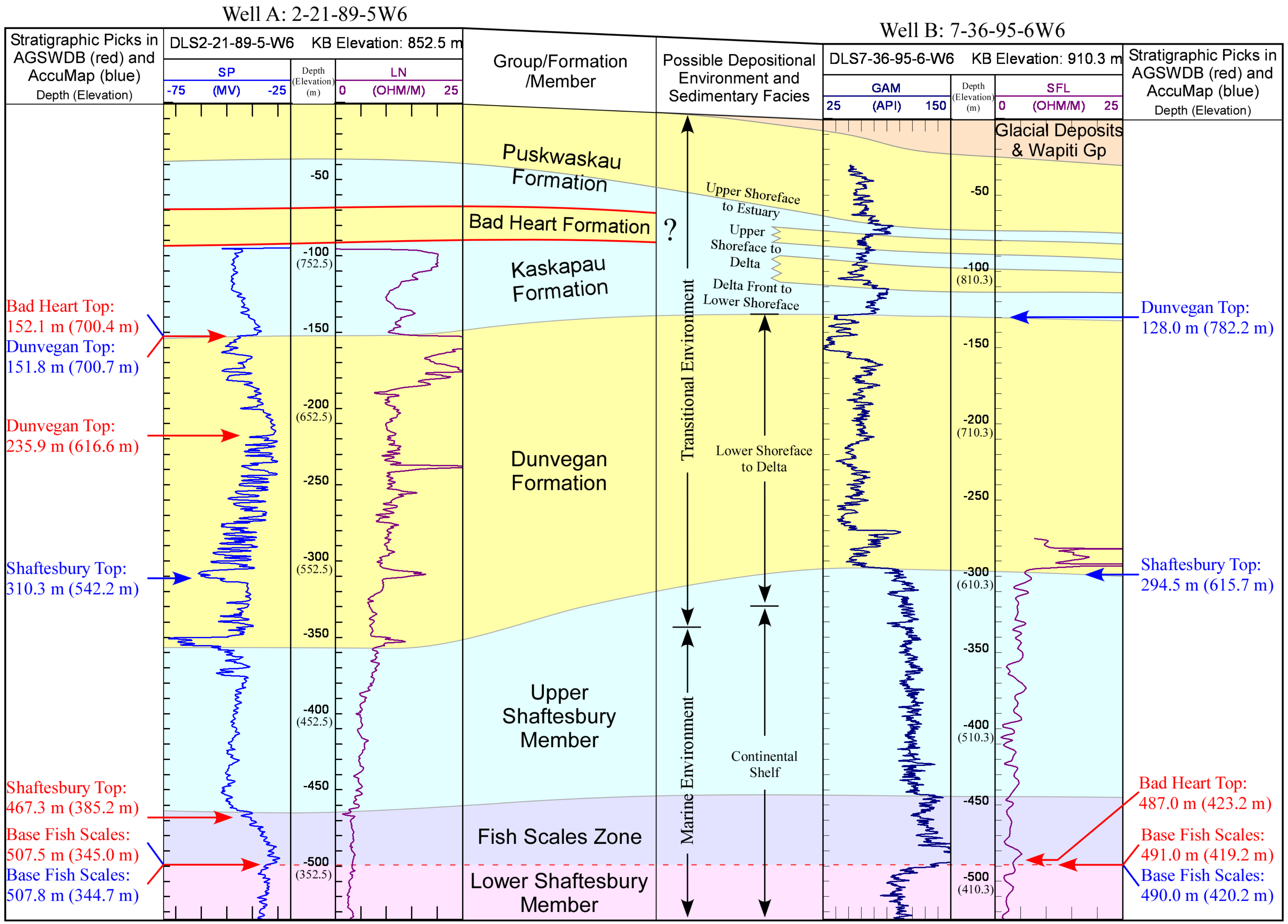

Figure 18. Comparison of Upper Cretaceous stratigraphic picks from AGSWDB and AccuMap databases with the correlation in Figure 17. Red arrows with text are AGSWDB records; blue arrows with text are AccuMap records; colour bands with black text are from Figure 17. See Figure 15 for well location. SP: spontaneous potential; LN: long normal; GAM: gamma ray; SFL: spherically focused resistivity log.

5 Formation Characteristics and Correlation

5.1 Formations Present in the Clear Hills–Smoky River Region

The Phanerozoic sedimentary cover in the Clear Hills–Smoky River region thickens to the southwest. It is about 3800 m thick in the southwest corner of the region, with the thickest Phanerozoic package found roughly along the Beaverlodge River (Figures 7 and 10). The depositional centre was in the northwest during Devonian time, moved to the Peace River Embayment during Carboniferous and Permian time, and shifted to the southwest during Jurassic and Cretaceous time. There are three first-order unconformities in the Phanerozoic sedimentary package: the sub-Devonian unconformity, sub-Cretaceous unconformity and sub-Quaternary unconformity.

The PRA depositional centre appears to be at or along the Peace River close to the Alberta-B.C. border. The size of the PRA and the extent of sedimentary deposition changed through time as shown in Figure 14. In this figure, the inferred PRA outlines over time are delineated in various red curves, including those for Devonian Muskeg (Meijer Drees, 1994), Beaverhill Lake (Oldale and Munday, 1994) and Winterburn (Switzer et al., 1994) time. The PRA outline in Frasnian time (Woodbend) is slightly larger than that of the Winterburn. The PRA ceased to be a topographic highland and was completely inundated in Latest Devonian Famennian time (Wabamun).

The zero edges in Figure 14 represent the erosional boundaries of the formations truncated by the Cretaceous. The Carboniferous zero edges (Banff, Pekisko, Shunda, Debolt and Stoddart) are indicated by purple curves (Richards et al., 1994). The Permian, Triassic and Jurassic zero edges are delineated with blue, sea-green and yellow-green lines, respectively (Henderson et al., 1994; Edwards et al., 1994; Poulton et al., 1994). Most of the zero edges strike NW-SE, except for the Stoddart and the Jurassic zero edges that bend toward or around the PRA.

The Clear Hills–Smoky River region began receiving now-preserved sedimentary deposits in mid-Devonian time. During subsidence of the entire region during Devonian time, formations onlapped on the PRA. Five separate groups of sedimentary strata were deposited in the Devonian, including (in ascending order) the following: the Elk Point, Beaverhill Lake, Woodbend, Winterburn and Wabamun groups. The basal siliciclastic unit, including the Basal Red Beds and Granite Wash, unconformably overlies the Precambrian igneous and metamorphic rocks (Figures 8 and 11). During mid-Devonian time, the broad area outside of the Muskeg Limit was exposed (Figure 14). Evaporite with some carbonate (Figure 8) onlapped onto the PRA from the surrounding areas, and their thickness reaches 400 to 440 m in the northwest in the Milligan Hills area.

To supplement the interpretations in cross-sections A-A’ to D-D’ (Figures 10 to 13), a series of 40 horizon contour maps and 30 isopach maps were prepared for the nine NTS map areas, using pick data in the AGSWDB. However, although these 70 maps are not shown in this report due to space limitations, some regional thicknesses and trends derived from these horizon contour and isopach maps are stated herein.

The Upper Elk Point Group can be divided into three units: the lower Keg River Member consists of various types of carbonate; the Muskeg Formation is dominated by evaporite and carbonate; and the Watt Mountain Formation is composed of shale and minor clastics. The upper Keg River carbonates are not distinguishable from the coeval Muskeg evaporites on the type log at Halverson Ridge (Figure 8). As a result, the units of the Lower Elk Point Group may be present northwest of the Chinchaga River. During Beaverhill Lake deposition sediments continued onlapping onto the ancestral PRA (Figures 11 and 13). The thickness of the Beaverhill Lake Group reaches 200 to 220 m in the area north of the Meikle

River. The group can be divided into three formations (Figure 8): The Fort Vermilion Formation consists mainly of evaporite; the Slave Point Formation is dominated by carbonate; and the Waterways Formation contains primarily argillaceous limestone and shale. The contact between the Fort Vermilion Formation and the overlying Slave Point Formation is not readily discernible on the type logs (Figure 8).

By the time of Woodbend deposition, the exposed PRA shrank to the size of an area between the Clear River and the Saddle Burnt River west of the town of Fairview (Figure 7). At that time, the main depositional basin was in the vicinity of Chinchaga River where the thickness of Woodbend Group sedimentary strata ranges from 400 m to 490 m. Within the study area, the Ireton Formation of Woodbend Group is dominated by shale with argillaceous limestone (Figure 8). Log signatures show that the shale content of the Ireton Formation may increase toward the north, and the limestone content of the formation may increase toward the south and southeast (Figures 12 and 13).

The exposed PRA was even more restricted during Winterburn deposition (Figure 14), and as a result thick deposits of carbonate accumulated on both flanks of the PRA. The thickness of the Winterburn Group is about 120 m in the area south of the PRA, about 120 to 140 m in the area north of the PRA, and up to 150 to 200 m northeast of the Buffalo River. The Winterburn group can be divided into the Redknife, Kakisa and Trout River formations, which are all dominated by carbonate with shale.

In latest Devonian time the Clear Hills–Smoky River region kept subsiding and the PRA eventually became completely submerged. The Wabamun Group consists primarily of carbonate with shale partings and can be divided into two formations: Tetcho and Kotcho (Figure 8). The thickness of Wabamun Group varies across the region, ranging from about 260 to 300 m in the area east of the Whitemud Hills, 220 to 240 m in the area north of the Notikewin River, and 240 to 260 m in the area southeast of the Saddle Burnt River. However, on the PRA crest the unit is thin, being less than 70 m thick (Figures 11 and 12).

During Carboniferous time the PRA area became an embayment and accumulated a thick package of sediments. The Carboniferous formations were then subjected to several erosional events before being covered by the Cretaceous. Due to down-warping of the Peace River Embayment and to the southwest of the region prior to Cretaceous time, preservation of the Carboniferous increases toward the southwest and the central area of the embayment. In contrast, erosion of the Carboniferous increases toward the northeast and the Carboniferous is completely removed northeast of the Wolverine River (Figure 14).

The preserved Carboniferous in the Clear Hills–Smoky River region includes eight formations that include the following (in ascending order): Exshaw, Banff, Pekisko, Shunda, Debolt, Golata, Kiskatinaw and Taylor Flat (Figure 8). The Exshaw Formation consists of shale and siltstone. The Exshaw shale has distinctive high gamma ray and low resistivity responses, and these are used as a regional correlation marker. The Exshaw Formation ranges only up to about 5 m thick in most of the region and it is thinnest at Halverson Ridge, although somewhat thicker, albeit irregular, patches are present locally. The Banff Formation appears to be shaly in the lowest part, limy in the middle part, and consist of interbedded shale and argillaceous limestone in the upper part (Figure 8). The Banff Formation ranges in thickness from about 240 to 330 m and is thicker in a northwest trending belt that extends largely from the Carboniferous zero edge southwest to the town of Fairview (Figure 14). However, its largest thickness is west of the town of Manning.

The Rundle Group contains the Pekisko, Shunda and Debolt formations that are truncated in the northeast of the study area. In general, the Pekisko Formation comprises dense limestones that are distinctive from the underlying and overlying formations that contain more shaly beds. The Shunda Formation consists mainly of interbedded limestone and shale. The Debolt Formation is made up of bioclastic and micritic carbonate. The thickness of the Pekisko, which varies across the area, is about 50 to 80 m within the PRA, 30 to 50 m north of the Arch, and 40 to 60 m south of the Arch. The thickness of the Rundle Group is about 400 to 460 m. The group thickens toward the centre of the Peace River Embayment and the thickness reaches 540 m close to the Alberta-B.C. border.

The Stoddart Group is largely constrained to the southeast flank of the ancestral PRA (Figure 14) and can be divided into the Golata, Kiskatinaw and Taylor Flat formations (Figure 8). The Golata Formation is dominated by argillaceous limestone and fine clastics. The Kiskatinaw Formation consists largely of quartz sandstone and calcareous clastics. The Taylor Flat Formation contains mainly calcareous shale and argillaceous limestone. The thickness of the Stoddart Group ranges from about 100 to 200 m over a large area and the unit may reach thicknesses of 400 to 470 m close to the Alberta-B.C. border.

In the Clear Hills–Smoky River region, the Permian is represented by sandstone and sandy dolostone of the Belloy Formation, which is part of Ishbel Group (Figure 8). The Permian covers an area larger than that of the late Carboniferous Stoddart Group, but is mainly confined to the southwest of the region (Figure 14). The thickness of Belloy Formation is at least 75 m over a large area and reaches more than 150 m close to the Alberta-B.C. border.

The Triassic is preserved in the southwest part of the study area and is represented by the Diaber Group, of which Montney and Doig formations are present in well D (Figure 8). The former consists of shale and siltstone, and the latter consists of argillaceous siltstone and calcareous shale. The Triassic thickens toward the west-southwest and is up to 650 m thick close to the Alberta-B.C. border. The upper Triassic Schooler Group is not shown in the reference well D in Figure 8, but it is present locally close to the Alberta-B.C. border and consists mainly of carbonate and evaporite.

The preserved Jurassic is largely constrained to the area south of the Clear Hills and southwest of the town of Peace River (Figure 14). The Jurassic is about 80 to 120 m thick and it is represented primarily by the Fernie Formation, which can be divided, in ascending order, into the Nordegg, Poker Chip, Rock Creek and Upper Fernie Shale members (Figure 8). The Nordegg Member consists of cherty and phosphatic limestone. The Poker Chip Member comprises mainly shale with thin calcareous-cemented beds. The Rock Creek Member is dominated by quartzose siltstone and sandstone. The Upper Fernie member is primarily a shale unit, and is overlain by the Nikanassin Formation. This formation is of latest Jurassic to earliest Cretaceous age and consists of sandstone with shale, which are distinctive from the underlying Upper Fernie shale (Figure 9).

The Cretaceous unconformably overlies the Jurassic to Carboniferous formations and is the predominant strata that outcrops and subcrops in the entire Clear Hills–Smoky River region. The Lower Cretaceous contains the following: a) the Bullhead Group, which consists of Cadomin and Gething formations, and b) Fort St. John Group, which comprises Bluesky, Spirit River and Peace River formations, and the lower member of the Shaftesbury Formation (Figure 9). The Upper Cretaceous includes the middle and upper members of the Shaftesbury Formation, then the overlying Dunvegan, Kaskapau, Cardium, Muskiki, Bad Heart and Puskwaskau formations, and, finally, the Wapiti Group.

The depositional paleoenvironments of the various Cretaceous formations were significantly affected by the initial phases of the Laramide orogeny to the west and the development of foreland basin structural zones to the east within Alberta or along the Alberta-B.C. border. For example, the Bullhead Group (Cadomin and Gething formations) and Bluesky Formation were mainly deposited in a 'foredeep' that developed southwest of the Spirit River Valley structural zone (Figures 2 and 10). This interval comprises a sequence of westward-derived continental clastics that reach a thickness of up to 440 m in the southwest corner of the study area, but are only about 80 m thick along Spirit River Valley, and thin to 40 to 60 m thick northeast of Spirit River Valley. The Cadomin Formation is dominated by conglomerate with interbedded sandstone, siltstone and mudstone. The Gething Formation consists mainly of sandstone and conglomerate. The Bluesky Formation is relatively thin and is predominantly shallow marine sandstone.

The Spirit River Formation is thick (up to 400 m in places) and blankets much of the Clear Hills–Smoky River region (Figure 7). The formation can be divided into the Wilrich, Falher and Notikewin members (Figure 9). The Wilrich Member consists of thin layers of shale with interbedded siltstone and sandstone. The Falher Member is dominated by greywacke, shale and siltstone. The Notikewin Member is composed largely of argillaceous sandstone and shale with ironstone concretions. The Spirit River Formation thickens toward the southwest where the Carboniferous Peace River Embayment used to be, which may have resulted from collapse of the PRA during Early Cretaceous Albian time. The thickness of the formation is about 360 to 400 m in the central parts of the embayment, becoming less than 300 m thick towards the periphery of embayment, being only 240 to 300 m in the east and southeast, and 220 to 240 m in the north.

The Peace River Formation can be divided into the Harmon, Cadotte and Paddy members (Figure 9). The Harmon Member is dominated by marine shale with thin beds of sandstone and siltstone. The Cadotte and Paddy members are both sandstone units, with the Paddy stacked on top of the Cadotte. The Cadotte Member consists of shallow marine sandstone, whereas the Paddy Members consists of sandstone with thin shale and local coal beds. The Peace River Formation is about 30 to 50 m thick towards the east and southeast parts of the study area, but it abruptly thickens to about 60 to 90 m near Saddle Burnt River and Fairview within the Hines Creek and Fort St. John grabens (Figure 2). The formation also thickens towards the west and reaches 100 m at Pouce Coupe River close to the Alberta-B.C. border (Figure 7).

The Shaftesbury Formation is essentially composed of marine shale and siltstone that are interbedded, in places, with highly radioactive siltstone, fine sandstone and shale. The formation is separated into three members: Lower Shaftesbury, Fish Scales Zone and Upper Shaftesbury. The Lower Shaftesbury Member is a northwest thickening wedge that in the southeast corner of the study area is about 60 m thick, but thickens to 260 m thick in the northwest corner. The Fish Scales Zone and Upper Shaftesbury vary in thickness across the region. Their combined thickness ranges from about 40 to 80 m in the east, northeast and southeast, but increases westerly to about 60 to 160 m in the northeast part of the Clear Hills and up to 200 m in the western part of the Clear Hills. The individual thickness of these two members in the Clear Hills ranges from about 35 to 70 m for the Fish Scales Zone and about 90 to 155 m for the Upper Shaftesbury Member (Figures 15 to 17).

The Dunvegan Formation is dominated by shoreface to deltaic sandstone with thin beds of shale, argillaceous limestone and coal. The basal Dunvegan sandstones are interfingered with the underlying Shaftesbury shale and siltstone (Figure 17). The Dunvegan Formation is a northwest thickening wedge that in general ranges from as little as 20 m thick in the southeast up to about 200 m thick in the northwesternmost parts of the study area. In the Clear Hills, however, the Dunvegan Formation is about 150 to 265 m thick (Figures 15 to 17).

The Smoky Group consists of five formations; in essence, these are two sandy units (Cardium and Bad Heart formations) that are underlain, separated and overlain by three shaly units (i.e., Kaskapau, Muskiki and Puskwaskau formations) (Figure 9). The available data indicate Kaskapau Formation thickens to the southwest. The formation is about 600 m thick in the southwest corner of the study area, but thins to 150 m to the east near South Heart River, decreasing to 115 m to the northeast near the west end of the Clear

Hills and then to as little as 5 m near the extreme northeast end of Halverson Ridge (Figure 17). The Cardium Formation and overlying Muskiki Formation exist in the southern part of the study area, but are believed to have been eroded in the Clear Hills area (Donaldson, et al., 1999). The Cardium Formation consists of a silty lower part, a sandy middle part and a silty upper part, and is locally up to about 70 m thick, but pinches out to the north. The Muskiki Formation is relatively thin (typically less than 20 m) in the study area and becomes un-differentiable from the Kaskapau Formation shale to the north where typical Cardium formation sandstones are not present (Figures 16 and 17).

The Bad Heart Formation was deposited in a shallow marine environment and consists of sediments ranging from mudstone to coarse sandstone and, in places, one or more thick (up to about 9 m) beds of intensely ooidal ironstone. In general, in outcrop the Bad Heart Formation thickness typically is less than 10 m thick, but at the type section near the confluence of the Bad Heart and Smoky rivers the thickness is up to a maximum of approximately 15 m thick and comprises two upward-coarsening sequences (Donaldson, 1997). In the subsurface, the Bad Heart Formation changes abruptly from a sandy unit in the east to a muddy unit in the west (named Marshybank Formation) along an irregular but generally north-northwesterly trending line. In contrast (based on the subsurface geophysical logs), in the subsurface the sandy unit between the Kaskapau and Puskwaskau formations is about 70 to 120 m thick in the extreme southwest part of the study area. The geophysical log interpretations for the Clear Hills area indicate the 'Bad Heart Formation' sandy unit thickness changes drastically from about 60 m in the west to 20 m in the east, and thins to perhaps less than 20 m in the north (Figures 16 and 17). At this time, the reason for this marked disparity in thickness of the 'Bad Heart' sandy unit between Kaskapau and Puskwaskau formation shale inferred in the subsurface from the geophysical logs and mapped in outcrop in the Clear Hills and at Smoky River, is uncertain. As a result, question marks have been placed at the base of the Bad Heart Formation on both Figures 16 and 17 because the inferred Bad Heart Formation in the subsurface is much thicker than that observed at outcrops in both the Clear Hills and at and near Smoky River (Donaldson, 1997; Olson, pers. comm., 2006). The dashed navy line within the inferred Bad Heart Formation shown on Figures 16 and 17 separates the distinctive upper package of low gamma ray and high resistivity responses from the lower package of medium responses. The upper part is about 1/3 to 1/4 of the Bad Heart Formation and may correlate with the Bad Heart Formation observed in outcrops. It is likely that drilling and core studies will be required to answer the question of whether it is the entire inferred sandy unit between the Kaskapau and Puskwaskau formations or only the coarser upper part of the unit in the geophysical log interpretation from this study that belong to the Bad Heart Formation. Finally, Figure 17 indicates there is much uncertainty regarding the correlation of the Bad Heart Formation in the southern and central Clear Hills, with sandy strata that are inferred to exist between Kaskapau and Puskwaskau formations in the northern parts of Halverson Ridge.

The Puskwaskau Formation consists of marine to coastal shale, with siltstone and sandstone in places. The formation is about 125 to135 m thick along the Puskwaskau River (Figure 7) and more than 200 m thick in the western part of the Clear Hills (Figure 16). To the north near the northern end of Halverson Ridge, there is an 8 to 18 m thick sandy unit in the Puskwaskau Formation (Figure 17); this inferred sandstone may correlate with the littoral sandstones and siltstones of the Chungo/Chinook Member, which is a prominent, ridge-forming sandstone in the upper Puskwaskau Formation and is overlain directly by non-marine beds of the Wapiti Formation (Stott, 1967).

Lastly, the overlying Wapiti Group consists of feldspathic, calcareous sandstone. The Wapiti Group is the youngest bedrock in northern Alberta and thus it caps the top of the Clear Hills and Halverson Ridge and the highlands to the south near the Pouce Coupe and Smoky rivers (Figure 7). The thickness of the Wapiti Group, plus the overlying Tertiary and Quaternary sediments, may reach 700 m in the southwest of the study area (Figure 10) and be up to 220 m in the Clear Hills (Figure 12).

5.2 Correlation of Upper Cretaceous Formations in the Clear Hills

As previously mentioned, prior to this study the Bad Heart Formation top had only been picked in two wells in the Clear Hills area; these two wells are labelled Wells A and B (Figures 7 and 15) and their geophysical logs are shown in detail in Figures 17 and 18. In this study of these two wells, eight Upper Cretaceous strata are identified by their log geophysical signatures: Lower Shaftesbury Member; Fish Scales Zone; Upper Shaftesbury Member; the Dunvegan, Kaskapau, Bad Heart and Puskwaskau formations; and Wapiti Group. The correlated formations and possible depositional environment and sedimentary facies are suggested in Figure 18. Interestingly, the two prior picks for the Bad Heart Formation that exist in the AGSWDB are believed not to be correct based on the log interpretation from this study.

In Figures 16 to 18, the formations and members between wells were correlated upwards starting with the easily and consistently recognizable Base Fish Scale Marker, then using log response trends and patterns to infer flooding surfaces and litho-contacts. Note that, in general, the specific values/readings of log responses are not used to correlate formations between wells, but instead the general 'pattern' of a log signature across an interval indicates different facies and depositional units.

In general, the log responses in wells A and B record an overall shallowing-up process during deposition of the Upper Cretaceous strata, i.e., from a marine to non-marine setting, in the Clear Hills area. More specifically, they record on a unit by unit basis; for the Fish Scales Zone the high gamma ray (GR) and low resistivity responses, especially the extreme high GR above the Base of Fish Scales, are distinctive and represent anomalously radioactive siltstone and shale that were deposited in a marine continental shelf environment. The Upper Shaftesbury Member has low resistivity and relatively high GR responses (slightly lower than that of the underlying Fish Scales Zone), and these geophysical signatures indicate marine shale and siltstone that probably were deposited in a continental shelf environment. The Dunvegan Formation has, in general, relatively low to medium-high GR and high to medium-low resistivity responses. These log signatures indicate the Dunvegan consists of marginal marine (i.e., lower shoreface to delta) sandstone and siltstone with shale. The Kaskapau Formation has medium-high GR and medium-low resistivity responses that represent marine (delta front to lower shoreface) deposits of siltstone and shale. The shallow marine sandstones of the Bad Heart Formation have distinctive low GR and high resistivity responses consisting of two or three coarsening-up packages. The Puskwaskau Formation has medium-high GR and medium-low resistivity responses and probably consists of marine to coastal (upper shoreline to estuary) shale, siltstone and sandstone. Finally, the sea retreated from the Clear Hills area during latest Cretaceous time and the Wapiti Group contains massive fluvial, non-marine sandstones with thin beds of siltstone and shale. In general, the sandstones tend to have more negative spontaneous potential (SP) responses than that of shales.

Figure 18 also shows Upper Cretaceous horizons recorded in the AGSWDB and AccuMap databases for wells A and B. Red arrows with text are from the AGSWDB records and blue arrows with text are from AccuMap records. Four AGSWDB picks and three AccuMap picks are shown in well A. Two AGSWDB picks and three AccuMap picks are shown in well B. Note that

- in well A, the Dunvegan top in AccuMap is recorded as the Bad Heart top in AGSWDB;
- in well A, the AGSWDB Shaftesbury top is 157 m lower than the AccuMap Shaftesbury top;
- in well B, the AGSWDB Bad Heart top is picked 4 m above the Base of Fish Scales, whereas the Bad Heart top should be more than 300 m above the Base of Fish Scales in most of the Clear Hills area (at least 150 m above the Base of Fish Scales in the east edge of the area); and

- for the Clear Hills area, this study postulates that neither of the two Bad Heart top picks in the AGSWDB is correct.

These inconsistent results between the AGSWDB and the AccuMap databases indicate that detailed stratigraphic and log studies are needed for the Cretaceous strata along the northwest flank of the PRA. As a starting point for such future studies, Figure 15 shows those wells in the Clear Hills–Halverson Ridge–Milligan Hills area where the geophysical logs that have, or may have, information about the Bad Heart Formation and/or the immediately overlying and underlying units. These wells were selected based on the following criteria: a) in general within the Clear Hills all known surface and subsurface exposures of the Bad Heart Formation are at or above approximately 775 m asl, and b) identifying those wells where the Kelly Bushing and geophysical log information exists at or above approximately 800 m asl. As a result, there are about 305 wells with log top above 800 m elevation, which include 86 wells with digital logs and 219 wells with raster log images. In Figure 15, red dots represent wells A and B with their digital logs shown in Figure 18; yellow dots represent 34 wells with digital logs across the inferred interval of Bad Heart Formation; green dots represent 19 wells with digital logs that may or may not have information across the inferred Bad Heart Formation interval; orange dots represent 34 wells with digital logs and a log top above 780 m asl, hence, the log probably ends at or just below the inferred Bad Heart Formation interval.; and finally purple dots represent 219 wells with raster logs that may or may not cross the Bad Heart Formation interval. The unique well identifier, KB elevation, ground elevation, log top elevation/depth and log type of these 305 wells are listed in Appendices A and B.

6 Highlights of the Results and Suggestions for Future Work

The Clear Hills–Smoky River region has been known as a prolific area of oil and gas production for many years, and currently there is extensive oil/gas well drilling in selected parts of this region. As a result, some of the exploratory or development wells that have been drilled since the AGSWDB data were collected in 2004 may provide geophysical logs for the Upper Cretaceous strata in general and the Bad Heart Formation in particular.

The Clear Hills iron deposits in the Bad Heart Formation were initially discovered in 1924 and have attracted considerable development interest, particularly during the 1950s and 1960s. Total iron resources have been estimated at over 1 billion tonnes grading about 34% iron (Hamilton, 1980).

Although many regional or targeted stratigraphic studies have been published on individual sedimentary intervals in the Clear Hills–Smoky River region, well log cross-sections showing the complete Phanerozoic section are rare. With specific respect to the Upper Cretaceous, most prior stratigraphic studies have been focused along the southeast flank of the Peace River Arch. In contrast, along the northwest flank of the PRA in the Clear Hills–Halverson Ridge area, there are relatively few Upper Cretaceous stratigraphic picks in the existing major geological databases (e.g., AGSWDB, AccuMap), and for the data that does exist there are serious problems caused by miscorrelation and wrong data entry.

This study a) constructed digital log and stratigraphic pick databases for nine 1:250 000 map areas (NTS 83M to 83O, and 84B to 84G, inclusive), b) compiled major structural lineaments and formational edges in the region, c) constructed four regional and two local cross-sections, d) identified 47 stratigraphic horizons, e) correlated subsurface formations along the cross-sections, f) evaluated bedrock top formation boundaries with cross-sections and digital elevation model data, and g) characterized Upper Cretaceous formations on selected logs and the cross-sections (A-A' to F-F' on Figures 10–13, 16 and 17). Finally, we note that cross-sections A─A' and D─D' specifically link to two cross-sections constructed previously for the Buffalo Head Hills area (Chen and Olson, 2005).

The Phanerozoic sedimentary sequence in the Clear Hills–Smoky River region thickens toward the southwest where a total thickness of 3800 m is reached near Beaverlodge River (Figure 7). The Precambrian basement beneath the Phanerozoic strata dips, in general, gently to the southwest across the study area, but in a northwest to southeast transect it is uplifted several hundred m in the core of the PRA (Figure 12). The PRA was a topographic highland during the early Paleozoic, but in mid-Devonian time the region began receiving preserved sedimentary deposits that onlapped the PRA. The PRA was completely submerged in latest Devonian time and became an embayment during Carboniferous and Permian time. The sub-Cretaceous unconformity truncates all of the underlying successions, including the Jurassic, Triassic, Permian, Pennsylvanian and Mississippian.

In the Clear Hills–Smoky River region, the Devonian comprises mainly carbonate (limestone and dolomite), shale and evaporite (anhydrite and halite); the Carboniferous consists largely of carbonate and shale with minor amounts of siltstone and sandstone; and the formations above the Carboniferous are dominated by shale and clastics (sandstone, siltstone and conglomerate) with minor amounts of carbonate. The depositional centre was in the northwest during Devonian time, but shifted to the axis of the PRA during Carboniferous and Permian time and then to the southwest during most of Jurassic and Cretaceous time. However, during deposition of Spirit River Formation in the Early Cretaceous the depositional centre was along the PRA, which may have resulted from collapse of the Arch during Early Cretaceous Albian time.

The region was affected by the onset of the Laramide Orogeny and the associated mega-tectonic uplift and down-buckling that accompanies such mountain building. For example, the area west of Spirit River Valley (Figure 2) may have been the ‘western foredeep’; the area between Spirit River Valley and Edmonton Valley may have been the ‘forebulge’, and the area northeast of the Edmonton Valley may have been the ‘west-median trough’ in Early Cretaceous Aptian time. As a result, superimposed on movements associated with the PRA structural evolution, the foreland basin zones and the migration of the ‘forebulge’ played an important role in controlling deposits and facies distribution in the foreland basin.

The PRA and the ‘forebulge’ zone were favourite localities for developing faults and fractures. However, at present there is no real convincing evidence to demonstrate that younger faults in the basement or overlying Phanerozoic strata were generated from pre-existing older faults. Nonetheless, the evolution of the PRA and activation of basement faults are believed to have had a profound influence on the development of sediment accumulations, and enrichment of hydrocarbon and minerals in the Arch area. For example, there seems to be a dominant northwest-trend for both oil and gas pools in northwestern Alberta (Figures 4 and 5). Evidently, the ‘foredeep’, ‘forebulge’, Keg River and Red Earth highlands, along with the Dunvegan, Tangent and Rycroft faults, played an important role in hydrocarbon accumulation. Oil production appears to have concentrated 1) to the southwest of the Spirit River Valley, 2) between the Dunvegan Fault/Fault 3 and the Tangent Fault/Fault 4, and 3) up-dip of the strata around the southeast boundary of the PRA (Figures 2 and 4). Gas production has a broader distribution than that of oil production, but does appear to have a high concentration in the areas 1) southwest of the Spirit River Valley, 2) along the Dunvegan and Tangent faults, and 3) around the Keg River Highlands (Figures 2 and 5).

The Upper Cretaceous formations in most of the Clear Hills–Smoky River region are poorly exposed or they have been significantly eroded, especially across the Peace River lowlands. Within the study area the Upper Cretaceous units in bedrock become younger to the south and, to a lesser extent, north of the Peace River; whereas the oldest units occur where the bedrock is deeply incised by rivers. In general, there is a good correlation between the formation boundaries derived from the cross-sections in this study coupled with DEM and the boundaries from AGS Map 236. However, the boundaries need work in three places: east of Peace River, in the westernmost Clear Hills, and along the northeastern part of Halverson Ridge (Figure 7).

In the Clear Hills area, the AGSWDB and AccuMap well databases stratigraphic picks above the Base of Fish Scales are relatively few and spatially scattered. The Bad Heart Formation in the Clear Hills is distributed higher than 775 m asl. A search of the well log databases compiled, as of early 2004, for the Clear Hills area identified 305 wells (86 wells with digital logs and 219 wells with raster log images) with a Kelly Bushing and log top above or near 800 m asl.

Eight Upper Cretaceous units were interpreted from the log responses for selected wells and two cross-sections (E-E' and F-F') were constructed (Figures 16 and 17) for the Clear Hills region. In these figures the formations and members between wells were correlated upwards, starting with the easily and consistently recognizable Base of Fish Scale Marker, then using log response trends and patterns to infer flooding surfaces and litho-contacts in each of the wells. Although the top of Lower Shaftesbury Member, Fish Scales Zone, Upper Shaftesbury Member and Dunvegan Formation can be reasonably readily identified on these sections across the Clear Hills, there is much less certainty with the interpreted contacts for Kaskapau, Bad Heart and Puskwaskau formations. In general, the Bad Heart Formation is believed to thin from west to east and south to north across the Clear Hills. As well, the interpreted thickness of the inferred 'sandy unit' (Bad Heart Formation?) between Kaskapau and Puskwaskau formations in the Clear Hills ranges from about 60 m in the west to perhaps less than 20 m in the eastern Clear Hills and at the northern end of Halverson Ridge. In contrast, in outcrop the Bad Heart Formation sandstone-ooidal ironstone unit tends to have an average thickness of about 10 m or less and a maximum thickness of perhaps 15 m in the western Smoky River region. The reason for this disparity between the measured thickness of the Bad Heart Formation in outcrop and that inferred for the subsurface from geophysical logs is uncertain.

As a result of these uncertainties, further detailed stratigraphic studies are required to better understand the stratigraphic correlations and depositional paleoenvironments of the Upper Cretaceous along the northwest flank of the PRA and in the entire northern part of Alberta. The list of 305 wells in the Clear Hills region (shown pictorially on Figure 15) with either digital logs (Appendix A) or raster logs (Appendix B) will be highly useful in support of any such future studies. However, this list should be supplemented by any wells drilled since early 2004 in the Clear Hills–Halverson Ridge–Milligan Ridge area that have Kelly Bushing and geophysical log top elevations above approximately 775 m.

7 References

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Appendix A – Digital Logs Showing or Partially Showing the Bad Heart Formation in the Clear Hills Area

UNIQUE WELL IDENTIFIER	KB ELEVATION (m)	GROUND ELEVATION (m)	LOG TOP ELEVATION (m)	LOG TYPE	RATE
00/02-09-090-07W6-0	1018.6	1014.4	829.6	AC (US/M)	3
00/02-09-090-07W6-0	1018.6	1014.4	843.6	GR (GAPI)	3
00/02-09-090-07W6-0	1018.6	1014.4	829.6	RES (OHMM)	3
00/02-09-090-07W6-0	1018.6	1014.4	829.6	SP (MV)	3
00/03-24-097-11W6-0	836.3	830.5	824.3	GR (GAPI)	3
00/03-26-087-04W6-0	903.7	898.9	891.45	GR (GAPI)	1
00/04-05-090-05W6-0	947.5	943.2	800.5	AC (US/M)	3
00/04-15-089-12W6-0	1100.3	1096.4	1081.8	GR (GAPI)	1
00/04-18-100-10W6-0	944.9	940.9	804.65	RES (OHMM)	3
00/04-25-100-13W6-0	878	874.2	868	GR (GAPI)	3
00/04-27-097-10W6-0	862.2	857.7	861.2	GR (GAPI)	3
00/05-16-101-09W6-0	848.5	842.9	848.5	GR (GAPI)	3
00/05-17-089-12W6-0	1007.6	1002.9	811.6	AC (US/M)	2
00/05-17-089-12W6-0	1007.6	1002.9	811.6	DEN (K/M3)	2
00/05-17-089-12W6-0	1007.6	1002.9	866.35	GR (GAPI)	2
00/05-17-089-12W6-0	1007.6	1002.9	811.6	RES (OHMM)	2
00/05-17-089-12W6-0	1007.6	1002.9	811.6	SP (MV)	2
00/05-17-101-09W6-0	904.3	900	838.3	GR (GAPI)	3
00/06-02-091-12W6-0	841.2	838.2	834.95	GR (GAPI)	1
00/06-06-090-10W6-0	1076.2	1072	929.7	AC (US/M)	1
00/06-06-090-10W6-0	1076.2	1072	954.2	GR (GAPI)	1
00/06-06-090-10W6-0	1076.2	1072	929.7	RES (OHMM)	1
00/06-06-090-10W6-0	1076.2	1072	929.7	SP (MV)	1
00/06-08-090-11W6-0	981.8	977.8	832.55	RES (OHMM)	3
00/06-08-090-11W6-0	981.8	977.8	832.55	SP (MV)	3
00/06-08-101-12W6-0	920.8	916	917.8	GR (GAPI)	1
00/06-14-097-04W6-0	888.3	884.8	813.3	GR (GAPI)	3
00/06-16-089-07W6-0	1026	1022	833.5	DEN (K/M3)	1
00/06-16-089-07W6-0	1026	1022	859.75	GR (GAPI)	1
00/06-17-089-07W6-0	1024.4	1020.5	834.65	DEN (K/M3)	1
00/06-17-089-07W6-0	1024.4	1020.5	841.65	GR (GAPI)	1
00/06-18-087-04W6-0	848.6	844.3	827.1	GR (GAPI)	1
00/06-21-095-07W6-0	935.1	931.2	910.6	GR (GAPI)	1
00/06-24-097-04W6-0	919.6	914.8	803.6	DEN (K/M3)	1

UNIQUE WELL IDENTIFIER	KB ELEVATION (m)	GROUND ELEVATION (m)	LOG TOP ELEVATION (m)	LOG TYPE	RATE
00/06-24-097-04W6-0	919.6	914.8	852.35	GR (GAPI)	1
00/06-24-097-04W6-0	919.6	914.8	803.6	SP (MV)	1
00/06-25-098-10W6-0	854	848.3	829	GR (GAPI)	3
00/06-27-088-07W6-0	1026.1	1022.1	819.1	AC (US/M)	2
00/06-27-088-07W6-0	1026.1	1022.1	837.1	GR (GAPI)	2
00/06-27-088-07W6-0	1026.1	1022.1	819.1	RES (OHMM)	2
00/06-27-088-07W6-0	1026.1	1022.1	819.1	SP (MV)	2
00/06-27-088-12W6-0	1081.9	1077.7	815.9	GR (GAPI)	2
00/06-28-095-06W6-0	981.5	977.2	971	GR (GAPI)	1
00/06-28-095-06W6-0	981.5	977.2	823.75	RES (OHMM)	1
00/06-28-095-06W6-0	981.5	977.2	823.75	SP (MV)	1
00/06-31-089-11W6-0	995.2	991.2	966.2	GR (GAPI)	1
00/06-34-100-10W6-0	967.6	963.8	957.6	GR (GAPI)	3
00/06-35-100-09W6-0	862.4	856.8	862.4	GR (GAPI)	1
00/07-03-089-12W6-0	1087.5	1083.3	897	AC (US/M)	1
00/07-03-089-12W6-0	1087.5	1083.3	904.5	GR (GAPI)	1
00/07-03-089-12W6-0	1087.5	1083.3	897	RES (OHMM)	1
00/07-03-089-12W6-0	1087.5	1083.3	897	SP (MV)	1
00/07-08-089-10W6-0	1092.7	1089.1	909.95	RES (OHMM)	3
00/07-08-089-10W6-0	1092.7	1089.1	909.2	SP (MV)	3
00/07-10-101-10W6-0	1013.5	1009.2	899.5	GR (GAPI)	3
00/07-10-101-10W6-0	1013.5	1009.2	889.75	RES (OHMM)	3
00/07-18-088-04W6-0	881.8	876.5	869.8	GR (GAPI)	1
00/07-18-101-10W6-0	973.5	969.3	862.75	AC (US/M)	2
00/07-18-101-10W6-0	973.5	969.3	862.75	DEN (K/M3)	2
00/07-18-101-10W6-0	973.5	969.3	876.25	GR (GAPI)	2
00/07-18-101-10W6-0	973.5	969.3	862.75	RES (OHMM)	2
00/07-19-101-09W6-0	955.9	950.1	955.9	GR (GAPI)	1
00/07-21-089-12W6-0	1020.5	1016.8	830	AC (US/M)	2
00/07-21-089-12W6-0	1020.5	1016.8	840.5	GR (GAPI)	2
00/07-21-089-12W6-0	1020.5	1016.8	826.25	RES (OHMM)	2
00/07-21-089-12W6-0	1020.5	1016.8	830	SP (MV)	2
00/07-25-096-04W6-0	828.8	825.1	811.8	GR (GAPI)	1
00/07-29-093-04W6-0	882.4	878.4	854.9	GR (GAPI)	1
00/07-29-100-12W6-0	829.3	825.3	824.3	GR (GAPI)	2
00/07-32-094-04W6-0	899.2	895.2	883.95	GR (GAPI)	1
00/07-36-095-06W6-0	910.2	904.3	884.2	GR (GAPI)	1

UNIQUE WELL IDENTIFIER	KB ELEVATION (m)	GROUND ELEVATION (m)	LOG TOP ELEVATION (m)	LOG TYPE	RATE
00/08-17-101-09W6-0	862.5	858.4	857.5	GR (GAPI)	2
00/08-26-097-04W6-0	945.6	941	855.6	GR (GAPI)	3
00/08-26-097-04W6-0	945.6	941	834.6	RES (OHMM)	3
00/08-26-097-04W6-0	945.6	941	834.6	SP (MV)	3
00/09-05-095-05W6-0	943.1	940.2	806.1	AC (US/M)	2
00/09-05-095-05W6-0	943.1	940.2	806.1	DC (K/M3)	2
00/09-05-095-05W6-0	943.1	940.2	806.1	DEN (K/M3)	2
00/09-05-095-05W6-0	943.1	940.2	856.1	GR (GAPI)	2
00/09-05-095-05W6-0	943.1	940.2	806.1	RES (OHMM)	2
00/09-05-095-05W6-0	943.1	940.2	806.1	SP (MV)	2
00/10-01-101-13W6-0	831.6	826.8	831.6	GR (GAPI)	3
00/10-09-101-10W6-0	987.6	983.3	803.35	DEN (K/M3)	2
00/10-09-101-10W6-0	987.6	983.3	807.1	GR (GAPI)	2
00/10-09-101-10W6-0	987.6	983.3	803.35	RES (OHMM)	2
00/10-11-090-11W6-0	1071.2	1067.2	880.2	AC (US/M)	2
00/10-11-090-11W6-0	1071.2	1067.2	884.2	GR (GAPI)	2
00/10-11-090-11W6-0	1071.2	1067.2	880.2	RES (OHMM)	2
00/10-11-090-11W6-0	1071.2	1067.2	880.2	SP (MV)	2
00/10-20-101-12W6-0	844.3	839.9	840.3	GR (GAPI)	3
00/10-25-092-10W6-0	1069	1065	923.5	DEN (K/M3)	1
00/10-25-092-10W6-0	1069	1065	925.5	GR (GAPI)	1
00/10-25-092-10W6-0	1069	1065	923.5	RES (OHMM)	1
00/10-27-090-09W6-0	1036.3	1032.4	841.05	DEN (K/M3)	1
00/10-27-090-09W6-0	1036.3	1032.4	844.05	GR (GAPI)	1
00/10-27-090-09W6-0	1036.3	1032.4	841.3	RES (OHMM)	1
00/10-27-090-09W6-0	1036.3	1032.4	841.3	SP (MV)	1
00/10-28-101-10W6-0	1035.4	1031.1	850.9	DEN (K/M3)	3
00/10-28-101-10W6-0	1035.4	1031.1	851.9	GR (GAPI)	3
00/10-28-101-10W6-0	1035.4	1031.1	850.9	RES (OHMM)	3
00/10-29-089-11W6-0	1046.4	1043	858.4	AC (US/M)	2
00/10-29-089-11W6-0	1046.4	1043	865.15	GR (GAPI)	2
00/10-29-093-06W6-0	853.4	849.2	822.9	GR (GAPI)	1
00/10-33-089-11W6-0	973.2	969.9	817.7	RES (OHMM)	3
00/10-33-089-11W6-0	973.2	969.9	815.7	SP (MV)	3
00/10-33-092-10W6-0	946.7	943.1	816.95	DEN (K/M3)	3
00/10-33-092-10W6-0	946.7	943.1	822.95	GR (GAPI)	3
00/10-33-092-10W6-0	946.7	943.1	816.95	RES (OHMM)	3

UNIQUE WELL IDENTIFIER	KB ELEVATION (m)	GROUND ELEVATION (m)	LOG TOP ELEVATION (m)	LOG TYPE	RATE
00/10-33-099-12W6-0	935.8	931.8	806.8	GR (GAPI)	2
00/10-35-089-06W6-0	990.4	986	806.4	AC (US/M)	3
00/10-35-089-06W6-0	990.4	986	806.4	DEN (K/M3)	3
00/10-35-090-07W6-0	999.1	995.2	805.85	DEN (K/M3)	2
00/10-35-090-07W6-0	999.1	995.2	811.1	GR (GAPI)	2
00/10-35-090-07W6-0	999.1	995.2	805.85	RES (OHMM)	2
00/10-35-090-07W6-0	999.1	995.2	805.85	SP (MV)	2
00/10-35-094-08W6-0	1005.5	1001.6	849	RES (OHMM)	2
00/10-35-094-08W6-0	1005.5	1001.6	849	SP (MV)	2
00/11-01-100-13W6-0	970.6	966.4	814.6	DEN (K/M3)	3
00/11-01-100-13W6-0	970.6	966.4	840.6	GR (GAPI)	3
00/11-01-100-13W6-0	970.6	966.4	814.6	RES (OHMM)	3
00/11-01-100-13W6-0	970.6	966.4	814.6	SP (MV)	3
00/11-09-089-12W6-0	1116.7	1111.4	923.7	AC (US/M)	1
00/11-09-089-12W6-0	1116.7	1111.4	967.7	GR (GAPI)	1
00/11-10-087-13W6-0	855.2	850.9	835.2	GR (GAPI)	1
00/11-10-091-08W6-0	986.6	982.7	804.1	GR (GAPI)	3
00/11-13-096-07W6-0	883.2	877.3	883.2	GR (GAPI)	1
00/11-14-089-11W6-0	1076.9	1073.5	888.9	AC (US/M)	1
00/11-14-089-11W6-0	1076.9	1073.5	959.65	GR (GAPI)	1
00/11-14-089-11W6-0	1076.9	1073.5	888.9	RES (OHMM)	1
00/11-14-089-11W6-0	1076.9	1073.5	888.9	SP (MV)	1
00/11-22-088-04W6-0	830.1	824.8	805.1	GR (GAPI)	1
00/11-22-100-12W6-0	887.1	882.3	884.1	GR (GAPI)	1
00/11-23-100-10W6-0	1017.4	1013.2	900.9	AC (US/M)	2
00/11-23-100-10W6-0	1017.4	1013.2	916.65	GR (GAPI)	2
00/11-23-100-10W6-0	1017.4	1013.2	900.9	RES (OHMM)	2
00/12-05-089-12W6-0	1118.3	1118.3	866.05	RES (OHMM)	3
00/12-05-089-12W6-0	1118.3	1118.3	866.05	SP (MV)	3
00/12-14-097-10W6-0	814.3	810	814.3	GR (GAPI)	3
00/12-23-102-11W6-0	822.5	818	802.75	GR (GAPI)	3
00/12-30-087-03W6-0	839.7	835.8	830.45	GR (GAPI)	1
00/13-14-088-08W6-0	1036	1033	804	GR (GAPI)	3
00/13-15-089-09W6-0	1044.9	1040.9	895.4	AC (US/M)	1
00/13-18-089-09W6-0	1062.8	1059.2	868.8	RES (OHMM)	1
00/14-25-088-11W6-0	1068.6	1065	888.35	RES (OHMM)	1
00/14-25-088-11W6-0	1068.6	1065	888.35	SP (MV)	1

UNIQUE WELL IDENTIFIER	KB ELEVATION (m)	GROUND ELEVATION (m)	LOG TOP ELEVATION (m)	LOG TYPE	RATE
00/14-29-095-04W6-0	835.1	830.3	830.6	GR (GAPI)	2
00/15-08-090-06W6-0	983.3	979	961.8	GR (GAPI)	1
00/15-19-089-10W6-0	1085.6	1080.1	803.6	AC (US/M)	3
00/15-23-089-06W6-0	973.5	969.2	805.5	AC (US/M)	3
00/16-06-089-12W6-0	1097.7	1093.6	812.7	AC (US/M)	3
00/16-08-099-03W6-0	830.9	826.6	823.4	GR (GAPI)	2
00/16-15-095-05W6-0	956.3	951.9	804.3	GR (GAPI)	3
00/16-17-088-07W6-0	1024.9	1020.6	825.9	AC (US/M)	3
00/16-23-095-04W6-0	878.6	874	810.85	GR (GAPI)	2
00/16-30-089-11W6-0	1027.4	1023.6	835.4	DEN (K/M3)	3
02/12-05-089-12W6-0	1108	1103.9	818	AC (US/M)	3
02/12-05-089-12W6-0	1108	1103.9	818	DEN (K/M3)	3

Total 86 wells with 157 logs: 34 wells rated 1, 18 wells rated 2, and 34 wells rated 3.

AC: acoustic, DEN: density, GR: gamma ray, RES: resistivity, SP: spontaneous potential.

Appendix B – Raster Logs Showing the Bad Heart Formation in the Clear Hills Area

UNIQUE WELL IDENTIFIER	KB ELEVATION (m)	GROUND ELEVATION (m)	LOG TOP DEPTH (m)	LOG TYPE
00/02-01-089-08-W6-0	1021.1	1017.1	141.4	INDUCTION-ELECTRIC
00/02-01-089-08-W6-0	1021.1	1017.1	141.4	MICROLOG
00/02-01-089-08-W6-0	1021.1	1017.1	141.4	SONIC-ACOUSTIC
00/02-04-100-12-W6-0	904.6	900.6	90.0	COMP NEUTRON FORM DENSITY
00/02-04-100-12-W6-0	904.6	900.6	90.0	DUAL INDUCTION LOG
00/02-09-090-07-W6-0	1018.6	1014.4	189.0	SONIC-ACOUSTIC
00/02-09-090-07-W6-0	1018.6	1014.4	189.0	DUAL INDUCTION
00/02-12-089-08-W6-0	1016.2	1012.5	162.8	INDUCTION-ELECTRIC
00/02-12-089-08-W6-0	1016.2	1012.5	162.8	SONIC-ACOUSTIC
00/02-14-088-06-W6-0	895.1	890.4	6.6	GAMMA RAY CORR
00/02-14-088-06-W6-0	895.1	890.4	6.6	GAMMA RAY CORR
00/02-25-090-07-W6-0	1006.2	1002.5	169.0	SONIC LOG
00/02-25-090-07-W6-0	1006.2	1002.5	169.0	COMP NEUTRON FORM DENSITY
00/02-25-090-07-W6-0	1006.2	1002.5	169.0	DUAL INDUCTION LOG
00/02-28-087-04-W6-0	854.7	850.7	30.5	NEUTRON
00/02-28-102-11-W6-0	848.8	844.3	10.0	GAMMA RAY NEUTRON
00/03-05-088-09-W6-0	1043.7	1039.8	170.5	MINILOG
00/03-05-088-09-W6-0	1043.7	1039.8	170.5	BHC SONIC
00/03-05-088-09-W6-0	1043.7	1039.8	170.5	COMP NEUTRON LITHO DENSITY
00/03-05-088-09-W6-0	1043.7	1039.8	170.5	DUAL INDUCTION LATEROLOG
00/03-07-089-08-W6-0	1017.8	1013.7	184.9	BHC SONIC
00/03-07-089-08-W6-0	1017.8	1013.7	184.9	COMP NEUTRON FORM DENSITY
00/03-07-089-08-W6-0	1017.8	1013.7	184.9	DUAL INDUCTION SPHER-FOC
00/03-09-101-12-W6-0	870.3	866.3	25.0	COMP NEUTRON SONIC
00/03-24-097-11-W6-0	836.3	830.5	15.0	COMP NEUTRON LITHO DENSITY
00/03-25-095-05-W6-0	839.3	835.5	2.0	MICROLOG
00/03-28-100-12-W6-0	873.8	869.4	10.0	COMPENSATED NEUTRON GAMMA C
00/03-28-100-12-W6-0	873.8	869.4	10.0	COMPENSATED NEUTRON GAMMA C
00/04-15-089-12-W6-0	1100.3	1096.4	18.3	GAMMA RAY
00/04-15-089-12-W6-0	1100.3	1096.4	18.3	GAMMA RAY
00/04-15-089-12-W6-0	1100.3	1096.4	18.3	GAMMA RAY
00/04-15-089-12-W6-0	1100.3	1096.4	18.3	GAMMA RAY
00/05-16-101-09-W6-0	848.5	842.9	10.0	GAMMA RAY NEUTRON
00/05-17-089-12-W6-0	1007.6	1002.9	196.0	BHC SONIC
00/05-17-089-12-W6-0	1007.6	1002.9	196.0	DUAL INDUCTION LOG
00/05-25-088-01-W6-0	838.7	830.3	10.0	COMP NEUTRON FORM DENSITY

UNIQUE WELL IDENTIFIER	KB ELEVATION (m)	GROUND ELEVATION (m)	LOG TOP DEPTH (m)	LOG TYPE
00/05-25-088-08-W6-0	1021.9	1016.6	196.0	BHC SONIC
00/05-25-088-08-W6-0	1021.9	1016.6	196.0	COMP NEUTRON FORM DENSITY
00/05-25-088-08-W6-0	1021.9	1016.6	196.0	DUAL INDUCTION LOG
00/06-02-091-12-W6-0	841.2	838.2	6.1	NEUTRON
00/06-03-090-09-W6-0	1047.0	1043.0	187.1	LATEROLOG
00/06-04-089-08-W6-0	1034.8	1030.0	172.5	BHC SONIC
00/06-04-089-08-W6-0	1034.8	1030.0	172.5	COMP NEUTRON FORM DENSITY
00/06-04-089-08-W6-0	1034.8	1030.0	172.5	DUAL INDUCTION SPHER-FOC
00/06-06-090-10-W6-0	1076.2	1072.0	146.3	INDUCTION-ELECTRIC
00/06-06-090-10-W6-0	1076.2	1072.0	146.3	SONIC-ACOUSTIC
00/06-06-101-09-W6-0	1029.9	1025.7	184.5	BHC SONIC
00/06-06-101-09-W6-0	1029.9	1025.7	184.5	COMP NEUTRON FORM DENSITY
00/06-06-101-09-W6-0	1029.9	1025.7	184.5	DUAL INDUCTION LOG
00/06-09-089-08-W6-0	1033.0	1028.9	171.1	MICRO ELECTRICAL LOG
00/06-09-089-08-W6-0	1033.0	1028.9	171.1	BHC SONIC
00/06-09-089-08-W6-0	1033.0	1028.9	171.1	COMP NEUTRON FORM DENSITY
00/06-09-089-08-W6-0	1033.0	1028.9	171.1	DUAL INDUCTION LOG
00/06-15-089-10-W6-0	1078.4	1074.4	193.5	LATEROLOG
00/06-15-096-06-W6-0	990.5	986.1	76.0	GAMMA RAY
00/06-16-089-07-W6-0	1026.0	1022.0	192.0	DUAL INDUCTION
00/06-17-089-07-W6-0	1024.4	1020.5	189.3	DUAL INDUCTION
00/06-21-095-07-W6-0	935.1	931.2	30.5	NEUTRON
00/06-21-095-07-W6-0	935.1	931.2	30.5	NEUTRON
00/06-24-088-11-W6-0	877.5	873.6	45.7	NEUTRON
00/06-24-101-10-W6-0	1042.3	1037.9	146.1	BHC SONIC
00/06-24-101-10-W6-0	1042.3	1037.9	146.1	DUAL INDUCTION LOG
00/06-26-101-10-W6-0	1036.1	1031.2	157.5	SONIC LOG
00/06-28-095-06-W6-0	981.5	977.2	30.5	NEUTRON
00/06-28-095-06-W6-0	981.5	977.2	30.5	NEUTRON
00/06-31-089-11-W6-0	995.2	991.2	30.5	NEUTRON
00/06-31-089-11-W6-0	995.2	991.2	30.5	NEUTRON
00/06-34-100-10-W6-0	967.6	963.8	10.0	COMP NEUTRON FORM DENSITY
00/06-34-100-10-W6-0	967.6	963.8	10.0	COMP NEUTRON FORM DENSITY
00/06-34-100-10-W6-0	967.6	963.8	10.0	COMP NEUTRON FORM DENSITY
00/06-35-100-09-W6-0	862.4	856.8	10.0	GAMMA RAY NEUTRON
00/06-35-100-09-W6-0	862.4	856.8	10.0	GAMMA RAY NEUTRON
00/07-03-089-12-W6-0	1087.5	1083.3	190.5	SONIC-ACOUSTIC

UNIQUE WELL IDENTIFIER	KB ELEVATION (m)	GROUND ELEVATION (m)	LOG TOP DEPTH (m)	LOG TYPE
00/07-03-089-12-W6-0	1087.5	1083.3	190.5	DUAL INDUCTION
00/07-08-089-10-W6-0	1092.7	1089.1	182.6	INDUCTION-ELECTRIC
00/07-09-089-07-W6-0	1015.2	1010.7	190.1	DUAL INDUCTION
00/07-10-101-10-W6-0	1013.5	1009.2	124.1	NEUTRON
00/07-10-101-10-W6-0	1013.5	1009.2	126.8	LATEROLOG
00/07-14-088-06-W6-0	863.2	860.1	15.2	SONIC-ACOUSTIC
00/07-14-088-06-W6-0	863.2	860.1	15.2	SONIC-ACOUSTIC
00/07-14-089-08-W6-0	1018.1	1013.7	186.0	COMP NEUTRON FORM DENSITY
00/07-14-089-08-W6-0	1018.1	1013.7	186.0	DUAL INDUCTION FOC-GR
00/07-14-089-08-W6-2	1018.1	1013.7	186.0	COMP NEUTRON FORM DENSITY
00/07-14-089-08-W6-2	1018.1	1013.7	186.0	DUAL INDUCTION FOC-GR
00/07-19-101-09-W6-0	955.9	950.1	10.0	GAMMA RAY NEUTRON
00/07-19-101-09-W6-0	955.9	950.1	10.0	GAMMA RAY NEUTRON
00/07-19-101-09-W6-0	955.9	950.1	10.0	GAMMA RAY NEUTRON
00/07-20-089-07-W6-0	1018.2	1014.2	187.0	SONIC-ACOUSTIC
00/07-20-089-07-W6-0	1018.2	1014.2	187.0	DUAL INDUCTION
00/07-21-089-12-W6-0	1020.5	1016.8	190.5	MICROLOG
00/07-21-089-12-W6-0	1020.5	1016.8	190.5	SONIC-ACOUSTIC
00/07-21-089-12-W6-0	1020.5	1016.8	190.5	DUAL INDUCTION
00/07-24-097-05-W6-0	865.0	861.1	10.0	GAMMA RAY CORR
00/07-24-097-05-W6-0	865.0	861.1	10.0	GAMMA RAY CORR
00/07-25-096-04-W6-0	828.8	825.1	16.8	SONIC-ACOUSTIC
00/07-26-094-05-W6-0	932.1	928.1	83.5	NEUTRON
00/07-29-093-04-W6-0	882.4	878.4	30.5	NEUTRON
00/07-32-094-04-W6-0	899.2	895.2	15.2	SONIC-ACOUSTIC
00/07-32-094-04-W6-0	899.2	895.2	15.2	SONIC-ACOUSTIC
00/07-32-095-04-W6-0	856.8	852.8	10.0	GAMMA RAY CORR
00/07-32-095-04-W6-0	856.8	852.8	10.0	GAMMA RAY CORR
00/07-36-095-06-W6-0	910.2	904.3	25.0	SONIC-ACOUSTIC
00/07-36-095-06-W6-0	910.2	904.3	25.0	SONIC-ACOUSTIC
00/08-17-101-09-W6-0	862.5	858.4	5.0	COMP NEUTRON LITHO DENSITY
00/08-17-101-09-W6-0	862.5	858.4	5.0	COMP NEUTRON LITHO DENSITY
00/08-36-089-07-W6-0	1013.8	1010.0	176.0	BHC SONIC
00/08-36-089-07-W6-0	1013.8	1010.0	176.0	COMP NEUTRON FORM DENSITY
00/08-36-089-07-W6-0	1013.8	1010.0	176.0	DUAL INDUCTION LOG
00/09-22-097-11-W6-0	882.0	875.0	10.0	COMP NEUTRON FORM DENSITY
00/09-22-097-11-W6-0	882.0	875.0	10.0	COMP NEUTRON FORM DENSITY

UNIQUE WELL IDENTIFIER	KB ELEVATION (m)	GROUND ELEVATION (m)	LOG TOP DEPTH (m)	LOG TYPE
00/09-24-088-06-W6-0	907.1	903.1	30.5	NEUTRON
00/09-24-088-06-W6-0	907.1	903.1	30.5	NEUTRON
00/09-35-088-11-W6-0	1009.8	1005.8	165.0	GAMMA RAY CORR
00/09-35-088-11-W6-0	1009.8	1005.8	186.3	MICRO LOG
00/09-35-088-11-W6-0	1009.8	1005.8	186.3	MICRO ELECTRICAL LOG
00/09-35-088-11-W6-0	1009.8	1005.8	186.3	BHC SONIC
00/09-35-088-11-W6-0	1009.8	1005.8	186.3	COMP NEUTRON FORM DENSITY
00/09-35-088-11-W6-0	1009.8	1005.8	186.3	DUAL INDUCTION SPHER-FOC
00/09-35-088-11-W6-2	1009.8	1005.8	165.0	GAMMA RAY CORR
00/09-35-088-11-W6-2	1009.8	1005.8	186.3	MICRO LOG
00/09-35-088-11-W6-2	1009.8	1005.8	186.3	MICRO ELECTRICAL LOG
00/09-35-088-11-W6-2	1009.8	1005.8	186.3	BHC SONIC
00/09-35-088-11-W6-2	1009.8	1005.8	186.3	COMP NEUTRON FORM DENSITY
00/09-35-088-11-W6-2	1009.8	1005.8	186.3	DUAL INDUCTION SPHER-FOC
00/09-35-088-11-W6-3	1009.8	1005.8	165.0	GAMMA RAY CORR
00/09-35-088-11-W6-3	1009.8	1005.8	186.3	MICRO LOG
00/09-35-088-11-W6-3	1009.8	1005.8	186.3	MICRO ELECTRICAL LOG
00/09-35-088-11-W6-3	1009.8	1005.8	186.3	BHC SONIC
00/09-35-088-11-W6-3	1009.8	1005.8	186.3	COMP NEUTRON FORM DENSITY
00/09-35-088-11-W6-3	1009.8	1005.8	186.3	DUAL INDUCTION SPHER-FOC
00/10-01-101-13-W6-0	831.6	826.8	10.0	BHC SONIC
00/10-06-089-09-W6-0	1067.4	1062.8	198.4	LATEROLOG
00/10-07-089-07-W6-0	1025.2	1020.8	183.3	SONIC LOG
00/10-07-089-07-W6-0	1025.2	1020.8	183.3	COMP NEUTRON FORM DENSITY
00/10-07-089-07-W6-0	1025.2	1020.8	183.3	DUAL INDUCTION SPHER-FOC
00/10-07-089-07-W6-2	1025.2	1020.8	183.3	SONIC LOG
00/10-07-089-07-W6-2	1025.2	1020.8	183.3	COMP NEUTRON FORM DENSITY
00/10-07-089-07-W6-2	1025.2	1020.8	183.3	DUAL INDUCTION SPHER-FOC
00/10-09-099-10-W6-0	897.7	893.0	35.0	COMP NEUTRON FORM DENSITY
00/10-09-099-10-W6-2	897.7	893.0	35.0	COMP NEUTRON FORM DENSITY
00/10-09-099-10-W6-3	897.7	893.0	35.0	COMP NEUTRON FORM DENSITY
00/10-11-090-11-W6-0	1071.2	1067.2	191.0	SONIC-ACOUSTIC
00/10-11-090-11-W6-0	1071.2	1067.2	191.0	DUAL INDUCTION
00/10-12-089-09-W6-0	1006.4	1001.9	196.3	DUAL INDUCTION
00/10-21-095-06-W6-0	975.9	972.7	53.0	COMP NEUTRON LITHO DENSITY
00/10-21-095-06-W6-0	975.9	972.7	53.0	DUAL INDUCTION LOG
00/10-25-092-10-W6-0	1069.0	1065.0	145.4	DUAL INDUCTION

UNIQUE WELL IDENTIFIER	KB ELEVATION (m)	GROUND ELEVATION (m)	LOG TOP DEPTH (m)	LOG TYPE
00/10-25-092-10-W6-0	1069.0	1065.0	145.4	DENSITY
00/10-26-099-12-W6-0	857.8	853.8	47.8	BHC SONIC
00/10-26-099-12-W6-0	857.8	853.8	47.8	COMP NEUTRON FORM DENSITY
00/10-26-099-12-W6-0	857.8	853.8	47.8	DUAL INDUCTION LOG
00/10-27-090-09-W6-0	1036.3	1032.4	194.8	LATEROLOG
00/10-28-101-10-W6-0	1035.4	1031.1	184.4	DUAL INDUCTION
00/10-29-089-11-W6-0	1046.4	1043.0	30.5	NEUTRON
00/10-29-089-11-W6-0	1046.4	1043.0	187.8	ELECTRIC LOG
00/10-29-089-11-W6-0	1046.4	1043.0	187.8	MICROLOG
00/10-29-089-11-W6-0	1046.4	1043.0	187.8	SONIC-ACOUSTIC
00/10-29-089-11-W6-0	1046.4	1043.0	30.5	NEUTRON
00/10-29-089-11-W6-0	1046.4	1043.0	30.5	NEUTRON
00/10-32-095-04-W6-0	864.1	860.1	9.4	NEUTRON
00/10-32-095-04-W6-0	864.1	860.1	9.4	NEUTRON
00/10-35-094-08-W6-0	1005.5	1001.6	30.5	NEUTRON
00/10-35-094-08-W6-0	1005.5	1001.6	156.1	MICROLOG
00/10-35-094-08-W6-0	1005.5	1001.6	156.4	ELECTRIC LOG
00/10-35-094-08-W6-0	1005.5	1001.6	30.5	NEUTRON
00/10-35-094-08-W6-0	1005.5	1001.6	30.5	NEUTRON
00/11-09-089-12-W6-0	1116.7	1111.4	193.0	SONIC-ACOUSTIC
00/11-09-089-12-W6-0	1116.7	1111.4	193.0	DUAL INDUCTION
00/11-10-087-13-W6-0	855.2	850.9	20.0	SONIC-ACOUSTIC
00/11-14-089-11-W6-0	1076.9	1073.5	187.8	SONIC-ACOUSTIC
00/11-14-089-11-W6-0	1076.9	1073.5	187.8	DUAL INDUCTION
00/11-14-095-05-W6-0	946.9	942.2	10.0	COMP NEUTRON LITHO DENSITY
00/11-14-095-05-W6-0	946.9	942.2	10.0	COMP NEUTRON LITHO DENSITY
00/11-14-095-05-W6-0	946.9	942.2	10.0	COMP NEUTRON LITHO DENSITY
00/11-23-100-10-W6-0	1017.4	1013.2	116.4	SONIC-ACOUSTIC
00/11-23-100-10-W6-0	1017.4	1013.2	116.4	LATEROLOG
00/11-32-087-09-W6-0	925.7	919.7	10.0	GAMMA RAY CORR
00/11-32-087-09-W6-0	925.7	919.7	10.0	GAMMA RAY CORR
00/11-32-087-09-W6-0	925.7	919.7	10.0	GAMMA RAY CORR
00/11-33-088-08-W6-0	1037.4	1031.8	175.6	BHC SONIC
00/11-33-088-08-W6-0	1037.4	1031.8	175.6	COMP NEUTRON FORM DENSITY
00/11-33-088-08-W6-0	1037.4	1031.8	175.6	DUAL INDUCTION SPHER-FOC
00/11-35-088-07-W6-0	1021.7	1018.3	190.8	LATEROLOG
00/12-05-089-12-W6-0	1118.3	1118.3	48.8	INDUCTION LOG

UNIQUE WELL IDENTIFIER	KB ELEVATION (m)	GROUND ELEVATION (m)	LOG TOP DEPTH (m)	LOG TYPE
00/12-05-089-12-W6-0	1118.3	1118.3	48.8	NEUTRON
00/12-05-089-12-W6-0	1118.3	1118.3	48.8	INDUCTION LOG
00/12-05-089-12-W6-0	1118.3	1118.3	48.8	NEUTRON
00/12-05-089-12-W6-0	1118.3	1118.3	48.8	INDUCTION LOG
00/12-05-089-12-W6-0	1118.3	1118.3	48.8	NEUTRON
00/12-07-089-07-W6-0	982.1	978.4	0.0	NEUTRON
00/12-07-089-07-W6-0	982.1	978.4	0.0	NEUTRON
00/12-07-089-07-W6-0	982.1	978.4	0.0	NEUTRON
00/12-07-101-12-W6-0	832.7	828.4	10.0	GAMMA RAY CORR
00/12-08-089-07-W6-0	1030.7	1025.9	187.5	BHC SONIC
00/12-08-089-07-W6-0	1030.7	1025.9	187.5	COMP NEUTRON FORM DENSITY
00/12-08-089-07-W6-0	1030.7	1025.9	187.5	DUAL INDUCTION SPHER-FOC
00/12-31-088-06-W6-0	1006.2	1001.6	189.0	SONIC LOG
00/12-31-088-06-W6-0	1006.2	1001.6	189.0	COMP NEUTRON FORM DENSITY
00/12-31-088-06-W6-0	1006.2	1001.6	189.0	DUAL INDUCTION LOG
00/12-31-088-06-W6-2	1006.2	1001.6	189.0	SONIC LOG
00/12-31-088-06-W6-2	1006.2	1001.6	189.0	COMP NEUTRON FORM DENSITY
00/12-31-088-06-W6-2	1006.2	1001.6	189.0	DUAL INDUCTION LOG
00/13-15-089-09-W6-0	1044.9	1040.9	149.4	INDUCTION-ELECTRIC
00/13-15-089-09-W6-0	1044.9	1040.9	149.4	SONIC-ACOUSTIC
00/13-18-089-09-W6-0	1062.8	1059.2	45.7	NEUTRON
00/13-18-089-09-W6-0	1062.8	1059.2	193.5	MICROLOG
00/13-18-089-09-W6-0	1062.8	1059.2	193.9	ELECTRIC LOG
00/13-18-089-09-W6-0	1062.8	1059.2	45.7	NEUTRON
00/13-18-089-09-W6-0	1062.8	1059.2	45.7	NEUTRON
00/13-29-087-09-W6-0	870.7	866.0	10.0	GAMMA RAY CORR
00/13-29-087-09-W6-0	870.7	866.0	10.0	GAMMA RAY CORR
00/13-31-094-04-W6-0	892.6	887.8	10.0	GAMMA RAY
00/13-31-094-04-W6-0	892.6	887.8	10.0	GAMMA RAY
00/14-05-089-07-W6-0	1029.1	1025.1	183.0	BHC SONIC
00/14-05-089-07-W6-0	1029.1	1025.1	183.0	COMP NEUTRON LITHO DENSITY
00/14-05-089-07-W6-0	1029.1	1025.1	183.0	DUAL INDUCTION SPHER-FOC
00/14-25-088-11-W6-0	1068.6	1065.0	180.1	INDUCTION-ELECTRIC
00/14-29-095-04-W6-0	835.1	830.3	10.0	GAMMA RAY
00/14-32-087-09-W6-0	1043.7	1039.8	167.5	MICRO LOG
00/14-32-087-09-W6-0	1043.7	1039.8	167.5	MINILOG
00/14-32-087-09-W6-0	1043.7	1039.8	167.5	BHC SONIC

UNIQUE WELL IDENTIFIER	KB ELEVATION (m)	GROUND ELEVATION (m)	LOG TOP DEPTH (m)	LOG TYPE
00/14-32-087-09-W6-0	1043.7	1039.8	167.5	COMP NEUTRON LITHO DENSITY
00/14-32-087-09-W6-0	1043.7	1039.8	167.5	DUAL INDUCTION LATEROLOG
00/15-08-090-06-W6-0	983.3	979.0	12.2	SONIC-ACOUSTIC
00/15-08-090-06-W6-0	983.3	979.0	12.2	SONIC-ACOUSTIC
00/15-08-090-06-W6-0	983.3	979.0	12.2	SONIC-ACOUSTIC
00/15-09-098-11-W6-0	877.8	872.5	10.0	ACOUSTIC LOG
00/15-09-098-11-W6-0	877.8	872.5	10.0	ACOUSTIC LOG
00/15-24-098-13-W6-0	939.5	935.6	4.5	COMPENSATED NEUTRON GAMMA C
00/15-24-098-13-W6-0	939.5	935.6	4.5	COMPENSATED NEUTRON GAMMA C
00/15-24-098-13-W6-0	939.5	935.6	4.5	COMPENSATED NEUTRON GAMMA C
00/15-27-098-25-W5-0	892.2	888.9	10.0	COMP NEUTRON FORM DENSITY
00/15-27-098-25-W5-0	892.2	888.9	10.0	COMP NEUTRON FORM DENSITY
00/15-27-098-25-W5-2	892.2	888.9	10.0	COMP NEUTRON FORM DENSITY
00/15-27-098-25-W5-2	892.2	888.9	10.0	COMP NEUTRON FORM DENSITY
00/16-08-099-03-W6-0	830.9	826.6	0.0	NEUTRON
00/16-11-099-11-W6-0	883.8	879.8	35.0	COMP NEUTRON LITHO DENSITY
00/16-12-089-08-W6-0	1010.4	1005.9	181.5	COMP NEUTRON FORM DENSITY
00/16-12-089-08-W6-0	1010.4	1005.9	181.5	DUAL INDUCTION FOC-GR
00/16-16-101-11-W6-0	973.1	969.1	98.5	COMP NEUTRON FORM DENSITY
00/16-16-101-11-W6-0	973.1	969.1	98.5	DUAL INDUCTION LOG
00/16-17-088-07-W6-0	1024.9	1020.6	199.2	SONIC LOG
00/16-17-088-07-W6-0	1024.9	1020.6	199.2	COMP NEUTRON FORM DENSITY
00/16-17-088-07-W6-0	1024.9	1020.6	199.2	DUAL INDUCTION LATEROLOG
00/16-21-088-07-W6-0	1018.7	1014.9	192.0	DUAL INDUCTION
00/16-23-089-07-W6-0	1022.4	1018.0	175.5	SONIC LOG
00/16-23-089-07-W6-0	1022.4	1018.0	175.5	COMP NEUTRON FORM DENSITY
00/16-23-089-07-W6-0	1022.4	1018.0	175.5	DUAL INDUCTION LOG
00/16-30-089-11-W6-0	1027.4	1023.6	192.0	DUAL INDUCTION
00/16-30-094-06-W6-0	933.5	929.8	50.0	COMP NEUTRON LITHO DENSITY
02/03-11-088-07-W6-0	935.2	934.2	30.0	BHC SONIC
02/03-11-088-07-W6-0	935.2	934.2	30.0	COMP NEUTRON FORM DENSITY
02/03-11-088-07-W6-0	935.2	934.2	30.0	DUAL INDUCTION LOG
02/03-11-088-07-W6-0	935.2	934.2	30.0	BHC SONIC
02/03-11-088-07-W6-0	935.2	934.2	30.0	COMP NEUTRON FORM DENSITY
02/03-11-088-07-W6-0	935.2	934.2	30.0	DUAL INDUCTION LOG
02/06-08-087-03-W6-0	887.2	883.4	23.2	COMP NEUTRON FORM DENSITY
02/06-08-087-03-W6-0	887.2	883.4	23.2	DUAL INDUCTION LATEROLOG

UNIQUE WELL IDENTIFIER	KB ELEVATION (m)	GROUND ELEVATION (m)	LOG TOP DEPTH (m)	LOG TYPE
02/06-08-087-03-W6-2	887.2	883.4	23.2	COMP NEUTRON FORM DENSITY
02/06-08-087-03-W6-2	887.2	883.4	23.2	DUAL INDUCTION LATEROLOG
02/06-19-088-05-W6-0	926.6	922.2	9.5	DUAL INDUCTION LATEROLOG
02/06-19-088-05-W6-0	926.6	922.2	10.2	COMP NEUTRON FORM DENSITY
02/06-19-088-05-W6-0	926.6	922.2	9.5	DUAL INDUCTION LATEROLOG
02/06-19-088-05-W6-0	926.6	922.2	10.2	COMP NEUTRON FORM DENSITY
02/06-19-088-05-W6-0	926.6	922.2	9.5	DUAL INDUCTION LATEROLOG
02/06-19-088-05-W6-0	926.6	922.2	10.2	COMP NEUTRON FORM DENSITY
02/10-32-086-03-W6-0	833.6	829.7	10.0	GAMMA RAY NEUTRON
02/11-32-087-09-W6-0	1043.7	1039.8	169.0	MICRO LOG
02/11-32-087-09-W6-0	1043.7	1039.8	169.0	MINILOG
02/11-32-087-09-W6-0	1043.7	1039.8	169.0	BHC SONIC
02/11-32-087-09-W6-0	1043.7	1039.8	169.0	COMP NEUTRON LITHO DENSITY
02/11-32-087-09-W6-0	1043.7	1039.8	169.0	DUAL INDUCTION LATEROLOG
03/08-29-087-09-W6-0	872.2	867.6	4.0	GAMMA RAY CORR
03/08-29-087-09-W6-0	872.2	867.6	4.0	GAMMA RAY CORR

Total 219 wells with 274 logs