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Alberta Energy Regulator

Subsurface Stratigraphic Picks for the Milk River ‘Shoulder,’ Alberta Plains: Including Tops for the Milk River Formation and Alderson Member of the Lea Park Formation

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Subsurface Stratigraphic Picks for the Milk River 'Shoulder,' Alberta Plains: Including Tops for the Milk River Formation and Alderson Member of the Lea Park Formation

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Abstract

This report provides documentation to accompany 25 069 new subsurface stratigraphic picks released for the informally termed Milk River 'shoulder' in the Alberta Plains (Townships 1 to 73, Ranges 1W4 to 2W6) made using wireline geophysical well logs. The stratigraphic picks are published separately as DIG 2013-0025 (Glombick and Mumpy, 2013). Representative wells are used to illustrate the criteria used to make the stratigraphic picks and to highlight regional geological variability. Well data were screened to detect potential error associated with deviated wells. Statistical methods were used to identify local and regional outliers, which were examined individually and either validated or removed from the data set. A structure contour map for the Milk River shoulder is included to illustrate regional structure in the southern and central Alberta Plains.

1 Introduction

This report is one of several recently released by the Alberta Geological Survey on the stratigraphy of Upper Cretaceous rocks in central and southern Alberta (e.g., Glombick, 2010a, b; Glombick, 2011a, b; Glombick, 2013a, b, c; Glombick and Mumpy, 2013). It documents the criteria used to generate a new set of subsurface stratigraphic picks for the informally termed Milk River 'shoulder' in the Alberta Plains—a distinctive signature recognizable on geophysical logs that is commonly used as a stratigraphic marker for correlation. The geology and published literature of the adjacent Milk River, Pakowki, and Lea Park formations are reviewed briefly, and the criteria used to pick the Milk River shoulder in this study are illustrated and described. Representative downhole geophysical well logs are included for different areas to highlight regional geological variability and the corresponding log response. Quality control procedures used to detect potential errors in kelly bushing (KB) and ground elevation data, as well as errors in pick elevation (subsea), are summarized briefly, and the methods used to model the data are described.

The stratigraphic interval associated with the picks presented here comprises the upper Santonian and lower Campanian of southern and central Alberta (Figures 1 and 2). The Milk River shoulder separates the Milk River Formation from the overlying Pakowki Formation and can be traced beyond the extent of the Milk River Formation into the Lea Park Formation. A substantial discussion on regional Santonian-Campanian stratigraphy is included because (1) the interval is stratigraphically complex and contains several unconformities of unknown origin and extent (including the surfaces represented by the Milk River shoulder itself); (2) the lithostratigraphic units above and below the Milk River shoulder are not always the same, but vary spatially; and (3) the published literature contains some potentially confusing nomenclature with respect to the interval. The section on general stratigraphy is intended to provide a solid stratigraphic context for the picked dataset.

2 General Stratigraphy

2.1 Milk River Formation

The Milk River Formation of southernmost Alberta is a northward-thinning, sandy clastic wedge (Meijer Drees and Mhyr, 1981; Leckie et al., 1994; O'Connell, 2003) that consists of transitional marine to continental sedimentary rocks. The Milk River Formation was first mapped by Dawson (1883, 1885) who included it within his 'Belly River series,' but it was first mapped as a separate unit and named by Dowling (1917). Based on subsurface correlations, Tovell (1956) introduced a three-part lithostratigraphic subdivision of the Milk River Formation comprising (in ascending stratigraphic order) the Telegraph Creek, Virgelle, and Deadhorse Coulee members. The scheme of Tovell (1956) remains widely accepted in Canada, though differing depositional interpretations and stratigraphic models have emerged over the years (e.g., Meijer Drees and Mhyr, 1981; Leckie and Cheel, 1986; McCrory and Walker, 1986; Cheel and Leckie, 1990; Meyer, 1994, 1998; Meyer et al., 1998; Payenberg et al., 2002; 2003).

The Telegraph Creek Member consists of interbedded marine shale and fine-grained sandstone and represents an offshore to shoreface transition (Meijer Drees and Mhyr, 1981). The Virgelle Member is composed of thick, massive packages of shoreface sandstone, and the overlying Deadhorse Coulee Member consists of paralic mudstone, siltstone, sandstone, and coal (Tovell, 1956; Payenberg et al., 2002). The entire succession is typically 80–100 m thick. The three-part subdivision of the Milk River Formation is confined to southernmost Alberta, as the units wedge out to the north and east, where they are transitional with the siltstone-dominated Alderson Member of the Lea Park Formation. Distal components of the Telegraph Creek Member constitute a thin condensed section that extends northward well beyond the depositional limit of the Virgelle and Deadhorse Coulee members (Figure 3). In the

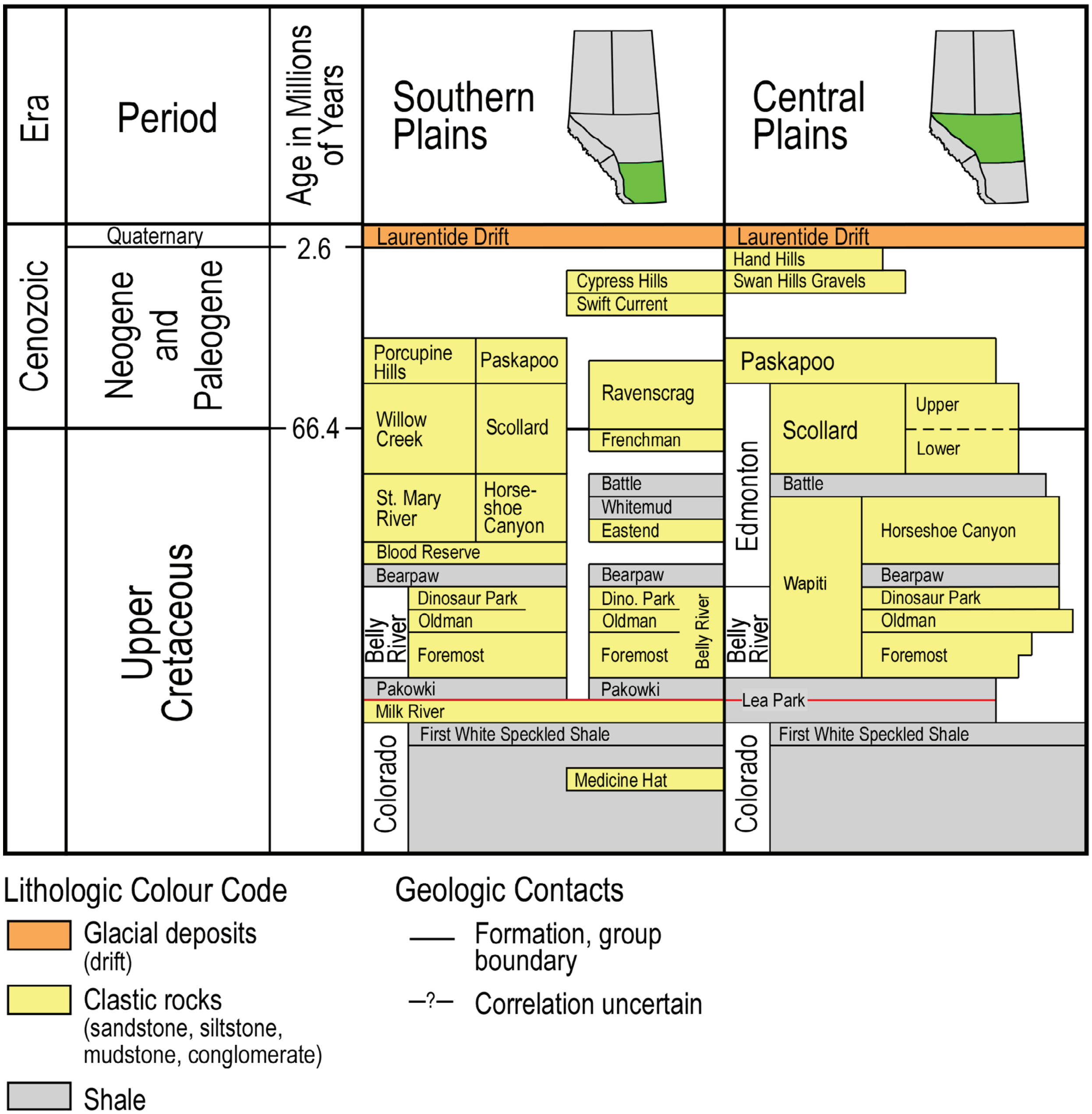

Figure 1. Schematic stratigraphic column showing the distribution of Upper Cretaceous bedrock in southern and central Alberta (modified from Alberta Energy Regulator, 2009; modifications include the addition of the Dinosaur Park Formation in southern and central Alberta and the Wapiti Formation in central Alberta). The stratigraphic contact picked in this report is shown in red.

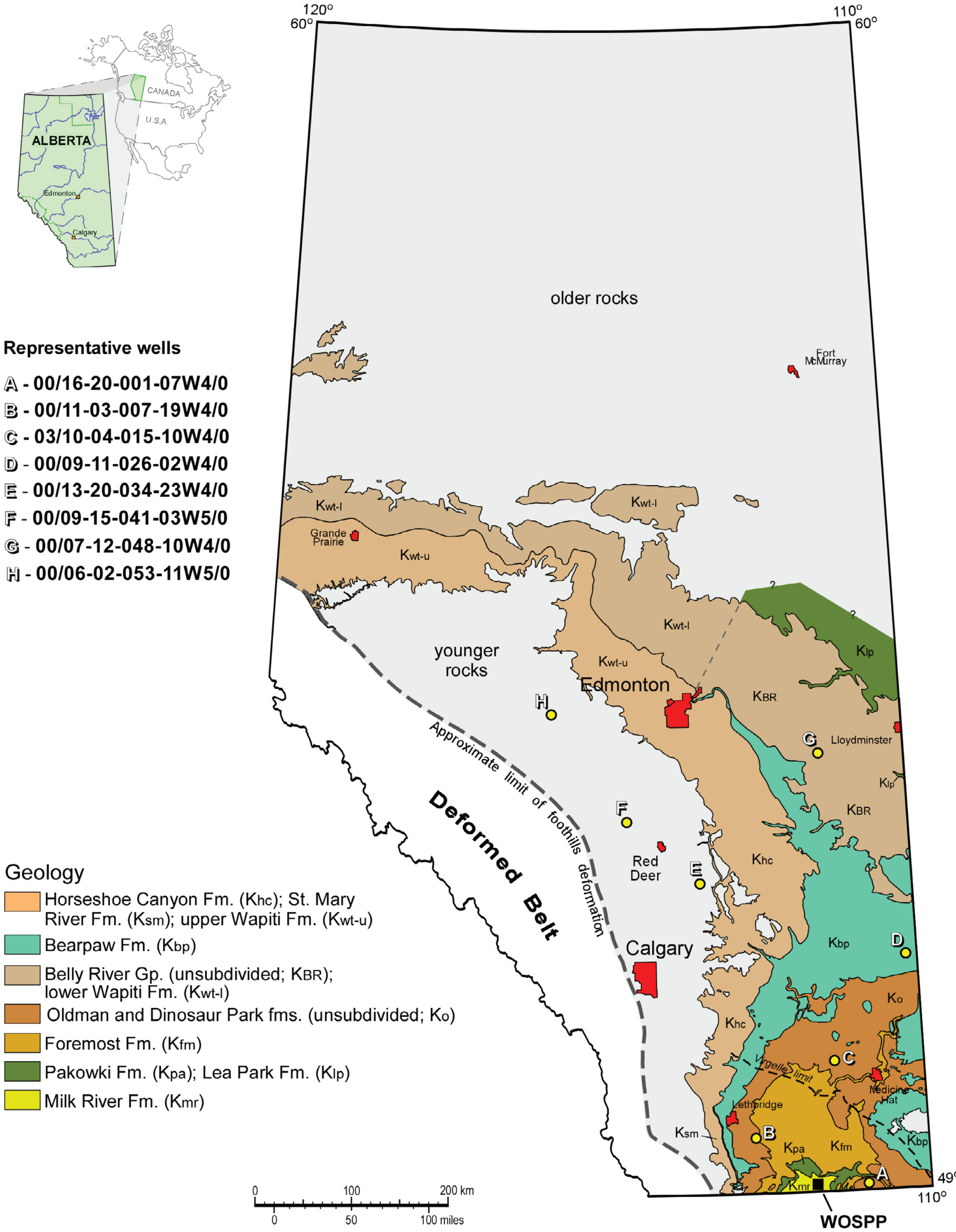

Figure 2. Simplified geological map showing the distribution of Upper Cretaceous rocks in central and southern Alberta and location of representative wells (A–H) used in this project (geology modified from Hamilton et al., 1999). Black dashed line indicates approximate northern limit of Virgelle Member (from Ridgley, 2000). Other abbreviations: WOSPP – Writing-On-Stone Provincial Park.

foothills to the west, the Milk River Formation is most likely age equivalent to portions of the Hanson and Chungo members of the Wapiabi Formation, though this relationship is not well established, and the correlation is hindered by inconsistent nomenclature and lack of adequate chronostratigraphic control (Collom and Kravec, 2000).

The Telegraph Creek Member of the Milk River Formation rests conformably on top of the First White Speckled Shale Member of the Niobrara Formation (Nielsen et al., 2003). Characterizing the upper boundary of the Milk River Formation is complicated by the presence of regional unconformities that truncate the unit and juxtapose different stratigraphic units in different geographic areas (Figure 3). In southernmost Alberta, the Pakowki Formation overlies an unconformity situated at the top of the Deadhorse Coulee Member of the Milk River Formation. Payenberg et al. (2002) demonstrated that a hiatus (~2.5 m.y.) is present at the Milk River–Pakowki contact in the vicinity of Writing-On-Stone Provincial Park (WOSPP; Figure 2) based on several lines of evidence, including isotopic ages, palynological contrasts, and the absence of several age-diagnostic Lower Campanian ammonite species. In areas to the north and east of WOSPP, where Milk River Formation strata descend into the subsurface, defining the top of the Milk River Formation is more difficult.

Ridgley (2000) and O'Connell (2003) argued that a major unconformity (the "basal Alderson unconformity" of O'Connell, 2003) separates the Milk River Formation from the overlying Alderson Member of the Lea Park Formation (Figure 3). This argument is based on evidence from well log correlations, a chert pebble lag observed in cores from southeast Alberta at the Telegraph Creek–Alderson boundary, and the aforementioned hiatus documented by Payenberg et al. (2002). However, the time gap noted by Payenberg et al. (2002) has only been documented in the outcrop area around WOSPP, and it is uncertain how the duration of this hiatus changes in areas to the north and east, as the age of the lower Alderson Member remains poorly constrained (Shurr and Ridgley, 2002).

Shurr and Ridgley (2002) suggested an alternative possible correlation between the upper part of the Milk River Formation (primarily the Deadhorse Coulee Member) and the lower Alderson Member. Nomenclatural inconsistencies further complicate the issue, as Alderson Member strata are sometimes

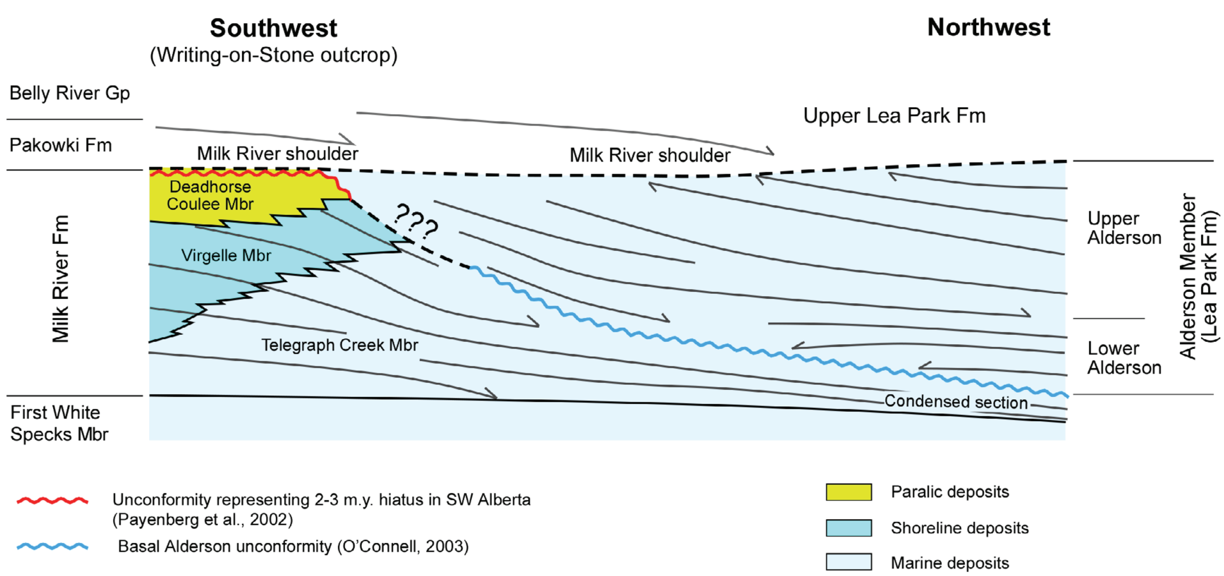

Figure 3. Schematic stratigraphy of the Milk River Formation–Alderson Member (Lea Park Formation) interval in southern Alberta (redrafted and modified after O'Connell, 2003).

considered to be part of the Milk River Formation (e.g., Pedersen, 2004), despite evidence for differing ages and an intervening unconformity. Until an improved chronostratigraphic framework becomes available for the Milk River–Alderson interval, the relationship between the Milk River Formation and adjacent strata of the Alderson Member will remain unclear.

2.2 Pakowki Formation

The Pakowki Formation consists largely of marine shale and overlies the Milk River Formation in southern Alberta (Figure 3; Dowling, 1917; Russell and Landes, 1940; Tovell, 1956). The unit is equivalent to the upper Lea Park Formation in areas to the north, where the Milk River Formation is no longer present (Glass, 1990). This is presumably in reference to the shoreface sandstones of the Virgelle Member and is a somewhat indistinct definition for the areal extent of the Pakowki Formation. In the foothills, the Pakowki Formation is equivalent to marine shales of the Nomad Member of the Wapiabi Formation (Jerzykiewicz, 1997). The contact between the top of the Pakowki / Lea Park Formation and the overlying Belly River Group is time transgressive, younging to the east (McLean, 1971; Dawson et al., 1994; Hamblin and Abrahamson, 1996). In eastern Alberta in particular, it is a cyclic, gradational, and highly diachronous boundary (Nauss, 1945; Shaw and Harding, 1949, McLean, 1971), and cannot be characterized as a single surface. On well logs, the base of the Pakowki Formation is generally marked by the Milk River shoulder.

2.3 Lea Park Formation

The Lea Park Formation is a regionally extensive, westward-thinning, generally fine-grained marine succession. The unit was originally defined by Allan (1918) on the North Saskatchewan River, where a mudstone-dominated succession with interbeds of fine-grained sandstone underlies shallow marine sandstone beds of the lower Belly River Group (Brosseau Member). Mudstone or shale of the Lea Park Formation is widespread beneath the plains of southern and central Alberta, where it overlies the First White Specks Member of the Niobrara Formation.

In central Alberta, the Lea Park Formation can generally be divided into an upper and a lower interval separated by a regional stratigraphic contact represented by the Milk River shoulder (Figure 3). The Pakowki Formation constitutes a southwestward extension of the upper Lea Park Formation, and the lower Lea Park Formation correlates with the Alderson Member, a prolific gas producer in southern Alberta. Although the Alderson Member was originally defined as part of the Lea Park Formation (Meijer Drees and Mhyr, 1981), it is commonly referred to as the Alderson Member of the Milk River Formation (e.g., Christopher and Yurkowski, 2003; O'Connell, 2003; Pedersen, 2003). This practice conforms to informal historical nomenclature used by industry and government geologists working on the unit. Based on the presence of a significant unconformity at the top of the Alderson Member, Pedersen (2004) argued that the Alderson Member is more closely related to the Milk River Formation than the Lea Park Formation and therefore proposed inclusion of the Alderson Member as part of the Milk River Formation. This conclusion is debatable, as much of the Alderson Member has been shown to be younger than the Milk River Formation (Payenberg et al., 2002), and the two units are thought to be separated by a major unconformity (Figure 3).

3 Picking Criteria

The Milk River shoulder is an informal term used to refer to a distinctive deflection (shoulder) visible on geophysical well logs. The marker is easiest to recognize on resistivity logs, though it is typically recognizable on SP, sonic, density, and porosity logs as well, especially south of Township 40. North of Township 40, the signature becomes more muted, and a second shoulder appears at a slightly lower stratigraphic level.

The Milk River shoulder corresponds to the top of the Milk River Formation in southernmost Alberta, where it represents the juxtaposition between paralic deposits of the underlying Deadhorse Coulee Member and overlying marine shale of the Pakowki Formation (Figure 3). Northeastward of the maximum extent of the Deadhorse Coulee Member, the Milk River shoulder is commonly recognized as the boundary between the Alderson Member (lower Lea Park Formation) and the upper Lea Park Formation (Pakowki Formation equivalent). In these areas, silty sandstone and mudstone of the Alderson Member is overlain by shale and mudstone of the upper Lea Park Formation. Interestingly, the Milk River shoulder remains a distinctive and consistent regional geophysical signature northward into central Alberta, despite the fact that lithologies above and below the boundary change from south to north (Deadhorse Coulee Member to Alderson Member).

The genetic significance of the Milk River shoulder is variable depending on location. A major sequence boundary is implied by the hiatus documented by Payenberg et al. (2002). However, this sequence boundary may have been reworked during the onset of the Pakowki transgression (transgressive surface of erosion), thus it is likely a composite stratigraphic surface in southernmost Alberta. In more distal areas to the north and east, the geological reasons for the expression of the Milk River shoulder are less well understood.

4 Representative Wells

Eight representative wells (locations shown in Figure 2) are used to illustrate the characteristic log response of the Milk River shoulder in different areas of Alberta and provide examples of the criteria used to make the picks during this study. For a guide to the use of unique well identifiers (UWI) in Alberta, see the Alberta Energy Regulator's *Directive 059: Well Drilling and Completion Data Filing Requirements* (Alberta Energy Regulator, 2012, p. 47). While the representative wells illustrate the log response of the Milk River shoulder locally, consistent mapping of the marker at a regional scale requires detailed stratigraphic correlation.

4.1 Representative Well A (00/16-20-001-07W4/0)

Well A (Figure 4) shows the characteristic log response of the Milk River shoulder in the subsurface of southeastern Alberta. In this area, paralic deposits of the Deadhorse Coulee Member—consisting of sandstone, sandy mudstone, mudstone, and minor coal—underlie an unconformity which is overlain by marine shale and mudstone of the Pakowki Formation (Figure 3). This unconformity is associated with a thin bed of sideritic mudstone with rounded black chert clasts immediately overlying the Deadhorse Coulee Member (Tovell, 1956; Meijer Drees and Mhyr, 1981).

In this area, the characteristic shoulder response is well developed on the resistivity log (Figure 4). While the Deadhorse Coulee Member has variable resistivity, it is, in general, higher than that for the overlying mudstone of the Pakowki Formation. Moving upward across the contact, a sharp and abrupt leftward shift (decrease) in resistivity is observed. A similar response is seen on the neutron- and density-porosity logs, which show a sharp increase in porosity upward across the contact (particularly the neutron-porosity log; Figure 4). Above the contact, the neutron- and density-porosity logs generally show more separation than below the contact due to the higher clay component within the Pakowki Formation. The spontaneous-potential (SP) log response is variable within the Deadhorse Coulee Member. Above the contact, within the Pakowki Formation, the SP log is characterized by a much more uniform response. The gamma-ray

(GR) and photoelectric factor (PEF) logs show little change across the contact and are generally not useful in picking the contact.

4.2 Representative Well B (00/11-03-007-19W4/0)

Well B is located in southwest Alberta (Figure 2). Below the Milk River shoulder, the Deadhorse Coulee Member is well developed and over 50 m thick. The log response at the upper contact of the member is similar to well A, as the same lithostratigraphic units are present above and below. The shoulder is visible on the resistivity and density logs, which show a leftward deflection upward across the contact (Figure 5). In this well, the GR and SP logs show little change across the contact, whereas the PEF log shows a slight increase.

4.3 Representative Well C (03/10-04-015-10W4/0)

Representative well C is located adjacent to the type well for the Alderson Member (00/10-04-015-10W4/0), northeast of the depositional limit of the Milk River Formation. According to Meijer Drees and Mhyr (1981, p. 61), “the [Alderson] member consists of grey to dark grey, bioturbated, silty, montmorillonitic shale with laminated lenses and interbeds of very fine-grained, silty sandstone.” A number of greyish-green bentonite layers and siderite and chert pebble beds are present within the Alderson Member.

Meijer Drees and Mhyr (1981) placed the upper contact of the Alderson Member at the sharp leftward deflection (decrease) of the resistivity curve (Figure 6). A similar leftward deflection is visible on the neutron- and density-porosity logs. The SP log shows an upward deflection to more positive values at the contact, whereas the GR and PEF logs are not useful in identifying the contact.

4.4 Representative Well D (00/09-11-026-02W4/0)

This well is located northeast of the previous well, in a more distal position with respect to the Virgelle Member shoreline. The Milk River shoulder divides the Lea Park Formation into an upper (Pakowki Formation equivalent) and a lower (Alderson Member) interval. The characteristic log response of the resistivity log is still present, although the leftward deflection (moving upward across the contact) is more muted (Figure 7). The neutron-porosity log still shows a leftward deflection, while the density-porosity log is not useful in identifying the contact. In this well, as in well C, the SP log shows a deflection to the right (more positive values) above the contact. The GR log, while less useful for precisely placing the shoulder, shows more variation above and below the contact than previous wells, with a change from an upwardly increasing trend in gamma-ray API in the upper part of the Alderson Member to a decreasing trend in the overlying upper Lea Park Formation. There is also a shift to lower (cleaner) values above the contact.

4.5 Representative Well E (00/13-20-034-23W4/0)

This well is located in south-central Alberta. The characteristic response of the resistivity log is present, showing a leftward deflection (decrease in resistivity) upward across the contact, though the shoulder is less sharp and more gradational than in the previous representative wells (Figure 8). The leftward deflection of the neutron-and density-porosity logs is present, but as with the resistivity log, the response is less sharp and picking the exact position of the contact is difficult. In general, the resistivity log is considered the most reliable. The SP and PEF logs show a slight deflection to the right upwards across the contact, whereas the GR log shows a leftward deflection to cleaner (lower API) values. In this area, the

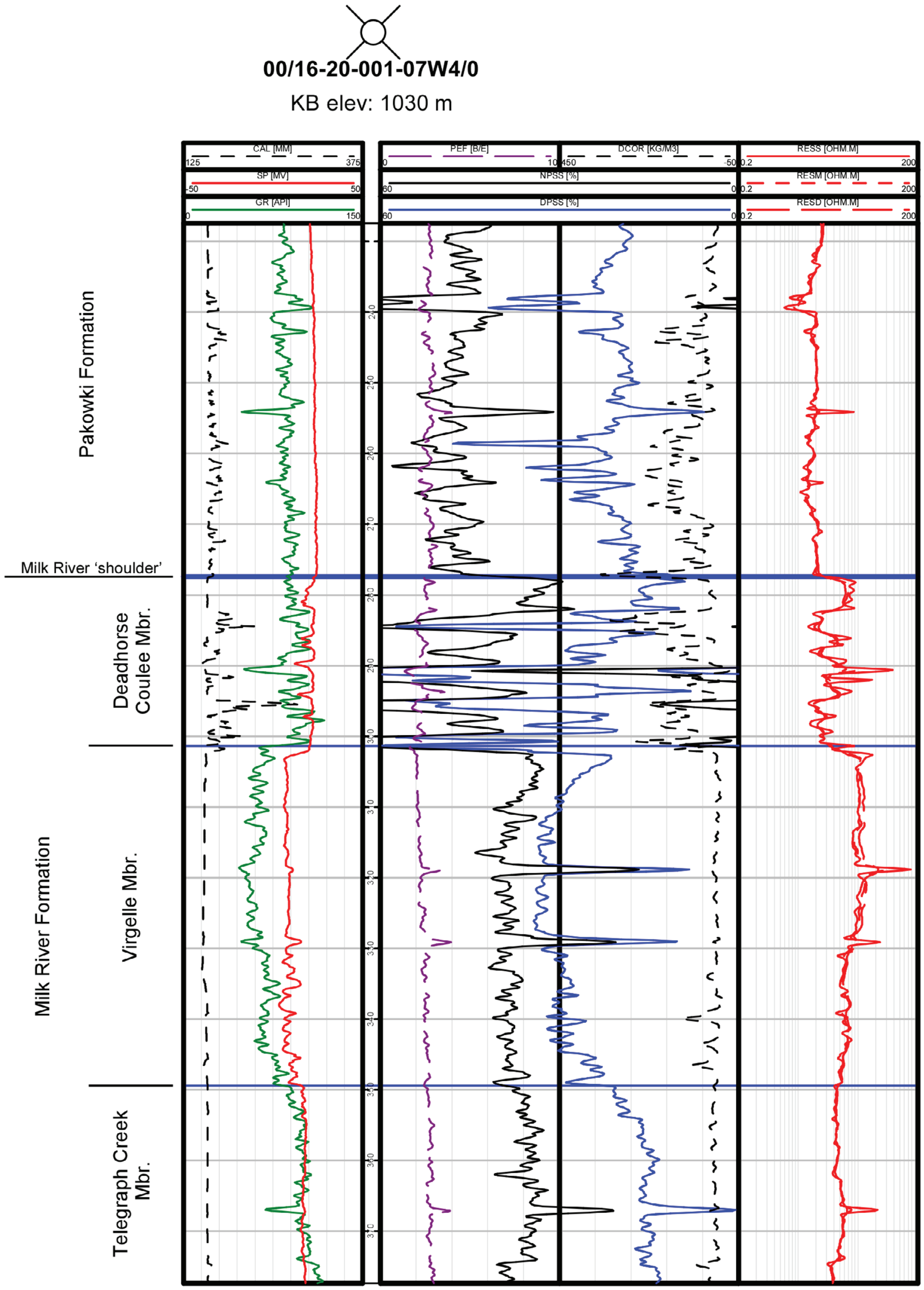

Figure 4. Representative well A (00/16-20-001-07W4/0). Logs shown are caliper (CAL in mm), spontaneous potential (SP in mV), gamma ray (GR in API units), density porosity (sandstone calibration; DPSS in %), neutron porosity (sandstone calibration; NPSS in %), photoelectric factor (PEF in barns/electron), density correction (DCOR in kg/m3), deep resistivity (RESD in ohm•m), medium resistivity (RESM in ohm•m), and shallow resistivity (RESS in ohm•m). KB elevation given is metres (m) above sea level. Vertical log scale is measured depth (in metres) below kelly bushing (KB). Other abbreviations: Mbr., Member.

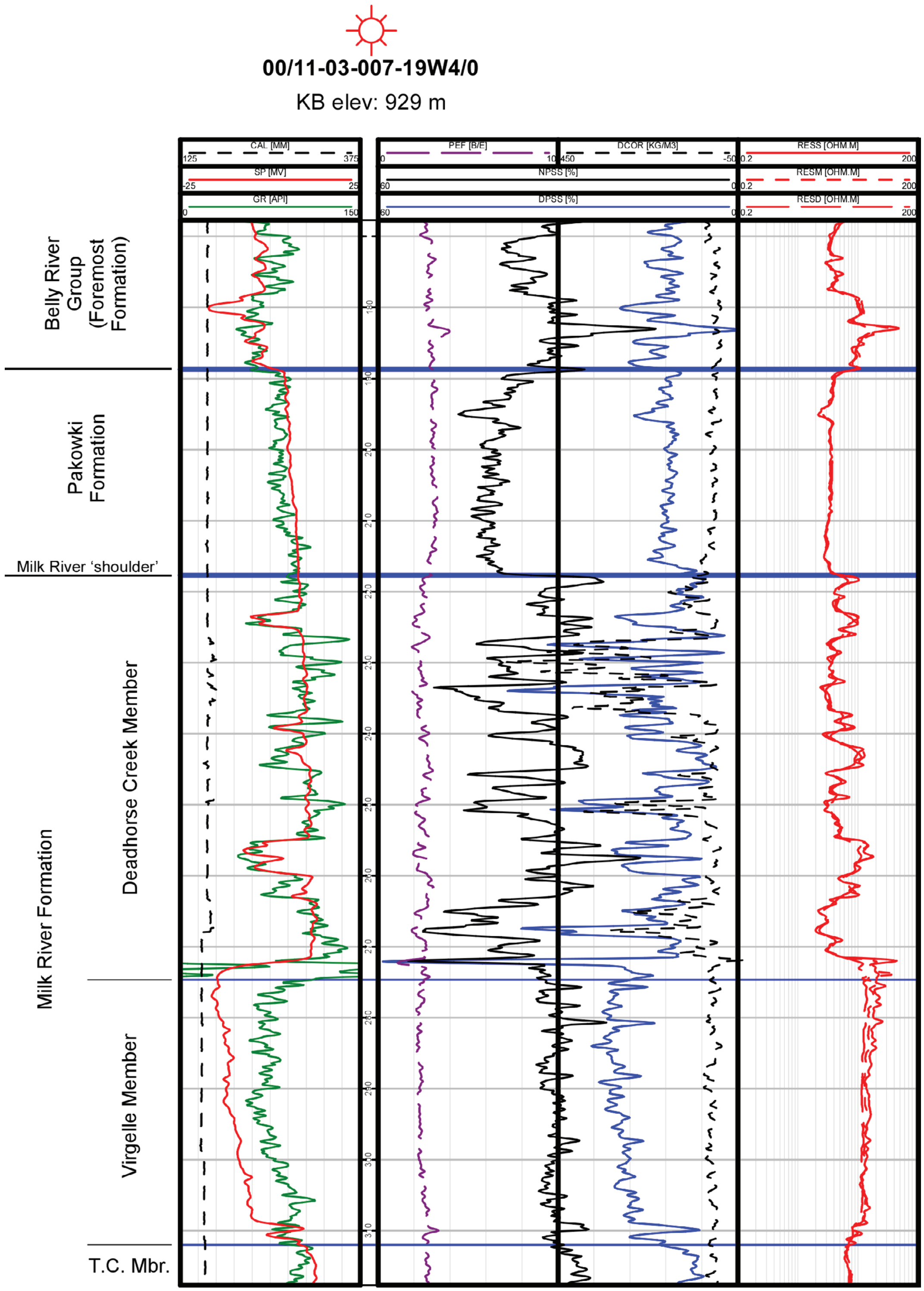

Figure 5. Representative well B (00/11-03-007-19W4/0). Logs shown are caliper (CAL in mm), spontaneous potential (SP in mV), gamma ray (GR in API units), density porosity (sandstone calibration; DPSS in %), neutron porosity (sandstone calibration; NPSS in %), photoelectric factor (PEF in barns/electron), density correction (DCOR in kg/m3), deep resistivity (RESD in ohm•m), medium resistivity (RESM in ohm•m), and shallow resistivity (RESS in ohm•m). KB elevation given is metres (m) above sea level. Vertical log scale is measured depth (in metres) below kelly bushing (KB). Other abbreviations: T.C., Telegraph Creek; Mbr., Member.

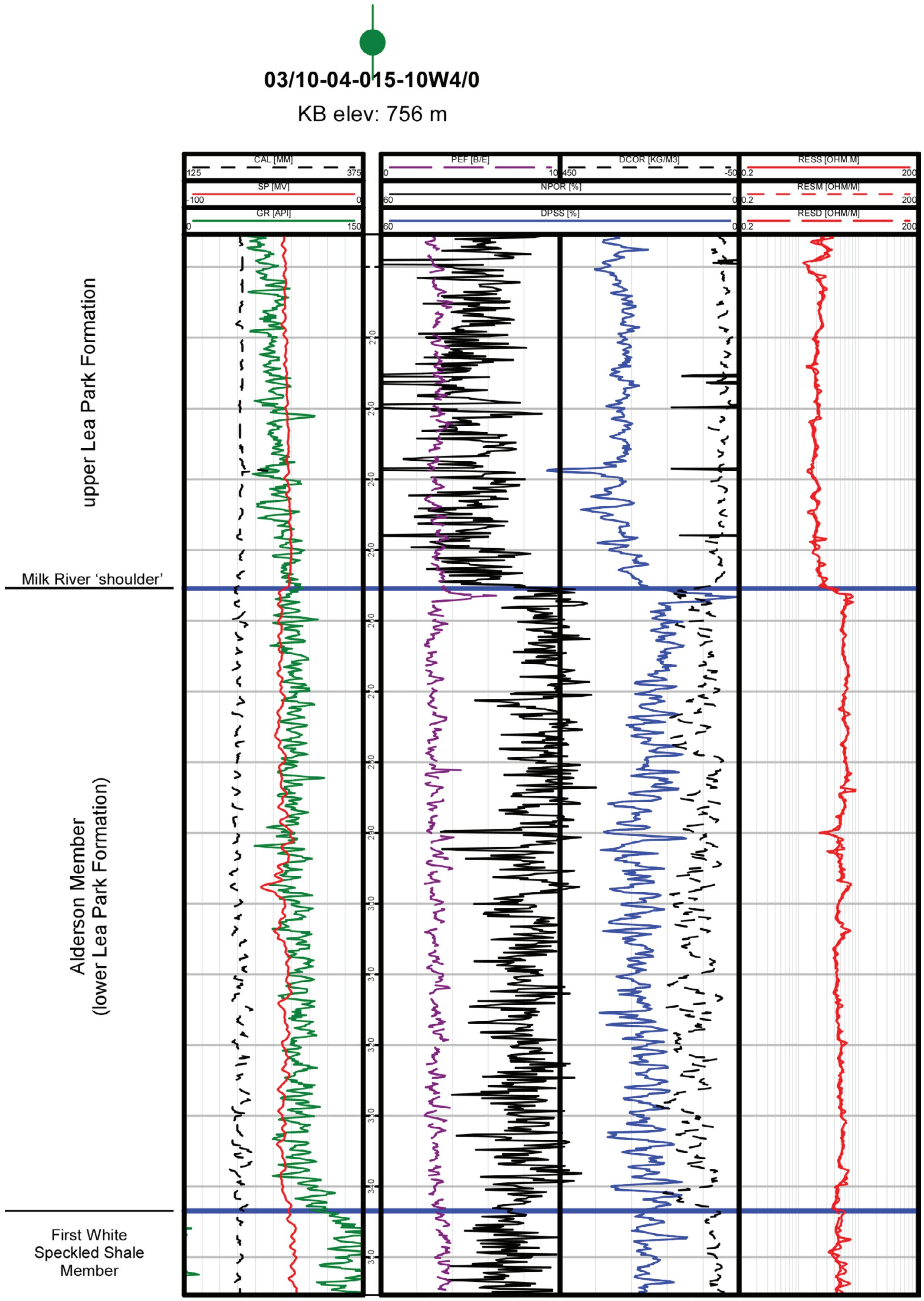

Figure 6. Representative well C (03/10-04-015-10W4/0). Logs shown are caliper (CAL in mm), spontaneous potential (SP in mV), gamma ray (GR in API units), density porosity (sandstone calibration; DPSS in %), neutron porosity (NPOR in %), photoelectric factor (PEF in barns/electron), density correction (DCOR in kg/m3), deep resistivity (RESD in ohm•m), medium resistivity (RESM in ohm•m), and shallow resistivity (RESS in ohm•m). KB elevation given is metres (m) above sea level. Vertical log scale is measured depth (in metres) below kelly bushing (KB).

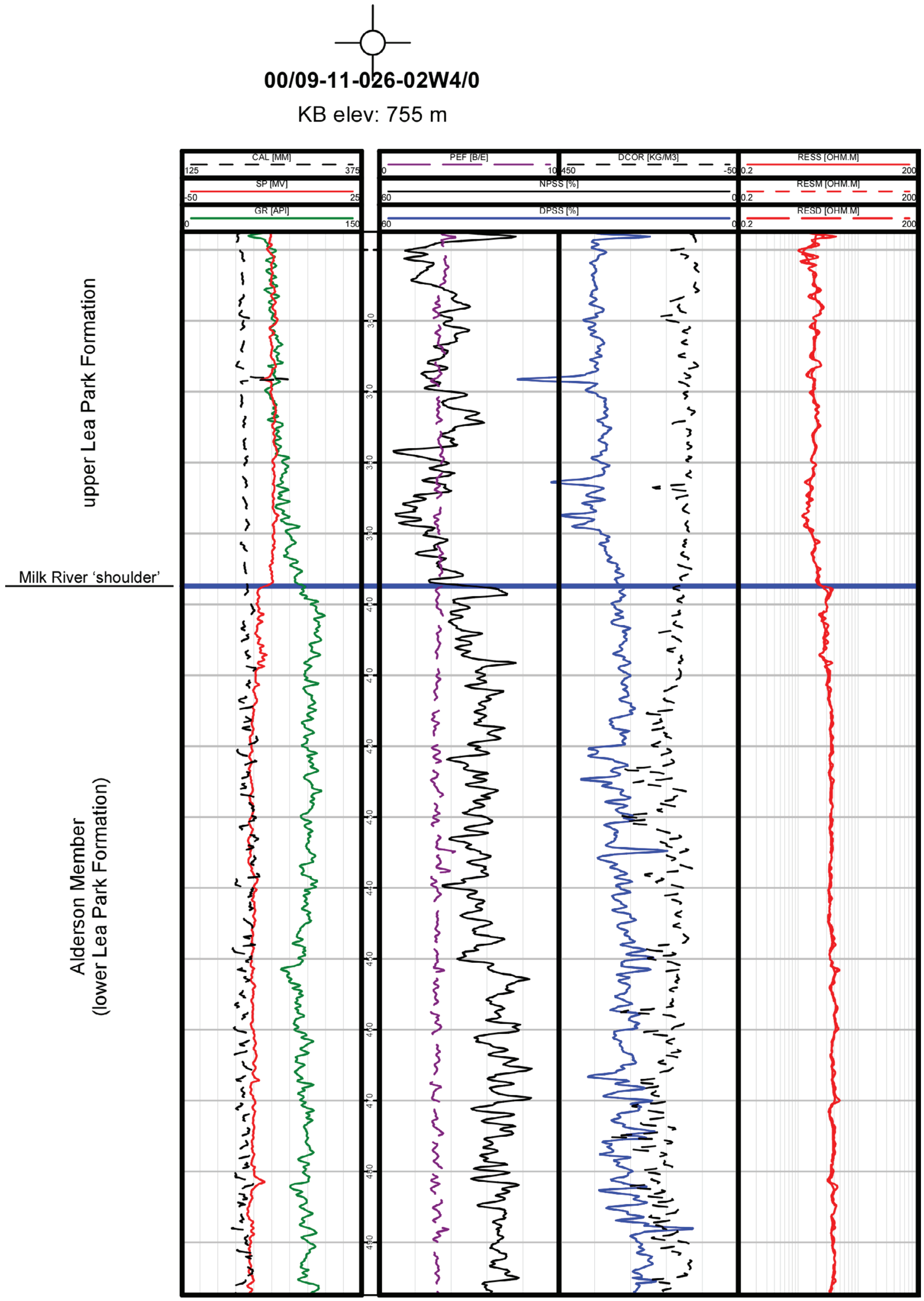

Figure 7. Representative well D (00/09-11-026-02W4/0). Logs shown are caliper (CAL in mm), spontaneous potential (SP in mV), gamma ray (GR in API units), density porosity (sandstone calibration; DPSS in %), neutron porosity (sandstone calibration; NPSS in %), photoelectric factor (PEF in barns/electron), density correction (DCOR in kg/m3), deep resistivity (RESD in ohm•m), medium resistivity (RESM in ohm•m), and shallow resistivity (RESS in ohm•m). KB elevation given is metres (m) above sea level. Vertical log scale is measured depth (in metres) below kelly bushing (KB).

position of the deflection on the gamma-ray log is commonly at a different stratigraphic level than that of the resistivity log and it is not considered a reliable marker.

4.6 Representative Well F (00/09-15-041-03W5/0)

Representative well F is located in central Alberta, northwest of well E (Figure 2). This well illustrates the increasing difficulty in picking the Milk River shoulder when correlating northward. The resistivity log is still considered to be the most reliable log when determining the stratigraphic position of the Milk River shoulder (Figure 9). The leftward deflection across the contact is rather weak, but the characteristic log motif can still be recognized, particularly when using stratigraphic cross-sections with closely spaced wells. The porosity logs (both neutron and density) no longer show the characteristic leftward deflection. The density-porosity log, in particular, shows an overall decrease in porosity values moving upward from the lower Lea Park Formation to the upper Lea Park Formation, but the major shift occurs approximately 5 m below the contact picked using the resistivity log. As in wells D and E, the GR log shows a change from an upwardly increasing to an upwardly decreasing trend but, again, is not useful in the precise placement of the contact.

4.7 Representative Well G (00/07-12-048-10W4/0)

Representative well G, located in eastern Alberta, is near the maximum northerly recognizable extent of the Milk River shoulder. Although resistivity values above and below the contact are similar, and a pronounced log shoulder is not developed, the characteristic log motif can nevertheless still be recognized (Figure 10). The porosity, SP, GR, and PEF logs are not useful by themselves for picking the contact. A more distinct shoulder is visible at a stratigraphically lower level (~340 m depth) on the resistivity log, but log correlation indicates that this is not the Milk River shoulder.

4.8 Representative Well H (00/06-02-053-11W5/0)

Representative well H is located in west-central Alberta, near the northern recognizable limit of the Milk River shoulder. As can be seen in Figure 11, the resistivity of the lower Lea Park Formation is approximately 5 ohm·m, whereas resistivity values are approximately 4 ohm·m above the contact. The neutron-porosity log shows a leftward deflection, whereas the density-porosity log shows a rightward deflection. Again, the GR log shows a change from an upwardly increasing trend at the top of the lower Lea Park Formation to an upwardly decreasing trend at the base of the upper Lea Park Formation, but the exact contact cannot be picked using the GR log in isolation.

5 Dataset and Methods

Digital Dataset 2013-0025 (Glombick and Mumpy, 2013) includes new stratigraphic pick data for the Milk River shoulder from 25 069 wells.

Prior to making picks, the published geological literature was studied with emphasis on type and representative sections. Studies that include both core and geophysical logs are particularly valuable, as they provide a link between the rock and geophysical signatures.

Geophysical well logs (both digital and raster format) were examined using IHS' Petra and Accumap software, and picks were recorded in a database. Where well density and log availability were sufficient, wells were selected according to the following criteria:

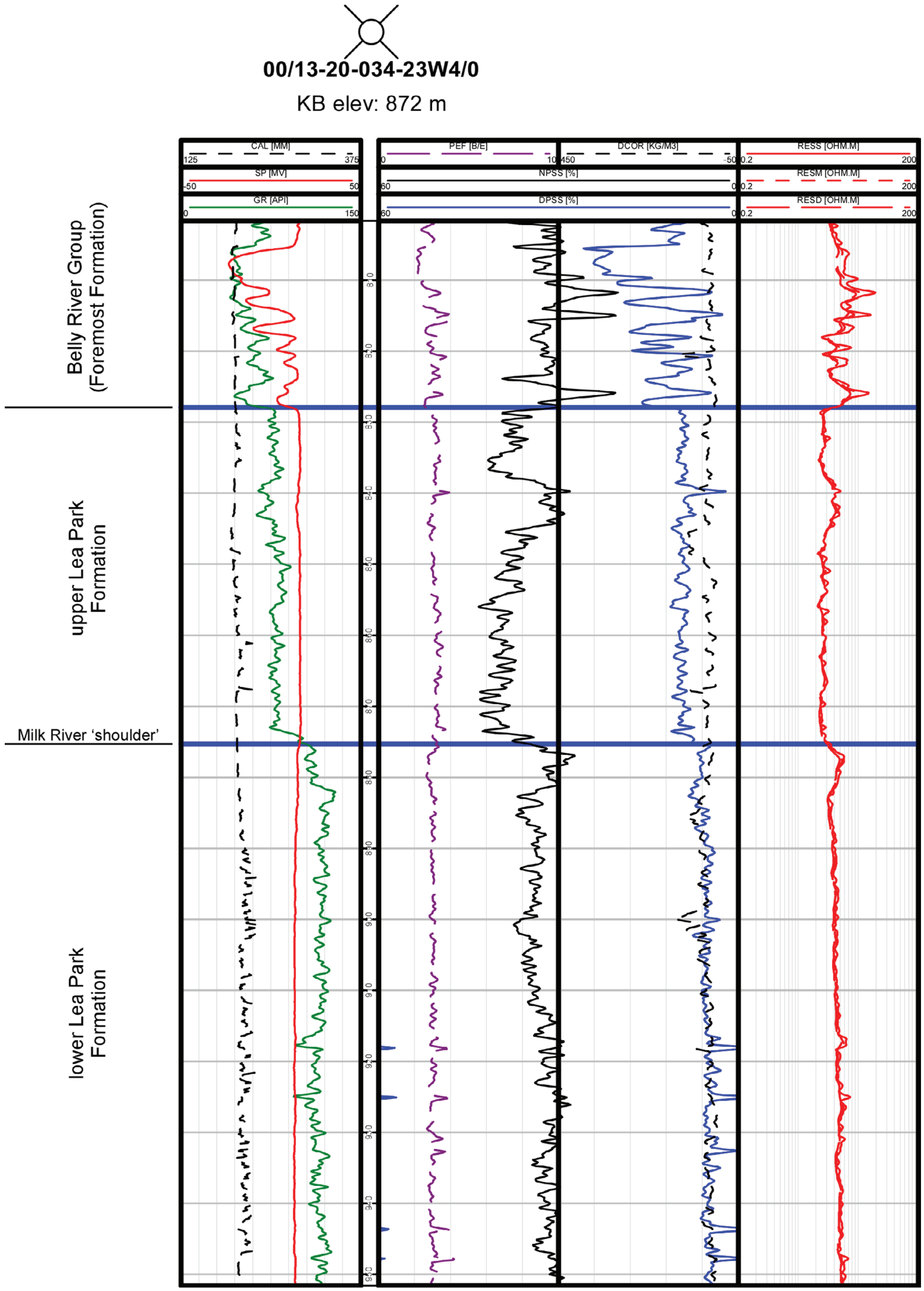

Figure 8. Representative well E (00/13-20-034-23W4/0). Logs shown are caliper (CAL in mm), spontaneous potential (SP in mV), gamma ray (GR in API units), density porosity (sandstone calibration; DPSS in %), neutron porosity (sandstone calibration; NPSS in %), photoelectric factor (PEF in barns/electron), density correction (DCOR in kg/m3), deep resistivity (RESD in ohm•m), medium resistivity (RESM in ohm•m), and shallow resistivity (RESS in ohm•m). KB elevation given is metres (m) above sea level. Vertical log scale is measured depth (in metres) below kelly bushing (KB).

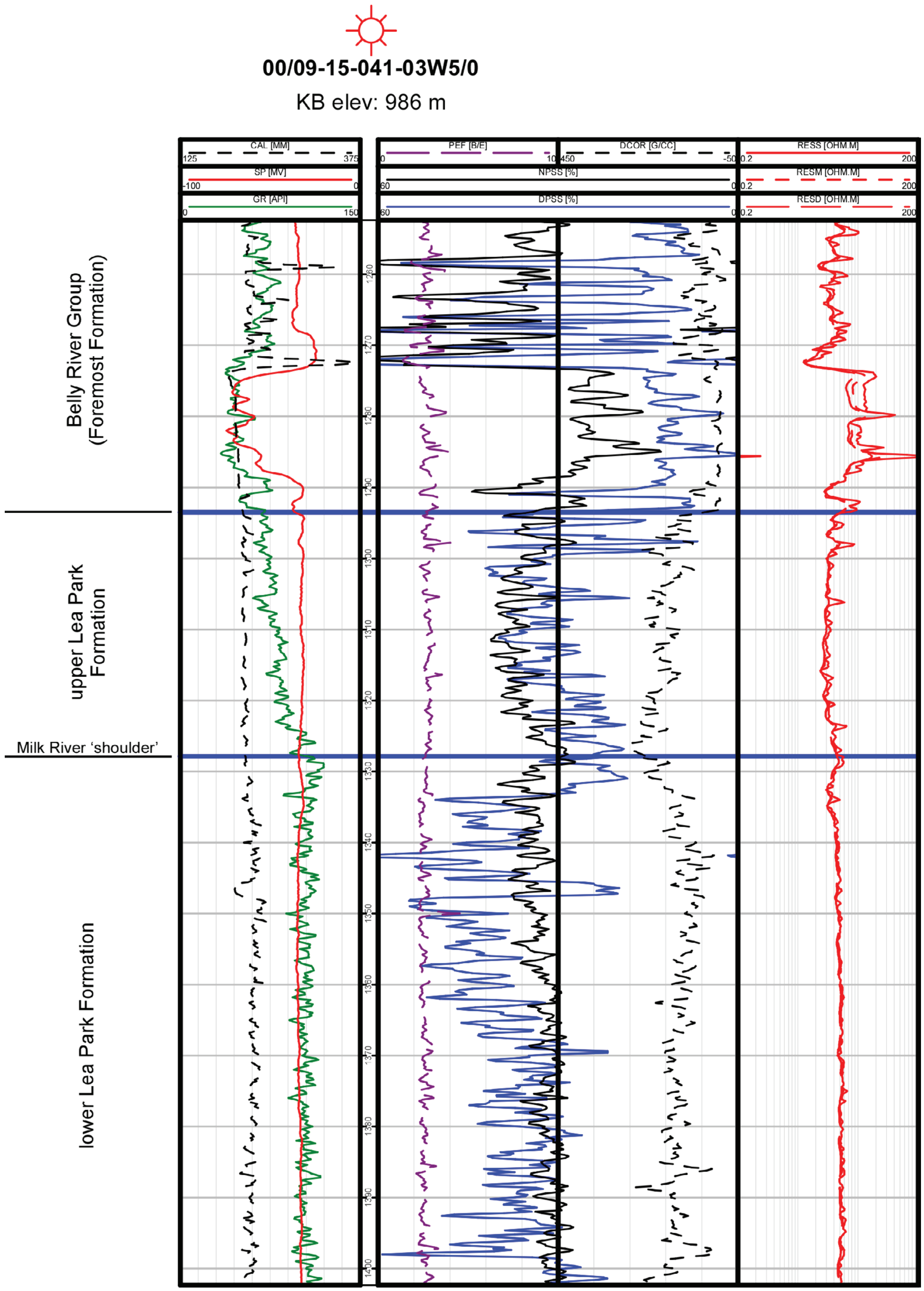

Figure 9. Representative well F (00/09-15-041-03W5/0). Logs shown are caliper (CAL in mm), spontaneous potential (SP in mV), gamma ray (GR in API units), density porosity (sandstone calibration; DPSS in %), neutron porosity (sandstone calibration; NPSS in %), photoelectric factor (PEF in barns/electron), density correction (DCOR in kg/m3), deep resistivity (RESD in ohm•m), medium resistivity (RESM in ohm•m), and shallow resistivity (RESS in ohm•m). KB elevation given is metres (m) above sea level. Vertical log scale is measured depth (in metres) below kelly bushing (KB).

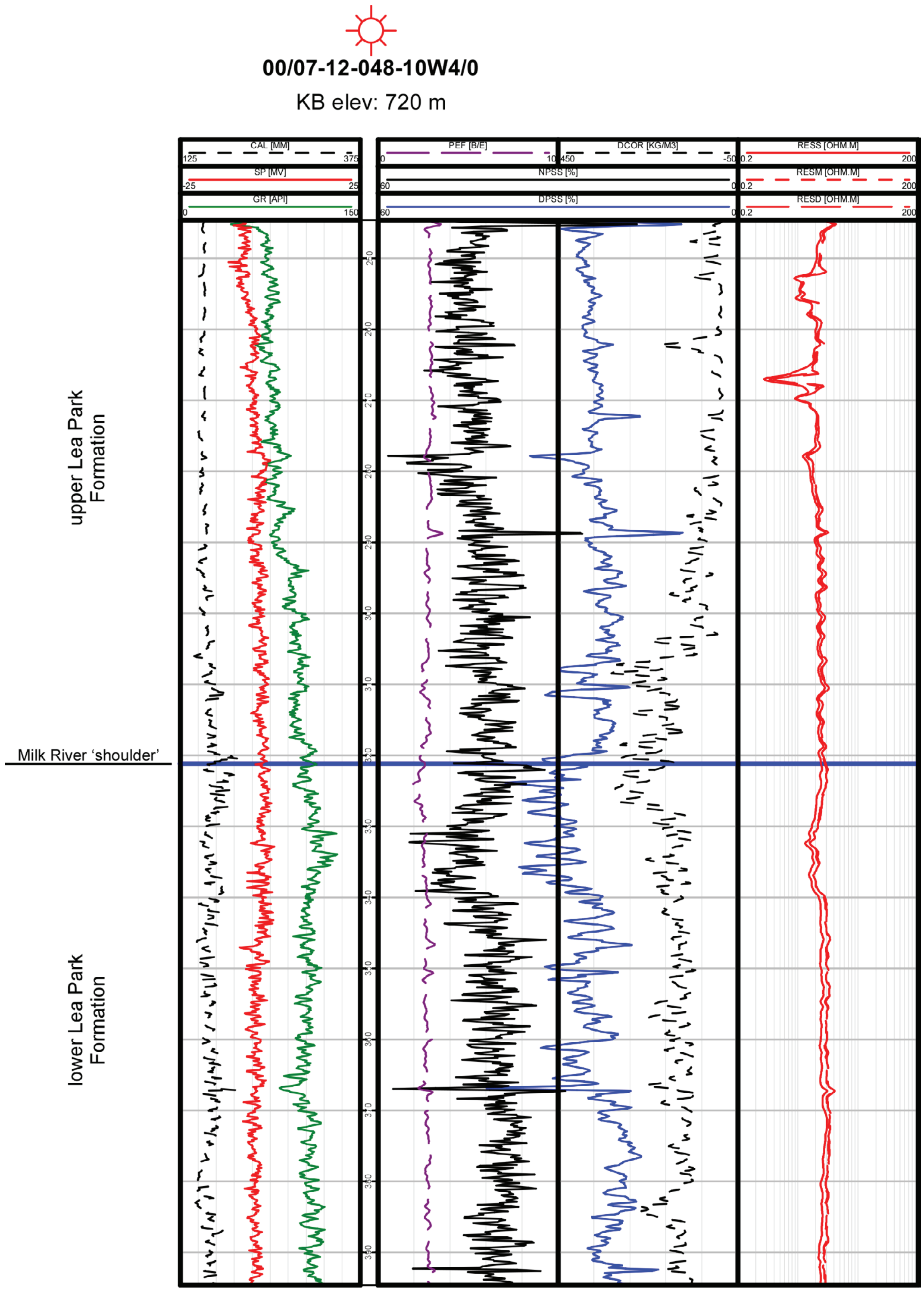

Figure 10. Representative well G (00/07-12-048-10W4/0). Logs shown are caliper (CAL in mm), spontaneous potential (SP in mV), gamma ray (GR in API units), density porosity (sandstone calibration; DPSS in %), neutron porosity (sandstone calibration; NPSS in %), photoelectric factor (PEF in barns/electron), density correction (DCOR in kg/m3), deep resistivity (RESD in ohm•m), medium resistivity (RESM in ohm•m), and shallow resistivity (RESS in ohm•m). KB elevation given is metres (m) above sea level. Vertical log scale is measured depth (in metres) below kelly bushing (KB).

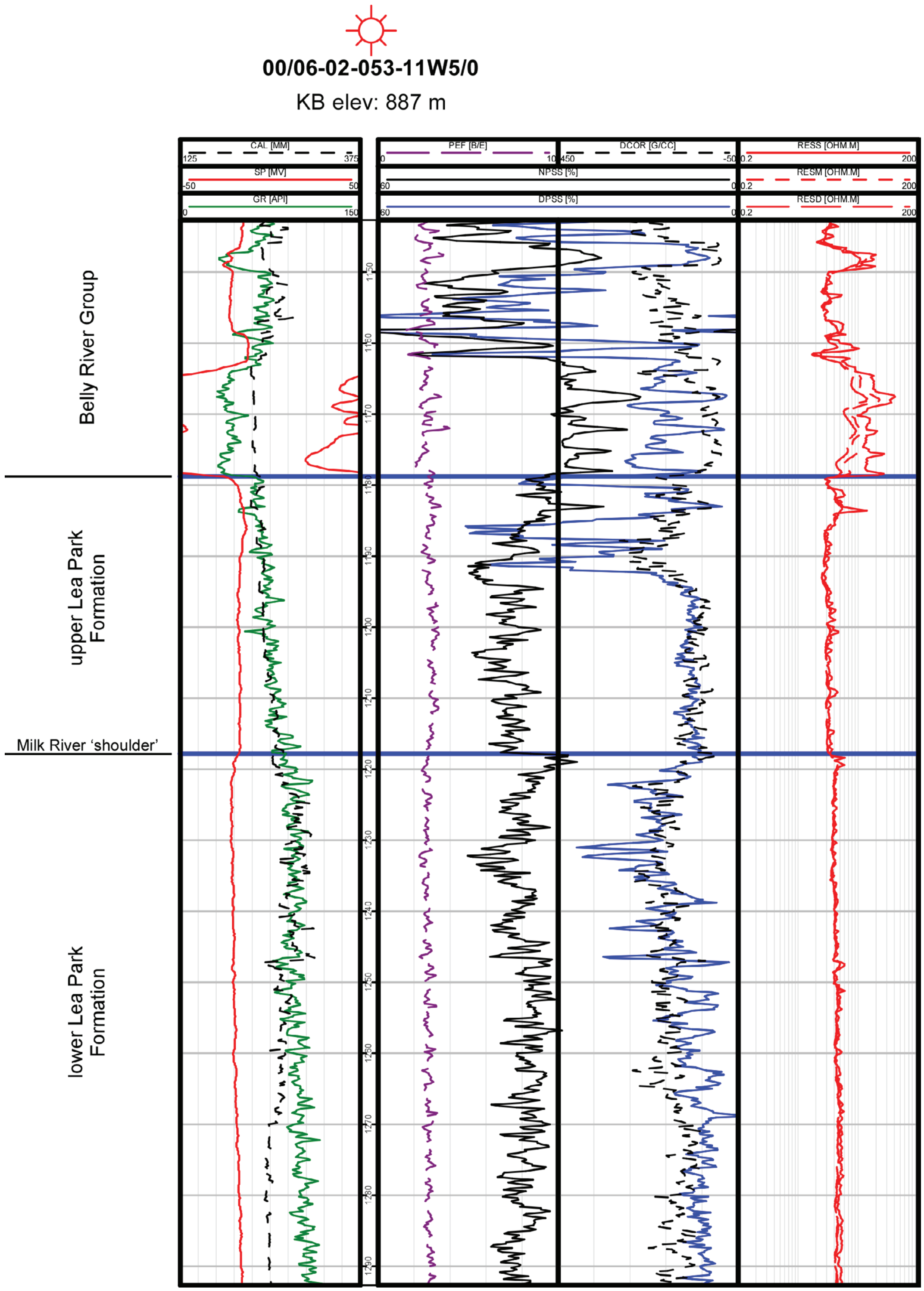

Figure 11. Representative well H (00/06-02-053-11W5/0). Logs shown are caliper (CAL in mm), spontaneous potential (SP in mV), gamma ray (GR in API units), density porosity (sandstone calibration; DPSS in %), neutron porosity (sandstone calibration; NPSS in %), photoelectric factor (PEF in barns/electron), density correction (DCOR in kg/m3), deep resistivity (RESD in ohm•m), medium resistivity (RESM in ohm•m), and shallow resistivity (RESS in ohm•m). KB elevation given is metres (m) above sea level. Vertical log scale is measured depth (in metres) below kelly bushing (KB).

- vertical wells only,
- wells with a spud date between 1975 and 2013, and
- wells with downhole geophysical well-log suites that include gamma-ray, density or sonic, and resistivity logs.

Preference was given to wells where the bottom of the surface casing shoe is less than 50 m deep. If sufficient well density was not available using this criterion, it was relaxed to include wells with the bottom of surface casing in the 50–150 m range. A minimum well density of one well per township was used, although well density greatly exceeds that number in most areas, especially where anomalous structure was detected.

To facilitate correlation and to check internal consistency, picks were made along a series of intersecting cross-sections spaced a maximum of 10 km (one township) apart. In this way, a pick in a well was typically compared with several picks in nearby wells to ensure consistency. Picks were gridded using the triangulation method to identify and check outliers, which appear as 'bull's eyes' on a structure contour map.

6 Quality Control Procedures

After making picks, steps were taken to eliminate error resulting from

- deviated wells,
- incorrect KB elevation data,
- incorrect ground elevation data, and
- incorrect pick depth (due to human error).

Picks and well-header information, including KB elevation, ground elevation, surface location (longitude and latitude in decimal format), and bottomhole location (longitude and latitude in decimal format), were exported from Petra software. The datum for the well location is NAD 83 and the picks are in metres, given as measured depth relative to KB elevation. Pick elevations (subsea) were calculated by subtracting vertical depth from the KB elevation.

A query of the well surface locations compared with the bottomhole location was run to check for deviated wells. If a well is deviated (not vertical), its surface and bottomhole co-ordinates should be different; these wells were removed from the dataset. As all remaining wells should be vertical if the surface and bottomhole co-ordinates are correct, measured depth and true vertical depth should be essentially equal.

Although incorrect KB elevation data can be difficult to detect, the data were screened by comparing the ground elevation and the KB elevation (approximately equal to the drilling derrick floor height) for each well. An acceptable range of derrick floor height—calculated by subtracting ground elevation from KB elevation—of 0 to 8 m was used. Wells with calculated derrick floor heights outside this range were excluded.

Data were then screened for both global and local outliers. Outliers are those values that are outside a specified normal range compared with the entire dataset (global outliers) or within a local area (local outliers). If outliers are caused by error, outliers can have a detrimental effect on the accuracy of the interpolated surface. They should be either corrected or removed before modelling a surface.

Outliers may result from one or more of the following factors:

- incorrect ground elevation or KB elevation data not detected during the initial screening,
- incorrect location data for a well,
- deviated wells that are not marked as such and have either incorrect surface or bottomhole location data,
- incorrect pick data due to picking (human) error, and
- geological structure.

Outliers were identified by creating structure and isopach grids in Petra, then examining outliers. Outliers were flagged and examined to determine whether the outliers were due to geological structure or incorrect well data. In cases where a pick was verified and no source of error could be identified, additional picks were made to increase data density in that area. If no geological explanation for the anomaly could be identified after increasing the data density, and the magnitude of the anomaly was greater than the expected geological variation for that area, then the data point was removed from the dataset. Once initial outliers were either removed or confirmed, the outlier screening process was repeated three times. This iterative process was used to effectively identify increasingly subtle outliers.

7 Implications

The data generated during this study provide an internally consistent set of subsurface stratigraphic picks for the Milk River shoulder in Alberta. The data built upon previous studies (e.g., Hamblin, 1993) and includes a much higher data density, particularly in areas with anomalous structure. A structure surface based on the stratigraphic picks made during this study is shown in Figure 12 to illustrate regional structure on the Milk River shoulder in the Alberta Plains. The data were modelled using Petra with the "highly connected features (least-squares)" method and a grid cell size of 2000 m by 2000 m.

The broad structural elements of the southern Alberta Basin are visible on Figure 12. The Kevin-Sunburst Dome extends northwards from northern Montana into southern Alberta and controls the regional structure and the trend of structure contours, which wrap around the northern margin of the dome. Numerous undulations are visible on the northwest margin of the dome (Figure 12, lower left). The deviations generally take the form of alternating northwest- and northeast-trending segments, resulting in a sawtooth pattern on the map. Both normal and reverse faults are visible in seismic reflection data of Upper Cretaceous and older strata in the area (e.g., Wright et al., 1994; Lemieux, 1999).

In southwestern Alberta, a west-plunging positive structural feature, known as the Calgary Arch (Dawson et al., 1994, Figure 24.2; Figure 12), divides the Alberta Basin into arcuate southern and northern sub-basins. The smaller (southern) region, bounded in the north by the Calgary Arch and in the west by the deformation front, exhibits relatively steep dips to the southwest. The extension of the Bow Island Arch northeastwards from the northern margin of the Kevin-Sunburst Dome separates the Alberta Basin to the west from the Williston Basin to the east (Tovell, 1958; Lorenz, 1982; Wright et al., 1994).

8 Summary

A new, internally consistent set of 25 069 subsurface picks for the Milk River shoulder in the Alberta Plains was generated using geophysical well logs. Well data were screened for potential errors in kelly bushing and ground elevation values and for errors resulting from deviated wells. Local and global outliers were identified using statistical methods and either rejected or confirmed based on well-by-well examination. Additional picks were made to delineate local structure, where necessary. The structure surface shows the regional structure on the top of the Milk River shoulder within southern Alberta.

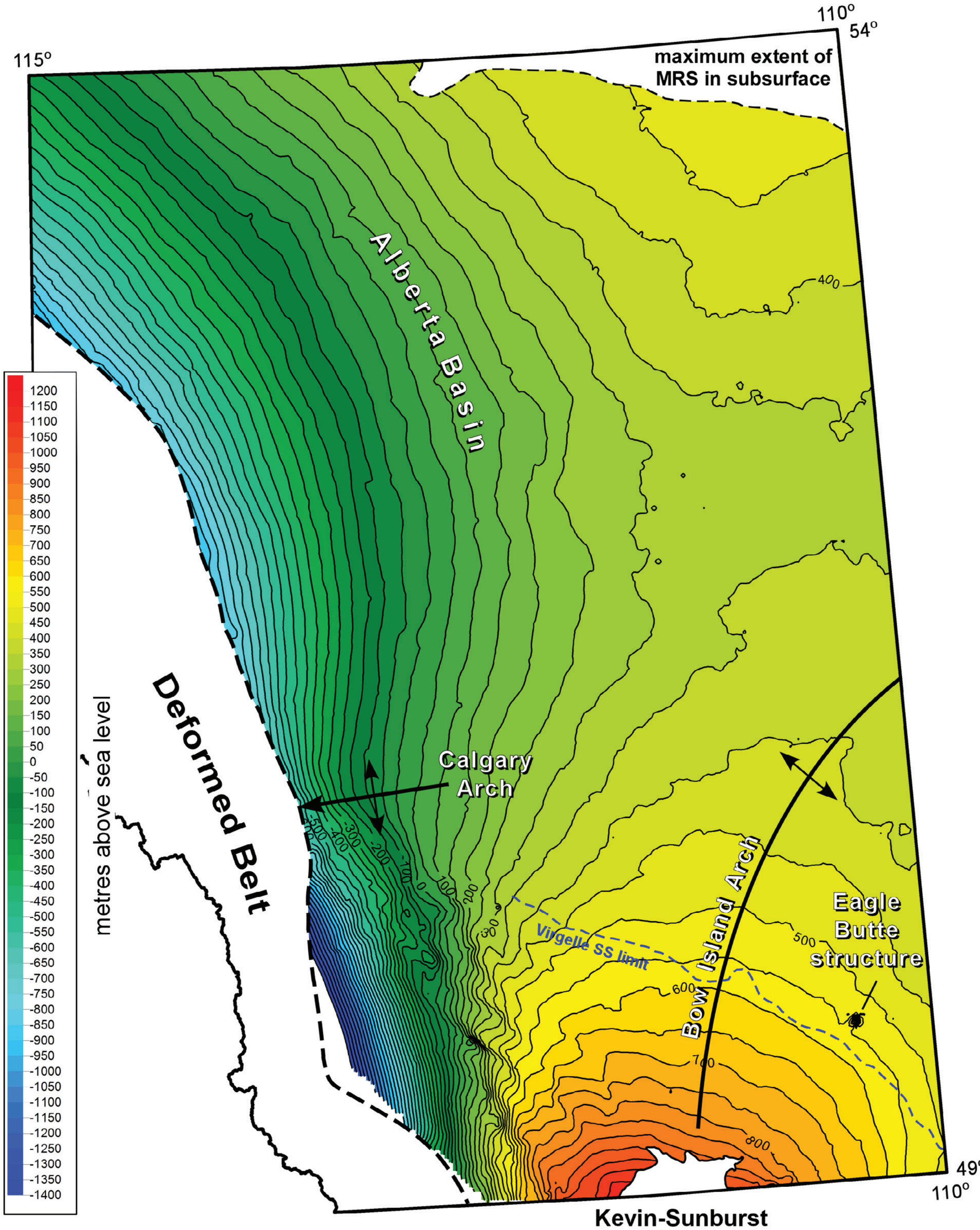

Figure 12. Structure map for the top of the Milk River shoulder in southern Alberta. Contour interval is 50 m; contour values are in metres above sea level. Surface trace for the top of the Milk River Formation in southern Alberta is shown as a solid black line and was modified from Hamilton et al. (1999).

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