29. Project Unit 09-024. Preliminary Results: Potential Ordovician Shale Gas Units in Southern Ontario

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INTRODUCTION

In 2009, the Ontario Geological Survey (OGS) initiated a project to evaluate the shale gas potential of Paleozoic shale units present in southern Ontario. Several units were initially identified for assessment based upon several criteria: high organic content; being the source rocks of economic hydrocarbon accumulations; and correlatives to shale gas units in contiguous states of the United States and/or Canadian provinces (Barker 1985; Béland Otis 2009, 2010, 2011). These units consist of the Upper Devonian Kettle Point and Marcellus formations, the Upper Ordovician Georgian Bay and Blue Mountain formations and the Upper Ordovician Collingwood Member of the Lindsay Formation, equivalent of the Cobourg Formation.

In the spring of 2010, 2 boreholes were drilled through the Kettle Point Formation (Béland Otis 2010, 2011). Core samples were collected to evaluate gas concentration and other key parameters. Similar work was performed in 2011 near Mount Forest in the County of Wellington to assess the shale gas potential of the Ordovician shale succession. Furthermore, in the summer of 2012, additional rock samples were collected from previously drilled wells from southern Ontario and were analyzed for mineralogy and Rock-Eval® 6 pyrolysis parameters. These analyses may assist in refining stratigraphic correlations across provincial and international borders.

ORDOVICIAN SHALES

The Ordovician shale sequence present in southern Ontario comprises, in descending stratigraphy, the Queenston, the Georgian Bay and the Blue Mountain formations and the Collingwood Member of the Lindsay Formation. Since the Queenston Formation is composed of a succession of red and green shales, has low organic content and, therefore, almost no shale gas potential, it is not being studied as part of this current project. The Georgian Bay Formation consists of up to 200 m of greenish- to bluish-grey shale, interbedded with limestone, siltstone and sandstone (Armstrong and Carter 2010). Its lower contact is gradational with the Blue Mountain Formation, which is characterized by up to 60 m of blue-grey to grey-brown shales with thin, minor interbeds of limestone and siltstone. The lowest part of the Blue Mountain Formation is called the Rouge River Member, a dark brown to black, noncalcareous shale that can reach up to 35 m in thickness (Armstrong and Carter 2010).

The Collingwood Member of the Lindsay Formation is referred to as an impure limestone or lime marlstone (Macauley et al. 1990). It is a dark grey to black, organic-rich, calcareous shale with very thin, fossiliferous bioclastic interbeds (Armstrong and Carter 2010). It is considered a shale unit because of its well-developed fissility (Macauley et al. 1990). Total organic carbon values of up to 8.31% have been reported in Ontario (Macauley and Snowdon 1984). The Collingwood Member is situated stratigraphically beneath the Blue Mountain Formation and the 2 units are separated by a phosphatic bed. This phosphate layer suggests a depositional time break between the units (Churcher et al. 1991; Rancourt 2009). A similar phosphatic horizon has been reported in some cores completed in the Montreal area of Quebec (Lavoie and Thériault 2012).

Summary of Field Work and Other Activities 2012,
Ontario Geological Survey, Open File Report 6280, p.29-1 to 29-12.

Table 29.1. Wells sampled for mineralogy and Rock-Eval® 6 pyrolysis in 2012.

Well Information		Location		Depth of Top of Unit (m)				
				Georgian Bay Formation	Blue Mountain Formation		Cobourg Formation	
Name	Number of Samples	Latitude (°N)	Longitude (°W)	—	—	Rouge River Member	Collingwood Member	—
CORE								
GSC #2 Russell	52	45.32047222	75.39594444	21.6	172.8	260.3	273.8	283.2
OGS 82-2 Chatham	31	42.38782250	82.07989500	731.5	848.7	872.9	899.4	899.6
OGS 82-4 Wiarton	21	44.79185583	81.23234972	156.1	265.8	287.7	291.1	292.9
OGS 82-3 Port Stanley	47	42.67076833	81.16139472	639.4	795.1	822.5	859.8	861.2
OGS 83-1 Halton	38	43.53479139	79.95857611	182.7	358.2	433.2	435.5	437.3
OGS 83-3 Pickering	13	43.81651639	79.05789056	N/A	22.8*	40.2	46.8	48.2
OGS 83-5 Little Current	23	45.94118222	81.94684528	4.0**	90.5	94.4	105.0	113.0
OGS 83-6 St. Joseph	31	46.09623778	83.92743250	43.3**	98.8	135.5	158.5	168.4
OGS-SG11-02 Mount Forest	30	43.95996417	80.63534694	304.1	444.5	473.5	479.9	488.6
CUTTINGS								
Imperial Lincoln	48	43.21346361	79.17188917	220.7	338.3	414.5	445.0	460.2
Texaco #6 Bruce	26	44.30411111	81.54727778	518.0	608.9	647.0	651.6	659.5

Abbreviations: *Mbr, Member; N/A, not analyzed.*
Notes: **The Blue Mountain Formation is the first geological unit intercepted by the well.*
***The Georgian Bay Formation is the first geological unit intercepted by the well.*

In neighbouring provinces and states, Ordovician shale gas potential has been confirmed for units thought to be equivalent to those found in southern Ontario. These include the Collingwood Member found in Michigan and the Utica Shale present in the province of Quebec and in the northeastern United States (Smith and Leone 2010; Rock, Harrison and Barranco 2010; Lavoie 2011). The Ordovician shale succession in southern Ontario has previously been extensively studied by the OGS for its potential as an oil shale resource (Barker 1985; Barker et al. 1983; Churcher et al. 1991; Harris 1984; Johnson 1983; Johnson, Russell and Telford 1983a, 1983b, 1985; Snowdon 1984; Stromquist, Dickhout and Barker 1984).

METHODOLOGY

In 2011, the well OGS-SG11-02, located 20 km east of the town of Mount Forest, in Arthur Township, was drilled down to the Cobourg Formation. The entire Ordovician shale succession, with the exception of the Queenston Formation, was intersected. Core samples, approximately 30 cm in length, were collected approximately every 3 m and stored in specialized canisters designed to measure gas content over time. These were also analyzed for gas composition, isotopic composition of methane, adsorption isotherms and rock mechanics; additional core samples were collected for total organic carbon, density, gas, oil and water saturation, permeability and porosity. The well was also geophysically logged for various parameters (gamma-ray, density, sonic, porosity, televiewer, etc.) and was then plugged.

In June and July 2012, also as part of the shale gas assessment project, 360 core and cuttings samples from 11 previously drilled wells (including OGS-SG11-02) were sampled and analyzed for mineralogy by X-ray diffraction (XRD) and for pyrolysis by Rock-Eval® 6 analyzer. Rock-Eval® 6 pyrolysis indicates the quantity, type and thermal maturity of organic matter. All cores and cuttings can currently be found either at the Ontario Oil, Gas and Salt Resources Library in London or at the Willet Green Miller Centre in Sudbury. Table 29.1 presents information about the sampled wells: location, the number of samples per well and the associated stratigraphy.

INITIAL RESULTS

Drilling and Sampling Program of Well OGS-SG11-02

The Ordovician shale stratigraphy of well OGS-SG11-02 is presented in Table 29.1 and in Figures 29.1 to 29.3. The well was bored through Quaternary deposits, Silurian bedrock and the Queenston Formation, to a depth of 304.1 m. Then, the well was cored through 140.4 m of Georgian Bay Formation and 35.4 m of Blue Mountain Formation down to a total depth of 496.5 m; the last 7.9 m were drilled into the Cobourg Formation. The Rouge River Member of the Blue Mountain Formation and the Collingwood Member of the Cobourg Formation are 6.4 m and 8.7 m thick, respectively, in this well.

All analytical results of well OGS-SG11-02, except the adsorption isotherms, were available at the time of publication (Tables 29.2 to 29.6). Gas analyses, which include desorption, gas composition, calorific value and isotopic composition of methane, are presented in Table 29.2. Total gas values (up to 18.4 standard cubic feet per ton (scft/ton)) are highest in the black shale units of the Rouge River and the Collingwood members, which are also the units with the greatest total organic carbon content values (up to 4.55 weight %) (*see* Table 29.3; *see* Figure 29.1). Some interesting total gas content values (up to 8.6 scft/ton) are also observed for the Georgian Bay Formation even if the total organic carbon is low (≤0.60 weight %). The calorific values can also be quite high in the Georgian Bay Formation. Throughout the Ordovician shale succession, gas is mostly composed of methane (73.92 to 94.57%) with varying amounts of ethane (3.94 to 8.76%), heavier hydrocarbons (1.49 to 14.70%) and carbon dioxide (0.00 to 7.19%) (*see* Figure 29.2). Carbon (> –60‰) and hydrogen (> –250‰) isotopic compositions of methane, as well as a $C_1/(C_2+C_3)$ ratio less than 10, all suggest a thermogenic origin for the gas (*see* Tables 29.2 and 29.3).

Core analyses indicate a clear relation between grain and bulk densities with total organic carbon content (*see* Table 29.4; *see* Figure 29.1). Also, permeability and porosity values are much lower in the Rouge River and Collingwood members (*see* Figure 29.3). However, the Rouge River Member has a good oil saturation (31.5%), whereas the Collingwood Member has a much higher gas saturation (77.2%). Rock mechanics results are presented in Tables 29.5 and 29.6. As shown in Figure 29.4, the Ordovician shales fall mostly in the ductile area with some exceptions for the Georgian Bay and Blue Mountain formations. Also, a brittleness index can also be calculated with rock mechanics parameters (Rickman et al. 2008). The values obtained give brittleness indices between 29 and 41%, which can be considered low (Buller 2010; Hall 2010). Finally, with the televiewer log, structural features in the wells were recorded; these are summarized in Figure 29.5.

Sampling Program of Summer 2012

Some of the lithostratigraphic contacts within the Upper Ordovician shale succession are somewhat unclear in previous literature (Churcher et al. 1991; Johnson et al. 1992; Russell and Telford 1983); therefore, new contacts were defined for this study. The lower contact of the Collingwood Member was described as the first appearance of a 10 cm bed of black calcareous shale or mudstone, in contrast with the underlying Cobourg Formation (subsurface equivalent to the Lindsay Formation), generally defined as a grey nodular limestone. The upper contact of the Collingwood Member with the Rouge River Member of the Blue Mountain Formation was easily recognized in most wells by the presence of a phosphatic and/or pyritic bed. The upper contact of the Rouge River Member was identified as the first appearance of a bluish-gray bed, characteristic of the overlying unnamed part of the Blue Mountain Formation. Finally, the Georgian Bay Formation was delimited at the bottom by the first appearance of a 1 cm fossiliferous limestone bed and, at the top, by the lowermost red shale beds of the overlying Queenston Formation. Results of the present study, including mineralogy and Rock-Eval® 6 pyrolysis analysis, may assist in refining these contacts.

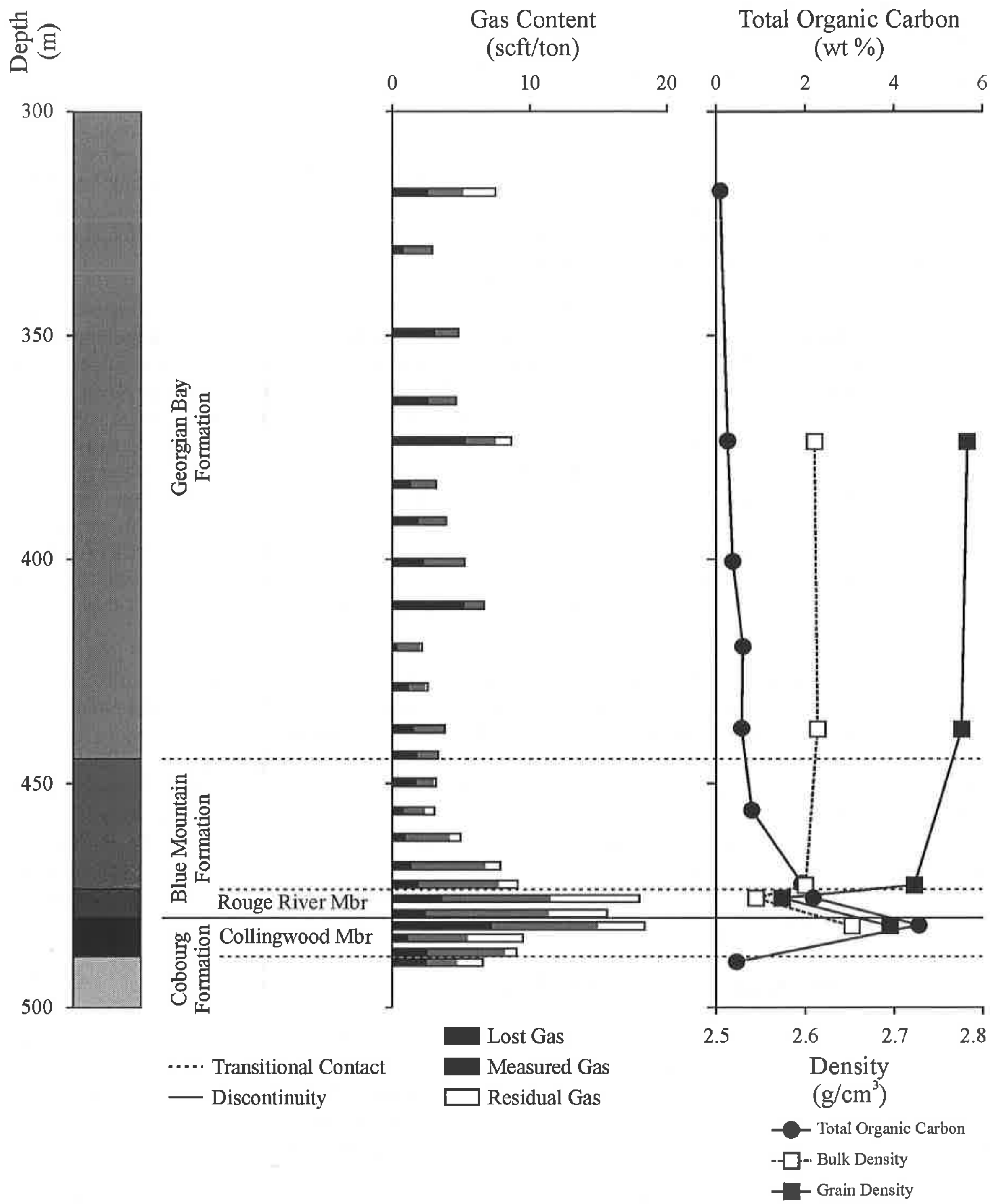

Figure 29.1. Stratigraphy, total gas content (standard cubic feet per ton (scft/ton)), total organic carbon (weight % (wt %)) and density (g/cm^3) logs of well OGS-SG11-02. Abbreviation: Mbr = Member.

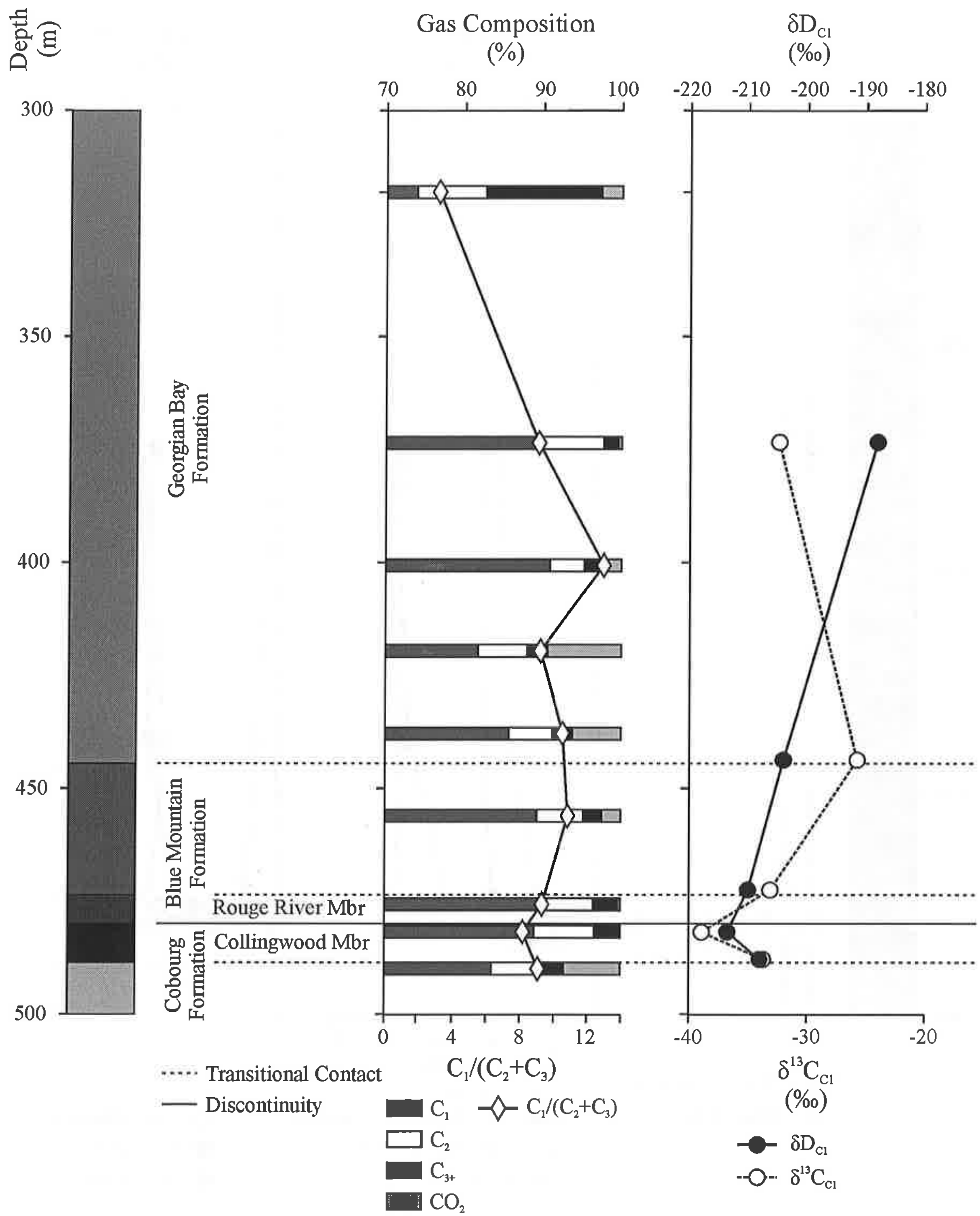

Figure 29.2. Stratigraphy, gas composition (%) and isotopic composition of methane (‰) logs of well OGS-SG11-02. Abbreviation: Mbr = Member.

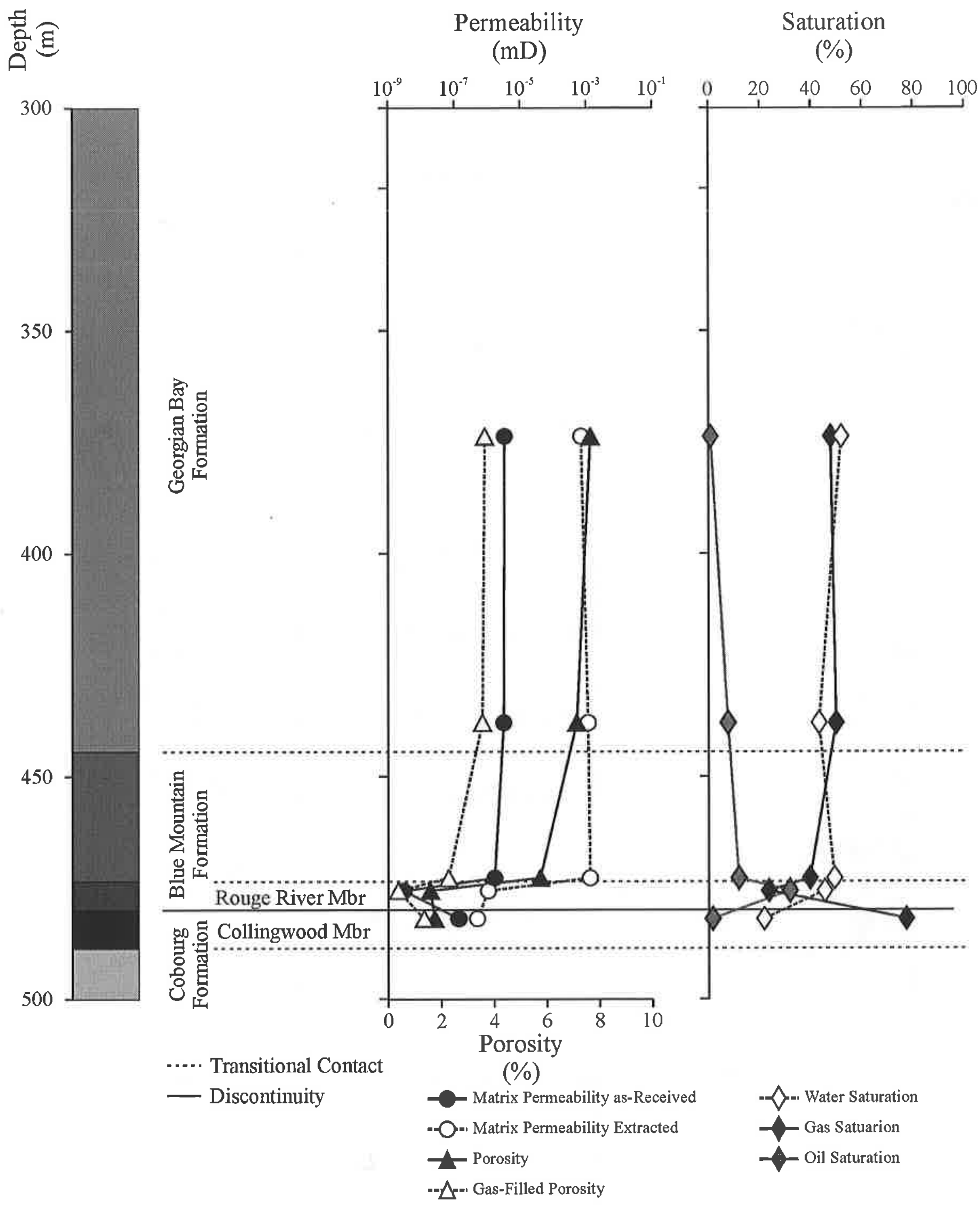

Figure 29.3. Stratigraphy, permeability (mD), porosity (%) and saturation (%) logs of well OGS-SG11-02. Abbreviation: Mbr = Member.

Table 29.2. Gas results from well OGS-SG11-02 (from samples CAN-01 to CAN-24).

Lithology	Sample ID (CAN-)	Depth Interval (m)	Desorption (scft/ton): Lost	Desorb.	Residual: Proj.	Residual: Meas.	Total Gas	Average Composition (mole %): C_1	C_2	$C_{3\text{-}10}$	CO_2	Calorific Value (BTU/ft^3): Dry	Sat.	Isotopes (‰): $\delta^{13}C$	δD
Georgian Bay Formation	01	317.85-318.15	2.6	2.6	0.0	2.3	7.5	73.92	8.76	14.70	2.62	1326.0	1302.9	—	—
	02	330.74-331.04	0.9	2.0	0.0	0.0	2.9	—	—	—	—	—	—	—	—
	03	349.24-349.54	3.1	1.7	0.9	—	4.8	—	—	—	—	—	—	—	—
	04	364.48-364.78	2.7	1.9	0.0	—	4.6	—	—	—	—	—	—	—	—
	05	373.41-373.72	5.4	2.2	0.0	1.1	8.6	89.71	7.98	1.89	0.42	1100.8	1081.6	–32.4	–188
	06	383.07-383.38	1.4	1.8	0.9	—	3.2	—	—	—	—	—	—	—	—
	07	391.24-391.55	1.8	2.1	0.0	0.0	3.9	—	—	—	—	—	—	—	—
	08	400.48-400.75	2.3	2.9	1.7	0.0	5.2	90.90	4.37	2.65	2.09	1073.2	1054.4	—	—
	09	409.99-410.29	5.3	1.4	0.0	—	6.7	—	—	—	—	—	—	—	—
	10	419.40-419.71	0.4	1.6	0.6	0.1	2.1	81.77	6.27	2.61	9.36	1010.6	992.9	—	—
	11	428.27-428.58	1.2	1.2	0.0	0.0	2.5	—	—	—	—	—	—	—	—
	12	437.63-437.94	1.6	2.2	0.0	—	3.8	85.70	5.52	2.61	6.16	1038.6	1020.4	—	—
	13	443.51-443.82	1.8	1.5	0.0	—	3.3	90.91	6.97	2.12	0.00	1100.3	1081.2	–25.7	–204
Blue Mountain Formation	14	449.61-449.92	1.8	1.3	0.0	0.1	3.1	—	—	—	—	—	—	—	—
	15	455.92-456.22	0.8	1.6	0.0	0.7	3.0	89.31	5.89	2.34	2.46	1073.7	1055.0	—	—
	16	461.86-462.17	1.0	3.2	0.8	—	4.9	—	—	—	—	—	—	—	—
	17	468.20-468.51	1.4	5.4	1.0	—	7.8	—	—	—	—	—	—	—	—
	18	472.26-472.56	1.9	5.8	1.1	1.4	9.1	94.57	3.94	1.49	0.00	1068.8	1048.2	–33.1	–210
Rouge River Member	19	475.49-475.79	3.6	7.9	0.4	6.4	18.0	90.02	6.49	3.16	0.33	1113.1	1093.6	*–15.5*	*–200*
	20	478.81-479.12	2.5	8.9	5.0	4.2	15.6	—	—	—	—	—	—	—	—
Collingwood Member	21	481.61-481.92	7.3	7.7	2.6	3.4	18.4	89.02	7.63	3.23	0.12	1125.4	1105.7	–38.9	–214
	22	484.36-484.66	1.2	4.3	1.4	4.0	9.5	—	—	—	—	—	—	—	—
	23	487.53-487.83	2.5	5.7	3.8	0.8	9.0	89.01	7.74	3.25	0.00	1123.1	1103.5	–33.7	–208
Cobourg Formation	24	489.81-490.12	2.5	2.2	1.8	—	6.5	83.61	6.63	2.56	7.19	1036.4	1018.3	*–18.7*	*–205*

Abbreviations: *BTU/ft^3 = British thermal units per cubic feet; Desorb. = desorbed; Meas. = measured, Proj. = projected, Sat. = saturated, scft = standard cubic feet per ton.*
Notes: *values underlined and in italics = presents air contamination. Total gas represents the sum of lost, desorbed and residual gas. When available, measured residual gas values are used instead of projected values.*

Table 29.3. Total organic carbon (TOC) results from well OGS-SG11-02.

Lithology	Sample ID	Depth (m)	Total Organic Carbon (wt %)
Georgian Bay Formation	TOC-01	317.72	0.09
	TOC-10	373.53	0.26
	TOC-15	400.42	0.37
	TOC-20	419.40	0.60
	TOC-24	437.66	0.57
Blue Mountain Formation	TOC-28	455.86	0.80
	TOC-34	472.23	1.92
Rouge River Member	TOC-37	475.46	2.18
Collingwood Member	TOC-39	481.61	4.55
Cobourg Formation	TOC-42	489.81	0.46

Abbreviation: *wt % = weight percent.*

Table 29.4. Core analysis results from well OGS-SG11-02.

Lithology	Sample ID	Depth Interval (m)	Density: Bulk (g/cm³)	Density: Grain (g/cm³)	Matrix Permeability: As-Received (mD)	Matrix Permeability: Extracted (mD)	Porosity: — (%)	Porosity: Gas-Filled (%)	Saturation: Oil (%)	Saturation: Water (%)	Saturation: Gas (%)
Georgian Bay Formation	GRI-05	373.51 - 373.81	2.611	2.783	3.25×10^{-6}	6.90×10^{-4}	7.66	3.65	0.6	51.7	47.6
	GRI-12	437.74 - 438.05	2.614	2.777	3.04×10^{-6}	1.12×10^{-3}	7.15	3.55	7.4	43.0	49.7
Blue Mountain Formation	GRI-18	472.78 - 472.68	2.601	2.723	1.59×10^{-6}	1.27×10^{-3}	5.75	2.27	11.5	49.0	39.5
Rouge River Member	GRI-19	475.46 - 475.76	2.545	2.574	2.85×10^{-9}	1.015×10^{-6}	1.58	0.37	31.5	45.2	23.3
Collingwood Member	GRI-21	481.74 - 482.04	2.653	2.696	1.30×10^{-7}	4.74×10^{-7}	1.74	1.34	1.4	21.4	77.2

Abbreviation: *mD = millidarcy (≈10^{-12} m²).*

Table 29.5. Triaxial static Young's modulus, Poisson's ratio and compressive strength results from well OGS-SG11-02.

Lithology	Sample ID	Depth Interval (m)	Confining Pressure (psi)	Bulk Density (g/cm³)	Compressive Strength (psi)	Young's Modulus (×10⁶ psi)	Poisson's Ratio
Georgian Bay Formation	CAN-03	349.24 - 349.54	250	2.58	16138	1.95	0.23
	CAN-12	437.63 - 437.94	310	2.55	9747	1.19	0.25
Blue Mountain Formation	CAN-18	472.26 - 472.56	330	2.6	15105	3.04	0.24
Rouge River Member	CAN-20	482.05 - 482.36	340	2.37	16968	1.59	0.24
Cobourg Formation	CAN-24	489.81 - 490.12	340	2.44	10444	1.13	0.26

Abbreviation: *psi = pounds per square inch.*

Table 29.6. Acoustic velocities and dynamic moduli at triaxial stress conditions from well OGS-SG11-02.

Lithology	Sample ID	Depth Interval (m)	Pressure: Confining (psi)	Pressure: Axial (psi)	Bulk Density (g/cm³)	Acoustic Velocity: Compressional (ft/s)	Acoustic Velocity: Shear (ft/s)	Modulus: Bulk (×10⁶ psi)	Modulus: Young's (×10⁶ psi)	Modulus: Shear (×10⁶ psi)	Poisson's Ratio
Georgian Bay Formation	CAN-03	349.24 - 349.54	250	250	2.58	12 075	7288	2.61	4.49	1.85	0.21
			250	8000	2.58	13 499	7859	3.47	5.34	2.15	0.24
	CAN-12	130.76 - 131.06	310	310	2.55	7184	4183	0.97	1.5	0.6	0.24
			310	5000	2.55	7550	4251	1.13	1.58	0.62	0.27
Blue Mountain Formation	CAN-18	23.47 - 23.77	330	330	2.6	14 066	8442	3.61	6.09	2.5	0.22
			330	6000	2.6	14 745	8732	4.06	6.58	2.68	0.23
Rouge River Member	CAN-20	482.05 - 482.36	340	340	2.37	11 207	6482	2.22	3.35	1.34	0.25
			340	8000	2.37	12 004	6674	2.71	3.63	1.42	0.28
Cobourg Formation	CAN-24	112.47 - 112.79	340	340	2.44	10 708	6398	1.97	3.29	1.35	0.22
			340	5000	2.44	11 588	6608	2.5	3.61	1.43	0.26

Abbreviation: *psi = pounds per square inch.*

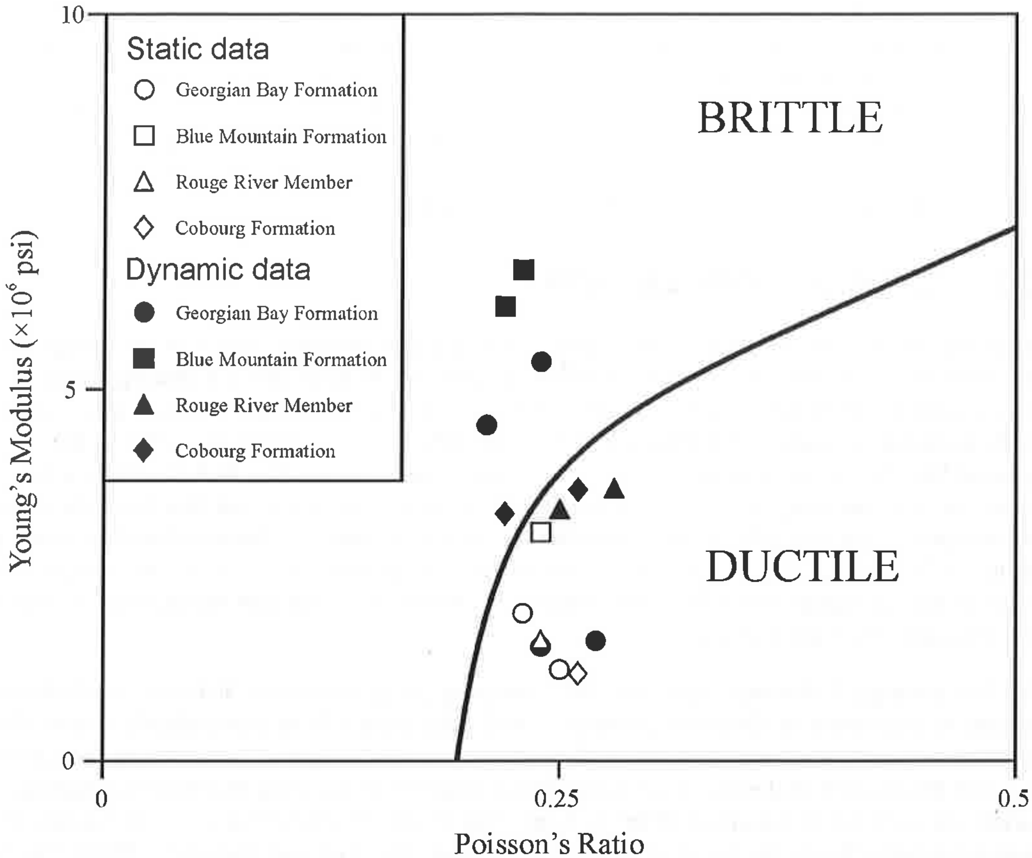

Figure 29.4. Cross-plot of Poisson's ratio and Young's modulus indicating brittle and ductile areas and well OGS-SG11-02 samples (*modified from* Grieser and Bray 2007).

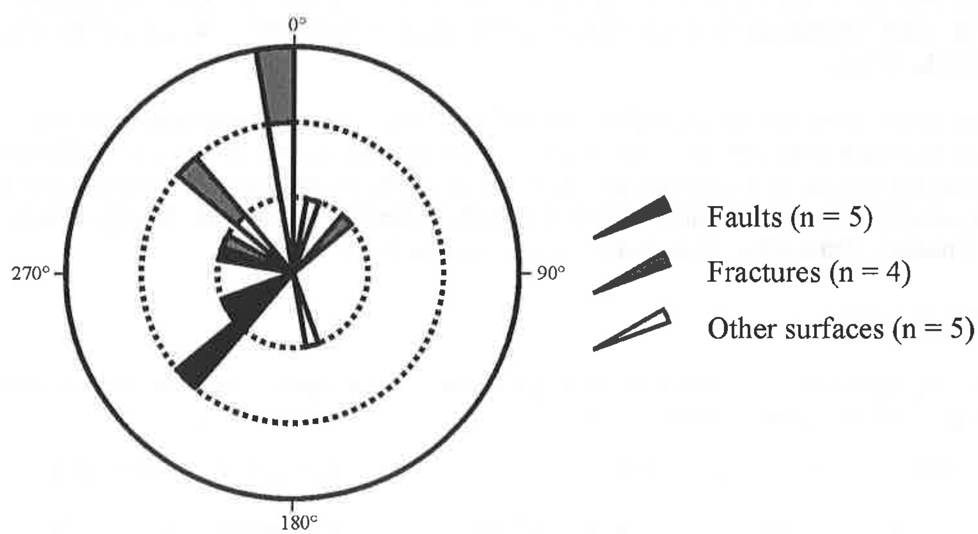

Figure 29.5. Rose diagram presenting structural features of well OGS-SG11-02 measured by the televiewer log.

At the time of publication, mineralogical and Rock-Eval® 6 pyrolysis results were not available from the 2012 sampling program. However, initial geological observations from the selected wells allow some regional trends in stratigraphy to be discerned. Indeed, the entire section of Ordovician shales tends to increase from the northwest to the southeast. This is even more pronounced for the Georgian Bay and Blue Mountain formations. However, the Collingwood Member shows a reverse trend based on the thickest section observed in the north. Also, the Rouge River Member, observed in cores located along lakes Erie and Ontario, seems more calcareous than in the other cores.

DISCUSSION AND CONCLUSION

Initial results from the OGS-SG11-02 drilling and sampling program show that the Rouge River Member of the Blue Mountain Formation and the Collingwood Member of the Cobourg Formation have the best potential for shale gas productive units when considering total organic carbon, gas content and hydrocarbon saturation. Indeed, the Rouge River Member has high oil saturation, whereas the Collingwood Member has a high gas saturation. However, the Georgian Bay and Blue Mountain formations can also have higher gas content values. In the case of the Georgian Bay Formation, the higher gas content samples are probably associated with limestone beds that are characterized by greater porosity (*see* Figure 29.3). For the Blue Mountain Formation, the best gas desorption values are associated with the transition into the Rouge River Member, which can also be observed with the increase of total organic carbon with depth (*see* Figure 29.1).

The first geological observations of the 2012 sampling program present different trends depending if the units are located under or above the phosphatic bed. This marker is stratigraphically situated between the limestone and calcareous mudstone of the Collingwood Member and of the Cobourg Formation and the black and bluish-grey shales from the Rouge River Member of the Blue Mountain Formation. Under this marker, the increase in thickness of the Collingwood Member to the north also corresponds to the depocentres identified in the northeast of Michigan by Rock, Harrison and Barranco (2010). The fact that the Georgian Bay and Blue Mountain formations increase in thickness to the southeast suggests these units originate from the erosion of the Appalachian Mountains. This is supported by the concordance between previously published mineralogy data of the Georgian Bay and Blue Mountain formations and similar data from the Utica Shale located in Quebec and New York State (Jackson and Murphy 2011; Martin et al. 2008; Martini and Kwong 1986; Skowron and Hoffman 2009; Thériault 2008; Wigston and Jackson 2010a, 2010b).

Future results from mineralogy and Rock-Eval® 6 pyrolysis analyses may help determine factors influencing important shale gas parameters such as reservoir capacity and brittleness. Furthermore, it may assist identifying organic-rich intervals, gas versus oil-prone zones and regional mineralogical variations within the same units, as preliminarily observed with the Rouge River Member. Finally, it may also help correlate Ontario's Ordovician stratigraphy with other jurisdictions.

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