Natural Gas Potential in the Saint Lawrence Lowlands of Quebec: A Case Study
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Abstract

Since the announcement made in April 2008 concerning the shale gas potential of the Southern Quebec Lowlands, almost 15 new wells have been drilled in the area. The calcareous and organic-rich Middle Ordovician Utica Shale is the main target of this recent exploration effort. Current knowledge of the area’s geology have led operators subdivide the shale gas potential into different play types. To date, most operations have been performed in approximately 1/3 of the shale basin in the medium to deep thermogenic shale gas play (1,000-2,000 meters), located in the central part of the Saint Lawrence Lowlands. With OGIP estimates ranging from 120 to 160 Bcf per section, the deep play is considered to be promising. Current efforts focus on determining the highest gas prone unit within the Utica. The remaining 2/3 of the shale basin has not been largely tested yet, but the potential remains promising.

Based on exploration work carried out over the past five years in Southern Quebec, four other play types have been described: 1) shallow to medium depth thermogenic shale gas; 2) overthrusted shale gas; 3) biogenic shale gas; 4) Intra-Appalachians sub-basin shale gas. They are less explored than the deep shale play, but also present interesting potential.

This paper describes the above mentioned plays using basin geology, shale mineralogy, organic matter type, gas geochemistry, structural style and infrastructure access. The characteristics of the above plays are reviewed from geological, geochemical, structural and production perspectives. Results of evaluations using the concept of flow units, and volumes of original-gas-in-place calculated by various organizations are compared with a recent evaluation using the Petroleum Resources Management System (PRMS).

It is concluded that there is promising hydrocarbon potential in the Saint Lawrence Lowlands of Quebec that continue to stimulate operators to pursue the exploration and development of these plays.

Introduction

Figures 1 shows the location of the study area, Utica shale, Quebec, Canada, relative to other shale basins in North America, particularly the Marcellus and Barnett shales in the United States. Figure 2 shows the stratigraphic column of the study area. The presence of natural gas in Ordovician shales of the Quebec’s Saint Lawrence Lowlands basin has been known for over a century. Odd jobs during the last few decades have shown a certain potential for gas but without achieving any commercial production. It is only in recent years, mainly due to relatively higher natural gas prices in Quebec, and access to new drilling and hydraulic fracturing technologies, that the true potential of Utica gas shales has been demonstrated. Several different scientific and technical studies were needed to evaluate this resource. Results published during the past three years, and the new work presented in this
paper, tend to show that the Utica shale compares favorably with other North American deposits such as the Barnett and Eagleford Shales, located in Texas.

The gas quality, the ability of hydraulically fracturing of the shale, its geographic location and the economic environment in Quebec are all factors that encourage development of this resource.

The gas in place accumulation in the Utica shale is gigantic (multi-Tcf). Effective methods of production are being investigated directly in the Utica shale and by careful examination of analogues in other regions particularly in the United States. Although all shale basins are different, the premises to assess them are essentially the same and include a clear understanding of:

- Basin geology
- Shale mineralogy
- Organic matter type
- Gas geochemistry
- Structural style
- Reservoir parameters
- Pilot wells, resources and reserves
- Infrastructure

Five shale gas plays in Southern Quebec (Figure 3) have been studied based on the above parameters:

1) Medium to deep thermogenic shale gas;
2) Shallow to medium depth thermogenic shale gas;
3) Deep shale and overthrusted shale gas;
4) Biogenic shale gas;
5) Intra-Appalachians sub-basin shale gas.

The most studied shale gas play in the Saint Lawrence Lowlands at this time is the medium to deep thermogenic shale. The play is now in a transition stage between exploration and drilling of pilot wells. Although the project’s development seems slower vis-a-vis other basins, work is progressing satisfactorily and positive results have been obtained over the last year.

**Basin Geology of the Quebec Lower Paleozoic Shale Gas Play**

**Figure 4** shows a schematic cross-section of key geologic elements in Southern Quebec, which are explained in the next sections.

**Calcareous and Organic-Rich Middle Ordovician Utica Shale**

The Utica Group belongs to the Saint Lawrence Lowlands geological province, a sedimentary basin formed during the Early Paleozoic time. Sedimentation starts at the Lower Cambrian time and continue until Devonian time. The Grenville Province, in the eastern part of the Laurentia continental shelf, is the basement of the basin. At present day, Silurian and Devonian rocks have been eroded in the basin. The calcareous and organic-rich Utica shales are Ordovician age marine shales deposited on top of the massive Trenton limestone sequence. The shales were deposited during the Taconic Orogeny, the result of the collision between the Laurentia shelf and a volcanic arc. At that time (455 to 445 Ma), a close sea, rich in organic matter, was forming at the equator latitudes, starting the regression of the Early Paleozoic Iapetus ocean. The Utica shales are time and lithological equivalent to the Ontario's Collingwood and Blue Mountain shales, and also to the eastern Quebec's offshore MacAsty shales in the Gulf of St. Lawrence. A typical description of the Utica shales includes about 100 meters of graptolitic, brownish, organic rich and laminated calcareous mudstone. In some parts of the basin, there is an unconformity contact between the Utica and the underlying Trenton Limestone. The maximal vertical extent of the Utica is 300 meters.

**Clastic Middle Ordovician Lorraine Shale**

While the Taconic orogeny evolves, the Utica shales were covered by a younger and more clastic sedimentary sequence, the Lorraine Group. This argillaceous mudstone is thick, reaching more than 3,000 meters in the central part of the St-Lawrence Lowlands. The basal unit of the Lorraine shales is the Nicolet Formation with a maximal vertical extent of 750 meters. The Nicolet shales are gray, quartzitic, slightly calcareous, and bioturbated. In some parts of the basin, the organic richness of the Nicolet
shales is far larger than in the Utica, implying a geographic displacement of the anoxic zone over time. The upper sequence of the Lorraine Shale is a gray non calcareous flysh deposition mixing siltstone, fine grain sandstone, shales and dolomites. There are some local evidences of an unconformity at the contact between the Utica Shale and the Lorraine Shale (Smith, 2009; Theriault, 2009).

Other Lower Paleozoic Sedimentary Basins of Southern Quebec

Several Ordovician shales with different names are described at the front of the Taconic belt. Bourret shales, Pointe-Aubin shales or Laurier shales form lithological and stratigraphic time-equivalent shales deposited somewhere between the evolving Taconic front and a distal sedimentary environment. In comparison to the Utica, these shales are often calcareous but organic-richer and less mature in term of sedimentation rapid exhumation.

Two shales units are found in the Intra-Appalachian basin; the Beauceville shales from the Middle Ordovician Magog Group and some un-named shales units in the Lower Devonian Saint-Francis Group. Very few studies have been completed on these shales. The Beauceville shale is an organic-rich quartzitic black shale, while the shales from the Saint-Francis Group are silty and argillaceous. More sampling and exploration work will be needed to obtain a better evaluation on the geology of these shales.

Structural Style of Southern Quebec Sedimentary Basins

Between its north-west limits, the Grenville Province and the Taconic Front (equivalent to the Logan Line shown on Figure 3), the Saint Lawrence Lowlands present a monoclinal structure dipping to the south-east. The basin is divided by normal faults oriented SW-NE. Large blocks of unfaulted rocks with rhomboedric shape are typical of this part of the basin, where the major structural event is the Yamaska fault system (Figure 3). This fault has a reject of 400 meters and separates the shallower and deeper shale plays.

At the Taconic Front, stacked thrust sheets are typical. Recently described by Konstantikaya (2008), a triangle zone is formed in the shale sequence at the front of the Taconic orogeny. The overthrust zone was emplaced over a deep through visible on seismic over a distance of 100 km. The St-Flavien gas field is located in the Taconic Front. The gas field, now converted in a gas storage reservoir, produced 5.7 Bcf from a dolomitized and brecciated Ordovician carbonate.

In the Intra-Appalachian basin, the rocks are more folded and highly deformed zones are recognized in some areas. Few subcrop information is available making structural interpretation difficult to constrain. Cross-sections realized by a research group (Cousineau, 1988) present the basin as a large monoclinal basin affected by intra-folding.

For all these areas, a fracture network evaluation has been completed using borehole imaging, remote sensing image, and regional geophysics (seismic, aeromagnetic and gravity). Predicted by researchers (Gayle et al., 2008) and highlighted by recent test results (Talisman, 2010), there is a clear relation between ‘structure’ and better gas production capabilities from Utica shales.

Shale Mineralogy

Basically the Utica shale is a marlstone, i.e., a highly calcareous shale. Calcite content may vary from 30 to 80% but normally is around 60%. Quartz and feldspar together never exceed 30% with an average of 15%. Clay content shows very little variation with an average between 20 and 30%. Similar to the Eagleford shale, the calcareous mineralogy of the Utica make the shale competent, hard and brittle. When stimulated by high pressure fluids and proppants, these mineralogic properties increase the probability of creating hydraulic fractures, which remain open once the well goes on production. The statement is based on successful hydraulic fracturing jobs in tested wells.

On the overall sequence, the undifferentiated Lorraine Shales consist of 50 to 60% of clay, with about 25% of quartz and very few carbonates. In the Lower Lorraine section, the quartz and carbonate contents increase, making this unit a good candidate for propped hydraulic fracturing. No test results have been published for this formation. Several gas shows occurring in the Lorraine shales indicate that some parts of the sequence are gas saturated. The stimulation of the quartzitic or dolomitic intervals could add production from this shale.

On the other side of the basin, the intra-Appalachian Beauceville and Saint-Francis shales are much more quartzitic. The Beauceville shales quartz content can reach almost 70%.
Organic matter type

Results of Utica and Lorraine geochemistry studies carried out independently by the Geological Survey of Canada and the Ministry of Natural resources of Quebec show that the present-day total organic carbon (TOC) ranges between 1 and 6% from the south to north-east of the Utica shale play (Figure 5).

All the Early Paleozoic shales studied in Quebec are pre-vitrinite rocks, deposited in marine environment prior to Carboniferous time. This situation makes the accurate estimation of the thermal maturity difficult. Reflectometry of bitumen, graptolites and amorphous organic matter are measured and converted into indicators for migration and maturity while prospecting for oil and gas (Jacob, 1985’s; Bertrand et al., 1987, 2003). Thermal maturity (TM), measured in reflectometry-vitrinite equivalence (R_o, eq.), varies between 1 and 4% from the north-west toward the south-east. This window places the present-day Utica shales in a zone mature to dry natural gas and condensate.

Regions with the lower maturity level (between 0.5 to 1.0% R_o, eq.) are found in shales with TOC ranging between 4 and 6%. Analyses from low maturity shales give an estimate of TOC_{original} and are used to estimate the transformation ratio (TR) and the kerogen type (Figure 5). Near TOC_{original} shale samples indicate that the organic matter of the Utica shale is of Type II. Based on an average TOC_{present-day} of 1% compared with a TOC_{original} of 4% with can assume a TR of 75%. A good estimate of TOC_{original} is also an important element when using the mass balance approach for the calculation of OGIP. In situations where the TR reaches 75%, almost all kerogen has been transformed and has generated large quantities of natural gas in the system.

Gas Geochemistry

In general, the gas encountered in the Saint Lawrence is a low (wet) to high maturity (dry) thermogenic gas. Basic gas chromatography analysis helped to determine the dryness of the gas. In the medium to deep thermogenic shale gas play, the gas contains more than 95% of methane. The same type of gas is found in the overthrust shale gas play. In the shallower shale gas play located on the North Shore of the Saint Lawrence River, the gas is less mature gas and has a higher content in ethane and propane, reaching nearly 20% in some areas. Condensates and light oil (45°API) have been produced from Junex’s well tests.

Gas isotope geochemistry is also a very useful tool for evaluating the gas origin, the gas maturity and the reservoir rock thermal maturity. Available data for Saint Lawrence Lowland shale gas well indicate that all the gas encountered is thermogenic, comes from the same source rock and plots over a curve of increasing maturity. Shallow biogenic gas occurred only in one locality in the vicinity of a fault zone.

Another important illustration of the use of isotope geochemistry in shales is the determination of the productive gas zone. Ethane Carbon Isotope anomalies called Isotope “Rollover” have been reported in highly productive zones of the Barnett, Haynesville and Marcellus shales. Data available for Quebec Utica shales have been plotted on the reported Barnett data on Figure 6. The two basins show essentially the same “Isotope Rollover” distribution adding more possibilities to the future of the Utica shale.

Reservoir Parameters

Few petrophysical shale data for estimating original gas-in-place (OGIP) have been published in the geologic and petroleum engineering literature. Information concerning properties such as shale porosity, permeability and pressure gradient variation has not been largely diffused by operators. The protocol for determining these properties in the laboratory has not been well established either Figure 7 presents a graph from public and internal Junex data measured on core samples. Permeability and porosity from the Saint Lawrence Lowland shales are compared with Fort Worth basin Barnett data. The comparison highlights the relatively higher permeabilities of the Utica shales while the total porosity is of the same order of magnitude. Some of the Utica samples show permeabilities that are 1 order of magnitude higher. A horizontal line has been drawn at the 300 nD level, which is generally considered a good permeability measure for a shale gas.

One important aspect is the apparent disorder of the cloud of data points shown on Figure 7. However, careful examination of the data indicates that pattern recognition can be used for determination of flow units, a concept that has been used for several decades in evaluation of conventional reservoirs, and that has been extended by Aguilera (2010) to the case of tight and shale gas formations. A flow unit in this graph is represented by similar apertures of pore throats (r_{p35}). The results show that there is a continuum from conventional to tight to shale gas reservoirs when a pore throat aperture (r_{p35}) is calculated for characterizing the
flow unit. The general solution to this concept, based on thousands of data points from several conventional and unconventional formations throughout North America, is presented in Figure 8. Note the separation of viscous and diffusion type flow using Knudsen number.

The graph showed on Figure 9 highlights in full yellow circles the data that are being disclosed in this paper for the Utica shale and a comparison with properties of several shales in the United States and Canada, including the Barnett, Marcellus, Horn River and Fayetteville. The uppermost curve is for the Nikanassin tight gas sand in the Western Canada sedimentary basin (WCSB). As in the case of the “Isotope Rollover” geochemistry discussed above, the r_p35 trends for the Utica compare well with those of the other shale formations. Figure 10 shows again in yellow circles the Utica data including all the Barnett information presented in Figure 7. The use of flow units puts some order in what at first glance appears as a chaotic cloud of data points in Figure 7. The pore throat apertures (r_p35) in the right hand side of the graph go all the way down to 0.00005 microns.

Another piece of important information for estimating original gas-in-place (OGIP) is the initial pressure in the shale. Figure 11 has been built from different sources. In the shallow shale gas play the pressure gradient range is normal to slightly over-pressured. The medium to deep shale gas play is clearly overpressure with gradient ranging from 11 to 17 kPa per meter. The possible presence of a regional seal between 600 and 800 meters can explain the overpressure extensive regime.

**Pilot Wells, Original Gas-in-Place and Resources**

Since the announcement made in April 2008 concerning the shale gas potential of the Southern Quebec Lowlands, almost 15 new wells have been drilled in the area. Different companies and organizations have evaluated the Utica and Lorraine shales with a view to estimating volumes of gas-in-place and recoveries. Forest Oil fractured and tested two pilot vertical wells in the Utica Shale in 2008. From their results, Forest estimated an average OGIP in the order of 93 Bcf per section. Talisman, another operator in the Saint Lawrence Lowlands of Quebec, has presented estimates ranging from 75 to 350 Bcf OGIP per section for the Utica and Lorraine groups combined. Netherland, Sewell & Associates using data from Questerra in November 2009 reported Utica OGIP volumes ranging between 102 and 220 Bcf. In February 2010, the same consulting firm provided a best estimate of 48.34 Tcf of undiscovered OGIP volumes for the Utica Shale for most of Junex’s permits in the St. Lawrence Lowlands.

The last published Utica study used the Petroleum resource Management System (PRMS) in efforts to quantify Utica gas-in-place (Chan et al., 2010). Recent innovative technologies, including horizontal wells and multi-stage hydraulic fracturing, are being applied in the Utica shales. Figure 12 attempts to show learning curves comparing gas production from the Fayetteville shale in the United States and the Utica shales. At first glance there appears to be a continuous improvement with time in gas production rates in both reservoirs.

The latest horizontal well drilled in the Utica shales in early 2010 was the Saint Eduard No. 1A with a reported maximum flow rate of over 5 MMscfd (Web Sites of Companies Operating in Shale Gas Reservoirs). This rate is anomalous compared to previous data. If sustained economic rates can be confirmed in additional pilot wells, portions of the Utica shale gas play can be reclassified as Contingent Resources and maybe even reserves. At present, Utica resources are sub-commercial but depending on the pilot results and other commerciality issues, portions of these resources may meet reserves criteria in the future.

An evaluation comparing the Barnett and Utica shales is presented in Table 1. The same methodology is used for consistency while comparing the Utica and Barnett shales using publically available data (Chan et al, 2010). Important objectives are determining OGIP and what portion of the total volume is stored as free gas. Some of the characteristics of the Utica and Barnett shales are different, for example, the published percent TOC. Others, such as free gas porosities are considered to be, from a practical point of view, of the same order of magnitude. For example, free gas porosity for the Barnett has been estimated at 1.7% by Wang and Reed (2009). Free gas porosity for the Utica shale has been estimated at 1.4% (Aguilera, 1978). Volumetric estimates of total OGIP per section are of the same order of magnitude (104.8 Bcf for the Barnett and 96.5 for the Utica). Volumetric estimates of free OGIP per section also compare reasonably well (50.9 Bcf for the Barnett and 40.9 for the Utica). Recovery per well over a 20-year period (assuming linear flow throughout the 20 years without reaching boundary dominated flow and assuming a positive skin) was estimated at 2.5 Bcf for the Utica shale (Aguilera, 1978). Chesapeake Energy (2010) has recently recently raised its estimated ultimate recovery (EUR) per well in the Barnett Shale from 2.65 to 3.0 Bcf. Furthermore both reservoirs have readily available access to markets.

However, in spite of the above reasonable comparisons (Table 1), the similar “Isotope Rollover” geochemistry (Figure 6), and the similar type of flow units (r_p35) shown on Figure 9, the Barnett is assigned reserves because the ‘project-base’ evaluation,
including pilots, is commercial, presents low risk, and has well defined production decline type curves that decrease significantly the range of uncertainty. On the other hand, the Utica is still lacking definitive results from pilot wells and clearly defined production decline curves (Chan et al., 2010). So from the point of view of the PRMS they correspond to “undiscovered” resources. But clearly the Utica potential is real as discussed in this paper. The following is a summary of Utica and/or Lorraine evaluations carried out to date by different organizations:

<table>
<thead>
<tr>
<th>Author (year)</th>
<th>Area Studied</th>
<th>Interval Studied</th>
<th>OGIP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aguilera (1978)</td>
<td>Villeroy</td>
<td>Utica</td>
<td>5–27 Bcf (free gas)</td>
</tr>
<tr>
<td>Encana (2007)</td>
<td>Regional Evaluation</td>
<td>Utica/Lorraine undifferentiated</td>
<td>7-99 Bcf</td>
</tr>
<tr>
<td>Forest Oil (2008)</td>
<td>Bécancour and Yamaska</td>
<td>Utica</td>
<td>93 Bcf</td>
</tr>
<tr>
<td>Talisman Energy (2008)</td>
<td>Bécancour and Lotbinière</td>
<td>Utica and Lorraine</td>
<td>75-350 Bcf</td>
</tr>
<tr>
<td>Questerre (2009)</td>
<td>Bécancour and Lotbinière</td>
<td>Utica</td>
<td>102-220 Bcf</td>
</tr>
<tr>
<td>Chan et al. (2010)</td>
<td>Villeroy</td>
<td>Utica</td>
<td>96 Bcf</td>
</tr>
</tbody>
</table>

It is noteworthy that a study completed by the Geological Survey of Canada suggests that the Utica-Lorraine shale sequence is one of the best prospects of shale gas in Canada (Hamblin, 2006).

**Infrastructure**

Historically, Quebec has not been a petroleum or gas production province. Two gas fields were produced in the 50’s and 60’s: Pointe-du-Lac and Saint-Flavien. Both are now converted into gas storage facilities. But Quebec is an important oil and gas consumer. International importation of oil reaches 140 MMbbl per year and annual gas imports from Western Canada range between 200 and 210 Bcf. Gas pipeline networks are developed all over the Saint Lawrence Lowlands and about 400 MMscf per day are available in the network.

While service equipment, like rig or logging units, are not steadily based in the province, several types of building equipment and general contractors are located in the industrial area all over the region. Land survey and environment services companies are based in Quebec. Junex operates its own rig to facilitate development of its projects.

Natural resources rights of exploration and production are delivered by the provincial government and regulated by the Natural Resources Ministry. For some specific types of exploration jobs, permits and authorization are delivered by the Ministry of Environment or the Agricultural Land Commission. Properties annual rental fees and production royalties are paid to the government only. Regulation framework is presently being updated due to intense activity associated with the Utica gas shales. Land is accessible all over the year for drilling. The current exploration activities are mainly located in forested and farm land.

The good infrastructure and access to land can impact positively the exploration in the Saint Lawrence Lowlands. Economic factors like low royalties (12.5%), no severance tax and NYMEX+ pricing will also help significantly development of the play.

**Conclusions**

From a geological point of view and a limited number of pilot wells, the Utica Shales have developed into a play with good natural gas potential. The Lower Lorraine group (Nicolet Formation) is also interesting and promissory. More work is being performed at this time in efforts to answer questions needed to set the play in production. Once pilot drilling demonstrates the presence of producible hydrocarbons in sufficient quantities to justify potential development, portions of the accumulation may be deemed “discovered” and thus reclassified from prospective to contingent resources and even reserves, if “project-base” justified.

**Acknowledgement**

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In spite of the reasonable comparisons shown below, the similar “Isotope Rollover” geochemistry (Figure 6), and the similar type of flow units (r_p35) shown on Figures 9 and 10, the Barnett is assigned reserves because the ‘project-base’ evaluation, including pilots, is commercial, presents low risk, and has well defined production decline type curves that decrease significantly the range of uncertainty. On the other hand, the Utica is still lacking definitive results from pilot wells and clearly defined production decline curves. So from the point of view of the PRMS the estimated volumes correspond to “undiscovered” resources. At present, Utica resources are sub-commercial but depending on the pilot results and other commerciality issues, portions of these resources may meet reserves criteria in the future (Adapted from Chan et al., 2010).

Table 1. Comparison of the Barnett Shale, Fort Worth Basin (FWB), United States; and Utica Shale, Quebec, Canada.

<table>
<thead>
<tr>
<th>Item</th>
<th>Characteristic</th>
<th>Barnett, FWB</th>
<th>Utica, Québec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total porosity of shale, ( \phi_{sh} )</td>
<td>0.050*</td>
<td>0.066**</td>
</tr>
<tr>
<td>2</td>
<td>Free gas porosity, ( \phi_{free} )</td>
<td>0.017*</td>
<td>0.014**</td>
</tr>
<tr>
<td>3</td>
<td>Percent total organic content by weight, ( TOC_{wgt} )</td>
<td>5.00*</td>
<td>1.70</td>
</tr>
<tr>
<td>4</td>
<td>Percent total organic content by volume, ( TOC_{vol} )</td>
<td>10.00*</td>
<td>3.40</td>
</tr>
<tr>
<td>5</td>
<td>Percent of total porosity filled with free gas, ( V_{free} )</td>
<td>34.00</td>
<td>21.21</td>
</tr>
<tr>
<td>6</td>
<td>Assumed temperature, Deg. F</td>
<td>180</td>
<td>115</td>
</tr>
<tr>
<td>7</td>
<td>Assumed pressure, psia</td>
<td>3,800</td>
<td>3,000**</td>
</tr>
<tr>
<td>8</td>
<td>Gas formation volume factor, Bgi, cf/scf</td>
<td>0.00419</td>
<td>0.00477**</td>
</tr>
<tr>
<td>9</td>
<td>Assumed ( S_{wfree} ) in free gas porosity, percent</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>Assumed ( S_{wt} ) total in composite system, percent</td>
<td>30.00</td>
<td>50.00**</td>
</tr>
<tr>
<td>11</td>
<td>Total gas porosity, ( \phi_{gas} )</td>
<td>0.035</td>
<td>0.033**</td>
</tr>
<tr>
<td>12</td>
<td>Free original gas-in-place, ( OGIP_{free} ), scf/acre ft</td>
<td>176,743</td>
<td>127,900</td>
</tr>
<tr>
<td>13</td>
<td>Total original gas-in-place, ( OGIP ), scf/acre ft</td>
<td>363,883</td>
<td>301,479</td>
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<tr>
<td>14</td>
<td>Original gas-in-place adsorbed in matrix, ( OGIP_{adsorbed} ), scf/acre ft</td>
<td>187,140</td>
<td>173,579</td>
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<tr>
<td>15</td>
<td>Percent of free gas</td>
<td>48.57</td>
<td>42.42</td>
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<td>16</td>
<td>Percent of adsorbed gas</td>
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<td>57.58</td>
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<td>17</td>
<td>Thickness, ft</td>
<td>450</td>
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<td>18</td>
<td>Total OGIP per section (Bscf/section)</td>
<td>104.80</td>
<td>96.48</td>
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<td>19</td>
<td>Free OGIP per section (Bscf/section)</td>
<td>50.90</td>
<td>40.93</td>
</tr>
<tr>
<td>20</td>
<td>Recovery, Bscf/well</td>
<td>2.65 – 3.0 (EUR)***</td>
<td>2.5 (20-year)**</td>
</tr>
</tbody>
</table>

* Data from Wang and Reed, 2009
** Data from Aguilera, 1978
*** Data from Chesapeake Energy Corporation (2010)
Figure 1. Location of the study area, Utica shale, Quebec, Canada, relative to other shale basins in North America, particularly the Marcellus and Barnett shales in the United States.

Figure 2. Stratigraphic column of the study area, Utica shale, Quebec, Canada.
Figure 3. Southern Quebec geology and shale gas play location (map modified from Thériault, 2009).

Figure 4. Basic geology schematic of Early Devonian time in the vicinity of transect X-X'.
Figure 5. Low maturity Utica Shale samples used to evaluate the original TOC and the transformation ratio of kerogen (Puits = wells, Affleurement = outcrop).

Figure 6. Ethane isotope rollover in the St Lawrence Lowlands of Quebec.
Figure 7. Comparison of Southern Quebec shale permeability and porosity compared with the Barnett shale.

Source: GFREE Research Team, U of Calgary, 2009

Figure 8. Flow units for conventional, tight and shale gas reservoirs including the location of soft shales and possible crushed samples. Viscous flow dominates in conventional and tight gas reservoirs. Diffusion base flow dominates in shale gas reservoirs (adapted from Aguilera, 2010).
Figure 9. Flow units. Permeability vs. porosity crossplot including shale data from the Utica shale (yellow circles), Horn River (HR) and soft shales in Canada; Fayetteville (F), Barnet (B) shales in the United States. Additional data include open circles, dark and light blue dots representing plug data from BC, Canada (Wang et al., 2009); purple triangles representing Huron shales, and red squares the Marcellus shales (Soeder, 1988) in the United States, and red dots in the upper part of the graph representing the Nikanassin tight gas formation in Canada (Adapted from Aguilera, 2010).

Figure 10. Flow units. Permeability vs. porosity crossplot including shale data from the Utica shales (yellow circles), Horn River (HR) and soft shales in Canada; Fayetteville (F), Barnet (B), Huron and Marcellus shales in the United States, and the Nikanassin tight gas formation in Canada. Information from Core Labs data includes the Fort Worth Barnett (B.FW), Delaware Barnett (B.DEL), and Barnett M1H well. Red circles, at the bottom of the graph represent possible crushed samples interpreted to correspond to matrix porosity (Wang et al, 2009; data from Cluff et al, 2007). Same might be true for purple diamonds and blue squares. Care must be exercised because this is a matrix porosity scaled to the bulk volume of only the matrix, not scaled to the bulk volume of the shale multiple-porosity system (Adapted from Aguilera, 2010).
Figure 11. Increase of pressure gradient with depth in the Saint Lawrence Lowlands.

Figure 12. Learning Curves Comparison between the Fayetteville and the Utica Shales (Sources: Web Sites of Companies Operating in Shale Gas Reservoirs, Questerre, Chan et al., 2010).