Distribution of arenites in the Fernie Formation in Northeastern British Columbia

Ed Janicki and Akindele Balogun

Petroleum Geoscience Section, BC Ministry of Natural Gas Development, Victoria, British Columbia, V9A 5N7

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Abstract

Although a unit of quartzose sandstone in the Fernie Formation (Jurassic) of northeastern British Columbia has produced hydrocarbons, a detailed investigation of this sandstone has not yet been published. Bounding beds have high organic content; therefore the presence of clean sandstone could enhance the Jurassic's potential for unconventional development. A similar correlatable sandstone unit, which produces hydrocarbons in central and southern Alberta, is called Rock Creek Member. There it contains Middle Jurassic (Bajocian) fauna. The age (Upper Jurassic?), stratigraphic affinity, and tectonostratigraphic significance of the rocks in northeastern British Columbia remain unclear, however we refer to them simply as Fernie Sand. As observed in core, and described in drill cuttings, the Fernie Sand consists of light greyish brown, bioturbated, glauconitic sandstone and siltstone. Despite subtle differences in grain size relative to bounding units, the Fernie Sand can be recognized on well logs by a leftward shift of the gamma-ray curve. An isopach map of relatively clean sand based on more than 700 wells indicates that: 1) the Peace River arch was a paleotopographic low during Jurassic sedimentation; 2) Fernie Sand appears to define discontinuous lenses encased in finer grained rocks rather than continuous tabular bodies; 3) ovoid accumulations of Fernie Sand define a northwest-southeast oriented trend extending across the axis of the Peace River arch; and a smaller body is present near the depositional-erosional edge of the unit farther to the northwest.

Key Words: Jurassic, unconventional hydrocarbon development, Rock Creek, Fernie Sand, erosional edge, Bajocian.

1. Introduction

The Fernie Formation is found in the subsurface over a large area extending from southern Alberta into northeastern British Columbia (Figure 1). It is constrained to the northeast by an erosional edge. Southwest of the Cordilleran deformation front it becomes dramatically deeper, and often greatly thickened due to structural disruption. The study area for this report concentrates on the area between the Fernie erosional edge and the deformation front in northeastern British Columbia (NEBC).

1.1 Economic Significance

The Jurassic section in British Columbia has attracted relatively little economic interest even though its high organic content (e.g., Fowler et al., 2001; Ferri et al., 2013) might make it an attractive target for unconventional development. In central Alberta, oil companies have produced hydrocarbons from the Rock Creek Member (Middle Jurassic) for several decades. In NEBC, several wells (Figure 2) have produced gas or condensate from relatively thick sections of a sand unit[1], we call Fernie Sand, similar in wireline log morphology and apparent stratigraphic position to the Rock Creek Member of Alberta.

On its own, the Fernie Sand in NEBC could be adequately porous and permeable to produce conventionally as it does at the wells shown in Figure 2, or as the Rock Creek Member does in Alberta. Even if uneconomic as a conventional producer it may enhance unconventional production due to its relatively favourable reservoir characteristics when compared with the bounding organic rich shale units below (Poker Chip member) and above (Upper Fernie Member). The possible economic advantage of having a thick section of Fernie Sand directs us to better document the stratigraphic relationships and extent of the Fernie Sand in the northeastern part of the province. Towards this purpose, gamma-ray well logs provide data for isopach

[1] The British Columbia Oil and Gas Commission, which is the regulatory body for oil and gas operations in the province, terms the productive interval in these wells "Rock Creek A". In this report we refer to this interval as Fernie Sand for reasons explained herein.

Figure 1. Study area is within the red outline. Most of the study is focused on the area between the Cordilleran deformation front and the erosional limit of the Fernie Formation.

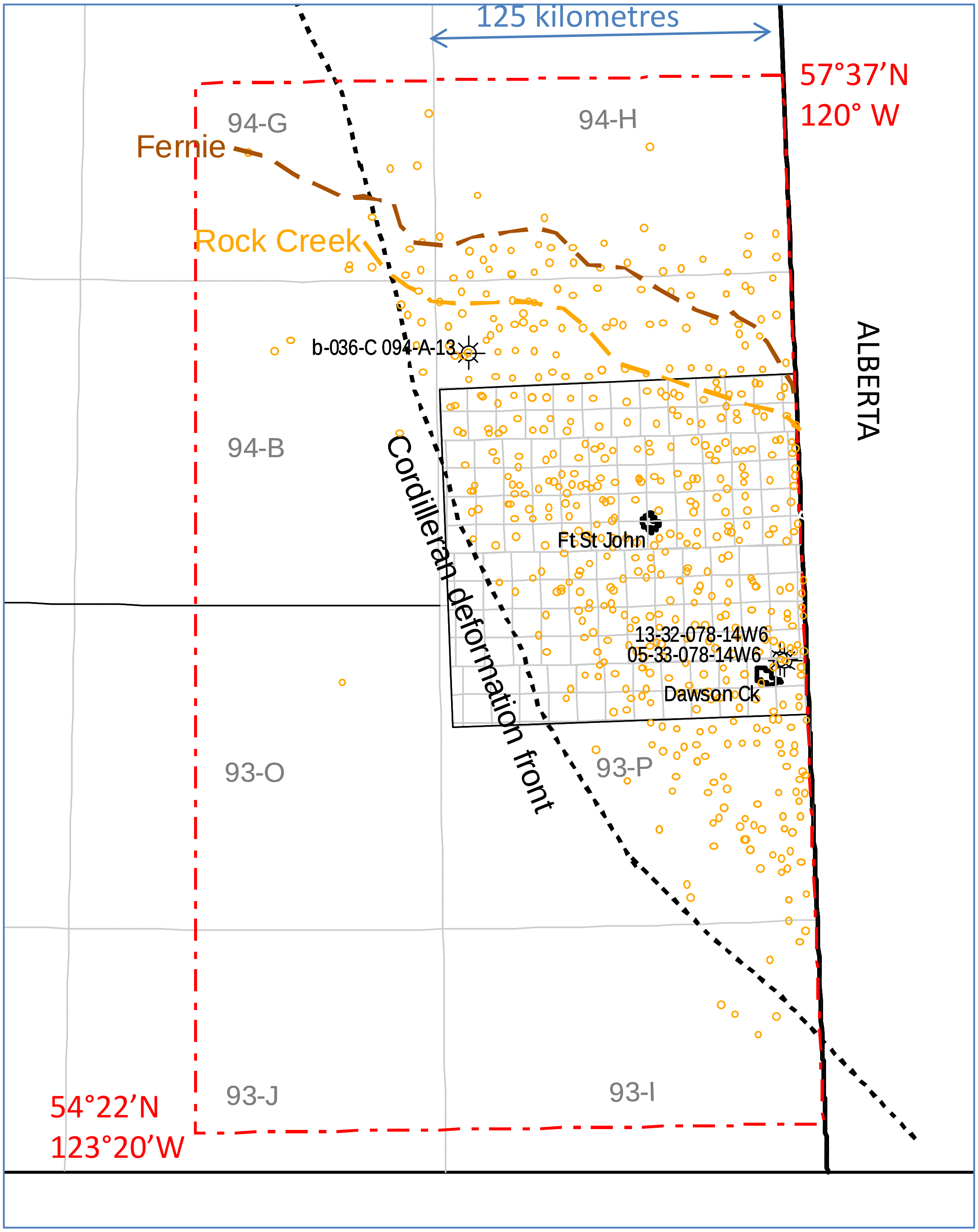

Figure 2. Three wells (b-36-C, 13-32 and 5-33) have produced gas or condensate from the Rock Creek Member (Fernie Sand) as designated by the British Columbia Oil and Gas Commission. Yellow dots symbolize wells with data used for this report. Fernie erosional edge is indicated; Rock Creek (Fernie Sand) can be either depositional or erosional.

maps; and stratigraphic cross sections provide estimates of where relatively clean sandstones may be found, and therefore possibly enhance unconventional production.

1.2 Nomenclature

Jurassic nomenclature was largely carried over from Alberta even though the tectonic and stratigraphic setting differs. In NEBC the Fernie Sand is also commonly called by industry Rock Creek (Figure 3), though it is likely of a different age and facies than the Rock Creek Member of central Alberta (Ford 2009, Poulton et al, 1990). In this paper we refer to the Jurassic sand unit of NEBC simply as Fernie Sand until its age and stratigraphic affinity become well established through further paleontological dating, detailed stratigraphic correlations and agreement among users on a new name. Fernie Sand is also the name currently used by the British Columbia Ministry of Natural Gas Development for the purposes of petroleum tenure.

Nomenclature is further confused by the common use of several other names for the Fernie Sand. Aside from the name Rock Creek, which is extant in the literature, industry wellfiles and regulatory bodies (British Columbia Oil and Gas Commission, Alberta Energy Regulator), the reader might also find the Fernie Sand in NEBC called: “Upper Fernie Sandstones” (Poulton et al, 1990), “Niton” (Alberta Geological Survey, 2015), “Green Beds” (e.g. Well File for ARCRES HZ PARKLAND A04-08-081-16), or perhaps other names.

2. Geological Setting

2.1 Tectonic Setting

The Jurassic section in British Columbia and Alberta provides a record of profound transition in the tectonic evolution of the Canadian Cordillera. The early Jurassic is characterized by stable shelf shales and limestones that formed a west-facing miogeoclinal prism extending over the western flank of North America (e.g., Miall et al., 2008). A significant hiatus intervened during the Middle Jurassic likely due to uplift and erosion at the initiation of the Columbian orogeny (Poulton et al, 1990). During the early part of the Late Jurassic an eastward-migrating foredeep took the place of the stable shelf.

Upper Jurassic sediment is characterized as an eastward thinning, clastic orogenic wedge. During the early part of the Late Jurassic an eastward-migrating foredeep took the place of the stable shelf. Subsidence of the foredeep was caused by the collision of accreted oceanic allochthonous terranes. Thick sediment was deposited and largely preserved in the foredeep, while a regional sub Upper Jurassic unconformity marked the eastern edge.

2.2 Stratigraphy

The Fernie Formation is a succession of predominantly shales, siltstones, and sandstones with a type section in the foothills of British Columbia near Fernie (Warren, 1934). Warren (1934) coined the term Rock Creek Member for a thin (~ 3-10 metre) unit of calcareous quartz arenites in the Fernie Formation, taking the name from a creek near Blairmore, Alberta where the unit is well exposed. The unit is extensively developed in the subsurface of central and southern Alberta, where it contains Middle Jurassic (Bajocian) fauna (e.g., Marion, 1984; Losert, 1986; Poulton et al., 1990, 1994), which would place it in the miogeoclinal succession. A similar sandstone unit occurs in NEBC and northwestern Alberta, which Lackie (1958) correlated with the Rock Creek Member of central Alberta. However, Poulton et al. (1990, 1994) argued that the northern sandstones are an entirely different unit and were deposited above the sub-Upper Jurassic unconformity during the Upper Jurassic (Figure 3). This conclusion was based on lithologic similarity of the sandstones to beds in the upper part of the Fernie Formation, and observation of a sub-sandstone unit unconformity in outcrop.

Poulton et al. (1994) restricted the use of 'Rock Creek Member' to demonstrably Middle Jurassic (Bajocian) sandstones in central and southern Alberta, and combined those rocks north of about latitude 54° 30' N with rocks of the Upper Jurassic (Oxfordian-Kimmeridgian) Upper Fernie Formation, while acknowledging that Bajocian sandstones might also be developed in the north. A palynological study by Ford

(2009), based on core from a well near Dawson Creek (13-32-078-14W6, Fig. 3), documented Oxfordian to Kimmeridgian microplankton taxa in siltstones and fine-grained glauconitic sandstones through an interval of about 7 metres. The underlying approximate 10 metre-thick section of fine-grained glauconitic sandstones yielded possible Middle Jurassic taxa, although Ford (2009) considered this result inconclusive. So although palynology from one core points to an Upper Jurassic age for these sandstones, the possibility remains that some sands are Middle Jurassic. Additional palynology at more locations will be needed to establish the age or ages of the Fernie Sand.

3. The Fernie Formation and Fernie Sand in NEBC

3.1 Observations

About 28,000 wells intersect the Fernie Formation in NEBC. Of these, we examined wireline logs from more than 700 (Figure 2) selected on the basis of geographic representation and availability of detailed lithological descriptions and gamma-ray curves. We used this data to examine the stratigraphic relationships of the Fernie Formation with emphasis on Fernie Sand. Isopach maps, stratigraphic cross-sections, and a map of relatively clean sandstone were drawn to show its distribution in relation to the bounding organic rich shales. Well logs also provided the control needed to draw formational edges (e.g. Figures 3 and 4).

An isopach map for the entire Jurassic section (Fig. 5) indicates that, although irregular in detail (e.g., over Peace River arch) thinning generally trends northeastward across regional strike up to its erosional edge. In general, Jurassic isopach thickens rapidly to the southwest into the foreland basin, and is more constant near the edge. The Peace River arch, where the Jurassic section is especially thick, is a long-lived structural feature with an early history (Neoproterozic to Paleozoic) as a positive topographic element and a later history as a depression (O'Connell et al, 1990). Increased thicknesses along the axis of the Peace River arch (Fig. 5; also noted by O'Connell et al., 1990 and Poulton et al., 1990) indicate that it was a paleotopographic low during the Jurassic.

As typically observed in core, the Fernie Sand consists of light greyish brown bioturbated, glauconitic sandstone and siltstone (Figs. 6, 7). The sandstones are moderately well sorted, very fine-grained subarkoses containing accessory glauconite, pyrite, and detrital carbonaceous material (Lackie, 1958). Clay partly occludes pore spaces. The fine grain sizes and preservation of delicate stratification indicate deposition in a relatively low-energy environment.

Where the Fernie Sand is relatively thick and clean, as at 7-1-80-15W6, porosity can exceed 10%, but generally averages 5 – 6%. Permeability reaches 0.1 millidarcies in places, though it is mostly much lower.

The upper part of the Fernie Formation contains thin siltstone interlayers that are similar to the Fernie Sand. Because of only subtle differences in grain size relative to bounding units, Fernie Sand is commonly recognized on well logs by a slight leftward shift of the gamma-ray curve (e.g., Fig. 8). It can only be confidently identified where sandstones are relatively clean and thick. Where the Fernie Sand is poorly developed, rocks of the Poker Chip Member cannot be readily distinguished from overlying Upper Fernie Formation shales. Figure 9 illustrates where Fernie Sand has been confidently identified from wireline logs. Subcrop edges of Fernie Formation subunits, based upon study wells, are also shown. Collectively, the Jurassic units define a southwestward thickening wedge beneath the Bluesky Formation[2] (Figs. 10, 11). Within its limited extent the Fernie Sand retains a relatively consistent thickness (10-20 m). West of location 10-8-77-20W6M (WA 10263, Fig. 10), the Fernie Sand loses its lithologic character and gamma-ray expression, and becomes indistinguishable from argillaceous rocks of the Poker Chip and Upper Fernie Formation. Along section B-B' (Fig. 11), the Fernie Sand appears to define discontinuous lenses rather than a single tabular body. In longitudinal profile

[2] The Bluesky Formation of Lower Cretaceous age is commonly used as a stratigraphic datum in the region based on its widespread occurrence and the assumption that its facies implies a near-level environment of deposition.

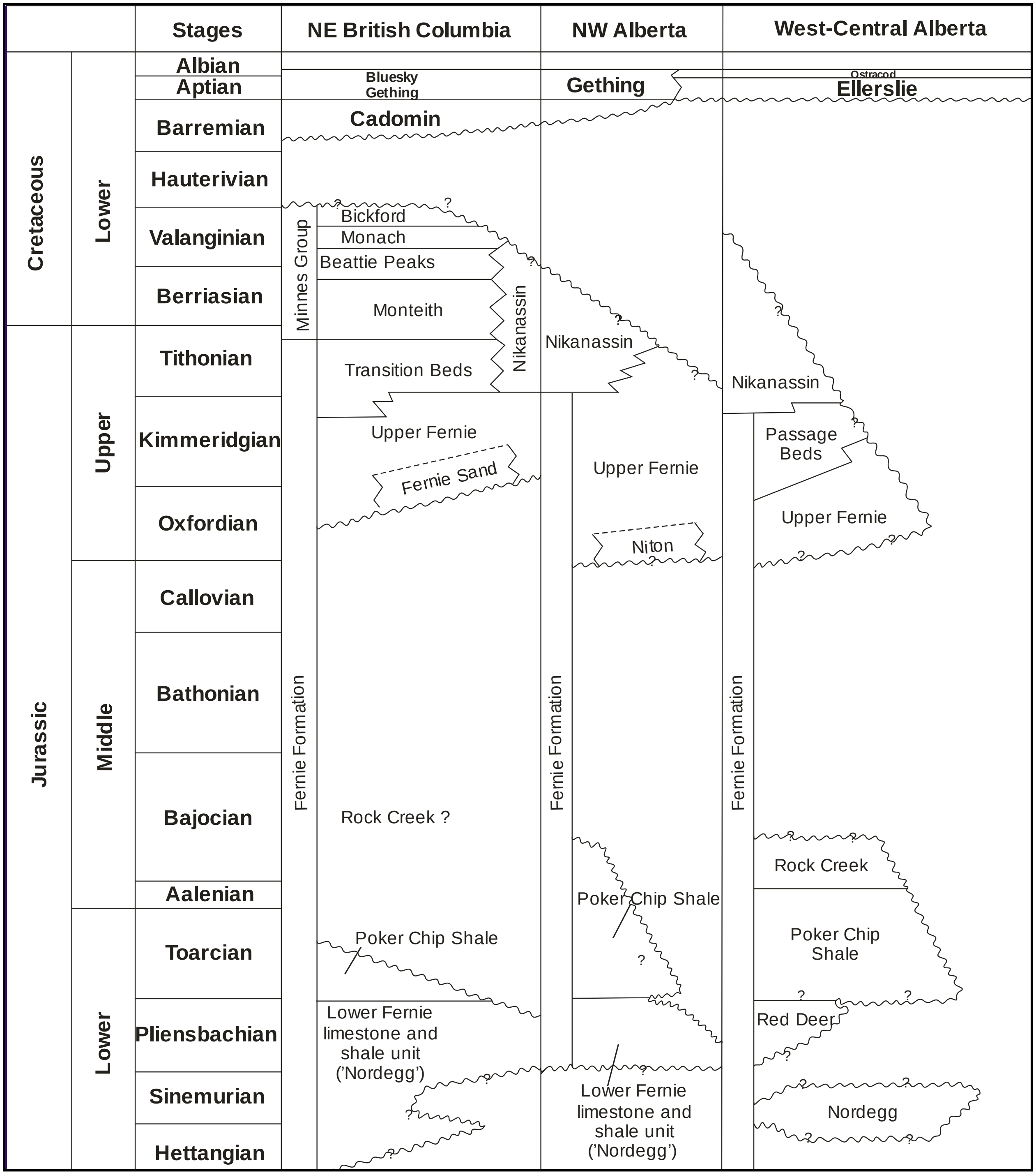

Figure 3. Stratigraphic correlation of Jurassic and Lower Cretaceous units in the Western Canada Sedimentary Basin (adapted from Poulton et al., 1994 and Tittemore, 1991). Although the Fernie Formation is often called "Fernie Group" (e.g. Frebold, 1957), it has not been sub-divided into formations (Glass, 1990). Fernie Sand is used here in place of Rock Creek, which is a name traditionally used by industry in British Columbia for sandstones in the Fernie Formation that are likely younger than the Rock Creek Member of west-central Alberta. Niton is the name adopted by the Alberta Energy Regulator for the Fernie Sand equivalent in northwestern Alberta. Rock Creek of Bajocian age might be present in northeastern British Columbia.

(Fig. 12) the Fernie Sand appears to maintain continuity along strike before ultimately pinching out to the northwest. Consistent with the general loss of the Jurassic section, the loss of Fernie Sand to the northeast is more due to erosion than non-deposition. The cross-sections across strike (Figures 10, 11) strongly suggest erosion to the northeast as the overall Jurassic section rises up from the foredeep unto a topographically higher shelf. However, the presence of thick clean Fernie Sand over the Peace River Arch also suggests the controlling influence of topography on distribution (O'Connell, 1990). Depressional lows, or lack thereof, could also be a primary controlling factor as to where Fernie Sand was deposited and preserved.

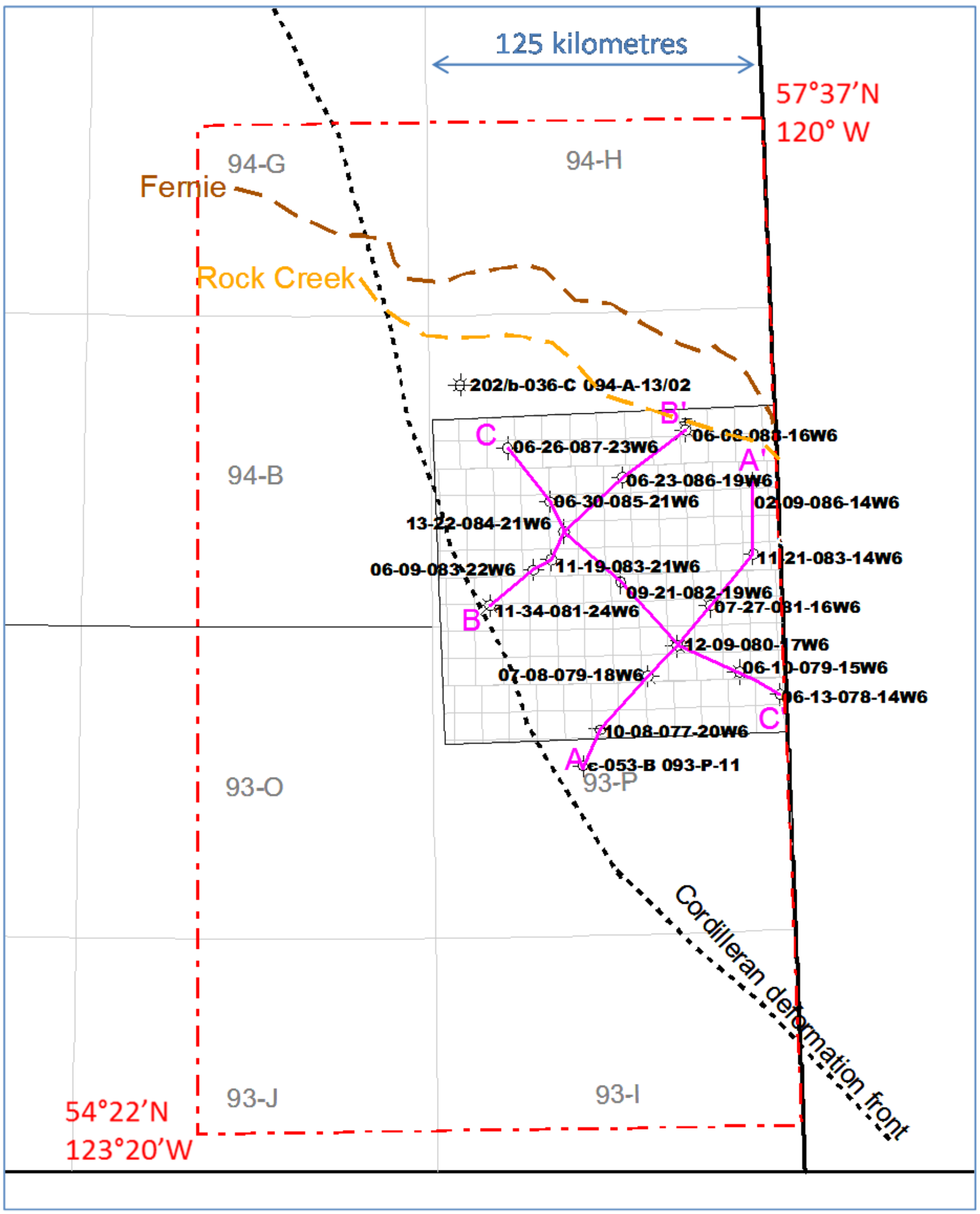

Figure 4. For cross-section A-A' see Fig. 12, for B-B' see Fig. 13 and Fig. 14 for C-C'. The location of the type well shown in Figure 8 is at 202/b-036-C 094-A-13/00.

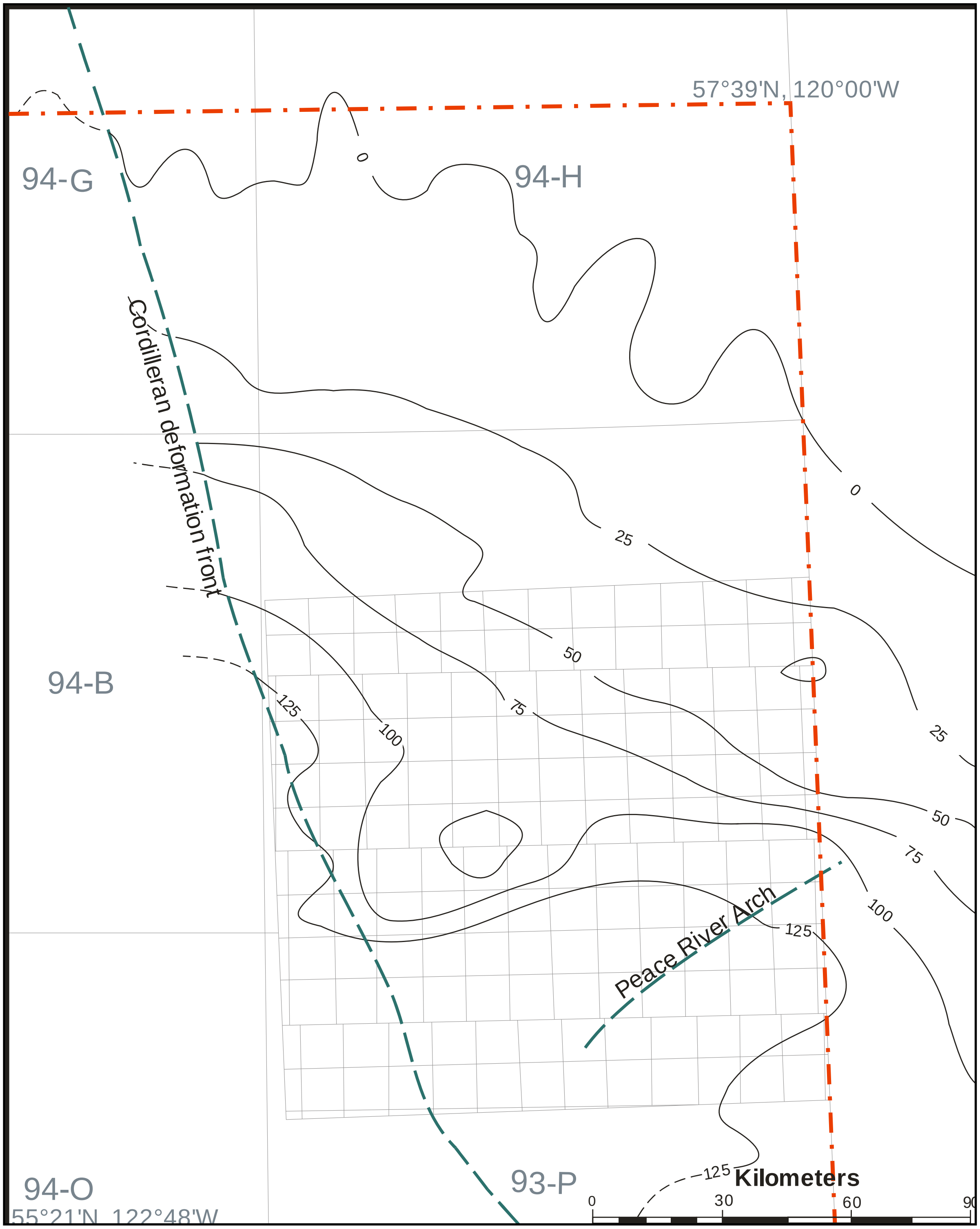

Figure 5. Isopach map of combined Jurassic units. Contour interval is 25 metres. During the Jurassic the Peace River arch appears to have been a northeast-trending depression that received sediment.

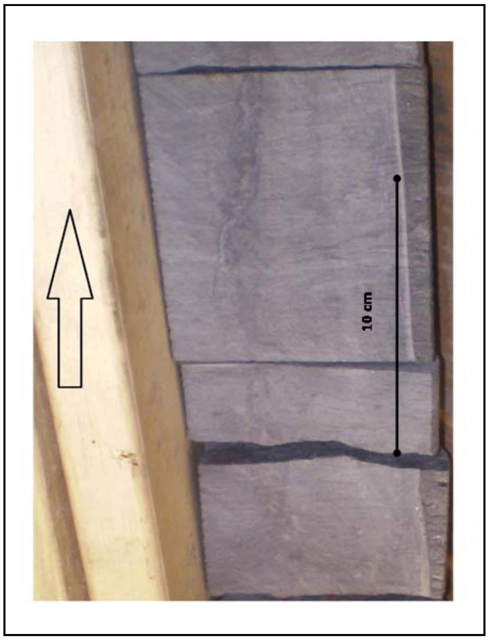

Figure 6. Rock Creek Member (Fernie Sand). Light grey bioturbated and burrowed siltstone. Note vertical burrow (1515 metres 4-14-79-14W6).

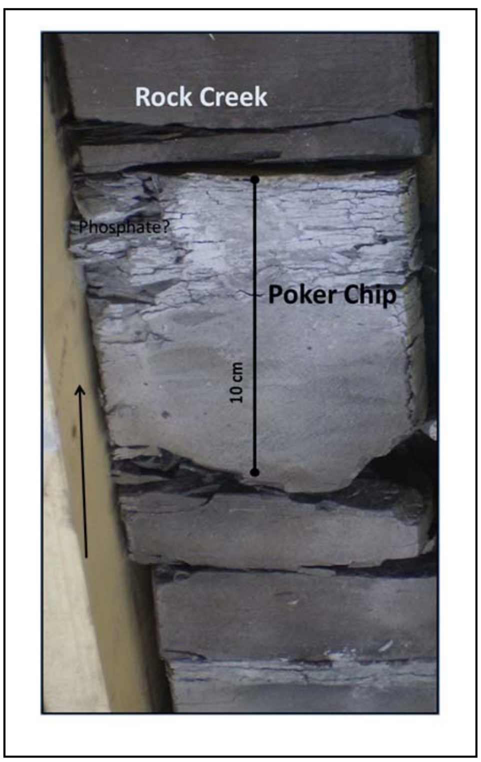

Figure 7. Rock Creek (Fernie Sand) is the dark rock at the top of the photo. It is in an abrupt unconformable contact above a rubbly, lighter coloured (phosphatic?) layer in Poker Chip shale; 1513 m, 12-7-81-16W6.

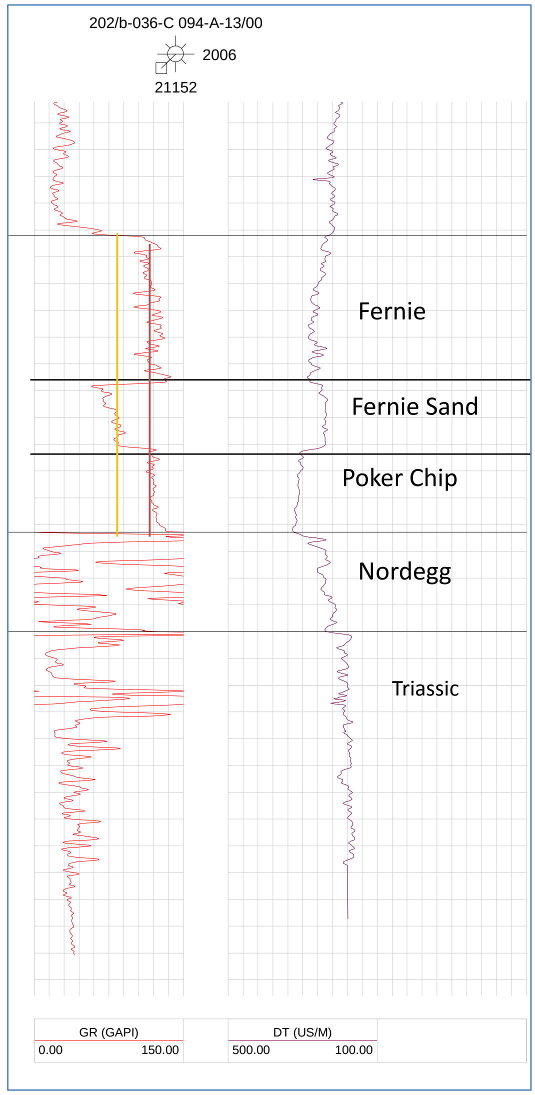

Figure 8. This Gamma Ray / Sonic log is a good example of Rock Creek (Fernie Sand) morphology, and one of the Rock Creek producers. Baseline gamma ray reading for Fernie shale is indicated by a red vertical line. The yellow line represents 30 API from baseline. Gamma Ray to the left of the yellow line was used to map Rock Creek clean sand. For location see Figure 4. BONAVISTA BLUEBERRY B-A036-C/094-A-13, Suspended Gas / Jurassic Rock Creek

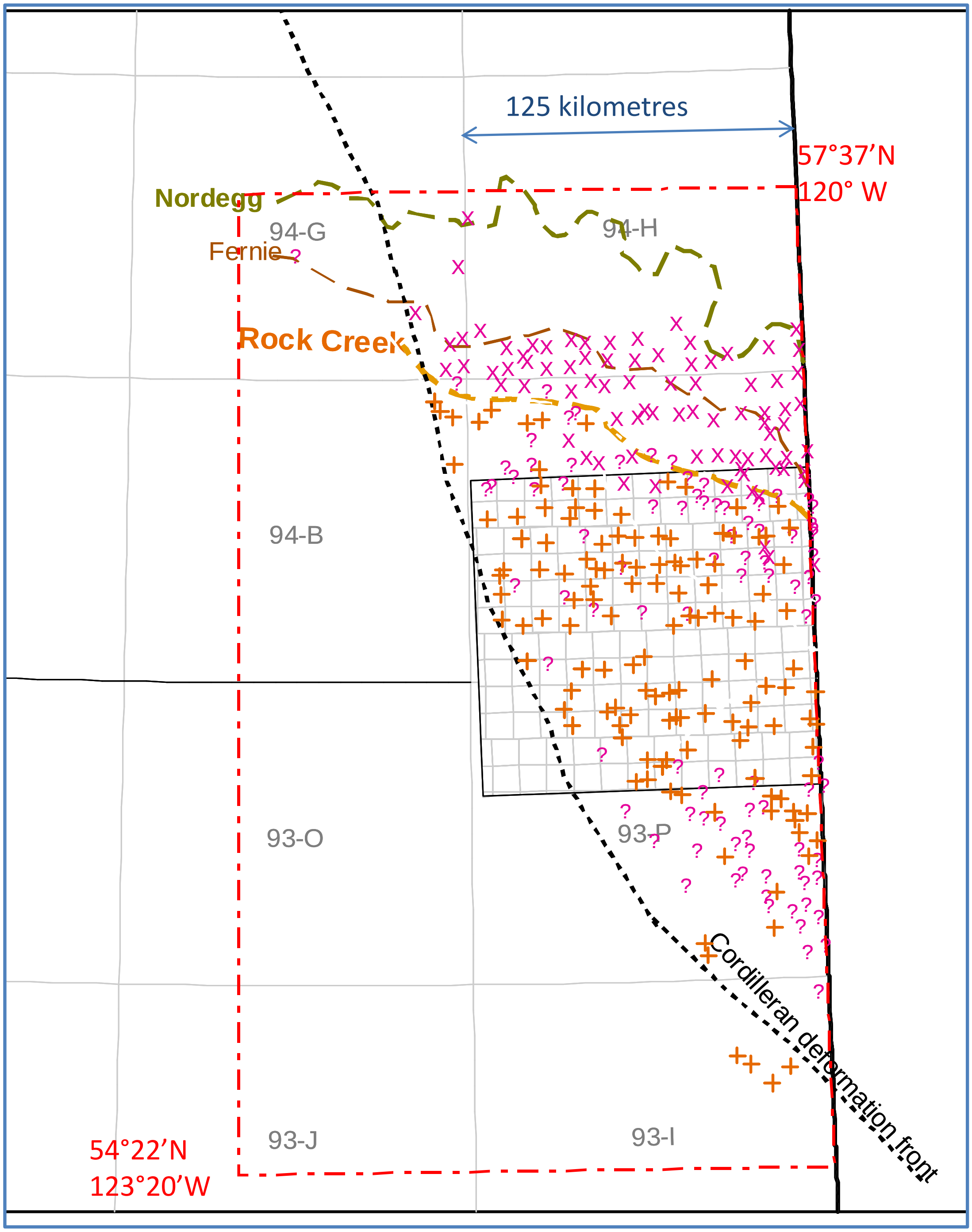

Figure 9. This map shows where Fernie Sand (Rock Creek Member) was confidently recognized on wireline logs. An "A" indicates where Fernie Sand may be present but poorly developed or difficult to recognize. An "X" indicates where it has been clearly eroded. Note that it has sometimes been eroded south of the erosional edge. Locations marked by "+" have easily recognizable Fernie Sand. A "?" indicates uncertainty. Nordegg and Fernie erosional edges are depicted in blue and brown respectively. Rock Creek edge, in orange, is limited by either erosion or non-deposition.

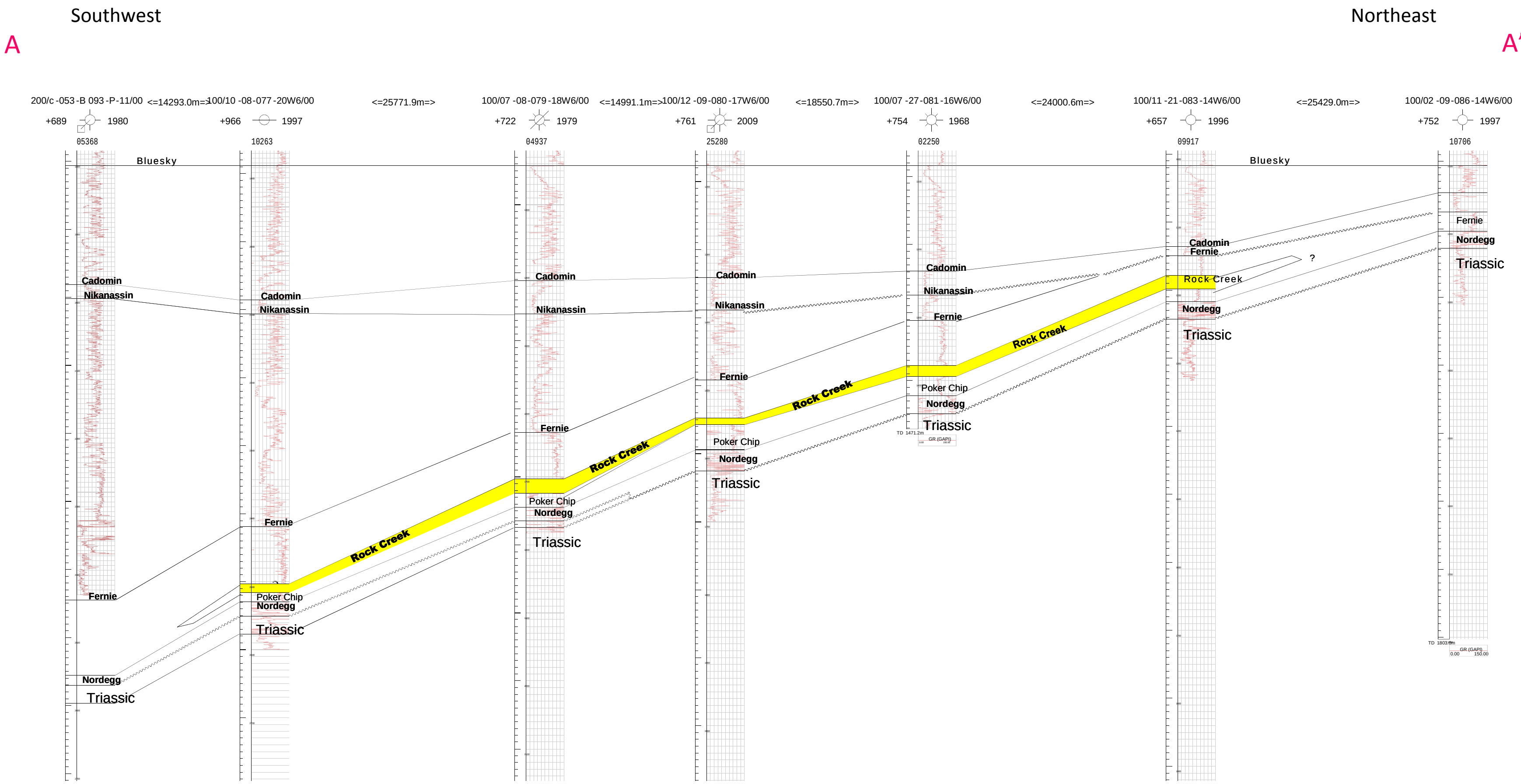

Figure 10. Stratigraphic Cross-section A – A'. The Rock Creek (Fernie Sand) appears to be as thick close to the northeastern edge as anywhere else. Its limit could be either depositional or erosional. To the southwest it becomes difficult to pick out from the surrounding shales.

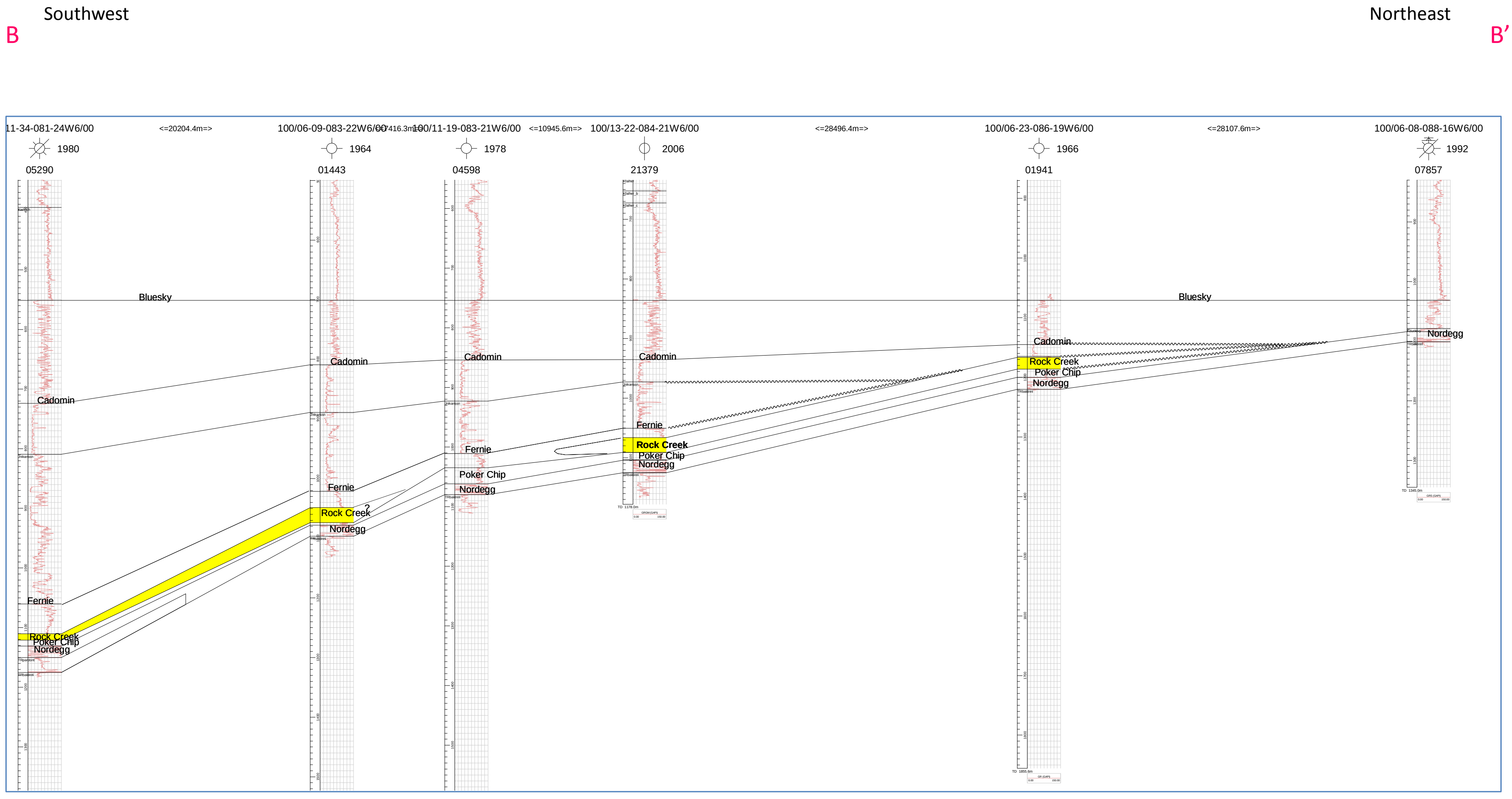

Figure 11. Stratigraphic Cross-section B – B’ The Cadomin directly overlies the Rock Creek (Fernie Sand) near the northeastern edge here; much of the Jurassic is eroded; even the Cadomin is missing near the Rock Creek edge at 06-08-88-16W6M (WA 7857).

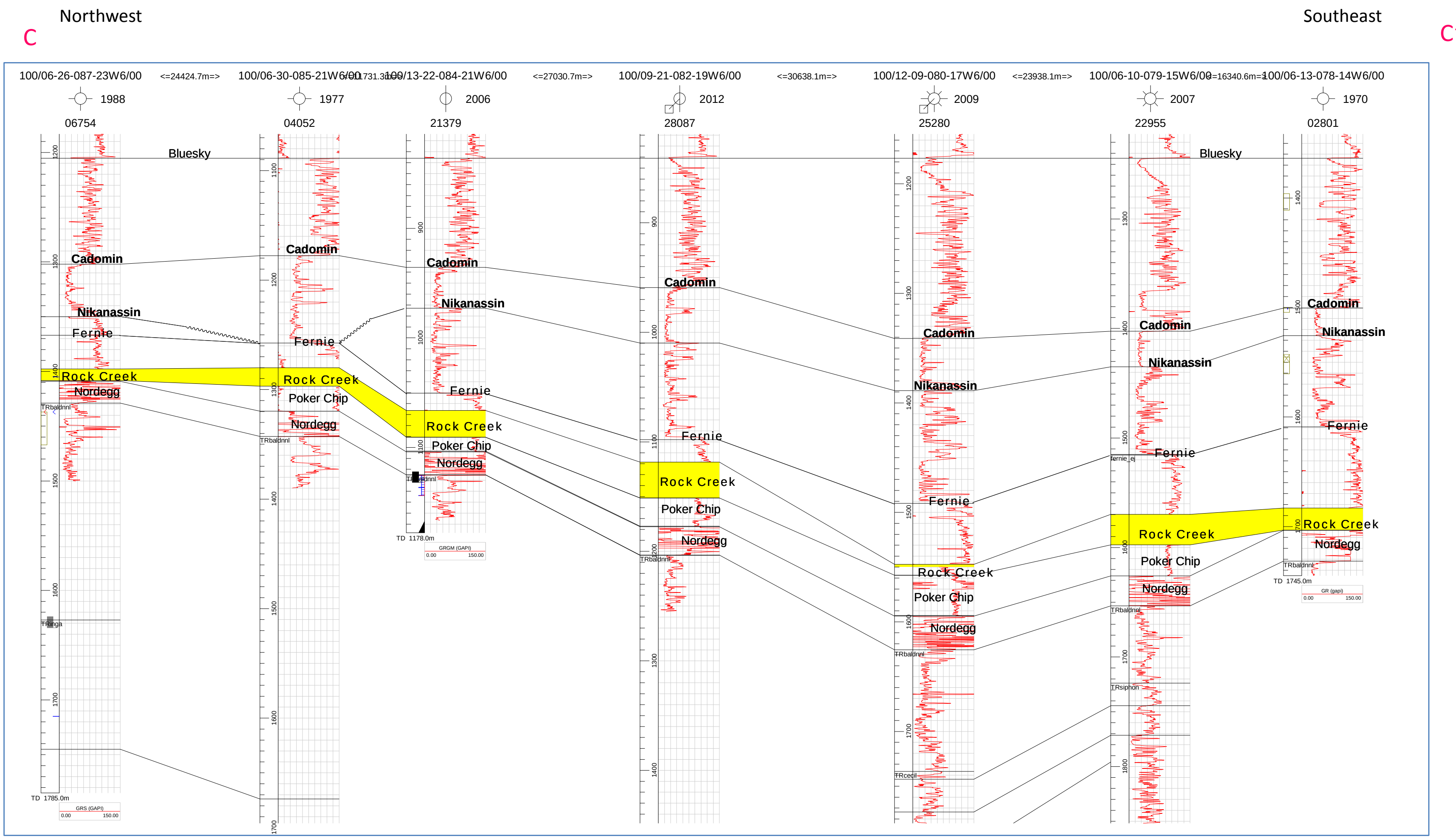

Figure 12. Stratigraphic Cross-section C – C’. Along strike, at a distance from its edge, the Rock Creek (Fernie Sand) is present to a greater or lesser extent everywhere. Thickness of Jurassic units varies due to variable degrees of erosion or possibly gaps in time between deposition.

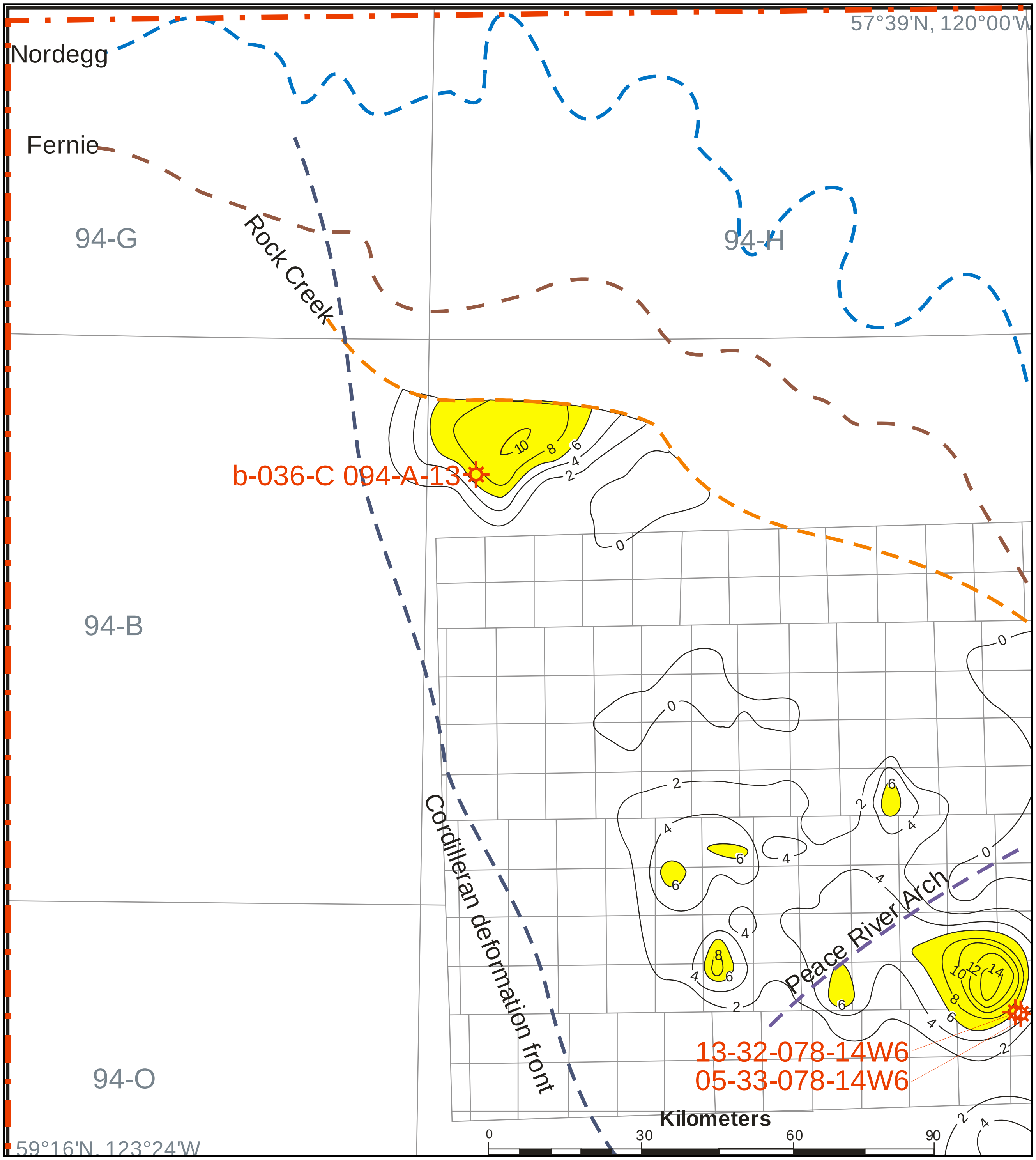

Figure 13. Isopach of Rock Creek Member (Fernie Sand) Clean Sand. Clean sand is defined by Gamma-Ray 30 API or more from a shale baseline. Current Rock Creek producing wells are indicated by red lettering. Contour interval is 2 metres. The study area is outlined by the red dashed line.

Relatively clean Fernie Sand, as defined by a 30 API gamma-ray deviation from a shale baseline (Fig. 8), appears to occur in two areas (Fig. 13). A group of ovoid accumulations define a northwest-southeast oriented trend that extends across the axis of the Peace River arch and likely continues into Alberta. Farther northwest, near the edge of the unit, is a smaller more discrete accumulation.

While Figure 13 represents the distribution of relatively clean sand, it does not show all clastic rock of siltstone grain size or greater. As mentioned above, sands may be present, and may be as coarse as fine-grained sandstone, but don't meet the strict 30 API criteria for appearing on the map. A gross sand isopach map for the Fernie Sand might capture those sands not represented on Figure 13, but would pose the difficult question of where to pick upper and lower boundaries, particularly where the sand is poorly developed. In summary, Figure 13 is a representation of the distribution of the best quality Fernie Sand, but not necessarily of all the sand that is present in the Upper Fernie.

3.2 Interpretation

Clear conclusions cannot be drawn about the environment of deposition at this time, but the uniformity and fineness of grain size, silty laminae disrupted by bioturbation and vertical burrowing would seem to preclude a high energy channel setting. These characteristics coupled with the uneven distribution of clean Fernie Sand in NEBC is consistent with ebb tidal shoal deposition (as characterized by Hubbard et al., 2002, in Alberta, for the Cretaceous Bluesky Formation), where a complex of relatively distal shoal sand bodies are encased in marine shale and mud. In Alberta, the observed lateral continuity of the Rock Creek Member (Losert, 1986) can be inferred to represent a more proximal shoal depositional facies (flood tidal shoals or shoal bars). Alternatively, higher gradients running down the foredeep may have played a role in concentrating somewhat coarser materials by localizing high-energy environments along spillway trends; or, subsidence of the Peace River Arch may have created depressional repositories of relatively coarse materials.

4. Summary

In central and southern Alberta quartzose sandstones of the Rock Creek Member contain Middle Jurassic (Bajocian) fauna and record the waning stages of miogeoclinal sedimentation on the western flank of North America. However, the stratigraphic affinity of the Fernie Sand in NEBC remains unclear. It may have been deposited above a regional sub-Upper Jurassic unconformity and record the onset of sedimentation in an eastward-migrating foredeep.

Sample descriptions and gamma-ray logs from more than 700 wells indicate that in NEBC the Fernie Sand forms discontinuous lenses bounded by finer-grained rocks. Several areas of relatively clean sandstones define a northwest-southeast oriented trend that extends across the axis of the Peace River arch (a paleodepression during Jurassic sedimentation) and likely continues into Alberta. Another sand body is close to the erosional-depositional edge of the Fernie Sand to the northwest. Other less clean sand in the Fernie section, not captured by the mapping criteria used here, is also likely present in the study area.

Acknowledgements

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