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Ontario Geological Survey Open File Report 6279

Gas Assessment of the Devonian Kettle Point Formation

2013



ONTARIO GEOLOGICAL SURVEY

Open File Report 6279

Gas Assessment of the Devonian Kettle Point Formation

by

C. Béland Otis

2013

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Foreword

Natural water quality variations exist in groundwater-sourced water supplies. These water quality variations have the potential to impact human health and limit the usability of the groundwater resource. In 2007, the Ontario Geological Survey Branch (OGS) of the Ministry of Northern Development and Mines initiated the multi-year Ambient Groundwater Geochemistry Project, which involves the sampling of domestic groundwater wells across southern Ontario. The geoscience objective is to identify areas of compromised water quality and determine if these areas are related to variations in rock and soil composition. Most of these variations, including well known regional water-quality problems, can be attributed to definable geological conditions. Therefore, in 2009, the OGS initiated a complementary three-year geoscience study of gas content in bedrock formations of southern Ontario by undertaking preliminary, science-based analyses of different bedrock units to assess and characterize the presence of gas and the possible implications for groundwater quality in areas of the province where natural gas is known to occur naturally in groundwater wells. The data from this current study, presented in this report, is used to 1) inventory and assess gas content in Devonian rocks in southwestern Ontario; 2) characterize the gas to better understand its composition and origin; and 3) test for correlation between the natural gas signatures and areas of compromised groundwater quality. These data will be correlated with data from the Ambient Groundwater Geochemistry Project to validate analytical results from groundwater wells.

J. A. Fyon Director Ontario Geological Survey

August 7, 2013

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Miscellaneous Release—Data 304 Geological, Geochemical and Geophysical Data from the Kettle Point Formation Drilling Program, Southern Ontario; by C. Béland Otis

This data release contains geochemical and geophysical data collected as part of the Kettle Point Formation drilling program that took place in March and April 2010, and is being released in conjunction with Open File Report 6279, *Gas Assessment of the Devonian Kettle Point Formation*. The release consists of 13 geochemistry tables as Microsoft® Excel® (*.xls*) files, 10 geophysical logs *.tif* files and 13 additional geophysical logs as Log ASCII Standard (*.las*) files.

MRD 304 is available separately from this report.

Abstract

The Devonian Kettle Point Formation has been identified as a potential source of gas in southwestern Ontario. The unit is the stratigraphic equivalent of the Antrim Shale in Michigan, which is a major microbial gas source. In Ontario, gas shows in water, oil and gas wells have been linked to the formation, which could support a microbial production for the Kettle Point Formation.

The Ontario Geological Survey drilled and cored 2 boreholes to collect core and gas samples throughout the Kettle Point Formation to assess and characterize gas within this unit. The OGS-SG11-01 well is located in Moore Township and the OGS-SG11-02 well in Sombra Township. Both holes extended about 5 m into the Hamilton Group, underlying the Kettle Point Formation. Samples from the holes were analysed for gas content, gas composition, isotopic composition of methane, total organic carbon, oil, gas and water saturation, permeability, porosity, mineralogy, adsorption isotherms and rock mechanics. The wells were also logged with downhole geophysics.

The Kettle Point Formation is situated stratigraphically above the Hamilton Group and under the Port Lambton Group and subcrops in southwestern Ontario and under Lake Erie. The average thickness of the unit is around 30 m. However, sections of more than 90 m have been identified between Sarnia and Wallaceburg and under Lake Erie. The Kettle Point Formation consists mostly of a succession of black and green shales. Black shales are associated with an anoxic environment, which enables the preservation of organic matter and therefore presents higher total organic carbon content, whereas, green beds indicate an oxidized environment with bioturbation.

The greatest gas content values are observed in the black beds while the lowest values were identified in the green beds, suggesting that gas content is strongly associated with total organic carbon content. This association with total organic carbon content, the predominance of methane and the fact that the highest values of gas content were observed at shallow depths in the OGS-SG11-01 well are all indicative of microbial gas. Indeed, methane isotopic composition suggests a definitive microbial component throughout the section, mainly for the OGS-SG11-01 well. A thermogenic component has also been identified, especially in the OGS-SG11-02 well, which could be related to the presence of a regional deep fault in the area. Oil saturation and storage capacity also seem to be influenced by the presence of pyrite.

Gas Assessment of the Devonian Kettle Point Formation

C. Béland Otis Ontario Geological Survey Open File Report 6279 2013

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Introduction

In 2007, the Ontario Geological Survey Branch (OGS) of the Ministry of Northern Development and Mines initiated the Ambient Groundwater Geochemistry Project, which is a long-term study focusing on sampling groundwater wells across southern Ontario to delineate areas of compromised water quality and attempt to relate them to variations in rock and soil composition (Hamilton 2011; Hamilton, Brauneder and Mellor 2007). Natural water quality variations exist in groundwater resourced water supplies that have the potential to impact human health and limit the usability of the groundwater resource. Most of these variations, including well known regional water-quality problems, can be attributed to definable geological conditions (Hamilton, Brauneder and Mellor 2007).

In 2009, the OGS initiated a complementary three-year geoscience study of bedrock formations of southern Ontario by undertaking preliminary, science-based analyses of different bedrock units to assess the presence of gas and the possible implications for groundwater quality in areas of the province where natural gas is known to occur naturally in groundwater wells (Figure 1). The data from this current study will be used and correlated with data from the Ambient Groundwater Geochemistry Project to validate analytical results from groundwater wells and to determine where the gas in the groundwater is coming from.

Unconventional gas can be described as "gas plays" for which the host rock acts as the source, reservoir and cap rock. The natural gas, usually produced *in-situ*, is found in fine-grained, organic-rich reservoir rocks and is stored mainly in the absorbed state, predominantly on organic matter or as free gas in the matrix or fracture porosity of the rock (Martini et al. 1998; Curtis 2002). Various parameters need to be defined in order to characterize a gas-bearing rock unit. These include reservoir thickness, thermal maturity of organic matter, total organic carbon content, type of gas generated (biogenic or thermogenic), total gas content, gas composition, mechanical behaviour, permeability and porosity, amongst others.

In American states adjacent to Ontario, like Michigan, Ohio, Pennsylvania and New York, unconventional gas resources have been confirmed. Indeed, the Devonian Antrim, Ohio and Marcellus formations are now considered major natural gas resources in the USA. More recently, gas production has also been reported in the Ordovician Collingwood Member in Michigan State (Daniels and Morton-Thompson 2010; Duszynski, Esch, and Organek 2010; Rock, Harrison and Barranco 2010). Furthermore, in the province of Quebec, the estimated recoverable gas resources of the Ordovician Utica shale located in the St. Lawrence Lowland have now been evaluated to reach 40 Tcf (Bureau d'audiences publiques sur l'environnement, 2011).

In Ontario, some Ordovician and Devonian rock units are the equivalents of these productive units in adjacent jurisdictions. Most of them have previously been characterized for oil potential in the 1980s by the Ontario Geological Survey (Johnson, Russell and Telford 1983a, 1983b; Barker et al. 1983; Stromquist, Dickhout and Barker 1984). Furthermore, some have been identified as the source rock of economical conventional hydrocarbon accumulations (Powell et al. 1984). Hamblin (2006) listed and described the various potential gas-bearing units in Canada, including Ontario. He also produced some detailed outcrop and core descriptions of the Kettle Point Formation (Hamblin 2010). Some additional data was obtained by the industry to evaluate the gas potential of southern Ontario (Samson 2007; Talisman 2006). However, no broader study has gathered previously published reports or presented new data to evaluate unconventional gas resources in southern Ontario.



Figure 1. Methane saturation (%) at depth and Kettle Point extent in southwestern Ontario (Hamilton 2011).

The current OGS study has been focused on rocks that are recognized for their high organic content, their potential as hydrocarbon source rocks or for being the equivalent of gas-producing units in adjacent states and/or provinces (Johnson, Russell and Telford 1983a, 1983b, 1985; Powell et al. 1984; Hamblin 2006; Béland Otis 2009). In southern Ontario, these formations include the Kettle Point, Georgian Bay and Blue Mountain formations and the Collingwood Member of the Lindsay Formation. Initially, a literature review was undertaken followed by acquisition of new data required to evaluate the gas content of these units. Archival cores and drill cuttings were studied and analysed. Finally, drilling of new wells was undertaken to obtain fresh samples for gas analysis. The first rock unit to be evaluated was the Devonian Kettle Point Formation. This report presents the results of this evaluation.

Methodology

The first phase of the project consisted of compiling all information relevant to assess gas potential for the Kettle Point Formation. This mainly included studying published literature and gathering data, such as geophysical logs, from the Ontario Oil, Gas and Salt Resources (OGSR) Library database. These logs were used to create a Kettle Point Formation isopach map (Figure 2) and a structure contour map for the top of the Hamilton Group (underlying stratigraphic unit) (Figure 3). The thickness of the Kettle Point Formation was calculated and the elevation of the Hamilton Group was reported for each well record present in the OGSR Library database. The isopach and elevation maps were interpolated using the natural neighbour function of the Spatial Analyst of ArcGIS 9.3.

The second part of this project involved gathering new data. Drill cuttings samples from previously drilled wells were collected from the OGSR Library. These samples were analysed for total organic carbon and Rock-Eval⁶ pyrolysis at the Geological Survey of Canada (GSC) organic geochemistry laboratory located in Calgary. Seven samples obtained from the Kettle Point Formation were analysed (Table 1, *see* Appendix).

Two wells were continuously cored through the Kettle Point Formation down to the Hamilton Group. The first well, OGS-SG10-01, is located in Moore Township, Lot 19, Concession III, and the second well, OGS-SG10-02, is situated in Sombra Township, Lot 24, Concession V. Exact locations of both wells are indicated in Figures 4 and 5. These wells were drilled in March and April 2010. In each well, core samples were collected and analysed for gas content, gas composition, isotopic composition of methane, total organic carbon, oil, gas and water saturation, permeability, porosity, mineralogy, adsorption isotherms and rock mechanics. Both wells were also logged with downhole geophysics for various parameters (gamma-ray, density, sonic, porosity, televiewer, etc.) and were then plugged. Finally, thin sections were made from samples collected from each well.

The main reason for drilling new core was to obtain desorbed gas measurements and other important parameters only measurable with fresh core. Thirty-centimetre long core samples were collected immediately after reaching surface and put into sealed canisters (Photo 1). These canisters, taken at about 3 m (10 ft) intervals, were then put in a water bath at reservoir temperature. Initially, gas content readings were done at the drill site at high frequency (every hour). When drilling was completed, the canisters were sent to Core Laboratories Ltd. in Calgary, where readings were taken weekly until gas measurements became negligible. All canister samples are assigned the term "CANISTER". Names of samples collected at the OGS-SG10-01 well include "KP1", while samples taken at the OGS-SG10-02 well include "KP2". The samples were then numbered accordingly from the top to the bottom of the well (CANISTER-KP1-01, CANISTER-KP1-02, etc.). Twenty-eight desorption canisters were obtained from the OGS-SG10-01 well and 27 from the OGS-SG10-02 well.



Figure 2. Isopach map of the Kettle Point Formation and location of the drill holes OGS-SG10-01 and OGS-SG-10-02. This map was produced by interpolating data from well records available at the OGSR Library.



Figure 3. Structural contour map of the contact between the Kettle Point Formation and the Hamilton Group. This map was produced by interpolating data from well records available at the OGSR Library (masl: meters above sea level).



Figure 4. Location of OGS drill hole OGS-SG10-01, indicated by the star. The well is situated west of Tecumseh Road, north of Oil Spring Line.



Figure 5. Location of OGS drill hole OGS-SG10-02, indicated by the star. The well is situated south of Charlemont Line, west of Simpson Road.

Total quantity of gas contained in the core is the sum of projected lost gas, measured desorbed gas in the canister and projected or measured residual gas. The lost gas content represents the quantity of gas released by the core sample before it was put in the canister. This is an estimated value calculated by Core Laboratories Ltd. with a specific algorithm. The measured desorbed gas content corresponds to the quantity of gas naturally released by the core sample in the canister over time. The residual gas content represents the gas still in the rock after the measurement of desorbed gas is completed. To determine residual gas, a rock sample is crushed to release the gas still trapped in the rock. Residual gas can also be calculated using an algorithm. Core Laboratories Ltd. measured the residual gas content of 10 samples of the OGS-SG10-01 well and 9 samples from the OGS-SG10-02 well and calculated the projected residual gas content for all gas samples of both wells. Some of the canister samples were also analysed by Core Laboratories Ltd. for gas composition (9 samples per well), isotopic gas composition of methane (3 samples per well), adsorption isotherms (3 samples per well) and rock mechanics (2 samples per well). Tables 2 and 3 present all analyses performed for each canister sample.

Additional core samples were collected and analysed for total organic carbon, Rock-Eval⁶ pyrolysis, mineralogy, standard GRI (Gas Research Institute) analysis and thin sections. Tables 4 and 5 list all the additional samples and the analyses performed. These sample codes start with "CORE" and are followed by KP1 if collected from the OGS-SG10-01 well and by KP2 if from the OGS-SG10-02 well. In general, samples were numbered from the bottom to the top of the cores. One of the analyses performed was total organic carbon. This was carried out either by Core Laboratories Ltd. (4 samples from the OGS-SG10-01 well and 4 samples from the OGS-SG10-02 well) or by the GSC laboratory (26 samples from the OGS-SG10-01 well and 21 samples from the OGS-SG10-02 well). The GSC laboratory also performed



Photo 1. Gas canister used to collect core samples for gas desorption analyses and adsorption isotherms.

Rock-Eval⁶ pyrolysis on all core samples. Core Laboratories Ltd. ran additional analyses on the rock samples. These included mineralogical analyses (4 samples from OGS-SG10-01 well and 3 samples from OGS-SG10-02 well) and standard GRI analyses (7 samples from OGS-SG10-01 well and 8 samples from OGS-SG10-02 well), including permeability, porosity, density and water, gas and oil saturations. Furthermore, Core Laboratories Ltd. produced 7 ultra-thin sections per well.

Both wells were logged with downhole geophysics by Weatherford International Ltd. The parameters measured were gamma-ray, density, porosity, spontaneous potential, temperature, conductivity, induction sonic and televiewer. After logging, the wells were plugged according to the Oil, Gas and Salt Resources of Ontario, Provincial Operating Standards.

Previous Work

Caley (1943, 1945) first studied the Kettle Point Formation and initially defined it as black fissile shale situated stratigraphically above the Hamilton Group. Sanford and Brady (1955) later refined the Kettle Point Formation to beds between the Hamilton and the Port Lambton groups. Macdonald (1960) produced the first structural map while Russell and Barker (1983) and Russell (1985, 1993) later refined the internal stratigraphy of the Kettle Point Formation.

Biostratigraphic work on the Kettle Point Formation was done by Winder (1966) and Uyeno, Telford and Sanford (1982). Other work on fossils and calcareous concretions include publications by Daly (1900), Arnold (1952), Coniglio and Cameron (1990) and Chitaley and Chongyang (2001).

The Kettle Point Formation has previously been considered as a potential oil resource and was studied in the 1980s by the OGS as part of the Hydrocarbon Energy Resources Program (Dusseault et al. 1983; Harris 1984; Barker 1985; Dusseault and Loftsson 1985; Johnson 1985; Johnson, Russell and Telford 1985; Russell 1985, 1993; Dusseault, Loftsson and Russell 1986). As part of this study, 20 new wells were cored through the Kettle Point Formation. These cores were analysed for Fischer Assay, total organic carbon, pyrolysis yield and elemental analysis.

In addition, the cores were also studied by the Geological Survey of Canada to assess the source rock potential of the Kettle Point Formation (Powell et al. 1984; Snowdon 1984; Macauley, Snowdon and Ball 1985; Obermajer 1997; Obermajer et al. 1997). Finally, some theses focusing on the mechanical properties, the mineralogy, petrology and geochemistry of the unit were also produced (Loftsson 1984; Delitala 1984; Armstrong 1986).

More recently, the Kettle Point Formation has been studied for its gas potential by Hamblin (2006, 2010), Hamblin, Carter and Lazorek (2008) and Carter, Fortner and Clark (2008) and by 2 private companies. Talisman (2006) cored a portion of the Kettle Point Formation in Lake Erie while Samson (2007) cored 1 well, the Gore of Chatham, just northeast of Wallaceburg. Initial data from this present study were published by Béland Otis (2009, 2010, 2011).

Geographic and Geological Setting

The Kettle Point Formation has a limited outcrop area in southwestern Ontario and under Lake Erie (*see* Figure 2). It is the stratigraphic equivalent of the Long Rapids Formation in far northern Ontario, the Antrim Shale of Michigan, the Ohio Shale of Ohio, the New Albany Shale of Illinois and Kentucky and the Rhinestreet Shale of New York State (Russell 1985; Bezys 1991; Roen and Kepferle 1993; Hamblin 2006; Lash and Blood 2006). The Kettle Point Formation is situated geographically between the Antrim

Shale of the Michigan Basin and the Ohio and Rhinestreet shales of the Appalachian Basin (Figure 6). The Kettle Point Formation represents almost all of the Upper Devonian, from early Frasnian to late Famennian (Uyeno, Telford and Sanford 1982).

The Kettle Point Formation and its equivalents are part of the Upper Devonian molasse sediments deposited as part of the Catskill delta in the Appalachian foreland basin (Hamblin 2010). This basin developed during and after the Acadian Orogeny when Avalon collided with Laurentia (Faill 1985). Two major depocenters, the Appalachian and the Michigan basins, were divided by the Algonquin Arch, which had a relatively low relief in the Late Devonian. By examining geophysical logs, Russell (1985) estimated that in the Devonian the arch had a maximum elevation of about 20 m. The Kettle Point Formation is preserved in the Chatham Sag, a structural low between the Algonquin and Findlay arches (*see* Figure 6; Russell 1993).

The maximum thickness of the Kettle Point Formation is 105 m (Armstrong and Carter 2010). However, its average thickness is on the order of 30 m. The Kettle Point Formation disconformably overlies limestones and shales of the Hamilton Group. It is disconformably overlain by shales and siltstones of the Port Lambton Group (Figure 7) near the St. Clair River. Elsewhere, the Kettle Point Formation is directly covered by Quaternary sediments.



Figure 6. Simplified geological map of northeast central North America showing distribution of Upper Devonian shales (grey) and major structural features (arches and basins) (modified from Russell 1985).

The Kettle Point Formation consists mainly of dark brown to black organic-rich shales and siltstones, interbedded with grey-green silty shale and siltstones (Armstrong and Carter 2010). The name of the formation originates from the large calcite concretions that occur in the lower part of the formation, observed at Kettle Point on Lake Huron, where the type section is situated (Photo 2). These spherical "kettles", reaching metre-size in diameter, were formed during shallow burial diagenesis before compaction of the terrigenous mud (Coniglio and Cameron 1990). Pyrite and marcasite are also present as disseminated and nodular iron sulphide minerals (Armstrong and Carter 2010). *Tasmanites*, pyritized radiolaria and sponge spicules, conodonts, ostracods, brachiopods, rare fish and coalified plant fragments are also found in the Kettle Point Formation (Armstrong 1986). The algal foram *Foerstia* (also called *Protosalvinia*) has also been identified (Russell 1985) and is used as a geological time marker for the Appalachian Devonian shales (Hasenmueller et al. 1983). Bioturbation is locally present, especially in and adjacent to the organic-poor green-grey beds (Russell 1993; Armstrong and Carter 2010).

The Kettle Point Formation has not been subdivided into formal members. However, Russell (1985, 1993) extended into southwestern Ontario the 6 subdivisions identified by Ells (1979) in gamma-ray logs for the Antrim Shale (Figure 8). Russell (1985) also identified 3 lithotypes, constituting the Kettle Point Formation, which are as follows:

- 1. Black, finely laminated, micaceous, silty, noncalcareous, pyrite-rich shale with numerous *Tasmanites* microfossils and occasional calcite concretions. This lithotype is present at the top and middle of the formation and can be interbedded with lithotype (b) and (c).
- 2. Beds of green or greenish grey, both bioturbated and laminated, shale or mudstone with some silty layers and occasional pyrite; bases usually burrowed, tops usually conformable, rarely disconformable. The green beds are organic-poor. This lithotype usually occurs in the middle of the formation.
- 3. Black to brown shale as in (a), but with numerous thin (0.5 mm to 10 mm) white quartz silt bands, occasionally slightly calcareous. This lithotype is dominant near the bottom of the formation but can also be present in the middle.



Figure 7. Stratigraphic chart of the Devonian of southern Ontario (modified from Armstrong and Carter 2010).

These black and green shales were probably deposited regionally in low-energy, shallow waters (Russell 1993; Obermajer 1997). The preservation of organic content indicates deposition in anoxic waters (Byers 1977; Cluff 1980; Russell 1985). Russell (1993) further suggested that the deposition of the black organic-rich shales were due to the stratification of the water column. Russell (1993) and Delitala (1984) proposed that vertical variations of the pycnocline induced deposition of black organic-rich beds in anoxic water and green organic-poor beds in oxygenated waters.

HYDROCARBON IN THE KETTLE POINT FORMATION

The Kettle Point Formation was evaluated as a potential oil source in the 1980s (Harris 1984; Johnson 1985; Russell 1985). Studies by the OGS and others have provided base data on the organic richness, maturity, mineralogy, geochemistry and mechanics of the Kettle Point Formation (Delitala 1984; Powell et al. 1984; Snowdon 1984; Barker 1985; Dusseault and Loftsson 1985; Johnson 1985; Johnson, Russell and Telford 1985; Russell 1985, 1993; Armstrong 1986; Obermajer 1997; Obermajer et al. 1997).

Total organic carbon is reported to be as high as 15.1 wt% (Obermajer 1997). The richest zones are easily identified by the highest values on gamma-ray logs (Russell 1985; Armstrong 1986). Russell (1985) identified a strong correlation between organic content and gamma-ray properties that may be due to the fact that uranium is usually enriched in organic matter (Delitala 1984; Armstrong 1986). The most organic-rich intervals are typically located at the top or lowest parts of the formation (Obermajer 1997).

Organic petrology studies (thermal alteration index, conodont alteration index, vitrinite reflectance) indicate that the Kettle Point Formation is thermally immature to marginally mature (Legall et al. 1981; Armstrong 1986; Obermajer 1997). This is confirmed by maximum temperature (Tmax = 422 - 437) measured by Rock-Eval⁶ pyrolysis and by vitrinite reflectance values (% V R_o = 0.42 - 0.70) (Obermajer et al. 1997; Samson 2007). The Kettle Point Formation is characterized by hydrogen-rich, marine type organic matter deposited in an algal-dominated environment (Obermajer et al. 1997).



Photo 2. Large carbonate concretions found in black shales of the Kettle Point Formation, at Kettle Point on the shore of Lake Huron, as indicated in Figures 2 and 3.



Figure 8. Kettle Point Formation basic lithologic types and gamma-ray log for the well OGS K.P. 24. Numbers on the gamma-ray log reflect the 6 subunits identified by Ells (1979) for the Antrim Shale, whereas the Roman numerals reflect the subunits identified by Russell (1985). *Modified from* Russell (1985) and Armstrong (1986).

The Kettle Point Formation is mainly composed of quartz (27-63 wt %), clay (18-55 wt %), dolomite (0-25 wt %), pyrite (1-12 wt %), potassium feldspar (1-6 wt %), and rutile (0.4 wt %) (Delitala 1984; Samson 2007). Clay composition includes illite (22 wt %), chlorite (3.4 wt %) and glauconite (2 wt %). Black and green shales have similar mineralogy (Samson 2007); however, sulphide mineral content is higher in black shales (Delitata 1984; Samson 2007). Some of the minerals found in the Kettle Point Formation, like quartz and sulphide minerals, are authigenic, meaning that they were produced *in-situ* either by bacteria or by clay mineral dewatering during diagenesis (Delitata 1984).

Very few studies have been dedicated to structural features of the Kettle Point Formation. However, fracture studies are required for an adequate gas assessment. Hamblin (2010) measured 2 orthogonal sets of vertical fractures (50/230° and 135/315°), similar to other measurements in Devonian shales in the United States (Ryder 1996; Lash, Loewy and Engelder 2004). Some mechanical behaviour studies have also focused on the oil potential of the Kettle Point Formation. Loftsson (1984) noticed the presence of a strong weakness plane parallel to bedding.

Samson Resources drilled a test hole near Wallaceburg in the Kettle Point Formation to evaluate the quantity of gas naturally desorbing from the rocks (Samson 2007). Their results show that total gas content ranges between 1.3 standard cubic feet per ton (scf/ton) and 13.9 scf/ton (1 scf/ton equals to 0.03121 m^3 /t). This is also confirmed by the reported storage capacity measurements (1.3-13.1 scf/ton). Samson (2007) determined that the gas was mainly composed of methane (82-96%) and ethane (2-13%). Heavier hydrocarbons represented less than 5% and carbon dioxide less than 1%. The dry calorific value of the gas was up to 1192 Btu/ft³. Porosity, which was also measured, was up to 11.5%. Up to 38.1% of this porosity was gas-filled while water saturation reached values up to 95.5% and oil saturation, up to 25.2%. Matrix permeability values ranged from 8.5×10^{-10} millidarcies (mD) to 7.0×10^{-7} mD. Talisman Energy Inc. also collected core samples to characterize the Kettle Point Formation in Lake Erie. The rock's porosity reached 7% while other results were never reported (Talisman 2006).

Results

LITHOLOGY

The OGS-SG10-01 and OGS-SG10-02 wells were collared at elevations of 188.30 masl and 180.25 masl, respectively. The OGS-SG10-01 well intersected bedrock at a depth of 46.9 m whereas the OGS-SG10-02 well encountered an overburden thickness of 20.0 m. Both OGS wells were continuously cored through the Kettle Point Formation and at least 5 m into the underlying Hamilton Group. OGS-SG10-01 also intersected the Port Lambton Group, overlying the Kettle Point Formation. In this well, the Port Lambton Group consisted of 10.5 m of soft, light grey shale with some thin silty intervals and clay seams with a disconformable contact with the underlying Kettle Point Formation. The Kettle Point Formation was 81.30 m thick in the OGS-SG10-01 well and 81.1 m in the OGS-SG10-02 well. The OGS-SG10-01 well was drilled to a total depth of 144.70 m while the well OGS-SG10-02 was drilled to a depth of 106.76 m.

Ells (1979) identified subunits in the Antrim Shale based on analysis of gamma-ray logs. These have also been identified in the Kettle Point Formation by Russell (1985) and in both OGS wells (Figure 9). In both wells, the upper and lower contacts of each subunit are easily identified with gamma-ray response. In the OGS-SG10-01 well, a higher gamma-ray signal is identified in the upper and lower section, while the middle section presents mostly lower gamma-ray values. Gamma-ray values for the OGS-SG10-02 well are far less variable. However, a slight decrease is associated with the presence of green beds.



Figure 9. Geological and gamma-ray logs of both OGS-SG10-01 and OGS-SG10-02 drill holes. Numbers on the gamma-ray logs refer to subunits identified by Ells (1979). GAPI: American Petroleum Institute gamma-ray units.

In both wells, the Kettle Point Formation consists mainly of dark brown to black shale with some silty intervals and some green interbeds in middle and bottom sections of each well (*see* Figure 9). Bioturbation and thin clay beds were sometimes associated with the green beds. Pyrite was also present, mostly in black shales, as nodular, disseminated or laminated.

GRI CORE ANALYSIS

Gas Research Institute (GRI) standard core analyses are reported in Tables 6 and 7 and graphically presented in Figures 10 and 11. Bulk density of the Kettle Point shale varies between 2.18 and 2.60 g/cm³ for the OGS-SG10-01 well and between 2.24 and 2.55 g/cm³ for the OGS-SG10-02 well. Grain density values are between 2.35 to 2.86 g/cm³ and 2.42 to 2.81 g/cm³ for the OGS-SG10-01 and OGS-SG10-02 wells, respectively. Greens interbeds have the greatest density values.

Porosity values are slightly greater in the OGS-SG-10-02 well (6.0 to 12.5%) than in the OGS-SG10-01 well (5.1 to 10.8%). Samples as received from OGS-SG10-02 well can have higher matrix permeability values (up to 1.76×10^{-5} mD) than those in the OGS-SG10-01 well (up to 7.70×10^{-6} mD). A similar trend is exhibited in the extracted matrix permeability values (OGS-SG10-01: up to 1.11×10^{-4} mD, OGS-SG10-02: up to 2.63×10^{-3} mD). The only sample from the Port Lambton Group does not have a significant matrix permeability value for *in situ* conditions (1.51×10^{-8} mD) but when hydrocarbons and water are removed, the same parameter could be considered high (1.66×10^{-4} mD). Porosity seems more developed in green beds.

Water saturation values are greater in the OGS-SG10-01 well (47.8 to 90.6%) than in the OGS-SG-10-02 well (39.9 to 67.8%). However, the greatest value was obtained for the Port Lambton Group sample (90.6%). Gas saturation values were greater for the OGS-SG-10-02 well (29.2 to 54.0%) as compared to the OGS-SG-10-01 well (9.4 to 50.0%) and the lowest value was measured in the Port Lambton sample (9.4%). Kettle Point oil saturation values are roughly similar in both wells (OGS-SG10-01: 2.3 to 14.6%, OGS-SG10-02: <0.01 to 18.8%), whereas values for the Port Lambton are very low (<0.01%). In the OGS-SG10-01 well, gas saturations seemed greater in green interbeds, while water saturation seemed lower. However, no such trend was observed in OGS-SG10-02 well.

Samson (2007) obtained similar core analysis values. However, permeability values were slightly lower (between 8.45×10^{-10} mD and 3.80×10^{-6} mD) and oil and water saturations were generally higher (up to 25% oil saturation and 93% water saturation).

ROCK-EVAL⁶ PYROLYSIS AND TOTAL ORGANIC CARBON

Rock-Eval⁶ pyrolysis parameters results from both OGS drill holes are presented in Tables 8 through 11. For these samples, Kettle Point Formation total organic carbon (TOC) contents vary between 0.39 wt % and 11.17 wt % for the well OGS-SG10-01 and between 0.47 wt % and 10.15 wt % for the well OGS-SG10-02. S₁ is the amount of free hydrocarbons in a sample. Its values for the Kettle Point Formation vary from 0.05 to 3.60 mg_{Hydrocarbon}/g_{Rock}. Kettle Point Formation values for S₂, which is the amount of hydrocarbon generated through thermal cracking of nonvolatile organic matter, vary from 0.52 to 58.28 mg_{Hydrocarbon}/g_{Rock}. The amount of CO₂ produced during pyrolysis of kerogen, represented by S₃, varies from 0.19 to 0.49 mg_{CO2}/g_{Rock} in both wells. Production index (PI), Hydrogen Index (HI), Oxygen Index (OI) and Pyrolyzable Carbon (PC) values for all Kettle Point samples range, respectively, from 0.03 to 0.09, 111 to 723 mg_{Hydrocarbon}/g_{TOC}, 3 to 55 mg_{CO2}/g_{TOC} and 0.06 to 5.17 wt %. Port Lambton Group



Figure 10. Standard Gas Research Institute (GRI) analysis logs for OGS-SG10-01 well. *See* Figure 9 for description of geological log. Abbreviation: mD = millidarcy.
values are generally distinct from those of the Kettle Point Formation (S_1 : 0.01 mg_{Hydrocarbon}/g_{Rock}, S_2 : 0.11 to 0.14 mg_{Hydrocarbon}/g_{Rock}, S_3 : 0.58 to 0.65 mg_{CO2}/g_{Rock}, PI: 0.09 to 0.10, HI: 41 to 47 mg_{Hydrocarbon}/g_{TOC}, OI: 193 to 241 mg_{Hydrocarbon}/g_{TOC}, PC: 0.04 wt %). For both wells, the temperature at which the maximum release of hydrocarbons from cracking of kerogen occurs during pyrolysis, generally referred as T_{max}, ranges from 424 to 440°C.

The chips sampled at the OGSR Library have similar Rock-Eval⁶ values (Tables 12 and 13). Total organic content values vary from 1.81 to 7.28 wt %, and S_1 , S_2 and S_3 values vary from 0.36 to 1.88 mg_{Hydrocarbon}/g_{Rock}, 7.06 to 36.3 mg_{Hydrocarbon}/g_{Rock} and 0.25 to 0.80 mg_{CO2}/g_{Rock}, respectively. PI, HI, OI and T_{max} values range from 0.03 to 0.06, 390 to 523 mg_{Hydrocarbon}/g_{TOC}, 8 to 21 mg_{CO2}/g_{TOC} and 426 to 437°C, respectively.



OGS-SG10-02

Figure 11. Standard Gas Research Institute (GRI) analysis logs for OGS-SG10-02 well. *See* Figure 9 for description of geological log. Abbreviation: mD = millidarcy.

In both newly drilled OGS wells and in chips sampled at the OGSR Library, the Kettle Point Formation has good organic content (up to 11.17 wt %). Also, S₁ and S₂ values greater than 2 and 10, respectively, indicate the Kettle Point Formation has very good source rock potential (Peters 1986). The total organic carbon and S₂ results are presented in Figure 12 and are compared with published data. Even if some values fall at the limit between fields of Type I and II, most of the data suggests a Type II kerogen, which corresponds to previously analysed samples from Snowdon (1984), Obermajer (1997) and Samson (2007). Type II kerogen indicates a mixture of zooplankton, phytoplankton, and bacterial debris in a reducing environment that may also contain terrestrial material (Bend 2008). However, when plotted on a pseudo Van Krevelen diagram (Figure 13), the data indicates a Type I kerogen associated to algal or bacterial material, which is also the most oil prone of the kerogen types (Bend 2008). This kerogen is possibly mixed with a Type II kerogen. Values with low Hydrogen Index (HI < 200) are associated with low total organic carbon (TOC <1 wt %) and should be considered carefully.

The early, peak and late oil-generation windows are characterized by T_{max} values between 435 and 445°C, 445 and 450°C, and 450 and 470°C, respectively (Peters and Cassa, 1994). The T_{max} values associated with the Kettle Point Formation indicate maturity levels from immature to early mature. These values correspond to previously published data (Snowdon 1984; Obermajer 1997; Samson 2007).

GAS CONTENT

Desorption results for all samples are presented in Tables 14 and 15 and in Figure 14. Total gas content values are equal to the sum of lost gas, desorbed gas and residual gas. In the OGS-SG10-01 well, total gas content varies from 3.3 scf/ton and 26.7 scf/ton for the Kettle Point Formation and decreases to values



Figure 12. Total organic carbon versus S_2 for the Kettle Point Formation. Fields of various types of organic matter are from Peters, Walters and Moldowan (2005).



Figure 13. Hydrogen Index versus Oxygen Index diagram showing Kettle Point Formation data.



Figure 14. Total gas content logs for both OGS-SG10-01 and OGS-SG10-02 drill holes (scf: standard cubic feet). See Figure 9 for description of geological log.

of 2.3 to 3.6 scf/ton for the Port Lambton Group. In OGS-SG10-02 well, total gas values vary from 6.2 scf/ton and 18.5 scf/ton. In both wells, the largest portion of total gas is represented by desorbed gas, which accounts for up to 71.3% of the total, followed by residual gas (up to 60.8%) and by lost gas (up to 8.5%). While projected residual gas values have been calculated for all samples, only about a third of the samples were analysed for measured residual gas. For those samples, the projected residual gas values (0.0 to 7.4 scf/ton) are always lower than the measured values (2.1 to 8.6 scf/ton) (*see* Figure 14). Also, highest total gas values (>20 scf/ton) of the OGS-SG10-01 well occur in the upper section while lowest values (<5 scf/ton) are associated with the deepest section and with green bed intervals (*see* Figure 14). In the OGS-SG10-02 well, total gas content values are less variable (6.2 to 18.5 scf/ton) than in OGS-SG10-01 well and no clear trend with geology or depth has been identified.

Adsorption isotherms are presented in Table 16 and in Figure 15. Samples with low total organic carbon content, representing green beds (OGS-SG10-01-13 and OGS-SG10-02-11), have low methane storage capacity while the samples with high total organic carbon show highest values, confirming that most of the gas is adsorbed on organic matter. Storage capacities at reservoir temperature range from 1.48 scf/ton to 19.78 scf/ton for the OGS-SG10-01 well and from 3.69 scf/ton to 12.29 scf/ton for the OGS-SG10-02 well.



Figure 15. Adsorption isotherms for both OGS-SG10-01 and OGS-SG10-02 drill holes. Squares and circles symbolize measured methane storage capacity values whereas lines represent the calculated Langmuir isotherms. The triangles correspond to corrected storage capacity at reservoir pressure. Abbreviations: scf, standard cubic feet; psia, pounds per square inch absolute.

GAS COMPOSITION AND METHANE ISOTOPES

The final apparent gas compositions are presented in Tables 17 and 18. The gas is mainly composed of methane (from 67.6% to 99.5%), which is greater in OGS-SG10-01 well (average: 88.1%) than in OGS-SG10-02 well (average 83.3%). In the OGS-SG10-01 well, propane and heavier hydrocarbons can represent up to 5% while carbon dioxide concentrations can reach 1.3% in the green beds situated at intermediate depth. For the OGS-SG10-02 well, ethane proportions can reach values as high as 16.0% and propane and heavier hydrocarbons values are as high as 16.4%. CO₂ concentrations are all lower than 0.89% and saturated calorific values do not exceed 1405 Btu/ft³.

Gas composition and methane isotopic composition data are presented in Table 19. Carbon isotope values for methane ($\delta^{13}C_{C1}$) range from -54.53 ‰ to -51.33 ‰ in the OGS-SG10-01 well and from -50.59 ‰ to -36.89 ‰ in the OGS-SG10-02 well. Deuterium isotope values for methane ($\delta^{2}D_{C1}$) range from -308.7 ‰ to -296.7 ‰ in the OGS-SG10-01 well and from -286.5 ‰ to -241.1 ‰ in the OGS-SG10-02 well. Gas compositions presented in Table 19 represent only a fraction of the total apparent compositions of Tables 17 and 18.

The Kettle Point Formation is considered to be a potential source for biogenic gas because of its proximity to the Antrim Shale (a known biogenic gas source), and the fact that it is spatially related to gas detected in water wells. However, to definitely determine the origin of the gas, one must measure the gas isotopic composition. Samples collected in both wells have been plotted on a $\delta^{13}C_{C1}$ versus δD_{C1} diagram (Figure 16). All OGS-SG10-01 well samples indicate a microbial origin for methane, more specifically in the fermentation field. However, for the OGS-SG10-02 well, only 1 sample (CANISTER-KP2-26) falls within this field. The sample CANISTER-KP2-13 is located in neither biogenic source or the combination of both processes could explain this composition. Finally, the isotopic composition of sample CANISTER-KP2-06 indicates a thermogenic source. However, it also could be argued that the composition can be attributed in part or totally to oxidation of microbial methane during the metabolic process of methane into carbon dioxide.

MINERALOGY, MECHANICAL PROPERTIES AND BRITTLENESS

Mineralogical analysis indicates that the Kettle Point Formation is mainly composed of quartz (35 to 51 wt %) and clays (31 to 53 wt %) (Table 20 and Figure 17). Clays are composed of illite (65 to 83 wt %), kaolinite (7 to 13 wt %), chlorite (10 to 16 wt %) and mixed illite/smectite layers (up to 15 wt %), where smectite represents no more than 30%. Carbonate content, negligible in most samples, can reach up to 5 wt % for the Kettle Point Formation in the OGS-SG10-01 well. Iron sulphide minerals (pyrite and marcasite) can represent up to 16 wt % of the rock. In the green beds, clay content tends to be higher and iron sulphide content is lower. Some previously published data (Snowdon 1984) indicates a higher content in non-clay silicate minerals (Figure 17). Data from Samson (2007) and the current project are comparable.

In the black shales, quartz grains, easily identified in thin sections, are up to 0.05 mm in size and rounded to angular (Photo 3a). Pyrite is also present, either disseminated, concentrated in laminae or as nodules (Photo 3b). Alganite of *Tasmanites* type is observed in both wells (Photo 3c). In green beds, grain size is considerably reduced and distinction of minerals is not possible petrographically (Photo 3d).



Figure 16. $\delta^{13}C_{C1}$ versus δD_{C1} diagram. *Modified from* Coleman et al. (1995) (C₁: methane, C: carbon, D: deuterium).



Figure 17. Ternary diagram presenting mineralogy data (quartz and feldspar, carbonates and clays) from Kettle Point Formation samples from both OGS-SG10-01 and OGS-SG10-02 drill holes and from previous publications (Snowdon 1984; Samson 2007).

Triaxial compressive test results are presented in Table 21. For samples from both wells, compressive strength values range from 8607 pounds per square inch (psi) to 20 408 psi (where 1 psi equals 6894.8 Pa). Young's modulus values differ slightly from 1.13×10^6 psi to 2.19×10^6 psi and Poisson's ratios values range from 0.08 to 0.16.

Acoustic velocities and dynamic elastic parameters are presented in Table 22. In both wells, compressional acoustic velocities (8235 to 10 839 psi) are higher than shear acoustic velocities (5444 to 6779 psi). Values vary from 0.85×10^6 to 1.78×10^6 psi for the bulk modulus, from 1.97×10^6 to 3.43×10^6 psi for the Young's modulus and from 0.89×10^6 to 1.46×10^6 psi for the shear modulus. Poisson's ratio values range from 0.11 to 0.18.

Both wells were logged with downhole geophysics for Poisson's ratio (Figure 18). However, the OGS-SG10-02 well was only logged in the bottom half. These logs indicate that the Poisson's ratio does not seem to vary widely, except for green interbeds, where it is generally higher.

Mineralogy and rock mechanics are important parameters when evaluating shale gas potential because both strongly affect the brittleness of the shale. The greater the brittleness, the easier it will be to develop fractures through the shale with external forces (Ding et al. 2012). Various methods can be used to quantify brittleness. We will focus here on only some of those.



Photo 3. a) Photo of rounded and angular quartz grains observable in sample CORE-KP2-03B. b) Photo of a pyrite nodule in sample CORE-KP2-02B. c) Photo of *Tasmanites*, as indicated by "T", in sample CORE-KP1-03B. d) Photo of "green" lithology in sample CORE-KP1-18B.



Figure 18. Geological, gamma-ray and Poisson's ratio logs. The OGS-SG10-02 well was not logged entirely for Poisson's ratio. *See* Figure 9 for description of geological log.

Jarvie and others (2007) indicate that the proportion of quartz relative to clay and carbonate is a good indicator of brittleness. As presented in Table 20 and Figure 17, quartz proportion can reach values between 35 and 51 wt %, suggesting a high brittleness.

Again, based on mineralogy, some other authors use a specific equation to calculate a brittleness index (e.g., Wang and Gale 2009). This index can then be used to identify higher "fracturability" zones. Equation 1, taken from Wang and Gale (2009), gives brittleness indices from 0.42 to 0.57 and tend to be greater at depth.

$$BI = \frac{Qtz + Dol}{Qtz + Dol + Cal + + Cla + TOC}$$
(1)

Where, BI is brittleness index,

Qtz is the proportion of quartz (wt %), *Dol* is the proportion of dolomite (wt %), *Cal* is the proportion of calcite (wt %), *Cla* is the proportion of clays (wt %),

TOC is total organic carbon (wt %).

Rock mechanics is another parameter used to evaluate brittleness and is sometimes preferred to a mineralogical analysis (Slatt and Abousleiman 2011). Indeed, a brittle rock is usually characterised by a high Young's modulus and a low Poisson's ratio. The Kettle Point Formation has both a low Young's modulus and Poisson's ratio (*see* Tables 21 and 22). Generally, shales with a Young's modulus less than 3×10^6 psi are considered nonprospective (Britt and Shoeffler 2009). As observed in Figure 19, the Kettle Point Formation samples fall in the brittle area, but close to the brittle-ductile line. A brittleness index can also be calculated with static rock mechanics parameters (Rickman et al. 2008). Their equations have been simplified to the following:

$$BI = 50 \times \left[\frac{Y - 1}{7} + \frac{0.4 - P}{0.25}\right]$$
(2)

Where, *BI* is the brittleness index (%),

Y is static Young's modulus ($\times 10^6$ psi),

P is Poisson's ratio.

Using Equation 2, calculated values for brittleness indices (*BI*) vary from 54.76 to 60.19% in the OGS-SG10-01 well and from 66.37 to 67.54% in the OGS-SG10-02 well. These values are considered low to medium (Buller 2010; Hall 2010).



Figure 19. Cross-plot of Poisson's ratio and Young's modulus showing brittle and ductile areas and both OGS drill holes samples (*modified from* Grieser and Bray 2007).

STRUCTURAL ANALYSIS

Many horizontal fractures were observed in the cores from the OGS drill holes. To confirm their presence, a televiewer log was run in both wells. Since most fractures in the core were not detected down the hole by the televiewer, they are assumed to be induced by drilling operations. Figure 20 is a stereonet showing vertical fracture orientations as measured by the televiewer. OGS-SG10-02, with 16 fractures, has more than twice the quantity of fractures as found in the OGS-SG10-01 well. Also, healed fractures were observed in only the OGS-SG10-02 well. Most interestingly, even if most fracture orientations are observed in both wells, one set of fractures (average strike: 351°, average dip: 81.5°), mainly composed of healed fractures, is present in only the OGS-SG10-02 well even if both wells are located only 20 km apart.

Interpretations

THE KETTLE POINT FORMATION: A POSSIBLE BIOGENIC GAS SOURCE

In Table 23, Kettle Point Formation data from the current study is compared to that of equivalent Devonian shales and to the data originating from the Gore of Chatham well drilled by Samson in 2007

(Samson 2007). The Kettle Point Formation is within the same ranges of values for most parameters, except for depth and gas content values. They are both much lower for the Kettle Point Formation. Shallower depths are also observed for the Antrim Shale, which is a well-documented microbial gas source. The Kettle Point Formation is also organic-rich and thermally immature, which are 2 characteristics usually associated with biogenic gas. Furthermore, methane isotopes from both wells indicate a biogenic component (*see* Figure 16).

Schurr and Ridgley (2002) divided biogenic gas into 2 groups, the early-generation systems and the late-generation systems. Early-generation systems have blanket shape and gas generation begins soon after deposition of the sediments. Late-generation systems, on the other hand, have ring-like geometries and long-time intervals separate deposition of the rocks from gas generation. Gas flows are usually lower in biogenic environments. Initial low gas production rates associated with open fractures usually decrease to steadier matrix flow. By far, the most studied of these late-generation biogenic gas source rocks is the Upper Devonian Antrim Shale in Michigan, equivalent of the Kettle Point Formation (Cercone 1984; Martini et al. 1996, 1998, 2003; Ryder 1996; Walter et al. 1996; Schurr and Ridgley 2002; Harrison 2010).

The Antrim Shale in Michigan is an organic-rich (up to 24 wt %) thermally immature shale (V % $R_o = 0.4$ to 0.6) up to 240 m thick (Cercone 1984; Walter et al. 1996). It was recently estimated that the Antrim produced about 120 bcf of gas in 9797 wells (Harrison 2010). The gas is mainly composed of methane with varying amount of carbon dioxide and ethane (Martini et al. 1996). Martini and others (Martini et al. 1996, 2003; Martini, Walter and McIntosh 2008) were the first to prove a major biogenic component in the gas produced from the Antrim Shale. Using methane isotopes and gas composition, they suggested that the measured gas composition reflects dilution of immature thermogenic gas by addition of



Figure 20. Stereonet showing fracture patterns in both OGS-SG10-01 and OGS-SG10-02 drill holes measured by the televiewer log. Only poles of fractures are shown.

microbial methane. Freshwater originating from Pleistocene glacial drift infiltrated the shale through natural near-surface fracture networks. Since the methanogens, the microorganisms able to produce methane under anoxic conditions, are introduced in the system by freshwater we can establish that the reservoir is replenishing itself. On the other hand, saline fluids circulating in the shale limit the microbial production of methane (Martini et al. 1998). Therefore, greater amounts of gas are generated in shallow fractured sections of the Antrim (Walter et al. 1996; Martini et al. 1996). Immature thermogenic gas probably originates from deeper in the central part of the basin. A natural fracture pattern is observed in the Antrim Shale (Ryder 1996). These fractures may be associated with various geological events such as 1) compressive deformation regime of the late Paleozoic Alleghanian Orogeny; or 2) the Mesozoic stress due to the upwelling of the asthenosphere (Ryder 1996). In the Kettle Point Formation, the fractures could also be associated with the underlying Silurian pinnacle reef fairway, dissolution of Silurian salts or loading and withdrawal of the Quaternary ice sheet (Hamblin 2010).

Numerous shallow gas shows have been identified in water and oil and gas wells completed in or passing through the Kettle Point Formation. Carter, Fortner and Clark (2008) compiled all the shows occurring on land and plotted their distribution on a bedrock geology map. These along with gas shows over Lake Erie are shown in Figure 21. Gas shows in drift and bedrock identified in water wells are clearly defined across the extent of the Kettle Point Formation. This strongly indicates a link between water and the Kettle Point Formation where gas shows are present, indicating a possible microbial gas source (McIntosh et al. 2012).



Figure 21. Kettle Point Formation's extent and location of gas shows in water and oil and gas wells (Quaternary drift and Kettle Point Formation). *Modified from* Carter, Fortner and Clark (2008).

GEOLOGICAL FACTORS INFLUENCING GAS CONTENT

In Figure 22, both wells are presented with their respective gas content logs, complemented with the geology, total organic carbon values and gamma-ray logs. The OGS-SG10-01 well presents good correlation between gamma-ray and total organic carbon. Similar trends are observed in the OGS-SG10-02 well and in other Kettle Point Formation wells. This is explained by the correlation between high organic content and uranium in anoxic environments (Swanson 1960; Russell 1985).

Gas content is generally lower in the Port Lambton Group and in the green beds of the Kettle Point Formation, probably because of the fact that organic content is almost negligible in these units. Indeed, correlation between total organic carbon and gas content can be explained by the important quantity of gas adsorbed on organic matter as observed in other gas reservoirs (de Witt 1986). Therefore, organic-poor lithologies like the Port Lambton Group and the green beds of the Kettle Point Formation will typically yield lower gas concentrations, as observed in Figure 22. Clearly, storage capacities in both wells will also be influenced by the organic content (Figure 23).

Interestingly, for samples deeper than 110 m in the OGS-SG10-01 well, total gas content does not correlate well with the gamma-ray content (*see* Figure 22). All these samples have lower gas content than what would be expected considering their total organic carbon and/or gamma-ray signal. Indeed, samples situated at depths shallower than 110 m tend to align along a trend line when comparing measured gas content versus gamma-ray (Figure 24). This can probably be explained by the presence of saline fluids at depth inhibiting or at least limiting the microbial production of gas. The gas observed at depth may be composed of a greater proportion of thermogenic gas.

Another hypothesis to explain the increase of gas content at the top of the Kettle Point Formation would be the presence of the Port Lambton Group, which presents low permeability values and could act as a cap rock and explain the high gas content. In the OGS-SG10-02 well, less variations in gamma-ray, organic and gas contents are observed and there seems to be less correlation between gamma-ray and gas content, as well. Moreover, no decrease in gas content is noticed at greater depths.

Gas content is not only dependent on organic matter. Fine-grained rocks have low permeability and primary porosity values. Hydrocarbon migration is therefore limited by the size of pores and micro fractures. As shown in Figure 25, permeability and gas saturation are positively correlated, inferring a limiting effect of permeability over gas saturation.

Finally, iron sulphide mineral content also does seem to positively affect gas storage capacity and even oil saturation (Figure 26). One possibility to explain such a link might be attributed to the reservoir capacity of the iron sulphide minerals. Indeed, previous studies have identified that pores can be associated with framboidal pyrite (Loucks, Reed et al. 2009; Loucks, Ruppel et al. 2011). However, scanning electron microscope work has not been conducted on these samples to support this hypothesis.

POSSIBILITY OF A THERMOGENIC SIGNAL

Initial isotopic data of methane indicates a strong biogenic influence. However, by only examining Figure 16, it is difficult to confirm or refute the presence of thermogenic gas in samples CANISTER-KP2-06 and CANISTER-KP2-13. Furthermore, there is strong evidence that thermogenic gas is present within the formation. Thermogenic gas is demonstrated by a higher proportion ($\leq 32.36\%$) of heavier hydrocarbon and greater calorific values in the OGS-SG10-02 well, as indicated in Tables 17 and 18. Also, on a



Figure 22. Geological, gamma-ray, total gas content and total organic carbon logs for both OGS-SG10-01 and OGS-SG10-02 drill holes. See Figure 9 for description of geological log. Abbreviations: GAPI, American Petroleum Institute gamma-ray units; scf, standard cubic feet; TOC, total organic content.



Figure 23. Total organic carbon versus storage capacity.



Figure 24. Gamma-ray versus measured desorbed gas plot for OGS-SG10-01 well. The linear trend line presented reflects only the samples shallower than 110 m deep. Abbreviations: GAPI, American Petroleum Institute gamma-ray units; scf, standard cubic feet.



Figure 25. Matrix permeability (as received) in log scale versus gas saturation graph. The solid trend line ($R^2 = 0.94$) is exponential while the dashed trend line ($R^2 = 0.89$) is linear. Abbreviation: mD, millidarcy.



Figure 26. Pyrite and marcasite versus oil saturation and versus storage capacity. Trend lines in both graphs are linear. Abbreviation: scf, standard cubic feet.

 $C_1/(C_2+C_3)$ versus $\delta^{13}C_{C1}$ diagram (Figure 27), all samples from both wells seem to have a strong thermogenic influence. Similarly, a thermogenic signal has also been identified in the Antrim Shale in Michigan and in organic-rich Devonian shale in northern Appalachian Basin (Martini et al. 2003; Osborn and McIntosh 2010). In both basins, the authors concluded that the signature observed was a result of mixing between thermogenic and microbial gas (Osborn and McIntosh 2010). To determine the possibility of the presence of oxidation of methane into carbon dioxide, additional isotopic analyses of heavier hydrocarbons like ethane and propane would be needed.

Where microbial gas production is present, it seems to originate from within the Kettle Point Formation. This is supported by the fact that microbial gas is present in water wells, mainly in the area underlain by the Kettle Point Formation and throughout the section of the OGS-SG10-01 well (McIntosh et al. 2012; Carter, Fortner and Clark 2008). However, the origin of the thermogenic gas is ambiguous. First, the thermogenic gas could originate directly from the Kettle Point Formation. On the other hand, the limited available maturation data tends to indicate that the Kettle Point Formation is immature to early mature and therefore can produce only limited quantities of thermogenic gas (Obermajer 1997; Samson 2007). Secondly, the gas could have migrated vertically from a deeper more thermally mature horizon. Indeed, the presence of a major fault has been identified close to the location of the OGS-SG11-02 well (Figure 28). Deeper thermogenic gas could originate from the Silurian Salina Group or Guelph Formation or from Ordovician reservoirs, as both Silurian and Ordovician natural gas pools have been identified in the study area (Carter et al. 2006).



Figure 27. $\delta^{13}C_{C1}$ versus $C_1/(C_2+C_3)$ diagram presenting isotopic and concentration methane data from both OGS drill holes. Fields associated with thermogenic and biogenic are from Osborn and McIntosh (2010). Abbreviations: C_1 , methane; C_2 , ethane; C_3 , propane.



Figure 28. Location of both drilling sites and identified subsurface faults (modified from Armstrong and Carter 2010).

Conclusions

There were significant differences in most of the key parameters (e.g., gas content, permeability, porosity, adsorption isotherm, fractures, methane isotopes and rock mechanics) between the 2 OGS wells. This was surprising given that the wells are located only 20 km apart. For instance, the OGS-SG10-01 well exhibits mostly a biogenic gas signature, probably explaining why the greatest gas content values are found at shallow depth. Similarly, in Michigan, the Antrim Shale produces microbial gas mostly at shallower depths. At depth, biogenic gas production is inhibited by the presence of saline water. As for the OGS-SG11-02 well, the methane isotopic signature indicates a biogenic signal but with some thermogenic mixing. This thermogenic component may originate from the Kettle Point Formation or may have migrated from a deeper reservoir. Indeed, the presence of a major fault and Ordovician and Silurian

hydrocarbon pools has been identified close to the location of the OGS-SG11-02 well. The presence and location of regional faults could also explain the different fracture patterns observed in both wells.

The Kettle Point Formation yields good hydrocarbon saturations (up to 18.8% of oil and 54% of gas saturations) and good porosity (up to 12.45%) values. However, compared to other Devonian rocks in eastern North America, the unit is much thinner and can yield high water saturation values (up to 85%). Also, initial data suggests lower gas content compared to other Devonian rocks. Still, additional samples should be collected and analysed, especially from the offshore portion of the unit, where the Kettle Point is thicker and at a lower elevation. As an economical consideration, the Kettle Point Formation is found close to the petrochemical industry located in Sarnia and to market.

Future work is needed to enhance our understanding of the Kettle Point Formation and its various parameters related to gas. This should include additional gas samples to investigate regional signals of biogenic versus thermogenic gas. Additional gas analyses should include isotopic analysis of ethane and propane. More work could also be performed on current samples, such as scanning electron microscopy (SEM) to study the microporosity and confirm where the hydrocarbons are found within the shale porosity. Regional fracture and hydrogeological studies are also required to identify areas with most gas content and to understand its interaction with groundwaters. In addition, the gas potential of the Kettle Point Formation situated under Lake Erie has not been studied, even if this area presents thicknesses greater than 90 m (*see* Figure 2). Also, gas shows within the formation have been identified (*see* Figure 21). Therefore, the Kettle Point Formation located under Lake Erie should be studied further.

In conclusion, the Kettle Point Formation can be classified mainly as a source of biogenic gas.

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Appendix

Tables

Well Licence	Well Name	Longitude	Latitude	Stratigraphy	Interval Sampled (m)
T000036	Kewanee Pelee No.5, Lake Erie 350 - E -	41.90699	-82.23601	KP Fm	61-64
T004180	Consumers' 13379, Lake Erie 243 - C -	42.16327	-81.54660	KP Fm	125-128
T006230	Consumers' 13831, Lake Erie 156 - N-3 -	42.36783	-80.81609	KP Fm	120-123
T006555	Cons/Pembina 13872, Lake Erie 181 - N -	42.29801	-81.21881	KP Fm	117-120
T007607	Telesis 13926, Lake Erie 126 - A-4 -	42.48890	-80.33666	KP Fm	84-87
T007671	Telesis 13929, Lake Erie 281 - F -	42.06667	-81.82819	KP Fm	93-96
T011541	Liberty Torque #2, Sombra 4 - 2 - XII	42.72583	-82.45158	KP Fm	116-119

Table 1. Drill cuttings samples collected at the OGSR Library and analysed for total organic carbon and Rock-Eval⁶ pyrolysis. Geographic Datum is NAD83. Well licence numbers are issued by Ontario Ministry of Natural Resources (MNR).

Abbreviation: KP Fm, Kettle Point Formation

Sample		Depth		Т	otal Gas		Gas Con	nposition		
CANISTER- KP1-	Lithology	Interval (m)	Lost	Desorbed	Measured Residual	Projected Residual	Average	Isotopes	Adsorption Isotherms	ROCK Mechanics
01	PL Gr	50.75 - 51.05	Х	Х		Х	Х			
02	PL Gr	54.22 - 54.53	Х	Х	Х	Х				
03	KP Fm / PL Gr	57.27 - 57.58	Х	Х		Х				
04	KP Fm	61.87 - 62.18	Х	Х		Х	Х	Х	Х	
05	KP Fm	64.89 - 65.20	Х	Х	Х	Х				
06	KP Fm	67.76 - 68.06	Х	Х		Х				
07	KP Fm	70.93 - 71.29	Х	Х		Х	Х			
08	KP Fm	73.79 - 74.10	Х	Х	Х	Х				
09	KP Fm	76.87 - 77.18	Х	Х		Х				
10	KP Fm	78.43 - 78.73	Х	Х		Х	Х			
11	KP Fm	83.00 - 83.30	Х	Х	Х	Х				
12	KP Fm	86.14 - 86.44	Х	Х		Х				
13	KP Fm	89.18 - 89.49	Х	Х		Х	Х		Х	
14	KP Fm	92.23 - 92.54	Х	Х	Х	Х				
15	KP Fm	97.26 - 97.57	Х	Х	Х	Х				
16	KP Fm	100.28 - 100.58	Х	Х		Х	Х	Х		
17	KP Fm	103.36 - 103.66	Х	Х	Х	Х				
18	KP Fm	106.38 - 106.68	Х	Х		Х	Х			
19	KP Fm	109.45 - 109.76	Х	Х	Х	Х				
20	KP Fm	112.47 - 112.78	Х	Х		Х				Х
21	KP Fm	115.46 - 115.76	Х	Х	Х	Х				
22	KP Fm	118.57 - 118.87	Х	Х		Х				
23	KP Fm	121.62 - 121.92	Х	Х		Х	Х		Х	
24	KP Fm	124.63 - 124.94	Х	Х	Х	Х				
25	KP Fm	127.35 - 127.65	Х	Х		Х				
26	KP Fm	130.76 - 131.06	Х	Х		Х				Х
27	KP Fm	133.81 - 134.11	Х	Х		Х	Х	Х		
28	KP Fm	136.82 - 137.13	Х	Х		Х				

Table 2. Canister samples and analyses performed for the OGS-SG10-01 well.

Abbreviations: KP Fm, Kettle Point Formation; PL Gr, Port Lambton Group.

Sample		Depth		Т	otal Gas		Gas Con	nposition	Adsorption	Dook
CANISTER- KP2-	Stratigraphy	Interval (m)	Lost	Desorbed	Measured Residual	Projected Residual	Average	Isotopes	Isotherms	Mechanics
01	KP Fm	22.19 - 22.49	Х	Х		Х	Х			
02	KP Fm	23.47 - 23.77	Х	Х	Х	Х				Х
03	KP Fm	27.13 - 27.43	Х	Х		Х	Х		Х	
04	KP Fm	30.18 - 30.48	Х	Х		Х				
05	KP Fm	33.22 - 33.53	Х	Х		Х				
06	KP Fm	35.94 - 36.24	Х	Х		Х	Х	Х		
07	KP Fm	40.84 - 41.15	Х	Х	Х	Х				
08	KP Fm	43.89 - 44.20	Х	Х		Х				
09	KP Fm	46.63 - 46.94	Х	Х	Х	Х				
10	KP Fm	49.53 - 49.53	Х	Х		Х	Х			
11	KP Fm	53.04 - 53.34	Х	Х		Х			х	
12	KP Fm	55.72 - 56.02	Х	Х	Х	Х				
13	KP Fm	59.01 - 59.31	Х	Х		Х	Х	Х		
14	KP Fm	62.15 - 62.45	Х	Х		Х				
15	KP Fm	65.11 - 65.41	Х	Х		Х				
16	KP Fm	68.12 - 68.43	Х	Х		Х	Х			
17	KP Fm	71.32 - 71.63	Х	Х	Х	Х				
18	KP Fm	74.37 - 74.68	Х	Х		Х				
19	KP Fm	75.44 - 75.74	Х	Х	Х	Х	Х			
20	KP Fm	78.82 - 79.13	Х	Х		Х			Х	
21	KP Fm	82.05 - 82.36	Х	Х		Х				Х
22	KP Fm	85.04 - 85.34	Х	Х	Х	Х	Х			
23	KP Fm	88.06 - 88.36	Х	Х		Х				
24	KP Fm	90.86 - 91.17	Х	Х	Х	Х				
25	KP Fm	94.27 - 94.58	Х	Х	Х	Х				
26	KP Fm	97.32 - 97.63	Х	Х		Х	Х	Х		
27	KP Fm	100.31- 100.61	Х	Х		Х				

Table 3. Canister samples and analyses performed for the OGS-SG10-02 well.

Abbreviation: KP Fm, Kettle Point Formation.

Sample CORE-KP1-	Stratigraphy	Depth (TOC, Rock-Eval ⁶ Pyrolysis) (m)	Depth Interval (GRI, XRD, Thin sections) (m)	Total Organic Carbon	Rock- Eval ⁶ Pyrolysis	GRI Analyses	XRD	Thin sections
01A	KP Fm	138.58		Х	Х			
02A	KP Fm	136.75		Х	Х			
03A	KP Fm	133.73		Х	Х			
03B	KP Fm		133.44 - 133.75			Х		Х
04A	KP Fm	130.71		Х	Х			
05A	KP Fm	127.74		Х	Х			
06A	KP Fm	124.56		Х	Х			
07A	KP Fm	121.23		Х				
07B	KP Fm		121.25 - 121.55			Х	Х	Х
08A	KP Fm	118.49		Х	Х			
09A	KP Fm	115.39		Х	Х			
10A	KP Fm	112.45		Х	Х			
11A	KP Fm	109.42		Х				
12A	KP Fm	106.05		Х	Х			
12B	KP Fm		106.07 - 106.38			Х		Х
13A	KP Fm	103.33		Х	Х			
14A	KP Fm	100.25		Х	Х			
15A	KP Fm	97.23		Х	Х			
16A	KP Fm	95.33		Х	Х			
17A	KP Fm	92.20		Х	Х			
18A	KP Fm	88.87		Х				
18B	KP Fm		88.91 - 89.22			Х	Х	Х
19A	KP Fm	86.11		Х	Х			
20A	KP Fm	82.98		Х	Х			
21A	KP Fm	79.93		Х	Х			
22A	KP Fm	76.86		Х	Х			
23A	KP Fm	73.46		Х	Х			
23B	KP Fm		73.49 - 73.79			Х		Х
24A	KP Fm	70.92		Х	Х			
25A	KP Fm	67.74		Х	Х			
26A	KP Fm	64.87		Х	Х			
27A	KP Fm	61.24		Х				
27B	KP Fm		61.27 - 61.57			Х	Х	Х
28A	KP Fm	58.78		Х	Х			
29A	PL Gr	53.90		Х	Х			
29B	PL Gr		53.92 - 54.22			Х	Х	Х
30A	PL Gr	51.08		Х	Х			

Table 4. Core samples and analyses performed for the OGS-SG10-01 well.

Abbreviations: GRI, Gas Research Institute; KP Fm, Kettle Point Formation; PL Gr, Port Lambton Group; TOC, total organic carbon; XRD: Xray diffraction.

Sample CORE-KP2-	Stratigraphy	Depth (TOC, Rock-Eval ⁶ Pyrolysis) (m)	Depth Interval (GRI, XRD, Thin sections) (m)	Total Organic Carbon	Rock- Eval ⁶ Pyrolysis	GRI Analyses	XRD	Thin sections
01A	KP Fm	100.78		Х	Х			
02A	KP Fm	96.98		Х	Х			
02B	KP Fm		97.02 - 97.32			Х	Х	Х
03A	KP Fm	94.23		Х	Х			
04A	KP Fm	90.98		Х	Х			
05A	KP Fm	88.06		Х	Х			
05B	KP Fm		87.75 - 88.06			Х		Х
06A	KP Fm	85.01		Х	Х			
07A	KP Fm	82.01		Х	Х			
08A	KP Fm	71.30		Х	Х			
09A	KP Fm	68.07		Х	Х			
10A	KP Fm	61.65		Х	Х			
10B	KP Fm		61.66 - 61.97			Х		Х
11A	KP Fm	58.67		Х				
11B	KP Fm		58.71 - 59.01			Х		Х
12A	KP Fm	55.68		Х	Х			
13A	KP Fm	53.01		Х				
13B	KP Fm		53.05 - 53.35			Х		
14A	KP Fm	49.45		Х	Х			
15A	KP Fm	78.74		Х				
15B	KP Fm		78.43 - 78.73			Х	Х	Х
16A	KP Fm	75.41		Х	Х			
17A	KP Fm	65.07		Х	Х			
18A	KP Fm	43.82		Х	Х			
19A	KP Fm	35.61		Х	Х			
19B	KP Fm		35.63 - 35.94			Х		Х
20A	KP Fm	46.56		Х	Х			
21A	KP Fm	30.15		Х	Х			
22A	KP Fm	33.20		Х	Х			
23A	KP Fm	27.13		Х				
23B	KP Fm		26.82 - 27.13			Х	Х	Х
24A	KP Fm	40.79		Х	Х			
25A	KP Fm	37.97		Х	Х			

 Table 5. Core samples and analyses performed for the OGS-SG10-02 well.

Abbreviations: GRI, Gas Research Institute; KP Fm, Kettle Point Formation; TOC, total organic carbon; XRD: Xray diffraction.

Table 6. Standard GRI (Gas Research Institute) results for samples collected from the OGS-SG10-01 well.

						CORE-KP1-			
			29B	27B	23B	18B	12B	07B	03B
	Stratigraphy		PL Gr	KP Fm					
	Depth Interval	(m)	53.92 - 54.22	61.27 - 61.57	73.49 - 73.79	88.91 - 89.22	106.07 - 106.38	121.25 - 121.55	133.44 - 133.75
	Bulk Density	(g/cm ³)	2.662	2.180	2.345	2.604	2.453	2.355	2.371
As Received	Matrix Permeability ⁽¹⁾	(mD)	1.51×10 ⁻⁸	3.33×10 ⁻⁶	1.40×10 ⁻⁶	7.70×10 ⁻⁶	7.56×10 ⁻⁹	1.43×10 ⁻⁶	1.27×10 ⁻⁶
	Gas-filled Porosity	(%)	0.65	3.69	2.62	5.38	0.48	2.32	3.25
	Gas Saturation	(%)	9.4	36.8	29.9	50.0	9.4	33.7	43.2
(2)	Grain Density	(%)	2.792	2.353	2.503	2.857	2.537	2.482	2.518
ı Starl ditions	Matrix Permeability ⁽³⁾	(mD)	1.66×10 ⁻⁴	1.11×10 ⁻⁴	1.11×10 ⁻⁵	1.42×10 ⁻⁵	1.51×10 ⁻⁵	3.16×10 ⁻⁶	5.41×10 ⁻⁶
Conc	Porosity	(%)	6.94	10.04	8.74	10.76	5.14	6.91	7.52
and D icted C	Oil Saturation ⁽⁴⁾	(%)	0.0	4.1	6.4	2.3	5.0	14.6	6.5
Dry Extra	Water Saturation ⁽⁵⁾	(%)	90.6	59.1	63.6	47.8	85.6	51.7	50.3

⁽¹⁾ Matrix Permeability is an effective gas permeability (k_g) determined from pressure decay results on the fresh, crushed, 20/35 mesh size sample.

⁽²⁾ Dean Stark extracted sample (20/35 mesh size) dried at 110°C. Porosity and saturations are relative to total interconnected pore space.

⁽³⁾ Matrix Permeability is determined from pressure decay results on the extracted, crushed, 20/35 mesh size sample.

⁽⁴⁾ Oil volume computed assuming an oil density of 0.8 g/cc.

⁽⁵⁾ Water volume corrected assuming a brine concentration of 30 000 ppm NaCl with an ambient density of 1.018 g/cc.

Abbreviations: KP Fm, Kettle Point Formation; mD, millidarcy; PL Gr, Port Lambton Group.

						CORE	с-КР2-			
			23B	19B	13B	11B	10B	15B	5B	02B
	Stratigraphy		KP Fm							
	Depth Interval	(m)	26.82 - 27.13	35.63 - 35.94	53.05 - 53.35	58.71 - 59.01	61.66 - 61.97	78.43 - 78.73	87.75 - 88.06	97.02 - 97.32
	Bulk Density	(g/cm ³)	2.237	2.296	2.516	2.408	2.549	2.398	2.333	2.282
As Received	Matrix Permeability ⁽¹⁾	(mD)	1.76×10 ⁻⁵	6.09×10 ⁻⁷	1.52×10 ⁻⁶	1.01×10 ⁻⁶	1.91×10 ⁻⁶	1.74×10 ⁻⁶	4.96×10 ⁻⁷	3.79×10 ⁻⁶
	Gas-filled Porosity	(%)	6.73	2.70	2.51	3.05	3.98	3.24	1.76	3.01
	Gas Saturation	(%)	54.0	33.2	30.7	33.2	32.2	37.2	29.2	41.9
3	Grain Density	(%)	2.490	2.440	2.678	2.583	2.811	2.567	2.439	2.415
ı Starl ditions	Matrix Permeability ⁽³⁾	(mD)	1.80×10 ⁻⁴	1.07×10 ⁻³	6.50×10 ⁻⁵	1.82×10-3	2.63×10-3	1.04×10 ⁻⁵	5.28×10-5	8.38×10 ⁻⁶
Dear	Porosity	(%)	12.45	8.13	8.19	9.20	12.37	8.71	6.03	7.2
y and] acted (Oil Saturation ⁽⁴⁾	(%)	6.0	5.4	3.8	2.2	0.0	8.3	18.8	13.0
Dr	Water Saturation ⁽⁵⁾	(%)	39.9	61.4	65.5	64.6	67.8	54.5	52.0	45.1

Table 7. Standard GRI (Gas Research Institute) data for samples collected from the OGS-SG10-02 well.

⁽¹⁾ Matrix Permeability is an effective gas permeability (k₈) determined from pressure decay results on the fresh, crushed, 20/35 mesh size sample.

⁽²⁾ Dean Stark extracted sample (20/35 mesh size) dried at 110°C. Porosity and saturations are relative to total interconnected pore space.

⁽³⁾ Matrix Permeability is determined from pressure decay results on the extracted, crushed, 20/35 mesh size sample.

⁽⁴⁾ Oil volume computed assuming an oil density of 0.8 g/cc.

⁽⁵⁾ Water volume corrected assuming a brine concentration of 30 000 ppm NaCl with an ambient density of 1.018 g/cc.

Abbreviations: KP Fm, Kettle Point Formation; mD, millidarcy; PL Gr, Port Lambton Group.

Table 8. Rock-Eval ⁶ pyrolysis data (S_1 , S_2 , S_3 and T_{max}) for samples from the OGS-SG10-01 well (HC: hydr	ocarbon). See text
for explanation of parameters.	

Sample	Stratigraphy	Depth	Total Organic Carbon	S_1	S_2	S_3	T _{max}
CORE-KP1-		(m)	(wt %)	(mg _{HC} /g _{Rock})	(mg _{HC} /g _{Rock})	(mg _{CO2} /g _{Rock})	(°C)
30A	PL Gr	51.08	0.30	0.01	0.14	0.58	438
29A	PL Gr	53.90	0.27	0.01	0.11	0.65	432
28A	KP Fm	58.78	9.50	1.33	44.34	0.37	426
27A	KP Fm	61.24	11.17				
26A	KP Fm	64.87	7.68	1.44	42.34	0.33	432
25A	KP Fm	67.74	8.27	1.46	45.42	0.36	431
24A	KP Fm	70.92	6.91	1.37	37.57	0.33	432
23A	KP Fm	73.46	7.11	1.46	35.69	0.40	426
22A	KP Fm	76.86	5.93	1.18	30.77	0.32	432
21A	KP Fm	79.93	4.95	1.01	24.52	0.30	431
20A	KP Fm	82.98	5.00	1.03	25.03	0.38	429
19A	KP Fm	86.11	2.12	0.31	6.91	0.24	436
18A	KP Fm	88.87	0.39				
17A	KP Fm	92.20	1.40	0.18	3.00	0.49	439
16A	KP Fm	95.33	6.07	1.31	29.96	0.25	430
15A	KP Fm	97.23	6.57	1.57	35.91	0.27	432
14A	KP Fm	100.25	3.78	0.83	17.46	0.39	431
13A	KP Fm	103.33	3.85	0.91	20.01	0.41	433
12A	KP Fm	106.05	7.58	2.09	47.16	0.33	435
11A	KP Fm	109.42	8.67				
10A	KP Fm	112.45	4.84	1.40	26.35	0.36	429
9A	KP Fm	115.39	4.25	1.21	21.27	0.34	429
8A	KP Fm	118.49	5.77	1.78	29.94	0.36	426
7A	KP Fm	121.23	9.22				
6A	KP Fm	124.56	9.05	2.89	48.02	0.48	424
5A	KP Fm	127.74	7.91	2.13	50.91	0.32	435
4A	KP Fm	130.71	6.47	1.69	36.97	0.33	427
3A	KP Fm	133.73	7.69	1.68	55.57	0.32	440
2A	KP Fm	136.75	8.49	2.65	46.95	0.22	428
1A	KP Fm	138.58	2.19	0.43	9.53	0.22	434

Sample	Stratigraphy	Depth	Production Index	Hydrogen Index	Oxygen Index	Pyrolyzable Carbon
CORE-KP1-		(m)		$(mg_{\rm HC}/g_{\rm TOC})$	(mg_{CO2}/g_{TOC})	(wt %)
30A	PL Gr	51.08	0.09	47	193	0.04
29A	PL Gr	53.90	0.10	41	241	0.04
28A	KP Fm	58.78	0.03	467	4	3.84
27A	KP Fm	61.24				
26A	KP Fm	64.87	0.03	551	4	3.67
25A	KP Fm	67.74	0.03	549	4	3.93
24A	KP Fm	70.92	0.04	544	5	3.27
23A	KP Fm	73.46	0.04	502	6	3.12
22A	KP Fm	76.86	0.04	519	5	2.68
21A	KP Fm	79.93	0.04	495	6	2.15
20A	KP Fm	82.98	0.04	501	8	2.20
19A	KP Fm	86.11	0.04	326	11	0.62
18A	KP Fm	88.87				
17A	KP Fm	92.20	0.06	214	35	0.29
16A	KP Fm	95.33	0.04	494	4	2.63
15A	KP Fm	97.23	0.04	547	4	3.14
14A	KP Fm	100.25	0.05	462	10	1.55
13A	KP Fm	103.33	0.04	520	11	1.76
12A	KP Fm	106.05	0.04	622	4	4.12
11A	KP Fm	109.42				
10A	KP Fm	112.45	0.05	544	7	2.33
9A	KP Fm	115.39	0.05	500	8	1.90
8A	KP Fm	118.49	0.06	519	6	2.66
7A	KP Fm	121.23				
6A	KP Fm	124.56	0.06	531	5	4.27
5A	KP Fm	127.74	0.04	644	4	4.44
4A	KP Fm	130.71	0.04	571	5	3.25
3A	KP Fm	133.73	0.03	723	4	4.79
2A	KP Fm	136.75	0.05	553	3	4.15
1A	KP Fm	138.58	0.04	435	10	0.85

Table 9. Production index, hydrogen index, oxygen index and pyrolyzable carbon data from Rock-Eval⁶ pyrolysis of samples from the OGS-SG10-01 well (HC: hydrocarbon; TOC: total organic carbon).

Sample	Stratigraphy	Depth	Total Organic Carbon	S_1	S_2	S ₃	T _{max}
CORE-KP2-		(m)	(wt %)	(mg_{HC}/g_{Rock})	(mg _{HC} /g _{Rock})	(mg _{CO2} /g _{Rock})	(°C)
23A	KP Fm	27.13	9.87				
21A	KP Fm	30.15	4.17	0.72	19.69	0.24	433
22A	KP Fm	33.20	4.61	0.70	22.06	0.25	433
19A	KP Fm	35.61	6.72	1.23	36.74	0.36	435
25A	KP Fm	37.97	7.65	1.47	44.20	0.29	435
24A	KP Fm	40.79	7.63	1.47	41.25	0.30	432
18A	KP Fm	43.82	5.99	1.36	29.56	0.31	427
20A	KP Fm	46.56	6.97	1.53	35.81	0.36	430
14A	KP Fm	49.45	5.29	1.21	25.57	0.36	432
13A	KP Fm	53.01	2.72				
12A	KP Fm	55.68	3.27	0.64	13.06	0.30	433
11A	KP Fm	58.67	5.18				
10A	KP Fm	61.65	0.47	0.05	0.52	0.26	432
17A	KP Fm	65.07	3.95	0.96	19.98	0.27	434
09A	KP Fm	68.07	6.84	1.94	41.56	0.31	435
08A	KP Fm	71.30	5.40	1.58	28.55	0.49	430
16A	KP Fm	75.41	4.84	1.49	26.86	0.30	431
15A	KP Fm	78.74	5.42				
07A	KP Fm	82.01	5.73	1.97	30.44	0.26	431
06A	KP Fm	85.01	5.74	1.85	30.16	0.45	429
05A	KP Fm	88.06	10.15	3.60	58.28	0.32	430
04A	KP Fm	90.98	6.24	1.89	37.10	0.19	432
03A	KP Fm	94.23	6.34	1.79	35.90	0.26	430
02A	KP Fm	96.98	5.46	1.38	30.45	0.27	432
01A	KP Fm	100.78	2.13	0.43	9.11	0.25	432

Table 10. Rock-Eval⁶ pyrolysis data (S_1 , S_2 , S_3 and T_{max}) for samples from the OGS-SG10-02 well (HC: hydrocarbon). *See* text for explanation of parameters.
Sample	Stratigraphy	Depth	Production Index	Hydrogen Index	Oxygen Index	Pyrolyzable Carbon
CORE-KP2-		(m)		(mg _{HC} /g _{TOC})	(mg_{CO2}/g_{TOC})	(wt %)
23	KP Fm	27.13				
21	KP Fm	30.15	0.04	472	6	1.72
22	KP Fm	33.20	0.03	479	5	1.92
19	KP Fm	35.61	0.03	547	5	3.19
25	KP Fm	37.97	0.03	578	4	3.82
24	KP Fm	40.79	0.03	541	4	3.59
18	KP Fm	43.82	0.04	493	5	2.60
20	KP Fm	46.56	0.04	514	5	3.13
14	KP Fm	49.45	0.05	483	7	2.25
13	KP Fm	53.01				
12	KP Fm	55.68	0.05	399	9	1.16
11	KP Fm	58.67				
10	KP Fm	61.65	0.09	111	55	0.06
17	KP Fm	65.07	0.05	506	7	1.76
09	KP Fm	68.07	0.04	608	5	3.64
08	KP Fm	71.30	0.05	529	9	2.54
16	KP Fm	75.41	0.05	555	6	2.38
15	KP Fm	78.74				
07	KP Fm	82.01	0.06	531	5	2.72
06	KP Fm	85.01	0.06	525	8	2.69
05	KP Fm	88.06	0.06	574	3	5.17
04	KP Fm	90.98	0.05	595	3	3.26
03	KP Fm	94.23	0.05	566	4	3.16
02	KP Fm	96.98	0.04	558	5	2.67
01	KP Fm	100.78	0.05	428	12	0.82

Table 11. Production index, hydrogen index, oxygen index and pyrolyzable carbon data from Rock-Eval⁶ pyrolysis of samples from the OGS-SG10-02 well (HC: hydrocarbon; TOC: total organic carbon).

Well Licence Number	Stratigraphy	Depth	Total Organic Carbon	S_1	S_2	S ₃	T _{max}
		(m)	(wt %)	(mg_{HC}/g_{Rock})	(mg_{HC}/g_{Rock})	(mg_{CO2}/g_{Rock})	(°C)
T007607	KP Fm	84 - 87	1.81	0.36	7.06	0.25	432
T006230	KP Fm	120 - 123	3.45	1.09	18.03	0.38	437
T007671	KP Fm	93 - 96	3.70	0.82	19.26	0.79	431
T006555	KP Fm	117 -120	4.68	1.40	23.77	0.40	435
T004180	KP Fm	125 - 128	4.88	1.41	24.84	0.70	436
T000036	KP Fm	61 - 64	5.49	0.91	25.11	0.80	433
T011541	KP Fm	116 - 119	7.28	1.88	36.30	0.60	426

Table 12. Rock-Eval⁶ pyrolysis data (total organic carbon, S_1 , S_2 , S_3 and T_{max}) data for drill cuttings samples from selected wells in southern Ontario (HC: hydrocarbon). *See* text for explanation of parameters.

Table 13. Production index, hydrogen index, oxygen index and pyrolyzable carbon data from Rock-Eval⁶ pyrolysis of drill cuttings from selected wells in southern Ontario (HC: hydrocarbon; TOC: total organic carbon).

Well Licence Number	Stratigraphy	Depth	Production Index	Hydrogen Index	Oxygen Index	Pyrolyzable Carbon
		(m)		(mg_{HC}/g_{TOC})	(mg_{CO2}/g_{TOC})	(wt %)
T007607	KP Fm	84 - 87	0.05	390	14	0.65
T006230	KP Fm	120 - 123	0.06	523	11	1.62
T007671	KP Fm	93 - 96	0.04	521	21	1.73
T006555	KP Fm	117 -120	0.06	508	9	2.14
T004180	KP Fm	125 - 128	0.05	509	14	2.23
T000036	KP Fm	61 - 64	0.03	457	15	2.23
T011541	KP Fm	116 - 119	0.05	499	8	3.23

Sample	Stratigraphy	Depth Interval	Lost Gas Polynomial Fit	Measured Desorbed Gas	Projected Residual Gas	Measured Residual Gas	Total Gas*
CANISTER- KP1-		(m)	(scf/ton)	(scf/ton)	(scf/ton)	(scf/ton)	(scf/ton)
01	PL Gr	50.75 - 51.05	0.9	1.4	0.0		2.3
02	PL Gr	54.22 - 54.53	0.7	1.3	0.0	1.7	3.6
03	KP Fm/PL Gr	57.27 - 57.58	0.4	9.4	0.0		9.8
04	KP Fm	61.87 - 62.18	2.2	18.4	0.0		20.6
05	KP Fm	64.89 - 65.20	0.6	11.1	6.8	7.2	18.9
06	KP Fm	67.76 - 68.06	1.1	14.1	0.0		15.2
07	KP Fm	70.93 - 71.29	1.3	16.2	0.0		17.5
08	KP Fm	73.79 - 74.10	1.9	16.5	6.8	8.3	26.7
09	KP Fm	76.87 - 77.18	1.7	15.9	4.3		21.9
10	KP Fm	78.43 - 78.73	1.9	12.6	1.9		16.4
11	KP Fm	83.00 - 83.30	1.1	11.5	0.0	5.9	18.5
12	KP Fm	86.14 - 86.44	1.6	9.6	0.0		11.3
13	KP Fm	89.18 - 89.49	1.3	2.2	0.0		3.5
14	KP Fm	92.23 - 92.54	1.0	2.0	0.0	1.7	4.8
15	KP Fm	97.26 - 97.57	1.2	7.9	1.1	5.3	14.4
16	KP Fm	100.28 - 100.58	1.0	12.4	0.0		13.4
17	KP Fm	103.36 - 103.66	0.8	11.5	0.0	3.8	16.1
18	KP Fm	106.38 - 106.68	1.6	9.0	0.1		10.7
19	KP Fm	109.45 - 109.76	0.4	10.2	3.1	3.8	14.4
20	KP Fm	112.47 - 112.78	0.4	7.4	0.0		7.8
21	KP Fm	115.46 - 115.76	0.2	4.3	1.5	2.1	6.6
22	KP Fm	118.57 - 118.87	1.3	5.9	1.0		8.1
23	KP Fm	121.62 - 121.92	1.1	4.8	0.9		6.8
24	KP Fm	124.63 - 124.94	0.9	4.5	5.6	8.0	13.4
25	KP Fm	127.35 - 127.65	0.7	3.0	1.2		4.9
26	KP Fm	130.76 - 131.06	0.4	3.0	0.0		3.4
27	KP Fm	133.81 - 134.11	1.2	7.7	0.0		8.9
28	KP Fm	136.82 - 137.13	0.3	3.0	0.0		3.3

Table 14. Gas desorption data for samples collected from the OGS-SG10-01 well.

scf: standard cubic feet.

*Total Gas is the sum of lost gas, desorbed gas and measured residual gas if available. If not, total gas represents the sum of lost gas, desorbed gas and projected residual gas.

Sample	Stratigraphy	Depth Interval	Lost Gas Polynomial Fit	Measured Desorbed Gas	Projected Residual Gas	Measured Residual Gas	Total Gas*
CANISTER- KP2-		(m)	(scf/ton)	(scf/ton)	(scf/ton)	(scf/ton)	(scf/ton)
01	KP Fm	22.19 - 22.49	0.6	6.5	1.4		8.5
02	KP Fm	23.47 - 23.77	0.4	4.8	6.0	6.6	11.7
03	KP Fm	27.13 - 27.43	4.5	9.6	1.3		15.4
04	KP Fm	30.18 - 30.48	3.6	4.4	0.0		8.0
05	KP Fm	33.22 - 33.53	3.0	7.5	0.0		10.5
06	KP Fm	35.94 - 36.24	1.3	8.2	1.1		10.7
07	KP Fm	40.84 - 41.15	1.1	7.8	5.1	5.8	14.6
08	KP Fm	43.89 - 44.20	0.7	11.9	3.0		15.5
09	KP Fm	46.63 - 46.94	0.3	7.9	5.7	5.5	13.7
10	KP Fm	49.53 - 49.83	0.9	7.0	2.1		10.0
11	KP Fm	53.04 - 53.34	1.3	4.7	3.4		9.4
12	KP Fm	55.72 - 56.02	0.8	9.1	3.7	4.5	14.3
13	KP Fm	59.01 - 59.31	1.3	10.5	3.5		15.3
14	KP Fm	62.15 - 62.45	1.8	2.9	2.9		7.7
15	KP Fm	65.11 - 65.41	1.8	8.0	0.7		10.6
16	KP Fm	68.12 - 68.43	1.0	5.0	0.2		6.2
17	KP Fm	71.32 - 71.63	1.1	5.1	7.4	8.6	14.8
18	KP Fm	74.37 - 74.68	0.3	6.6	2.6		9.6
19	KP Fm	75.44 - 75.74	1.1	7.8	1.6	5.9	14.7
20	KP Fm	78.82 - 79.13	2.7	10.2	0.3		13.2
21	KP Fm	82.05 - 82.36	1.1	7.2	0.1		8.3
22	KP Fm	85.04 - 85.34	2.1	5.7	1.2	4.2	12.0
23	KP Fm	88.06 - 88.36	1.0	9.4	0.3		10.7
24	KP Fm	90.86 - 91.17	1.3	7.4	3.4	6.0	14.7
25	KP Fm	94.27 - 94.58	1.7	5.8	5.8	7.4	14.9
26	KP Fm	97.32 - 97.63	3.2	12.6	2.7		18.5
27	KP Fm	100.31-100.61	0.9	10.1	2.5		13.4

Table 15. Gas desorption data for samples collected from the OGS-SG10-02 well.

scf: standard cubic feet

*Total Gas is the sum of lost gas, desorbed gas and measured residual gas if available. If not, total gas represents the sum of lost gas, desorbed gas and projected residual gas.

CANISTER-KP1-CANISTER-KP2-04 23 03 20 13 11 KP Fm KP Fm KP Fm KP Fm KP Fm KP Fm Stratigraphy 53.04 -78.82 -61.87 -89.18 -121.62 -27.13 -**Depth Interval** (m) 62.18 89.49 121.92 53.34 79.13 27.43 (°C) 15 15 15 Temperature 15 15 15 **Corrected Langmuir** (scf/ton) 56.57 1.83 34.05 60.73 6.83 43.96 Storage Capacity **Corrected Langmuir** 288.70 (psia) 183.46 30.33 124.71 188.37 64.68 Pressure **Reservoir Pressure** 88.00 127.00 173.00 39.00 76.00 112.00 (psia) (Midpoint) Adsorbed Phase (g/cm^3) 0.372 0.37 0.37 0.37 0.37 0.37 **Methane Density Storage Capacity** (scf/ton) 18.34 1.48 19.78 10.42 3.69 12.29

Table 16. Adsorption isotherm values for both OGS-SG10-01 (CANISTER-KP1-) and OGS-SG10-02 (CANISTER-KP2-) wells.

scf: standard cubic feet

psia: pounds per square inch absolute

	Sample	Collection	Gas	Incremental	G	as Analysis (A	djusted for A	ir)	Calorific Value	
		Point	Content	Volume	C ₁	C ₂	C3-10	CO ₂	Dry	Saturated
		(hours)	(scf/ton)	(scf/ton)	(mole %)	(mole %)	(mole %)	(mole %)	(Btu/ft ³)	(Btu/ft ³)
e.	CANISTE	R-KP1-01-			96.24	1.37	1.81	0.58	1052.4	1034.1
pto _	А	405.85	1.7	1.7	98.76	0.55	0.18	0.51	1016.4	998.8
me	В	1387.98	1.7	0.0	99.06	0.34	0.25	0.35	1018.1	1000.4
Ë E	С	2059.50	2.0	0.3	83.62	5.45	10.26	0.67	1241.6	1220.0
01	D	2619.97	2.2	0.2	97.63	0.72	0.63	1.02	1022.2	1004.4
Ч	Е	2950.02	2.3	0.1	88.30	4.53	6.60	0.57	1159.4	1139.2
	CANISTE	R-KP1-04-	10.4	10.4	91.54	7.64	0.61	0.21	1081.3	1062.5
	A	402.27	10.4	10.4	93.19	6.22	0.46	0.13	1068.6	1050.0
	В	1050.93	14.9	4.5	91.20	7.85	0.64	0.31	1082.5	1063.7
	С	1701.42	16.7	1.8	89.65	9.45	0.75	0.15	1098.3	1079.2
	D	2616.35	20.1	3.4	88.32	10.46	0.86	0.36	1105.8	1086.6
	E	2946.45	20.6	0.5	89.00	9.71	1.11	0.18	1107.9	1088.6
	CANISTE	R-KP1-07-			89.92	8.09	1.90	0.09	1106.7	1087.5
	A	399.98	9.6	9.6	90.48	7.68	1.76	0.08	1101.1	1082.0
	В	1048.52	13.2	3.6	92.46	6.18	1.28	0.08	1082.0	1063.2
	С	1699.10	14.7	1.5	88.80	8.98	2.10	0.12	1116.8	1097.3
	D	2613.92	17.3	2.6	85.34	11.49	3.06	0.11	1152.2	1132.2
	E	2944.12	17.5	0.2	85.29	11.39	3.21	0.11	1153.7	1133.6
	CANISTE	R-KP1-10-			88.86	8.43	2.62	0.09	1121.6	1102.0
	A	379.87	8.0	8.0	88.14	8.88	2.94	0.04	1130.7	1111.0
	В	1028.28	10.9	2.9	93.72	5.12	1.07	0.09	10/0.3	1051.6
	C	1678.83	12.3	1.4	88.21	8.96	2.70	0.13	1126.6	1107.0
	D	2593.67	14.3	2.0	85.18	11.05	3.53	0.24	1155.4	1135.3
	E	2923.92	14.4	0.1	88.13	9.03	2.75	0.09	1128.4	1108.8
	CANISTE	R-KP1-13-*			85.69	8.89	4.11	1.31	1138.7	1118.9
	A	362.08	2.1	2.1	88.98	7.83	3.14	0.05	1126.2	1106.6
m E	В	1343.92	2.3	0.2	98.99	0.28	0.20	0.53	1014.6	997.0
IT]	D	25/5.82	3.3	1.0	//.83	11.98	6.16	4.03	11/0.6	1150.2
Poi	E	2906.08	3.5	0.2	//.06	13.22	/.96	1./6	1235.0	1213.5
ie]	CANISTE	R-KP1-16-	5.0	5.0	86.54	9.11	4.21	0.14	1153.6	1133.6
ett	A	49.37	5.9	5.9	86.35	8.70	4.94	0.01	1164.4	1144.1
¥	В	355.85	/.3	1.4	84.91	9.36	5.35	0.38	11/3.3	1152.9
	C D	1004.13	10.4	3.1	90.73	7.03	2.18	0.06	1103.7	1084.5
	D	1654.68	11.4	1.0	85.87	10.45	3.66	0.02	1107.1	1135.0
	E	2509.48	13.4	2.0	82.06	12.73	4.09	0.52	1184.8	1104.2
	CANISTE	K-KP1-18-	5 1	5 4	85.52	10.16	4.01	0.31	1127.0	1130.0
	A	354.55	5.4 9.1	5.4 2.7	87.03	8.99	5.30	0.08	1157.0	111/.2
	Б	1652.08	0.1	2.7	02.09 95.21	11.41	2.04	0.33	1163.9	1105.5
		1055.08	9.0	0.9	85.31	10.74	5.94	0.01	1162.0	1141.8
	D	2307.87	10.4	1.4	82.99	11.05	4.45	0.93	1107.8	1147.5
	CANISTE	2090.22 D KD1 23	10.0	0.2	82.01 83.40	10.84	5.15	0.24	1109.5	1108.6
		336.92	27	27	82.40	11.15	5.10 6.41	0.00	1210.4	1180.0
	R	985.02	2.1	07	80.43	13.24	5.87	0.00	1210.4	1189.5
	C	1635.62	4.0	0.7	85 72	9.66	3.07	1 1 5	1134.8	1115.0
	D	2550 33	5.5	1.5	84 19	10 39	3.87	1.15	1141 5	1121 7
	E	2880 77	5.8	03	90.45	7.06	2.25	0.24	1103 5	1084 3
	CANISTE	R-KP1-77- *	2.0	0.0	85 74	10 39	3 51	0.86	1143 3	1123.4
	A	330.82	48	48	86 46	9 84	3 39	0.31	1142 5	1122.7
	B	617.67	53	0.5	85.44	10.18	3.70	0.68	1146.8	1126.9
	D	1629 57	69	1.6	83.95	11.06	3.62	1.37	1145.2	1125.3
	E	2544.10	8.7	1.8	83.09	11.30	3.69	1.92	1142.6	1122.8

Table 17. Hydrocarbon gas composition and calorific data for samples collected from the OGS-SG10-01 well.

* Sample CANISTER-KP1-13C and CANISTER-KP1-27C were air contaminated.

Abbreviations: C₁, methane; C₂, ethane; C₃₋₁₀, propane and heavier hydrocarbons; scf: standard cubic feet; Btu; British thermal units.

		Collection	Gas	Incremental	G	as Analysis (A	diusted for A	ir)	Calori	fic Value
	Sample	Point	Content	Volume	C ₁	C2	C3 10	, CO2	Drv	Saturated
	~ ·····P···	(hours)	(scf/ton)	(scf/ton)	(mole %)	(mole %)	(mole %)	(mole %)	(Btu/ft^3)	(Btu/ft ³)
	CANIST	ER_KP2_01_	(~~~~)	(313,1011)	93.07	4 58	1 46	0.89	1065.0	1046.4
		81 33	15	1.5	91 59	4.30 5.42	2.98	0.01	1106.8	1087.5
	B	668 80	23	0.8	95.33	3.58	0.90	0.19	1054.5	1036.2
	C	1653.03	5.0	27	94 30	435	1.03	0.32	1061.5	1043.0
	D	1968.17	5.0	0.2	94 64	4 36	0.99	0.01	1064.0	1045.5
	F	2884.67	6.8	1.6	91.06	4 69	1.11	3 14	1036.9	1018.8
	CANIST	FR_KP2_03_	0.0	1.0	87.05	9.50	3.16	0.29	1122.8	1103.2
	A	138 47	73	73	85.07	10.51	4 42	0.00	1171.6	1151.2
	B	567.10	9.0	17	90.81	7 53	1.52	0.14	1095.9	1076.8
	C	1217 52	10.9	1.7	93.16	5 39	1.15	0.14	1072.2	1053.5
	D	1866 52	11.9	1.0	86.95	10.52	2.06	0.47	1124.4	1104.8
	E	2782.93	13.6	1.0	85.03	11.13	2.00	1.57	1124.4	1107.0
	CANIST	FR_KP2_06_	15.0	1.7	99.47	0.04	0.07	0.43	1012.0	994 3
		549 23	52	5.2	100.00	0.04	0.00	0.00	1012.0	996.8
	B	1533.38	8.2	3.0	98.86	0.00	0.13	0.00	1009.0	991.5
	C	1848.68	8.4	0.2	99.57	0.03	0.08	0.32	1013.1	995.5
	D	2765.00	0.4	0.2	99.37	0.03	0.08	1.38	1002.9	995.5
	F	3095 73	9.2	0.3	98.47	0.04	0.10	0.44	1025.1	1007.3
	CANIST	FD KD2 10	7.7	0.2	67.57	16.00	16 36	0.44	1429.5	1404.6
		237 30	3.0	39	52 79	20.31	26.90	0.07	16567	1627.8
	R	5/3 38	13	0.4	88.43	8/13	20.90	0.00	1126.7	1107.1
	C	1527.48	4.5 6.5	2.7	85.03	11.00	3.88	0.09	1161.5	11/1 3
	D	1842.80	6.7	0.2	82.82	12.37	4.66	0.15	1185.0	1164.4
	F	2759.07	7.2	0.2	83.25	11.96	4.00	0.13	1176.2	1155.7
<i>.</i> :	CANIST	ED KD2 13	1.2	0.5	85.34	0.34	5.12	0.20	1170.2	1150.7
Εn		176.05	57	57	82 24	10.62	7.13	0.01	1217.2	1196.0
int	B	525.28	6.5	0.8	90.51	5 26	2 43	1.81	1077.9	1059.1
\mathbf{P}_{0}	C	1175 35	9.2	27	91.61	6.11	2.13	0.11	1096.3	1077.2
tle	D	1824.65	10.3	11	84.85	10.87	413	0.15	1164.6	1144.4
Ket	E	2740.93	11.2	0.9	82.13	12.67	4 89	0.31	1190.0	1169.3
	CANIST	ER-KP2-16-	11.2	0.9	84.33	10.91	4.64	0.12	1173.4	1153.0
	A	522.45	2.6	2.6	82.93	11.54	5.52	0.01	1193.4	1172.6
	В	1506.43	4.8	2.2	86.74	9.65	3.47	0.14	1144.4	1124.5
	C	2184.03	5.2	0.4	82.71	12.01	4.90	0.38	1184.8	1164.1
	D	2738.02	5.5	0.3	82.55	11.96	5.01	0.48	1185.6	1165.0
	Е	3068.80	5.9	0.4	83.12	11.84	4.81	0.23	1182.8	1162.3
	CANIST	ER-KP2-19-			75.68	14.50	9.65	0.17	1288.6	1266.2
	А	67.57	4.2	4.2	71.97	14.78	13.08	0.17	1352.0	1328.5
	В	520.55	5.4	1.2	82.78	11.91	5.07	0.24	1187.0	1166.3
	С	1170.38	7.4	2	78.93	14.44	6.52	0.11	1232.0	1210.6
	D	1819.75	8	0.6	80.98	13.42	5.54	0.06	1209.5	1188.4
	Е	2736.12	8.7	0.7	71.96	18.34	9.43	0.27	1312.1	1289.3
	CANIST	ER-KP2-22-			84.15	11.00	4.64	0.21	1178.1	1157.6
	А	504.20	4.4	4.4	84.19	10.94	4.65	0.22	1172.7	1152.3
	В	1488.05	6.4	2	84.60	10.52	4.76	0.12	1172.5	1152.1
	С	2165.67	7	0.6	84.12	11.61	3.96	0.31	1165.8	1145.5
	D	2719.73	7.4	0.4	81.69	12.80	5.12	0.39	1287.5	1265.1
	Е	3050.60	7.6	0.2	83.91	11.75	4.17	0.17	1171.5	1151.1
	CANIST	ER-KP2-26-			72.99	13.87	12.90	0.23	1355.0	1331.4
	Α	71.20	5.7	5.7	54.18	18.58	27.21	0.03	1668.0	1638.9
	В	500.67	11.4	5.7	85.33	10.14	4.09	0.44	1155.6	1135.5
	С	1149.88	14	2.6	82.99	12.09	4.69	0.23	1182.7	1162.1
	D	1799.67	14.4	0.4	82.56	12.70	4.51	0.23	1184.4	1163.7
	Е	2716.12	15.2	0.8	81.86	13.26	4.65	0.23	1191.6	1170.9

Table 18. Hydrocarbon gas composition and calorific data for samples collected from the OGS-SG10-02 well.

* Sample CANISTER-KP1-13C and CANISTER-KP1-27C were air contaminated.

Abbreviations: C_1 , methane; C_2 , ethane; C_{3-10} , propane and heavier hydrocarbons; scf: standard cubic feet; Btu; British thermal units.

		C.	CANISTER-KP1-			CANISTER-KP2-		
		04-B	16-B	27-В	06-B	13-B	26-B	
Depth Interval	(m)	61.87 - 62.18	100.28 - 100.58	133.81 - 134.11	35.94 - 36.24	59.01 - 59.31	97.32 - 97.63	
He	(%)	0.0292	0.0034	0.0034	0.0255	0.0044	0.0063	
H_2	(%)	0	0	0	0	0	0	
Ar	(%)	0.898	0.856	0.886	0.956	0.986	1.000	
O_2	(%)	22.38	18.88	17.02	22.39	22.74	24.49	
CO ₂	(%)	0.100	0.079	0.100	0.100	0.089	0.100	
N_2	(%)	44.21	59.43	67.26	65.64	71.34	51.52	
СО	(%)	0.000	0.000	0.006	0.000	0.000	0.000	

17.69

1.95

0

0.899

0.0658

0.112

0.0225

0.0070

0.0081

-52.90

-305.4

0.933

244

12.67

1.51

0

0.471

0.0253

0.0409

0.0048

0.0037

0.0030

-51.33

-308.7

0.947

170

10.86

0.0102

0

0.0061

0.0020

0.0021

0.0010

0.0016

0.0018

-39.75

-241.1

0.958

111

4.46

0.259

0

0.0966

0.0073

0.0116

0.0018

0.0013

0.0012

-36.89

-269.1

0.986

53

19.61

2.33

0

0.793

0.0552

0.0756

0.0097

0.0043

0.0025

-50.59

-286.5

0.932

265

Table 19. Gas composition for both OGS-SG10-01 (CANISTER-KP1-) and OGS-SG10-02 (CANISTER-KP2-) wells. Sample codes refer to tables 17 and 18.

BTU: British thermal units

 C_1

 C_2

 C_2H_4

 C_3

 iC_4

nC₄

iC5

nC₅

C₆+

 $\delta^{13}C_{C1}$

 δD_{C1}

Specific

Gravity BTU (%)

(%)

(%)

(%)

(%)

(%)

(%)

(%)

(%)

(‰)

(‰)

29.62

2.55

0

0.166

0.0240

0.0139

0.0026

0.0012

0.0009

-54.53

-296.7

0.883

351

				CORE	-KP1-		(CORE-KP2	-
			29B	27B	18B	07B	23B	15B	02B
	Stratigraphy		PL Gr	KP Fm	KP Fm	KP Fm	KP Fm	KP Fm	KP Fm
	Depth Interval	(m)	53.92 - 54.22	61.27 - 61.57	88.91 - 89.22	121.25 - 121.55	26.82 - 27.13	78.43 - 78.73	97.02 - 97.32
	Quartz	(wt %)	50	44	35	51	43	51	44
	Potassium Feldspar	(wt %)	3	3	2	2	2	3	3
	Plagioclase	(wt %)	0	2	3	2	Trace	0	0
	Siderite	(wt %)	6	0	2	0	0	0	0
tock	Calcite	(wt %)	0	0	0	0	2	1	0
'hole R	Dolomite and Fe-Dolomite	(wt %)	0	0	3	2	0	2	1
*	Halite	(wt %)	0	0	0	Trace	0	0	0
	Marcasite	(wt %)	0	3	0	6	4	0	0
	Pyrite	(wt %)	0	4	2	6	4	7	16
	Total Clay	(wt %)	41	44	53	31	45	36	36
	Total	(wt %)	100	100	100	100	100	100	100
	Smectite	(%)	0	0	0	0	0	0	0
y	Illite / Smectite Mixed-Layer Clay	(%)	10	15	12	0	14	0	0
Cla	Illite	(%)	54	66	65	76	66	83	71
tive	Kaolinite	(%)	21	9	10	10	9	7	13
Rela	Chlorite	(%)	15	10	13	14	11	10	16
	Smectite Layers in Illite / Smectite Clay	(%)	20-30	10-20	20-30		10-20		

Table 20. Mineralogical results for both OGS-SG10-01 (CORE-KP1-) and OGS-SG10-02 (CORE-KP2-) wells.

Table 21. Triaxial static Young's modulus, Poisson's ratio and compressive strength results for samples of Kettle Point Formation for both OGS-SG10-01 (CANISTER-KP1-) and OGS-SG10-02 (CANISTER-KP2-) wells.

		CANIST	ER-KP1-	CANIST	ER-KP2-
		20	26	02	21
Depth Interval	(m)	112.47 - 112.78	130.76 - 131.06	23.47 - 23.77	82.05 - 82.36
Confining pressure	(psi)	80	186	34	117
Bulk Density	(g/cm ³)	2.35	2.42	2.22	2.35
Compressive Strength	(psi)	16355	16913	8607	20408
Young's Modulus	(psi)	1.62×10^{6}	1.69×10 ⁶	1.13×10 ⁶	2.19×10 ⁶
Poisson's ratio		0.16	0.14	0.08	0.14

psi: pounds per square inch

Table 22. Acoustic velocities and dynamic moduli and triaxial stress conditions for samples of Kettle Point Formation for both OGS-SG10-01 (CANISTER-KP1-) and OGS-SG10-02 (CANISTER-KP2-) wells. CANISTER-KP1-CANISTER-KP2-20 02 21 26 112.47 - 112.78 130.76 - 131.06 23.47 - 23.77 82.05 - 82.36 **Depth Interval** (m) 186 33.6 116.8 **Confining Pressure** 80 80 186 33.6 116.8 (psi) 2080 4080 186 33.6 3034 117 3117

2.42

9897

6434

 1.40×10^{6}

 3.06×10^{6}

 1.35×10^{6}

0.13

1186

2.42

10027

6480

1.45×10⁶

3.13×10⁶

1.37×10⁶

0.14

2.22

8235

5444

 0.85×10^{6}

 1.97×10^{6}

 0.89×10^{6}

0.11

2.22

8633

5634

0.96×10⁶

 2.14×10^{6}

 0.95×10^{6}

0.13

2.35

10538

6702

1.62×10⁶

3.30×10⁶

 1.42×10^{6}

0.16

2.35

10839

6779

 1.78×10^{6}

3.43×10⁶

 1.46×10^{6}

0.18

Poisson's Ratio	-
psi: pounds per square inch	

Axial Pressure

Compressional

Acoustic Velocity

Acoustic Velocity

Young's Modulus

Bulk Modulus

Shear Modulus

Bulk Density

Shear

(psi)

 (g/cm^3)

(ft/sec)

(ft/sec)

(psi)

(psi)

(psi)

2.35

10004

6360

 1.46×10^{6}

 2.98×10^{6}

 1.28×10^{6}

0.16

Table 23. Comparison table of the various Upper Devonian shale units in northeastern United States.

2.35

10177

6387

 1.56×10^{6}

3.04×10⁶

1.29×10⁶

0.18

	Antrim Shale	New Albany Shale	Ohio Shale	Kettle P	Point Fm.
		Curtis (2002, 200	9)	(Samson 2007)	(Current Study)
Lithology	Black shale	Black shale	Black and grey shale	Black and green shale	Black and green shale
Play type	Biogenic	Thermogenic and biogenic	Thermogenic	Not determined	Biogenic and thermogenic
Richness (wt % TOC)	5 - 15	5 - 20	2 - 6	0 - 12	0 - 11
Maturation (Vr %)	0.6 - 0.7	0.6 - 1.2	0.6 - 1.9	0.4 - 0.7	Not determined
Mineralogy (% non-clay)	55 - 70	50 - 70	45 - 60	45 - 87	47 - 69
Porosity (%)	5 - 12	5 - 12	2 - 6	6.5 - 12	5 - 12.5
Gas-filled porosity (%)	4	5	2.0	0 - 4.4	0.5 - 6.7
Water-filled porosity (%)	4	4 - 8	2.5 - 3.0	0.2 - 2.6	3.1 - 8.4
Thickness (m)	50	55	90 - 300	110*	81*
Depth (m)	150 - 750	300 - 750	750 - 1800	30 - 140	20 - 140
Gas content (scft/ton)	40 - 100	40 - 80	60 - 100	0 - 29 Residual: <90%	2.0 - 26.7 Residual: <60%

*The average Kettle Point Formation thickness averages 30 to 35 m.

Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	Multiplied by	Gives	Imperial Unit	Multiplied by	Gives
		LEN	IGTH		
1 mm	0.039 37	inches	1 inch	25.4	mm
1 cm	0.393 70	inches	1 inch	2.54	cm
1 m	3.280 84	feet	1 foot	0.304 8	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	1.609 344	km
		AR	REA		
1 cm^2	0.155 0	square inches	1 square inch	6.451 6	cm^2
1 m^2	10.763 9	square feet	1 square foot	0.092 903 04	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km ²
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOI	UME		
1 cm^3	0.061.023	cubic inches	1 cubic inch	16.387 064	cm ³
1 m^3	35 314 7	cubic feet	1 cubic foot	0.028 316 85	m ³
1 m^3	1.307 951	cubic vards	1 cubic vard	0.764 554 86	m^3
			ACITY		
1 T	1 759 755	nints	1 nint	0 568 261	T
1 L 1 I	0 879 877	quarts	1 guart	1 136 522	I I
1 L	0.219.969	gallons	1 gallon	4.546.090	L
12	0.219 909	Surrous	A G G	1.0 10 070	Ľ
1 ~	0 025 272 062	NIA (avda)	1 own on (overlap)	28 240 522	~
1 g	0.033 273 902	ounces (avup)	1 ounce (avup)	20.349 323	g
1 g	0.032 150 /4/	ounces (troy)	1 ounce (troy)	31.103 4/6 8	g Ira
1 Kg	2.204 022 0	pounds (avup)	1 pound (avap)	0.453 592 37	кg
I Kg	0.001 102 5	tons (short)	1 ton(short)	907.184 74	кg
1 L 1 L	1.102 311 3	tons (snort)	1 ton (Short)		ا ا
I Kg	0.000 984 21	tons (long)	1 ton (long)		кg
1 t	0.984 200 3	tons (long)	T ton (long)	1.010 040 9	ι
		CONCEN	TRATION		,
1 g/t	0.029 166 6	ounce (troy) /	1 ounce (troy) /	34.285 714 2	g/t
1 /4	0 502 222 22	ton (short)	ton (short)	1 71 4 205 7	4
I g/t	0.583 333 33	pennyweights /	I pennyweight /	1./14/285/	g/t
		ton (short)	ton (snort)		
	O	THER USEFUL CO	NVERSION FACTO	RS	
		Multip	olied by		
1 ounce (troy) per ton (short)			.103 477 grams per ton (short)		
1 g	ram per ton (short)	0.03	0.032 151 ounces (troy) per ton (short)		
1 0	unce (troy) per ton (sh	nort) 20.0	pennyw	reights per ton (short)	
1 p	ennyweight per ton (si	hort) 0.05	ounces	(troy) per ton (short)	

Note: Conversion factors in **bold** type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

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