HYDROCARBON SOURCE ROCK POTENTIAL AS DETERMINED BY ROCK-EVAL 6/TOC PYROLYSIS, NORTHEAST BRITISH COLUMBIA AND NORTHWEST ALBERTA

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KEYWORDS: Hydrocarbon source rocks, organic geochemistry, thermal maturity, petroleum systems.

ABSTRACT

The potential for conventional and/or unconventional hydrocarbon exploration requires the presence of organic-rich, thermally mature rock units containing oil or gas-prone kerogen. This potential is poorly known in large parts of northeastern B.C., and northern Alberta due to a paucity of organic geochemical studies.

Here, we investigate Lower Triassic to Lower Cretaceous potential source rocks within a large area of northeastern British Columbia and northwestern Alberta (118°-124°W and 57°- 58°N). Hydrocarbon source rock parameters, including type and amount of kerogen, and thermal maturity of these formations, are assessed by analyzing 74 core samples from 23 wells using Rock-Eval 6/TOC pyrolysis.

In general all units are immature in northwestern Alberta with increasing maturity to the west where they become overmature. The Lower Triassic Montney Formation contains Type II kerogen with TOC (Total Organic Carbon) values up to 4.2 wt.%, suggesting that this unit generated significant amount of hydrocarbons where it is mature.

The base of the Doig Formation comprises a highly radioactive zone, the "Phosphate Zone" which contains Type II kerogen with TOC values up to 11 wt.%. This interval is an excellent hydrocarbon source rock.

The Upper Triassic Baldonnel and Pardonet formations are late mature to overmature where sampled. The Baldonnel Formation contains up to 1.4 wt.% TOC indicating only poor to fair source rock potential. The Pardonet Formation is overmature, and contains residual TOC values up to 2.8 wt.%, which suggests this marine unit may have initially been a good source rock for hydrocarbons, but is now spent.

The Lower Jurassic Gordondale Member comprises Type II kerogen with TOC values up to 10.45 wt.%, indicating that this unit is an excellent hydrocarbon source rock. The Lower Cretaceous Wilrich Shale is also of interest, as it has been suggested as a potential target for shale gas exploration. This unit is immature to mature within the study area. It contains Type III kerogen with TOC values up to 4.28 wt.%.

Future investigation will involve 1D basin modeling in order to understand the amount and timing of hydrocarbon generation from these units with respect to timing of trap formation and accumulation of hydrocarbons.

INTRODUCTION

Hydrocarbon prospectivity in the Western Canada Sedimentary Basin (WCSB), or in any basin, hinges on the availability of oil and/or gas-prone rock units that have generated and expelled hydrocarbons. Potential and proven hydrocarbon source rock intervals of Mesozoic age are known throughout much of the WCSB, with most available data from the Alberta portion of the basin (e.g. Creaney and Allan, 1990; Creaney et al., 1994). Results of the previous works are summarized in Table 1.

However, in the area of this study, bounded by 57°-58°N latitude, and 118°-124°W longitude (Figure 1) there are few data available pertaining to hydrocarbon source rock potential. Furthermore, little is known of the thermal maturity of Paleozoic and Mesozoic strata in this area and such information is critical for predicting what type of hydrocarbons, if any, may have been generated.

This paper reports the results of hydrocarbon source rock characterization of six formations of interest within the study area namely, the Montney Formation, the "Phosphate Zone" at the base of Doig Formation, the Baldonnel and the Pardonet formations, the Gordondale Member (for discussion of the Gordondale, formerly Nordegg, terminology see Asgar-Deen et al., in press) and Wilrich Formation (Figure 2). Samples were collected from cores in British Columbia and Alberta and were analyzed by Rock-Eval 6/TOC pyrolysis.

Future investigation will involve 1D quantitative basin modeling in order to understand the amount and timing of hydrocarbon generation relative to trap formation and the accumulation of hydrocarbons.

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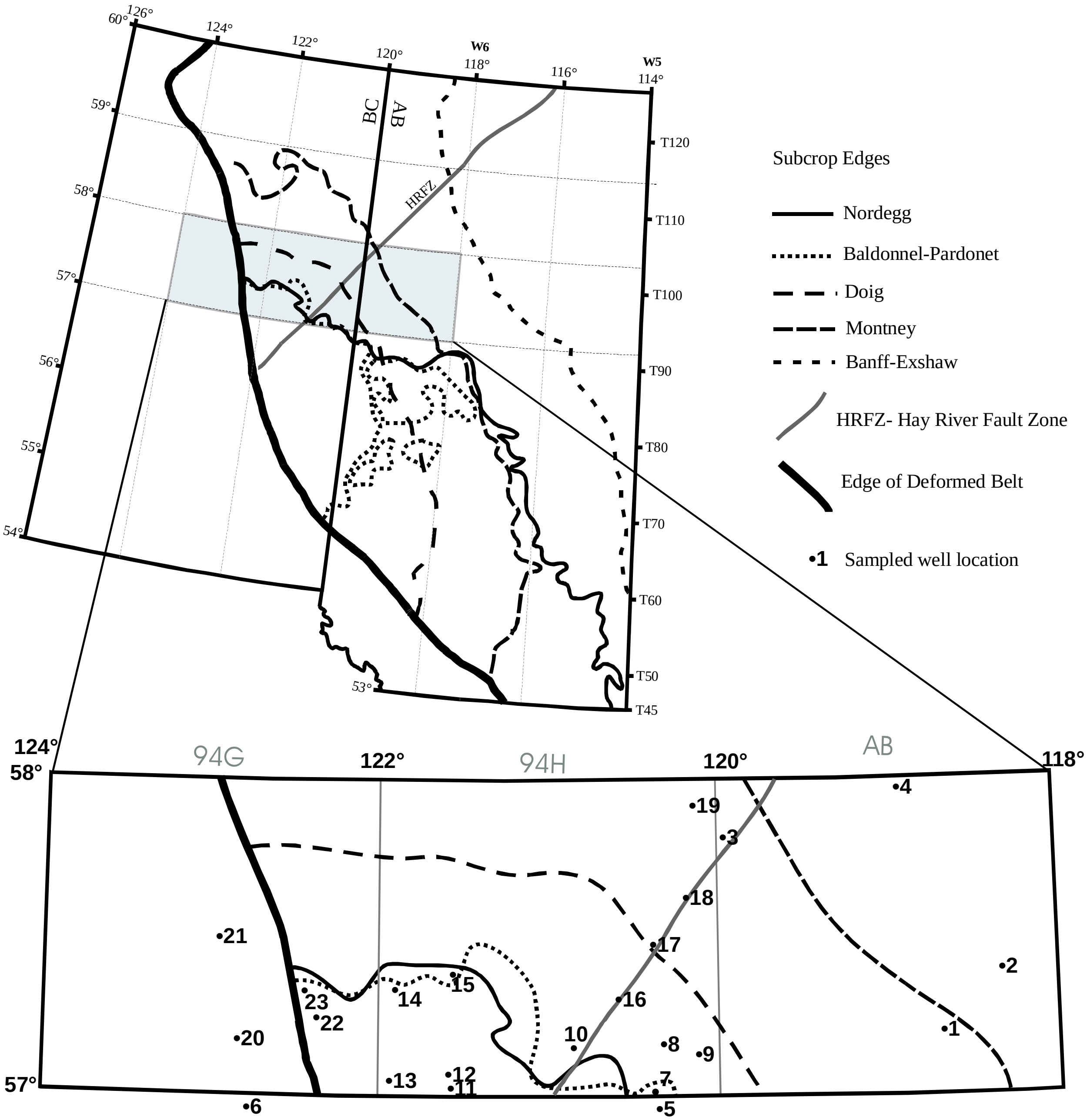

Figure 1. Map showing the study area, core sample locations, and the subcrop edges of the formations of interest (Compiled from Richards et al., 1994; Edwards et al., 1994; Poulton et al., 1994).

STRATIGRAPHY

Devonian to Cretaceous stratigraphy in the study area is shown in Figure 2. Potential hydrocarbon source rock intervals are highlighted by shading. We use the new Gordondale Member terminology to refer to the organic-rich, fine-grained strata that are laterally equivalent of Nordegg Member. These relationships are described by Asgar-Deen (2003) and Asgar-Deen et al. (in press).

Although the Devonian-Mississippian Exshaw Formation is a well-known and proven source rock for hydrocarbons, the lack of core through this zone precluded acquisition of samples during this study. However, Rock-Eval/TOC analysis of drill cuttings samples are planned.

Details of the stratigraphy shown in Figure 2 are not given here but interested readers can find this information in the appropriate chapters of the Geological Atlas of the Western Canada Sedimentary Basin (Mossop and Shetson, 1994).

TABLE 1. PREVIOUS STUDIES OF ROCK-EVAL/TOC DATA SHOWING THE TOC'S AND THE KEROGEN TYPES OF THE UNITS OF INTEREST (*TOC VALUES WILL VARY, DEPENDING ON MATURITY)

Unit	*TOC range (average)(wt. %)	Kerogen Type	References
Wilrich	0.45-2.05 (1.4)	Type III	Faraj, 2003;Ibrahimbas, (Unpublished results)
Gordondale	0.55-28 (5)	Type I/IIS	Riediger et al., 1990b; Asgar-Deen, 2003; Faraj, 2003
Pardonet	0.26-6.5 (0.94)	Type II	Riediger, 1997; Carrelli, 2002
Baldonnel	0.14-2.08 (<1)	Type II	Riediger 1997; Carrelli 2002
Phosphate Zone	1.12-11 (3.6)	Type II	Riediger et al.,1990a; 1990b; Creaney and Allan, 1992; Faraj, 2003
Montney	0.8-4.7 (1.3)	Type II	Riediger et al., 1990a; 1990b; Hankel, 2001; Faraj, 2003

METHODOLOGY

For this study 74 core samples were taken from 23 well locations (Figure 1). Samples were selected based on core availability within the zones of interest in the study area. Each sample was crushed to a fine powder prior to analysis. All samples were weighed to 100 mg and subjected to Rock-Eval 6/TOC analysis in order to determine the kerogen type, TOC content and thermal maturity, which are the main parameters for characterizing a hydrocarbon source rock. Analyses were conducted at the Organic Geochemistry Labs of the Geological Survey of Canada (Calgary). Measured parameters include S1 (mg HC/g rock), S2 (mg HC/g rock), S3 (mg CO_2/g rock), Tmax (°C), and TOC (wt.%) (see Table 2). Several additional parameters including HI (Hydrogen Index, S2/TOCx100), OI(Oxygen Index, S3/TOCx100), and PI (Production Index, S1/(S1+S2)) are calculated from these measured values, and are shown in Table 2. Pyrolysis experiments were repeated for some samples at lower sample weight to ensure that the Rock-Eval/TOC detector was not overloaded by generated hydrocarbons during the original runs.

Details of the analytical procedure and discussion of Rock-Eval parameters are available in Espitalié et al. (1977), Peters (1986), and Snowdon et al. (1998). Peters (1986), and Peters and Cassa (1994) provide a summary of interpretive guidelines for Rock-Eval data.

RESULTS AND DISCUSSION

Rock-Eval 6/TOC results are summarized in Table 2. Of the 7 potential hydrocarbon source rocks shown in Figure 2, geochemical data from only the Montney, Phosphate Zone, Baldonnel/Pardonet, Gordondale, and Wilrich intervals are reported. As noted previously, no samples from the Exshaw Formation were collected for this study due to a lack of core through this zone.

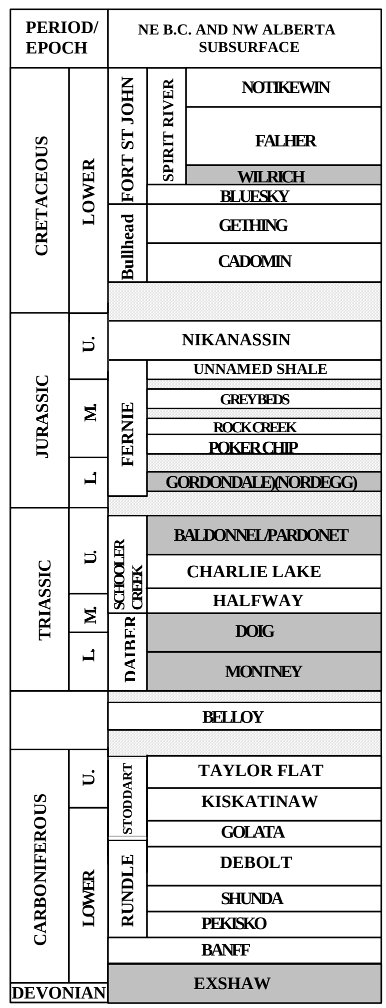

Figure 2. Stratigraphic chart of the study area (compiled from Richards et al., 1994; Henderson et al., 1994; Edwards et al., 1994; Poulton et al., 1994; Hayes et al., 1994). Potential source rocks are highlighted by shading.

However, geochemical data from well cuttings will be incorporated in the second phase of the study.

In this section, the thermal maturity, and amount and type of organic matter are discussed. Interpretive guidelines from Peters (1986) and Peters and Cassa (1994) are used to evaluate the hydrocarbon source rock potential of each unit, and these guidelines are reproduced in Table 3. In Table 4 thermal maturity, TOC content, HI and kerogen type are summarized for each unit.

Thermal Maturity

Rock-Eval Tmax data given in Table 2 are used to assess thermal maturity in the study area. Each unit is mapped individually in Figure 3 because variations in kerogen type affect the Tmax values (Peters, 1986). The overall maturity trend in the study area shows that the maturity of the units increases from east to west towards the Cordilleran deformation front. All units are thermally mature throughout the central part of the study area, (Beatton River Map Area, 94H). Most of the studied units are immature in Alberta, and are overmature in the Trutch Map Area (94G).

TOC Content, Kerogen Type and Hydrocarbon Source Rock Potential

The ranges of TOC values for each unit are summarized in Table 4. Histograms showing the TOC variation for each unit with mean TOC values and standard deviations are also given in Figure 4. The plot of S2 against TOC for immature to early mature samples is used to determine the proportion of the inert carbon in the TOC measured by pyrolysis (Conford et al., 1998). During pyrolysis, only the labile kerogen will generate hydrocarbons to be recorded in S2 peak. Thus by discounting the proportion of inert carbon, it is possible to obtain a more accurate HI (S2/TOCx100) value from the slope of the best fitted lines of S2 vs. TOC data (Figure 5). A bivariate plot of HI vs. OI (Pseudo-Van Krevelen diagram) is also commonly used to assess the kerogen type (Figure 6).

In this section information on TOC and kerogen type for each unit are used to evaluate the hydrocarbon source rock potential based on criteria outlined in Table 3.

The TOC values for the Montney Formation range from 0.51 wt.% to 4.18 wt.% with a mean value of 2.01 wt.% (std. dev. =1.24) (Figure 4). It contains 0.35 wt.% inert carbon (Figure 5), hence the proportion of organic carbon content which has the capacity to generate hydrocarbons range from 0.16 to 3.83 wt.%, with a mean value of 1.66. The unit yields HI values of 43-450 mg HC/g TOC, which is typical for oil and gas-prone Type II kerogen (Figure 6). Considering only the immature samples, adjusted HI_0 (original HI prior to maturation) is 571 mg HC/g TOC. These TOC and HI_0 values indicate good to very good source rock potential in the Montney Formation.

The "Phosphate Zone" has high TOC values ranging from 1.76 to 10.98 wt.% (Table 4), with a mean value of 6.14 wt.% (std. dev.=3.35) (Figure 4). The amount of the inert carbon in the "Phosphate Zone" is also high with a value of 1.4 wt.% (Figure 5); therefore the true organic carbon content of the unit is than between 0.4 to 9.6 wt.%. The unit comprises Type II, oil and gas-prone kerogen with HI values ranging 189-489 mg HC/g TOC (263-645 mg HC/g TOC after discarding the effect of inert carbon (Figure 5)). The unit has excellent source rock potential.

The TOC values for Pardonet and Baldonnel formations are fair to moderate. The samples are all overmature, and hence original kerogen type cannot be determined from geochemical data. However, these are marine carbonate units, and thus likely contained Type II kerogen. This interpretation is also supported by the results of a previous study by Carrelli (2002) on these formations. The residual TOC values for Pardonet Formation range 0.97 to 2.79 wt.%, with a mean value of 1.73 wt.% (std. dev.=0.60). Bordenave et al. (1993) suggested that overmature Type II source rocks would have lost 50 % of their original TOC due to generation and expulsion of hydrocarbons. Hence, the original TOC values for Pardonet Formation were likely over 4 wt.%. The TOC values measured from the Baldonnel Formation range 0.65 to 1.39 wt.%, which by the same reasoning, were likely 1 to 2 wt.% originally. The Pardonet Formation had fair to good initial source rock potential, and the Baldonnel Formation had poor to fair initial source rock potential.

The Gordondale Member contains high TOC values ranging 0.66 to 10.45 wt.% (mean=5.71 wt.%, std. dev.=2.66) (Figure 4). The unit yields HI values of 26 to 273 mg HC/g TOC, and OI values of 3-23 mg CO_2/g TOC (Figure 6), and the high degree of maturity precludes a precise assessment of the organic matter type. Riediger et al. (1990b), and Asgar-Deen (2003) proposed this unit having Type I/IIS kerogen, therefore, the unit most likely comprises Type II kerogen, considering its marine origin. This interval has excellent source rock potential where mature.

The TOC values of the Wilrich Shale ranges from 1.08 to 4.28 wt.% (mean=2.12 wt.%, std. dev.=0.91) (Figure 4). After considering the approximately 0.5 wt.% inert carbon (Figure 5), it will contain 0.58 to 3.78 wt.% TOC with a mean value of 1.62 wt.%. The unit contains Type III, gas-prone kerogen, with HI values ranging 138 to 393 mg HC/g TOC (Figure 6). The mean value of HI is 235 mg HC/g TOC after eliminating the effect of 0.5 wt.% inert carbon. The TOC and HI values indicate that the unit has good to very good source rock potential for gas generation.

TABLE 2. ROCK EVAL/TOC RESULTS FROM CORE SAMPLES IN THE STUDY AREA
(+REPEAT RUN AT LOWER SAMPLE WEIGHT)

Unit	Well #	Well ID	Depth (m)	Tmax (°C)	S1 (mg HC/ g rock	S2 (mgHC/ g rock)	S3 (mg CO_2/ g rock)	PI S1/ (S1+S2)	TOC (wt.%)	HI (mgHC/ g TOC)	OI (mgCO/ g TOC)
Wilrich	1	11-17-94-5W6	932.2	431	1.65	4.28	0.49	0.28	2.36	182	21
	2	7-25-96-4W6	827	428	1.06	3.15	0.38	0.25	1.96	161	19
	4	10-36-103-7W6	698.9	431	1.58	2.83	0.4	0.36	1.97	144	20
			704.8	429	0.59	4.8	0.44	0.11	3.16	153	14
	16	D-69-A/94-H-7	1100.5	441	0.22	2.69	0.16	0.08	1.83	148	9
			1103.1	442	0.3	2.84	0.16	0.10	1.83	156	9
	17	A-43-K/94-H-8	1194.5	438	0.14	1.49	0.27	0.09	1.08	139	25
			1196	438	0.27	2.84	0.26	0.09	1.47	194	18
	19	B-81-G/94-H-16	809.5	436	0.18	1.7	0.23	0.10	1.23	138	19
			811.4	437	1.06	16.8	0.18	0.06	4.28	393	4
Gordondale	5	A-58-K/94-A-16	1010.9	439	1.08	6.27	0.09	0.15	3.03	208	3
			1012.4	441	2.05	6.53	0.06	0.24	2.4	273	3
			1013.5	438	1	4.3	0.06	0.19	2.05	210	3
	11	A-43-A/94-H-4	1277.6	461	2.93	8.48	0.18	0.26	7.29	119	2
			1277.6	461	2.71	8.34	0.2	0.25	7.35	116	3
			1279.1	454	1.13	2.99	0.23	0.27	3.55	85	6
			1281.1	464	1.85	6.02	0.23	0.24	4.14	74	3
	12	D-93-A/94-H-4	1262.5	460	0.64	1.08	0.12	0.37	1.48	74	8
			1264.1	456	1.46	6.82	0.3	0.18	6.32	109	5
			1265.6	463	2.27	8.47	0.33	0.21	8.91	97	4
			1267.1	446	3.8	8.19	0.26	0.32	5.94	139	4
			1268.6	443	6.21	10.19	0.26	0.38	6.85	150	4
			1270.1	448	6.77	12.77	0.2	0.35	7.84	165	3
			1271.6	449	2.93	5.58	0.21	0.34	3.87	146	5
			1273.1	448	1.78	3.3	0.15	0.35	2.35	142	6
	13	D-65-D/94-H-4	1387.4	472	0.62	1.56	0.16	0.28	5.18	31	3
			1388.4	481	0.52	2.93	0.31	0.15	8.12	37	4
			1389.2	484	0.3	2.36	0.35	0.11	5.89	42	6
			1389.9	484	0.25	2.05	0.38	0.11	5.25	41	7
			1390.6	484	0.18	0.77	0.2	0.19	3.03	26	7
			1391.8	484	0.32	1.37	0.37	0.19	4.98	29	7
			1392.4	484	0.62	3.34	0.3	0.16	9.48	37	3
			1393	480	0.68	3.35	0.29	0.17	10.45	33	3
	14	A-5-E/94-H-6	1145.5	452	0.25	1.12	0.3	0.18	1.33	85	23
	15	B-54-H/94-H-5	1218.7	443	0.49	2.23	0.12	0.18	2.19	102	5
	22	C-86-C/94-G-8	1426.9	456	0.22	0.16	0.21	0.58	0.66	24	32
			1429.1	453	0.19	0.18	0.18	0.51	0.58	31	31
Pardonet	6	A-77-K/94-B-15	1050.4	480	0.27	0.84	0.15	0.24	1.73	51	9
			1055.8	461	0.36	0.42	0.19	0.46	1.83	23	10
			1059.3	471	0.21	0.39	0.17	0.35	1.16	34	15
			1061.8	468	0.33	0.34	0.21	0.49	1.34	26	16
	23	D-99-F/94-G-8	1316.6	468	0.65	1.44	0.15	0.31	2.29	64	7
			1317.6	464	0.53	0.92	0.11	0.37	0.97	96	11
			1319.1	466	0.73	1.6	0.15	0.31	2.79	58	5
Baldonnel	6	A-77-K/94-B-15	1065.1	472	0.14	0.24	0.16	0.37	0.86	29	19
	12	D-93-A/94-H-4	1274.1	452	0.52	0.56	0.13	0.48	0.98	57	13

TABLE 2. ROCK EVAL/TOC RESULTS CONTINUED.

Unit	Well #	Well ID	Depth (m)	Tmax (°C)	S1 (mg HC/ g rock	S2 (mgHC/ g rock)	S3 (mg CO_2/ g rock)	PI (S1/ (S1+S2))	TOC (wt.%)	HI (mgHC/ g TOC)	OI (mgCO_2/ g TOC)
	22	C-86-C/94-G-8	1434.4	469	0.56	0.77	0.17	0.42	1.39	57	12
			1439.8	464	0.69	0.63	0.2	0.52	1.02	63	20
			1443.2	478	0.74	0.63	0.16	0.54	0.65	98	25
Phosphate Zone	8	A-78-F/94-H-1	1069.2	447	0.99	10.21	0.22	0.09	2.95	346	7
			1073.4	445	0.93	9.02	0.21	0.09	2.63	343	8
			1075	443	0.76	5.9	0.19	0.11	1.9	311	10
			1076.4	437	1.29	14.51	0.23	0.08	5.26	277	4
	9	D-48-H/94-H-1	1051.3	425	0.01	0.05	0.31	0.17	0.12	42	258
			1053.8	438	0.9	12.44	0.3	0.07	2.65	469	11
			1056	433	1.78	28.61	0.33	0.06	5.86	489	6
	10	D-72-E/94-H-2	1176.3	443	1.57	3.9	0.18	0.29	1.76	189	3
			1180.6	443	1.62	9.93	0.18	0.14	5.27	189	3
			[+]1180.6	441	1.59	9.79	0.21	0.14	5.02	196	4
			1182.9	442	1.64	15.9	0.2	0.09	7.73	207	3
			[+]1182.9	442	1.57	15.49	0.18	0.09	7.58	206	2
			1186.1	445	2.01	25.17	0.22	0.07	10.98	231	2
			[+]1186.1	445	2.08	24.62	0.21	0.08	10.79	230	2
			1187.4	444	2.14	25.68	0.18	0.08	10.95	236	2
			[+]1187.4	445	2.1	25.13	0.2	0.08	10.76	235	2
Montney	3	6-36-101-13W6	908.3	288	2.75	0.7	0.26	0.8	0.51	137	51
	7	D-13-D/94-H-1	1133.2	447	1.19	8.8	0.17	0.12	4.03	219	4
			1134.8	447	0.83	5.18	0.19	0.14	2.37	219	8
	18	D-45-G/94-H-9	905.8	431	0.8	4.8	0.23	0.14	1.23	390	19
			909.2	433	0.33	2.91	0.19	0.1	0.82	355	23
			914.5	439	0.41	9.09	0.26	0.04	2.02	450	13
			917.4	435	0.36	5.4	0.22	0.06	1.28	422	17
	20	D-88-F/94-G-2	2130.8	490	0.02	0.02	0.11	0.5	0.87	2	13
			2131.3	490	0	0.01	0.08	0	0.64	2	13
			2132.4	-40	0	0	0.15	0	0.4	0	38
			2133.1	500	0	0	0.1	0	0.43	0	23
	21	C-80-L/94-G-7	869.9	477	0.67	2.02	0.26	0.25	4.18	50	6
			873.4	466	0.48	0.69	0.18	0.41	1.63	43	11

TABLE 3. HYDROCARBON SOURCE ROCK EVALUATION PARAMETERS FOR ROCK-EVAL/TOC PYROLYSIS DATA (MODIFIED FROM PETERS, 1986). (TABLE 3 (C) INCLUDES RANGES OF VITRINITE REFLECTANCE THAT ARE APPROXIMATELY EQUIVALENT TO ROCK-EVAL TMAX VALUES. VITRINITE REFLECTANCE DATA ARE NOT USED IN THIS STUDY)

Petroleum Potential	Organic Matter		
	TOC	Rock-Eval Pyrolysis	
	(wt.%)	S1	S2
	0-0.5	0-0.5	0-2.5
	0.5-1	0.5-1	2.5-5
	1-2	1-2	5-10
	2-4	2-4	10-20
	>4	>4	>20

(A) Parameters for describing the Petroleum Potential of an Immature Source Rock.

TABLE 3. HYDROCARBON SOURCE ROCK EVALUATION PARAMETERS CONTINUED.

Kerogen Type	HI (mg HC/g TOC)	S2/S3
I	>600	>15
II	300-600	10-15
II/III	200-300	5-10
III	50-200	1-5
IV	<50	<1

(B) Parameters for describing Kerogen Type (Quality) of an Immature Source Rock.

Stage of Thermal Maturity for Oil	Maturation	
	Vitrinite Reflectance Ro (%)	Rock-Eval Tmax (°C)
Immature	0.2-0.6	<435
Mature		
Early	0.6-0.65	435-445
Peak	0.65-0.9	445-450
Late	0.9-1.35	450-470
Postmature	>1.35	>470

(C) Parameters for describing the level of Thermal Maturation.

TABLE 4. SUMMARY OF ROCK-EVAL/TOC DATA FROM CORE SAMPLES (RAW DATA)

UNIT (number of samples)	DEPTH (m)	Tmax (°C) range	TOC (wt.%)	HI (mg HC/g TOC)	Kerogen Type	Source Rock Potential
WILRICH (10)	809.5-1196	428-442	1.08-4.28	138-393	Type III	Good to very good (gas only)
GORDONDALE (27)	1010.9-1429.1	438-484	0.66-10.45	26-273	Type II	Excellent (oil+gas)
PARDONET (7)	1050.4-1319.1	461-480	0.97-2.79	23-96	Type II	Fair to good (oil+gas)
BALDONNEL (5)	1065.1-1443.2	452-478	0.65-1.39	29-98	Type II	Poor to fair (oil+gas)
PHOSPHATE ZONE (12)	1051.3-1187.4	433-447	1.76-10.98	189-489	Type II	Excellent (oil+gas)
MONTNEY (13)	869.9-2133.1	431-500	0.51-4.18	43-450	Type II	Good to very good (oil+gas)

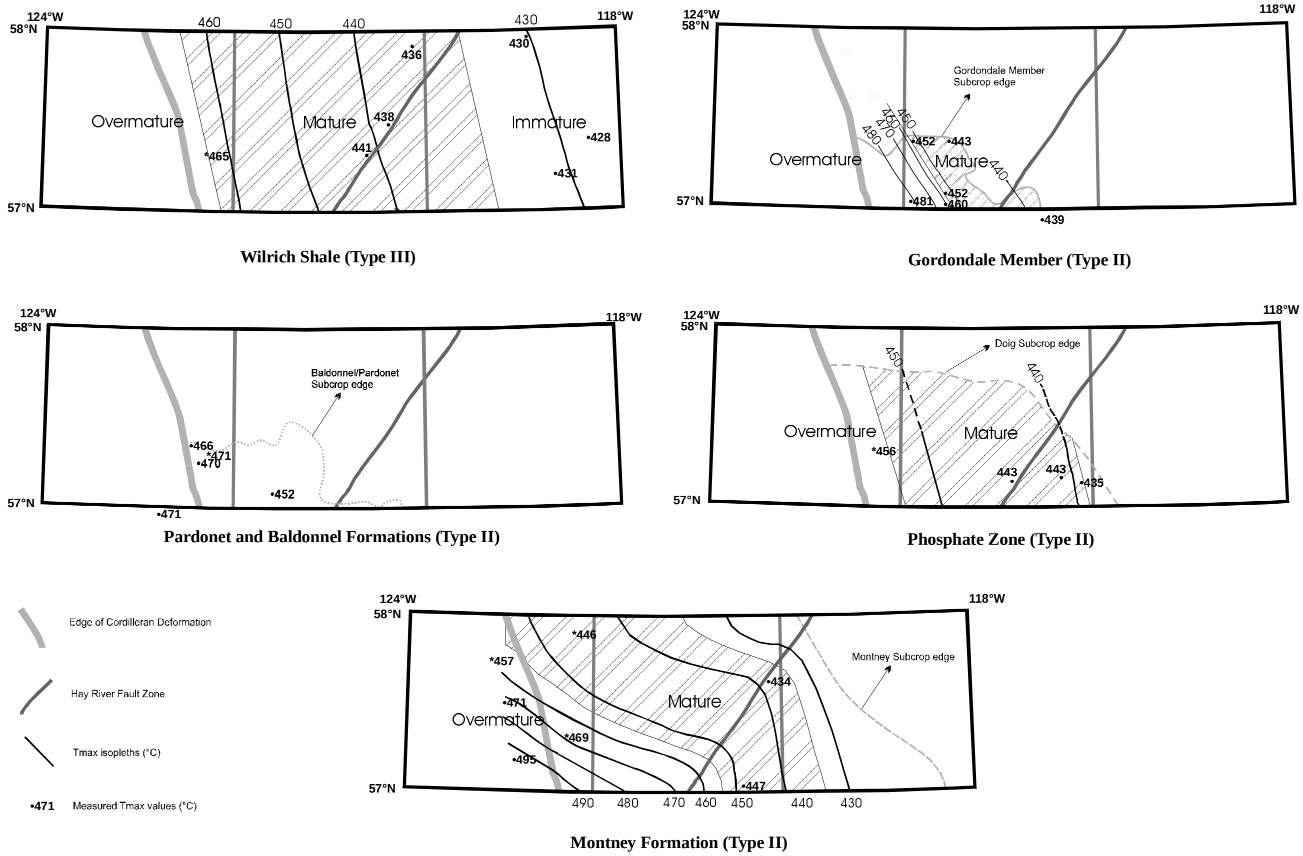

Figure 3. The thermal maturity distribution of each unit based on Rock-Eval Tmax values (ºC). * Tmax values from unpublished results (Dr. Larry Lane (GSC, Calgary), personal communication, 2003).

CONCLUSIONS

Six units of Early Triassic to Early Cretaceous age have been assessed for their hydrocarbon source potential in the study area. A total of 74 samples from 23 wells were analyzed by Rock-Eval 6/TOC pyrolysis.

The Montney Formation within the study area is thermally immature to overmature with increasing maturity from northeast to southwest. It contains Type II kerogen with TOC values up to 4.18 wt.%. This suggests that the Montney Formation may have generated significant amounts of hydrocarbons where it is mature in the B.C. part of the study area.

The highly radioactive "Phosphate Zone" at the base of Doig Formation contains Type II kerogen with TOC's up to 10.98 wt.%. The maturity increases from east to west and it is mature in the Beatton River Map area (94H). The high TOC values suggest that this unit has excellent hydrocarbon source potential where mature.

The Baldonnel and Pardonet formations are overmature in the west part of the study area where sampled. Both likely comprise Type II kerogen, although the high degree of maturity precludes a direct assessment of kerogen type. The Baldonnel Formation has TOC values up to 1.39 wt.% suggesting that it had poor to fair initial source rock potential. The Pardonet Formation has TOC values up to 2.8 wt.%, which suggests that it had fair to good initial hydrocarbon generation potential when mature.

The Gordondale Member samples vary from peak mature to overmature. It contains Type II kerogen with TOC's up to 10.45 wt.% suggesting that it is an excellent source rock where mature.

The Wilrich Shale contains Type III kerogen with TOC's up to 4.28 wt.%. Therefore, it has good to very good generation potential for gas. It is immature in the east part of the study area with increasing maturity to west.

The next step in this project is to apply 1D basin modeling to understand the amount and timing of hydrocarbons generated from these units, which will then be correlated with the timing of trap formation and accumulation of the hydrocarbons in the study area.

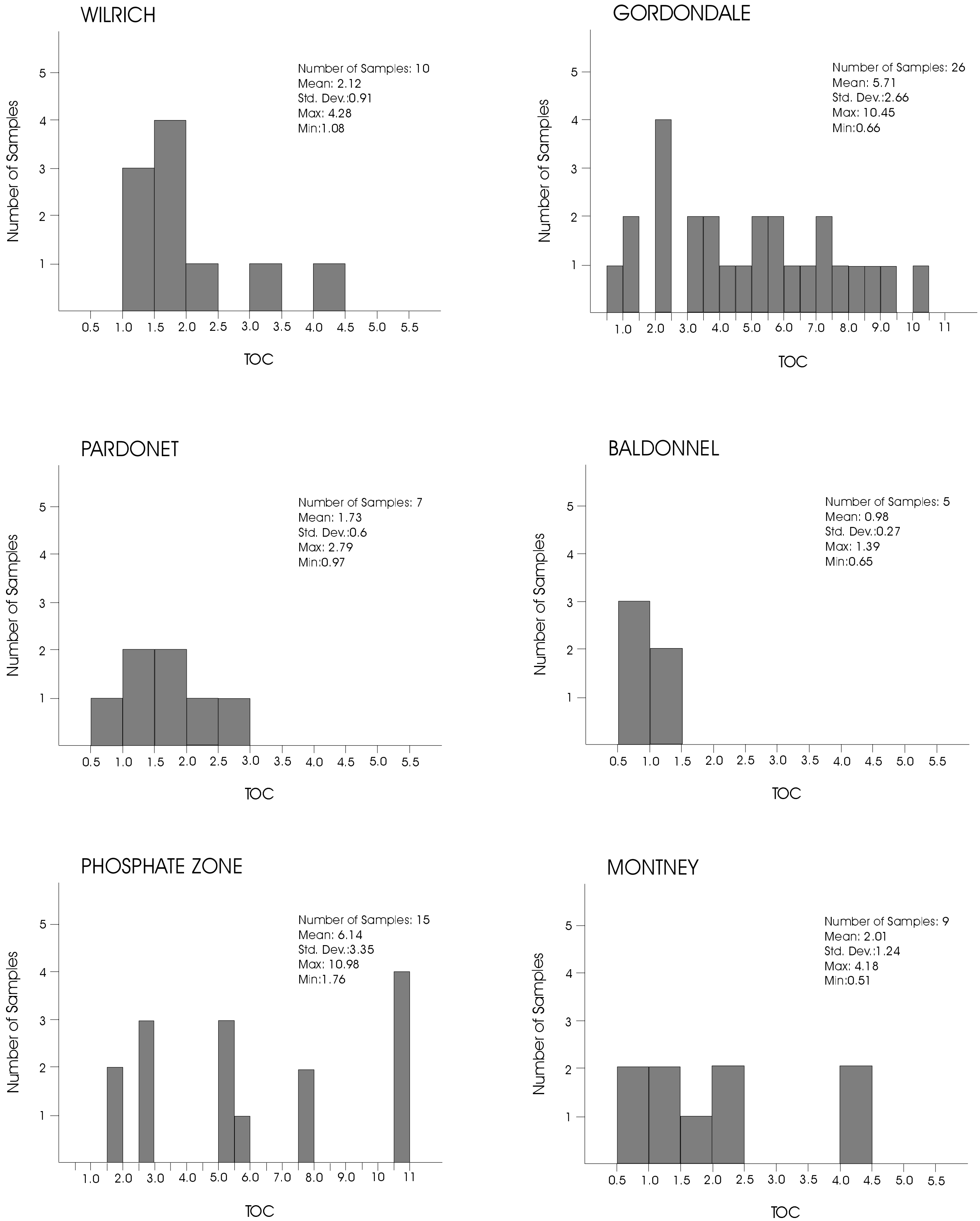

Figure 4. TOC histograms for the units with mean and standard deviation values. Note scale change for organically-richer units (Phosphate Zone; and Gordondale).

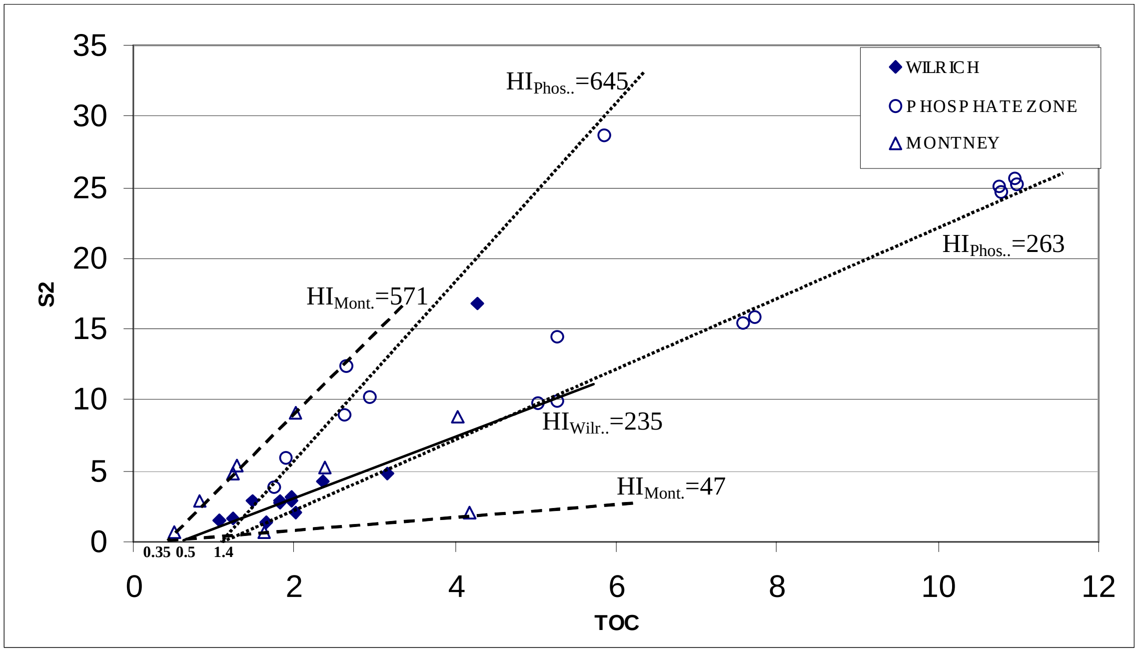

Figure 5. Rock-Eval pyrolysis S2 versus TOC, showing Hydrogen Index and Inert Carbon content of the units which have immature to early mature samples.

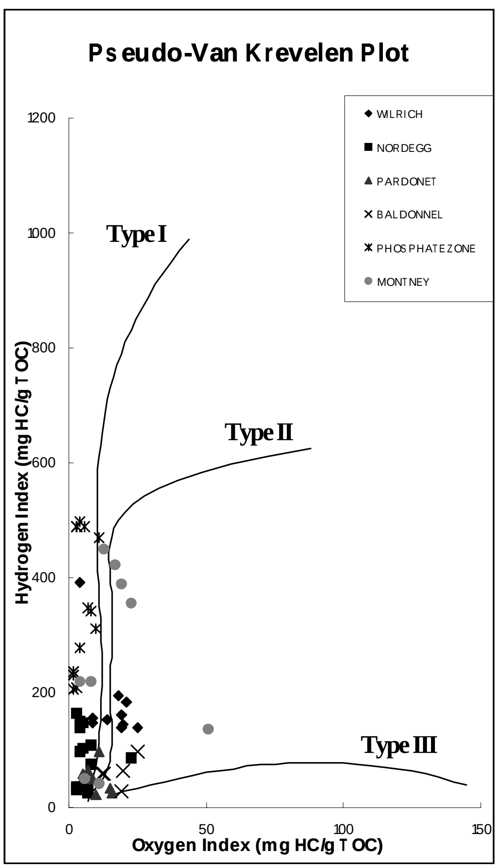

Figure 6. Pseudo-Van Krevelen diagram, showing Rock-Eval Hydrogen Index vs. Oxygen Index for the sampled units.

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