EVALUATION OF ORDOVICIAN AND SILURIAN STRATIGRAPHY FOR HYDROCARBON SOURCE-ROCK POTENTIAL IN THE NORTHERN HALFWAY RIVER MAP AREA, BRITISH COLUMBIA (NTS 094B/13)

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ABSTRACT

Over 500 m of Middle Ordovician to Lower Silurian silty dolomite, calcareous siltstone and quartzite of the upper Skoki Formation and the Road River Group were examined and sampled for hydrocarbon source-rock potential in the northern Halfway River map area. Road River Formation units investigated are basinal equivalents of the Nonda and Muncho-McConnell formations and an unnamed quartzite-dolomite unit. Source-rock potential for the upper Skoki Formation is poor, whereas limited data from the overlying calcareous siltstone of the Road River Group exhibit values that suggest they originally may have had fair to good source-rock characteristics. Further sampling is required to verify these limited results and to test the more basinal, Lower–Middle Ordovician succession for source-rock potential.

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Key Words: British Columbia, Rocky Mountains, Halfway River, 094B/13, Lower Paleozoic, Road River Group, Skoki Formation, stratigraphy, measured section, Rock-Eval, petroleum system, hyrdorcarbons.

INTRODUCTION

In 2005, the BC Ministry of Energy, Mines and Petroleum Resources published a preliminary assessment of the petroleum potential of pre-Givetian strata in northeast British Columbia (Ibrahimbas and Walsh, 2005). This report focused on the stratigraphy and reservoir development of the strata and noted that prospective zones exist within carbonate rocks of the Lower Keg River–Chinchaga, Chinchaga and Stone formations, quartz arenite of the Wokpash Formation and unnamed Cambrian units (Ibrahimbas and Walsh, 2005). Although the authors noted high gas recoveries from some carbonate horizons (4.18 mmcf/day), no potential source rock has been identified in the subsurface to date. The recognition of pre-Givetian source rocks would lay the foundation for petroleum systems of this age and increase the probability that economic hydrocarbon accumulations exist.

Unpublished Rock-Eval data from surface samples of Ordovician and Silurian strata in the Trutch map area (NTS 094G) reportedly contained total organic carbon (TOC) of up to 10% (Ibrahimbas and Walsh, 2005). In light of this, a section of basinal Ordovician and Silurian strata was chosen for systematic sampling of potential source rocks in an attempt to corroborate this unpublished data and establish the presence of a Lower Paleozoic petroleum system. Rationale for the sampling area was based on proximity to Lower Triassic strata 20 km to the east, the detailed study of which formed the main focus of the 2009 field program (Ferri et al., 2010).

LOCATION

The section sampled is located in the northwest corner of the Halfway River map area (NTS 094B/13), near the Graham River headwaters, approximately 10 km south of Robb Lake (Figure 1). Access was by helicopter and the section was measured and sampled through the set-up of a camp about 1.5 km to the northeast.

GENERAL GEOLOGY

The area sampled is found in the eastern Northern Rocky Mountains, north-northwest of the Bernard anticline (Figures 2, 3). Lower–Middle Paleozoic strata exposed in the immediate area represent off-shelf equivalents to continental carbonate deposits in the Western Canada Sedimentary Basin. The demarcation line between shelf and basinal deposition moved through time and carbonate debris flows

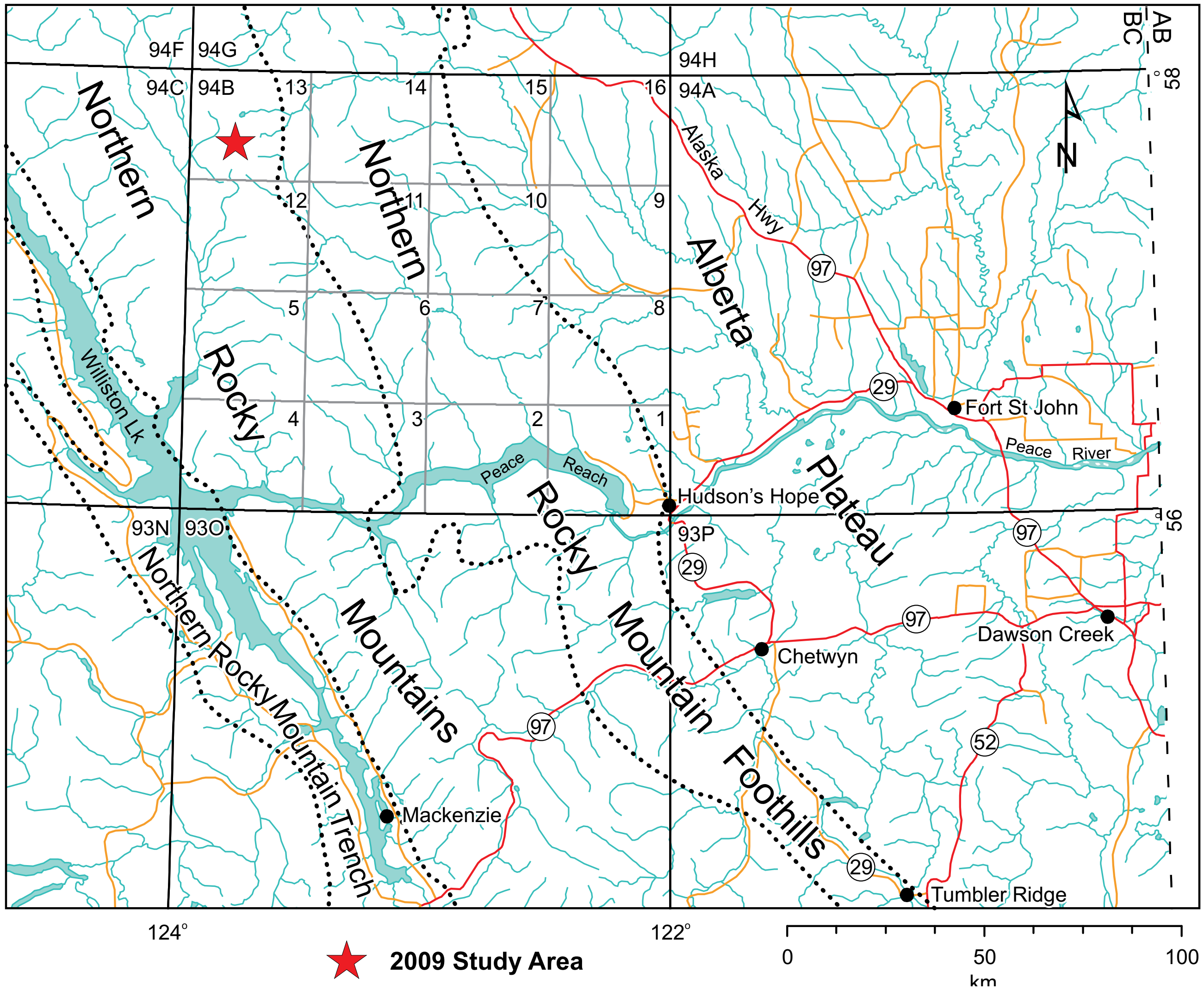

Figure 1. Location of the study area within northeast British Columbia.

suggests the shelf edge was relatively abrupt (Figure 4; Cecile and Norford, 1979). Thompson (1989) broadly referred to the off-shelf sedimentary rocks as 'Road River strata'. More recent work (see Pyle and Barnes, 2000) redefined this stratigraphy and renamed these strata as the Road River Group and defined a series of formations (Figure 5). Some of the rock types observed in this report can be directly correlated with these new units, whereas the relationship to other units is more problematic.

Rocks examined during the 2009 field season encompassed an overturned section of the Lower Ordovician Skoki Formation and the lower–middle part of the Road River Group. Thompson (1989) informally referred to this Road River strata as, from bottom to top, the graptolitic shale-quartzite unit (Middle–Upper Ordovician), the carbonaceous limestone unit (Lower Silurian), the breccia unit (Lower Silurian) and the brown siltstone unit (Upper Silurian to Lower Devonian). Correlation of these units with the work of Pyle and Barnes (2000) is shown in Figure 5.

The Skoki Formation and overlying Silurian to Devonian Nonda, Muncho-McConnell, Stone and Dunedin formations define a carbonate shelf sequence that 'shales out' westward into the Road River Group. Dark grey shale, calcareous shale, siltstone, limestone and quartzite of the graptolitic shale-quartzite unit (Ospika Formation) are basinal equivalents of a more proximal quartzite-dolomite unit (Thompson, 1989). The overlying carbonaceous limestone and carbonate breccia units (Pesika Formation) are off-shelf equivalents of the Nonda Formation. This limestone breccia suggests the presence of a well-developed carbonate escarpment during deposition of the Nonda Formation that shed carbonate debris to the west (Cecile and Norford, 1979). The overlying orange to tan weathering, brown calcareous siltstones of the brown siltstone unit (Kwadacha Formation) are time-equivalent to the Muncho-McConnell Formation. The westward equivalents of this unit represent the typical 'Silurian siltstone' division of the Road River Group that is found throughout the more basinal Kechika Trough and Selwyn Basin (Ferri et al., 1999).

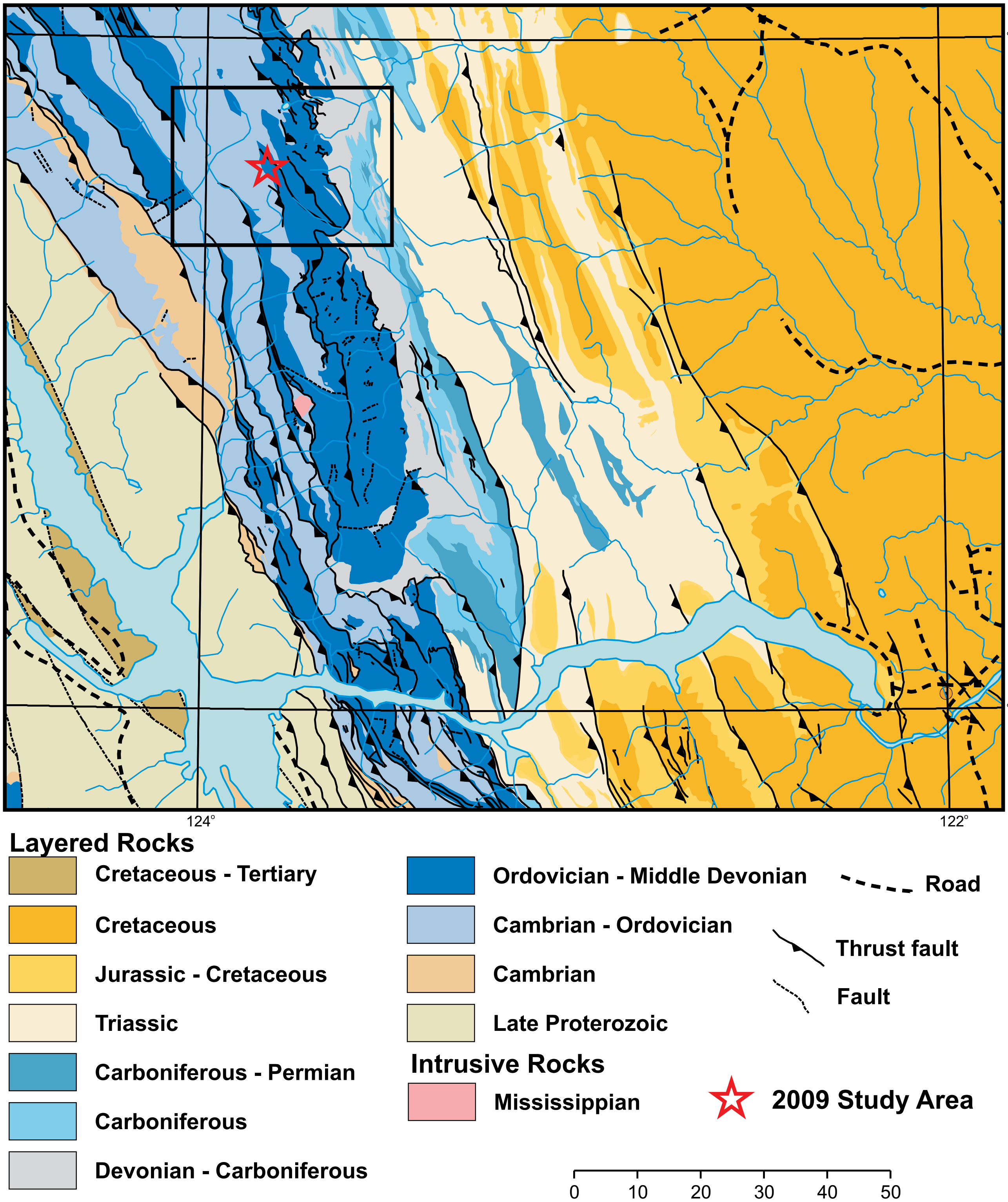

Figure 2. General geology of the Halfway River map area, British Columbia. Geology from the BC Geological Survey MapPlace website (MapPlace, 2010;www.mapplace.ca).

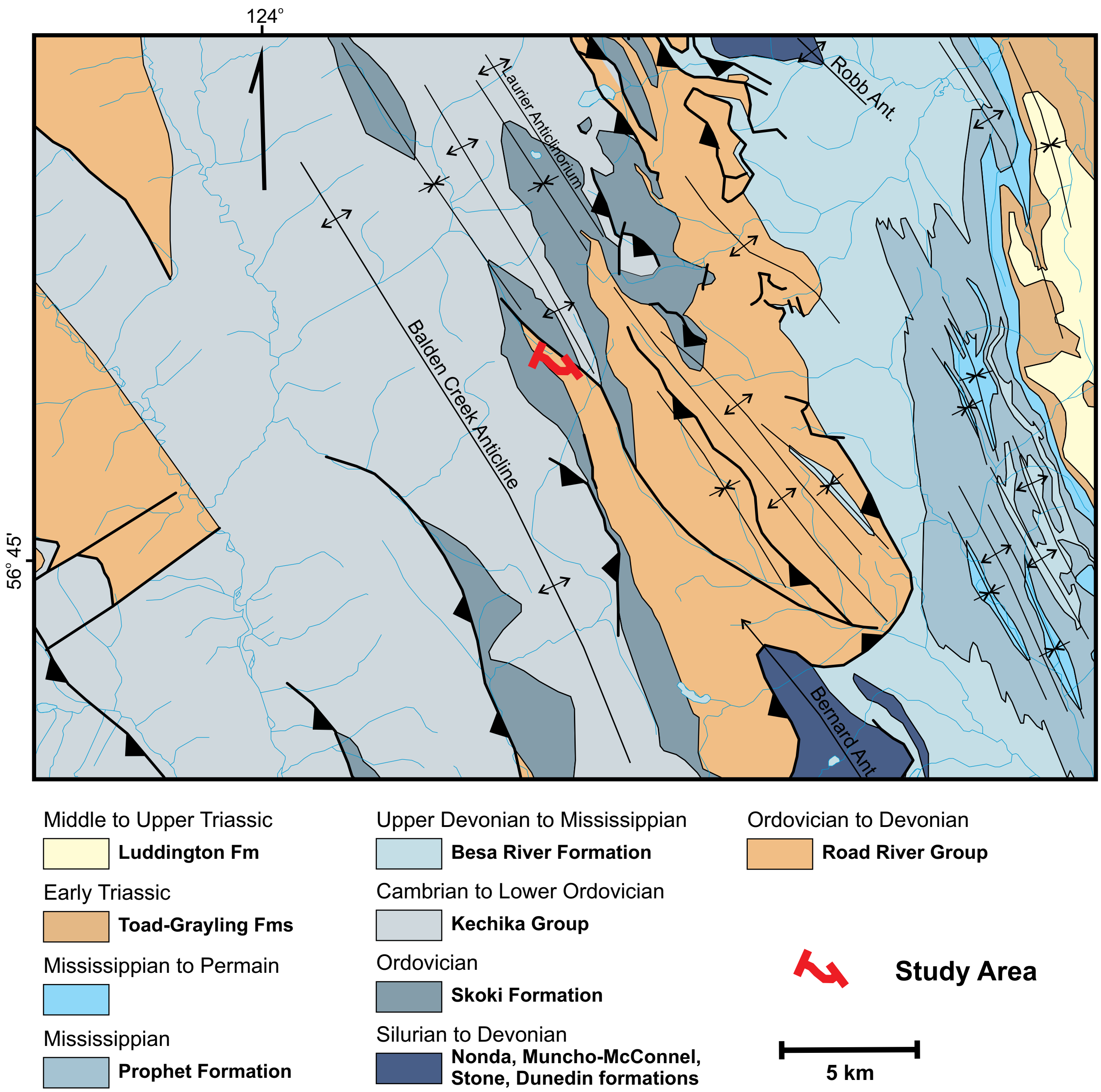

Figure 3. General geology in the immediate vicinity of the study area.

DETAILED SECTION

Approximately 540 m of semicontinuous section were measured near the headwaters of Graham River (Figures 6, 7). The UTM coordinates (NAD 83) are 449184E, 6296474N for the base of the section and 450321E, 629349N for the top. The lower 220 m, below a thick quartzite of the graptolitic shale-quartzite unit, were measured continuously, with samples of material taken every 5 m for Rock-Eval analysis. Above the quartzite, outcrop is less continuous and thicknesses are based on detailed mapping and are thus more approximate. The carbonaceous limestone unit is crumbly and poorly exposed in this area, and lithological descriptions are based on limited exposures.

Although the sampled section encompasses the upper part of the Skoki Formation, aspects of this section, particularly the carbonate debris flows below the thick quartzite, bear a strong lithological resemblance to similar deposits within the Chesterfield Member described by Pyle and Barnes (2000), the latter being a basinal equivalent to the Skoki Formation. This suggests that these rocks in the study area reflect an initial shale-out of the upper Skoki Formation. Conodont samples were collected and may provide evidence for these correlations.

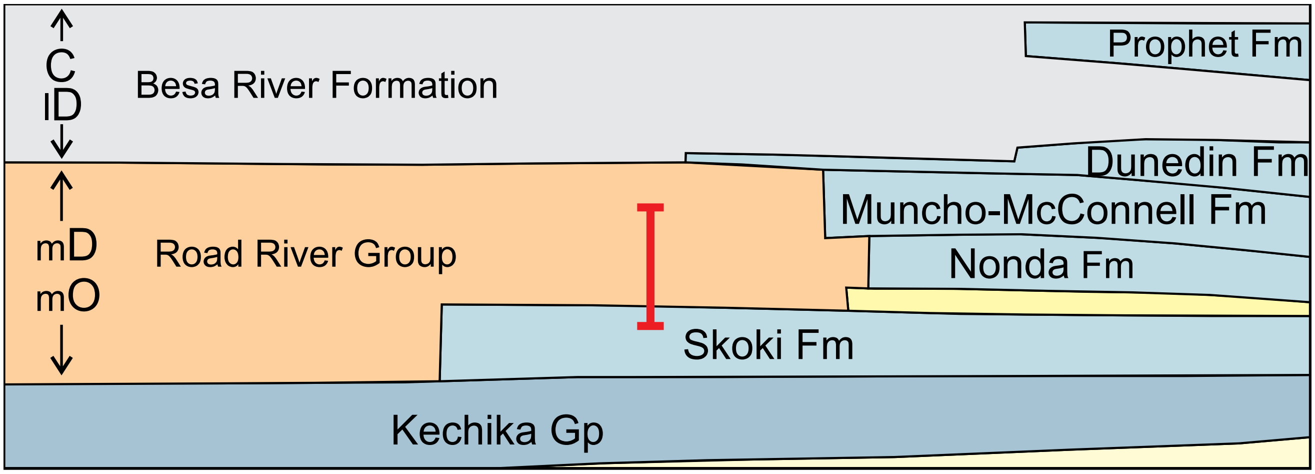

Figure 4. Schematic representation of Lower Paleozoic carbonate to shale transition in the Halfway River map area, British Columbia; adapted from Thompson (1989). Abbreviations: mO – Middle Ordocivian; mD – Middle Devonian; lD – Lower Devonian; C – Carboniferous.

Skoki Formation

In the northern Halfway River map area, the Skoki Formation is divided into three members: a middle pale grey dolostone bounded on the top and the bottom by dark grey dolostone (Thompson, 1989). The upper dark grey siliceous dolostone unit was sampled for source-rock potential. The middle part of the Skoki Formation consists of wavy-bedded, light grey to buff weathering, medium- to thick-bedded dolostone to dolomitic siltstone. Considerable rubble of this unit was observed at the base of the section, including a section of carbonate breccia floating in a matrix of light green sericitic shale to siltstone, suggesting a volcanic origin (Figure 8). Mafic volcanic rocks have been mapped within the middle Skoki Formation west of Bernard anticline (Thompson, 1989).

UPPER SKOKI FORMATION

The upper Skoki Formation consists of approximately 200 m grey to dark grey weathering, silty dolomite and lesser amounts of carbonate breccias (Figure 9, 10). Silty dolomite is thin bedded, platy and commonly has very thin dark grey shaly partings. Locally the dolomite is quite siliceous. Shale interbreeds appear to thicken into centimetre-thick layers at the top of the unit.

The middle–upper part of this siltstone succession is punctuated by 1 to >30 m thick horizons of tan to buff weathering, grey dolomitic crinoidal packstone to grainstone interbedded locally with carbonate breccia or conglomerate (Figures 10, 11). These are commonly massive in nature, with local wavy bedding developed. The nature of these deposits, and surrounding thin-bedded dark grey silty dolomite, are similar to off-shelf rock types described by Cecile and Norford (1979) in the Ware map area (94F) located just west of the Skoki Formation ‘shale-out’. This suggests the carbonate breccia represents debris flows off the carbonate bank edge and that the upper part of the Skoki Formation may be transitioning to basinal environments.

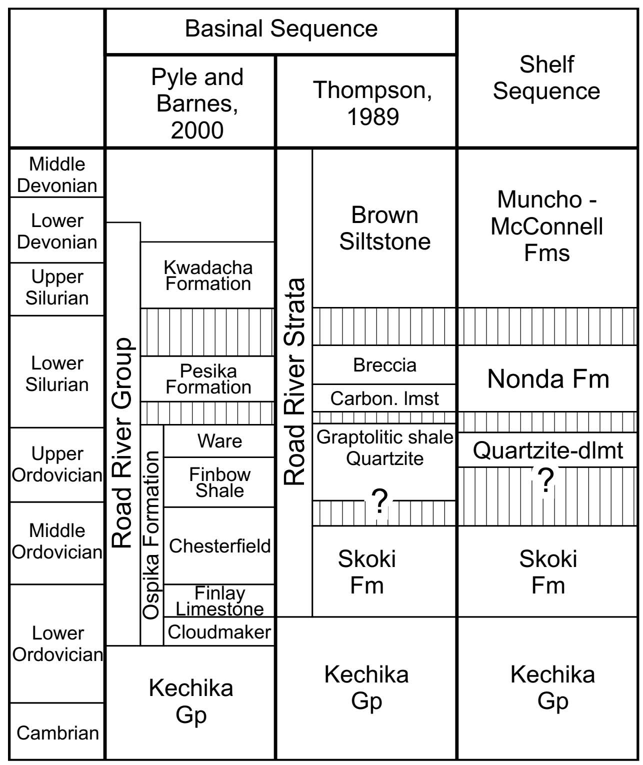

Figure 5. Correlation chart showing relationships between shelf strata and Road River stratigraphy as defined by Thompson (1989) and Pyle and Barnes (2000). Abbreviations: Carbon. lmst, Carbonaceous Limestone unit; Quartzite-dlmt, Quartzite-Dolomite unit.

Graptolitic shale-quartzite unit

Some 230 m of siltstone, carbonate clastic rocks and quartzite make up the graptolitic shale-quartzite unit in the

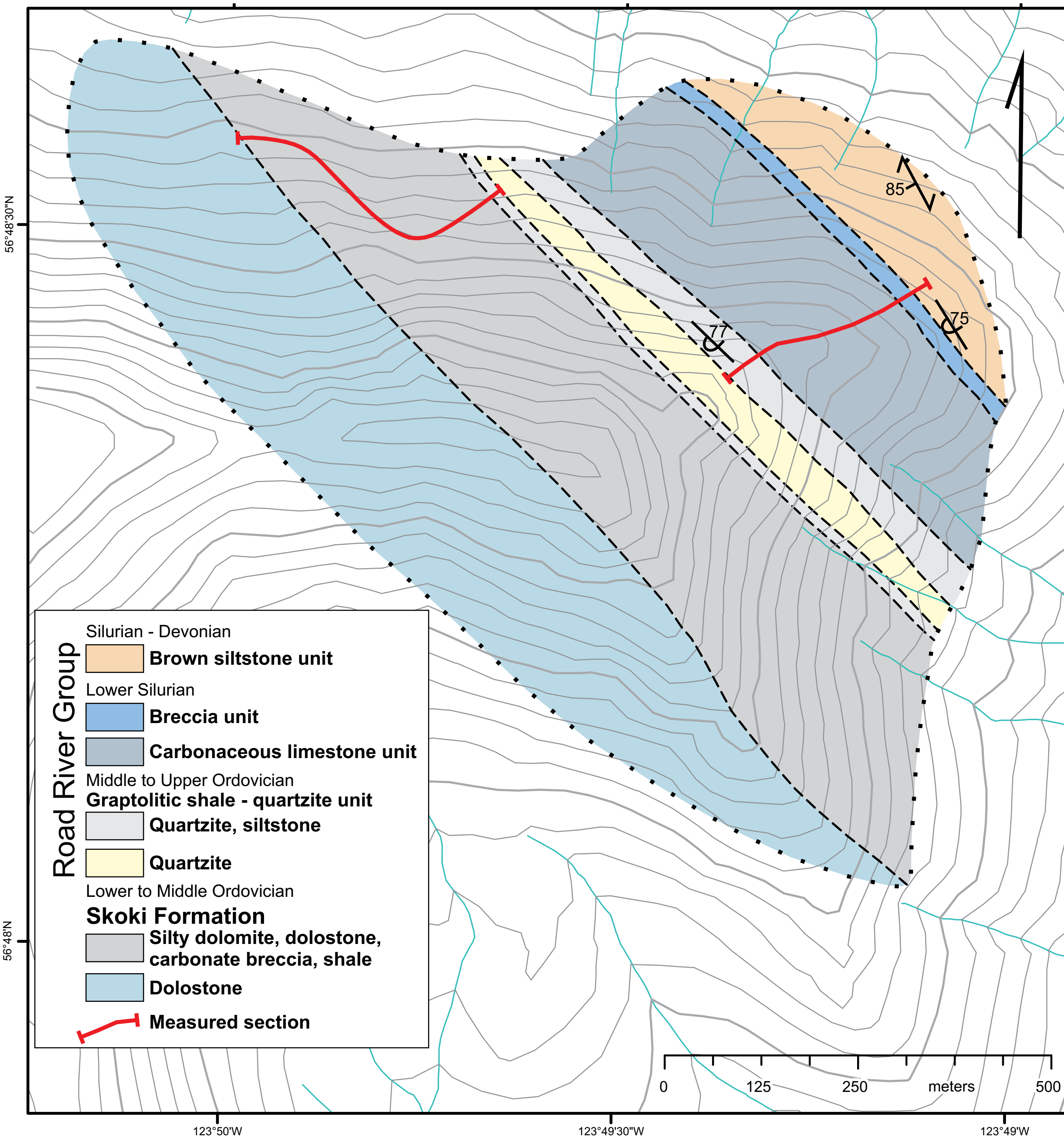

Figure 6. Geology in the vicinity of the studied section.

study area. The lowest part consists of dark grey silty dolomite and shale overlain by approximately 75 m of tan to brown or grey weathering, grey to beige quartzite. It is massive in appearance and thick bedded, consisting of sugary, medium- to fine-grained quartz (>99%) with minor white lithic sediments. Above this is a rubbly zone consisting of quartzite boulders and dark grey to black shale, which on structural sections suggests a unit approximately 35 m thick. Thompson (1989) indicates that these quartzitic deposits are turbiditic in nature and correlative with a quartz-dolomite unit on the shelf sequence located unconformably above the Skoki Formation.

Quartzite is succeeded by approximately 95 m of a poorly exposed section of blocky to platy, dark grey to black calcareous siltstone that is locally very rubbly and/or cleaved. The section consists of scree punctuated by several semicontinuous outcrops (from 355 to 360 m and from 400 to 440 m; Figure 7).

Carbonaceous limestone unit

Succeeding the graptolitic shale-quartzite unit is a poorly exposed section of thinly bedded grey to dark grey silty limestone assigned here to the carbonaceous limestone unit. The thickness of this unit is approximately 65 m, which is based on structural sections as no exposure or rubble was found below the base of the breccia unit.

Breccia unit

This unit is approximately 20 m thick and consists of grey to dark grey weathering, grey lime mudstone breccia to conglomerate. Clasts are rounded to tabular, up to 20 cm in size, floating or clast supported, and surrounded by a sparry to crinoidal packstone or grainstone matrix.

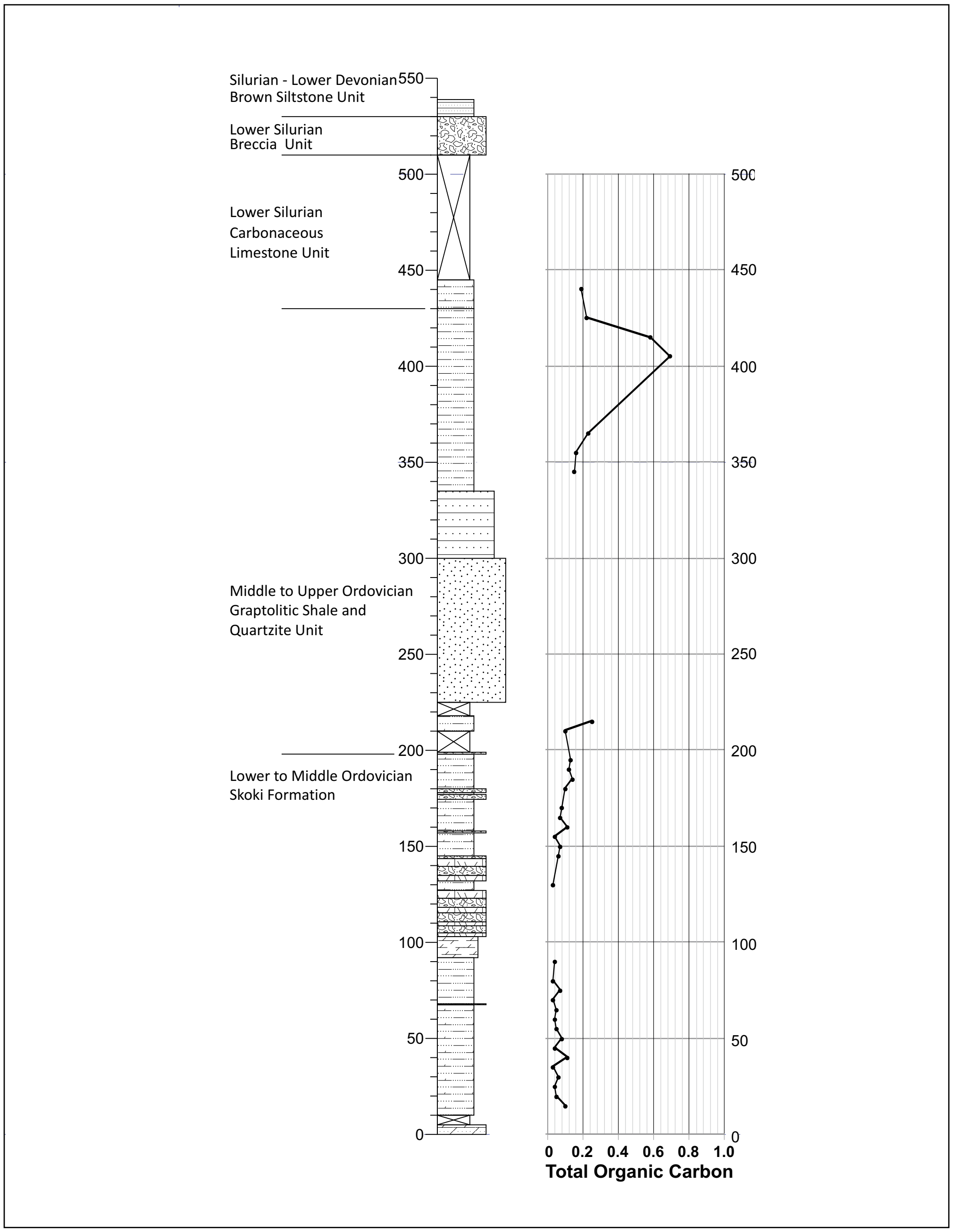

Figure 7. Schematic stratigraphic section sampled for Rock-Eval analysis. The right-hand side of the figure shows the abundance of total organic carbon within collected samples.

Figure 8. Carbonate breccia boulder from the Skoki Formation. The matrix of this breccia is sericitic, suggesting a volcanic origin.

Figure 9. Platy calcareous to dolomitic siltstone of the upper Skoki Formation.

Figure 10. Carbonate breccia to conglomerate horizons within the upper Skoki Formation. Note how these horizons pinch out along strike.

Figure 11. Close-up photo of breccia within the upper Skoki Formation showing the nature of clasts.

ROCK-EVAL DATA

The presence of cleavage in these rocks indicates that temperatures probably exceeded the upper dry gas window. Due to the high thermal maturity, no generative capacity would remain in any organic-rich horizon and the organic carbon content is the only parameter that can be used to measure the original source-rock potential (Table 1).

Total organic carbon values from the Skoki Formation are all less than 0.2% and are of questionable significance. Even if the original TOC values were 2–4 times higher prior to thermal maturation (Jarvie, 1991), most of these samples suggest that Skoki Formation rock types originally had poor source-rock potential (0.06–0.25% TOC). Total organic carbon values are higher just below and above the thick quartzite, with values in the range of 0.23–0.67%, suggesting original values of 0.5–1.5%. Although only a limited number of samples returned these higher values, they originate from a section approximately 100 m thick.

DISCUSSION

Total organic carbon values obtained from Upper Ordovician calcareous black shale and siltstone in the northern Halfway River map area suggest these rock types may originally have been fair to good hydrocarbon source rocks (Peters, 1986). This is assuming the kerogen within the sequence was oil prone and had high initial hydrogen to carbon ratios. Although only a limited amount of data is available, the relatively thick section (~100 m) indicates the potential presence of a large volume of organic matter that could have been part of a petroleum system, although the low amount of original TOC may not have been sufficient to make the unit an effective source rock (because it expelled its generated hydrocarbons). Further sampling is required to verify these initial results.

TABLE 1. ROCK-EVAL DATA FOR SAMPLES COLLECTED ACROSS THE SECTION. SAMPLES ANALYZED USING ROCK-EVAL 6 APPARATUS AT GEOLOGICAL SURVEY OF CANADA LABORATORIES IN CALGARY, ALBERTA.

Height in section	Sample	Qty	Tmax	S1	S2	S3	PI	S2/S3	PC(%)	TOC(%)	HI	OI
440	09FF-163g	70.9	430	0.01	0.03	0.22	0.15	0.14	0.01	0.19	16	116
425	09FF-163f	70.6	337	0.00	0.00	0.26	0.31	0.00	0.01	0.22	0	118
415	09FF-163e	70.6	502	0.00	0.03	0.27	0.16	0.11	0.02	0.58	5	47
405	09FF-163d	70.8	501	0.00	0.02	0.48	0.13	0.04	0.02	0.69	3	70
365	09FF-163c	70.8	492	0.00	0.01	0.48	0.17	0.02	0.02	0.23	4	209
355	09FF-163b	70.4	494	0.01	0.03	0.32	0.15	0.09	0.01	0.16	19	200
345	09FF-163a	70.5	440	0.00	0.02	0.42	0.09	0.05	0.01	0.15	13	280
215	09FF-165	70.0	494	0.00	0.01	0.51	0.22	0.02	0.02	0.25	4	204
210	09FF-166	70.6	494	0.00	0.02	0.35	0.16	0.06	0.01	0.10	20	350
195	09FF-167	71.2	427	0.00	0.02	0.30	0.13	0.07	0.01	0.13	15	231
190	09FF-168	70.1	444	0.00	0.03	0.31	0.14	0.10	0.02	0.12	25	258
185	09FF-169	69.9	425	0.00	0.03	0.22	0.14	0.14	0.01	0.14	21	157
180	09FF-171	70.9	425	0.00	0.02	0.23	0.12	0.09	0.01	0.10	20	230
170	09FF-172	70.2	423	0.00	0.02	0.03	0.13	0.67	0.00	0.08	25	38
165	09FF-173	70.2	432	0.01	0.04	0.22	0.13	0.18	0.01	0.07	57	314
160	09FF-174	70.2	494	0.00	0.01	0.27	0.18	0.04	0.01	0.11	9	245
155	09FF-175	70.7	494	0.00	0.01	0.17	0.18	0.06	0.01	0.04	25	425
150	09FF-176	70.6	440	0.00	0.02	0.24	0.12	0.08	0.01	0.07	29	343
145	09FF-177	70.0	440	0.00	0.02	0.20	0.15	0.10	0.01	0.06	33	333
130	09FF-178	70.9	437	0.00	0.01	0.20	0.14	0.05	0.01	0.03	33	667
90	09FF-179	70.2	434	0.00	0.04	0.23	0.10	0.17	0.02	0.04	100	575
80	09FF-180	70.8	436	0.00	0.03	0.25	0.11	0.12	0.01	0.03	100	833
75	09FF-181	70.4	429	0.01	0.03	0.21	0.16	0.14	0.01	0.07	43	300
70	09FF-182	70.5	433	0.00	0.03	0.28	0.09	0.11	0.01	0.03	100	933
65	09FF-184	70.3	423	0.00	0.02	0.27	0.17	0.07	0.01	0.05	40	540
60	09FF-185	70.7	416	0.00	0.01	0.16	0.20	0.06	0.01	0.04	25	400
55	09FF-186	70.7	439	0.01	0.03	0.23	0.17	0.13	0.01	0.05	60	460
50	09FF-187	70.2	413	0.00	0.01	0.26	0.18	0.04	0.02	0.08	12	325
45	09FF-188	70.9	441	0.00	0.02	0.00	0.11	0.00	0.00	0.04	50	0
40	09FF-189	70.3	437	0.00	0.01	0.34	0.16	0.03	0.02	0.11	9	309
35	09FF-190	70.9	444	0.00	0.02	0.21	0.15	0.10	0.01	0.03	67	700
30	09FF-191	71.1	494	0.00	0.01	0.23	0.20	0.04	0.01	0.06	17	383
25	09FF-192	71.0	452	0.00	0.01	0.30	0.10	0.03	0.01	0.04	25	750
20	09FF-194	71.0	442	0.00	0.02	0.21	0.12	0.10	0.02	0.05	40	420
15	09FF-195	70.6	437	0.00	0.01	0.29	0.10	0.03	0.02	0.10	10	290

Qty = mg; TOC = Total Organic Carbon, weight per cent; S1, S2 = mg hydrocarbons (HC)/g rock; S3 = mg CO_2/g rock;

PI = Production Index = S1/(S1+S2);

PC = Pyrolyzable Carbon(weight per cent) = ((0.83*(S1+S2))+(S3*.273)+ ((S3CO+(S3'CO/2))*0.4286))/10

Tmax = ^{o}C; HI = Hydrogen Index = (100*S2)/TOC; OI = Oxygen Index = (100*S3)/TOC

The high TOC values reported from the Trutch map area (94G) were not encountered during 2009 sampling. This may be a reflection of the more shelfward nature of the section sampled in 2009, with transition to Nonda and Muncho-McConnell formation carbonate rocks occurring only 10–20 km to the east. Furthermore, the Skoki Formation does not shale out for another 10–20 km westward. This western, more basinal setting (i.e., Kechika Trough), contains a thinner, more condensed section with zones higher in organic matter, particularly in the Lower–Middle Ordovician and Silurian (see Ferri et al, 1999). Further sampling is required to test these more western Lower–Middle Ordovician sections equivalent to the Skoki Formation for hydrocarbon source-rock potential.

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