Bedded Barite-Pyrite Occurrences in upper Besa River Formation, western Liard Basin, British Columbia and Regional Correlations with Devonian to Mississippian Sub-surface Formations

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KEYWORDS: Liard Basin, Horn River Basin, Liard River, Toad River, Caribou Range, Besa River Formation, gamma ray, oil, gas, pyrite, barite, mineralization, Earn Group, Kechika Trough

INTRODUCTION

The Geoscience and Natural Gas Development Branch of the British Columbia Ministry of Energy, in conjunction with the Geological Survey of Canada, undertook an examination of outcrop exposures of Middle Devonian to Early Mississippian siltstone sequences of the Besa River Formation which are equivalent, in part, to rocks currently being exploited for natural gas resources in the Horn River Basin and to sections being examined for similar potential in the Liard Basin (Figures 1, 2). The main objective was to delineate shale gas-equivalent horizons in outcrop so that they could be used as potential reference sections to aid in understanding of the subsurface geological setting in Horn River Basin. Characterization of the section was accomplished through lithologic description and collection of samples for lithologic and organic geochemistry, and geochronological analysis. In addition, a gamma ray spectroscopic survey of the outcrop was performed for use in correlating the section with subsurface sequences in the Liard and Horn River basins. During the course of this investigation several horizons of bedded and disseminated pyrite, together with a horizon of nodular barite, were observed within the upper part of the Besa River section. This report summarizes findings related to this sulphide-barite mineralization. A more in depth description of the results as they pertain to the natural gas potential of the sequence can be found in Ferri *et al.* (2011).

This study is part of a collaborative program between the Geological Survey of Canada and the British

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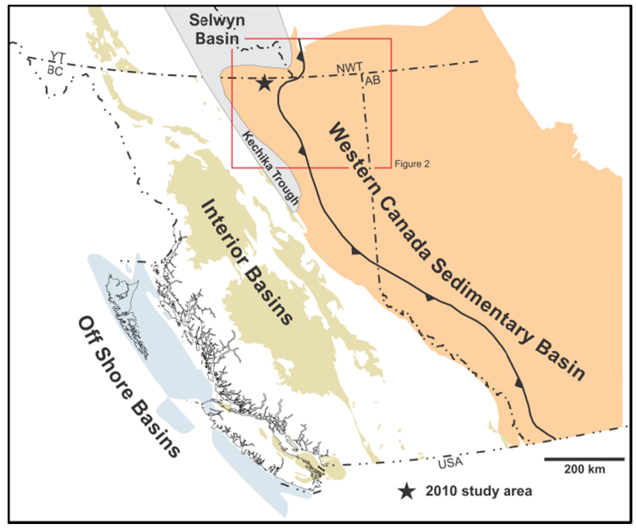

Figure 1. Location of the Liard Basin with respect to the principal sedimentary basins of western Canada. Also shown are the Lower Paleozoic off-shelf depocentres of the Selwyn Basin and Kechika Trough. Red box outlines area of Figure 2.

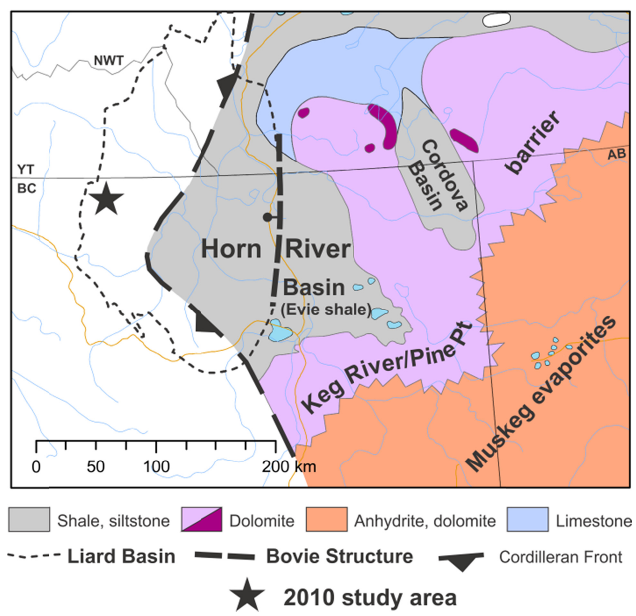

Figure 2. Schematic representation of the Horn River Basin (and Codorva Basin) during upper Keg River times (Givetian). Superimposed on this is the outline of the Liard Basin. This reef/carbonate/shale basin configuration persisted until the end of Slave Point times (end of Givetian; modified from Meijer Drees, 1994; outline of Liard Basin from Mossop *et al.*, 2004).

Columbia Ministry of Energy, and is under the umbrella of the federal government's Geo-mapping for Energy and Minerals program (GEM) that is specifically examining petroleum related geoscience of the Liard and Horn River basins. A major focus of this program has involved mapping of resources associated with surficial geology that are used during drilling and completion of shale gas wells (Huntley and Sidwell, 2010; Huntley and Hickin, 2010).

LOCATION AND REGIONAL GEOLOGY

The Liard Basin is located in northeastern British Columbia, straddling the British Columbia – Yukon – Northwest Territories border (Figures 1, 2), spanning NTS map sheets 094N and O, and 095B and C. It is traversed by the Liard River and defines a relatively high plateau between the southern Selwyn Mountains and northern Rocky Mountains. Highway 77 runs along the eastern half of the basin and joins with the Alaska Highway, which cuts across the southern margin. Numerous petroleum development roads and forestry access roads extend from these two main highways across parts of the basin. Vehicle access across the Liard River is provided by a barge which originates at Fort Liard, Northwest Territories and terminates south of the confluence of La Biche River, where a road connects to the Beaver River gas field (Figure 3).

The Liard Basin was originally defined on the basis of the thick Late Paleozoic succession in southeastern Yukon by Gabrielse (1967) and extended into northeastern British Columbia by Morrow *et al.* (1993) and Richards *et al.* (1994; Figures 4, 5). The Liard Basin formed subsequent to the Horn River Basin and is superimposed on the western part of the Horn River Basin Figure 2). The Bovie Lake structure marks the eastern margin of the Liard Basin, west of which is found an anomalously thick section of the Mississippian Mattson Formation (Figure 4). Subsequent Late Cretaceous movement on this fault has also preserved a thick sequence of Early to Late Cretaceous rocks within the confines of the basin (Leckie *et al.*, 1991). Although development of the Liard Basin had no influence on depositional facies and thicknesses within pre-Mattson Formation units with shale gas potential (*i.e.* Muskwa, Horn River formations), its initiation has effectively marked the current western limit of shale gas development in the Horn River Basin. Prospective shale horizons in eastern Horn River Basin (Figure 2) have been dropped deeper by some 2000 m west of the Bovie fault (Figure 4), imposing drilling and completion challenges. A consequence of this within the Liard Basin, has been a shift to the exploitation of the stratigraphically higher Exshaw Formation, which is at a depth and thermal maturation that potentially can be economically developed for its shale gas resources.

The Middle Devonian to Middle Mississippian Besa River Formation represents the western basinal equivalents of predominantly carbonate successions between the Upper Keg River and Debolt Formation (Figures 4, 5). Further west, in the Selwyn basin and Kechika Trough, these rocks correlate with the Devono-Mississippian Earn Group (Figure 6). Selwyn Basin and Kechika Trough are deep water equivalents to Early Paleozoic carbonate shelf deposition along the Western Canada Sedimentary Basin (MacDonald Platform; Ferri *et al.*, 1999) and are filled primarily by shales and siltstones of the Kechika and Road River groups.

In the study area, Besa River shales and siltstones sit above carbonates of the Middle Devonian Dunedin Formation, which can be traced westward into the subsurface where it is equivalent to parts of the Chinchaga and Lower Keg River formations (Meijer Drees, 1994; Figure 5). During Upper Keg River and Slave Point deposition, a well defined barrier reef complex developed that marked the eastern limit of the Horn River Basin (Oldale and Munday, 1994; Figure 2). West of the barrier edge, shales of the Horn River Formation include two members, a lower radioactive, bituminous shale assigned to the Evie Member, overlain by shales of the Otter Park Member (Figures 4, 5). A transgression followed Slave Point deposition and pushed the shallow carbonate edge eastward (Leduc facies), leading to deposition of highly bituminous shales of the Muskwa Formation (Duvernay equivalent; Switzer *et al.*, 1994). Carbonate conditions were re-established to the west during Frasnian and Famennian times, resulting in deposition of Kakiska to Kotcho formations along a broad shelf (Figures 4, 5). A major transgression occurs across the Devono-Mississippian boundary, represented by deposition of the highly radioactive and bituminous shales of the Exshaw Formation. Carbonate deposition again migrated westward in Early Carboniferous times, with the deposition of the Banff Formation and succeeding Rundle Group.

In the subsurface, shales of the Fort Simpson Formation encompass the westward shale-out of carbonate units above the Muskwa Formation. Carbonates of the Banff Formation and Rundle Group disappear into basinal shales above the Exshaw Formation and transition into the Besa River Formation (Figures 4 and 5). Approximately 300 m of Besa River siltstones and shales equates to over 2000 m of carbonate and siltstone section along the Keg River barrier edge.

The upper part of the Besa River Formation interfingers with the Middle to Late Mississippian sandstones, siltstones and minor carbonates of the Mattson Formation. These exceed 1000 m in thickness within the Liard Basin west of the Bovie fault structure. This fault has been interpreted as a Late Paleozoic extensional structure that was later re-activated during Laramide compression (Wright *et al.*, 1994). This is based on the preservation of thick Mattson sands, and succeeding Kindle Formation, below the Permian Fantasque Formation west of the Bovie fault whereas only a thin Mattson section occurs below the Fantasque Formation east of the fault (Monahan, 2000; MacLean

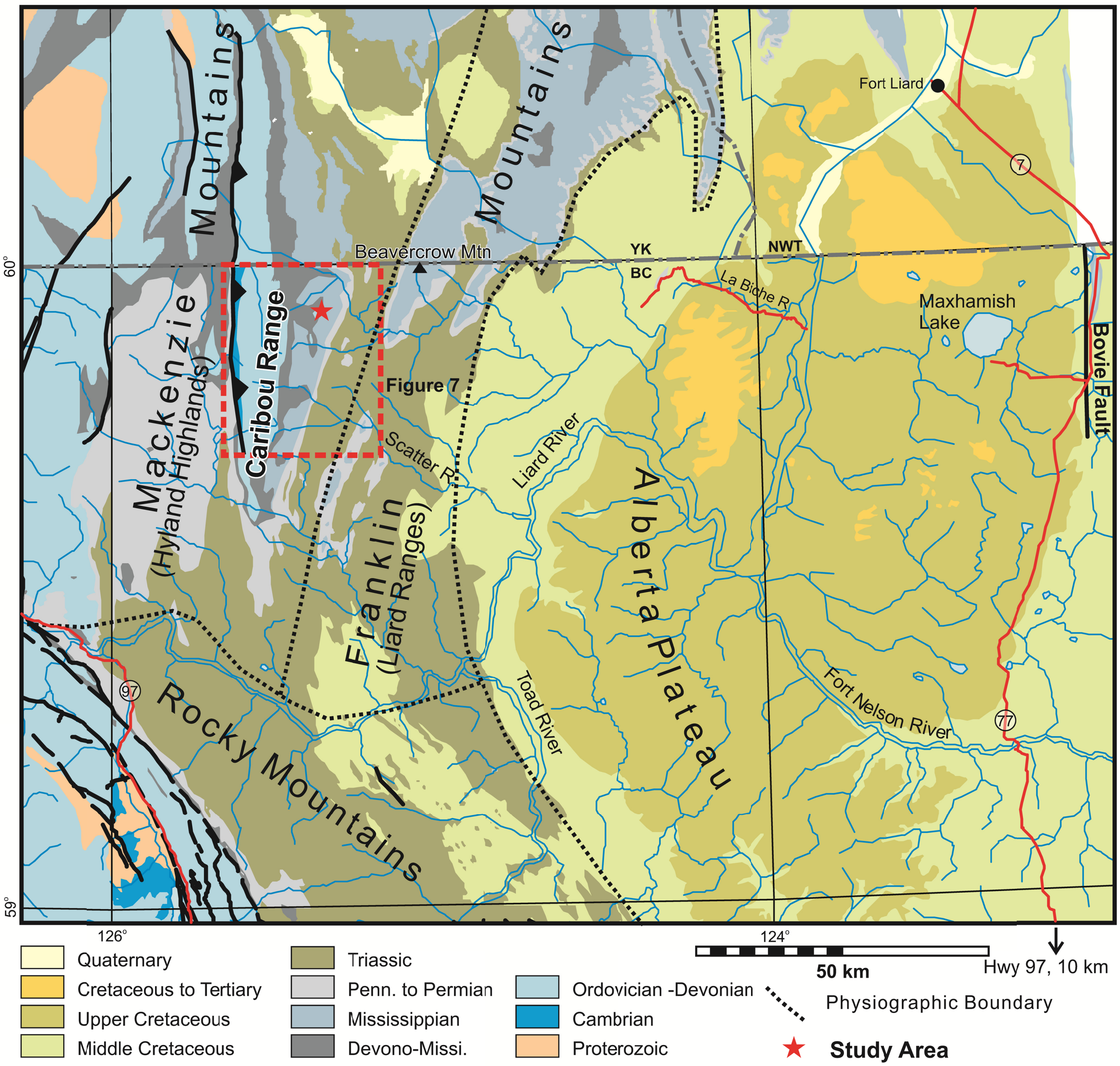

Figure 3. Geology of the western portion of the Liard Basin. Box outlines the geology depicted in Figure 7. Geology from MapPlace.ca (URL: http://www.mapplace.ca/).

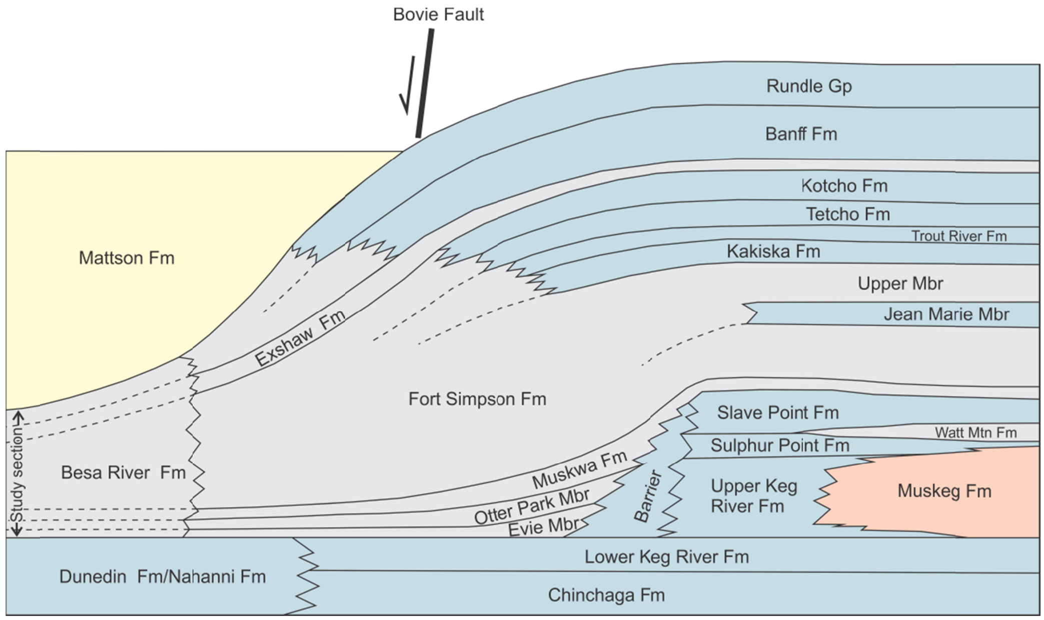

Figure 4. Schematic diagram showing relative thickness variations between mid to Upper Paleozoic shelf and off-shelf sequences depicted in Figure 5.

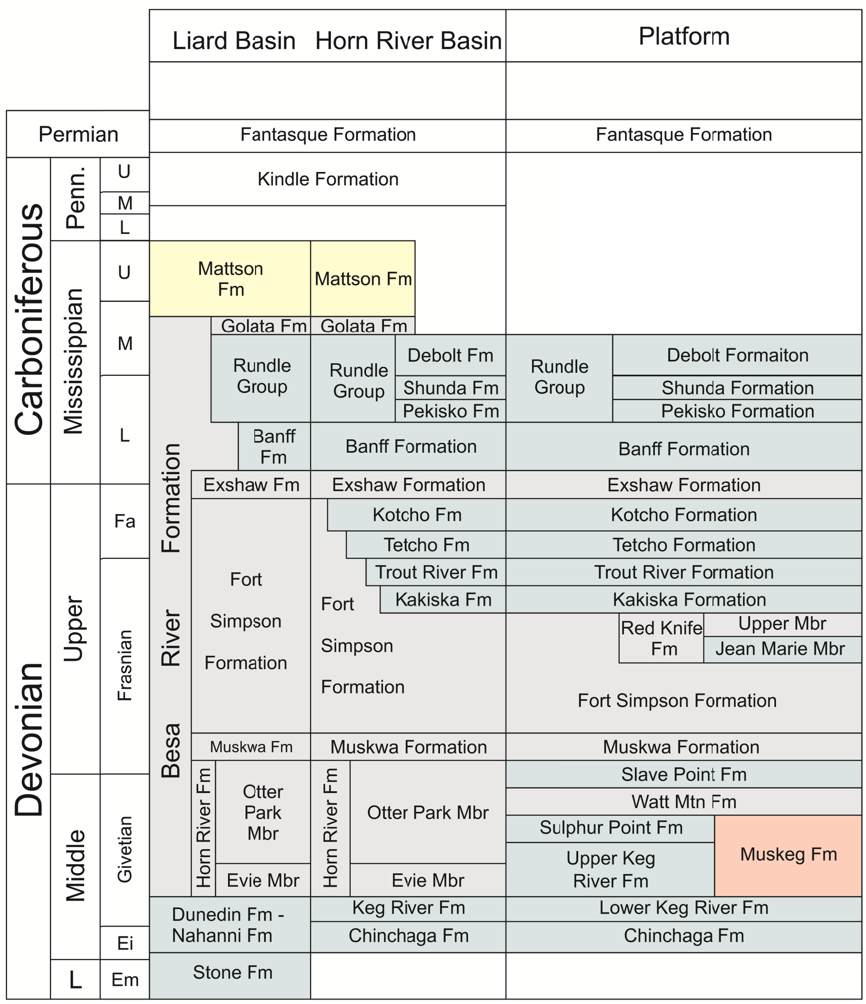

Figure 5. Time stratigraphic chart of the mid to Upper Paleozoic showing the main stratigraphic units along the northwestern part of the Western Canada Sedimentary Basin falling within northeastern British Columbia and the relationship between shelf and off-shelf sequences.

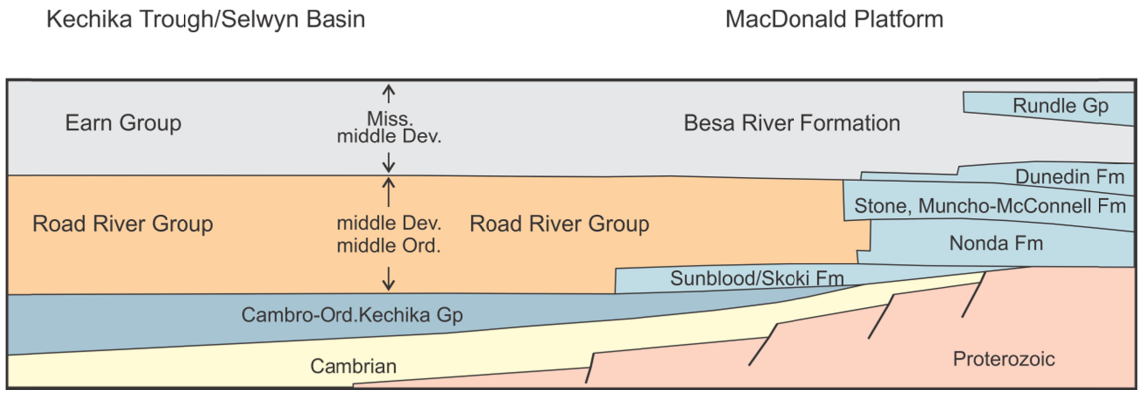

Figure 6. Schematic representation of westward shale-out of Lower Paleozoic carbonates into Road River siltstone and shales within the Kechika Trough and Selwyn Basin, and the relationship between the Besa River Formation and the Earn Group.

and Morrow, 2004). In addition, the westerly directed thrust associated with the Bovie fault structure, is probably related to compressional re-activation of this graben structure (McLay and Buchanan, 1992). This pre-existing fault allowed compressional structures to form outboard of major Laramide structures (Figure 3). MacLean and Morrow (2004), using seismic data, interpret Bovie fault as having Late Paleozoic and Mesozoic compressional tectonics followed by extension in the Cretaceous. Mattson clastics are part of a slope to delta plain and shallow marine sandstone succession that was sourced from the north (Bamber *et al.*, 1991). These rocks correlate with similar deposits of the Carboniferous Stoddart Group, deposited within the Late Paleozoic Dawson Creek graben complex (Barclay *et al.*, 1990). Deltaic deposits of the Mattson Formation disappear westward and are replaced by upper Earn Group siltstones and shales within the Kechika Trough.

To the west, within the Kechika Trough and Selwyn Basin, Besa River shales and siltstones correlate with the Middle Devonian to Early Mississippian Earn Group (Ferri *et al.*, 1999; MacIntyre, 1998; Paradis *et al.*, 1998). These deeper water siliciclastic strata overlie Middle Ordovician to Middle Devonian siltstone, shale and minor carbonate of the Road River Group, representing basinal equivalents of coeval carbonates of the MacDonald Platform (Figure 6).

The Kechika Trough and Selwyn Basin host widespread and locally significant sedimentary exhalative (SEDEX) Pb-Zn-Ba deposits within the Earn Group, including the Cirque, Driftpile Creek and Akie deposits of the Kechika Trough (Paradis *et al.*, 1998; MacIntyre, 1998) and the Tom and Jason deposits of the Selwyn Basin (Goodfellow and Lydon, 2007). Major sulphide mineralization is of Late Devonian age (Frasnian to Famennian), although barite mineralization with minor sulphides also occurs in Early Mississippian sections (Tournaisian; Paradis *et al.*, 1998; Irwin and Orchard, 1991).

Besa River rocks examined during the 2010 field season are located within the northern part of the Caribou Range, part of the southern Hyland Highlands and represent the southernmost extent of the Mackenzie Mountains (Mathews, 1986). The broad highland that constitute the Caribou Range is underlain by a westwardly directed thrust panel of gently, east dipping Paleozoic rocks (Figures 3, 7). These north to northeast-striking rocks follow the general trend of structures within the Mackenzie and Franklin mountains, and are at almost right angles to the northwest structural grain of the Rocky Mountains, resulting in the large bend in the trace of major structures across the Liard River (Figure 3). Furthermore, the southern portion of the Mackenzie and Franklin mountains represents a portion of the Foreland Belt dominated by west-verging structures, compared to overall northeast vergence (see Fallas *et al.*, 2004).

Rocks as old as Cambrian are mapped within the Caribou Range, although these can be traced northward into the Yukon where they assigned a Proterozoic age (Taylor and Stott, 1999; Fallas *et al.*, 2004). Cambrian siliciclastics are succeeded by shelf carbonates of the Nonda, Muncho-McConnell, Wokpash, Stone and Dunedin formations of broadly Silurian to Middle Devonian age (Figure 7). Generally, rocks of the Besa River Formation overlie the Dunedin Formation, although in the north, all of the Dunedin and parts of the upper Stone formations shale out into the Besa River Formation (Taylor and Stott, 1999; Figure 7).

In British Columbia, the regional geological data base in the vicinity of the section includes mapping within Toad River (Taylor and Stott, 1999), Tuchodi Lakes (Stott and Taylor, 1973) and Rabbit River (Gabrielse, 1963; Ferri *et al.*, 1999) map areas. In Yukon and Northwest Territories, La Biche River (095C) has been compiled at 1:50 000 (Fallas, 2001; Fallas and Evenchick, 2002) and 100 000 scales (Fallas *et al.*, 2004). The Besa River Formation was first defined by Kidd (1963) north of the Muskwa River, and Pelzer (1966) further described its mineralogy and broad stratigraphy. The organic petrography and thermal maturity of similar rocks in Yukon and Northwest Territories were described by Potter *et al.*, (1993) and Morrow *et al.* (1992). A recent sub-surface evaluation of Devono-Mississippian fine clastic sequences was published by Ross and Bustin

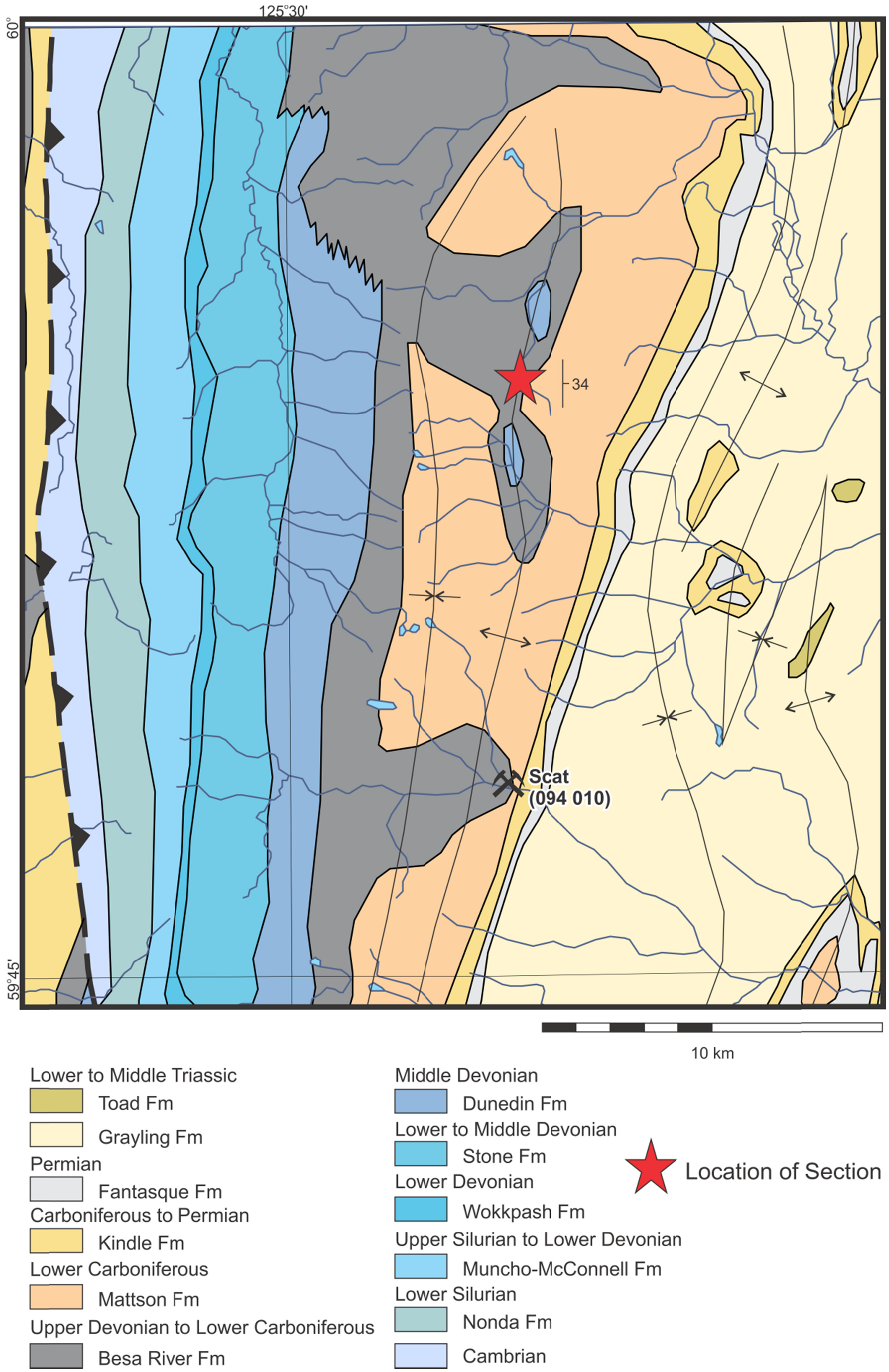

Figure 7. Geology of the Caribou Range, showing the location of the measured section. Geology from MapPlace.ca (URL: http://www.mapplace.ca/).

(2008) which included Besa River rocks within the Liard Basin area. An assessment of the conventional hydrocarbon resources of the Liard Basin was produced by Monahan (2000).

METHODOLOGY AND RESULTS

A nearly complete section of Besa River Formation was measured and described through use of a 1.5 m staff along a west-facing valley, approximately 22 km southwest of Beavercrow Mountain (base of section; UTM 367107E, 6643192N; Zone 10, NAD 83; Figure 7). Representative chip samples were acquired across 2 m intervals along the entire section. Samples were split, with one group being analysed for whole rock, trace and rare earth element abundances at Acme Analytical Laboratories in Vancouver, and a second group, at 4 m spacings, for Rock Eval analysis at Geological Survey of Canada (GSC) laboratories in Calgary. A smaller sub-set of these samples will also be analysed by x-ray diffraction (XRD) at GSC laboratories for semi-quantative determination of mineral abundances. Another subset will be processed for their potential to contain palynomorphs for biostratigraphy. Separate samples were collected for thermal maturity determination at GSC laboratories in Calgary through reflected light microscopy. In addition, a hand held gamma ray spectrometer (RS-230 by Radiation Solutions Inc.) was used to measured natural gamma radiation every 1 m over a 2 minute time interval allowing the calculation of K (%), U (ppm), Th (ppm) and total gamma ray count. Data were plotted against depth and variation in total natural radiation along the section is approximately equivalent to the subsurface gamma ray trace routinely collected in oil and gas wells. This assists in the correlation of the outcrop section with equivalent rocks in the subsurface.

Approximately 285 m of siltstone and shale belonging to the Besa River Formation were measured west of Beavercrow Mountain (Figure 8). The upper and lower parts of the Besa River Formation were not exposed, but examination of rocks to the north indicate approximately 15 m of missing Besa River rocks below the base of the Mattson Formation, and a structural section suggests some 25 m of covered rocks above the Dunedin Formation.

Generally, the Besa River Formation consists of dark grey to black, carbonaceous siltstone and shale (Figure 8). Besa River rocks along the measured section can be subdivided into 6 units consisting of, from the base (Figure 9); 1) Tan to orange-brown or beige weathering, dark grey to black carbonaceous siltstone to blocky siltstone with shale partings (34 m; Figure 10a); 2) 34 m of dark grey to beige weathering, dark grey to black, fissile to blocky carbonaceous siltstone; 3) Rusty to grey or dark grey weathering, dark grey to black carbonaceous blocky siltstone and shale (32 m; Figure 10b); 4) Rusty to light grey weathering, grey to light grey, blocky to platy

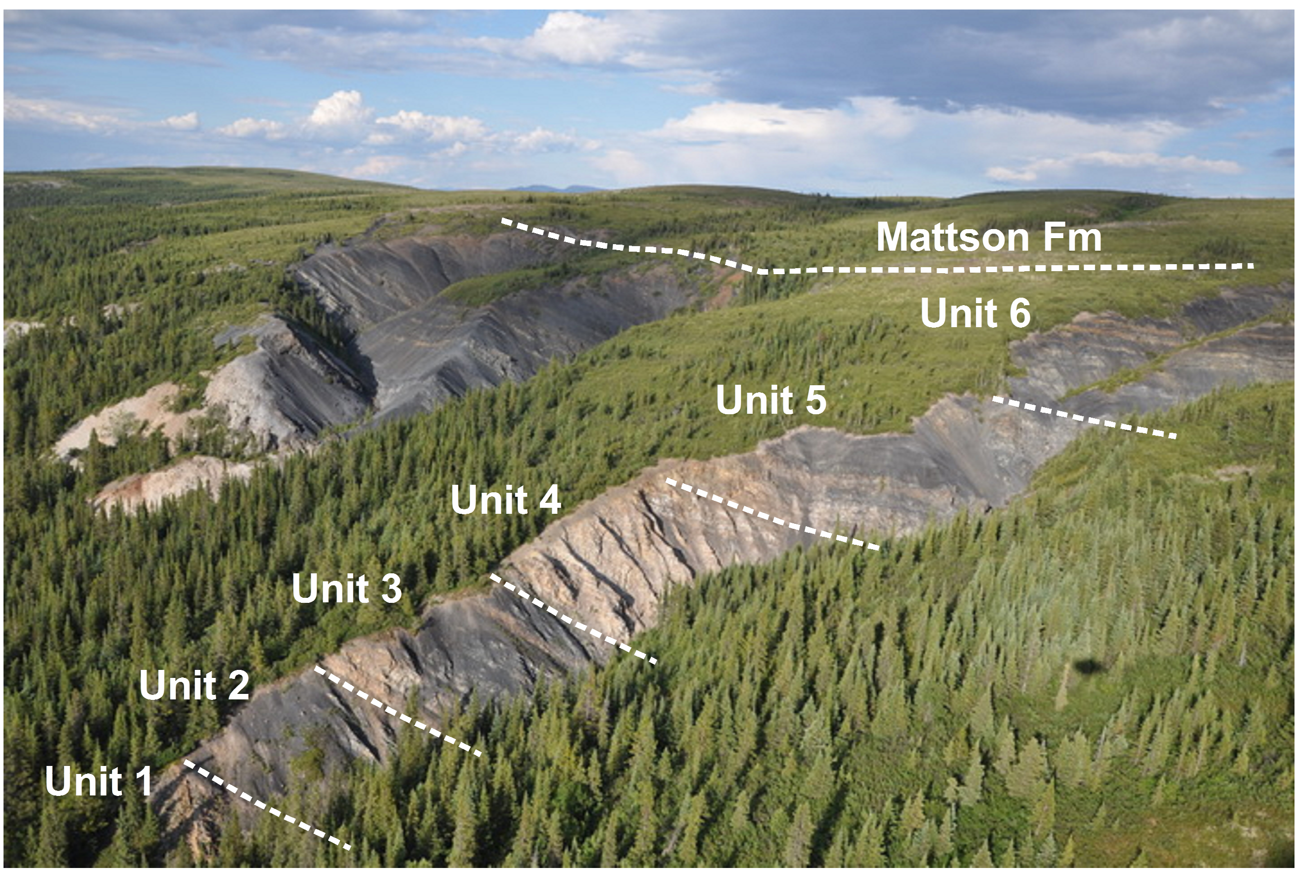

Figure 8. Aerial photograph of the measured section of Besa River Formation showing the character of exposed lithologies. The light coloured material is produced by the more siliceous siltstones of unit 4. Upper Besa River siltstones (unit 6) appear somewhat more recessive than the underlying siltstones of unit 5.

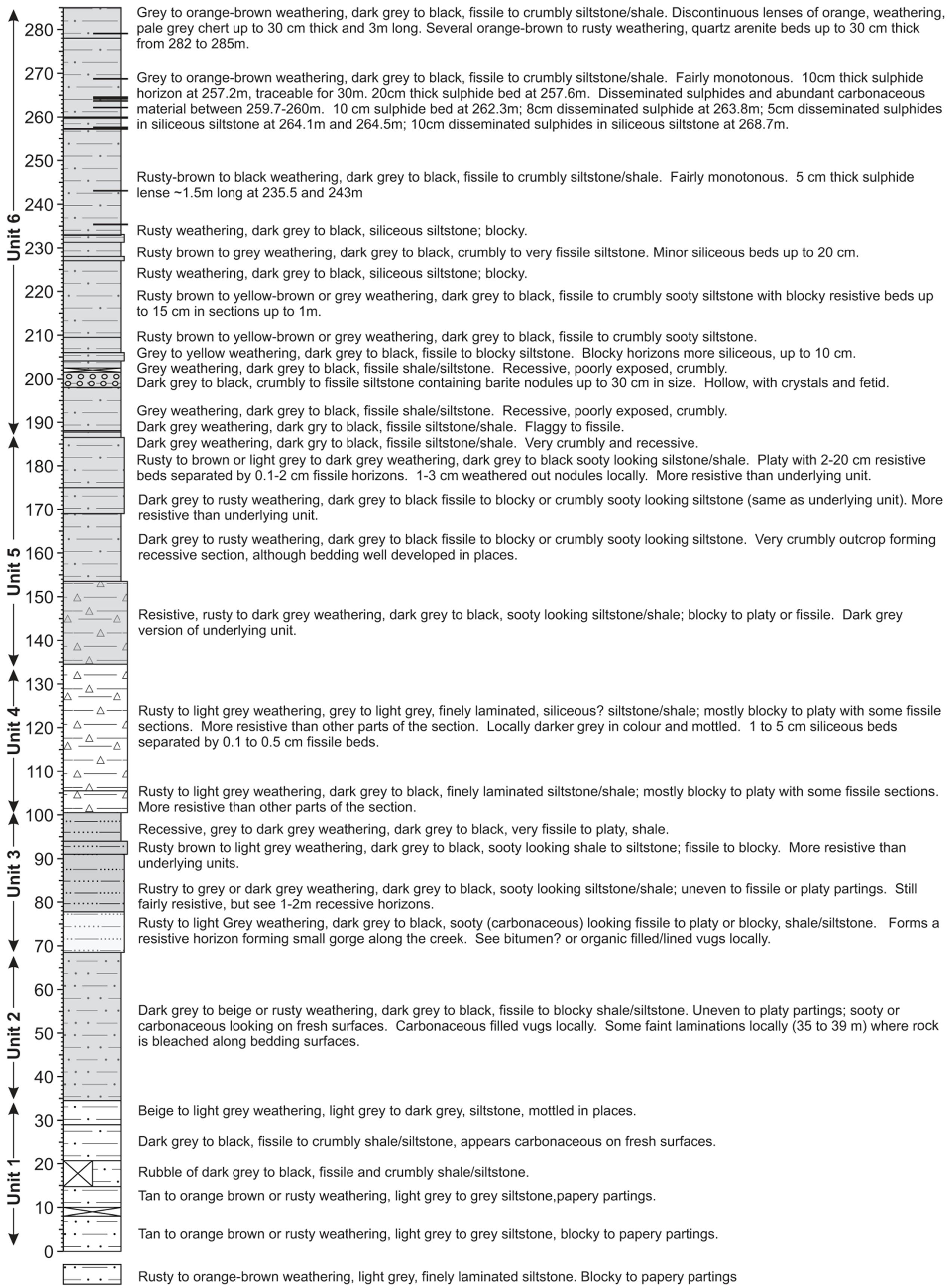

Figure 9. Lithologic section of Besa River Formation measured along the eastern part of the Caribou Range.

and laminated siliceous siltstone (34 m; Figure 10c); 5) Rusty to dark grey weathering, dark grey to black, blocky to platy and laminated, carbonaceous and siliceous siltstone (51 m; Figure 10d); 6) Dark grey to rusty weathering, dark grey to black crumbly siltstone to shale with uneven partings, with lesser blocky siltstone in the lower and middle parts (100 m; Figure 10e). Exposures of Besa River Formation in the Caribou Range displays the distinctive light grey weathering of unit 4 together with the recessive, crumbly nature of the upper part of unit 6 (Figures 8 and 10e). Distinctive rusty to ochre coloured run-off in channels emanating from exposures of unit 6 can also be observed within the central part of the Caribou Range.

Comparison of the broad lithologic composition, total gamma ray counts, K, Th and U concentrations and total organic carbon (TOC) contents along the section are shown in Figure 11. TOC levels are relatively high across several portions of the formation, nearing 5% by weight in some parts and consistently higher than 2% for the upper half of the section. There is a very good correlation between relative abundances of uranium and organic

Figure 10a. Rusty weathering siltstone of unit 1 at the 5 m level.

Figure 10b. General shot of grey to dark grey weathering siltstones of unit 3 at the 80 m level.

Figure 10c. Light grey and rusty weathering siltstone of unit 4, 116 m level.

Figure 10d. Dark grey and resistive siltstones with shaly partings within unit 5 at the 150 m level.

Figure 10e. Transition from more resistive ribs of siltstone in unit 5 into more recessive siltstones of unit 6.

Figure 10f. Barite nodules within unit 6 at the 198-200 m level.

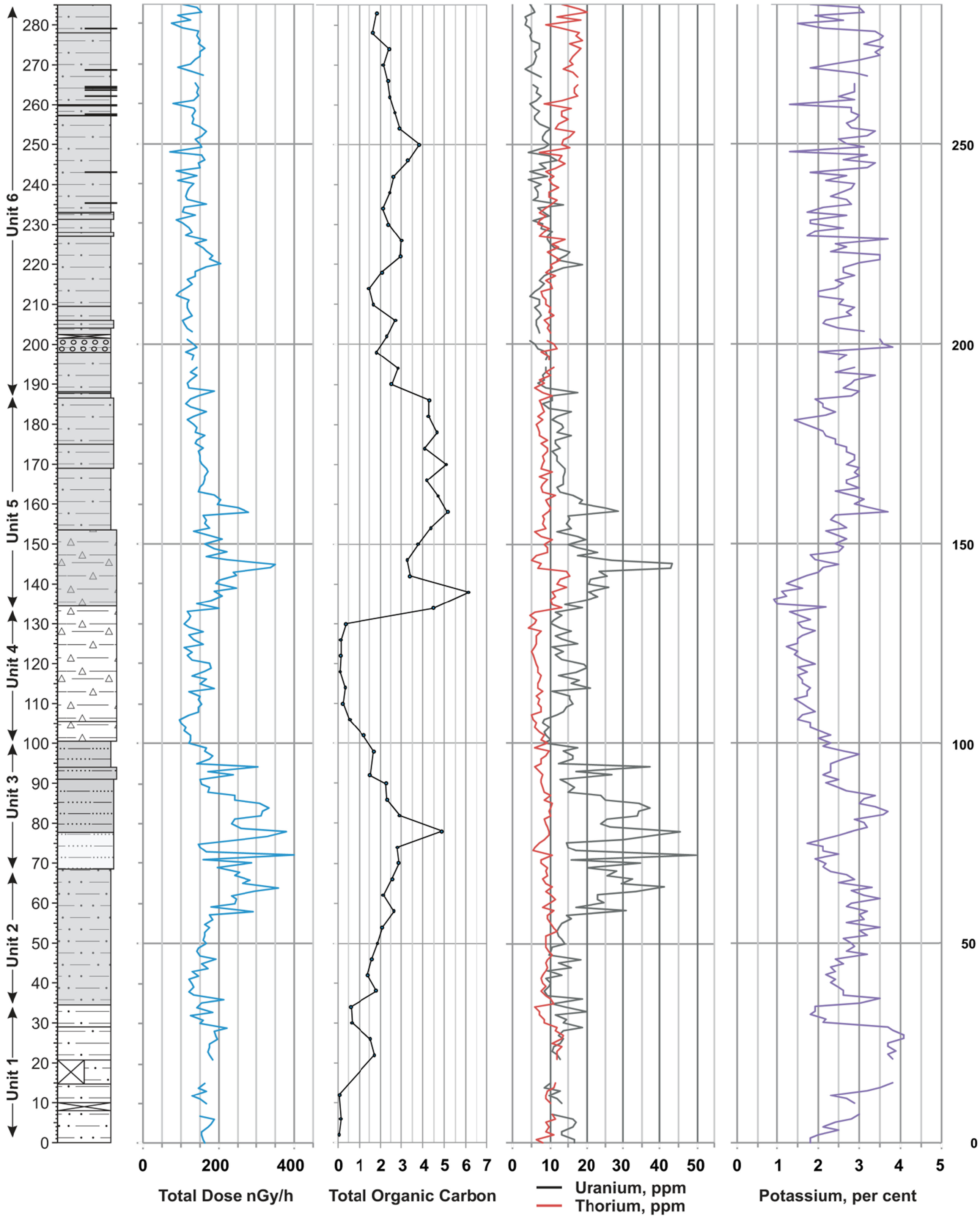

Figure 11. Comparison of main lithologic units of the measured Besa River Formation section with measured levels of total gamma ray counts, uranium, thorium, potassium and total organic carbon.

carbon content, suggesting precipitation of uranium either syngenetically during periods of higher anoxia or diagenetically within horizons rich in organic material. Although uranium concentrations appear to generally decrease towards the upper part of the section, thorium shows an increase in abundance. The concentration of potassium does not appear to correlate with the abundances of the other elements, and is probably tied to the mineralogy of the sediments being deposited.

The carbonaceous (*i.e.* organic-rich) nature of these sediments is a reflection of the reducing conditions present during deposition (Goodfellow and Lydon, 2007). These very low oxygen conditions did not permit aerobic organic activity and led to the preservation of organic matter (Fowler *et al.*, 2005). In these anoxic waters, bacteria that respire through reduction of sulphur became *abundant, producing a large amount of reduced sulphur* which could then be utilized in the precipitation of metal sulphides from any metalliferous brines being expelled on the sea floor (Goodfellow and Lydon, 2007). Even if these brines had sufficient reduced sulphur, this anoxic environment favoured the preservation of any precipitated sulphides. Oxygenated bottom waters, as in today's oceans, would have led to the oxidation of the sulphides in the water column or along the sea floor, shrinking the size of, or totally eliminating, any sulphide mineralization (Force *et al.*, 1983).

BARITE AND SULPHIDE MINERALIZATION

Barite and sulphide mineralization discovered in this section is located within the middle to upper part of unit 6 (Figures 10f, 12a, b). This new showing is named the MT occurrence (MINFILE 094N 012). It contains mineralization similar to that described within the Scat occurrence some 10 km to the south (MINFILE 094N 010; Burt, 1982).

At the MT showing, barite nodules over 30 cm in diameter are found between the 198 and 202 m level of the section, where they constitute up to 15% of the section (Figure 10f, 12a, b). The nodules vary in morphology from smooth or composite spheres to spheres or coatings displaying colloform texture (Figure 12a). Morphologically, many nodules have one flat surface devoid of colloform texture, suggesting growth on the sediment surface (Figure 12b). Other nodules are essentially coatings, also suggesting they grew along the sediment surface (Figure 12b). These observations imply precipitation of barite from ocean waters and would support a hydrothermal vent source for the barium, as opposed to diagenetic precipitation within the sediment. Many of the nodules contain vugs lined with fine, prismatic, needle-like crystals consistent with barite, although their composition has not been confirmed by x-ray diffraction. These vugs also give off a very strong fetid to petroliferous odour when broken.

Sulphide mineralization is found at ten levels between 235.5 and 279 m of the section and manifests as beds 5 to 20 cm in thickness. Most of the sulphide beds are thin, less than 10 cm thick and consist of disseminated pyrite forming discontinuous horizons traceable laterally for several metres, suggesting they may be diagenetic in origin (Figures 12c-f). Only two beds (at 257.2 m and 259.7 m) can be traced for over 30 m along strike (Figure 12c) and display textures indicative of sedimentary exhalative processes (*e.g.* laminations and graded sulphides beds). Sulphide mineralization at 257.2 m is 10 cm in thickness, contains up to 50% sulphides and displaying variation in sulphide contents suggesting settling from the water column (Figure 12e). A thicker sulphide bed (20 cm), with similar texture, occurs 20 cm above the first bed, but is only traceable for a few metres. The horizon at 259.7 m is 30 cm thick and traceable across the entire section (>50 m). This horizon consists of oxidized pyrite and abundant carbonaceous material containing remnant sulphides in the upper part (Figure 12f). This horizon is also visible in the next gulley, approximately 250 m to the north.

Chemical analysis of these beds (Table 1) suggests that pyrite constitutes the bulk of the sulphide mineralization. Interestingly, there are several horizons that are rich in Mn (0.2 to 0.4%), relatively poor in Ba, but elevated in Zn, Co and Ni. Although these horizons are rich in Fe, the highest horizons are comparatively poor in S, suggesting perhaps that the main iron-bearing mineral is a non-sulphide and likely a carbonate. This may be corroborated by the relatively higher Ca content of these horizons. These sulphur-poor horizons may reflect changing oxygen levels within the water column during deposition resulting in lower amounts of reduced sulphur. Mn, which is relatively soluble in anoxic waters, readily precipitates when the water column is oxygenated (Force *et al.*, 1983). Alternatively, these iron-rich horizons may be diagenetic in origin (*i.e.* nodules). Concentrations of elements presented here are comparable to pyritic shales of the Akie Formation, in the upper part of the Earn Group of the Kechika Trough and correlative with the upper Besa River Formation (MacIntyre, 1998).

DISCUSSION

SEDEX-style mineralization in the Caribou Range

Previous exploration, as part of the extensive exploration boom for SEDEX mineralization within the Selwyn and Kechika basins in the late 1970s to early 1980s, led to recognition of anomalous levels of Pb, Zn, together with Ba mineralization within Besa River rocks of the Caribou Range (Burt, 1982). This mineralization has been catalogued as the Scat mineral occurrence (MINFILE 094N 010) and is located within the upper Besa River Formation exposed along the Scatter River, approximately 10 km due south of the current mineralization (Burt, 1982). Lithologic units, geochemical

Figure 12a. Close-up of barite nodules. Sample on the left shows colloform encrustation of bedding surface; the nodule on the left also shows large and small colloform texture and flat bottom. The habit of barite mineralization shown here suggests growth at the seafloor.

Figure 12b. Prismatic barite crystals found within the vugs. Colloform text of barite growing along a bedding layer.

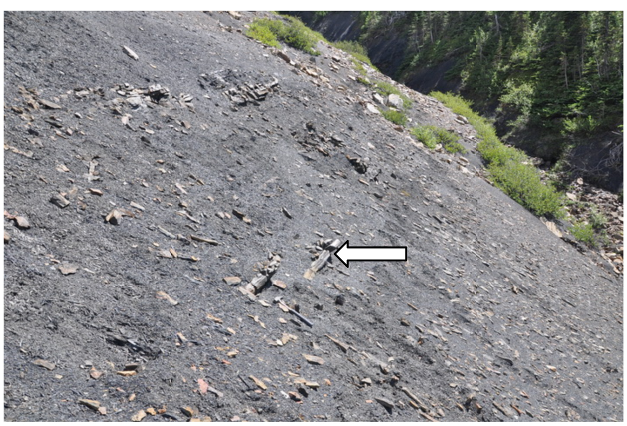

Figure 12c. Outcrop picture of Besa River rocks and the sulphide horizons at the 257 m level. The arrow points to exposed portions (with a nearby hammer for scale). The lower sulphide horizon can be traced for up to 30 m across the outcrop.

signatures and Ba mineralization in the vicinity of the Scat occurrence are very similar to those observed in the present study area, although the Besa River section is considerably thicker along the Scatter River. Burt (1982) noted that anomalous zinc values (0.3%) were found as fracture fillings within siliceous and pyritic nodules in the

Figure 12d. Photograph showing the sulphide horizon at the 257 m level.

Figure 12e. Close-up of fresh surface across the lower sulphide horizon at the 257 m level showing the bedded nature of the pyrite mineralization and the variation in its concentration which could be attributed to settling from the water column.

Figure 12f. Pyritiferous zone at the 260 m level of the Besa River section (above the hammer) showing the continuity of the horizon. This horizon was also noted on the next gulley to the north.

upper Besa River Formation. He attributed this to leaching of metals from the surrounding shales during diagenesis. These nodules have some similarities to the discontinuous pyrite bearing horizons described in the study area, suggesting they may have a common origin.

Burt (1982) noted that the barite nodules were likely of hydrothermal origin, but the relatively low concentrations and lack of any sulphide mineralization

Table 1. Geochemical analysis of several sulphide horizons from the upper part of the Besa River Formation, as measured within the study area.

		Sample	**FF10-116**	**FF10-117**	**FF10-162**	**FF10-165**	**FF10-168**	**FF10-169**	**FF10-171**	**FF10-173**	**FF10-176**	**FF10-177**	**FF10-179**	**FF10-181**
		Thickness	2 m	2 m	1 m	15 cm	10 cm	10 cm	30 cm	10 cm	8 cm	5 cm	20 cm	10 cm
		Elevation	198-200 m	200-202 m	225-226 m	243 m	257.2 m	257.5 m	259.7 m	262.3 m	263.8 m	264.1 m	268.7 m	279 m
Element	**Accuracy**	**Detection Limit**												
Au	ppb	0.5	<0.5	<0.5	<0.5	0.8	<0.5	0.6	<0.5	0.5	<0.5	<0.5	<0.5	<0.5
Mo	ppm	0.1	0.6	0.5	0.7	1.9	0.7	0.8	1.5	0.4	0.6	1	0.3	0.5
Cu	ppm	0.1	3	8.1	11.1	13.1	30.7	37.5	15.8	44.9	22	26.2	7.7	6.8
Pb	ppm	0.1	34	13.5	27.9	8.2	32.2	21.1	17.5	37	17.6	18.7	10.3	6.9
Zn	ppm	1	8	16	9	567	57	109	68	92	358	92	221	308
Ag	ppm	0.1	0.7	0.9	0.7	0.3	0.6	0.7	1	1.1	1.1	1.5	0.4	0.2
Ni	ppm	0.1	4.4	6.3	2.2	261.1	43.2	57.4	30.8	43.2	82	70	32.6	60.8
Co	ppm	0.2	0.7	0.6	0.2	41.7	7.5	9.4	3.5	5.2	8.8	8.7	4.9	16.6
Mn	ppm	1	28	65	30	3793	88	88	98	108	201	168	1973	2997
Fe	%	0.01	0.74	1.18	1.04	39.87	25.24	19.82	11.97	34.19	16.11	9.96	30.62	31.7
As	ppm	1	3	1	4	6	9	11	7	7	9	12	4	9
U	ppm	0.1	1.6	3.3	1.3	1.3	1.9	2.8	2.4	1.8	2	2.7	0.7	0.8
Au	ppm	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Th	ppm	0.1	2.8	4.7	1	1.8	3.8	5.4	5.9	2.5	7	8.6	2.9	1.8
Sr	ppm	1	34	61	12	22	33	49	31	22	34	45	26	49
Cd	ppm	0.1	<0.1	0.2	<0.1	0.5	<0.1	0.2	<0.1	<0.1	0.4	<0.1	0.4	0.3
Sb	ppm	0.1	1.1	0.6	0.9	0.2	0.7	0.7	0.6	0.4	0.5	0.7	0.3	0.3
Bi	ppm	0.1	0.2	0.2	<0.1	<0.1	0.1	0.2	0.2	<0.1	0.2	0.2	<0.1	<0.1
V	ppm	1	236	229	21	59	139	204	190	70	179	218	69	91
Ca	%	0.01	0.02	0.05	0.01	0.36	0.12	0.1	0.02	0.28	0.05	0.03	0.57	1.17
P	%	0.001	0.011	0.037	0.016	0.042	0.072	0.066	0.031	0.178	0.026	0.031	0.037	0.162
La	ppm	0.1	3.7	16.2	4	16.2	26.7	35.5	23.8	16	25.6	28.9	13.4	18.6
Cr	ppm	1	99	101	14	37	59	86	73	38	90	99	34	27
Mg	%	0.01	0.41	0.32	0.02	0.75	1.53	1.67	2.01	0.88	2.44	1.99	5.6	4.75
Ba	ppm	1	5720	4014	845	64	137	236	36	12	99	138	159	284
Ti	%	0.001	0.408	0.245	0.058	0.059	0.145	0.196	0.201	0.089	0.26	0.29	0.103	0.086
Al	%	0.01	7.16	5.17	0.5	1.87	3.71	4.91	5.06	2.35	6.95	7.94	2.81	1.77
Na	%	0.001	0.195	0.13	0.017	0.016	0.01	0.03	0.017	0.006	0.053	0.13	0.014	0.011
K	%	0.01	3.03	2.02	0.12	0.18	0.04	0.4	0.14	0.03	0.4	0.96	0.03	0.02
W	ppm	0.1	1.4	0.9	0.3	0.2	0.5	0.7	0.7	0.4	0.7	0.9	0.4	0.4
Zr	ppm	0.1	87	62.7	16.4	24.2	43.3	61.9	61.9	27.8	61	71.2	33.2	38.9
Ce	ppm	1	10	38	8	26	64	79	50	31	51	61	26	37
Sn	ppm	0.1	2.4	1.4	0.3	0.7	1.1	1.5	1.1	1.1	1.7	2.2	0.8	0.5
Y	ppm	0.1	2.6	10.6	2.1	69.2	23.8	27.7	18.2	23.9	16.3	19.1	14.9	28.9
Nb	ppm	0.1	10.7	6.7	1.6	1.8	5	6	6.8	2.8	7	9	3.4	2.8
Ta	ppm	0.1	0.7	0.4	<0.1	0.1	0.2	0.3	0.4	0.2	0.4	0.5	0.2	0.1
Be	ppm	1	2	2	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Sc	ppm	1	9	9	1	5	9	12	8	8	11	14	5	7
Li	ppm	0.1	18.7	12.3	14.2	30.2	59.4	69.4	70.4	30.6	135.7	132.4	40.8	40
S	%	0.1	0.3	0.1	0.2	4.2	>10.0	>10.0	2.6	>10.0	5.6	2.2	0.4	0.4
Rb	ppm	0.1	125.9	95.4	4.1	9.8	2.3	20.1	6.9	0.6	18.1	44.3	<0.1	0.1
Hf	ppm	0.1	2.3	1.6	0.4	0.4	0.8	1.3	1.3	0.6	1.5	1.8	0.7	0.5

Analysis performed at ACME Analytical Laboratories Ltd., Vancouver, BC.

Au; 0.5g sample leached in hot Aqua Regia and analyzed by ICP-MS.

All other elements; 0.25g processed by 4-acid digetstion (HNO_3-$HClO_4$-HF and HCL) analyzed by ICP-MS.

precluded any estimate on distance to the vent system. The presence of bedded sulphide mineralization associated with nodular barite in the current study area supports the inference that this is of hydrothermal origin and that it may be in a more proximal setting to the source of the mineralization.

REGIONAL CORRELATIONS AND METALLOGENY

Besa River rocks in the study area can be broadly correlated with the Earn Group of the Kechika Trough (Figure 6). Units 1 through 5 most likely correlate with cherty argillite, carbonaceous siliceous shale and lesser black carbonaceous siltstone and shale of the Middle to Late Devonian Gunsteel Formation (MacIntyre, 1998). The succeeding more recessive and crumbly siltstone and shales of unit 6 are probably correlative to recessive dark grey siltstone of the Akie Formation, postulated to be Late Devonian to Early Mississippian in age (MacIntyre, 1998).

Correlation of the outcropping Besa River Formation with subsurface formations to the east is suggested based on the total gamma ray trace across the measured section (Figures 13, 14). In the subsurface, as the Keg River reef and successive Devonian and Mississippian carbonate successions shale out westward into fine clastics of the Horn River, Fort Simpson and Besa River successions, the distinctive radioactive shales of the Evie, Muskwa and Exshaw formations can be traced across into the thick, monotonous siltstone sequence. The Exshaw Formation can be traced with confidence as it forms a regional marker horizon throughout a large part of the Western Canada Sedimentary Basin. The Evie shales above the Lower Keg River carbonates also define a distinctive package, and together with the succeeding Muskwa horizon define a recognizable sequence.

Suggested correlations for several wells west of the Liard River are depicted in Figure 14. The Exshaw Formation can be traced into the strongly radioactive central part of the Besa River section, and the lower most radioactive zone equates to the Muskwa Formation. Approximately 25 m of basal Besa River siltstones are covered; they are assumed to represent the Evie member of the Horn River Formation. The siltstones below Muskwa-equivalent rocks would be equivalent to the Otter Park siltstones, and those between the Muskwa and Exshaw horizons to the Fort Simpson Formation. These correlations also correspond broadly to the main lithologic units described previously: unit 1 corresponds to the Otter Park Member, units 2 and 3 to the Muskwa Formation, unit 4 to the Fort Simpson Formation, and unit 5 to the Exshaw Formation (Figure 14). Note that the distinctive light grey weathering panel within Besa River Formation exposures in the Caribou Range, which corresponds to the Fort Simpson equivalent horizon, is

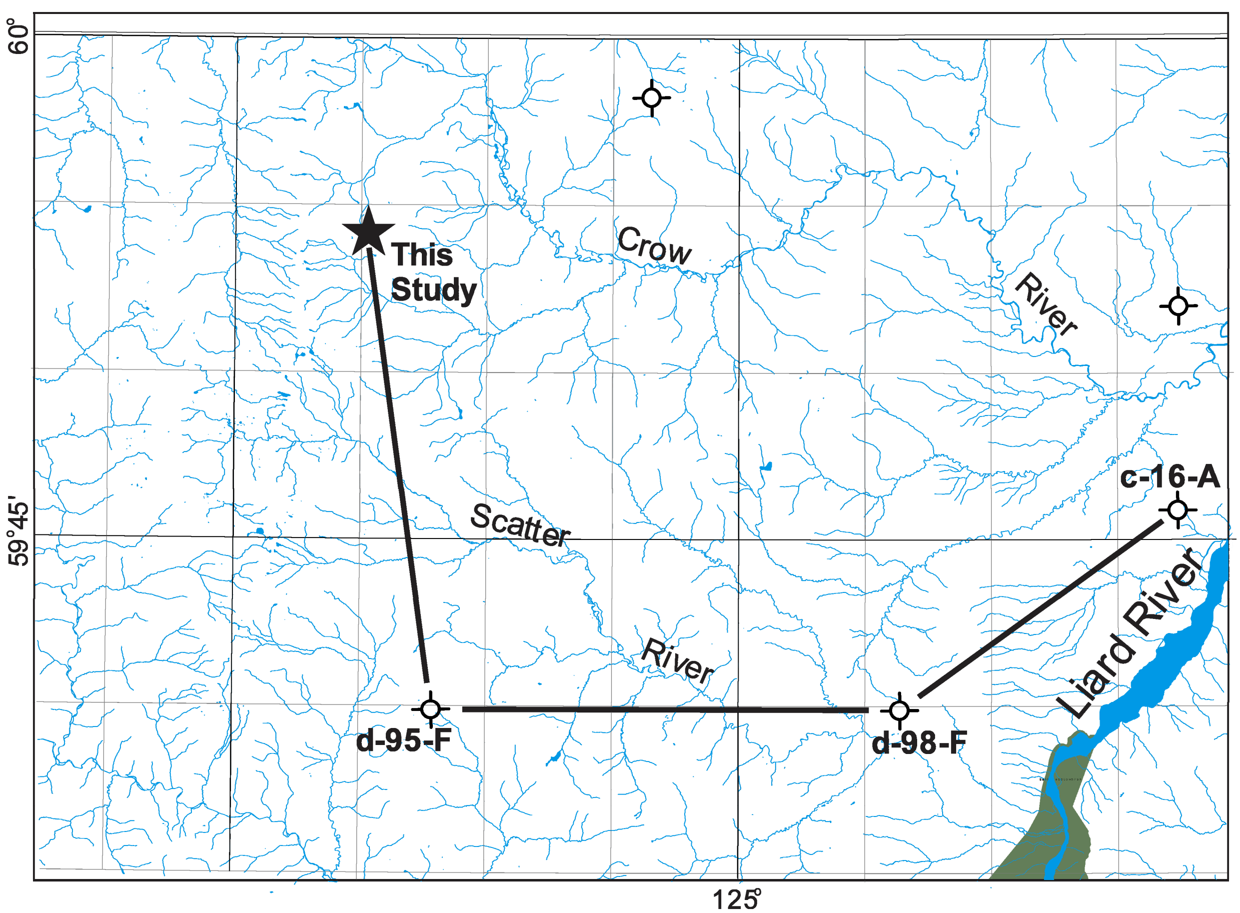

Figure 13. Map showing well locations used in the correlations depicted in Figure 14. Study area is shown by the star symbol.

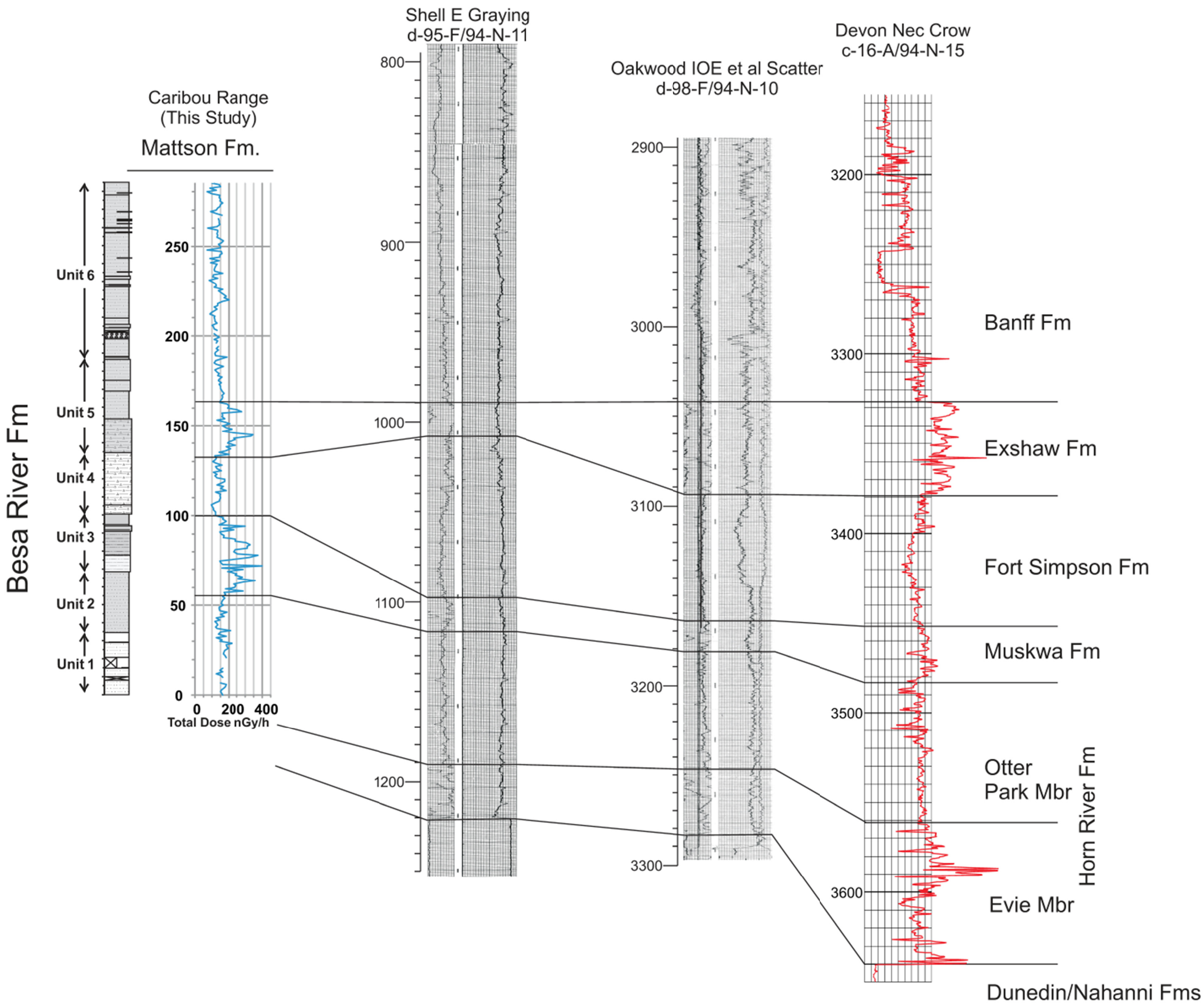

Figure 14. Correlation of measured Besa River section, using the trace of total gamma ray counts, with several subsurface sections, the location of which are shown in Figure 13. Only the gamma ray log is shown for the c-16-A well. Bulk density is shown for the d-98-F well and the acoustic log for the d-95-F well.

only some 25 to 35 m in thickness, attesting to the extremely condensed nature of this section. In outcrop, the succeeding section that correlates with the Exshaw Formation appears as siliceous as underlying Fort Simpson equivalent strata, but is considerably darker and more carbonaceous.

Although the overall trace of the gamma ray log across the outcrop is very similar to subsurface gamma ray logs, the unit boundaries defined by this methodology do not necessarily correspond to those defined within the lithologic log (Figures 11, 14). The relatively sharp contacts of unit 4 correlate with breaks in the gamma ray trace (Fort Simpson Formation equivalent, Figure 11). The upper boundary of the Exshaw marker, as defined by the gamma ray trace, falls within the upper part of unit 5. This unit is also defined by high organic contents and higher uranium concentrations than the base of unit 6 (Figure 11), suggesting this may be the upper contact of the Exshaw marker.

The contact between units 2 and 3 occurs within the lower part of the Muskwa marker. Furthermore, the contact between unit 1 and 2 is not very distinctive on the gamma ray trace, although total organic carbon contents are higher in unit 2 and potassium levels are higher in unit 1. Even though the overall organic content and uranium level are increasing within unit 2, the general lithologic character is not changing. This should be reflected in the lithogeochemistry.

This correlation technique is powerful in that it allows one to assign approximate stratigraphic ages to the various units within an otherwise monotonous sequence, based on the linkages to defined stratigraphy in other parts of the basin (Figure 14). A consequence of this is that the sulphide mineralization within the section is probably Tournaisian or Visean in age, based on its position above the Exshaw marker within the section. In Kechika and Selwyn basins, major exhalative sulphide deposits are of Frasnian to Famennian age, with minor sulphide and barite mineralization within rocks as young as Early Mississippian (Paradis *et al.*, 1998; Irwin and Orchard, 1991). This younger sulphide mineralization is roughly coeval with major volcanogenic massive sulphide deposits within arc sequences that lay immediately outboard of the Selwyn Basin (Wolverine deposit; Piercey *et al.*, 2008 Paradis *et al.*, 1998).

CONCLUSIONS

- Approximately 285 m of the Besa River Formation outcrops along the western margin of the Liard Basin and consists of light grey to black weathering carbonaceous siltstone to siliceous siltstone. The lower 25 m of the unit was not exposed.
- The Besa River Formation has been subdivided into 6 informal units based on overall outcrop composition.
- Rock Eval analysis of representative samples on 4 m spacing across the outcrop indicate two zones of high organic carbon content, with levels reaching 6% by weight.
- A gamma ray spectroscopic log across the outcrop defines several zones of higher radiation which correlate to higher concentration of uranium and organic carbon.
- Correlation of the gamma ray trace with subsurface sections to the east suggests that the lower and upper radioactive zones in the outcrop correlate with the Muskwa and Exshaw markers, respectively.
- Nodular barite and bedded pyrite mineralization was discovered in the upper part of the Besar River section (MT showing, MINFILE 094N 012) which is similar to mineralization at the nearby Scat showing (MINFILE 094N 010).

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