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The Cambrian – Devonian Frontier Basins in Eastern Canada: Assessment of Hydrocarbon Potential of the Most Promising Plays

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Summary

The Paleozoic successions of eastern Canada represent hydrocarbon frontier basins. The successions consist of three major tectonostratigraphic packages that are bounded by tectonically-controlled unconformities. The basins which have unique source rock and reservoir units and specific trap types include 1) the Cambrian-Ordovician autochthonous St. Lawrence shallow marine platform and coeval allochthonous deep water facies preserved in the Taconian thrust nappes of the Humber Zone, 2) the Silurian-Devonian shallow to deep marine Gaspé Belt and 3) the Devonian-Permian mostly terrestrial Maritimes Basin (Fig. 1). The Taconian unconformity separates the Cambrian-Ordovician from the Silurian-Devonian whereas the Acadian unconformity occurs at the base of the Late Devonian-Permian rock package. These basins currently produce various volumes of hydrocarbons or are host to discovered fields but there has been no independent evaluation of their overall oil and gas resource potential. Over the past five years the Geological Survey of Canada and its partners have acquired new hydrocarbon systems data, to produce the first ever regional hydrocarbon play assessment for Paleozoic strata in eastern Canada.

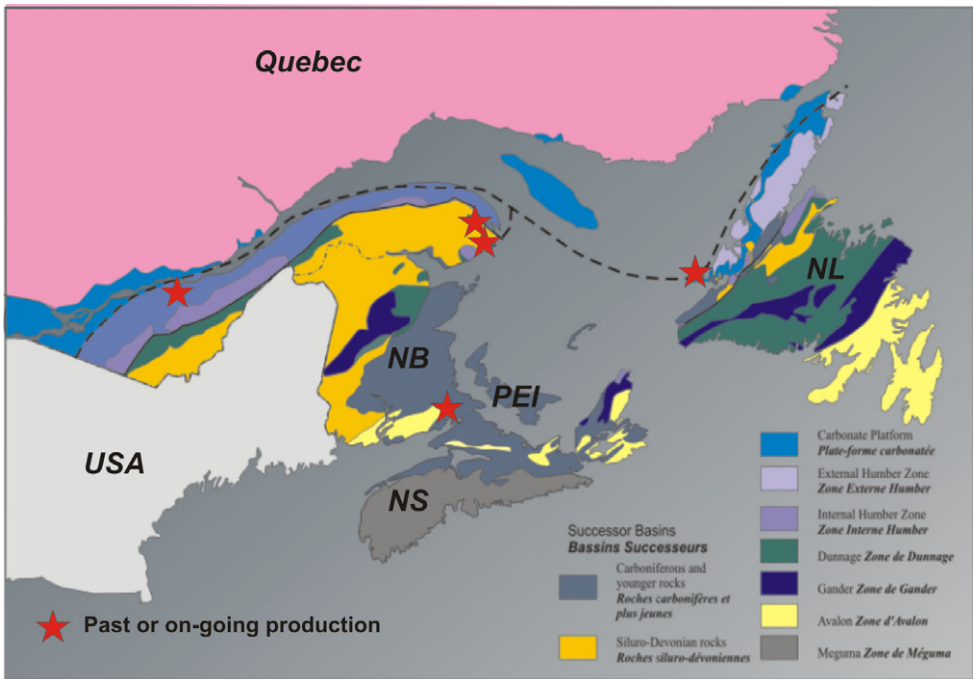

Figure 1: Main tectonostratigraphic domains in eastern Canada and location of producing or discovered fields.

A total of 13 conventional and 1 unconventional (shale gas) plays have been identified in Cambrian-Devonian strata. The conventional plays include seven plays in Cambrian-Ordovician strata (Fig. 2): 1) Cambrian rift sandstones, 2) Lower Ordovician hydrothermal dolomite (HTD), 3) carbonate thrust slices at the Appalachian structural front, 4) Middle-Upper Ordovician HTD, 5) passive margin slope clastics, 6) foreland sandstones and carbonates, and six plays in Silurian-Devonian strata (Fig. 3): 1) Lower Silurian sandstones, 2) Lower Silurian HTD, 3), Upper Silurian HTD reefs, 4) lowermost Devonian HTD reefs, 5) Lower Devonian fractured carbonates, and 6) Lower Devonian nearshore sandstones. Quantitative assessments of in-place oil and gas resource potential have been derived for four conventional plays (Lower and Middle-Upper Ordovician HTD, carbonate thrust slices, and Devonian sandstones). The other plays are described in qualitative terms, due to the limited availability of production or exploration data. Plays recognized in the Maritimes Basin are not discussed in this abstract.

Hydrocarbon systems and plays in the Cambrian-Ordovician

In the Canadian Appalachians, potential hydrocarbon source rocks occur in organic-rich shales deposited in Lower Ordovician passive margin, Middle Ordovician deep ocean basin and Upper Ordovician foreland basin (Obermajer and Lavoie, 2009). Geochemical analyses suggest that oil from Lower Ordovician reservoirs in Newfoundland is from the Lower Ordovician passive margin shales. Hydrocarbons in Ordovician reservoirs in southern Quebec were sourced from Upper Ordovician foreland basin black shales (Lavoie et al., 2009). The best quality reservoirs in the Cambrian-Ordovician are hydrothermal dolomites (HTD) in Lower Ordovician passive margin and in the Middle/Upper Ordovician foreland basin successions. Secondary potential reservoirs consist of nearshore and fluvial sands, and thick successions of turbidites and slope channel-fill sands (Lavoie et al., 2009). The carbonate and clastic reservoirs are involved in stratigraphic and tectono-diagenetic traps in the St. Lawrence Platform and in foothill-style traps at the Appalachian structural front (Lavoie et al., 2009). Of the 7 conventional and one unconventional plays identified (Fig. 2), only three have enough production or exploration data to prepare quantitative estimates of resource potential: the Lower Ordovician and Middle-Upper Ordovician HTD plays and the carbonate thrust slice play (plays 2, 3 and 4; Fig. 2). The other plays are evaluated on a qualitative basis.

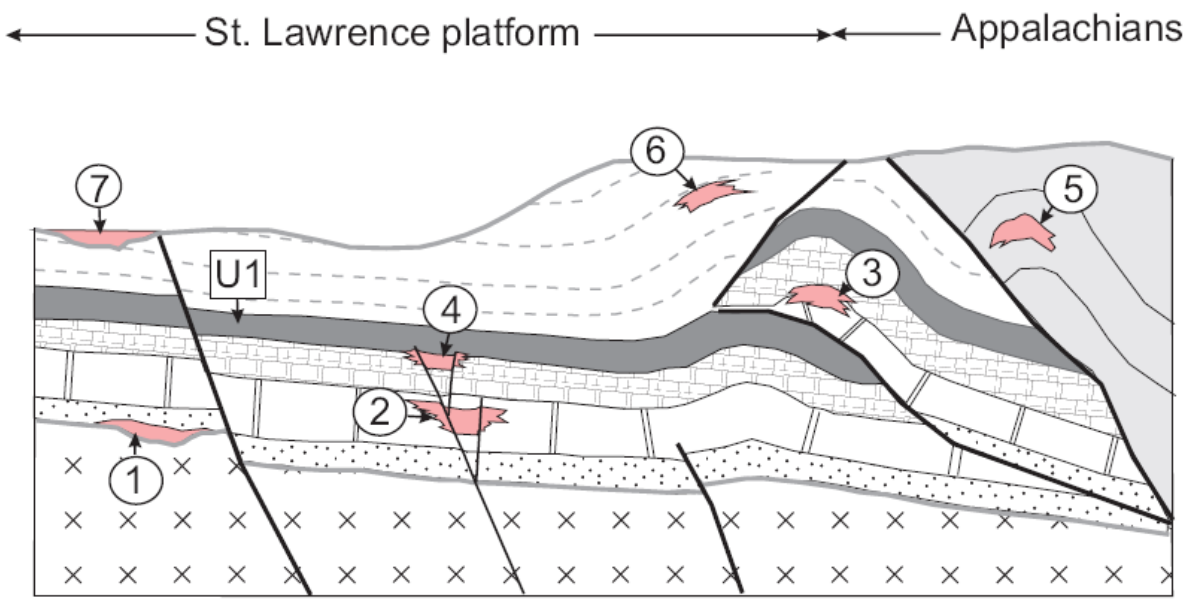

Figure 2: Schematic cross-section of the Cambrian-Ordovician St. Lawrence Platform and coeval Appalachian Humber Zone. The 7 conventional and one unconventional (U1) plays are presented. The plays 2, 3 and 4 are quantitatively assessed.

The mapped distribution of the hydrothermal dolomites is largely the same for both Ordovician successions. From our current understanding of thermal maturation, both the Ordovician HTD plays have gas and oil components with the oil play occurring in the northern part of the Gulf of St. Lawrence. Hydrothermal alteration of Lower Ordovician carbonates (play 2 on Fig. 2) is well documented on Anticosti Island (Lavoie et al., 2005) as well as in Middle/Upper Ordovician carbonates (play 4 on Fig. 2) in both the St. Lawrence Lowlands (Thériault, 2007; Lavoie et al., 2009) and Anticosti Island (Lavoie and Chi, in press). An HTD gas reservoir discovered in southern Quebec by Talisman in 2006 provides information on the effectiveness of hydrocarbon charging from Utica Shale source rocks. Based on the recognition of fault-bounded sags on 2D seismic and time-structure maps, an average pool-size of 10 km^2 is proposed for both hydrothermal dolomite plays (similar structure sizes are documented in the contiguous Appalachian Basin in New York State). Based on petrophysical analyses of Anticosti Island wells, average net pay values of 5m gas and 10m oil are assigned to the Lower Ordovician play, and 14m gas and 4m oil for the Middle/Upper Ordovician play. The most significant risk factor in the Ordovician HTD plays is trap preservation.

The carbonate thrust slices at the Appalachian structural front (play 3 on Fig. 2) have been seismically identified in a ca. 30 km wide zone from the international border to Quebec City. Extension of this zone is postulated from limited seismic data, from Quebec City to western Newfoundland. This carbonate play is mainly a gas play with oil potential limited to a small zone in western Newfoundland (Port-au-Port Peninsula). The play consists of fractured and hydrothermally-altered segments of the Lower Ordovician carbonate platform in thrust slices, with trap configurations associated with fault-bend folds (Bertrand et al., 2003). The 5 Bcf Saint-Flavien gas field in southern Quebec is a type example of this play. Production data from the 4km^2 Saint-Flavien field indicate an average pay of 3.5 m (using a 6% porosity cut-off). Many other exploration wells have encountered gas in carbonate thrust slices and up to 50 of these slices have been seismically interpreted in southern Quebec. The Garden Hill oil-gas discovery in western Newfoundland (Cooper et al., 2001) is another example of carbonate play at the Appalachian structural front but unlike those of the Quebec Reentrant, the trap is associated with a thick-skinned Acadian tectonic wedge. The most significant risk factor for the carbonate thrust slice play is trap preservation.

The unconventional shale gas play in southern Quebec (Utica) is currently at the forefront of exploration efforts. Multiple Tcf potential of recoverable resources has been announced by exploration companies based on positive testing from vertical and horizontal wells.

Hydrocarbon systems and plays in the Silurian-Devonian

Rock-Eval analyses identify fair to poor source rocks in the Silurian-Devonian succession of the Gaspé Belt, limited to Lower Devonian foreland basin shaly limestone and thin Lower Devonian coals. Oil-source rock correlation indicates that oil in Lower Devonian reservoirs in Gaspé can best be tied with either Middle or Upper Ordovician shales with some contributions from these Devonian sources. Six conventional plays are recognized (Fig. 3) with production currently established in the Lower Devonian fractured and hydrothermally-altered carbonate breccia (Galt field) and in fluvial sandstones (Haldimand field) (plays 5 and 6, respectively on Fig. 3). The Lower Devonian sandstones are highly porous and are very prospective shallow targets (Lavoie et al., 2009). The Lower Devonian HTD formed in association with significant fracture networks, a prerequisite for enhanced permeability and reservoir potential (Lavoie et al., 2009). Other targets consist of Lower Silurian nearshore sands (play 1 on Fig. 3) and Lower Silurian to lowermost Devonian HTD (plays 2, 3 and 4 on Fig. 3). The Silurian-Devonian succession is involved in major folds and cuts by faults that exhibit a variable cinematic (Pinet et al., 2008). A significant number of seismic anomalies and bright spots (hydrocarbon indicators?) are observed in the untested Silurian succession. Maturation data for the Silurian-Devonian domain indicate both oil and gas potential (Roy, 2008; Lavoie et al., 2009). Given the limited modern sub-surface information for the Silurian – lowermost Devonian plays (plays 1 to 4 on Fig. 3) and the unpredictable nature of the fracture carbonate play (play 5 on Fig. 3), only the Lower Devonian sandstone play (play 6 on Fig. 3) will be quantitatively assessed. The other plays will be evaluated on a qualitative basis.

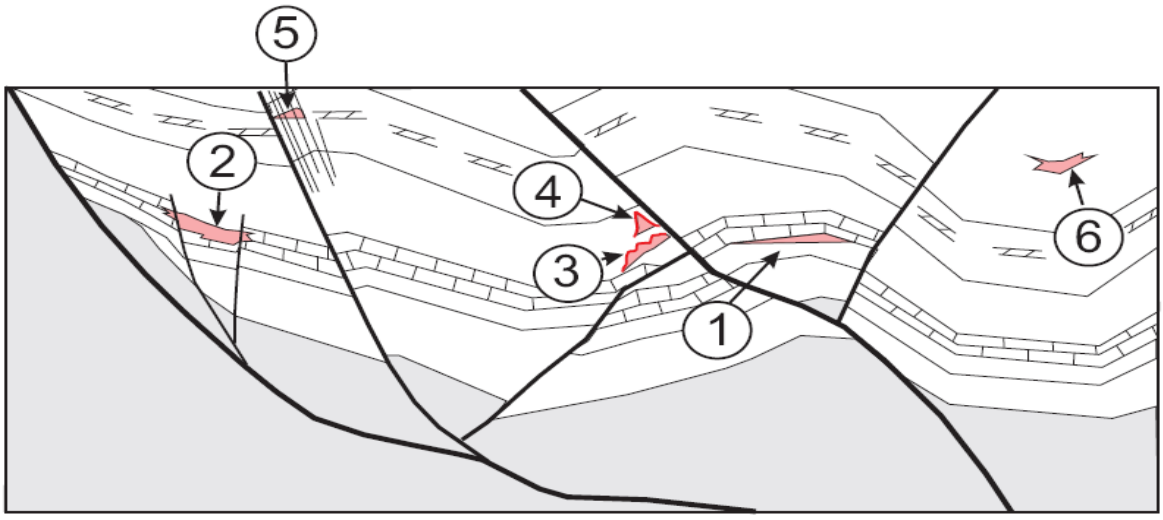

Figure 3: Schematic cross-section of the Silurian-Devonian Gaspé Belt. The 6 conventional plays are presented. Only the play 6 (Lower Devonian sandstone) will be quantitatively assessed..

The map distribution of the Lower Devonian sandstones of the York River Formation is well documented and regional maturation data indicates that this play is oil-prone. Some production data are available from the discovery at Haldimand near Gaspé (34 BOE/d; 47° API oil). At this locality, the hydrocarbon pay zone is 22 metres thick with reservoir porosity ranging between 5 to 15%. The reservoir is sealed by a fault and extends over an area of about 30 km^2. The porous sandstones are well documented in the petrophysical summary for wells in the Gaspé (Hu and Lavoie, 2008); these sandstones are correlative with the producing

Lower Devonian Oriskany Sandstone in the eastern US Appalachians. The main risk factor is trap seal, as these sandstones are overlain by a coarsening-upward succession of Lower Devonian alluvial fan facies. An overview of the qualitative plays will also be presented.

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