HORN RIVER BASIN–EQUIVALENT STRATA IN BESA RIVER FORMATION SHALE, NORTHEASTERN BRITISH COLUMBIA (NTS 094K/15)

Filippo Ferri[1], Adrian S. Hickin[1] and Julito Reyes[2]

ABSTRACT

In the summer of 2011, approximately 310 m of shale and siliceous siltstone of the Besa River Formation was measured in the Stone Mountain area of northeastern British Columbia (NTS 094K/15). In addition to a lithological description, a gamma-ray spectrometry (U, Th and K) survey was conducted and Rock Eval™ samples were collected across the section. Results show similarities between this section and a section of the Besa River Formation measured in the Caribou Range along the northern border of the Toad River map area (NTS 094N) in 2010. Although a comparison of U, Th and K logs from each section are in general agreement, absolute levels, particularly with respect to U, are higher within the Caribou Range. Comparison of the gamma-ray log with similar subsurface sections shows good correlation and indicates the presence of the Evie and Muskwa markers of the Horn River succession, and the Exshaw Formation within the Besa River section. Total organic carbon levels are high (up to 7 wt.%) within Evie-, Muskaw- and Exshaw-equivalent strata. There is also a zone with high total organic carbon (up to 8 wt.%) above the Exshaw marker, in the upper part of the Besa River Formation.

Ferri, F., Hickin, A.S. and Reyes, J. (2012): Horn River basin–equivalent strata in Besa River Formation shale, northeastern British Columbia (NTS 094K/15); in Geoscience Reports 2012, *British Columbia Ministry of Energy and Mines*, pages 1–15.

[1]Geoscience and Strategic Initiatives Branch, British Columbia Ministry of Energy and Mines, Victoria, British Columbia; Fil.Ferri@gov.bc.ca

[2]Geological Survey of Canada, Calgary, Alberta

Key Words: Liard basin, Horn River basin, Liard River, Toad River, Caribou Range, Stone Mountain, Besa River Formation, Horn River Formation, Evie Member, Muskwa Member, Evie Member, Fort Simpson Formation, Exshaw Formation, Mattson Group, Stoddart Group, geochemistry, gamma ray, rock Eval, total organic content, oil, gas, sulphides

INTRODUCTION

This report summarizes preliminary results from the 2011 field season, part of an ongoing project examining surface exposures of Horn River basin–equivalent strata within the Besa River Formation in northeastern British Columbia (Ferri et al., 2011). The main objective of this project is to delineate units in outcrop that are equivalent to shale gas–producing horizons in the subsurface, thereby providing potential reference sections for understanding the geological setting of the strata in the Horn River basin. The rationale for investigating the 2011 section was primarily its proximity to the Slave Point–Keg River carbonate edge (Fig. 1, 2). Characterization of the section was accomplished through lithological description and collection of samples for lithological and organic geochemical and geochronological analysis. In addition, a gamma-ray spectroscopic survey of the outcrop was performed and used to correlate the section with subsurface sequences in the Liard and Horn River basins.

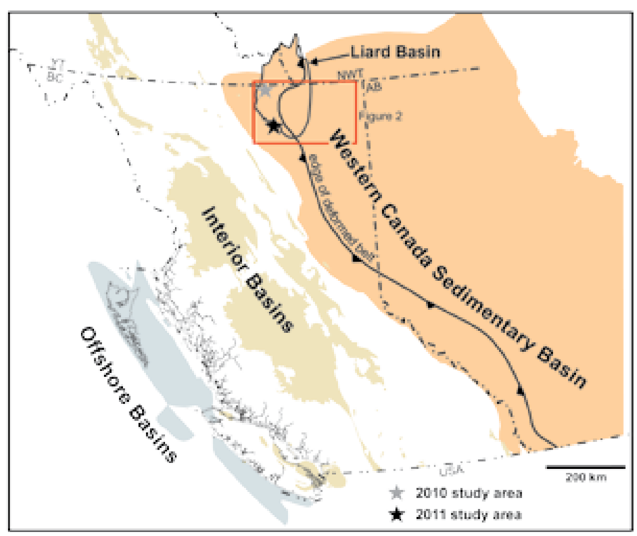

Figure 1. Location of the 2011 study area. Outline of basins adapted from Mossop et al. (2004).

This study is part of a collaborative program between the Geological Survey of Canada (GSC) and the British Columbia Ministry of Energy and Mines. It is part of the Liard and Horn River basins projects, which fall under the umbrella of Natural Resources Canada's Geo-mapping for Energy and Minerals program (GEM). These projects are focused on examining petroleum-related geoscience data for these basins, a regional bedrock mapping project in the Toad River map area (NTS 094N) to update the regional geological database (McMechan et al., 2012) and mapping the surficial geology resources that are relevant to operational aspects of oil and gas resource development (e.g., infrastructure, surface engineering, drilling and completion; Huntley and Hickin, 2010; Huntley and Sidwell, 2010).

LOCATION AND REGIONAL GEOLOGY

The 2011 Besa River Formation section is located along the southwestern margin of the Liard basin, 80 km northwest of the Slave Point carbonate edge (Fig. 2). It is found within the northern part of the Tuchodi Lakes map area (NTS 094K/15) approximately 10 km east of the small community of Toad River and 5 km east of the Alaska Highway (Fig. 2, 3). This section was first recognized by Bamber et al. (1968) as part of a regional study examining Carboniferous and Permian strata. More than 300 m of Besa River Formation shale and siltstone are exposed on the western limb of a large, northwest-plunging, faulted anticline that is cored by carbonates of the Dunedin and Stone formations (Fig. 4). Diagrammatic representations of the time and lithostratigraphic relationships of the Besa River Formation to other units in the study area and to units in the subsurface are shown in Figures 5 and 6. Horn River basin strata correlate with the lower parts of the Besa River Formation. Ferri et al. (2011) provided a brief summary of the regional geology of the study area.

The age of the Besa River Formation is mid-Middle Devonian to Early Carboniferous. Nadijwon (2001) reported conodont collections from the top of the Dunedin Formation and lowermost Besa River Formation in the Stone Mountain area as latest Eifellian to mid-Givetian age. Although Besa River rocks are shown to be capped by the Kindle Formation in the map area (Taylor and Stott, 1973), sandstone observed at the top of the section likely

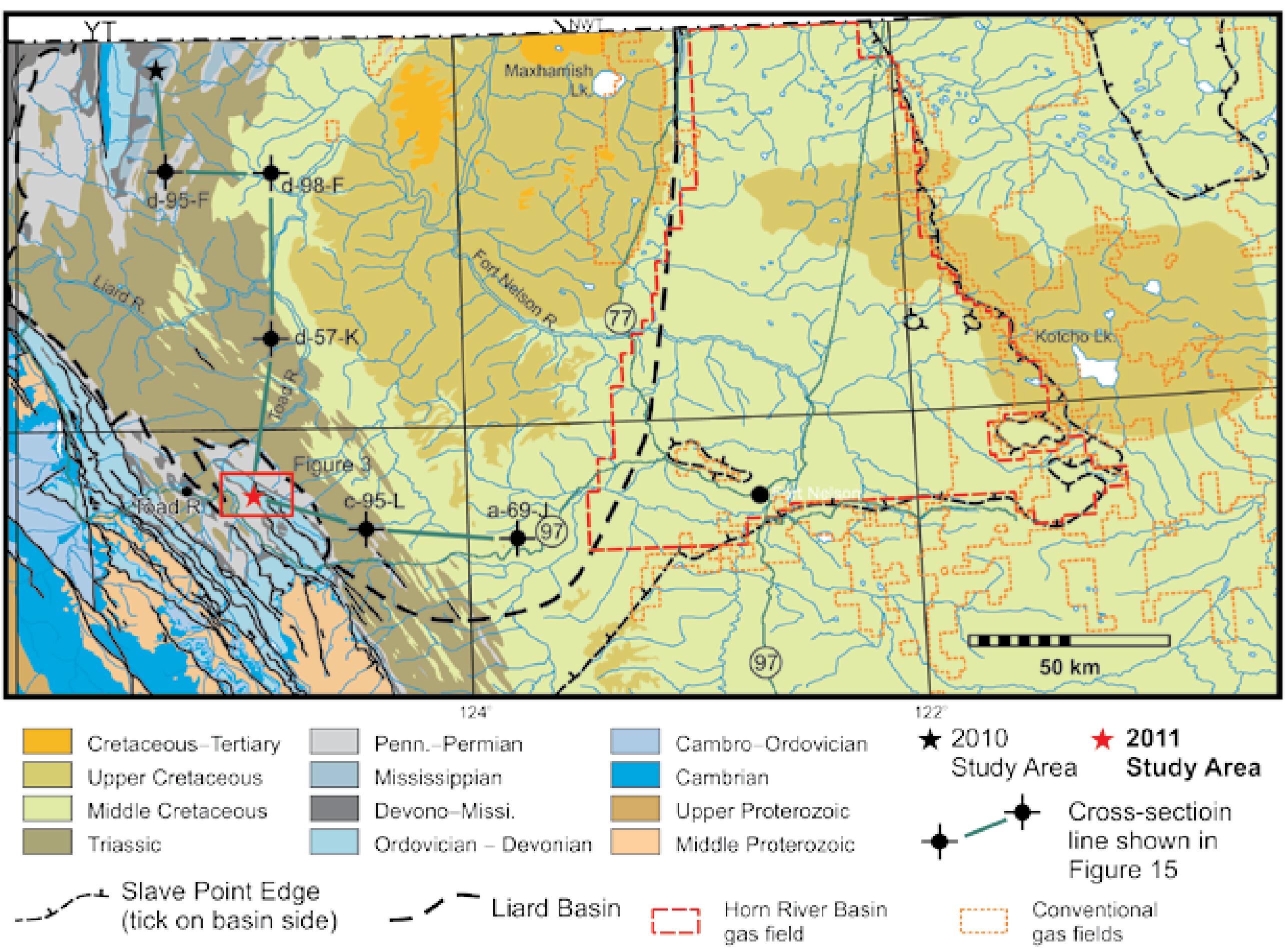

Figure 2. Regional geology of the Rocky Mountains and plains in the vicinity of the 2011 study area (Massey et al., 2005). The outline of the Liard basin is from Mossop et al. (2004). Slave Point edge taken from Petrel Robertson Consulting Ltd. (2003).

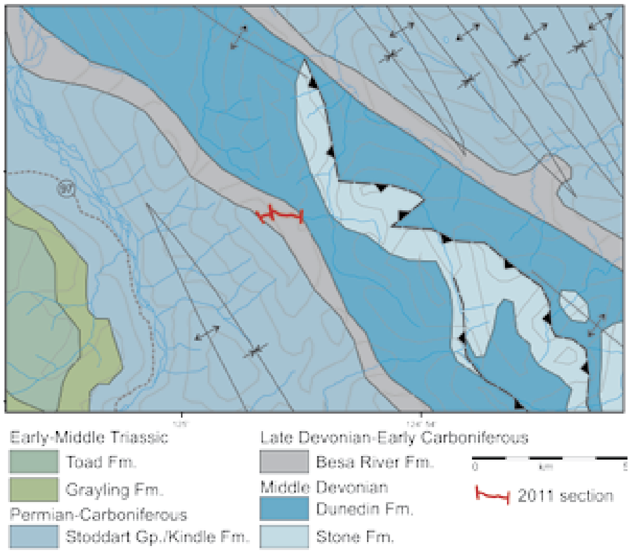

Figure 3. Geology in the immediate vicinity of the 2011 measured section (Massey et al., 2005)

belongs to the Stoddart Group (Halbertsma, 1959; Bamber et al., 1968; Taylor and Stott, 1973), which is equivalent, in part, to the Upper Mississippian Mattson Formation. In the Peace River area, the Stoddart Group is divided, in ascending order, into the Golata, Kiskatinaw and Taylor Flats formations (Halbertsma, 1959). The base of the Golata succession, which sits above the Prophet Formation along the eastern Rocky Mountain Foothills, contains fossils of late Middle to early Late Mississippian age (i.e., early Chesterian; Bamber et al., 1968; Okulitch, 2004). The Prophet Formation disappears further west and northwest such that shale of the Golata Formation is equivalent to the upper Besa River Formation and the top of the latter unit is placed at the first sandstone horizons within the base of the Stoddart Group. These relationships suggest the top of the Besa River Formation is likely Middle to Late Mississippian in age. The Besa River Formation is thus time equivalent to strata between and including Upper Keg River and Golata units found within the eastern Rocky Mountain Foothills and subsurface of the plains in northeastern British Columbia (Fig. 5).

METHODOLOGY AND RESULTS

Field sampling, analysis and reporting generally follows that described in Ferri et al. (2011). Approximately 310 m of rocks belonging to the Besa River Formation were measured and described in two sections along a small, west-facing gully (Fig. 7) located approximately 12 km northwest of Stone Mountain (Fig. 3). Steep terrain prevented the examination of a continuous section resulting in the measurement of two nearly contiguous sections (Fig. 7). The top of the lower section was accessed from a small, parallel tributary to the main creek. The beginning of the upper section is offset approximately 75 m laterally from the lower section, but mapping suggests that little or no overlap or separation occurs between the two sections. Coordinates (UTM, NAD83) for the base and top of the first section, respectively, are 387019E, 6523897N and 386732E, 6523960N and for the base and top of the second section, respectively, are 386742E, 6523899N and 386600E, 6523870N.

Representative chip samples were acquired through 2m intervals along each section. Samples were split, with one group being analyzed for whole-rock, trace and rare earth element abundances by inductively coupled plasma–emission spectroscopy (ICP-ES) and inductively coupled plasma–mass spectrometry (ICP-MS) following a lithium metaborate-tetraborate fusion or aqua regia digestion at Acme Analytical Laboratories (Vancouver, British Columbia) and a second group for rock-eval analysis at the GSC laboratories (Calgary, Alberta). A smaller subset of these samples will also be analyzed for semiquantitative determination of mineral abundances by X-ray diffraction (XRD). Separate samples were collected for thermal maturity determination at the GSC laboratories in Calgary, Alberta through reflected light microscopy. Samples were also acquired from several horizons for Re-Os geochronology at laboratories at the University of Alberta in Edmonton, Alberta. In addition, a handheld gamma-ray spectrometer (RS-230 by Radiation Solutions Inc.) was used to measure natural gamma radiation every 1 m. Gamma-ray spectrometry data was collected over a 2 minute time interval providing concentrations of K (%), U (ppm) and Th (ppm) in addition to total gamma-ray counts. The resulting diagram shows the variation in total natural radiation along the section and is approximately equivalent to conventional gamma-ray readings collected from boreholes in the subsurface. Results of this analysis, together with other compositional parameters, were used to assist in the correlation of the outcrop section with equivalent rocks in the subsurface.

In total, 312 m of Besa River Formation shale and siltstone were measured across two sections (Fig. 4). Although the top of the Dunedin Formation was observed, the lowermost 2.5 m of the Besa River Formation was not exposed at the measured section. Several other minor unexposed sections occur in the lower and middle part of the section. Approximately 18 m of the upper section is covered, just below the contact with the Stoddart Group.

The contact with the Dunedin Formation, where exposed, is sharp, but conformable (Nadijwon, 2001). The upper contact with the Stoddart Group appears gradational where more than a 3 m interval of calcareous, coarse siltstone to very fine sandstone beds of the Stoddart Group is intercalated with Besa River shale. This is similar to the upper Besa River Formation contact with the Mattson Formation in the Caribou Range (Ferri et al., 2011).

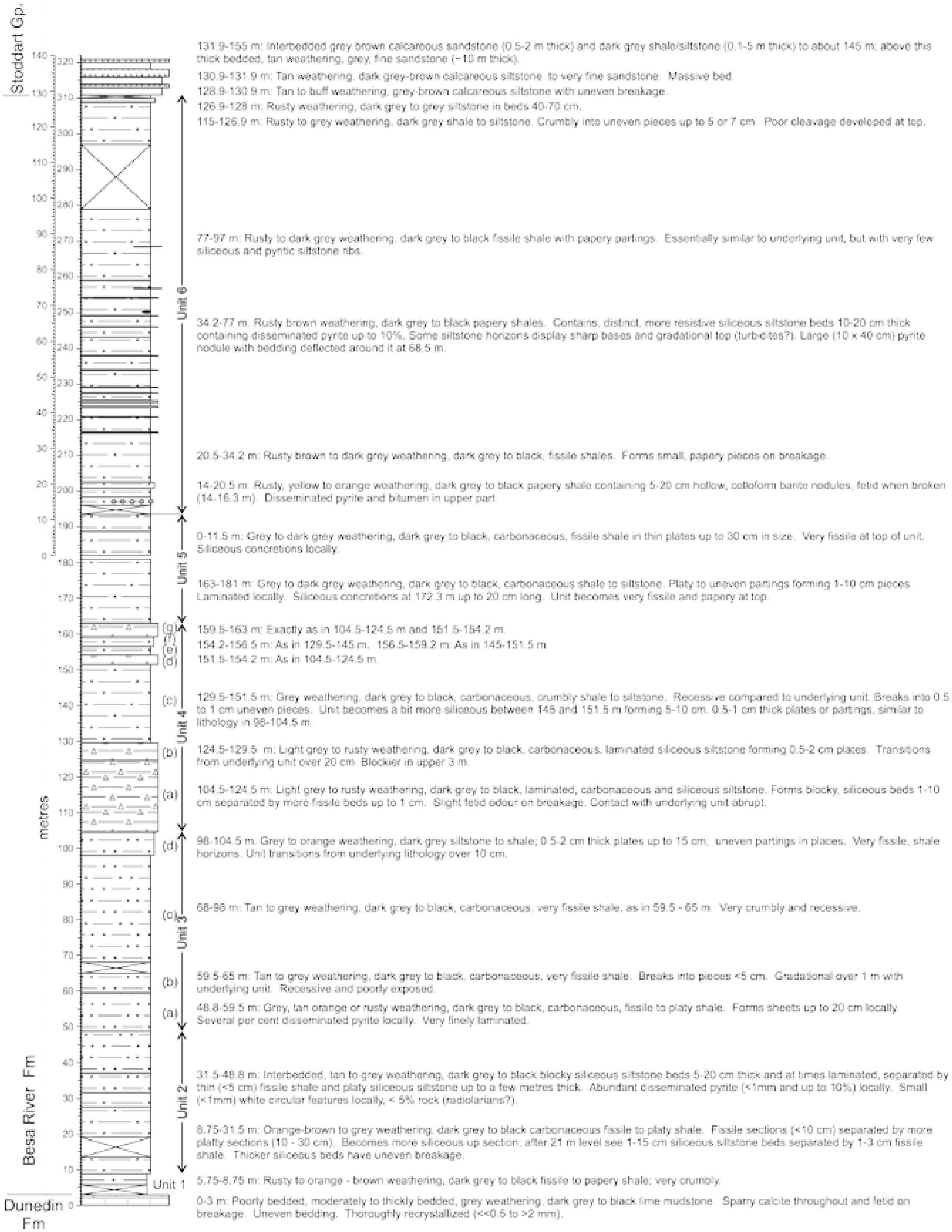

Figure 4. Lithological section of the Besa River Formation measured in the vicinity of Stone Mountain during the 2011 field season; the right-hand scale records cumulative thicknesses for combined sections from the base of section 1; the left-hand scale at the top of the diagram represents height in section with respect to section 2. Thicknesses in descriptive notes are with reference to each section.

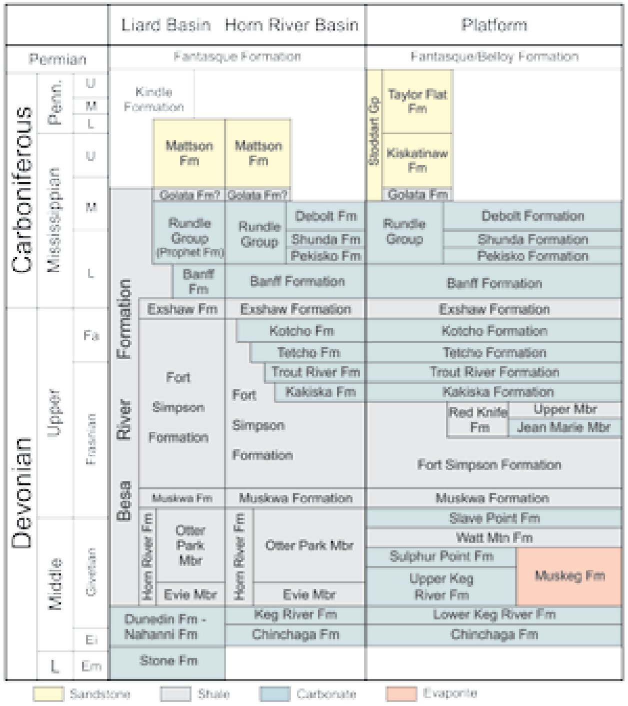

Figure 5. Time stratigraphic chart of the middle to upper Paleozoic showing the main stratigraphic units along the northwest part of the Western Canada Sedimentary Basin (falling within north-eastern British Columbia) and the relationship between shelf and off-shelf sequences.

Thickness and overall rock types of the 2011 section are similar to those measured during the 2010 field season in the Caribou Range. At a distance, both sections contain a lighter weathering zone in the lower part (unit 4; Ferri et al., 2011) that is more siliceous than other units (Fig. 7a, b), although the horizon assumed to be equivalent to this in the Caribou Range is much lighter coloured. Based on field observations, the 2011 section has been subdivided into six units reflecting colour (fresh and weathered), fissility or competence, and overall composition (Fig. 4). The lower half of the section appears generally more carbonaceous and competent than the upper part; i.e., more siliceous, although rock eval data (see below) indicates high organic carbon in the uppermost part. The lowest unit of the section is fissile (Fig. 8a, b) and is overlain by more resistive, platy to blocky shale of units 2 and 3 (Fig. 4, 8c–g). These units locally contain abundant disseminated pyrite and can be rich in organic matter. Unit 4 is characterized by several horizons of blocky, siliceous siltstone/shale beds up to 10 cm thick, separated by thinner, fissile horizons (Fig. 7b, 8h, 9a–g). Unit 4 is overlain by less siliceous, fissile to platy carbonaceous shale of unit 5 (Fig. 9h, 10a). Unit 6 is the thickest package in the section and is represented by a monotonous sequence of fissile shale, which in the lower half contains abundant, more competent, horizons (Fig. 4, 10c, d). Several of these horizons contain disseminated pyrite and are associated with pyrite nodules (Fig. 10e). Small

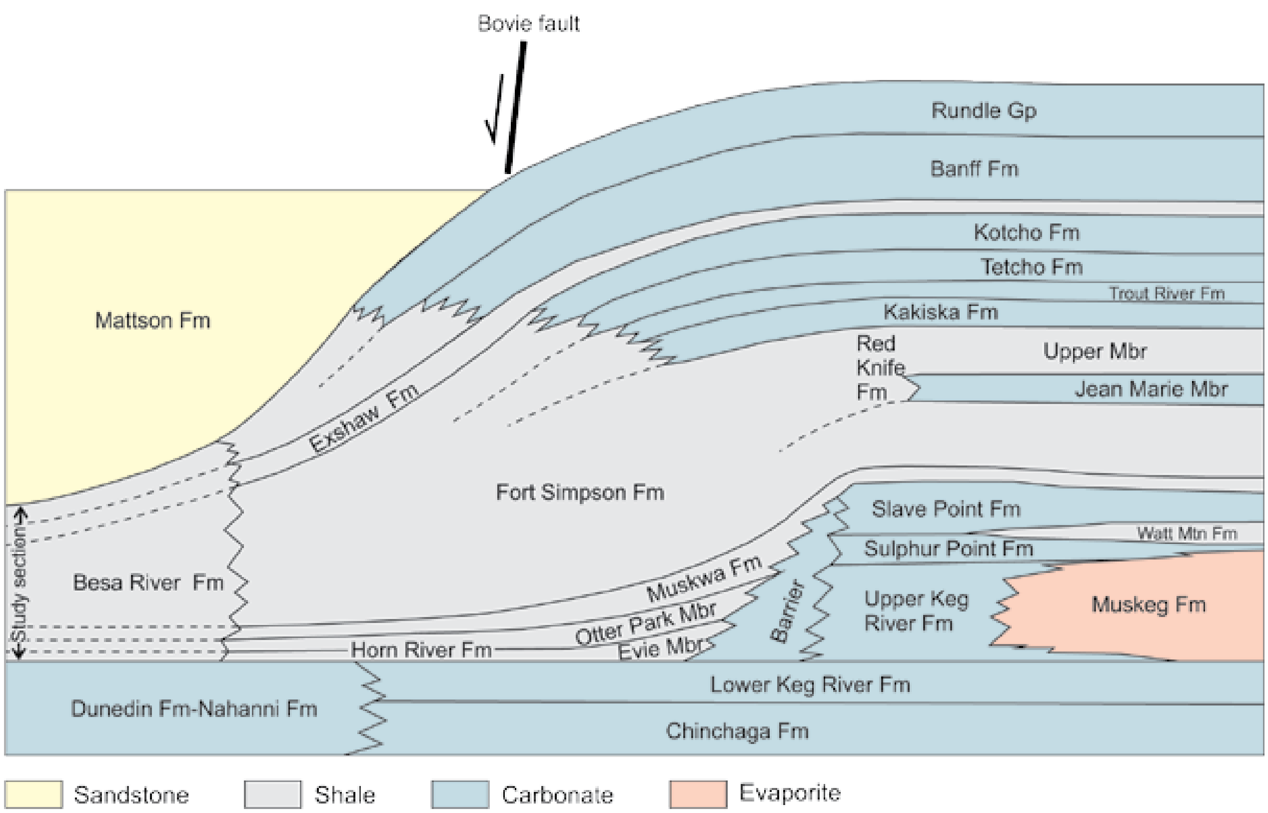

Figure 6. Schematic diagram showing relative thickness variations between middle to upper Paleozoic shelf and off-shelf sequences depicted in Figure 5.

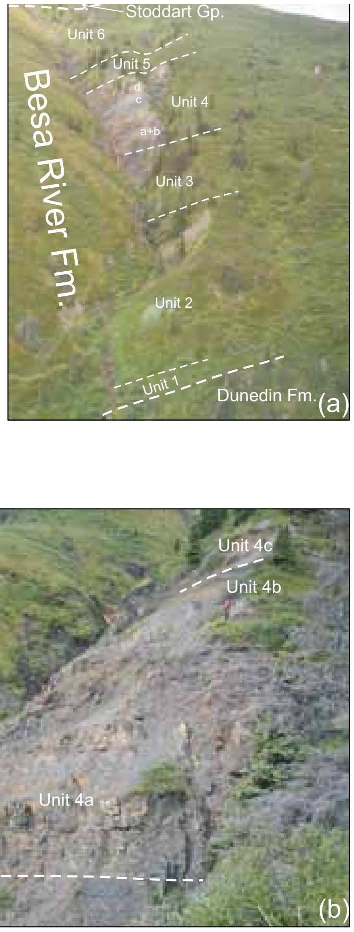

Figure 7. a) Looking west at the 2011 measured section of the Besa River Formation in the vicinity of Stone Mountain; note the light weathering characteristics of unit 4; b) looking west at more resistive, lighter grey weathering lithology of unit 4.

nodules (5–10 cm in diameter), displaying a coliform texture and having a strong fetid odour on breakage, are found along the lower part of unit 6 (Fig. 10b; 15 m level of section 2). Preliminary geochemical analysis of these nodules suggests that they are composed of barite. These nodules are found in roughly the same stratigraphic level as barite nodules observed in the Besa River section of the northern Caribou Range (Ferri et al., 2011).

Rock types spanning units 3 to 4 comprise a repetitive sequence of rock packages suggesting cyclic deposition. The sequences noted in subunits 3c to 4b, 4c to 4d and 4e to 4g define a succession repeated three times in the section (Fig. 8g–9g). The repeated sequence consists of blocky siliceous siltstone and thin shale partings (subunits 4a, b, d, g) overlain by recessive fissile shale (subunits 3c, 4c, e) that transitions upwards into more competent shale (subunits 3d, upper parts of 4c, 4f).

ANALYTICAL RESULTS

Gamma-ray Spectrometry

The trace of total gamma-ray dose (nGy/h) across the section shows several elevated zones spanning unit 1, the lower half of unit 2, across unit 5 and the lowermost part of unit 6 (Fig. 11). Generally baseline total gamma-ray levels and U content (approximately 10 ppm) are similar to the 2010 section. Zones of elevated gamma-ray levels or peaks in the 2011 section only reach intensities of 240 nGy/h, less than half the intensities recorded at the Caribou Range section (Fig. 12; Ferri et al., 2011). Uranium levels in these anomalous zones are also less than half of those seen in the 2010 section (20 versus 50 ppm, respectively) and subsequently the overall gamma-ray trace for the 2011 section is quite different from the 2010 section at the Caribou Range. Thorium levels in the 2011 section, as in the 2010 section, gradually increase towards the top of unit 6 and the relative abundance follows the concentration of K, suggesting its concentration may be tied to clay content. Potassium concentrations are as high as 4% in units 3, 4 and 6 and are at the lowest (1%) within the siliceous zone of unit 4a.

Rock-Eval and Thermal Maturity

Thermal maturity deduced by reflectance microscopy on bitumen and vitrinite range from 2.39 to 3.25% Ro_R, indicating upper dry gas conditions. The scatter of these data, when plotted against depth, does not allow the recognition of a geothermal gradient (Fig. 13).

Due to the high thermal maturity, some rock eval parameters will have questionable significance. Although total organic carbon (TOC) values are generally greater than 1 wt.%, S2 values across the section are generally less than 0.05 mg HC[1] /g rock and S1 values are normally less than 0.02 mg HC/g rock. The T_{max} values from the lowermost part of unit 1, where S2 values are the highest (0.07 mg HC/g rock) and pyrograms show a well-developed S2 peak, are approximately 530°C. The correlation of these T_{max} and average $\%Ro_R$ values are similar to empirical data presented by workers elsewhere (Fig. 14; cf. Dow, 1977; Teichmuller and Durand, 1983; Leckie et al., 1988).

Total organic carbon values range up to 8 wt.% in the upper part of unit 6 (Fig. 11) and concentrations averaging greater than 3 wt.% occur at four levels in the combined sections: unit 1 and the lower part of unit 2, the upper part of unit 3 and the lower part of unit 4, unit 5 and lower unit 6, and the upper-middle part of unit 6 (Fig. 11). Considering the level of thermal maturity displayed by these rocks, TOC levels were likely two to four times higher, depending

[1] Hydrocarbons

Figure 8. a) Fissile, crumbly shale of unit 1 between the 6 and 8.75 m levels of section 1; b) contact between fissile shale of unit 1 and more competent shales of unit 2 (9–10 m level of section 1); c) fissile to blocky shale of unit 2 between the 21 and 23 m levels of section 1; d) fissile to blocky shale of unit 2 between the 46 and 48 m levels of unit 2; e) fissile to platy shale of unit 3 between the 50 and 53 m levels of section 1; f) more fissile shale of unit 3 between the 68 to 73 m level of section 1; g) fissile to platy shale of unit 3 between the 99 and 104 m level of unit 3 section 1 (immediately below the contact with unit 4); h) competent, blocky, siliceous siltstone with fissile shale partings of unit 4 between the 108 and 109 m level of section 1.

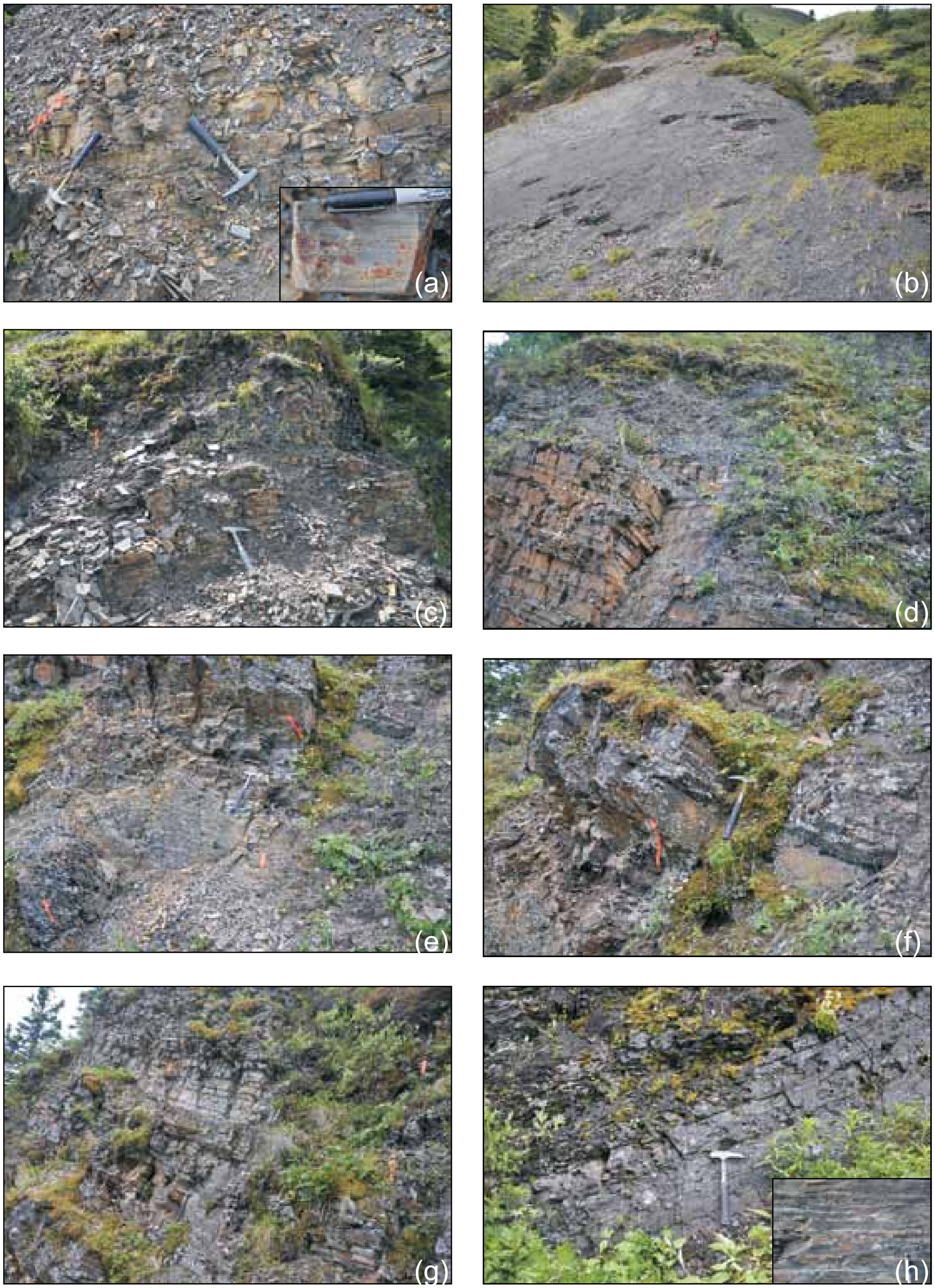

Figure 9. a) Laminated siltstone of unit 4 at the 126 m level of section 1. A close-up of this lithology and the laminations, is shown in the lower right corner inset; b) crumbly, siltstone of unit 4c between the 130 and 150 m levels of section 1; c) more competent and platy shale to siltstone of unit 4c between the 148 and 151 m levels of section 1, just below siliceous siltstone of unit 4d; there is a gradational change from the crumbly shales in the lower part of unit 4c into this lithology; rocks of unit 4d sit sharply on upper unit 4c rocks; d) upper gradational contact between siliceous siltstone and shale of unit 4d and crumbly shale of unit 4e (153 to 157 m level of section 1); e) fissile to platy shale of unit 4f between the 156 and 159 m levels of section 1, just below the contact with overlying siliceous siltstone and shale of unit 4g. This succession (units 4e to 4f to 4g is similar to that of units 4c to 4d); f) contact between units 4f and 4g (159.2 m level of section 1); g) siliceous siltstone of unit 4g between the 159 and 163 m level of section 1; note its similarity to rock types of units 4a and 4d; h) fissile to platy shale of unit 5 at the 172 m level of section 1. Inset in lower-right corner shows siliceous nodules to lenses within parts of this unit.

Figure 10. a) Siliceous nodules to lenses in fissile to platy shales of unit 5 at the 2 m level of section 2; b) close-up of barite nodules along the 15 m level of section 2 within the lower part of unit 6; inset in lower right corner shows internal structure with prismatic crystals; c) fissile to platy shale in the lower part of unit 6 between the 25 to 29 m levels of section 2; d) recessive fissile to platy shale of unit 6 between the 37 and 43 m levels of section 2. Note the more resistant siliceous bed at the 41.5 m level (close-up in inset); these more competent horizons are typically found in the lower part of unit 6; e) a 30 cm long ovoid pyrite nodule within unit 6 at the 68.5 m level of section 2. Inset is a close-up of the nodule showing the coarser pyrite crystals in its core; f) fissile to crumbly shale of the middle part of unit 6 between the 72 to 75 m level of section 2; g) uppermost fissile shale of unit 6 between the 124–128 m level of section 2; the first more resistive calcareous siltstone beds of the Stoddart Group can be seen in the upper left part of the picture; h) grey, calcareous, fine-grained sandstone horizon approximately 1 m thick at the base of the Stoddart Group, 131 m level of section 2.

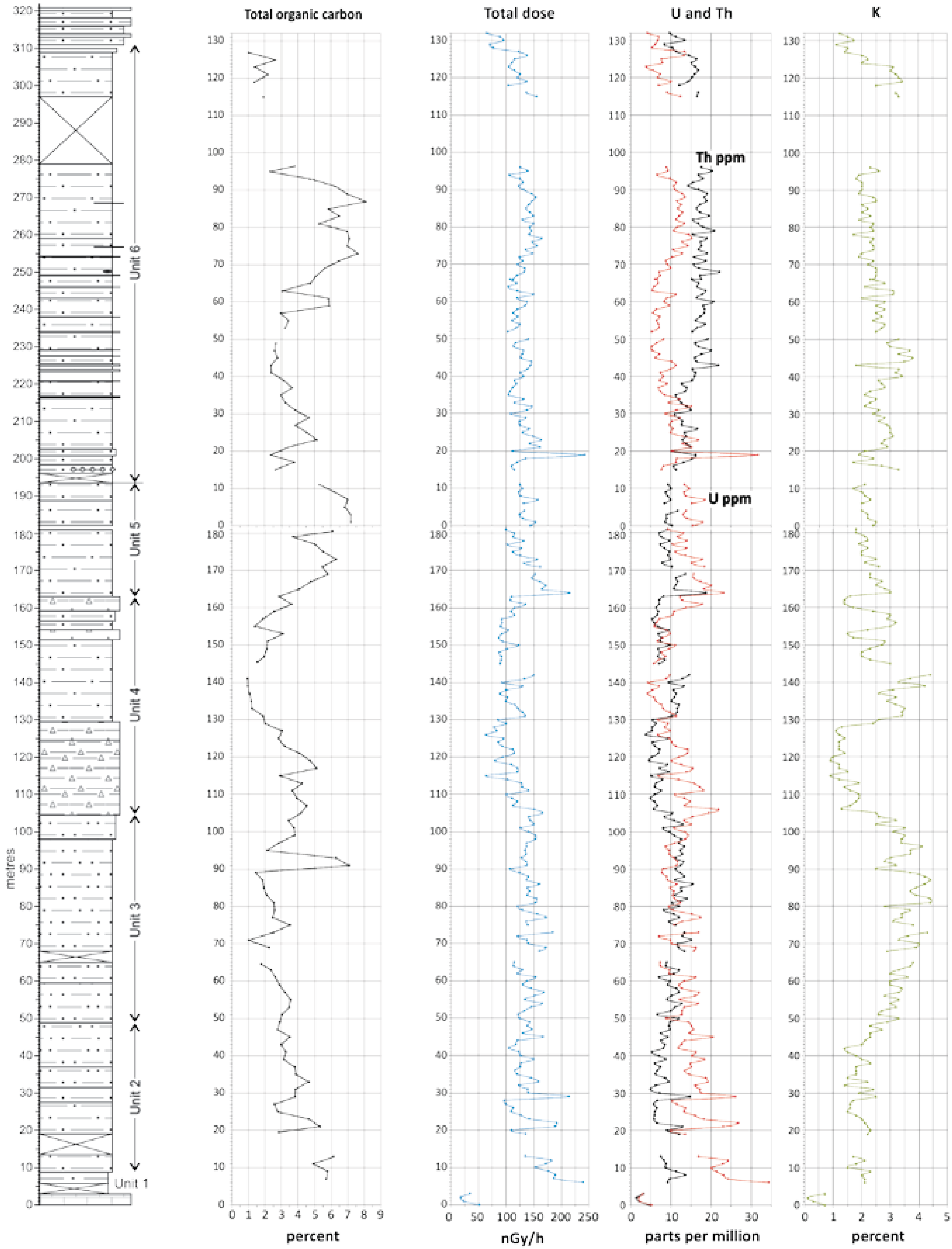

Figure 11. Lithological log of the Besa River section (Stone Mountain area) compared to total organic carbon (TOC) content, total natural radiation (dose) and U, Th and K concentrations. Natural radiation, U, Th and K were determined through a handheld gamma-ray spectrometer.

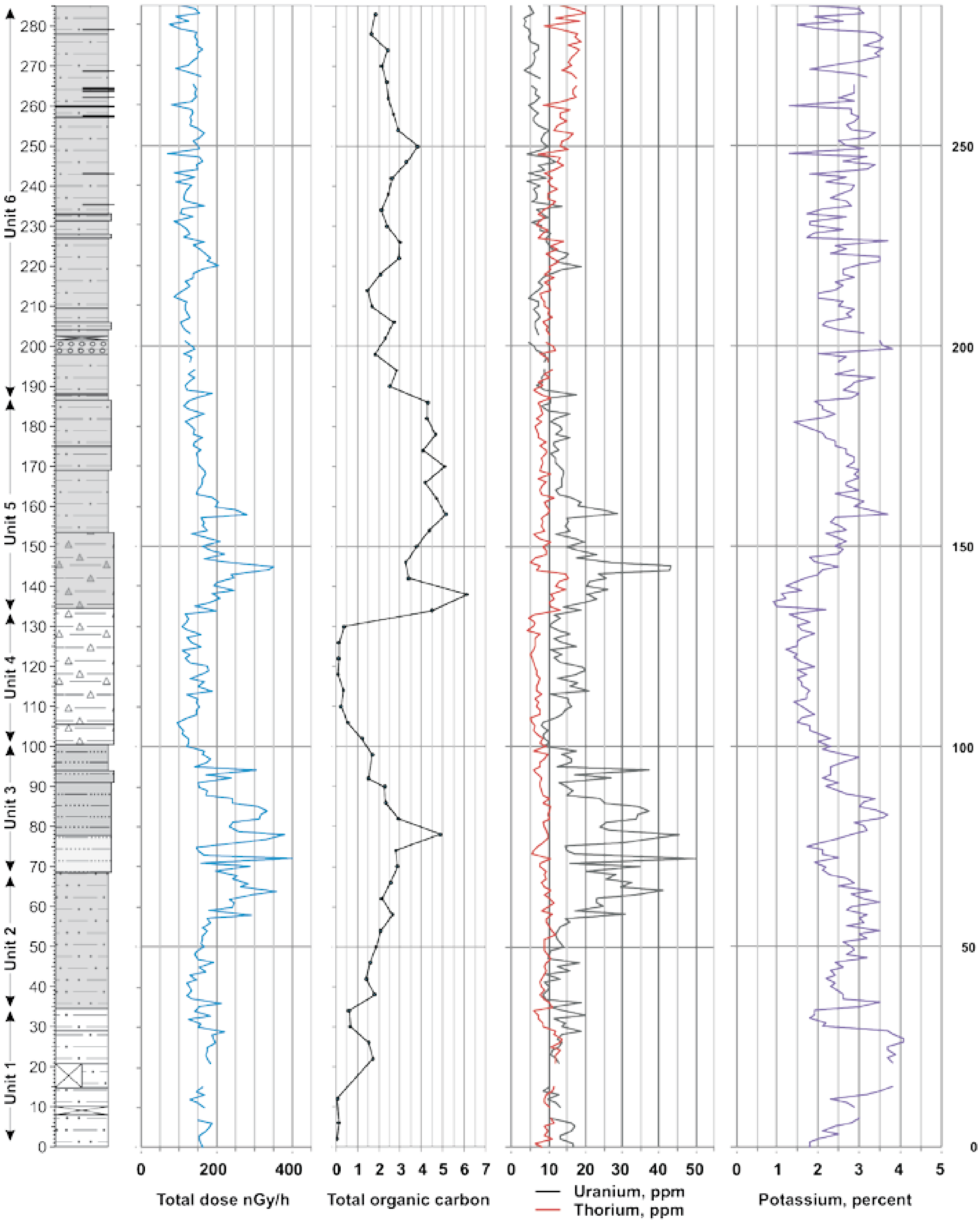

Figure 12. Lithological log of the Besa River section (Caribou Ranges) showing total organic carbon (TOC) content, total natural radiation (dose) and U, Th and K concentrations. Natural radiation, U, Th and K were determined through a handheld gamma-ray spectrometer.

on the original type of organic matter (Jarvie, 1991). The trace of TOC levels with depth generally follows gamma-ray counts and U concentrations, although the magnitude of U concentration excursions from baseline levels does not mimic increases in TOC (i.e., a fivefold increase in TOC content does not equate with a similar increase in U concentrations). In the 2010 section, tripling or quadrupling TOC levels led to roughly similar increases in U content. Empirical evidence from subsurface petrophysical logs has shown that 'hot' gamma-ray zones (i.e., higher than normal

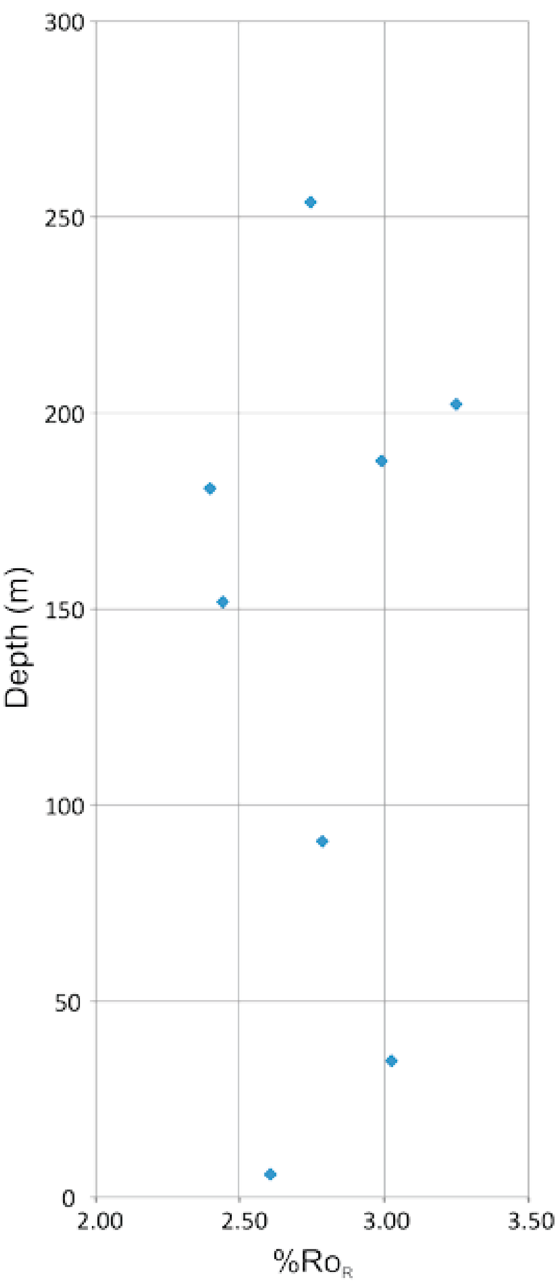

Figure 13. Thermal maturation levels within the measured section based on reflected light microscopy of bitumen and vitrinite macerals. All data has been converted to vitrinite-equivalent values.

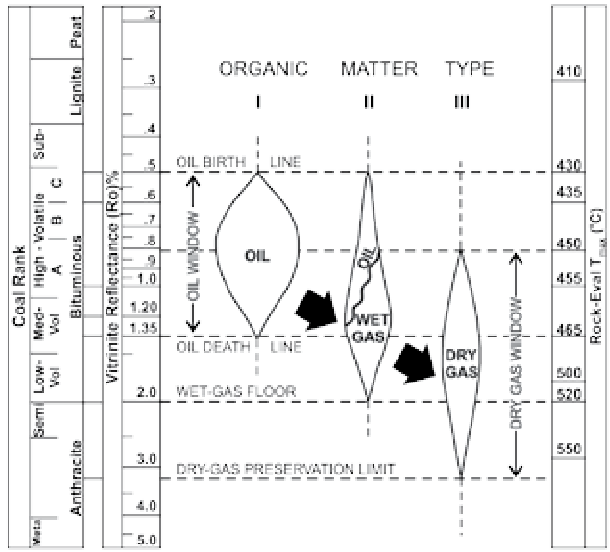

Figure 14. Zones of petroleum generation and destruction for various types of organic matter with reference to coal rank, vitrinite reflectance and Tmax values from Rock Eval analysis (modified from Leckie et al., 1988; cf. Dow, 1977; Teichmuller and Durand, 1983).

U levels) usually correlate with elevated TOC content. This relationship is evident within parts of the current section (i.e., units 1, 2, 5 and the lower part of unit 6), but the correlation fails for the upper-middle part of unit 6, where TOC levels are greater than 4 wt.% over 30 m, with some peaks over 7 wt.%, yet U concentrations increase by only 2.5 times (Fig. 11). The trace of total gamma rays across this zone would not suggest the elevated organic carbon levels within this horizon. This discrepancy may be a surface phenomenon related to oxidation. This shale was deposited under highly reducing conditions, which led to the concentration of U together with other metals. Oxidation of iron sulphides and the subsequent increase in the Eh of surface waters (i.e., acidification) may have led to greater mobility and leaching of U and other metals at the surface.

CORRELATIONS

The 2011 measured section of the Besa River Formation is tentatively correlated with similar sequences in the subsurface, particularly those of the Horn River succession within the Horn River basin. This is based on stratigraphic position, lithology and the outcrop-derived gamma-ray log. The edge of Slave Point carbonate deposition, which defines the southern limit of the Horn River basin, is believed to extend westward into the disturbed belt (Fig. 2). This edge likely swings southward within the disturbed belt, following the trend of the eastern margin of the Kechika Trough connecting with the upper Dunedin carbonate shale-out (upper Keg River to Slave Point) that has been defined in the Williston Lake area (Thompson, 1989; Nadijwon, 2001). A northwest-trending cross section incorporating the measured section and several nearby wells was constructed across the western margin of the Horn River basin and extending into the southern end of the younger Liard basin (Fig. 2).

Due to the rapid southeast increase in the thickness of the Fort Simpson Formation, only five wells that include the Exshaw Formation are incorporated into this cross section (Fig. 15). Reasonably confident correlations of the lower part of the measured section (unit 1 and lower half of unit 2) and subsurface sequences likely associated with the Evie marker of the Horn River succession can be achieved from gamma-ray patterns (Fig. 15). Overlying rocks, up to the base of the lower thick siliceous section of unit 4a, display gamma-ray patterns very similar to those assigned to the Muskwa marker in the subsurface. Gamma-ray spikes displayed within unit 5 and the lower part of unit 6 are correlated with markers assigned to the Exshaw Formation (Fig. 15). This would suggest that the siliceous successions of unit 4 are equivalent to the succession within the Fort Simpson to Kotcho formations. Although blocky siliceous siltstone to shale of unit 4 in the 2011 section has comparable thickness, lithological character and occupies the same stratigraphic position as unit 4 in the 2010 section, the organic carbon content of unit 4 in the 2011 section is considerably higher. The high organic carbon levels of unit 4a are not reflected by the relatively low levels of gamma-ray counts (Fig. 15).

The organic-rich horizon within the upper-middle part of unit 6 was not observed in the 2010 section. Corresponding gamma-ray levels in the 2010 section are subdued across this zone and correlation into the subsurface is difficult. This zone, between the Exshaw and Mattson formations and Stoddart sequences, correlates, in part, with the western shale-out of Rundle Group–equivalent strata (i.e., the Prophet Formation).

CONCLUSIONS

- Approximately 310 m of shale and siltstone belonging to the Middle Devonian to Middle Mississippian Besa River Formation were measured in the vicinity of the Stone Mountain area of northeastern British Columbia.
- The 2011 Besa River Formation section in the Stone Mountain area is broadly similar to that measured in the Caribou Ranges during the 2010 field season. Both are roughly of the same thickness and have a lighter weathering, siliceous siltstone package near the middle part of the succession.
- Peak natural gamma-ray levels (and uranium contents) of the 2011 section are half the levels seen in the 2010 section.
- Correlation of the surface gamma-ray log with the subsurface section to the southeast and northeast indicates the presence of the Evie, Muskwa and Exshaw markers at the surface. This exercise also allows correlation between the 2010 and 2011 sections, confirming subsurface correlations of Besa River rock types in the Caribou Range.
- Rock eval analysis indicates TOC levels of 5–7 wt.% within Evie-, Muskwa- and Exshaw-equivalent strata. In addition, there is another zone of high TOC (up to 8 wt.%) above the Exshaw marker, within the upper part of the Besa River Formation.

ACKNOWLEDGMENTS

The authors thank Gabriel Altebaumer of the Geological Survey of Canada for enthusiastic and competent assistance in the field. Thanks also to Margot McMechan of the Geological Survey of Canada for the use of the gamma-ray spectrometer. Bailey Helicopters Ltd. provided competent service in the location and demobilization of the field camp.

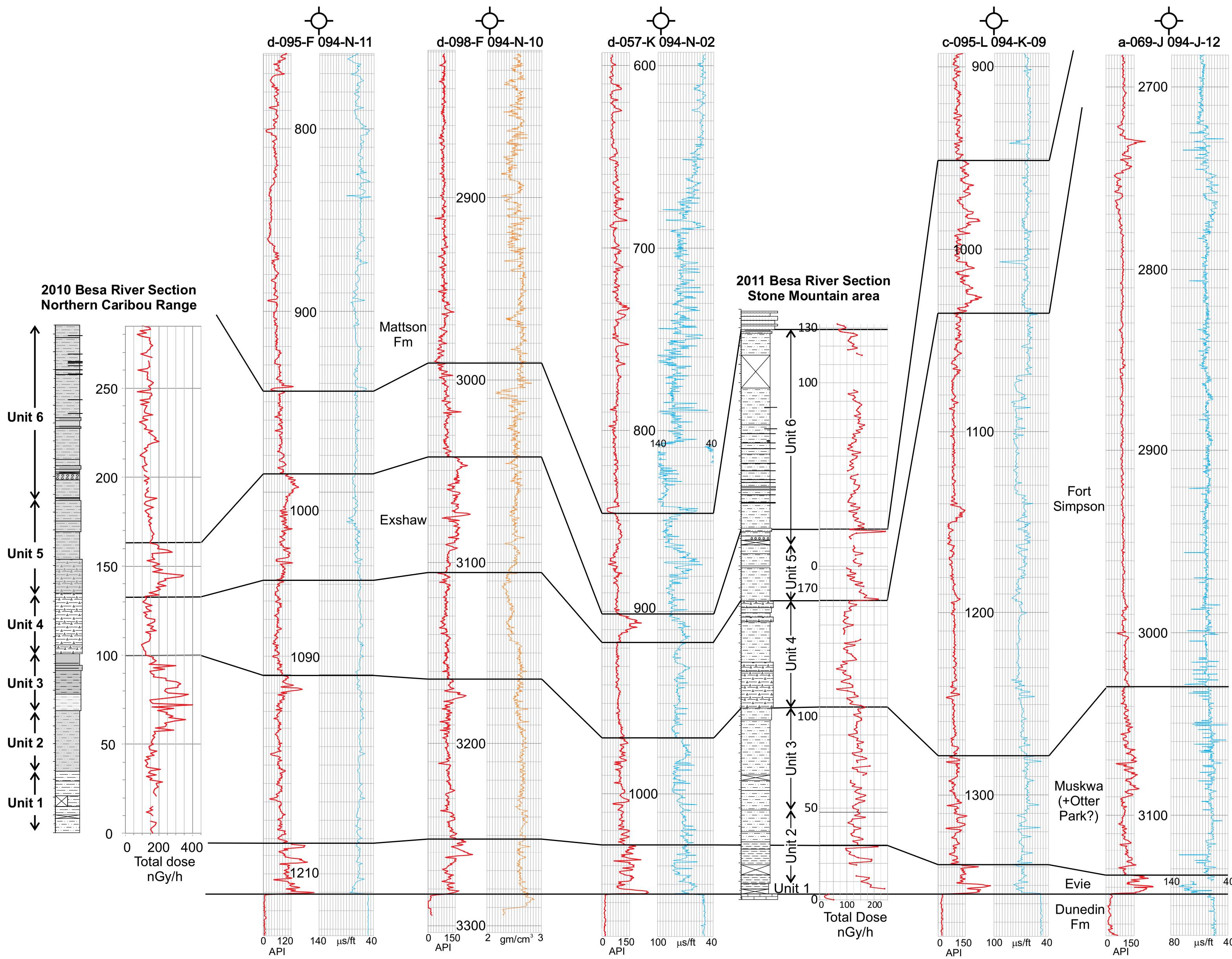

Figure 15. Correlation of the 2011 measured section of the Besa River Formation (Stone Mountain area), several nearby subsurface gamma-ray sections from well-bores, and the 2010 measured section of the Besa River Formation (Caribou Ranges). Location of the section is shown in Figure 2.

REFERENCES

Bamber, E.W., Taylor, G.C. and Procter, R.M. (1968): Carboniferous and Permian stratigraphy of northeastern British Columbia; *Geological Survey of Canada*, Paper 68-15, 25 pages.

Dow, W.G. (1977): Kerogen studies and geological interpretations; *Journal of Geochemical Exploration*, Volume 7, pages 79–99.

Ferri, F., Hickin, A.S. and Huntley, D.H. (2011): Besa River Formation, western Liard Basin, British Columbia (NTS 094N): geochemistry and regional correlations; in Geoscience Reports 2011, *British Columbia Ministry of Energy and Mines*, pages 1–18.

Halbertsma, H.L. (1959): Nomenclature of Upper Carboniferous and Permian strata in the subsurface of the Peace River area; *Journal of the Alberta Society of Petroleum Geologists*, Volume 7, pages 109–118.

Huntley, D.H. and Hickin, A.S. (2010): Surficial deposits, landforms, glacial history and potential for granular aggregate and frac sand: Maxhamish Lake map sheet (NTS 94O), British Columbia; *Geological Survey of Canada,* Open File 6430, 17 pages.

Huntley, D.H. and Sidwell, C.F. (2010): Application of the GEM surficial geology data model to resource evaluation and geohazard assessment for the Maxhamish Lake map area (NTS 94O), British Columbia; *Geological Survey of Canada*, Open File 6553, 12 pages.

Jarvie, D.M. (1991): Total organic carbon (TOC) analysis; in Source Migration Processes and Evaluation Techniques, Merrill, R.K., Editor; *American Association of Petroleum Geologists*, Treatise of Petroleum Geology, pages 113–118.

Leckie, D.A., Kalkreuth, W.D. and Snowdon, L.R. (1988): Source rock potential and thermal maturity of Lower Cretaceous strata, Monkman Pass area, British Columbia; *American Association of Petroleum Geologists*, Bulletin 72, pages 820–838.

Massey, N.W.D., MacIntyre, D.G., Desjardins, P.J. and Cooney, R.T. (2005): Digital geology map of British Columbia: whole province; *British Columbia Ministry of Energy and Mines*, GeoFile 2005-1.

McMechan, M.E., Ferri, F. and MacDonald, L. (2012): Geology of the Toad River area (NTS 094N), northeast British Columbia; *in* Geoscience Reports 2012, B*ritish Columbia Ministry of Energy and Mines*, pages 17-39.

Mossop, G.D., Wallace-Dudley, K.E., Smith, G.G. and Harrison, J.C., Compilers (2004): Sedimentary basins of Canada; *Geological Survey of Canada*, Open File Map 4673.

Nadijwon, L.M. (2001): Facies analysis, diagenesis and correlations of the Middle Devonian Dunedin and Keg River formations, northeastern British Columbia; MSc thesis, *University of Waterloo*, Waterloo, Ontario, 221 pages.

Okulitch, A.V. (2004): Geological time chart, 2004; *Geological Survey of Canada*, Open File 3040.

Petrel Robertson Consulting Ltd. (2003): Exploration assessment of deep Devonian gas plays, northeastern British Columbia; *British Columbia Ministry of Energy and Mines*, Petroleum Geology Open File 2003-4.

Taylor, G.C. and Stott, D.F. (1973): Tuchodi Lakes map area, British Columbia; *Geological Survey of Canada,* Memoir 373, 37 pages.

Teichmuller, M. and Durand, B. (1983): Fluorescence microscopical rank studies on liptinites and vitrinites in peat and coals, and comparison with results of the rock-eval pyrolysis; *International Journal of Coal Geology*, Volume 2, pages 197–230.

Thompson, R.I. (1989): Stratigraphy, tectonic evolution and structural analysis of the Halfway River map area (94B), northern Rocky Mountains, British Columbia; *Geological Survey of Canada*, Memoir 425, 119 pages.