TOAD FORMATION (MONTNEY AND DOIG EQUIVALENT) IN THE NORTHWESTERN HALFWAY RIVER MAP AREA, BRITISH COLUMBIA (NTS 094B/14)

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ABSTRACT

Approximately 600 m of calcareous siltstone and fine sandstone of the Toad Formation (Montney and Doig equivalent strata) were measured in a section immediately south of Halfway River, within the northwestern part of the Mount Laurier map area (NTS 094B/14). Spectral gamma-ray measurements were obtained every metre throughout the section. In addition, semicontinuous chip samples were collected every 5 m for Rock-Eval analysis together with 11 representative samples across the section for thermal maturation determination via reflective microscopy.

The basal part of the Toad Formation is not exposed in this area. The Toad Formation comprises a coarsening-upward succession of distal turbidites, which become more proximal in the uppermost part of the succession. The lower 140 m of the measured section is dominated by uniform dark, calcareous to dolomitic carbonaceous siltstone, which locally displays faint laminar bedforms. This sequence is followed by a repetitive section some 200 m thick, containing metre-thick beds of slightly coarser and cleaner dolomitic siltstone displaying laminar and graded bedding. The upper 250 m of the section records a greater influx of coarser siltstone with a corresponding decrease in carbonaceous content. Thinly laminated and graded sequences of coarse siltstone to very fine sandstone are common, together with thicker metre-thick successions of cleaner fine sandstone containing current ripples and soft sediment deformation. These increase in abundance up-section until the base of the Liard Formation, designated by continuous thinly to thickly bedded fine–medium sandstone. The base of the Liard Formation also corresponds to the first appearance of bioturbation.

Thin-section examination of representative samples indicates that the darker siltstone samples are rich in carbonate, containing on average 30% carbonate. Siltstone and fine sandstone are dominated by angular to semirounded quartz with up to 20% feldspar (potassium feldspar and plagioclase) followed by mica, chert and minor mafic minerals (hornblende).

Comparisons of gamma-ray patterns obtained from the measured section with subsurface sections immediately to the east suggest correlation of these rocks with the Montney and Doig formations. This is based primarily on the presence of a relatively more radioactive section some 150 m thick, which is correlated with the Doig phosphate zone. The succeeding section displays a pattern consistent with the upper Doig Formation.

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Key Words: British Columbia, Foothills, Halfway River, 094B/14, Triassic, Toad Formation, Liard Formation, Montney Formaton, Doig Formation, stratigraphy, measured section, spectral gamma ray, Rock-Eval, hydrocarbons, correlation.

INTRODUCTION

The Montney Formation shale gas play has been described as one of the most significant unconventional gas resource plays in North America (Canadian Discovery Digest, 2008). Total petroleum and natural gas tenure sales in the Montney play area totalled $1.74 billion for 2008 and 2009, and daily gas production from this play in 2009 averaged 8.5 × 10^6 m^3/day (300 mm cf/d). In addition, 2009 tenure sales show interest in the play area extending to the northwest and into the outer foothills.

In light of this high level of interest, the Resource Development and Geoscience Branch of the BC Ministry of Energy, Mines and Petroleum Resources (BCMEMPR), in cooperation with the Geological Survey of Canada, the University of British Columbia and the University of Alberta, undertook a detailed examination of Montney and Doig formation equivalent strata (Toad Formation) within the western foothills of the northern Halfway River map area (NTS 094B/14) with the goal of better understanding this sequence and assisting with its regional characterization. This work builds on recent mapping by the senior author within the Foothills of the Halfway River map area (Ferri, 2009a, b) and on regional thematic studies of Triassic rocks by the University of Alberta and the Geological Survey of Canada (see Zonneveld and Moslow, 2005; Orchard and Zonneveld, 2009). In addition, this new data will form part of a PhD thesis recently started at the University of British Columbia that will examine provenance of clastic detritus within Early and Middle Triassic rocks of the Western Canada Sedimentary Basin (Golding et al., 2010).

The measured section was previously described by Gibson (1975) and was chosen because it affords one of the most complete sequences of the Toad Formation in this area. In addition to a detailed lithological description, samples were taken to determinate organic carbon content (using Rock-Eval), level of thermal maturation (reflectance microscopy), biostratigraphy (micro- and macrofossils) and detrital zircon geochronology (provenance studies). In addition, several thin sections were made for a more detailed examination of clast compositions.

This report summarizes the preliminary findings from the 2009 field season. A more detailed lithological log, together with full descriptions and analytical data (Rock-Eval, thermal maturity, gamma ray) will be available as a BCMEMPR open file later in 2010. Detrital zircon geochronology, biostratigraphy and micropaleontology are described in more detail by Golding et al. (2010), as they form the basis of the ongoing PhD thesis.

LOCATION

The measured section is located within the northern part of NTS map area 094B/14 and a few kilometres south of the Halfway River, near McQue Flats (Figure 1). It is found along a gulley, incised on the west-facing side of a north-trending ridge. Access to the section was provided through the establishment of a helicopter fly camp within a cirque approximately 1 km to the east.

GENERAL GEOLOGY

The section lies along the western margin of the Foothills subprovince of the Foreland Belt (Wheeler and McFeely, 1991), approximately 7 km west of the northern tip of the Carbon Fault (Figures 2, 3). Strata in this area dip moderately to steeply eastward and comprise the western limb of Fiddes Syncline, which is a tight, northwest-trending chevron to box-like fold structure. Units exposed on this limb encompass the Early Carboniferous Prophet Formation to the Early Cretaceous Gething Formation and include Triassic strata over 1700 m thick. The entire Triassic sequence is represented in this section and belongs to the Early Triassic Grayling Formation, the Early–Middle Triassic Toad Formation, the Middle–Late Triassic Liard Formation and the Late Triassic Charlie Lake, Baldonnel and Pardonet formations (Figures 4, 5). A more detailed description of these units and structures can be found in Thompson (1989) and Ferri (2009a).

Due to its thinness (~35 m) and recessive rock types (shale and siltstone), the Grayling Formation is typically poorly exposed and commonly grouped with the Toad Formation. The lower 200 m of the Toad Formation (including the Grayling Formation) within the study area is covered by scree. Structural sections suggest that there is upward of 850 m of the Toad and Grayling formations along the western limb of the Fiddes syncline.

The Toad and Grayling formations are equivalent to the Montney Formation and lower parts of the Doig Formation in the subsurface (Figure 6), and correlations indicate a westward-thickening wedge. West of the study area, across the large fold cored by Carboniferous strata, only a few hundreds of metres of the Toad and Grayling formations are present below the Ludington Formation, the latter of which represents the westward deeper-water equivalents of the Charlie Lake and Baldonnel formations (Gibson, 1975; Zonneveld, 2008). This implies either the nondeposition or removal of the Liard Formation some 10 km west of the study area. Alternatively, Gibson (1991) suggests that the Ludington Formation also transitions into the Liard Formation, although fossil and depositional relationships are inconclusive.

DETAILED SECTION

Approximately 609 m of siltstone and fine sandstone were measured as part of the Toad Formation (Figures 5, 7). The base of the unit was not observed and structural sections suggest that there is another 200–250 m of the Toad Formation to the top of the Carboniferous. The base of the overlying Liard Formation was placed where moderately to thickly bedded, very fine sandstone comprised more than 90% of the section and corresponded to the start of a section of resistive, relatively clean sandstone some 100 m thick (Figures 8, 9). This is followed by a horizon of siltstone and very fine sandstone similar to Toad Formation rock types approximately 50 m thick, which is abruptly followed by Liard Formation sandstone several hundreds of metres

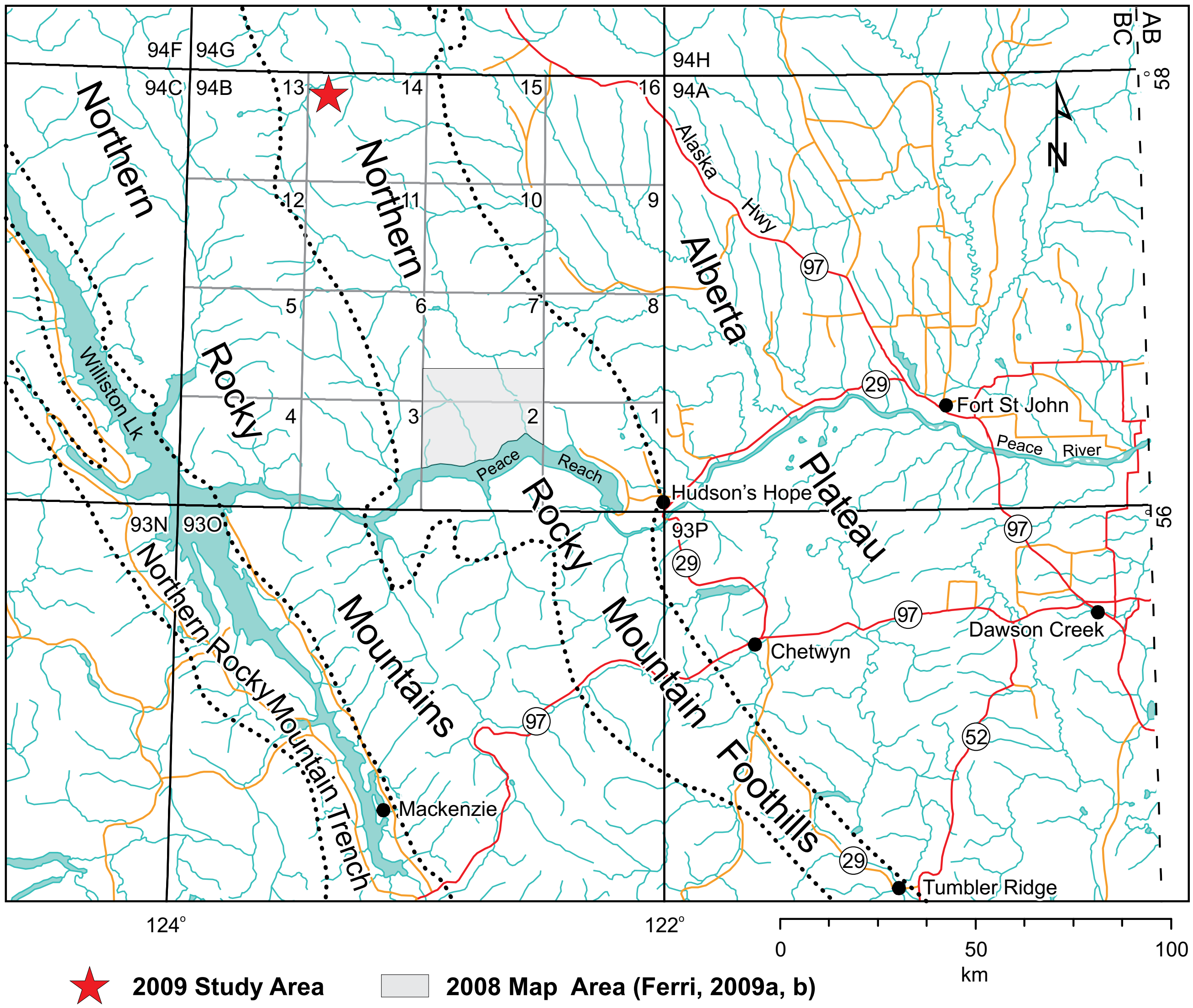

Figure 1. Location of the study area in northeast British Columbia.

thick. Abundant bioclastic debris dominated by terebratulid brachiopods (*Aulacothyroides liardensis*) and lesser spiriferid brachiopods (*Spiriferina borealis*) and ammonoids were found in scree at the foot of the Liard section. These may be sourced from a biostrome developed at the top of the first Liard sandstone section or within the Toad Formation–like siltstone at the base of the Liard Formation. This assumption is based on the presence of a similar build-up observed to the north along this horizon by previous workers (Zonneveld, 2001). The Toad-Liard formation contact defined here is similar to that used by Ferri (2009a, b) in the southern Halfway River area. Thompson (1989), following the work of Gibson (1975), places the Toad-Liard formation contact at the base of the second sandstone section.

The Toad Formation displays a general coarsening-upward succession, which can be subdivided into three broad packages: 1) a lower section, approximately 140 m thick, composed of nondescript, dark grey to grey, calcareous to dolomitic carbonaceous siltstone; 2) a middle section containing similar dark grey siltstone but also containing beige weathering, more resistive ribs of cleaner and coarser dolomitic to calcareous siltstone to very fine sandstone and forming a section up to 160 m thick; and 3) an upper section where thin, graded laminar bedding is common within the siltstone together with resistive sections of coarse siltstone to very fine or fine sandstone locally displaying higher-energy bedforms such as current ripples. All sedimentary features seen within the succession (see below) are consistent with the deposition of the sediments as turbidites (density flows). This general threefold subdivision (described above) is also evident within the gamma-ray pattern obtained from the outcrops.

The lower part of the Toad section consists of uniform to faintly laminated dark grey calcareous to weakly dolomitic siltstone (Figure 10). These recessive rocks are typically grey to pale buff weathering, are platy to blocky

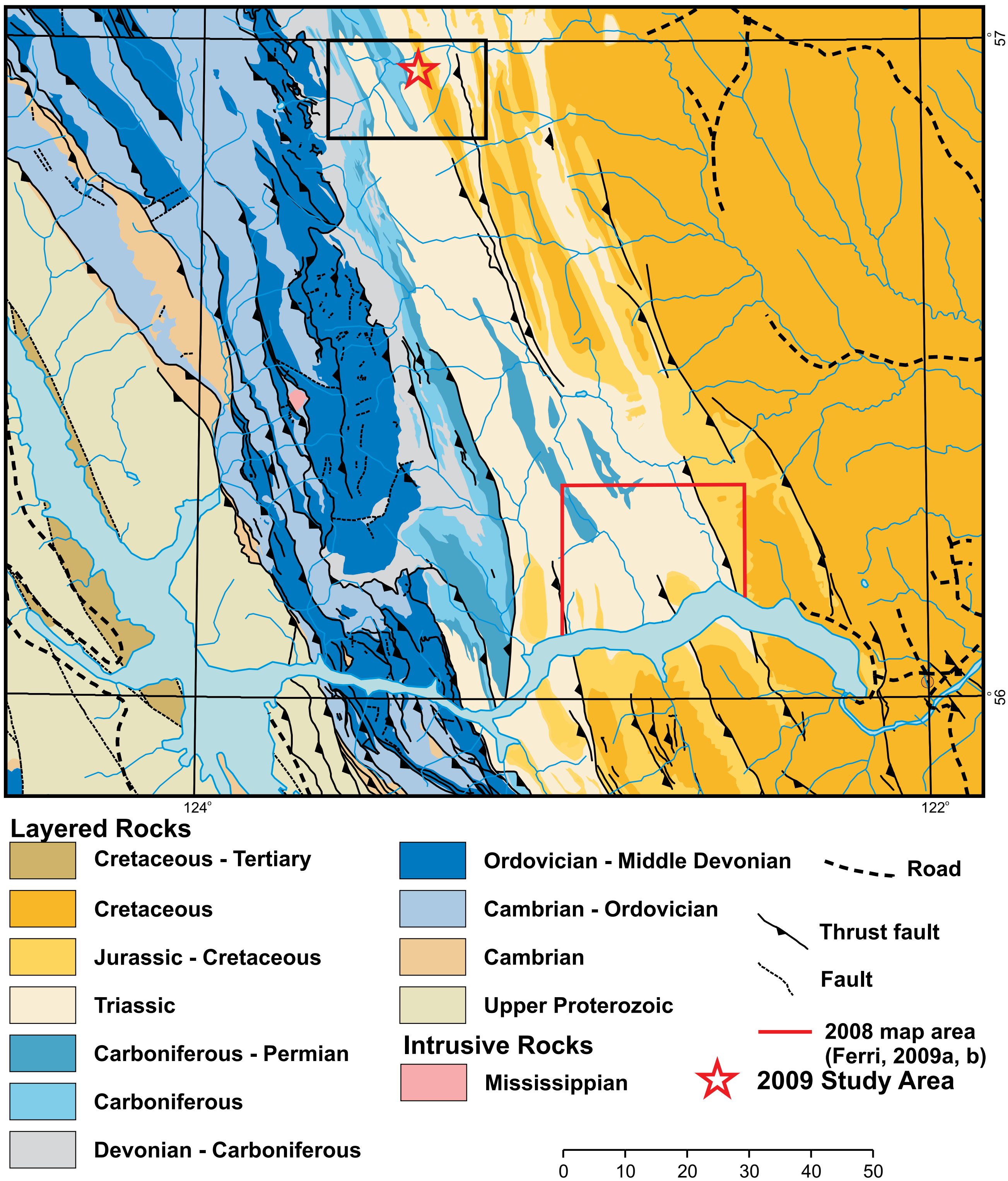

Figure 2. Regional geology of the Halfway River map area (NTS 094B/14). The black box outlines the area shown in Figure 3.

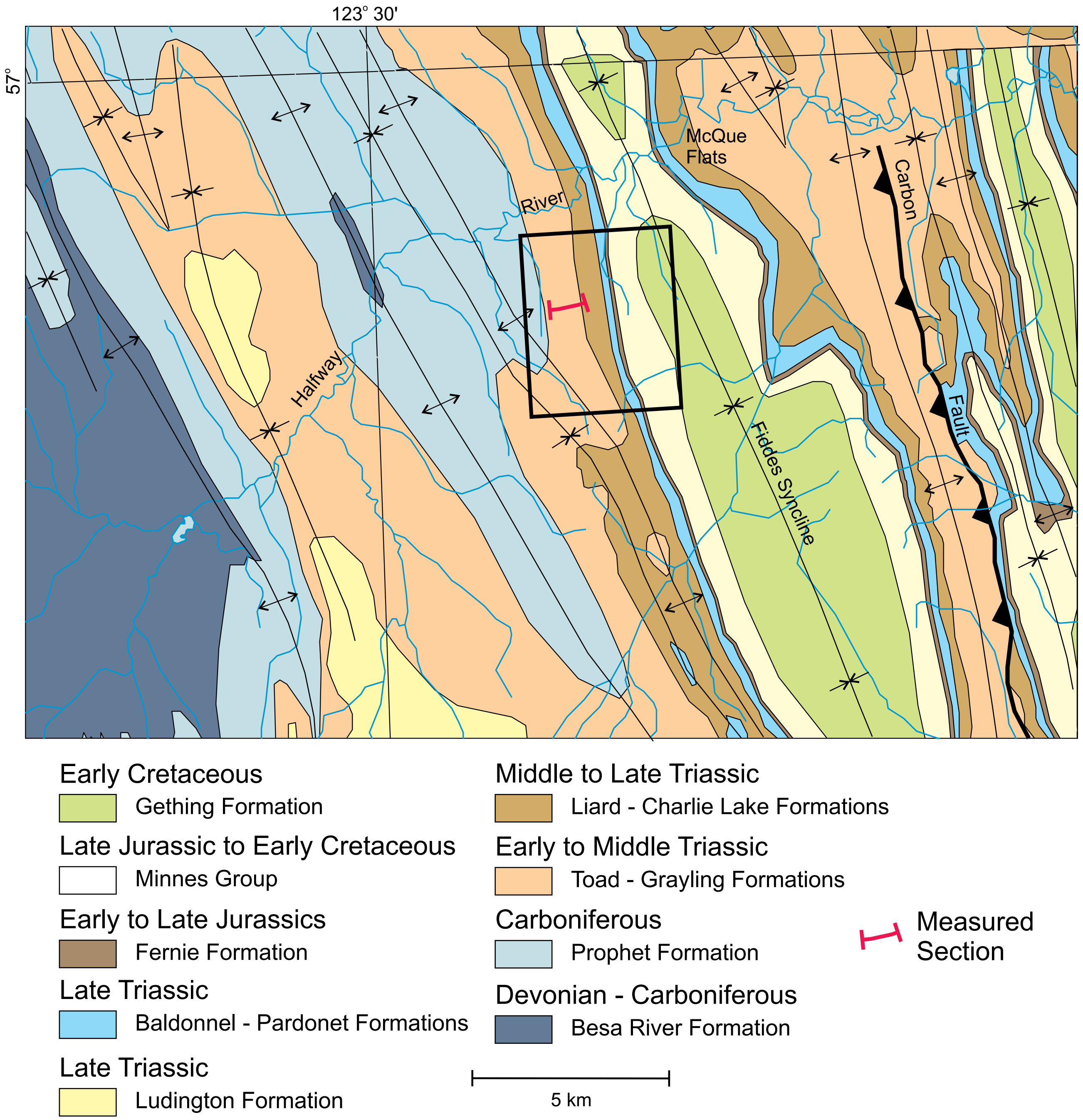

Figure 3. Geology in the vicinity of the measured section. The box outlines the area shown in Figure 5.

or crumbly and are slightly fetid on breakage. This rock type comprises the 'background' rock type throughout the section and becomes less abundant upwards as the amount of coarser clastic material increases.

The middle part of the Toad section is characterized by more resistive ribs of beige to buff weathering, cleaner and coarser dolomitic siltstone to very fine sandstone (Figures 11–13). These beds range in thickness from 0.1 to 4 m in thickness and average 1 m. They are commonly internally uniform, although in the upper part of this sequence they display laminar bedding and graded bedding. Lower and upper contacts can be sharp to gradational with surrounding dark grey calcareous siltstone. Intervening dark grey siltstone can be quite carbonaceous and crumbly (Figure 14) within specific horizons and correspond to some of the highest gamma-ray counts within the outcrop. Overall, these more prominent ribs comprise up to 60% of the section.

Locally, there is a rhythm to the pattern of the more resistive beds whereby the thickest beds are followed immediately by a thicker section of dark grey siltstone (Figure 12). Above these beds, the amount and thickness of the resistive

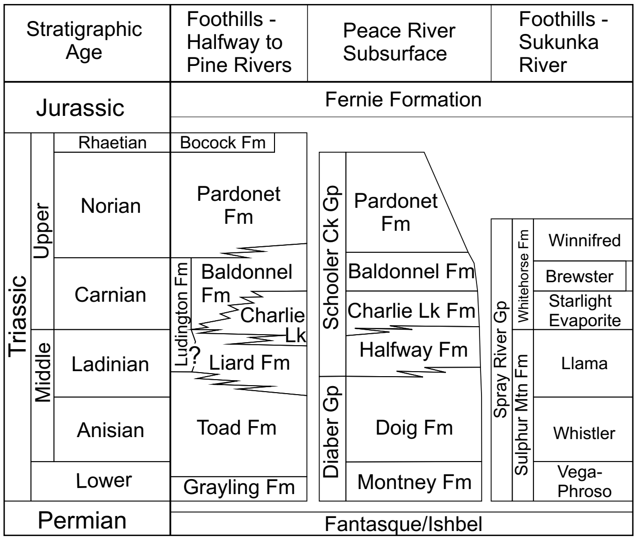

Figure 4. Stratigraphic nomenclature used in the surface and subsurface areas of northeastern British Columbia.

beds increase until a very thick resistive bed is encountered and the pattern repeats (Figure 12). The significance of this is not known but it may possibly reflect episodic shallowing within the basin, or increased sediment influx.

These prominent ribs continue into the upper part of the section, becoming thicker and coarser grained, although not as abundant as in the middle section. The intervening dark grey siltstone begins to contain coarser, thin laminar bedding, which commonly displays grading (Figure 15, 16). A prominent 8 m thick section of very fine to fine-grained sandstone begins at the 476 m mark of the section. This thick sandstone horizon is characterized by current ripples, load casts and tool marks. In addition, there are horizons displaying convoluted bedding due to soft sediment deformation (Figures 17–20). These features become more common above this level, within thinner sandstone ribs and thinly interlayered coarse siltstone and fine sandstone beds. At several horizons in the upper part of the Toad section, convoluted bedding is associated with low-angle erosional cutoffs where conglomeratic lag occurs at the erosional base (Figure 20). These features are consistent with derivation from high-energy turbid flows.

Compositionally, siltstone in the lower part of the Toad section contains approximately 30–40% carbonate (and locally up to 60%), 10–20% feldspar (potassium and plagioclase), 40–60% quartz and several per cent muscovite. Clasts are angular to subangular. Less argillaceous and coarser siltstone and very fine sandstone contain less carbonate (20–30%) and higher concentrations of subrounded to subangular clastic rocks. Although quartz dominates coarse clastic rocks (70–80%), feldspar can comprise up to 20% and muscovite, chert and rare hornblende are minor constituents. Lower Liard Formation sandstone is very similar in composition to sandstone horizons in the Toad Formation. Coarser, clean (less argillaceous and radioactive) Liard Formation sandstone at ~635 m is subrounded to rounded and dominated by quartz (80%), feldspar (10%), chert (up to 5%) and rare hornblende, with the remainder being carbonate cement.

Several current flow directions were measured, which, upon rotation of bed inclinations, give original flow directions of 200^{o}–219^{o} and an average of 219^{o}. Pelletier (1960, 1961, 1965) recorded similar southwesterly flow directions from the Toad and Grayling formations north of Halfway River.

The lower 25 m of the Liard Formation consist of tan to beige weathering, very fine to medium-grained, massive to crossbedded calcareous sandstone. Bedding is thin to thick or very thick and typically massive. Low-angle crossbeds are locally developed. Several metres of pale grey to grey, medium-grained, thick-bedded sandstone were observed near the top of the section. This section appears consistently less argillaceous and coarser grained than other parts of the Liard section.

The lower part of the Liard Formation, near its contact with the Toad Formation, contains large burrows assigned to *Cruziana* and *Thalassinoides* (Figure 21). Large Cruziana are locally common in the Upper Toad–Lower Liard formation interval (Zonneveld et al., 2002). No other bioturbation was observed below the Toad-Liard formation contact. Macrofossils were found at various horizons throughout the Toad section and consist of brachiopod, pelecypod, ammonoid and possibly vertebrate remains. Brachiopods were observed in the lowermost part and are smooth-shelled terebratulids. Pelecypod remains typically consist of individual flat-clam (daonellids) imprints, although 'crinkly' beds a few millimetres thick at the 275 m mark are composed almost entirely of flat-clam remains. Ammonoids, up to a few centimetres in diameter were also observed at various horizons.

Fifteen conodont samples were obtained throughout the section in hopes of better defining the age range of the sequence so as to help with regional correlations and the interpretation of geochemistry and detrital zircon samples.

ROCK-EVAL

A total of 114 samples were obtained from the Toad Formation and analyzed by programmed pyrolysis via a Rock-Eval 6 apparatus at the organic geochemistry laboratories of the Geological Survey of Canada, in Calgary, Alberta. Each sample consists of representative material taken across 5 m intervals. A profile of total organic carbon (TOC) content across the section is shown in Figure 7.

Generally, TOC decreases up-section, reflecting the overall upward-coarsening of the sequence. Total organic carbon levels fall below 1% at approximately the 450 m level. Although the zone containing the highest gamma-

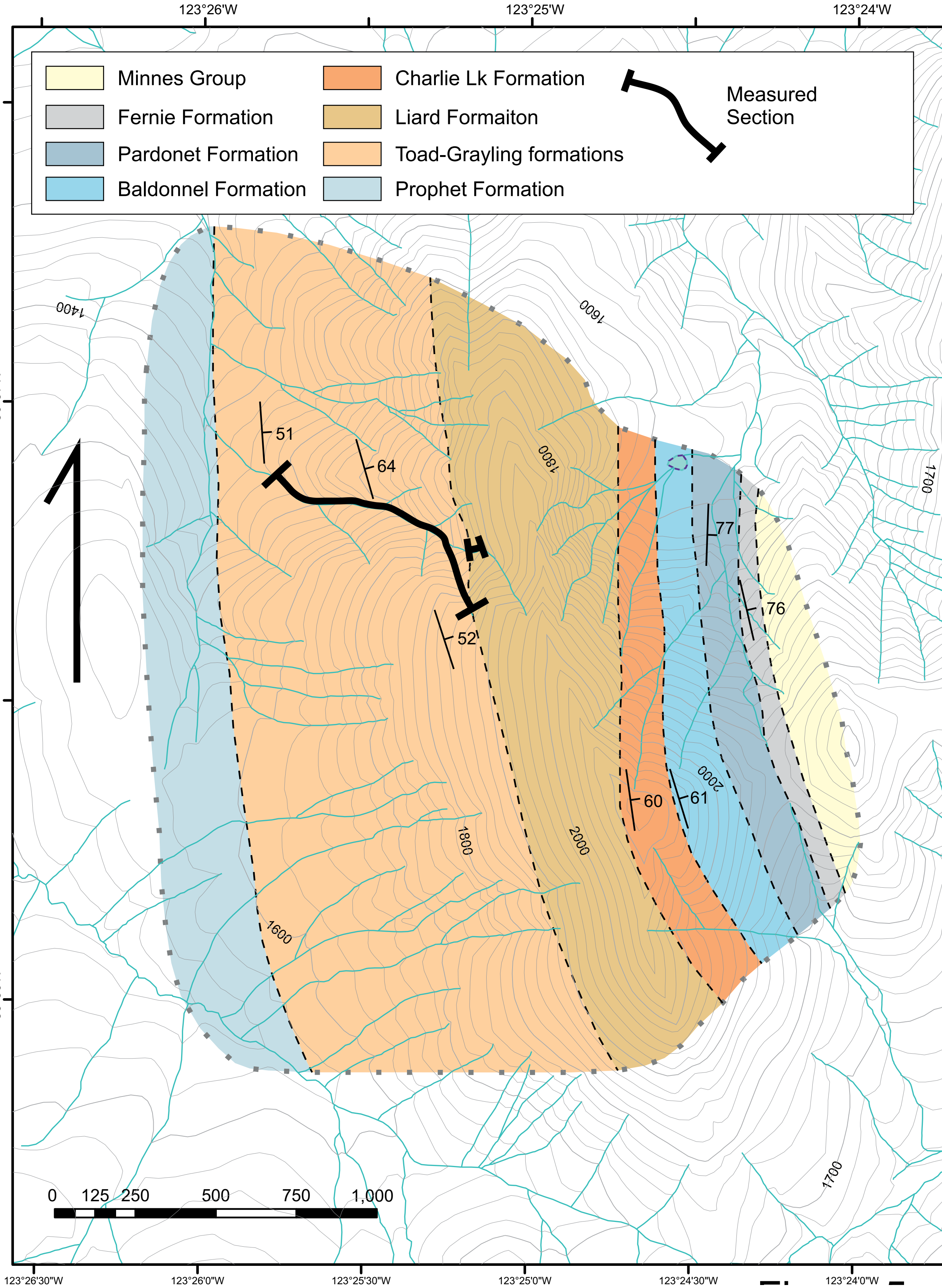

Figure 5. Geology mapped in the vicinity of the measured section.

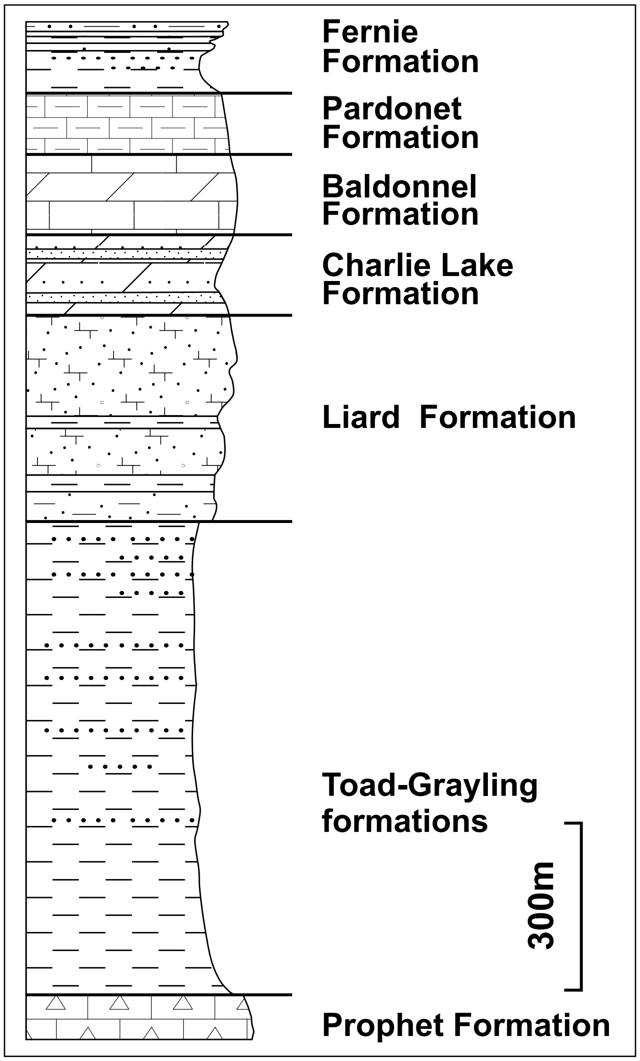

Figure 6. Generalized stratigraphy in the vicinity of the measured section; modified from Davies (1997).

ray readings (140–300 m) has high TOC concentrations (1–4%), the highest levels were found in the lower 140 m (up to 5%). Little generative capacity remains in these thermally mature rocks as shown by HI (hydrogen index) levels of less than 10 mg of hydrocarbons per gram of TOC. Assuming that much of the hydrocarbons have been expelled from the organic matter, then TOC levels originally were most likely at least two times higher (Jarvie, 1991).

THERMAL MATURITY

Eleven samples were collected during the 2010 field season for reflected-light microscopy determination of thermal maturity. Seven samples were obtained from the measured section and the remainder originated from units higher in the Triassic. Gradients measured within the southern Halfway River area suggest that Toad Formation rock types should occupy the middle–upper dry gas zone (R_o values of 2–3; Ferri, 2009a).

GAMMA-RAY MEASUREMENTS

A handheld spectrometer (RS-125 by Radiation Solutions Inc.) was used to acquire a gamma-ray profile across the section to facilitate the correlation of these rocks with subsurface gamma-ray traces acquired across age-equivalent strata to the east. In addition to total counts per second, concentrations of K (%), Th (ppm) and U (ppm), and total dose (nGy/h) were acquired. Elemental concentrations and total dose were acquired every 1 m during a 30 s time period. A total count rate per second was determined through the averaging of maximum and minimum count rates at each sample site. Counts per second and total dose both measure the total level of radioactivity from the section and the respective profiles should mimic each other (Figure 7). The raw data acquired during the 2009 field season will be included with the upcoming open file report.

The trace of total gamma-ray counts per second (dose) shows a zone of higher total counts beginning at approximately 140 m. This zone continues up to about 300 m, at which point the general baseline level decreases up-section until the lowest counts per second were encountered within the coarser sandstone of the Liard Formation. The zone of higher radioactivity (140–300 m) roughly corresponds to the middle part of the lithological section containing the prominent siltstone ribs separated by organic-rich siltstone. The upward decrease in gamma-ray levels reflects the general upward-coarsening and decrease in argillaceous content up the section.

Interestingly, there is no significant decrease in radioactivity at the Toad-Liard formation contact as the gamma-ray trace crosses into fine-grained sandstone of the Liard Formation. The lowest gamma-ray counts are only recorded within the coarser, thicker-bedded sandstone at approximately the 637 m level. The higher radioactivity levels within the Lower Liard Formation sandstone are probably a reflection of the potassium feldspar and mica in this finer sandstone. This is borne out of thin section examinations. Feldspar and mica are probably mechanically removed in the coarser sandstone as they most likely represent higher-energy shoreface environments typical of the Liard Formation (i.e. more akin to Halfway Formation sandstones).

CORRELATIONS

Although there is a direct correlation of exposed carbonate-dominated Triassic stratigraphy with similar subsurface units (as shown by similar terminology; i.e., Pardonet, Baldonnel, Charlie Lake), direct correlation of formations in the underlying clastic succession is not as straightforward. Though the Halfway, Doig and Montney formations are the combined subsurface equivalents to the Liard, Toad and Grayling formations, defined contacts between each unit are not correlatable. An exercise of tracing the Halfway

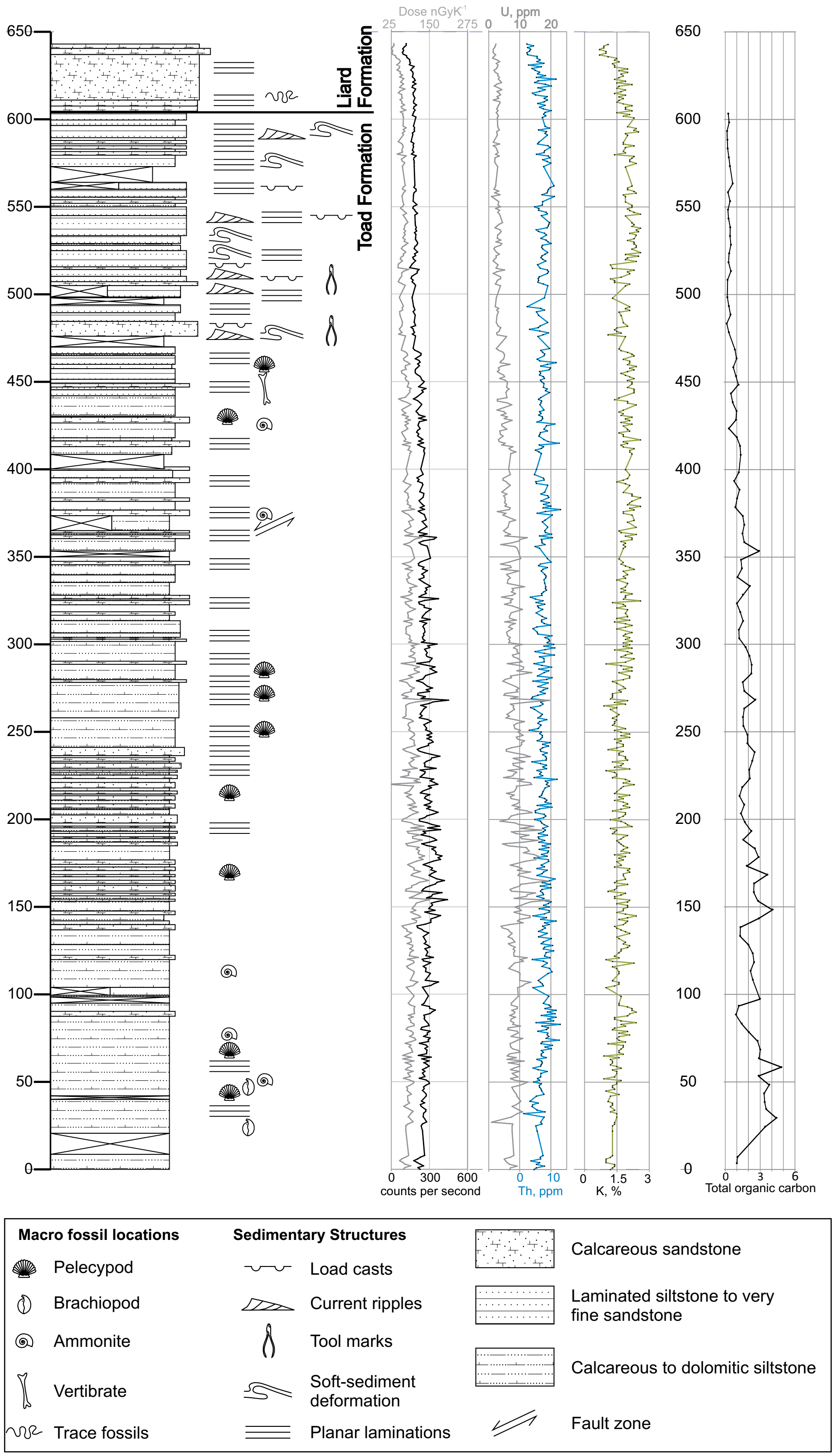

Figure 7. Generalized representation of measured section of Toad and lower Liard formations rock types. Accompanying this are traces of total dose, counts per second and concentrations of U, Th and K.

Formation sandstone westward within the ever-thickening Triassic clastic wedge suggests that these would occupy the upper part of the Liard Formation, and that the Doig Formation correlates with parts of the Liard Formation. Furthermore, the relative thinness of the Grayling Formation (~50 m) suggests that the Toad Formation is equivalent to the Montney Formation and perhaps parts of the Doig Formation.

It is hoped that the gamma-ray trace, together with lithological descriptions from the study area, will shed some light on the correlation of these units. The ability to integrate the detailed lithological descriptions from the described section is a powerful tool in the regional correlation and depositional understanding of these sequences.

Correlation of the gamma-ray trace with nearby wells indicates that the higher zone of radioactivity displayed between the 140 m and the 300 m marks is most likely equivalent to the Doig Formation phosphate (Figure 22). This is based on the overall thickness of the Triassic section together with the relative position of the gamma-ray trace within the section. One of the closest wells to the measured section, c-54-G/94-G-3, contains a Triassic sequence of equal thickness to that in the study area. Although Lower Triassic thicknesses in this well could be structurally related, they are similar to those seen in other wells along strike (e.g., a-4-L/94-B-1) and follow an overall westward thickening of the Triassic sequence shown in Figure 22 (see also Edwards et al., 1994).

The thickness and gamma-ray character of the lower Doig Formation phosphatic zone in the c-54-G well is roughly the same as that in the measured section. Furthermore, the thickness of the underlying Montney Formation in this well is similar to values obtained for the underlying Toad Formation based on the measured and structural sections in the study area.

It appears that the lower Doig Formation phosphatic zone thickens to the west and becomes more diffuse within the western part of the foothills. In Figure 22, the sharp gamma-ray spike at the base of the Doig Formation phosphatic zone shown in wells east of c-54-G is lacking within this well and the study area. No phosphatic horizons or nodules were noted within the measured section. The highest gamma-ray readings in the study area correspond to the most carbonaceous horizons.

These correlations would also suggest that the Liard Formation as described here is probably correlative to parts of the Charlie Lake, Halfway and upper Doig formations in the subsurface and that the Toad Formation is equivalent to the Montney and Doig formations in the subsurface (see also Orchard and Tozer, 1997).

Figure 8. View looking south at the gulley where the section of Toad and Liard formations was measured. The Toad-Liard formation contact is shown by the dashed white line.The sandstone section in lower Liard Formation is approximately 50 m thick.

Figure 9. View looking south at the Toad-Liard Formation contact and the lower part of the Liard Formation. The latter contains a tongue of Toad Formation–like siltstone and fine sandstone approximately 75 m thick above a section of equally thick Liard Formation sandstone. The lower part of this siltstone tongue contains a horizon that supplies the abundant bioclastic debris found in the upper part of the gulley. The sandstone section in lower Liard Formation is approximately 50 m thick.

Figure 10. Typical grey to dark grey calcareous to dolomitic siltstone within the lower part of the Toad section.

Figure 11. Characteristic ribbing within the lower-middle part of the section (~140–300 m). Here, resistive, buff-weathering, dolomitic siltstone is interlayered with dark grey calcareous siltstone. These buff-weathering horizons (approximately 1 m thick) are cleaner and somewhat coarser than the recessive units.

Figure 12. Close-up view of part of the section seen in Figure 11. Note that the buff-weathering horizons show an overall coarsening or cleaning upwards (to the left in the photo). Also note (along with Figure 11) that the section shows a rhythm, whereby there is an increase in development of the buff-weathering horizons towards the next-thickest resistive rib. Thick, buff-weathering beds are approximately 1 m thick.

Figure 13. Less weathering is seen in the ribbed zone shown in Figures 11 and 12 where erosion has exposed a section.

Figure 14. Contact between carbonaceous siltstone and buff-weathering siltstone. These carbonaceous horizons produced some of the highest readings on the scintillometer.

Figure 15. Laminated and graded fine- to coarse-grained siltstone of the middle part of the section. These rock types become more abundant in the upper half of the section (>300 m).

Figure 16. View looking north at the 450 m level of the section. Here, coarser grained siltstone horizons exist between more recessive, laminated siltstone. The resistive bed on the left side of photo is approximately 2 m thick.

Figure 17. Soft sediment deformation in a fine-grained sandstone to coarse-grained siltstone horizon at the 480 m level.

Figure 18. Current ripples in very fine sandstone, 480 m level.

Figure 19. Graded, finely laminated fine sandstone to coarse siltstone also displaying load casts (lowest part of slab), 506 m level.

Figure 20. Low-angle, angular disconformity. Lower beds are at an angle to the uppermost horizons with the contact between the two at the midway point of the mechanical pencil. Note that the contact is uneven and marked by coarse lag material; 522 m level.

Figure 21. Bedding-parallel burrows (Cruziana?) within the very fine sandstone of the Lower Liard Formation, 611 m level. Burrows are 3–5 cm in width.

SUMMARY

- Over 600 m of the Toad Formation were measured within the western Foothills of northern Halfway River map area (NTS 094B/14). A further 200 m of the lower part of this formation was not exposed.
- Sedimentary structures indicate deposition through low-density flows (turbidites).
- Current indicators suggest south-southwesterly to southwesterly directions.
- A gamma-ray trace across the measured section suggests that the Toad Formation is equivalent to the Montney and Doig formations.

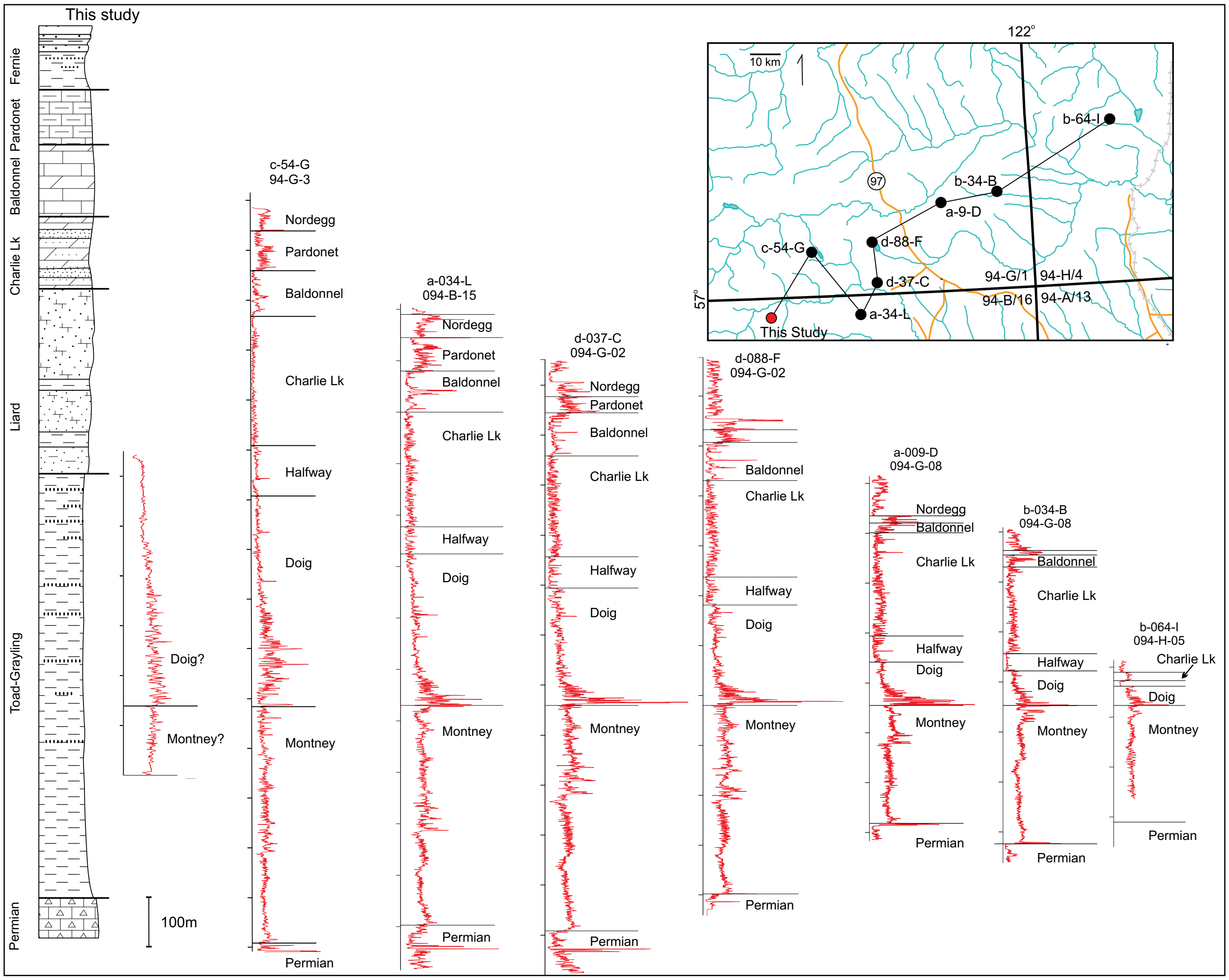

Figure 22. Correlation of lithological section and gamma-ray count trace from the study area (stratigraphic column and gamma-ray trace at the left-hand side of the diagram), with gamma-ray traces from selected wells to the east. Note that the trace of the gamma-ray count from the study area, together with the relative position within the lithological section, suggests that the zone of highest readings in the study area probably corresponds to the phosphatic part of the Doig Formation seen to the east. The correlation is most convincing with the trace from the nearest well (c-54-G). Inset shows location of the sections with respect to the study area.

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