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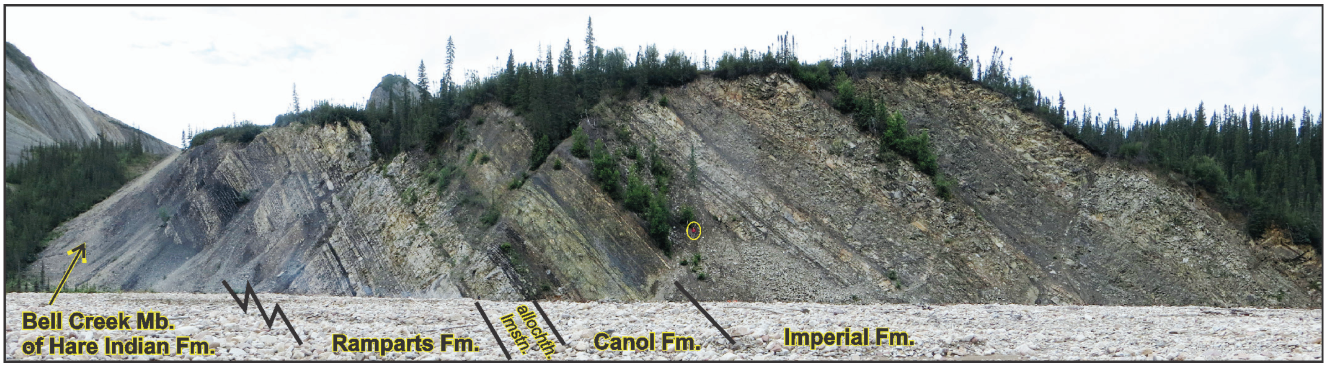

Geological and geochemical data from Mackenzie Corridor. Part VIII: Middle-Upper Devonian lithostratigraphy, formation tops, and isopach maps in NTS areas 96 and 106, Northwest Territories and Yukon

P. Kabanov and C. Deblonde

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Publications in this series have not been edited; they are released as submitted by the author.

Contents

Title page photo: The type section of Canol Formation at Powell Creek with interpreted lithostratigraphic units; *allochth. lmstn.* is the allochthonous limestone informal member of the Canol or Ramparts formations. Geologist in yellow oval for scale. Photo by the first author from July 2016.

SUMMARY

The lithostratigraphy of Eifelian-Frasnian strata in the subsurface of Mackenzie Valley, Peel Plain and Plateau between 64.5ºN and 68ºN is upgraded through revised formation tops in 126 exploration wells and rectification of formal and informal members within the Hume, Hare Indian, Ramparts, and Canol formations. In the westernmost part of the study area, insufficient resolution of legacy borehole logs is compensated by XRF surveys of cuttings. The Horn River Group is considered equivalent to the Canol Formation of northwestern Peel Plain and Plateau and the adjacent Richardson Mountains. The lateral facies changes in these strata lead to the recognition of four paleogeographic zones, each having a separate layout of member-rank traceable units. True vertical thickness (TVT) isopach maps and depth maps of selected units are created with Kriging methods in the ArcGIS Geostatistical Analyst wizard.

RESUME

La lithostratigraphie des strates de l'Eifelien au Frasnien dans le sous-sol de la vallée du Mackenzie ainsi que dans la plaine et le plateau Peel entre 64,5oN et 68oN est révisée grâce à une nouvelle analyse des sommets de formation des carottes de 126 puits d'exploration et la rectification des membres formels et informels des formations Hume, Hare Indian, Ramparts et Canol. Dans la partie la plus occidentale de la zone d'étude, des mesures de la fluorescence X des déblais de forage compensent la résolution inadéquate des diagraphies des puits existants. La formation de Horn River est considérée comme équivalente à celle de Canol du nord-ouest de la plaine et du plateau de Peel et des monts Richardson adjacents. Les changements des facies latéraux dans ces strates conduisent à la reconnaissance de quatre zones paléogéographiques, chacune étant caractérisée par une configuration distincte d'unités rattachables aux membres selon leur rang. Nous avons conçu des cartes de profondeur et des cartes isopaques de l'épaisseur verticale réelle d'unités sélectionnées à l'aide de méthodes de krigeage dans l'assistant d'analyse géostatistique d'ArcGIS.

INTRODUCTION

Driven by major shale hydrocarbon prospectivity (NEB-NTGS, 2015), the Eifelian-Frasnian strata in the subsurface of Mackenzie Valley, Peel Plain and Peel Plateau have been a focus of research for over a decade (Hamblin, 2006; Hayes, 2011; Hannigan et al., 2011; Enachescu et al., 2013a,b; Pyle et al., 2014, 2015; Pyle and Gal, 2016; Fraser, 2014; Hutchison and Fraser, 2015; Kabanov and Gouwy, 2017; Fraser and Hutchison, 2017; Kabanov, 2019). The focus of this paper is on the Horn River Group, a heterolithic stratal package dominated by organic-rich basinal shales (Figs. 1 and 2). The Horn River Group consists, from base to top, of the shale-dominated Hare Indian Formation, the limestone-dominant Ramparts Formation, and the black siliceous shales and cherts of the Canol Formation (Fig. 2; Pugh, 1983, 1993; Pyle and Gal, 2016; Kabanov and Gouwy, 2017; Kabanov, 2019). In the western Peel Plain and Plateau and the adjacent Richardson Mountains, the term 'Horn River Group' is not used as it consists entirely of mudrocks and cherts of the Canol Formation (Pugh 1983; Fraser and Hutchison, 2017). This paper also reflects progress in understanding of the Hume Formation beneath the Horn River Group and the overlying basal shales of the Imperial Formation.

UPDATES IN FORMATION TOPS

Interpretation of formation tops in wellbores have been evolving during the past two decades alongside a dramatic increase in the amount of thermal maturity, geochemical and mineralogical data (Fraser and Hogue, 2007; Gal and Pyle, 2008; Pyle et al, 2014; Kabanov and Gouwy, 2017). Tops of lithostratigraphic units are picked here in historical wells based on equal use of gamma, resistivity and sonic logs and, in part of the study area, definition of lithostratigraphic contacts is augmented with XRF surveys of rock cuttings. This approach proves very viable for mudrock sequences where historical resistivity logs (RES, LL, IL) show strong stratigraphic signal over a wide range of thermal maturity. Resistivity logs also link well sections drilled after the advent of gamma and acoustic logging with the original subsurface units defined by Tassonyi (1969) using RES and SP logs from Camp Canol wells (Kabanov and Gouwy, 2017). Exploration wells drilled in central Mackenzie Valley in 2012-2013, with their representative core coverage and advanced geophysical logging, added a lot to the understanding of the Horn River Group (Kabanov and Gouwy, 2017).

New picks of lithostratigraphic units change thicknesses quite significantly (Appendix 1). For example, the top of Canol picked in 101 historical wells in NWT has 46 entries that are different in more than 3 m from tops collected by Hogue and Gal (2008). Thirty-five out of 55 wells are in likewise disagreement with the Canol tops of Pyle et al. (2014). Major change in excess of 15 m occurs in 32 out of 101 Canol tops of Hogue and Gal (2008) and 26 out of 55 tops of Pyle et al. (2014). Lithostratigraphic tops picked in the Mackenzie Valley by Kabanov et al. (2016a) are mostly preserved unchanged. Arguments for the proposed change were discussed by Kabanov and Gouwy (2017) for the Mackenzie Valley and for the Peel area are summarized below with more details to be given in forthcoming publications.

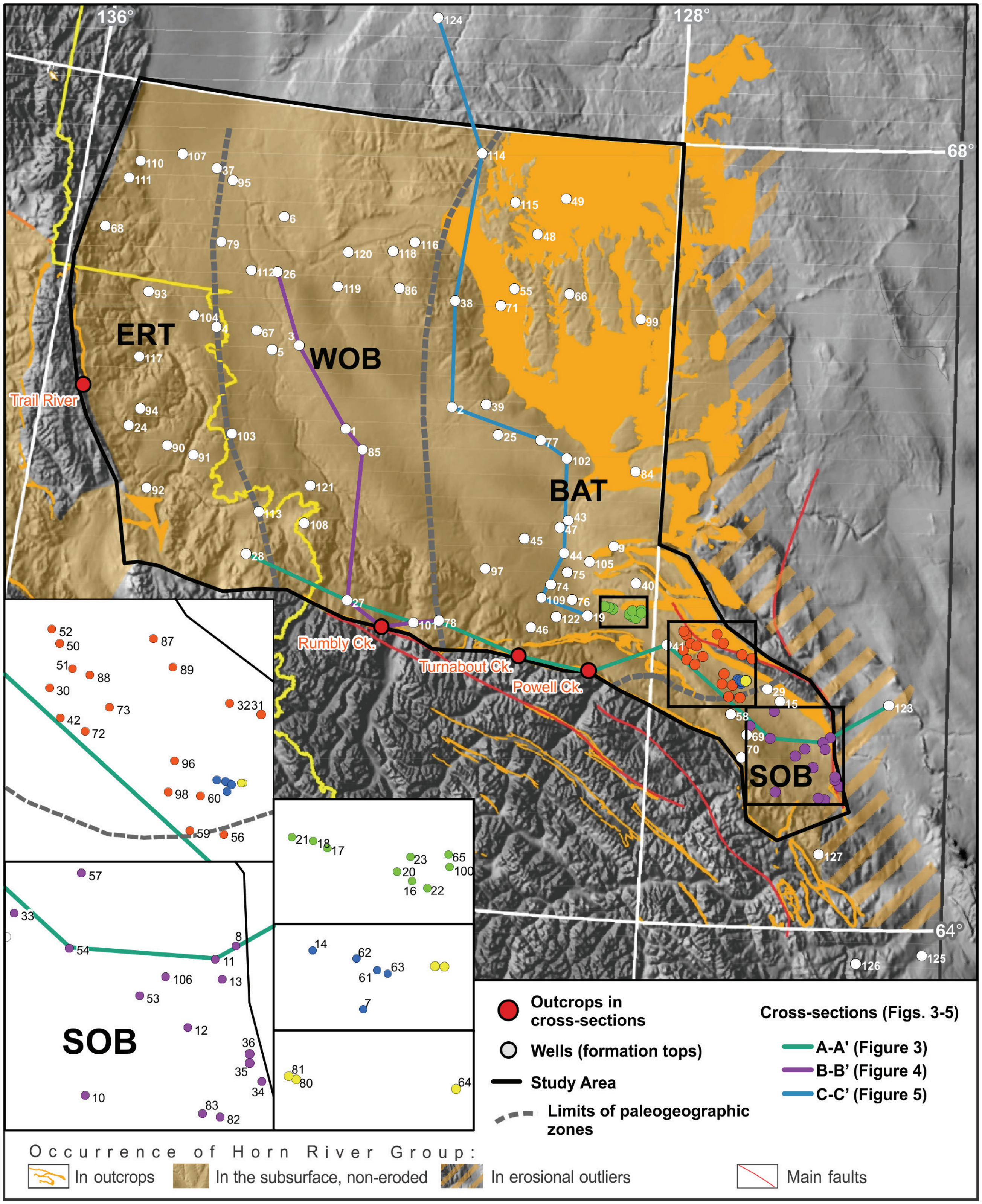

Figure 1. Geographic spread of the Horn River Group in the Cordillera and the adjacent Interior Plains between 64°N and 68°N overlain by contour of the study area and locations of studied wells. Insets enlarge densely drilled areas. Palaeogeographic zones: (ERT) western Peel Shelf –eastern Richardsons Trough, (WOB) western off-bank area, (BAT) bank-and-trough area, (SOB) southern off-bank area. Modified from Kabanov (2017) with changes in paleogeographic zone limits. Kugaluk N-02 and outcrop sections are included as they appear on cross-sections (Figs. 3-5).

Number	Well name	Number	Well name	Number	Well name
1	Arctic Circle Ontaratue H-34	44	Hume River D-53	87	OSCAR CREEK H-71
2	Arctic Circle Ontaratue K-04	45	Hume River I-66	88	OSCAR CREEK H-77
3	Arctic Red River O-27	46	Hume River L-09	89	OSCAR CREEK J-48
4	Arctic Red River YT C-60	47	Hume River N-10	90	PEEL RIVER Y.T. I-21
5	Arctic Red West G-55	48	Iroquois D-40	91	PEEL RIVER Y.T. M-69
6	Attoe Lake I-06	49	Iroquois I-11	92	PEEL RIVER Y.T. N-77
7	BEAR ISLAND R-34X	50	JUDILE NO.1(H-40)	93	PEEL Y.T. F-37
8	BEAR ROCK O-20	51	JUDILE O-17	94	PEEL Y.T. H-71
9	Beavertail G-26	52	JUDILE O-41	95	Pt. Separation no. 1 (A-05)
10	BLUEBERRY CREEK K-53	53	LITTLE BEAR H-64	96	RAIDER ISLAND NO.1(F-39)
11	BLUEFISH A-49	54	LITTLE BEAR N-09	97	Ramparts River F-46
12	BLUEFISH K-71	55	Little Chicago N-32	98	RAY NO. 1 (B-46)
13	CANOL BLUEFISH NO. 1A (A-37)	56	LOON CREEK NO. 1 (A-52)	99	Rond Lake no. 2 (F-56)
14	Canol Goose Island O-12X	57	LOON CREEK NO.2(G-78)	100	S. MAIDA CREEK G-56
15	CANYON CREEK NO.1(G-51)	58	LOON CREEK O-06	101	S. Ramparts I-77
16	CARCAJOU D-05	59	LOONEX NO. 1 (G-12)	102	S.W. Airport Creek no. 1 (D-72)
17	CARCAJOU D-07	60	MAC NO.2 (P-05)	103	Sainville River D-08
18	CARCAJOU J-27	61	Mackenzie River no. 1 (C-47)	104	SATAH RIVER Y.T. G-72
19	CARCAJOU L-24	62	MACKENZIE RIVER NO.2(H-57)	105	SHOALS C-31
20	CARCAJOU O-25	63	MACKENZIE RIVER NO.3(A-47)	106	SLATER RIVER A-37
21	CARCAJOU O-47	64	MACKENZIE RIVER NO.4(E-27)	107	South Delta J-80
22	CARCAJOU O-74	65	MAIDA CK F-57	108	South Peel D-64
23	CARCAJOU P-16	66	Manuel Lake J-42	109	Sperry Creek N-58
24	CARIBOU Y.T. N-25	67	Martin House L-50	110	Stony G-06
25	Circle River no. 1 (K-47)	68	McPherson B-25	111	Stony I-50
26	Clare F-79	69	MIRROR LAKE N-20	112	Swan Lake K-28
27	Cranswick A-22	70	MIRROR LAKE N-33	113	TAYLOR LAKE Y.T. K-15
28	CRANSWICK Y.T. A-42	71	Moose Lake D-07	114	Tenlen A-73
29	DEH CHO-1 B-25	72	MORROW CREEK J-71	115	Thunder River D-69
30	DEVO CREEK P-45	73	MORROW CREEK NO.1(G-44)	116	Thunder River N-73
31	DISCOVERY RIDGE D-04	74	Mountain R. A-23	117	TRAIL RIVER Y.T. H-37
32	DISCOVERY RIDGE H-55	75	Mountain River H-47	118	Tree River B-10
33	DODO CANYON K-03	76	MOUNTAIN RIVER O-18	119	Tree River F-57
34	EAST MACKAY I-55	77	N. Circle River no. 1 (A-37)	120	Tree River H-38
35	EAST MACKAY I-77	78	N. Ramparts A-59	121	Weldon Creek O-65
36	EAST MACKAY I-78	79	Nevejo M-05	122	Whirlpool no. 1 (H-73)
37	Ft. McPherson C-78	80	Norman Wells E-46X	123	BRACKETT L C-21
38	Grandview Hills no. 1 (A-47)	82	NORTH LITTLE BEAR L-21	124	KUGALUK N-02
39	Grandview L-26	83	NORTH LITTLE BEAR O-51	125	SUMMIT CREEK k-44
40	HANNA RIV. J-05	84	Ontadek Lake N-39	125	DAHADINNI 2M-43
41	HOOSIER F-27	85	Ontaratue I-38	126	SILVAN PLATEAU G-51
42	HOOSIER RIDGE N-22	86	Ontaratue River D-39	127	SUMMIT CREEK K-44
43	Hume R. A-53				

Table 1. List of studied well sections. Numbering corresponds to Figure 1.

A total of 177 exploration wells in NTS map areas 96 and 106 intersecting one or more of Hume, Hare Indian, Ramparts, or Canol formations, or the Road River Group, were screened for quality and availability of borehole data, and 126 wells were selected to trace lithostratigraphic units (Fig. 1, Table 1, and Appendix 1). One hundred twenty-two wells listed in Appendix 1 are used in the GIS modelling of isopach maps. Only four exploration wells listed in Appendix 1 occur outside the analysis area east of the Norman Range (Brackett L. C-21) and south of the Keele Arch (Summit Creek K-44, Dahadinni 2M-43, and Silvan Plateau G-51). Initial assessment of stratigraphy in these four wells indicates that subdivisions of the central Mackenzie Valley proposed by Kabanov and

Gouwy (2017) are likely not applicable in the Great Bear Plain and the southern Mackenzie Valley and that redefinition of formation tops may be necessary for certain wells (*e.g.,* Silvan Plateau G-51 as discussed by Kabanov et al., 2016c). Table 1 also lists Kugaluk N-02 well drilled to the north of the study area and included in the Cross-section C-C' (Fig. 5).

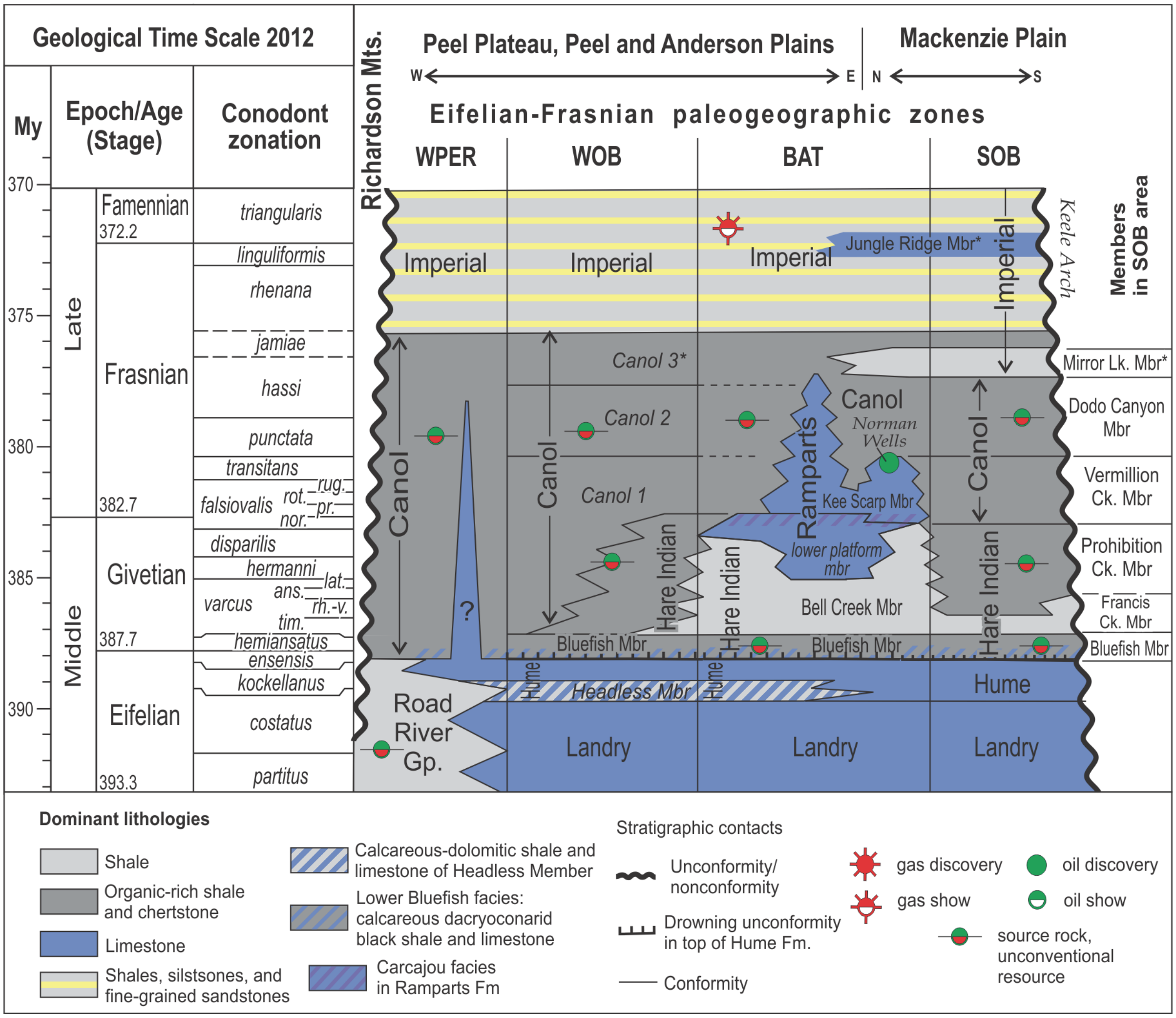

Figure 2. Eifelian-Frasnian lithostratigraphic chart across study area. Asterisk (*) denotes units of notably poor age constraints. Conodont zonation is based on summary and new data of S.A. Gouwy as reviewed in (Kabanov, 2019). Paleogeographic zones are defined on Figure 1. Alternative conodont zones in Givetian-Frasnian (Narkiewicz and Bultynck, 2007; Becker et al 2016): *tim.=timorensis, rh.-v.=rhenanus-varcus, ans.=ansatus, lat.=latifossatus/semialternans*, *nor.=norrisi, pr.=pristina, rot.=rotundiloba, rug.=rugosa.*

PALEOGEOGRAPHIC ZONES AND LITHOSTRATIGRAPHIC SUBDIVISIONS

The proposed lithostratigraphic layout of the Horn River Group recognizes four paleogeographic zones in the study area, each with a separate set of sub-formational units (Figs. 1 and 2). This layout originated during the latest Eifelian - Frasnian by a sequence of depositional events involving widespread and uniform deposition of the Bluefish Member over the drowned Hume carbonate platform followed by progradation of a deltaic complex from the easterly located sourceland (Muir et al., 1984). These deltaic clinoforms of the Hare Indian Formation formed seafloor highs above chemocline allowing growth of carbonate platforms (banks) of the Ramparts Formation upon waning of siliciclastic influx (Muir et al., 1984; Muir, 1988). The thickness of the Ramparts is very uneven (Figs. 3-5), and in some sections the

Ramparts is absent (e.g., Hoosier F-27), which justifies the name *bank and trough area* (BAT) for this paleogeographic zone (Kabanov and Gouwy, 2017).

In present-day structural configuration, the BAT area divides the Givetian-Frasnian black-shale basin into the southern off-bank area (SOB) and broader area in the Peel Plain and Plateau straddling the *western off-bank* (WOB) and the *eastern Richardson Trough – western Peel Shelf* (ERT) paleogeographic zones (Fig. 1). Kabanov and Gouwy (2017) proposed new subdivisions within the Hare Indian Formation, Canol Formation, and the basal portion of the Imperial Formation within SOB and redefined the Bell Creek Member of Pyle et al. (2014) and Pyle and Gal (2016) to be restricted to thick grey shales and siltstones typifying the upper Hare Indian in BAT area. The WOB area has been defined, without a proper description, in preceding publications (Kabanov, 2018, 2019). Recognition of ERT is a new idea described below in substantial detail.

The Canol Formation is the most geographically extensive unit traced within the limits of the ancestral North America (east of Tintina Fault Zone) from its eastern erosional edge to western limits of the Eagle Plain where it likely merges into thicker McCann Hill Chert of western Yukon and adjacent Alaska (A.W. Norris, 1997; Hutchison and Fraser, 2015). The Canol is composed of siliceous pyritic shales and muddy chertstones containing nodules and beds of authigenic carbonate (Pyle and Gals, 2016; Fraser and Hutchison, 2017; Kabanov and Gouwy, 2017; Kabanov, 2019). The Canol is thick (>60 m in most well sections) in off-bank areas, but thins to a few meters in BAT (Fig. 1C), up to complete disappearance of its high gamma-ray log marker above the tallest carbonate banks intersected by wells in the subsurface of NTS map area 106H (Pugh, 1983). The absence of Canol facies was first noted by Tassonyi (1969) in Whirlpool no. 1 well. Re-examination of cuttings from this well, drilled in 1946, confirms that samples at 920, 930, 940, and 950 ft (original MD footage) are populated with dark grey silty micaceous shale characteristic of the lower Imperial Formation. This shale contains significantly less disseminated pyrite than would be expected in a typical Canol facies. Cuttings of Ramparts limestone appear downhole in sample 950ft. Nearby wells Mountain River O-18 and Mountain River D-53 have feeble total gamma-ray signatures and insignificant development of Canol facies as seen in cutting samples.

Two scenarios may explain the fact that the Canol pinches out above tall carbonate banks: (1) small banks of benthic carbonate survived rises of chemocline in the Canol basin until their burial by Imperial siliciclastics; (2) benthic carbonate production ceased at one of anoxic events recognized in the upper Canol (Kabanov, 2019), but tallest carbonate banks remained in sediment bypass regime until their burial by Imperial shales. The lithostratigraphic chart of BAT depicts the first scenario (Fig. 2).

Cross-section A-A' (Fig. 3) is an example of correlation across paleogeographic zones involving reference outcrops in the Canyon Ranges of the northern Mackenzies. The cross-section B-B' (Fig. 4) shows traceability of the proposed subdivisions in the WOB zone. Cross-section C-C' (Fig. 35) exemplifies BAT sections with thick Hare Indian and Ramparts and correlation with Kugaluk N-02 off-bank section. The physical character of the Horn River Group in the WOB is testified by the two Rumbly Creek outcrops included in the cross-section B-B' as a composite Rumbly Creek section. Descriptions and spectral gamma-ray logs (SGR) of outcrops are available in (Kabanov et al., 2016b).

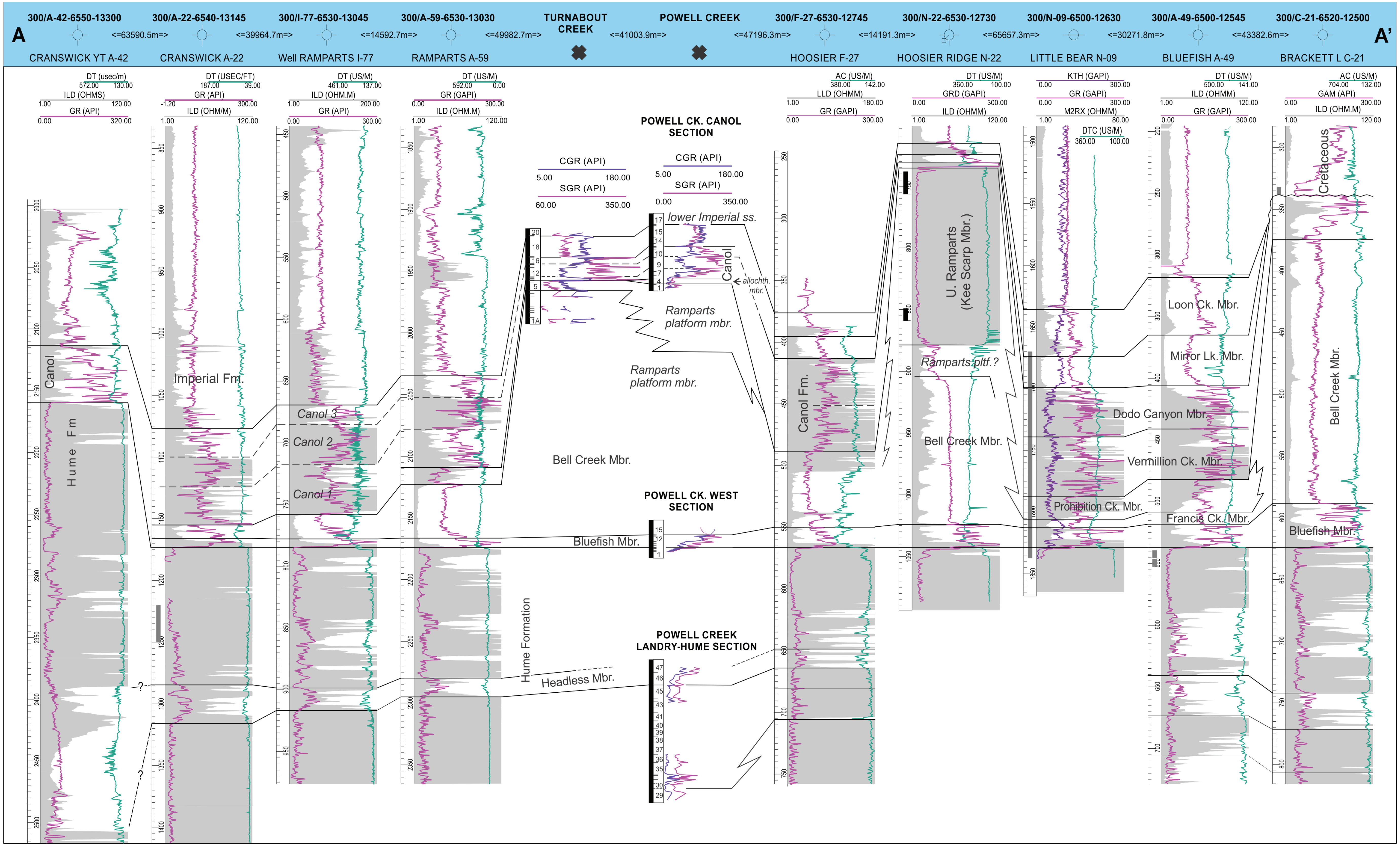

Figure 3. Cross-section A-A'.

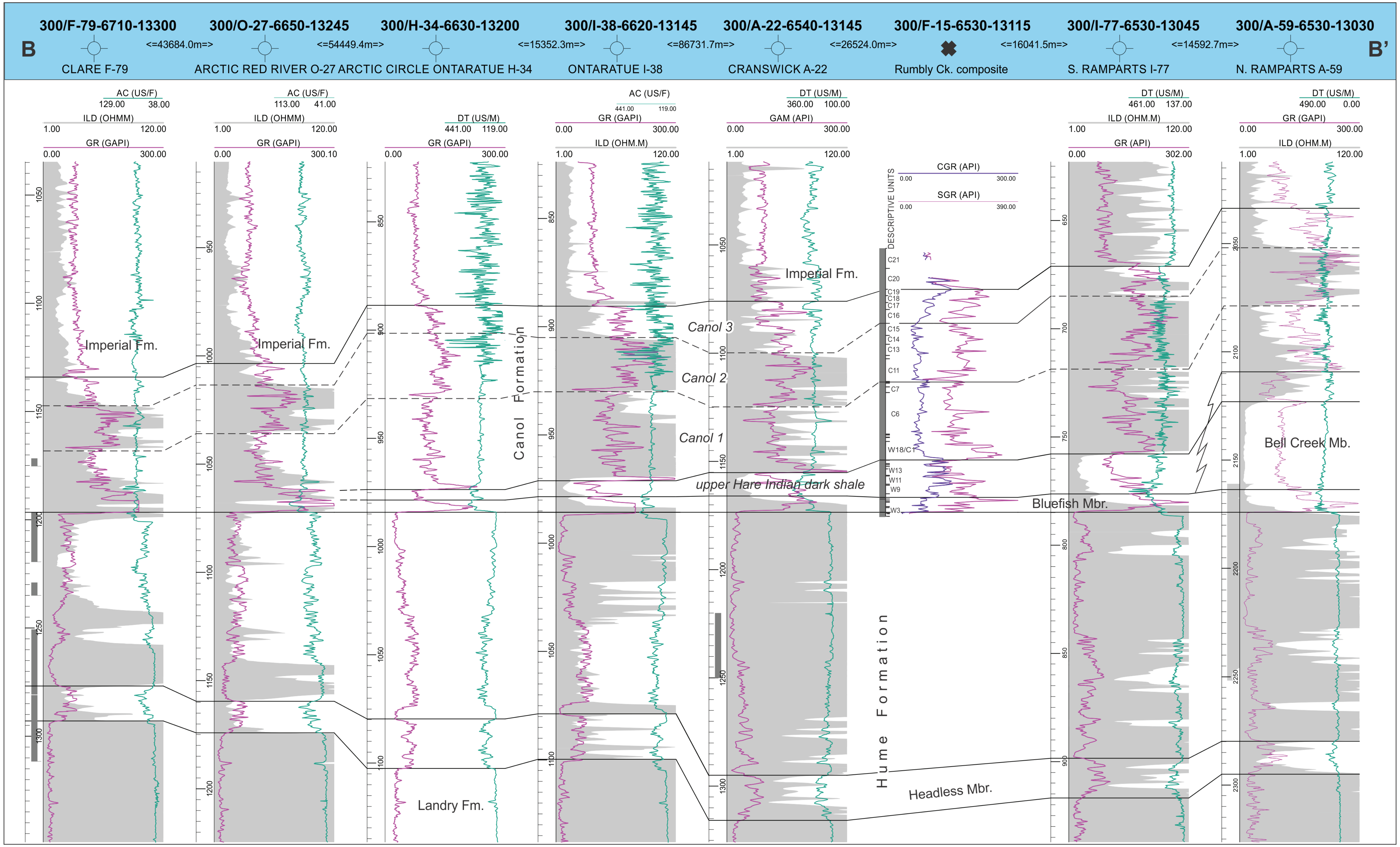

Figure 4. Cross-section B-B'. In the Rumbly Creek composite section, descriptive units W refer to the Rumbly Creek tributary waterfall (16KOA020), and descriptive units C refer to the Rumbly Creek Canol section (16KOA021)

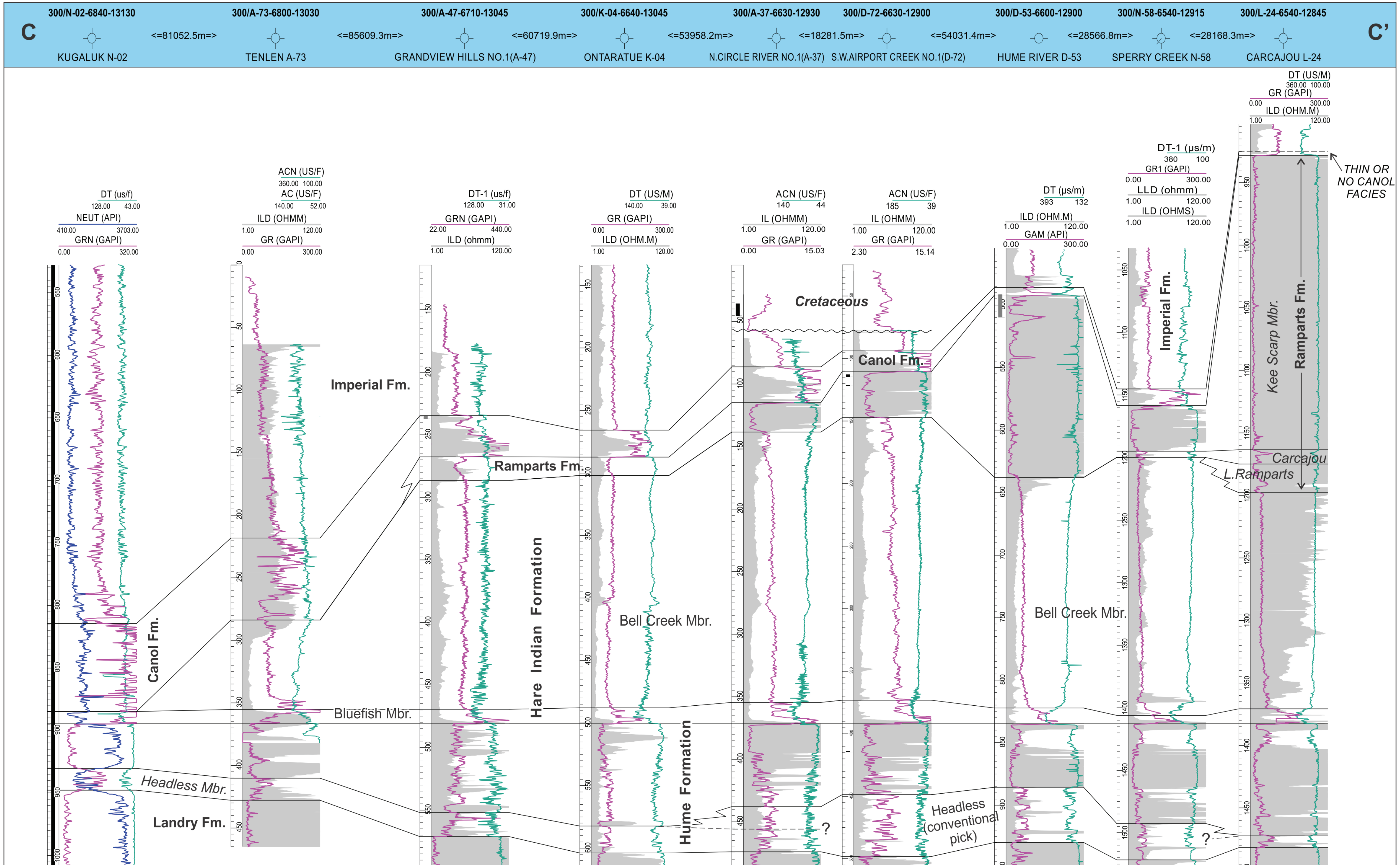

Figure 5. Cross-section C-C'

“Headless Member” of Hume Formation

The Hume Formation (Bassett, 1961) is a succession of medium-bedded variously argillaceous limestones and calcareous shales ranging between 90 and 140 m in thickness. The Hume is dominated by shallow to deep subtidal facies with rich assemblages of benthic fossils (Pugh, 1983, 1993; Norris, 1985; Morrow, 1991). Internal subdivisions of the Hume Formation were based on alternating strongly and weakly argillaceous intervals. Five informal members (three limestones and two intervening calcareous shales to limestones) have been traced by Tassonyi (1969) and Pugh (1983) in the subsurface of our study area. Later Pugh (1993) concluded that the upper shaly unit does not show wide traceability and proposed a three-fold subdivision with the lower prominently argillaceous and thin-bedded unit named the Headless Member, after its apparent formation-rank equivalent in the southern Mackenzie Mountains and the subsurface of the Great Slave Plain (Law, 1971; Mejer-Drees, 1993). In outcrops, the two-fold subdivision into lower more argillaceous, recessive member and upper somewhat cleaner and more resistant limestone was found most reliable (Morrow, 1991; Gal et al., 2009). Quotation marks are used further in the text for the “Headless Member” as its validity is being discussed.

Subsurface traceability of the basal argillaceous unit of Hume is frequently masked by development of marlstones with similar log response in the upper Hume. This masking is especially severe in the southern part of the study area, but traceability greatly improves northward across 66°30’ (Fig. 5). In some seismic transects, the “Headless Member” of the study area matches with a reflection marker separating Hume Formation from underlying shallow-water peritidal carbonates (MacLean, 2012). Minor black shale occurrences within “Headless” were reported from outcrops (Gal et al., 2009) and wells (Tassonyi, 1969; Pugh, 1983), including a distinct tongue of black pyritic shale in the basal part of Hume Formation intersected by Cranswick A-42 (Pugh, 1983).

This paper upgrades definition of the basal shaly unit of the Hume Formation by assigning reference sections in continuously cored intervals 930.6-949.1 m of Kugaluk N-02, 427.0-440.7 m of Crossley Lake South K-60, and 1276.8-1293.6 m of Clare F-79 (Figs. 4 and 5). The first two wells occur in the Anderson Plain north of 68º. Illustrated descriptions of these cores are available in Kabanov (2014, 2015) and Kabanov (2018a). The latter work reports formation tops for both wells. The Clare F-79 well is located in the study area (Fig. 4), and the core description of Hume interval is available in Kabanov and Borrero Gomez (In press). The character of the Headless Member is very similar in all three wells. It is a dolomitic calcareous shale to argillaceous limestone (*i.e.,* marlstone) characterized by suppressed bioturbation as opposed to thoroughly bioturbated limestones of the upper Hume and the uppermost few meters of the Landry. The unit is also characterized by rhythmic bedding interpreted as distal tempestites deposited during the “Headless highstand”. In Kugaluk N-02, elemental data with flat logs of Al-normalized Mo, V, Pb, Zn, Cu, Ni, and U indicates lack of authigenic enrichment of redox-sensitive trace metals (Kabanov, 2015). This indication of oxic sedimentary regime can be extrapolated to the majority of other sections where black shales are absent. Subsurface traceability of the basal shaly unit of Hume Formation within the study area is thus restricted to sections where the facies of the “Headless highstand” can be confidently separated, with available logs, from the overlying argillaceous facies of the upper Hume (Appendix 1). The name “Headless Member” is retained here to comply with conventional usage, but a new name may be proposed in future to refer to one of cored sections in geographic proximity and resolve inconsistencies with the facies character of the type Headless of the southern Mackenzie Corridor (Meijer Drees, 1993).

The Landry/Hume contact is a conformity described as sharp (Gal et al., 2009) or gradational with deepening-upward facies succession (Pugh, 1993; Kabanov, 2014; Kabanov et al., 2016b). Historical biostratigraphic age determinations used to place this contact at or close to the Emsian/Eifelian boundary (review in Kabanov, 2014), but recent developments, reflected in the lithostratigraphic chart on Figure 2, suggest younger Eifelian age in the *costatus* Zone (Uyeno et al., 2017; Gouwy, 2017).

Horn River Group in WOB area

Transition of the Horn River Group from BAT to WOB across 131° meridian is flagged by thinning of the grey-shale Bell Creek Member into black-shale strata of only 10-26 m in thickness, disappearance of Ramparts carbonates, and correspondent thickening of the Canol Formation (Fig. 3). Historically the overall recessive black-shale package developed between the Hume limestone and the basal Imperial sandstone to the west of BAT area was mapped as undivided Dhci unit at surface (Aitken et al., 1982) and the Horn River Formation in the subsurface (Pugh, 1983). The western edge of the WOB area is here delineated as approximating the 134ºN in the Peel Plateau where facies transitions characteristic of the ERT zone occur.

Hare Indian Formation

The Hare Indian Formation is traced only partly in wells located in the eastern side of the WOB zone between 131ºW and 132ºW and in a few wells to the west of 132º meridian (Figure 4; Appendix 1). A complete section of the Bluefish Member and the upper Hare Indian of the WOB zone was measured at the Rumbly Creek tributary waterfall section (16KOA-20) where the upper Hare Indian is composed of dark-colored fissile mudrocks of recessive to semi-resistant aspect, and containing authigenic dolostones (descriptive units 8-16; Kabanov et al., 2016c). The low-resistivity and lowered GR marker of the upper Hare Indian thins and fades westward precluding its prompt recognition to the west of 132º (e.g., South Peel D-64 and Weldon Creek O-65 wells). This poses a problem of separating the highly radioactive Bluefish Member from the similarly high gamma-ray base of Canol, although typical lower Bluefish facies of black calcareous tentaculitic mudrocks is routinely encountered in samples from the basal few meters of the black-shale package. The solution offered here is to abandon formal recognition of the Bluefish Member in wells where the upper Hare Indian cannot be readily traced. In this solution, the Hare Indian is considered entirely merging into the basal part of Canol between 132º and 133ºN (Fig. 2 Appendix 1, and isopach maps below).

Canol 1 (Lower Canol)

This informal unit encompasses a succession of pyritic siliceous shales and cherts typical of the Canol Formation with base defined by the high-gamma excursion sharply overlying the fissile shale of the upper Hare Indian (Figs. 3 and 4). The GR response of this basal Canol horizon is coupled with high resistivity. Where the upper Hare Indian marker is not developed, the high-gamma horizons of the Bluefish and the basal Canol merge in one unit with very high GR signature of 250-350 API (Figs. 3 and 4). Examples of this merged high-gamma horizon occur in Arctic Red River West G-55, Arctic Red River O-27, Arctic Red River YT C-60, Sainville River D-08, and Clare F-79 wells. A thin (< 2 m) horizon of receding resistivity in the middle of this merged high-gamma unit occurs in some wells indicating possible position of the offshore tail of the Hare Indian siliciclastic wedge (e.g., Arctic Red River O-27 and Clare F-79 on Fig. 4). The top of Canol 1 is traced by the moderately lowered GR (150-200 API) and a pronounced low-resistivity log marker.

In the Rumbly Creek Canol outcrop (16KOA021), this marker appears as slightly recessive black fissile shale containing at least one horizon of authigenic dolomite (descriptive units 7-10 of Kabanov et al., 2016b), which makes it very similar to the "Canyon Creek electric marker" of Tassonyi (1969) separating the Vermillion Creek and Dodo Canyon members in the SOB area (Kabanov and Gouwy, 2017). This marker in top of Canol 1 can be miscorrelated with the top of Hare Indian (e.g., Ontaratue I-38; Hogue and Gal, 2008).

Canol 2 (Middle Canol)

This informal unit is defined as an interval of moderately high GR (typically 200-250 API) and a distinctive elevated resistivity. In the Rumbly Creek Canol outcrop (16KOA021; Kabanov et al., 2016b), the Canol 2 is identified in descriptive units 11-15 composed of resistant, wall-forming bedded cherts and hard siliceous shales with some authigenic carbonates. This interval at Rumbly Creek has notably receding K-Th component of spectral GR indicating lean terrigenous content. The Canol 2 unit is very similar in stratigraphic position and physical properties to the Dodo Canyon Member of the SOB area (Kabanov and Gouwy, 2017). In some wells the Canol 2 unit shows two horizons of high GR (Figs. 3 and 4) that probably correlate with the anoxic horizons AH-III and AH-IV of the Dodo Canyon Member (Kabanov, 2019). The authors exert caution in naming this unit Dodo Canyon because the two are geographically separated by the BAT facies zone and until additional evidence in favor of their correlation arrives. Application of the name Vermillion Creek for the Canol 1 informal member has to be considered as well.

Canol 3 (Upper Canol)

This informal unit is traced as a transitional Canol-Imperial interval of black to dark grey shales characterized by high total GR that tends to fluctuate close to median values of Canol GR (Figs. 3 and 4). The resistivity tools provide the record of rocks increasingly conductive upwards due to increasing content of terrigenous fines. The Canol 3 unit is identified in the Rumbly Creek Canol outcrop (16KOA021) in descriptive units 15 (upper part) through 18 (Kabanov et al., 2016b). Assignment of this unit to either Canol or Imperial remains controversial. It was routinely placed in the Canol Formation in the subsurface correlations based on total GR (Hogue and Gal, 2008), and equivalent intervals of outcrops were referred to as the "upper recessive unit" of Canol Formation (Pyle et al., 2014). Pyle and Gal (2016) reconsidered assignment to the Imperial, which was followed by Kabanov et al. (2016b) in picking the top of Canol at Rumbly Creek. The way to resolve this nomenclatural controversy is seen in correlation with the type Canol section in its historical definitions (Bassett, 1961; Braun, 1966; W.C. Mackenzie in Lenz and Pedder, 1972), although complications are foreseen from rather compressed nature of the type Canol at Powell Creek (Fig. 3). Until this is achieved, the unit is being placed in the Canol to comply with the way it was previously picked in most wells of Peel Plain and Plateau (Appendix 1).

Canol Formation of ERT area

The sub-Imperial Middle-Upper Devonian strata of the Peel Plateau undergo prominent facies changes between 134ºN and the eastern erosional edge of the Richardson Anticlinorium: (1) the Hume Formation thickens, becomes shalier, and grades into the upper Road River Group where the Headless log marker is no longer traceable with any confidence; (2) the Canol Formation no longer retains resistivity and total gamma-ray signatures of its WOB subdivisions. Instead, some vintage borehole sections have deceptive total GR partly or entirely at the background of the underlying Road River and the overlying shale of the Imperial Formation.

Trail River outcrop

In the absence of cored well sections, the Trail River outcrop appears to be the best chance to understand the nature of the Canol in this area. This section recently received ample characterization with field descriptions, gamma spectrometry (SGR), elemental, pyrolysis, and carbon isotope geochemistry (Fraser, 2014; Hutchison and Fraser, 2015; Fraser and Hutchison, 2017). Proxies employed herewith to analyze the section (Fig. 6) have been applied to the Horn River Group and the Canol Formation in recent years (Pyle et al., 2014; Hutchison and Fraser, 2015; Pyle and Gal, 2016; Fraser and Hutchison, 2017; Kabanov and Gouwy, 2017; Kabanov, 2019). The geochemical proxies were calculated from data published by Fraser and Hutchison (2017). These data include total organic carbon content (TOC) identified with Rock-Eval pyrolysis, SiO_2, and parameters calculated from ICP-ES/MS data: terrigenous input proxy or the sum of four refractory oxides (TIP), proxy for the degree of pyritization (DOP_t), and proxies to authigenic U and Mo in the enrichment factor notation (EFU and EFMo; Kabanov, 2019). Respective formulas are given below. Lab protocols, discussion and rationale for the use of proxies and coefficients (such as PAAS) as applied to the studied rocks are available in aforementioned citations.

$$TIP[\%] = Al_2O_3[\%] + K_2O[\%] + Fe_2O_3[\%] + TiO_2[\%] \quad (1)$$

$$EF(\text{element } X) = (X/Al)_{sample} / (X/Al)_{PAAS} \quad (2)$$

where PAAS is the average post-Archean Australian shale value (Algeo and Tribovillard, 2009)

$$DOP_t = Fe_S / Fe_{tot} \quad (3)$$

where Fe_S is iron calculated from total sulphur (LECO combustion) based on the assumption that S is entirely bound in FeS_2; Fe_{tot} is total iron (Algeo and Maynard, 2004)

On Trail River, the thick (229 m) Canol Formation is very distinct with dominant rock types being bedded cherts and hard siliceous shales and characteristic presence of large dolomitic nodules in its upper part (Fraser, 2014; Hutchison and Fraser, 2015; Fraser and Hutchison, 2017). However, the total gamma-ray response is overall lower (< 250 gAPI) compared to the Canol of the WOB, BAT and SOB where it typically fluctuates between 200 and 350 gAPI (Fraser, 2014). Only the lower 1/3 of the Canol stands out by moderately elevated GR (20.0-95.0 m), whereas the upper part of Canol stays at the background of the underlying and overlying mudrocks, close to the median for the entire measured section. The GR of the uppermost Canol is even slightly lower than the total gamma response of the basal Imperial (Fraser, 2014).

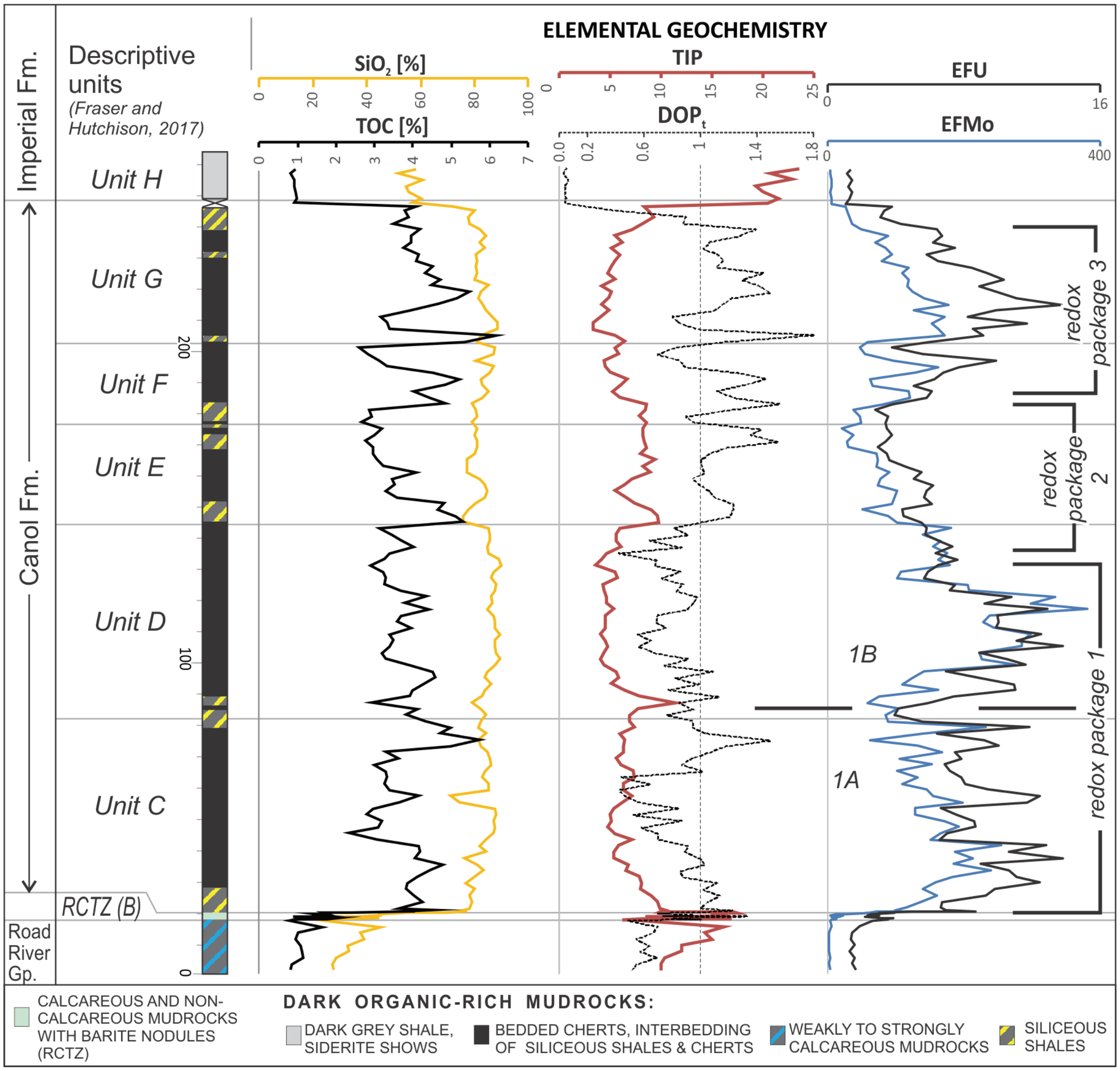

Figure 6. Litho- and chemostratigraphy of Trail River section (based on data from Fraser, 2014; Hutchison and Fraser, 2015; Fraser and Hutchison, 2017). Lithologic column is a simplified interpretation from observations of Fraser (2014). Descriptive units are lithochemozones defined by Fraser and Hutchison (2017). RCTZ is the Road River – Canol transitional zone *(ibid.) Redox packages* bracketed next to EFMo and EFU are recognized in this paper. Dashed vertical line traces 1.0 cutoff at DOP_t log.

Proxies other than total GR pronouncedly delineate the Canol Formation as an integral lithologic package with strongly attenuated siliciclastic components (receding K and Th components from SGR and TIP from major oxide data) and conversely strong enrichment in TOC (3.8% median) and pelagic silica (80-85% SiO_2). The Canol interval is dominated by anoxic facies as attested by elevated EFMo, EFU, and DOP_t (Fig. 6). The DOP_t is overall close to 1 (median 0.95 for the Canol interval) indicating that the bulk of detectable Fe and S are bound in FeS_2 minerals. The lower Canol (below 86 m) shows an overall excess of Fe ($DOP_t < 1$), whereas its upper part has a surplus of S ($DOP_t > 1$). This character does not project in other proxies and may have an explanation in either subtle primary difference in mineral composition between the upper and lower Canol or redistribution of Fe and S under surface weathering.

Further detail of the redox character with EFMo and EFU reveals three robust packages: the stronger anoxic *redox units 1 (*20-130 m) and *3* (184-240 m) and the intervening milder anoxic *redox unit 2* at 130-184 m (Fig. 6). The latter is characterized by the slightly elevated TIP, and lithologically it is expressed in greater proportion of fissile shales (Fraser, 2014). The *redox package 1* is further subdivided into *subunits 1A* and *1B* by a spike of TIP and the receding uranium proxies at 86.0 m (Fig. 6).

The described above trace – major element stratigraphy of the Canol at Trail River cannot be correlated with two well-studied sections Loon Creek O-06 and Little Bear N-09 of the SOB (Kabanov and Gouwy, 2017), neither does it show obvious traceability with the Rumbly Creek Canol section of WOB (Kabanov, 2019). This changing character of the Canol Formation deserves further scrutiny under the working hypothesis that across 134ºN siliciclastic provenance ultimately attenuates, leaving pelagic siliceous sediments beyond the reach of Laurentian clastics but maybe under the distal influence of the Ellesmerian-derived siliciclastic fines.

Subsurface traceability of Canol Formation augmented with XRF surveys

1. Technique

Improvement in picking the top and base of Canol in the subsurface of the ERT is achieved through XRF surveys of cutting samples with Brooker Tracer IV-SD tool. Samples from NEB collections curated at GSC-Calgary were measured in their original vials with GeoQuant Majors method. The instrument aperture is 10 mm in long axis so that 17 mm wide standard vials cover it completely. Caps in vials were replaced for measurement with Prolene® 4µm film having one of the highest photon transmittances relative to uncovered pressed pellets of rock reference materials: 67-71% for Mg, 80-86% for Al, 87-92% for Si (Hall et al., 2014). Difference in photon transmittance between Prolene-covered and uncovered samples decreases further with increasing atomic number (Hall et al., 2014). No vacuum or He has been applied between the detector and the rock container. Rough surfaces of rock chips and their random piling, along with uncontrollable presence of borehole cavings and particulate drilling-mud additives, discourage the quantification of elements that appear in < 1 wt. %.

2. Results

In ERT wells, the Canol interval is characterized by lowered Al_2O_3 and TIP, whereas SiO_2 stays elevated attesting to cherty lithology. The siliciclastics-bound elements show strong covariation with SiO_2 in the Imperial and weakened, sometimes no covariation in the Canol (Figs. 7-11). In the upper Canol, co-manifesting spikes of MgO and CaO, sometimes solo spikes of CaO, probably represent a signature of authigenic dolomite and calcite, respectively (Figs. 7-9). Pyritic aspect of the Canol expresses in the raised content of sulphur and its positive covariation with Fe. This character of Fe-S logs continues in many sections downhole into the Road River Group, which may be explained by a mixture of signal from caving Canol chips and Road River / Hume rocks (Figs. 7, 8, and 11). This S-Fe covariation is not characteristic of the Imperial Formation. The base of the Canol is usually distinct on borehole logs, which can be confirmed with XRF by major increase in CaO across the base of Canol. XRF logs appear especially useful to improve picks of Canol in wells that were abandoned without geophysical logging as exemplified by Peel River YT N-77 (Fig. 11).

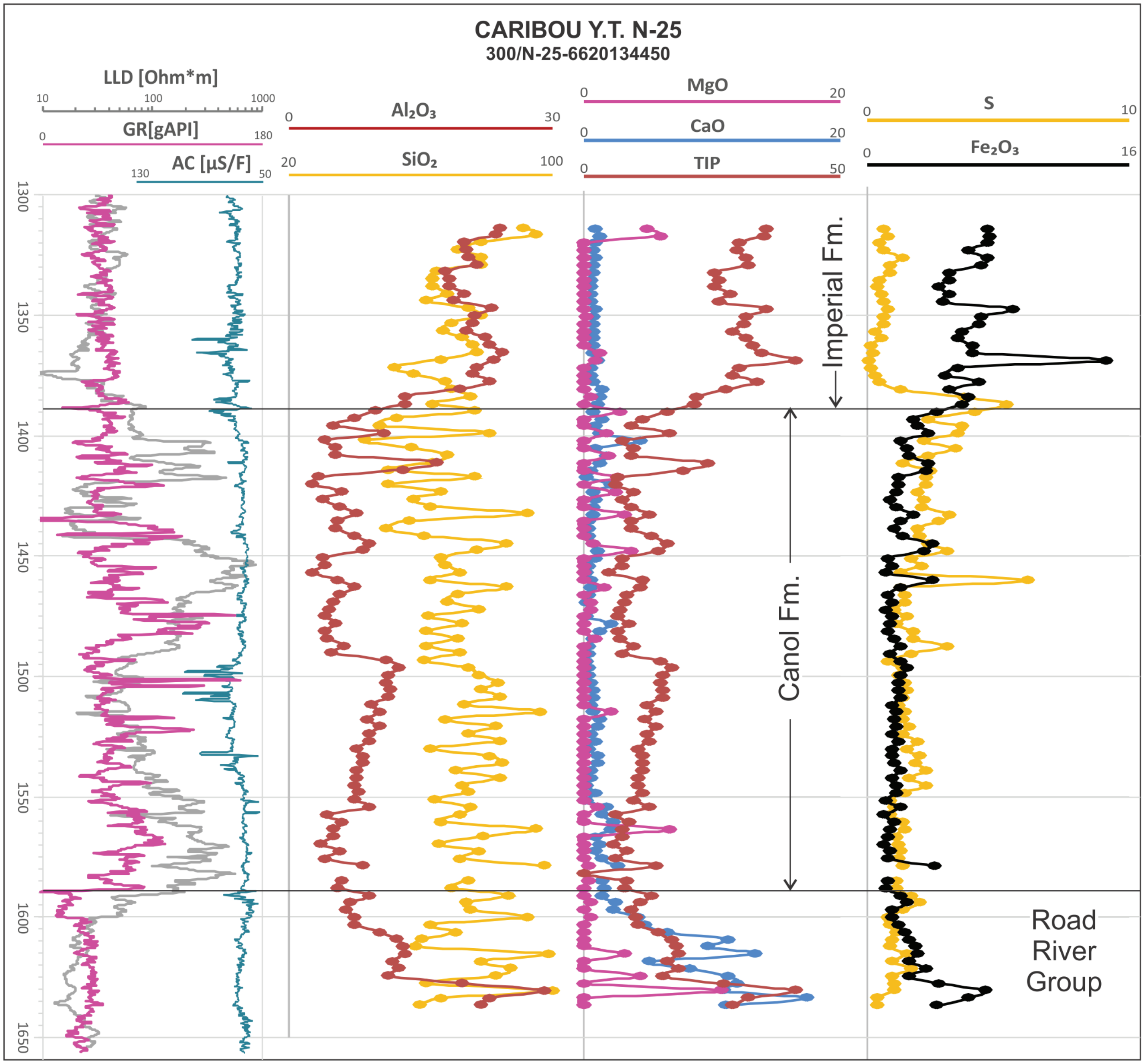

Figure 7. Borehole and XRF major oxide logs in Caribou YT N-25 well.

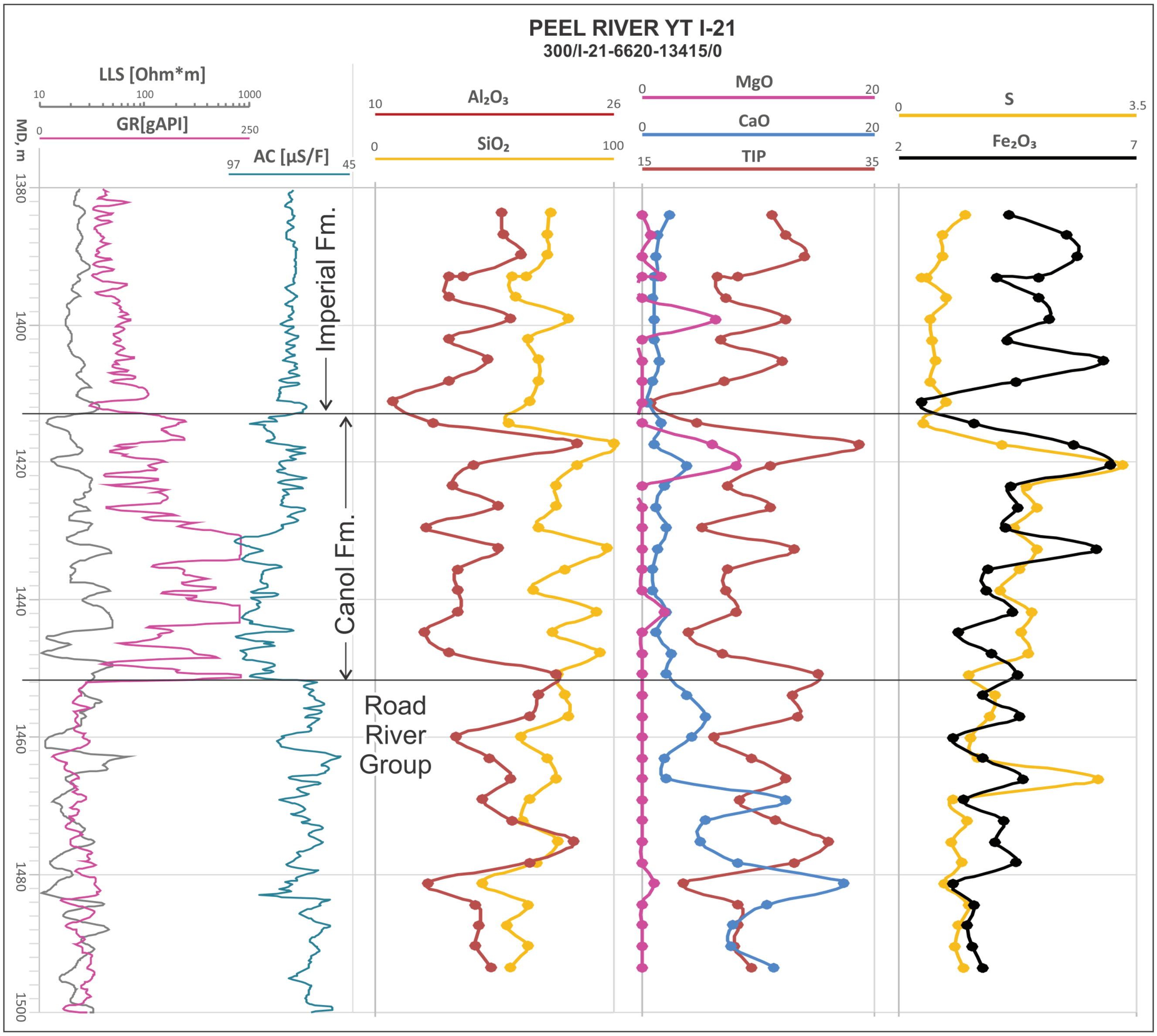

Figure 8. Borehole and XRF major oxide logs in Peel River YT I-21 well.

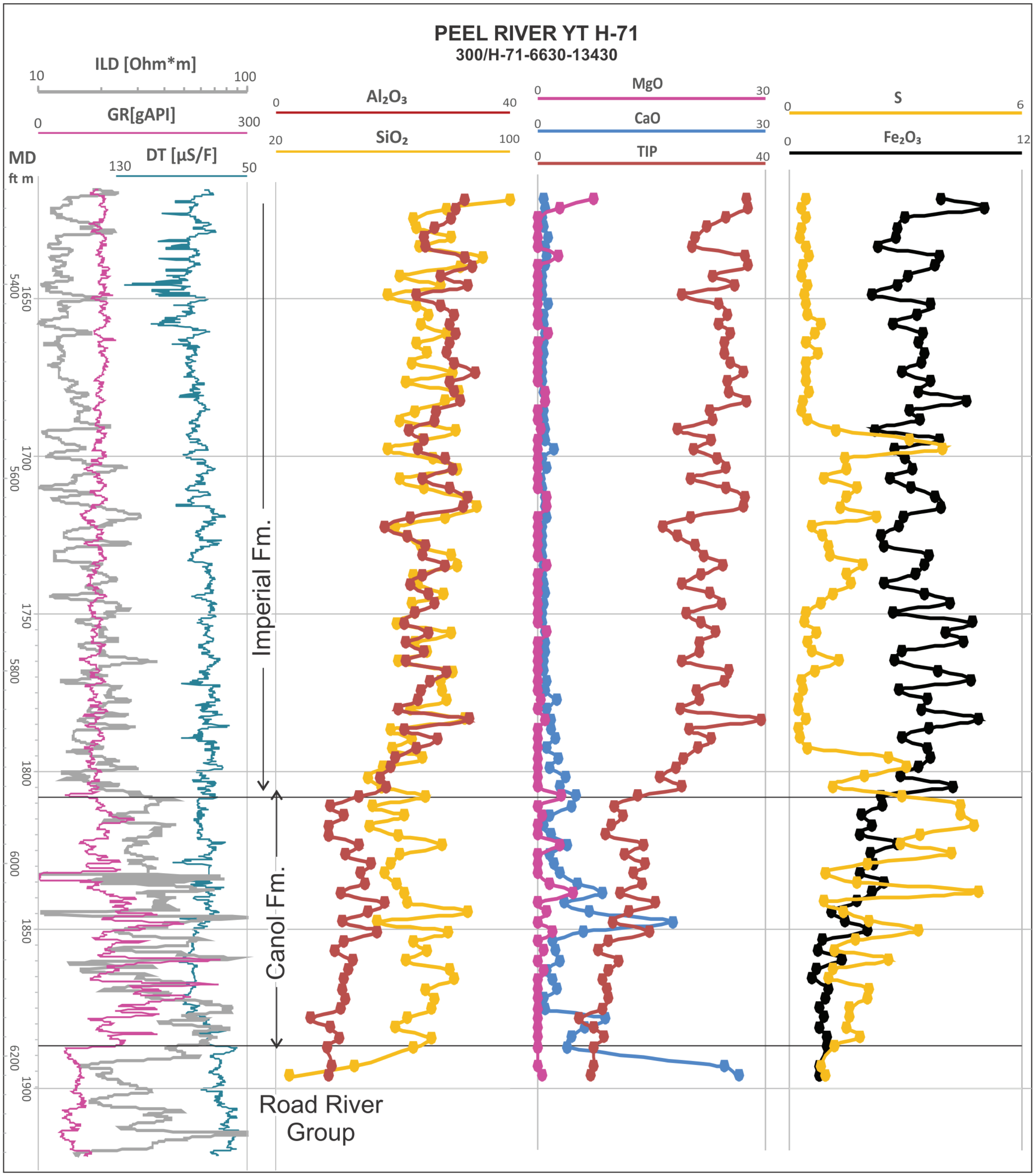

Figure 9. Borehole and XRF major oxide logs in Peel YT H-71 well.

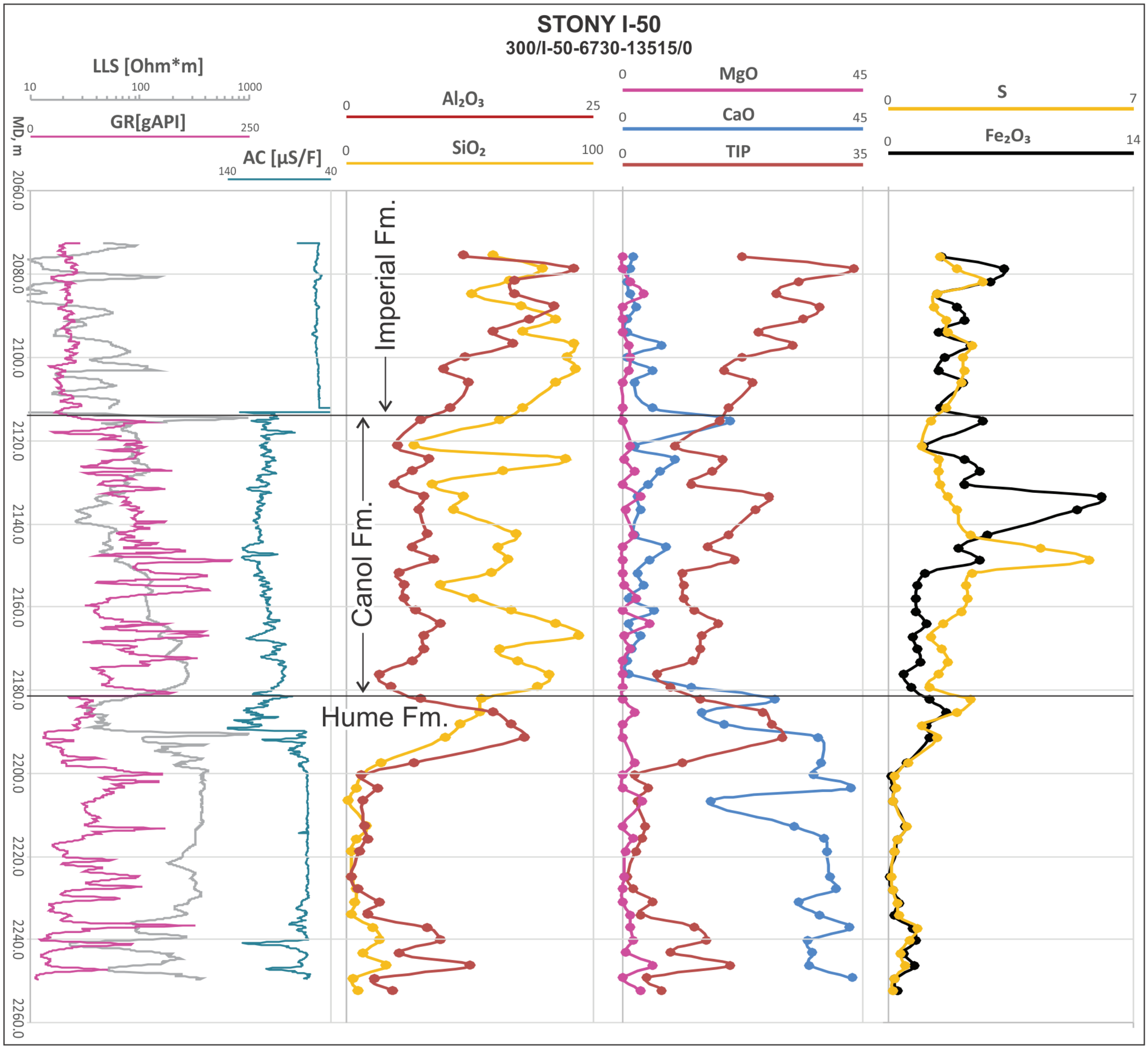

Figure 10. Borehole and XRF major oxide logs in Stony I-50 well.

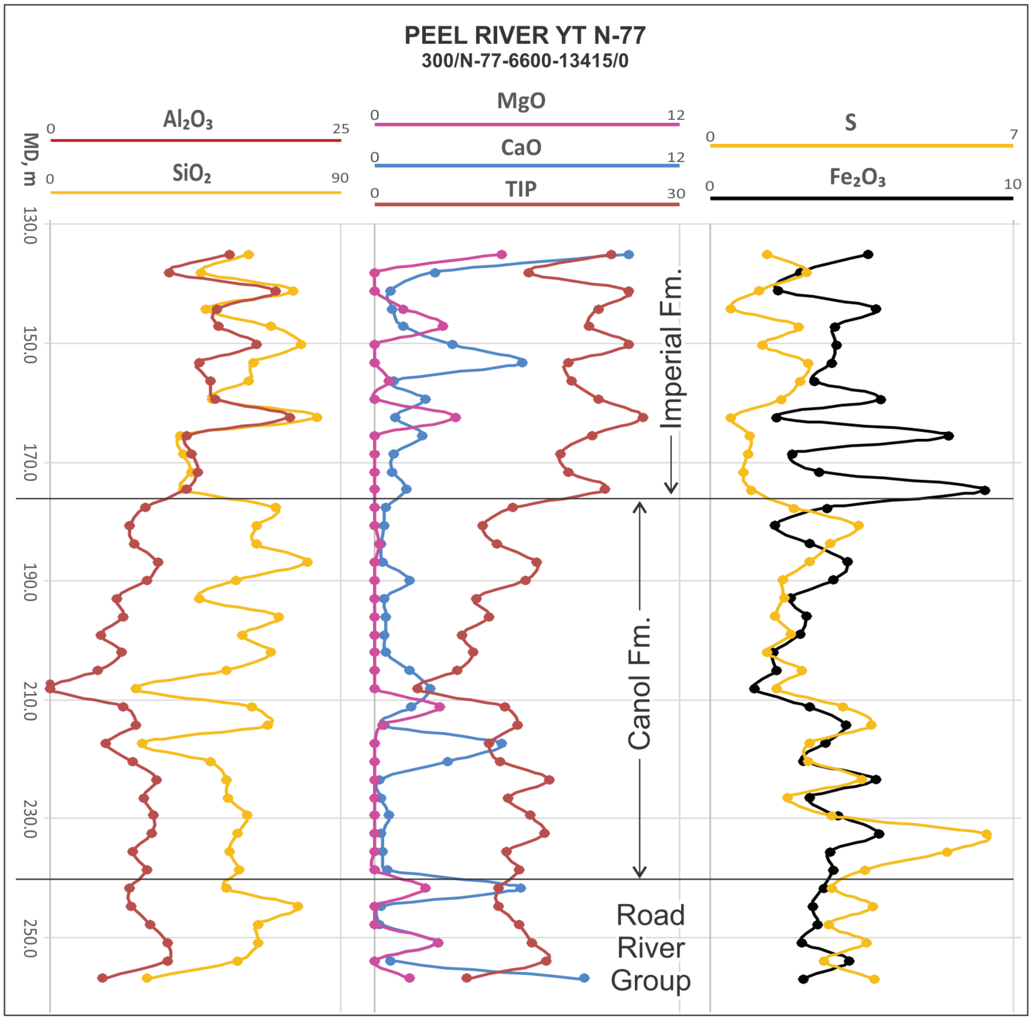

Figure 11. XRF major oxide logs in Peel River YT N-77 well. This well has not been logged with geophysical tools.

Givetian carbonate mounds?

The Canol section of Trail River H-37 stands out of all other subsurface sections of this facies zone. The high-GR Canol interval in Trail River H-37 is only 5.8 m thick (Fig. 12), overlain by Imperial shales with its typical high Al_2O_3 and TIP on XRF logs coupled with low-resistivity signature. Underneath this thin Canol, there is an interval of 131 m of clean benthic limestone with crinoid ossicles (sample descriptions in well file) characterized by low GR of 30-38 gAPI and high LLD of 300-3000 Ohm*m. These signatures are disparate from variously argillaceous limestones of the Hume Formation and calcareous shales of the upper Road River Group, but they are very similar to the log response of the Kee Scarp Member of the upper Ramparts (e.g., Hoosier Ridge N-22 well on Fig. 3). It is speculated that Trail River H-37 has penetrated the carbonate buildup similar in age and stratigraphic position to the Givetian Horn Plateau reef mounts of the Great Slave Plain (Meijer Drees, 1993). No other buildups are intersected by other ERT wells due to scarce coverage of exploration drilling, but at larger geographic scale this section is not unique. Similar section with thick carbonates biostratigraphically dated as Givetian, exhibiting mud mound fabrics in a short core, and overlain by a compressed, atypical section of basinal mudrocks, was intersected by Parker River J-72 well of northeastern Banks Island (Kabanov, 2018). The pronouncedly uneven surface of the Devonian carbonates and inversely fluctuating thickness of overlying black shales of the

Kitson Formation and its equivalents is traced further north across Parry Islands, although these carbonates seem to be older than Givetian (Embry and Klovan, 1976; Harrison, 1995; Harrison and Brent, 2005).

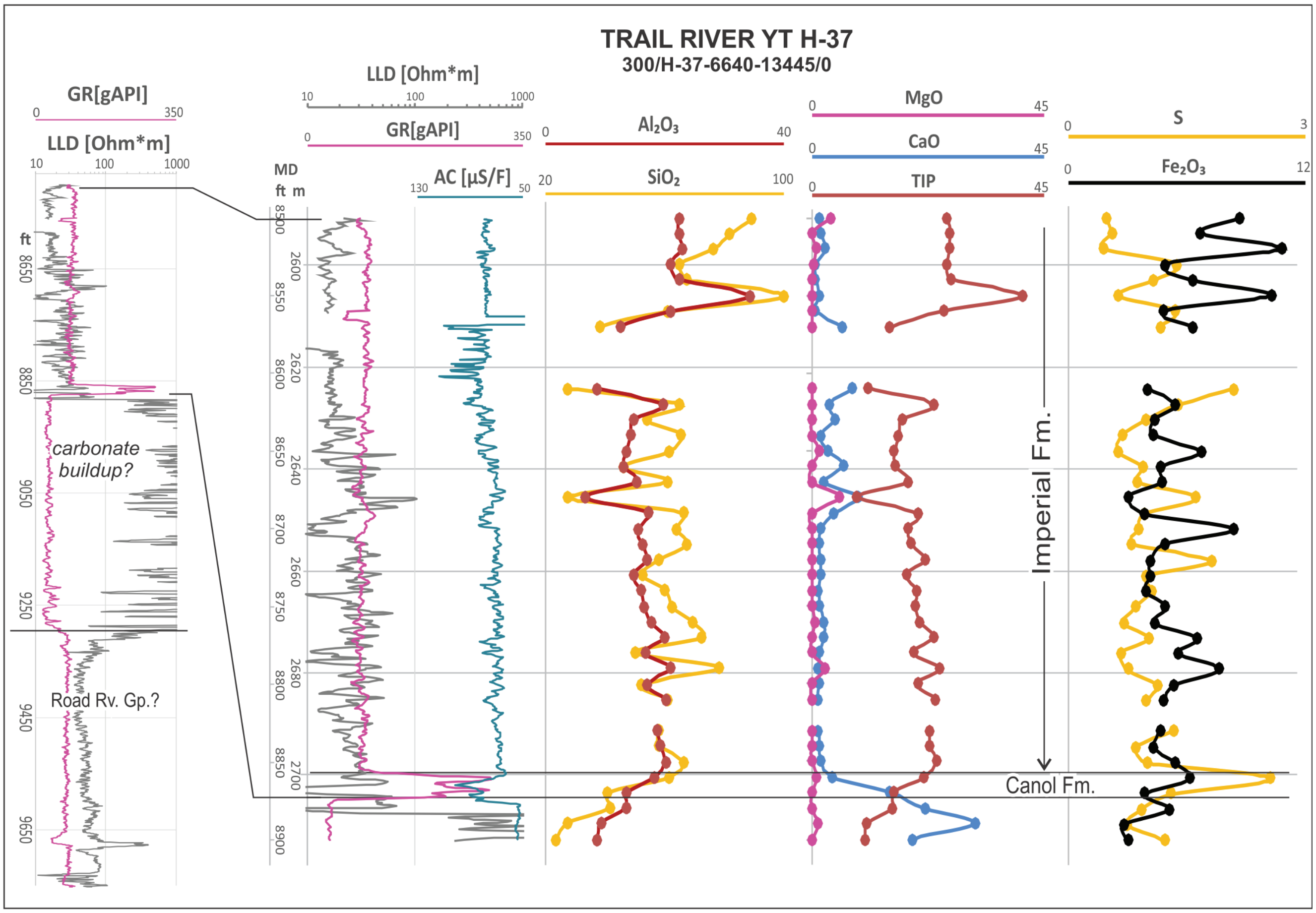

Figure 12. Borehole and XRF major oxide logs of the Canol and underlying carbonate strata in Trail River YT H-37 well.

ISOPACH AND FORMATION-TOP DEPTH MAPS

TVT isopach and formation-top depth maps (Figs. 13-23) were modelled from picks of lithostratigraphic units from 121 wells located within NTS map areas 106F,G,H,I,J,K,L,M,N,O,P and 96C,D,E (Fig. 1 and Table 1). The contours and isopach classes were interpolated using the ArcGIS Geostatistical Analyst wizard™. Empirical Bayesian Kriging prediction models were used to create the formation-top depths and the isopach classes.

There is no well data in proximity to the western extension of the facies limit between SOB and BAT in the Mackenzie Valley (Fig. 1A). In this area, the SOB/BAT limit was drawn based on outcrop information measured along the Canyon Ranges of the Mackenzie Mountains (Pyle et al., 2014), although questions in interpretation and correlation in these descriptions cannot be considered resolved. Improvement in isopach models is achieved though addition of *interpolation points* that assign thicknesses of Ramparts, Canol, and hare Indian formations on both sides of the limit (Figs. 15-20) based on best guess from nearest well data points. *Wells with no values assigned* on Figures 13-23 denote thicknesses or depths that were not used in a model for being truncated partly or completely by post-Devonian erosion or if the well did not penetrate to the top (in case of a depth model) or reached TD above the base of the lithostratigraphic unit (in isopach models).

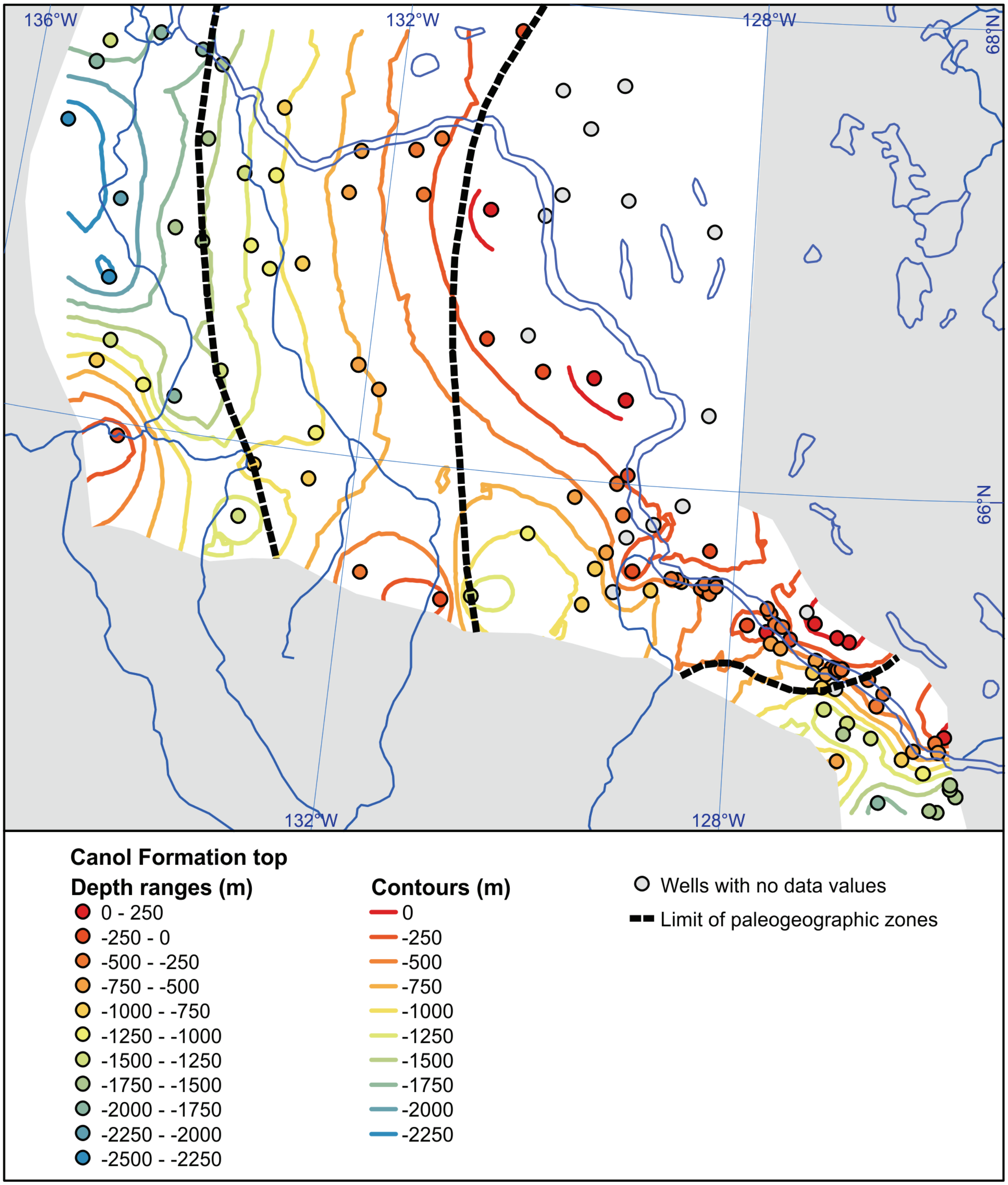

Figure 13. Top of Canol Formation

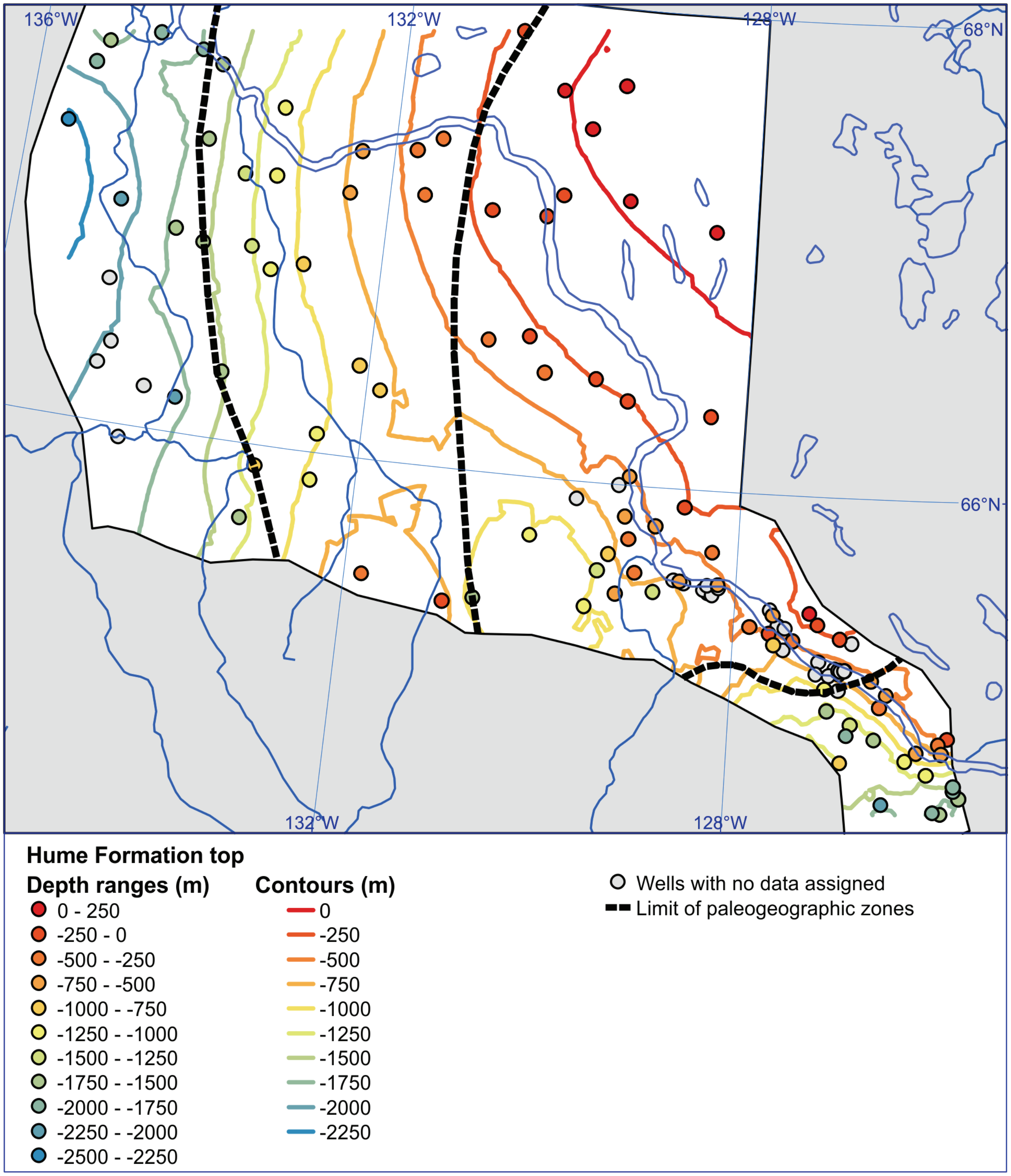

Figure 14. Top of Hume Formation

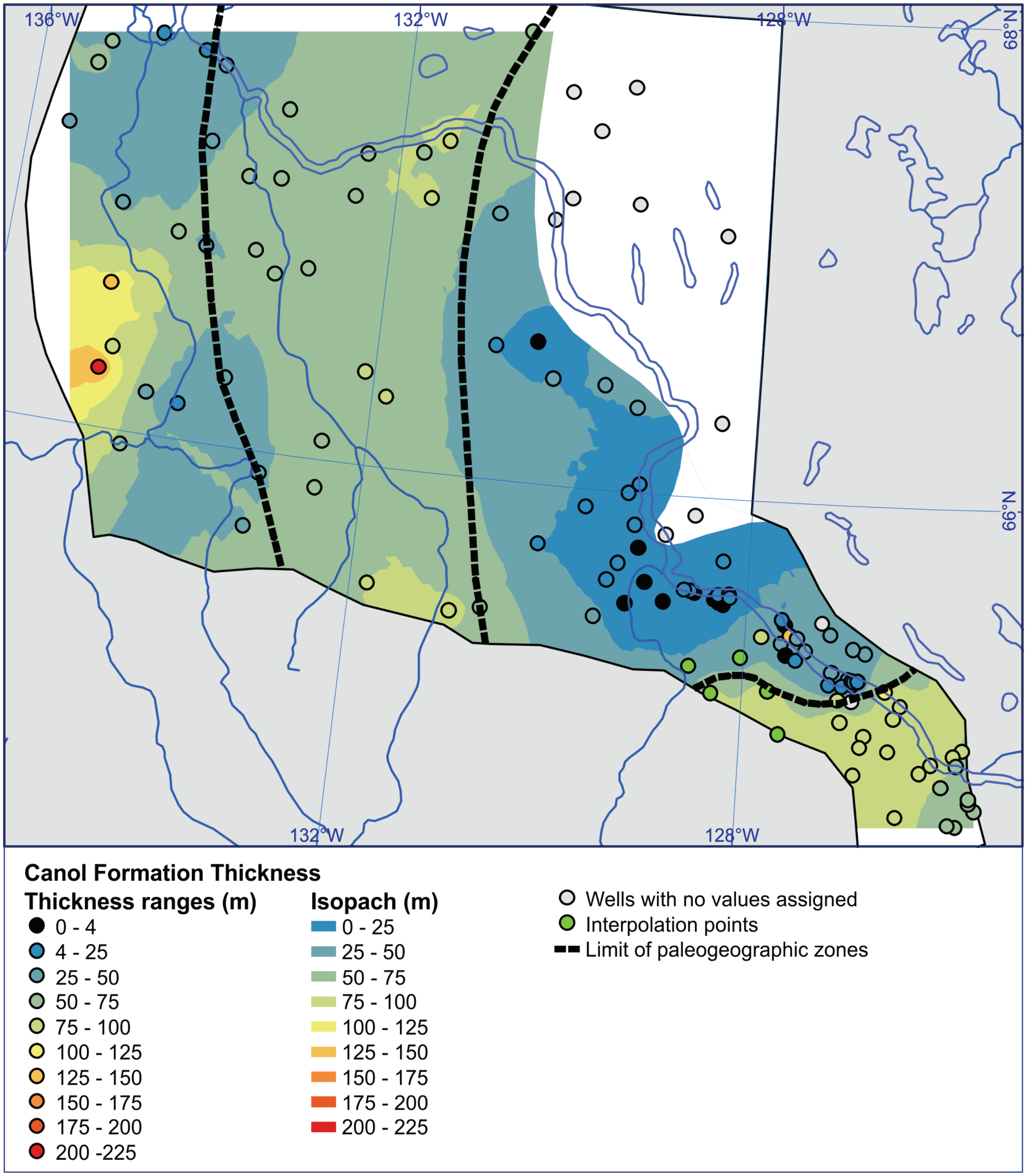

Figure 15. TVT isopach map of Canol Formation

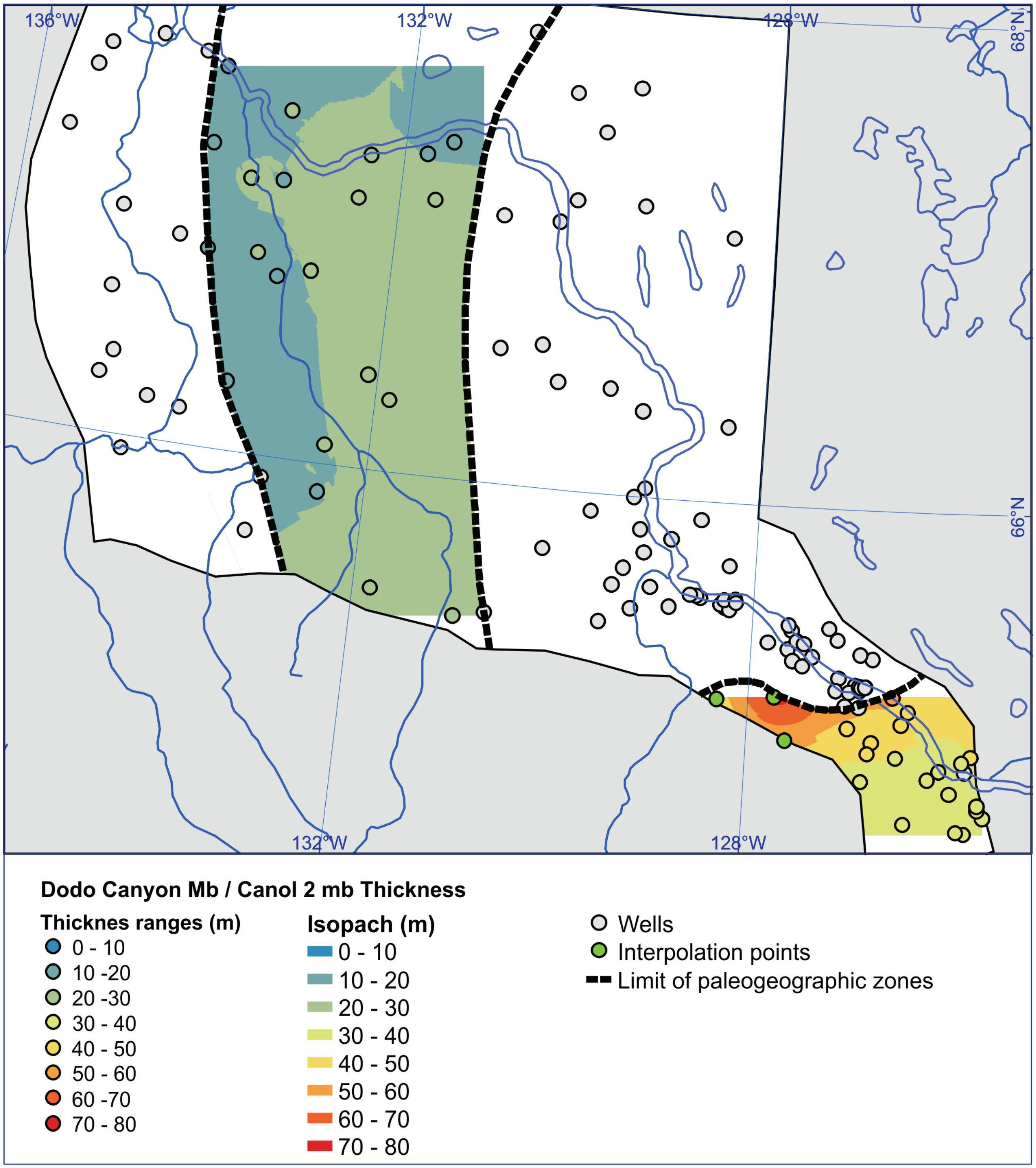

Figure 16. TVT isopach map of the Dodo Canyon Member (SOB area) and the Canol 2 informal member (WOB area)

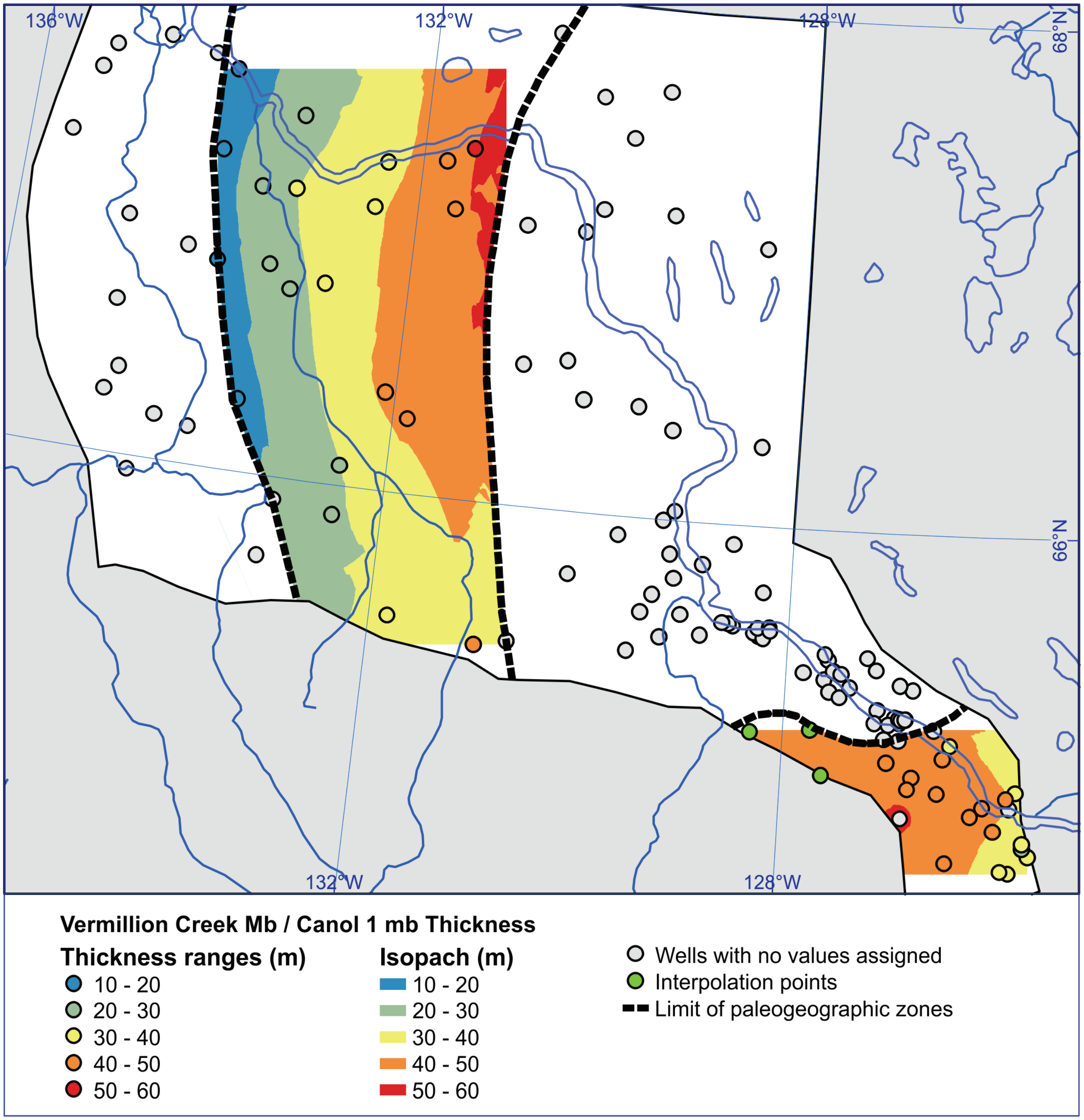

Figure 17. TVT isopach map of the Vermillion Creek Member (SOB area) and the Canol 1 informal member (WOB area)

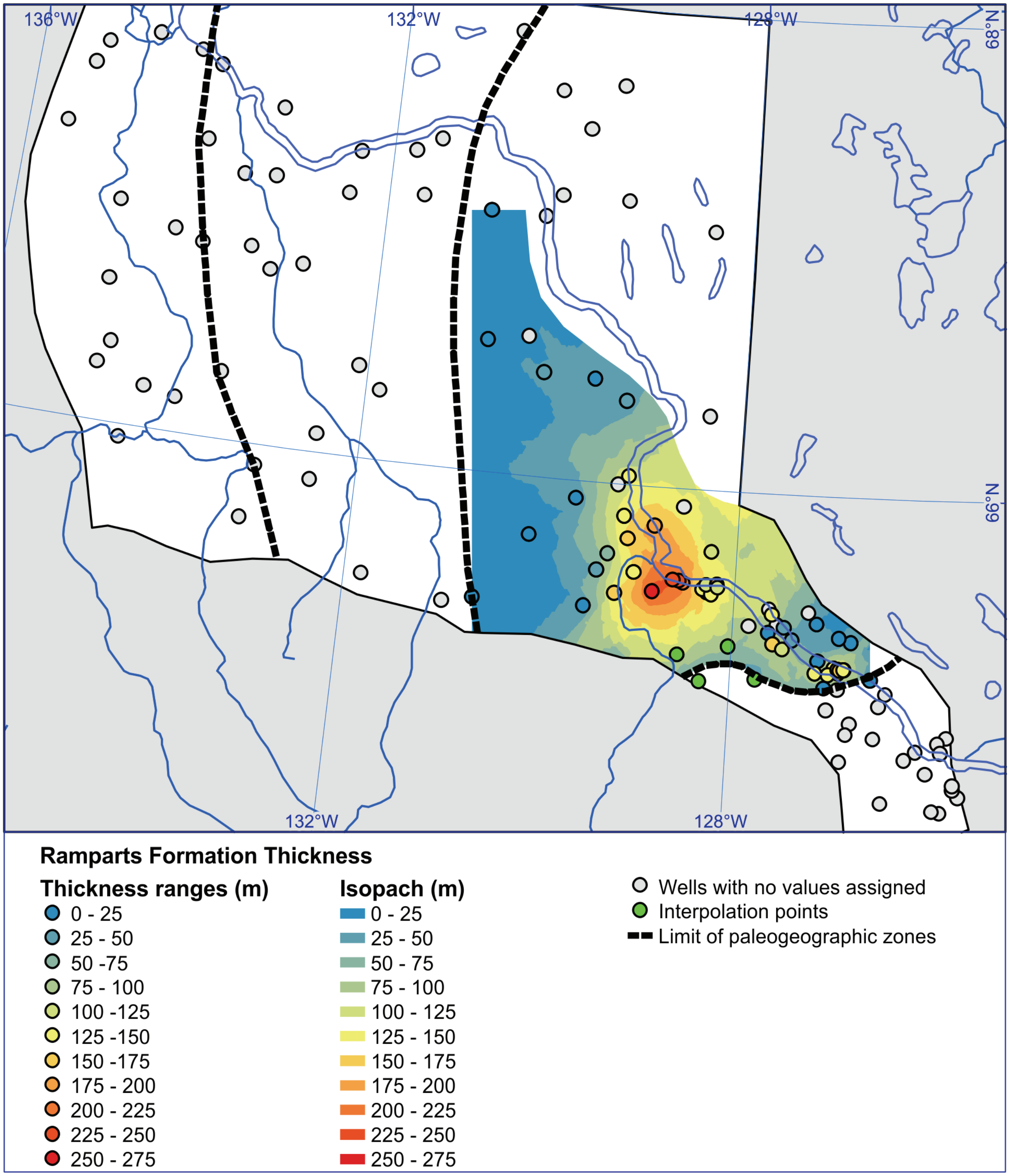

Figure 18. TVT isopach map of the Ramparts Formation

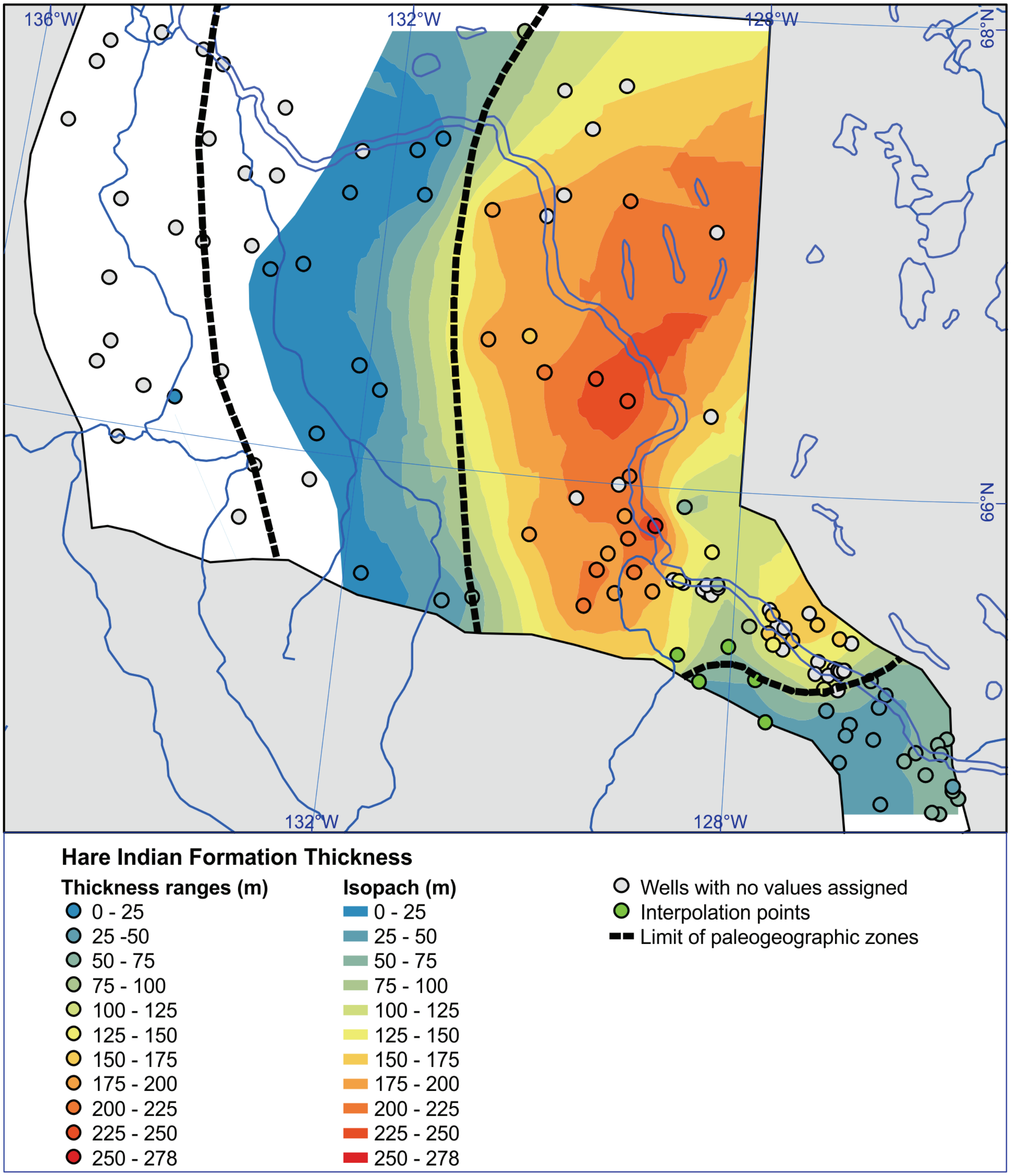

Figure 19. TVT isopach map of the Hare Indian Formation

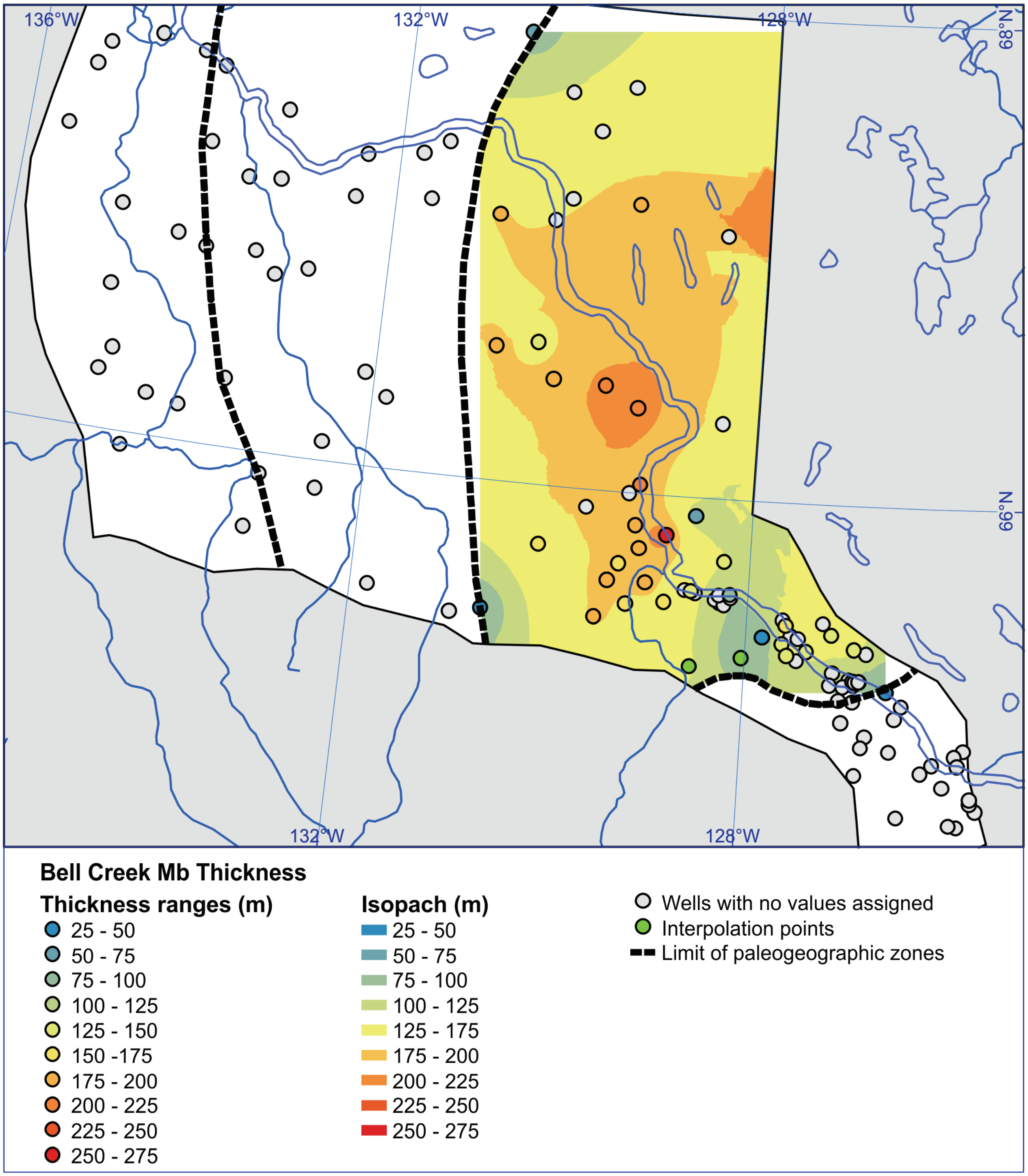

Figure 20. TVT isopach map of the Bell Creek Member of the Hare Indian Formation

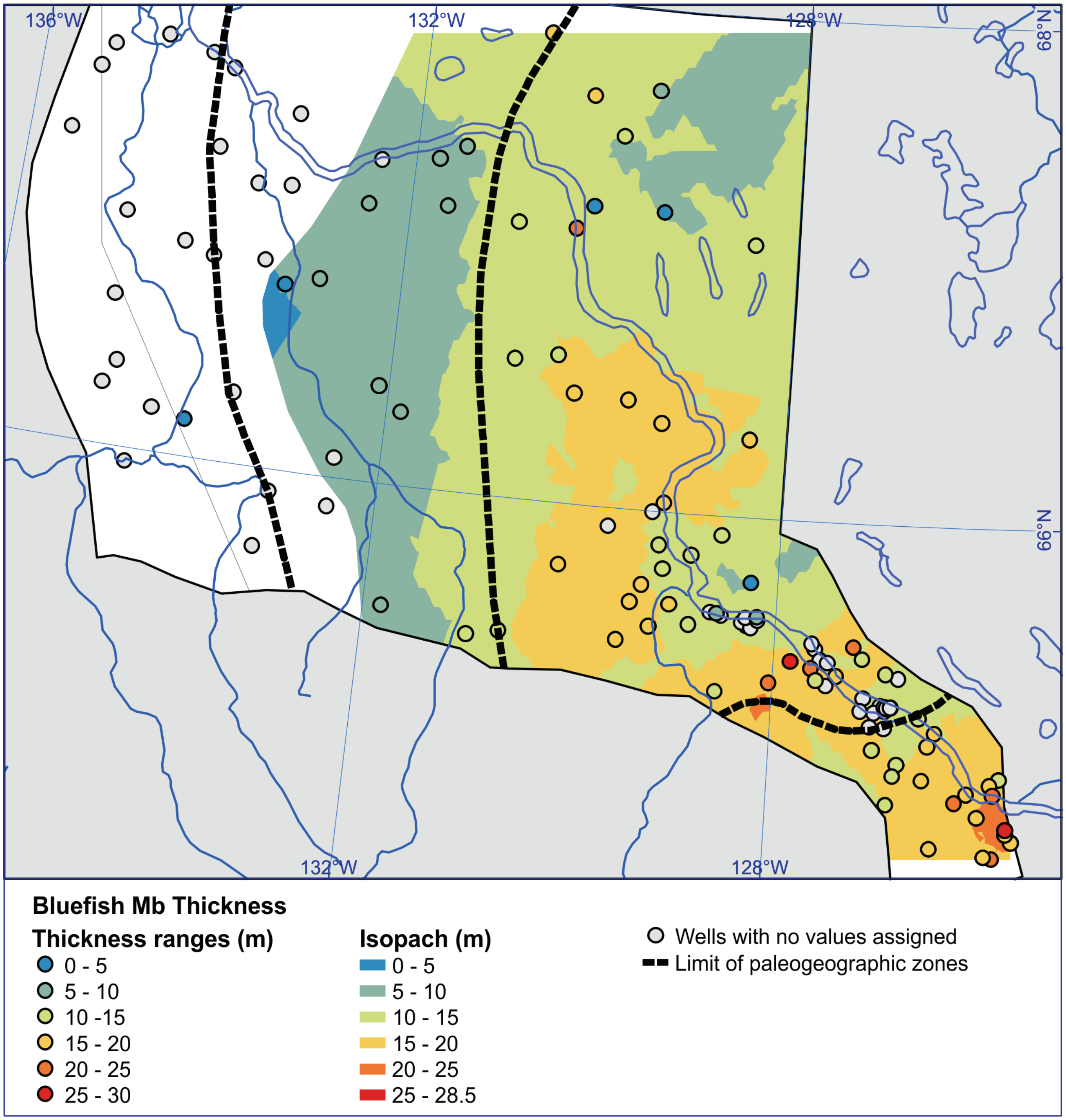

Figure 21. TVT isopach map of the Bluefish Member of the Hare Indian Formation

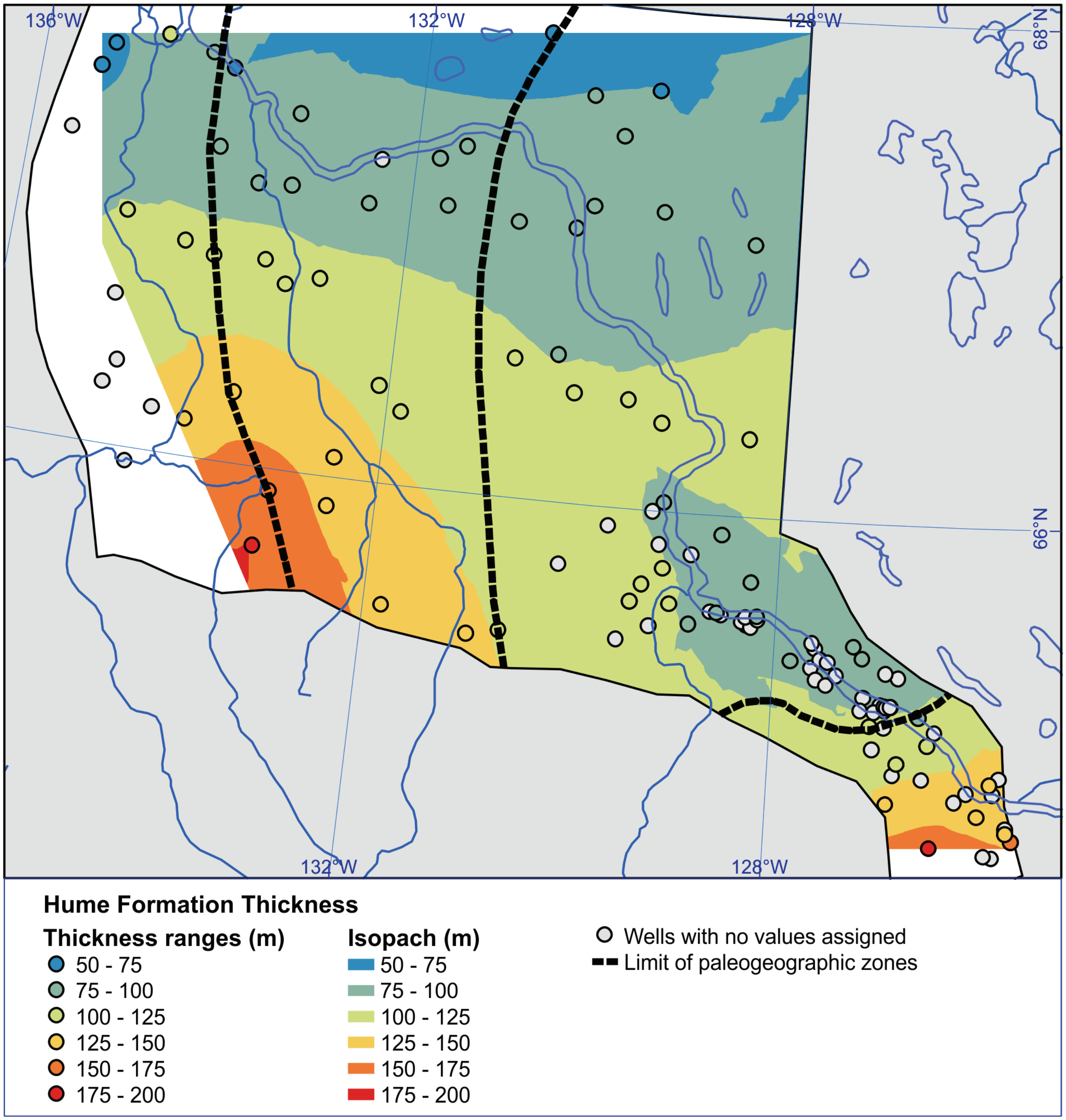

Figure 22. TVT isopach map of the Hume Formation

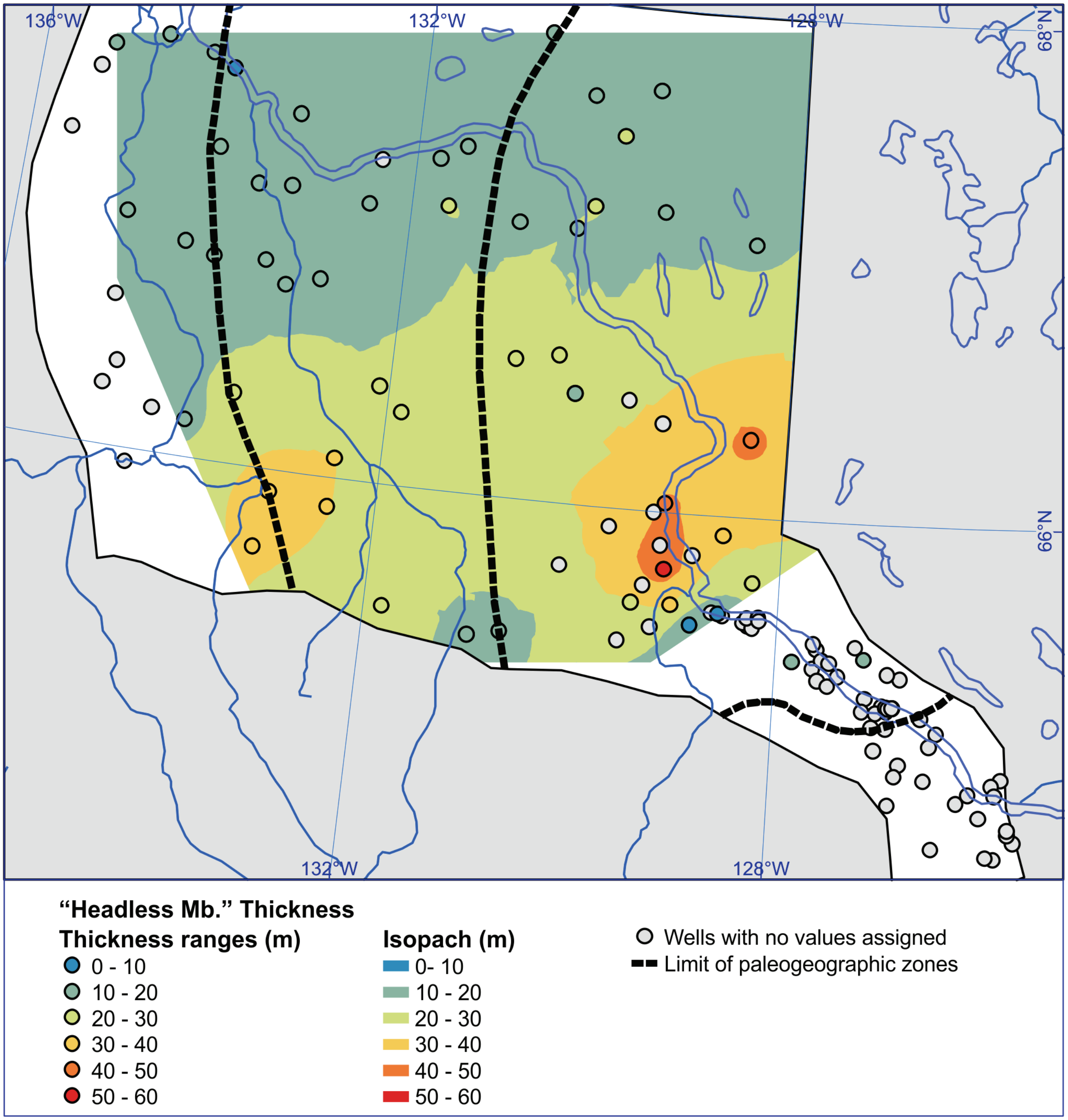

Figure 23. TVT isopach map of the Headless Member of the Hume Formation

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