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Measured porosity in Horn River Group outcrop samples, Central Mackenzie Valley, NWT

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Cover photos (left to right)

- Canol Formation along Rumbly Creek tributary
- The Canol Formation at Dodo Canyon section
- The type locality for the Canol Formation at Powell Creek

INTRODUCTION

There is currently a new phase of exploration investment targeting shale oil reservoirs in the Canol Formation, part of the Devonian Horn River Group, within central Mackenzie Valley, Northwest Territories (NWT). The Canol Formation contains source rocks for a conventional oil field at Norman Wells, NWT that produces oil out of reef carbonates of the Ramparts Formation (Feinstein et al., 1988). The Horn River Group also contains fine-grained siliciclastics with high weight percent total organic carbon (TOC) in the Hare Indian Formation and within the Ramparts Formation (Carcajou member; Pyle and Gal, 2012, 2013; Pyle et al., 2011, 2014).

Studies of shale porosity and its variance and controls are an emerging science, and are important parameters to examine as part of unconventional shale reservoir evaluation. There is no published data on the nature of porosity within potential shale reservoirs in the Horn River Group in central NWT. The purpose of this report is to provide a reconnaissance dataset of measured porosity values from 38 outcrop samples from the Bluefish Member (3 samples), Hare Indian Formation (3 samples), Canol Formation (31 samples), and Imperial Formation (overlying the Canol Formation, 1 sample). The samples represent a subset of a larger study being conducted by the NWT Geoscience Office in Mackenzie Plain (Pyle et al., 2014) complemented by some samples from the adjacent Peel Plateau and Plain area (Gal et al., 2009). This study compares relationships between porosity measurements and shale rock properties such as total organic carbon (TOC) content, thermal maturation level of TOC, and selected oxides determined from whole rock geochemistry.

GEOLOGICAL BACKGROUND

Samples for this porosity study come from Horn River Group outcrops in the central NWT. The samples were collected during research programs conducted by the NWT Geoscience Office in Mackenzie Plain and Peel Plain and Plateau exploration areas (Pyle et al., 2014; Gal et al., 2009). These exploration areas are part of the northern Canadian mainland sedimentary basin (Figure 1, after Morrow et al., 2006). Outcrop samples are from sections within the Mackenzie Plain, Peel Plain, and flanking parts of the northern Mackenzie Mountains south of Peel Plateau, and southwest of Mackenzie Plain (Figure 2).

Within the study area, the Horn River Group consists of the Hare Indian, Ramparts and Canol formations (Pugh, 1983; Figure 3). The mixed siliciclastic-carbonate succession lies between the carbonate-dominated Hume Formation and the siliciclastic-dominated Imperial Formation, or may be truncated by a sub-Cretaceous unconformity (Figure 3, from Pyle et al., 2014). The Middle Devonian Hume Formation is extensive and maintains a uniform thickness in the study area (Williams, 1986). It represents the last phase of carbonate shelf deposition on a long-lived continental margin platform setting referred to as Mackenzie-Peel Shelf (Morrow and Geldsetzer, 1988). The overlying Horn River Group marks a significant change to an oxygen-stratified basinal setting in the study area beginning with deposition of organic-rich source rocks of the basal Bluefish Member of Hare Indian Formation, followed by another rapid sea level rise with the deposition of black mudrock-dominated Canol Formation. The intervening upper Hare Indian Formation (informal Bell Creek member) contains mixed siliciclastic-carbonate basin margin facies overlain by shale ramp and platform margin facies of the Ramparts Formation.

The uppermost part of the Ramparts Formation is the reefal Kee Scarp Member, which is the primary reservoir of the Norman Wells oil field (Muir and Dixon, 1984; 1985). Typically, the Ramparts carbonate developed upon the Bell Creek member. Where the Ramparts Formation is absent, a shale-on-shale succession occurs in which the Canol Formation overlies the Hare Indian Formation.

SAMPLES AND ANALYTICAL TECHNIQUES

A total of 38 hand samples were collected from eleven outcrop sections (Figure 2, Table 1). The Canyon Creek and Walker Creek sections lie within Mackenzie Plain exploration area. The Little Bear 1 and 2 sections, Dodo Canyon, Mountain River Tributary, Powell Creek, and Shortcut Creek sections lie southwest and west of Mackenzie Plain within the northern Mackenzie Mountains. The Airport Creek section lies within Peel Plain exploration area. The Rumbly Creek Tributary and Monument Creek sections lie south of Peel Plateau, also within the northern Mackenzie Mountains. The first seven sections listed in Table 1 were measured during fieldwork conducted by the Northwest Territories Geoscience Office (NTGO) during the Mackenzie Plain Petroleum Project (Pyle et al., 2014). The Rumbly Creek and Airport Creek sections are shorter partial sections examined during the NTGO's Peel Petroleum Project (Pyle and Gal, 2007), and the Monument Creek and Shortcut Creek samples are representative spot samples from the Canol Formation taken at sites where the Imperial Formation was measured (Hadlari et al., 2009).

Sample interval levels are illustrated next to a lithologic log for each measured section (Figures 4, 5, 6, 7, 8, 9, 10, 11, and 12). The samples from the Mackenzie Plain area sections represent chip samples through either one-, two-, or three-metre intervals depending on the thickness of the units in outcrop. Those from the Peel area (Rumbly Creek and Airport Creek, Figures 11 and 12) are representative spot samples. Spectral gamma radiation measurements were taken with a hand-held spectrometer (RS-120 Super-Scint and RS-220 Super-Scint by Radiation Solutions Inc.) at either one-metre, 1.5 metre, or three-metre intervals through each measured section in Mackenzie Plain area (gamma measurements were not taken on the Peel area sections). The organic-richness of chip samples was evaluated using Rock-Eval pyrolysis and total organic carbon (TOC) analyses provided by the Geological Survey of Canada (GSC) in Calgary (summarized in Table 1, full data in Appendix A). A ten gram split of the same chip sample was analysed by inductively coupled plasma–emission spectroscopy (ICP-ES) and inductively coupled plasma–mass spectroscopy (ICP-MS) for whole-rock, trace-, and rare earth element abundances by Acme Analytical Laboratories in Vancouver, BC (Appendix B). A five gram split from select samples was analysed for mineral species present by X-ray diffraction (XRD) at GSC-Calgary and GSC-Ottawa (semi-quantitatively, Appendix C). The spot samples from the Peel area represent one horizon rather than a chip sample collected over an interval, and have only Rock-Eval analyses reported (Table 1, Appendix A).

The textural properties were measured by N_2 adsorption at –196ºC in a Micromeritics TriStar 3000 automated system. The method of gas adsorption can probe the surface irregularities and pore interiors even at the atomic level. In this manner a very powerful method is available which can generate detailed information about the morphology of surfaces (Lowell et al., 2004).

To determine the surface area, solid samples are pretreated by applying some combination of heat and flowing gas to remove adsorbed contaminants acquired from atmospheric exposure. The solid is then cooled, under vacuum, to cryogenic temperature. An adsorptive (N_2 in this case) is admitted to the solid in controlled increments. After each dose of adsorptive, the pressure is allowed to equilibrate and the quantity of gas adsorbed is calculated. The surface area or pore volumes and pore sizes are then calculated by means of an appropriate theory used to treat the adsorption and/or desorption data.

Nitrogen isotherms were obtained in both adsorption and desorption modes. The surface areas were determined by the Brenauer-Emmett-Teller (BET) method. The total pore volume was calculated from the amount of vapor adsorbed at a relative pressure (P/Po) close to unity, where P and Po are the measured and equilibrium pressures, respectively. Pore size distribution was established from the desorption branches of the isotherms using the Barrett–Joyner–Halenda (BJH) method.

Prior to the adsorption measurements, samples were hand ground to the desired size using a mortar. The grinding was needed in order to fit them in the holder used to measure their textural properties. For maximum accuracy and reproducibility it is necessary that the sample chosen for the analysis be representative of the larger initial quantity. The samples were then outgassed overnight at 150ºC.

Because adsorption depends on the expose surface area, crushing rock may create surface area. For this reason, when samples with very small areas are compared, the effective surface area is not necessarily equal to the surface area as measured by gas adsorption. In general, however, it can be observed that the grain size decreases, the porosity increases, and the size of pores decreases, the greater its effective surface area.

Measured porosity data (as volume of pores in cm^3/g) are listed for each measured section (Figures 4, 5, 6, 7, 8, 9, 10, 11, and 12) and tabulated with average pore width (BJH adsorption/desorption analyses), BET surface area, and Langmuir surface area (Table 2). Analyses were carried out by the Catalysis for Bitumen Upgrading In Situ Energy Facilities at the University of Calgary.

Table 1. *List of sample locations, unit sampled, and summary of Tmax and TOC values.*

Section/Sample	NTS Mapsheet	UTM E (NAD 83)	UTM N (NAD 83)	UTM Zone	Formation/ Member	Tmax	TOC
Canyon Creek							
11CC-006	96E	618106	7239145	9	Bell Creek	436	4.96
11CC-016	96E	618106	7239145	9	Canol	426	6.74
11CC-019	96E	618106	7239145	9	Canol	434	5.09
11CC-024	96E	618106	7239145	9	Canol	432	2.90
Walker Creek							
11WC-002	96E	551616	7245351	9	Canol	433	4.63
11WC-013	96E	551616	7245351	9	Canol	437	4.48
Dodo Canyon							
11DC-001	96E	578059	7210407	9	Bluefish	448	7.46
11DC-007	96E	578059	7210407	9	Bell Creek	448	4.23
11DC-010	96E	578059	7210407	9	Canol	446	5.72
11DCE-002	96E	578964	7210364	9	Canol	443	5.03
11DCE-011	96E	578964	7210364	9	Canol	443	4.40
11DCE-017	96E	578964	7210364	9	Canol	442	4.00
11DCE-023	96E	578964	7210364	9	Canol	442	3.68
11DCE-029	96E	578964	7210364	9	Canol	441	5.30
11DCE-033	96E	578964	7210364	9	Canol	443	4.98
11DCE-035	96E	578964	7210364	9	Imperial	442	2.47
Little Bear 2							
11LB-001	96D	627330	7155802	9	Bluefish	440	5.05
11LB-008	96D	627330	7155802	9	Bluefish	450	5.08
Little Bear 1							
LG10-023	96D	620865	7152336	9	Bell Creek	452	7.20
LG10-028	96D	620895	7152360	9	Canol	451	7.32
LG10-036	96D	620945	7152399	9	Canol	438	3.59
LG10-041	96D	620975	7152423	9	Canol	440	3.74
LG10-047	96D	621012	7152452	9	Canol	446	5.13
LG10-052	96D	621043	7152477	9	Canol	449	4.17
Mountain River Tributary							
12-MR-45 (107-110m)	106H	519062	7235306	9	Canol	445	2.82
12-MR-51 (125-128m)	106H	519074	7235323	9	Canol	447	4.93
12-MR-63 (161-164m)	106H	519088	7335338	9	Canol	444	3.61
Powell Creek							
LP10-002	106H	510549	7239391	9	Canol	442	3.93
LP10-008	106H	510554	7239394	9	Canol	444	5.46
LP10-011	106H	510555	7239395	9	Canol	445	4.50
LP10-017	106H	510561	7239399	9	Canol	441	3.39
Rumbly Creek Tributary							
06LP-07-05	106G	392840	7255969	9	Canol	596	6.80
06LP-14-06	106G	389858	7255391	9	Canol	603	3.10
06LP-14-07	106G	389831	7255368	9	Canol	602	7.54
Airport Creek							
06LP-20-02	106I	499693	7366664	9	Canol	424	4.89
06LP-20-03	106I	499709	7366676	9	Canol	487	2.92
Shortcut Creek							
06LP-18-11	106G	469913	7244785	9	Canol	456	8.29
Monument Creek							
06TH-06-E	106G	418214	7250364	9	Canol	594	6.13

Table 2. List of sample locations, unit sampled, and porosity data.

Sample/Section	Formation/ Member	BET Surface Area (m^2/g)	Langmuir Surface area (m^2/g)	Volume of pores BJH (Desorption) (cm^3/g)	Average pore width BJH (Desorption) (Å)
Canyon Creek					
11CC-06	Bell Creek	0.7629	1.1399	0.007027	125.485
11CC-016	Canol	0.1389	0.2071	0.002197	309.793
11CC-019	Canol	2.8990	4.3013	0.013956	70.777
11CC-024	Canol	12.2712	17.9923	0.032157	60.670
Walker Creek					
11WC-002	Canol	0.7570	1.1452	0.008575	166.250
11WC-013	Canol	0.6488	0.9650	0.006914	170.930
Dodo Canyon					
11DC-01	Bluefish	0.2070	0.3037	0.002014	401.037
11DC-07	Bell Creek	7.5000	10.8684	0.019547	94.508
11DC-10	Canol	0.8349	1.2260	0.003844	79.726
11DCE-02	Canol	2.4384	3.6376	0.011565	72.292
11DCE-011	Canol	0.2593	0.3790	0.002157	408.402
11DCE-017	Canol	5.1870	7.5453	0.017708	90.897
11DCE-023	Canol	0.9555	1.4128	0.007395	142.787
11DCE-029	Canol	1.6469	2.4433	0.010444	93.508
11DCE-033	Canol	1.8816	2.7743	0.009477	75.827
11DCE-035	Imperial	7.1271	10.3568	0.015887	86.437
Little Bear 2					
11LB-001	Bluefish	1.1769	1.7420	0.004960	80.357
11LB-008	Bluefish	7.4775	10.8443	0.011911	69.819
Little Bear 1					
LG-10-023	Bell Creek	5.0033	7.4371	0.013464	56.905
LG-10-028	Canol	1.2839	1.8818	0.009788	160.622
LG-10-036	Canol	3.9964	5.9162	0.022361	110.351
LG-10-047	Canol	3.9829	5.8812	0.020764	101.474
LG-10-041	Canol	4.3618	6.4700	0.022266	82.474
LG-10-052	Canol	10.5084	15.3583	0.029714	72.852
Mountain River Tributary					
12MR-107	Canol	2.1432	3.1243	0.009359	135.208
12MR-127	Canol	0.6254	0.8951	0.000868	848.064
12MR-163.5	Canol	0.6574	0.9675	0.003334	106.001
Powell Creek					
LP-10-02	Canol	0.6599	0.9924	0.004455	145.486
LP-10-08	Canol	1.6680	2.4177	0.008563	162.043
LP-10-11	Canol	0.4377	0.6664	0.002294	79.487
LP-10-17	Canol	1.3387	1.9386	0.001762	80.298
Rumbly Creek Tributary					
06LP-07-05	Canol	15.5236	22.3619	0.002237	0
06LP-14-06	Canol	8.7253	12.5158	0.022765	91.280
06LP-14-07	Canol	15.8230	22.9584	0.028022	61.703
Airport Creek					
06LP-20-02	Canol	9.1921	13.3081	0.032551	113.341
06LP-20-03	Canol	5.6424	8.1765	0.030817	129.360
Shortcut Creek					
06LP-18-11	Canol	0.0223	0.0303	0.000651	515.146
Monument Creek					
06 TH-06-E	Canol	28.8435	41.3378	0.033273	48.886

SAMPLE LOCATION DESCRIPTIONS AND LITHOGEOCHEMISTRY

Seven sections within and flanking the Mackenzie Plain area are described in detail in Pyle et al. (2014) and summarized here. Additional details on two partially measured sections (Rumbly Creek Tributary and Airport Creek) from Peel area are in Pyle and Gal (2007). Figures 4 through 10 illustrate the sections with their gamma profile, TOC values, and changing trends in select whole rock lithogeochemical data. The profiles and proxies used to characterize the units of the Horn River Group include: uranium, silica to zirconium ratio, terrigenous input profile (TIP=a summation of aluminum oxide, iron oxide, potassium oxide, and titanium oxide) and thorium to uranium ratio, enrichment in calcium oxide, and elevation in trace elements such as molybdenum, vanadium, and nickel. The data presented for the Walker Creek section differs slightly by showing select oxides and trace elements without ratios and TIP because it is a partial section containing only Canol Formation (Figure 5). Using the TIP follows work on the Horn River Formation in British Columbia by Hildred and Rice (2012) who illustrate fluctuations in the concentrations of major oxides related to land-derived sediments. The ratio of Th/U is also plotted to accentuate the abundance of terrigenous input and clays relative to organic matter, for which U is a proxy.

Lithogeochemistry trends and lithological descriptions for each section are described in detail in Pyle et al. (2014). In general, the Canol Formation is characterized by elevated gamma radiation counts and corresponding high TOC trends and enriched uranium. The Canol Formation has a high trend of the SiO_2/Zr ratio, indicative of biogenic silica enrichment. Terrigenous input is low in the Canol Formation, indicated by low TIP values and corresponding low Th/U ratio. In contrast to the Canol Formation, the underlying Bell Creek member displays a high TIP trend and Th/U ratio trend, lower SiO_2/Zr ratio, and leaner TOC values (Figures 7 and 9). The Bluefish Member (trends illustrated for Dodo Canyon and Little Bear River 2 sections, Figures 6 and 7) has elevated gamma radiation counts, high TOC and U values, lower SiO_2/Zr ratio compared to the Canol Formation, and TIP and Th/U ratio values comparable to those of the Canol Formation (however, Th/U ratio is lower than that of the Canol Formation at Little Bear River 2 section).

Canyon Creek

A section exposed along Canyon Creek (NTS 96E) contains an almost complete section of the Canol Formation, underlain by the Hare Indian Formation. Sample 11CC-006 is from the top of the Hare Indian Formation (Bell Creek member) that contains dark grey shale and silty mudstone. Samples 11CC-016 and -019 are from the middle resistant unit of the Canol Formation and consist of black shale and silty mudstone. Sample 11CC-024 is from the upper recessive unit of the Canol Formation and consists of dark grey shale with thin siltstone beds.

Walker Creek

A partial section of the Canol Formation is located on the northwest side of Walker Creek in the Norman Wells map area (NTS 96E). Two samples from near the base and top of the middle resistant unit of the Canol Formation consist of black mudstone and shale (11WC-002 and -013).

Dodo Canyon

Along the west side of Dodo Creek (NTS 96E), the Hare Indian Formation overlies the Hume Formation and is overlain by the basal Canol Formation. For the porosity study, one sample of black shale from each of the Bluefish Member (11DC-001), Bell Creek member (11DC-007) and basal Canol Formation (11DC-010) were analysed.

Two additional black shale samples from near the base and near the top of the basal recessive unit of the Canol Formation (11DCE-002 and -011) were taken at the continuation of the section across the creek on the east side of Dodo Canyon. The lower part of the outcrop contains black shale and thin beds of silty black mudstone. Three samples represent the base, middle and top of the middle resistant unit (11DCE-017, -023, -029) and come from a unit of black siliceous and silty mudstone with shale interbeds. The upper recessive unit of the Canol Formation is marked by a change to black, friable weathering shale (11DCE-033). A gradational change to dark grey shale and siltstone marks the change to the Imperial Formation (11DCE-035).

Little Bear River 1 and 2

The Little Bear River 2 sections along the north side of the Little Bear River (NTS 96D) expose the Hare Indian Formation above the Hume Formation, overlain by an incomplete cliff section of the Canol Formation. Two samples of black shale from the Bluefish Member of the Hare Indian Formation were analysed from this locality (11LB-001 and -008; Figure 7). A complementary section called Little Bear River 1 contains a complete thickness of the Canol Formation, but the Hare Indian Formation is more poorly exposed compared to the Little Bear River 2 section. One dark grey, silty shale sample of the upper Hare Indian Formation was analysed (Bell Creek member, LG10-023, Figure 8). Samples from the Canol Formation include two dark grey to black, silty shale intervals of the basal recessive unit (LG10-028 and -036), two dark grey, silty shale and mudstone intervals of the middle resistant unit (LG10-041 and -047), and one dark grey, silty, friable shale interval in the upper recessive unit (LG10-052) just below the transition to the Imperial Formation.

Mountain River Tributary

The section is located along the north side of a tributary to the Mountain River (NTS 106H), and consists of a complete exposure of the Canol Formation. Two black mudstone samples come from the intervals of samples 12MR-45 (=12MR-107, at 107 m above section base) and 12MR-51 (=12MR-127, at 127 m above section base) from within the middle resistant unit. One black mudstone (12MR-163.5, at 163.5 m above section base, within interval sample 12MR-63) lies in an interval of largely friable black shale in the upper recessive unit of the Canol Formation (Figure 9).

Powell Creek

The Powell Creek section is the type section for the Canol Formation (defined by Bassett, 1961; NTS 106H), where it is 18.2 m thick (Pyle et al., 2014). Four black shale samples were analysed for porosity, three from within the base, middle and top of the middle resistant unit (LP-10-002, -008, and -011), and one from the upper recessive unit (LP-10-017).

Rumbly Creek Tributary

The site is mapped as an undifferentiated Dhci unit that outcrops along a tributary to Rumbly Creek (Hare Indian, Canol, and basal Imperial formations on NTS 106G, 1:250,000 map by Aitken et al., 1982). Only the basal 5 m of the Canol Formation was examined on the west side of the tributary, and spot sampled (06LP-07-05) where it contains black shale with bedding parallel lime mudstone concretions and dark grey lime mudstone and siltstone interbeds (Figure 11). Two other samples along another tributary to Rumbly Creek were taken in black shale of the Canol Formation (06LP-14-06, -07), but this partial section was not measured.

Airport Creek

Along the west side of Mackenzie River (in Fort Good Hope map area, NTS 96L), a cliff of upper Hare Indian and Ramparts Formation outcrops is overlain by Canol Formation in the north side of a creek bed. Two spot samples of dark brown-black shale were taken from the basal two metres of the Canol Formation (06LP-20-02 and -03; Figure 12).

Shortcut Creek

The Canol Formation was not measured along the east side of a creek bed near Shortcut Creek (in Sans Sault Rapids map area, NTS 106H), instead a representative spot sample of blocky weathering, siliceous black shale was taken from the Canol Formation near the contact with the Hare Indian Formation (sample LP-18-11).

Monument Creek

The Canol Formation was not measured at this section location, where the focus was on a measured section of Imperial Formation (NTS 106G), but a spot sample of black shale was taken within the middle of the Canol Formation, well below the top of the unit.

RESULTS

Organic Carbon Content

Samples from the Canol and Hare Indian formations all contain elevated TOC values (Table 1, Appendix A). The Bluefish Member (3 samples) has a range of TOC values from 5.05 to 7.46%. The Bell Creek member (3 samples) has a range of TOC values from 4.23 to 7.2%. The Canol Formation (31 samples) has a range of TOC values from 2.82 to 8.29%. One Imperial Formation sample had a characteristically leaner value of 2.47% TOC. TOC values for the subset of samples in this study are taken from Pyle et al. (2014) and Gal et al. (2007, 2009).

In the study area from which the subset of porosity samples were taken, Pyle et al. (2014) report median values for Canol Formation (298 samples) and Bluefish Member (56 samples) each greater than 5% TOC. The Bell Creek member of the Hare Indian Formation (64 samples total) contains organic-lean samples where the unit is green-grey, silty shale and limestone (less than 1% TOC), and medians ranging from 3.4 to 6.8% TOC where the unit is dark grey mudrock and limestone. The variability of TOC values through sections of Horn River Group is illustrated in Figures 4 through 10, with the subset of samples highlighted in each figure.

Porosity

Canol Formation samples that had porosity measurements (Table 3) yielded a range in the pore volume of 0.000651 to 0.033273 cm^3/g and a mean pore volume of 0.013667 cm^3/g. A histogram of pore volume shows a multi-modal distribution (Figure 13), in which 16 samples have 0.01 cm^3/g pore volume or less, and 14 samples have greater than 0.012 cm^3/g pore volume. Measured porosity values are plotted next to each sample in Figures 4 through 12 to show the stratigraphic horizon of each subsample in the present study. In the section with the most samples, Dodo Canyon (Figure 6), pore volume values do not show any stratigraphic trends as values for the Bluefish and Bell Creek member, and that for the Imperial Formation are comparable to values within the Canol Formation.

Pore width measurements for the Canol Formation samples (Table 3) have a mean value of 15.95 nanometres (nm) for the average pore width from each sample. Values range from 4.8886 to 84.8064 nm (Table 3) and a histogram shows 70% of samples within the 10 to 15 nm range (Figure 14).

Variation in shale porosity may be directly related to organic matter, maturity, or mineralogical composition. Possible controls on porosity can be examined by comparing porosity to TOC content, in which porosity may be associated with organic matter thus showing a positive relationship between organic matter content and pore volume (or total porosity), such as in the Barnett Shale and Marcellus Formation (Loucks et al., 2009; Milliken et al., 2013). Harris and Dong (2013) also showed a moderate correlation of porosity to TOC values in the Evie and Otter Park members of the Horn River Formation in BC, which are correlative units to the Bluefish and Bell Creek members of the Hare Indian Formation, but not in the Muskwa Formation in BC, which is equivalent to the Canol Formation. In this present subset of samples, no relationship was detected between pore volume and TOC (Figure 15).

In a study of the New Albany Shale by Mastalerz et al. (2013), a similar observation was made where there was no clear relationship between porosity and organic matter, thus they suggest interparticle and intraparticle pores may be more significant to the pore systems. From the dataset of the present study, a comparison of the pore volume and Tmax values also did not show any relationship (Figure 16), where it might be expected that pore volume could be related to maturity.

Variation in shale porosity may also be related to mineralogical composition, additionally substantiated by whole rock geochemistry datasets. Relationships between volume of pores and silica content (using silica dioxide) and between volume or pores and terrigenous input (using the TIP, determined by summation of weight % of Al_2O_3, Fe_2O_3, K_2O and TiO_2 to approximate fluctuations in land-derived sediments) are examined in Figures 17 and 18. Among the Horn River Group samples, the Canol Formation samples are quartz rich (up to 98% from XRD results, Appendix B) and contain high amounts of silica dioxide (up to 88% as determined by whole rock lithogeochemistry, Appendix C); however, there is no clear relationship between silica content and volume of pores in the subset of samples for any of the Horn River Group units (Figure 17). There is also no clear relationship between the TIP and volume of pores, even though in lithogeochemistry trends, the TIP trends higher for the Hare Indian and Imperial formations in contrast to the Canol Formation.

There is no apparent relationship of pore width to pore volume among the sample subset (Figure 19).

Additional samples and measurements are needed to confirm these preliminary results of data analysis on the relationships between measured porosities and shale rock properties.

Table 3. *Summary of volume of pores and pore width for the Canol Formation samples.*

	Canol Fm Volume of pores (cm^3/g)	**Canol Fm Pore width (nm)**
Mean	0.013667	15.9531
Median	0.009633	10.3738
Standard Deviation	0.010984	16.5916
Minimum	0.000651	4.8886
Maximum	0.033273	84.8064

CONCLUSIONS

This report presents preliminary results of measured porosity values from outcrop samples from two members of the Hare Indian Formation (Bluefish and Bell Creek), the Canol Formation, and the Imperial Formation. The data do not show a significant difference in the volume of pores between units; however, the sample subset size is small (38 analyses). Additional samples and measurements would be useful for a more comprehensive analysis of the relationship between shale porosity and shale rock properties. Pore volume did not correlate well with either TOC values or with Tmax to suggest any relationship with organic matter or maturity patterns. No relationship was found between volume of pores varying with silica content or with fluctuations in land-derived sediments (using a summation of weight % of Al_2O_3, Fe_2O_3, K_2O and TiO_2 as a proxy) within this subset of samples from the Central Mackenzie Corridor.

ACKNOWLEDGEMENTS

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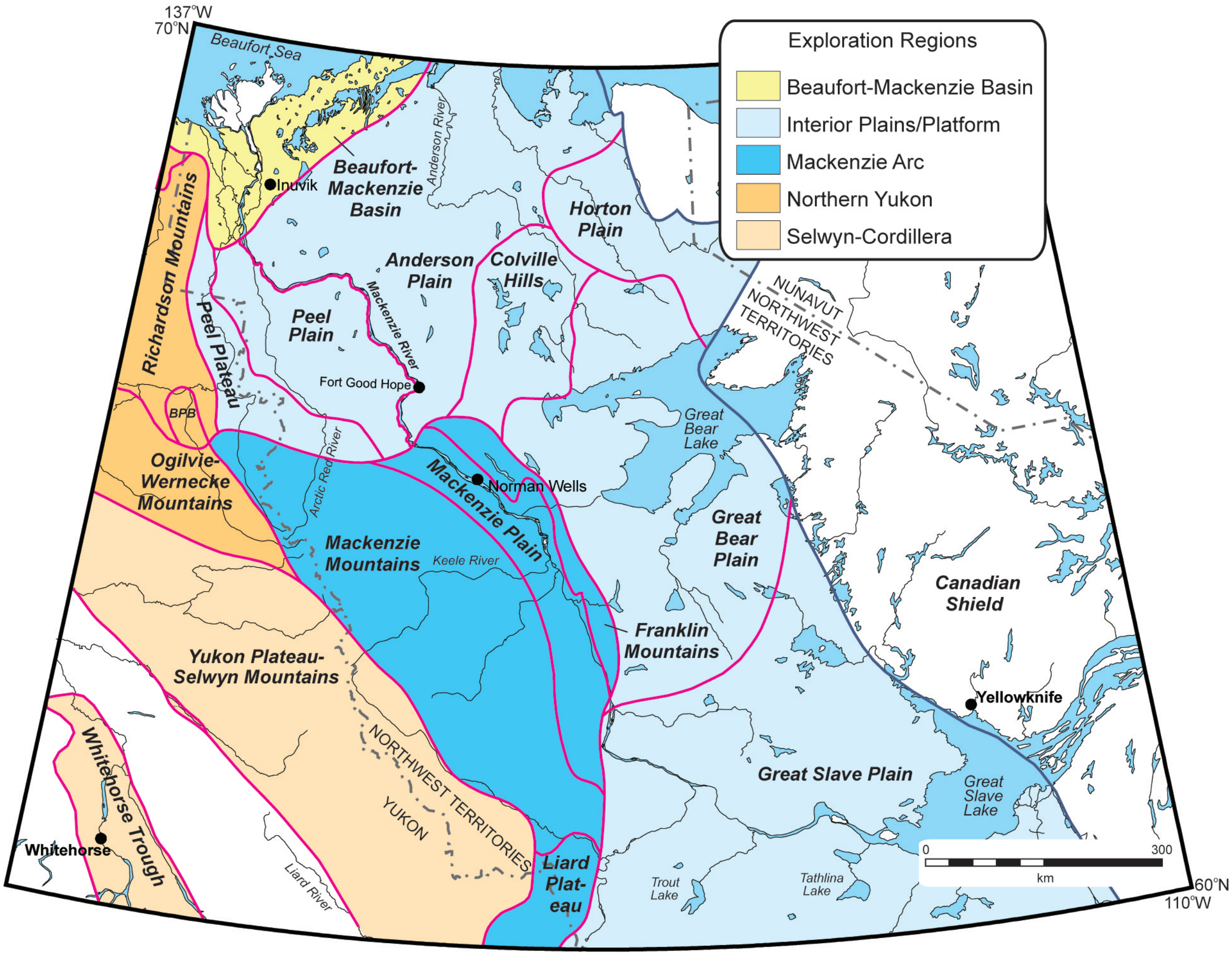

__Figure 1.__ Exploration regions of the Northern Canadian mainland sedimentary basin (after Morrow et al., 2006).

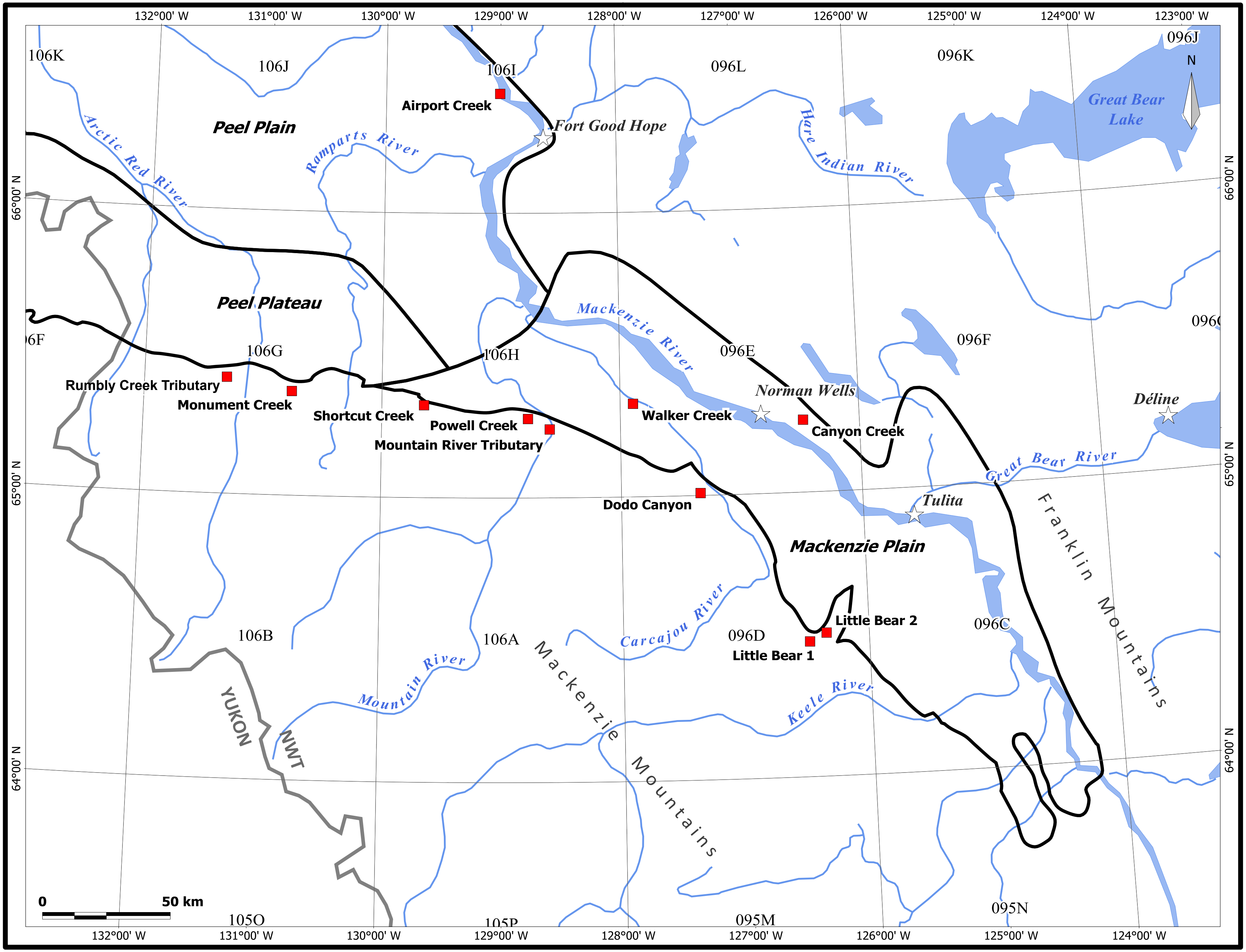

Figure 2. *Locations of measured sections and stations from which Rock-Eval and porosity samples were taken.*

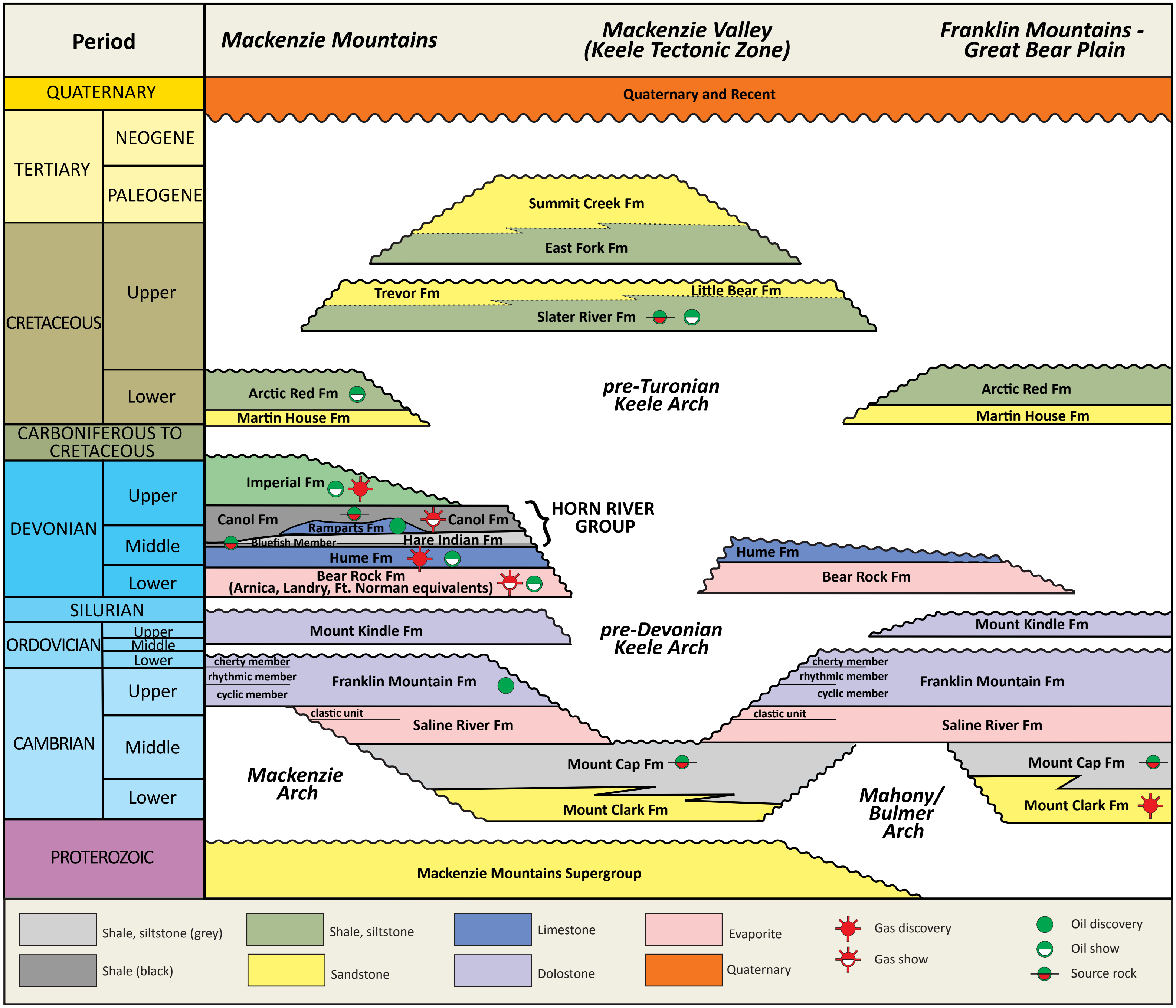

Figure 3. *Stratigraphy in the Mackenzie Plain area, modified from MacLean and Cook (1999).*

Canyon Creek Section

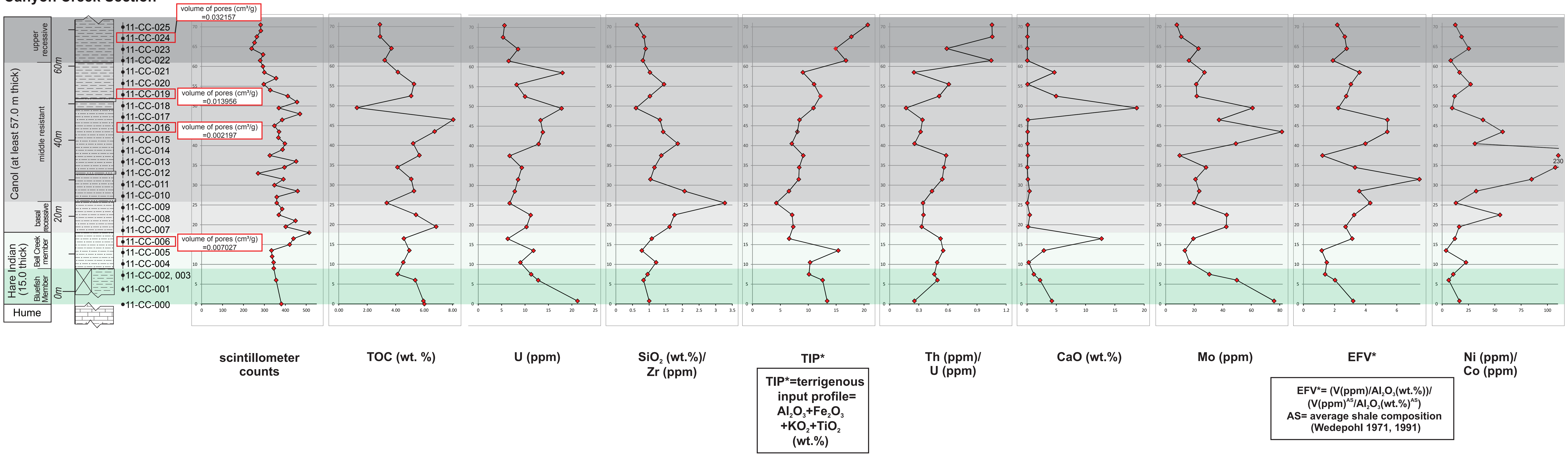

Figure 4. Canyon Creek lithologic section, showing the stratigraphic horizons of the porosity samples analysed in the present study (highlighted by red boxes). Section is plotted with scintillometer readings, TOC from Rock-Eval, and the following proxies from whole rock lithogeochemistry analyses: U (ppm), ratio of SiO2 (wt.%) to Zr (ppm), TIP (=terrigenous input profile=summation of Al3O2+Fe2O3+KO2+TiO2 wt.%); ratio of Th (ppm) to U (ppm); CaO (wt.%); Mo (ppm); EFV (=enrichment factor of vanadium after Tribovillard et al., 2006); and ratio of Ni (ppm) to Co (ppm), using data reported by Pyle et al. (2014).*

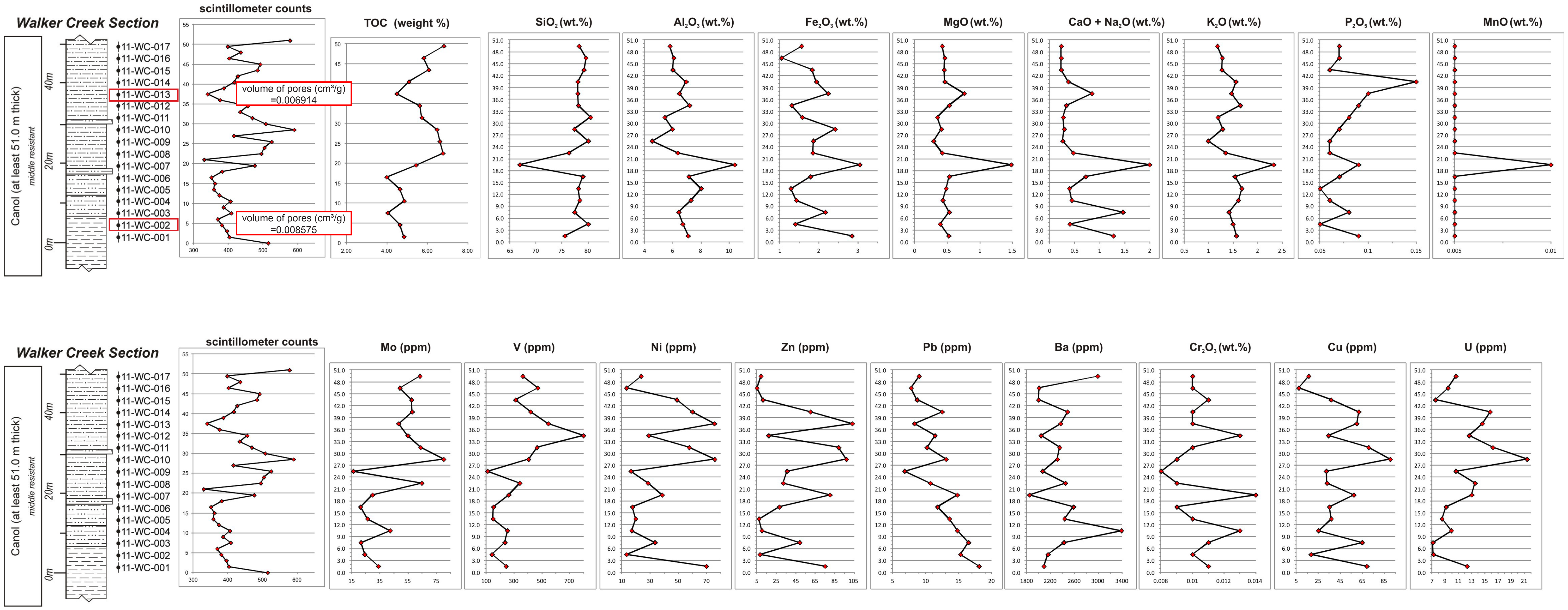

Figure 5. Walker Creek lithologic section, showing the stratigraphic horizons of the porosity samples analysed in the present study (highlighted by red boxes). Section is plotted with scintillometer readings, TOC from Rock-Eval, and select whole rock lithogeochemistry analyses using data reported by Pyle and Gal (2012).

Dodo Canyon East & Dodo Canyon Composite Section

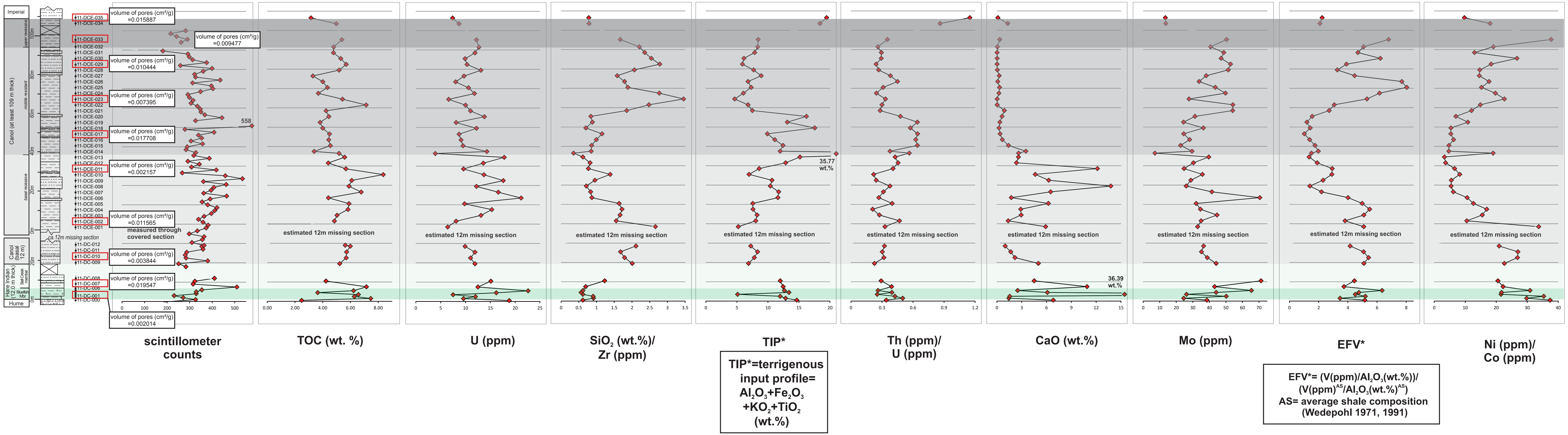

Figure 6. Dodo Canyon lithologic section, showing the stratigraphic horizons of the porosity samples analysed in the present study (highlighted by red boxes). Section is plotted with scintillometer readings, TOC from Rock-Eval, and the following proxies from whole rock lithogeochemistry analyses: U (ppm), ratio of SiO2 (wt.%) to Zr (ppm), TIP (=terrigenous input profile=summation of Al3O2+Fe2O3+KO2+TiO2 wt.%); ratio of Th (ppm) to U (ppm); CaO (wt.%); Mo (ppm); EFV (=enrichment factor of vanadium after Tribovillard et al., 2006); and ratio of Ni (ppm) to Co (ppm), using data reported by Pyle et al. (2014).*

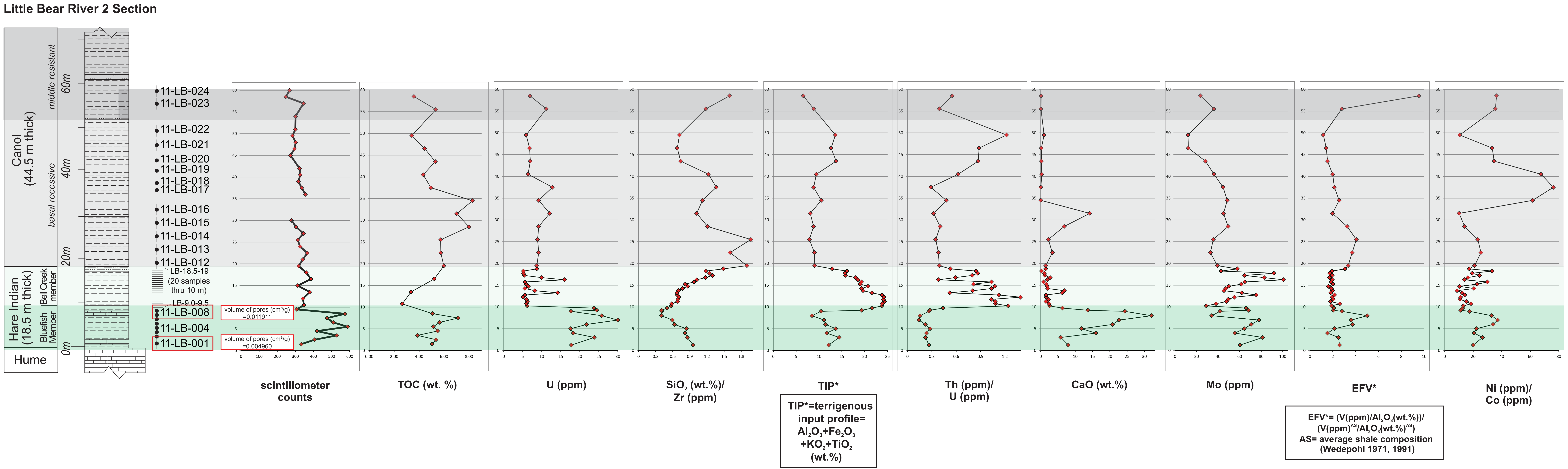

Figure 7. *Little Bear River 2 lithologic section, showing the stratigraphic horizons of the porosity samples analysed in the present study (highlighted by red boxes). Section is plotted with scintillometer readings, TOC from Rock-Eval, and the following proxies from whole rock lithogeochemistry analyses: U (ppm), ratio of SiO2 (wt.%) to Zr (ppm), TIP (=terrigenous input profile=summation of Al3O2+Fe2O3+KO2+TiO2 wt.%); ratio of Th (ppm) to U (ppm); CaO (wt.%); Mo (ppm); EFV* (=enrichment factor of vanadium after Tribovillard et al., 2006); and ratio of Ni (ppm) to Co (ppm), using data reported by Pyle et al. (2014).*

Figure 8. *Little Bear River 1 lithologic section, showing the stratigraphic horizons of the porosity samples analysed in the present study (highlighted by red boxes). Section is plotted with scintillometer readings, TOC from Rock-Eval, and the following proxies from whole rock lithogeochemistry analyses: U (ppm), ratio of SiO2 (wt.%) to Zr (ppm), TIP (=terrigenous input profile=summation of Al3O2+Fe2O3+KO2+TiO2 wt.%); ratio of Th (ppm) to U (ppm); CaO (wt.%); Mo (ppm); EFV* (=enrichment factor of vanadium after Tribovillard et al., 2006); and ratio of Ni (ppm) to Co (ppm), using data reported by Pyle et al. (2014).*

Figure 9. Mountain River Tributary lithologic section, showing the stratigraphic horizons of the porosity samples analysed in the present study (highlighted by red boxes). Section is plotted with scintillometer readings, TOC from Rock-Eval, and the following proxies from whole rock lithogeochemistry analyses: U (ppm), ratio of SiO2 (wt.%) to Zr (ppm), TIP (=terrigenous input profile=summation of Al3O2+Fe2O3+KO2+TiO2 wt.%); ratio of Th (ppm) to U (ppm); CaO (wt.%); Mo (ppm); EFV (=enrichment factor of vanadium after Tribovillard et al., 2006); and ratio of Ni (ppm) to Co (ppm), using data reported by Pyle et al. (2014).*

Figure 10. *Powell Creek lithologic section, showing the stratigraphic horizons of the porosity samples analysed in the present study (highlighted by red boxes). Section is plotted with scintillometer readings, TOC from Rock-Eval, and the following proxies from whole rock lithogeochemistry analyses: U (ppm), ratio of SiO2 (wt.%) to Zr (ppm), TIP (=terrigenous input profile=summation of Al3O2+Fe2O3+KO2+TiO2 wt.%); ratio of Th (ppm) to U (ppm); CaO (wt.%); Mo (ppm); EFV* (=enrichment factor of vanadium after Tribovillard et al., 2006); and ratio of Ni (ppm) to Co (ppm), using data reported by Pyle et al. (2014).*

Rumbly Creek Tributary Section (LP-07)

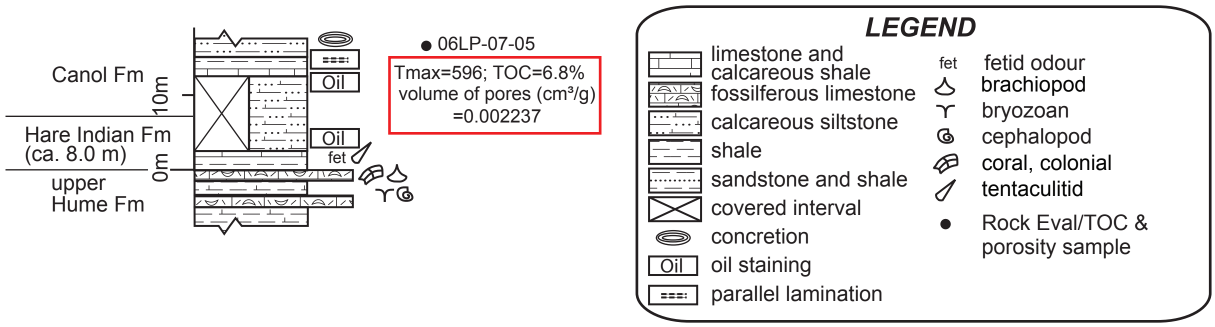

Figure 11. *Partial measured section at Station LP-07 showing stratigraphic level of porosity sample, stratigraphic log modified from Pyle and Gal (2007).*

Airport Creek Section (LP-20)

Figure 12. *Partial measured section at Station LP-20 (thicknesses estimated), showing stratigraphic level of Rock-Eval and porosity samples; stratigraphic log modified from Pyle and Gal (2007).*

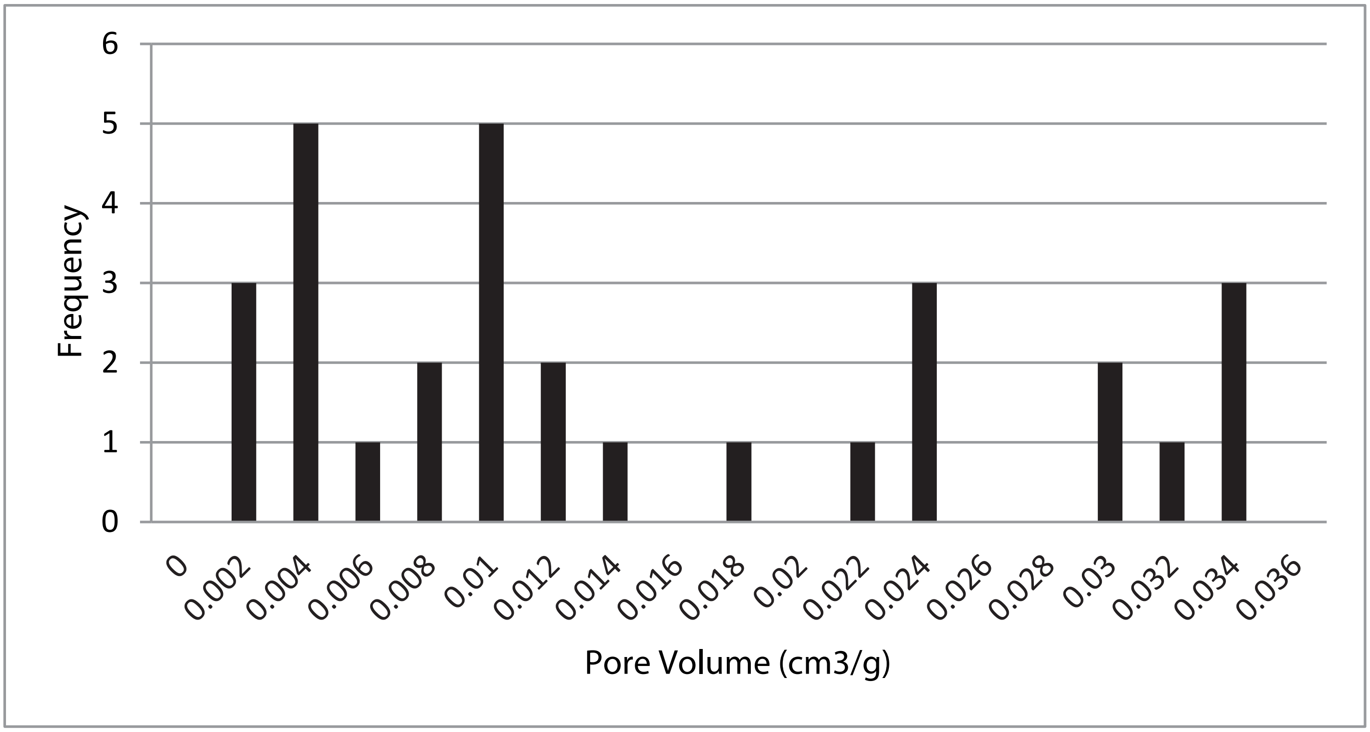

Figure 13. *Histogram showing the distribution of pore volume for Canol Formation samples.*

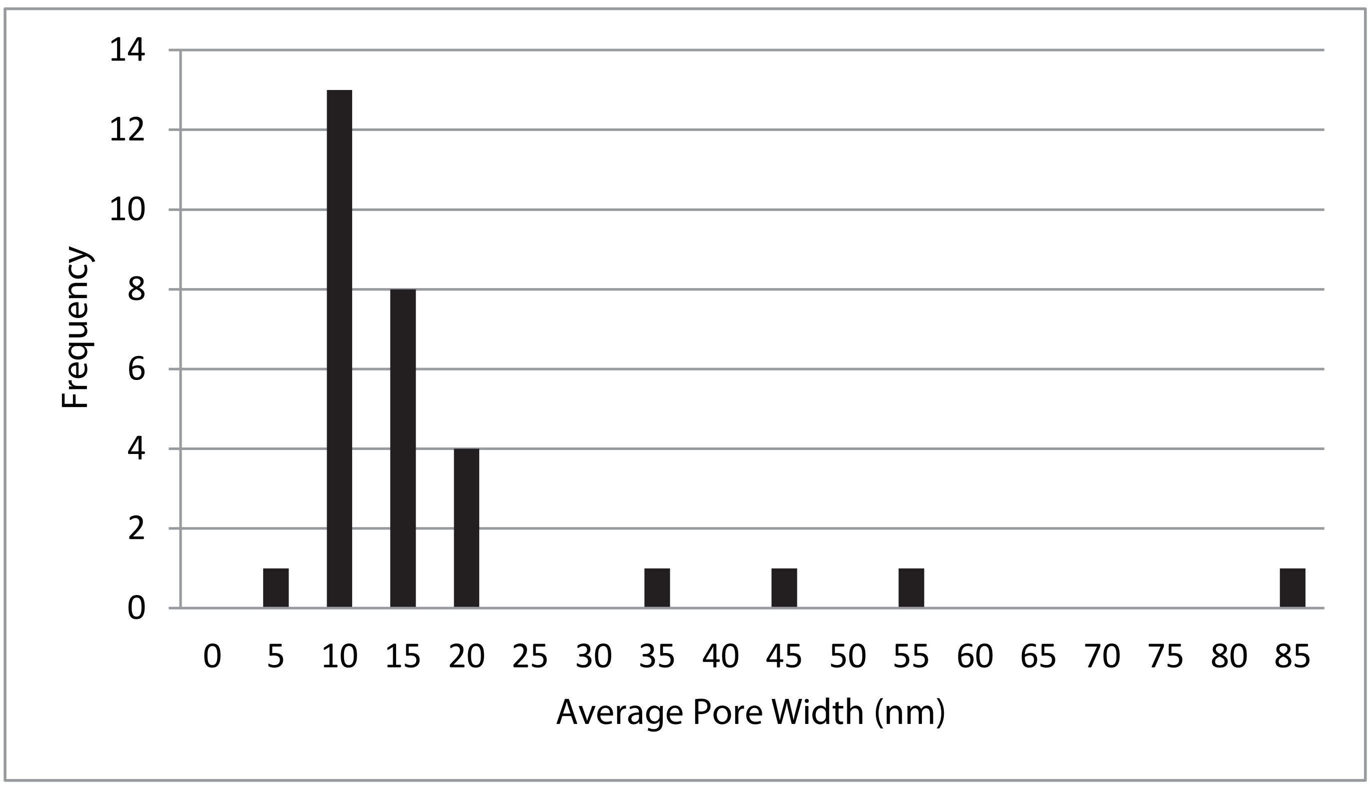

Figure 14. *Histogram showing the distribution of pore width for Canol Formation samples.*

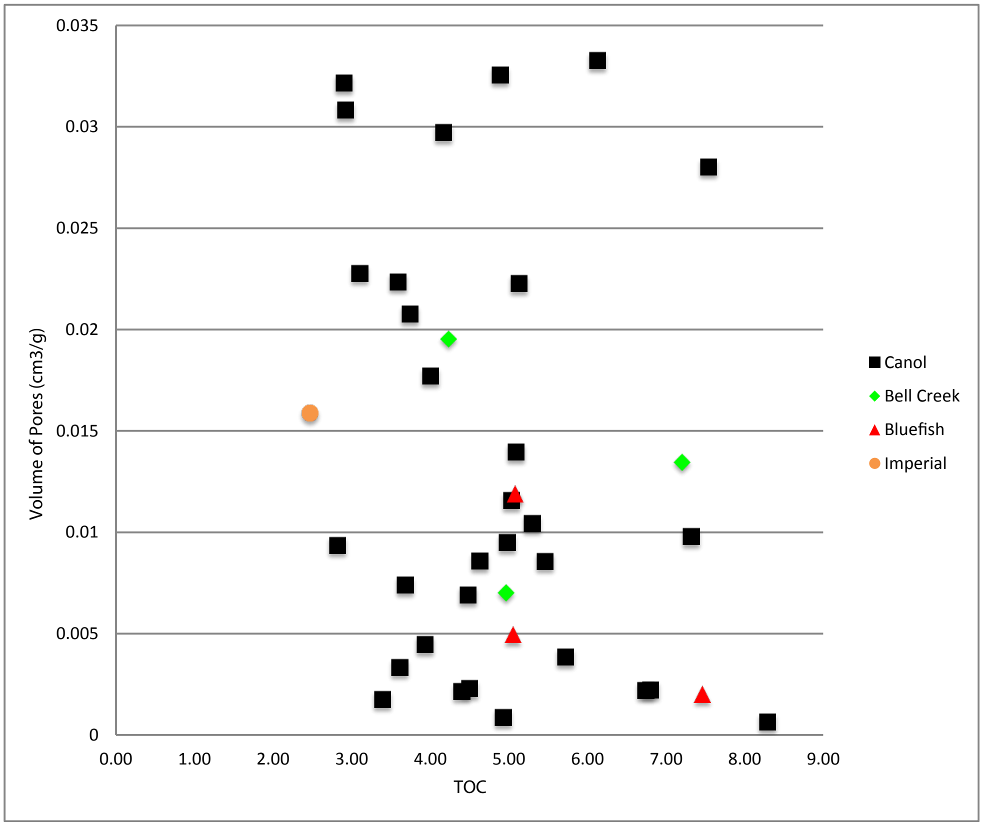

Figure 15. *Relationship between TOC and volume of pores for Horn River Group samples.*

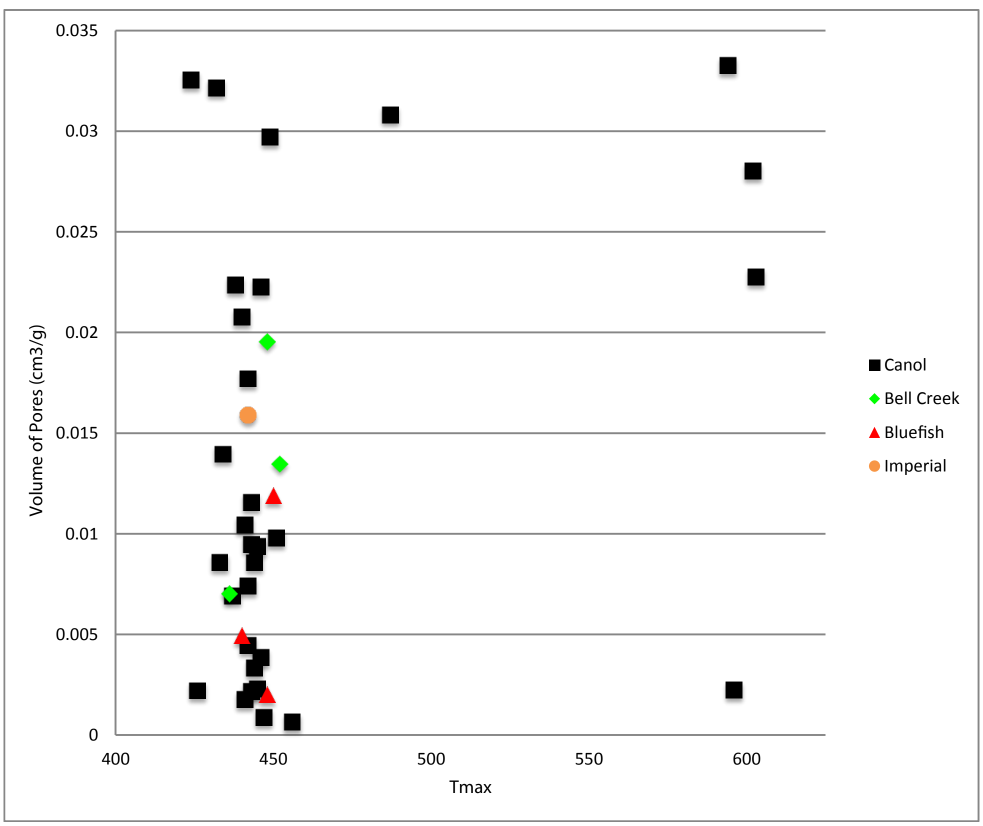

Figure 16. *Relationship between Tmax and volume of pores for Horn River Group samples.*

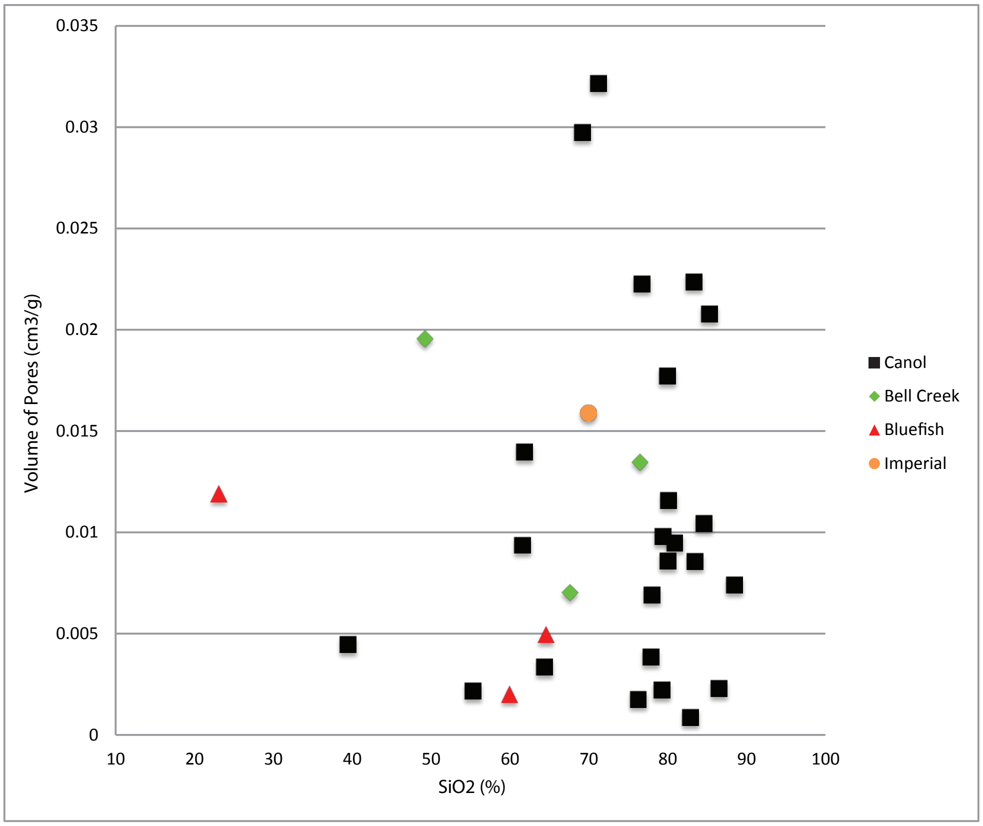

Figure 17. *Relationship between silica and volume of pores for Horn River Group samples.*

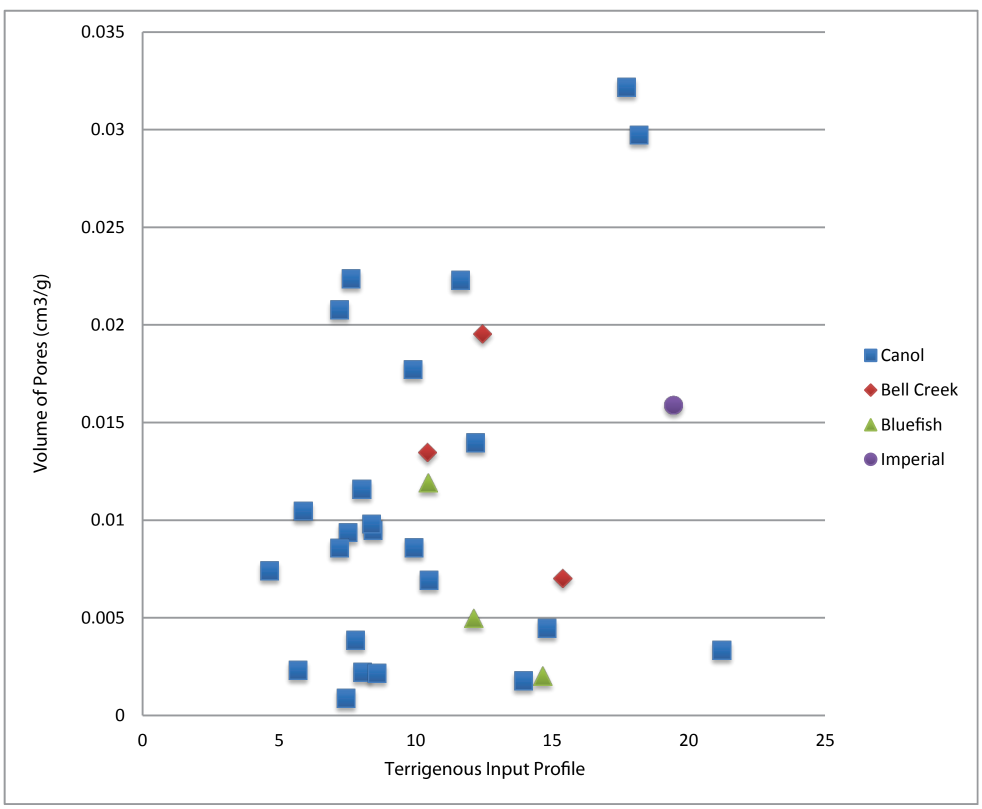

Figure 18. *Relationship between terrigenous input profile values and volume of pores for Horn River Group samples.*

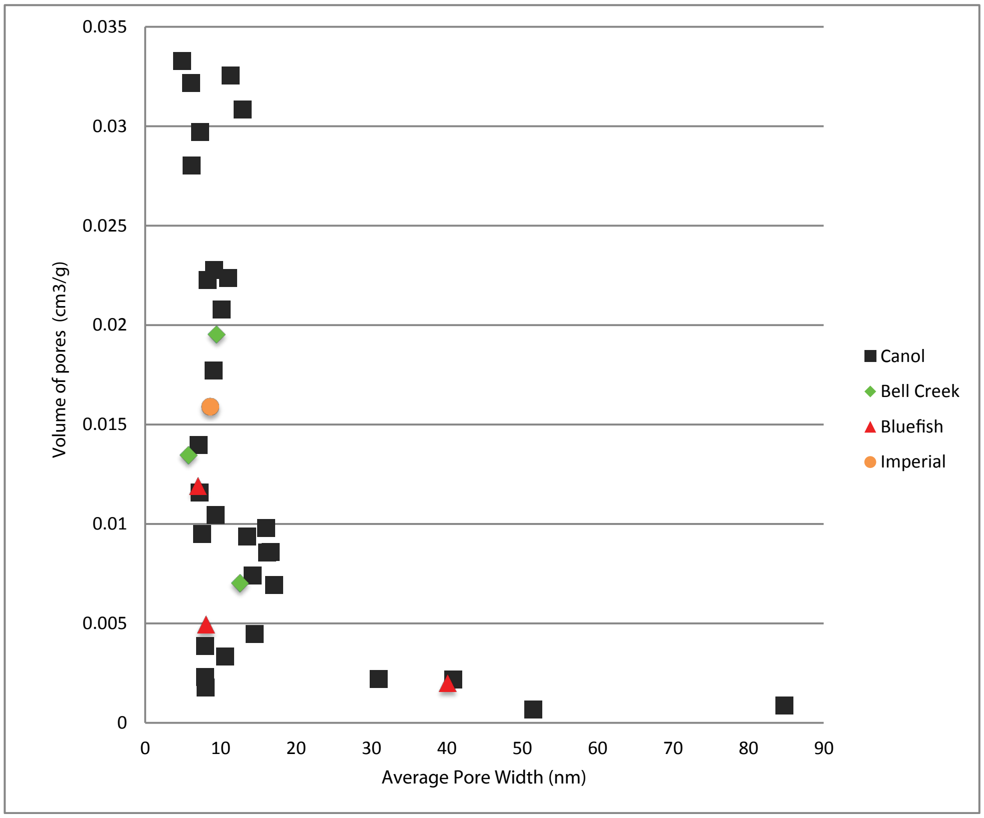

Figure 19. *Relationship between average pore width and volume of pores for Horn River Group samples.*