Hydrocarbon Systems in the Frontier Paleozoic Basins of Eastern Canada – Recent Data and Synthesis*

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Abstract

Three major hydrocarbon systems have been recognized in the Paleozoic rocks of eastern Canada, all differ with regard of source rocks, reservoirs and traps and seals. The Taconian system has multiple potential source rocks; hydrothermal dolomites are huge producers in the USA and tectono-diagenetic traps are common. The Acadian system is likely feed from the Ordovician source rocks, both clastics and hydrothermal dolomites are producing, Foothill-style traps have the greatest potential. The Alleghenian systems are characterized by excellent lacustrine and coal measures for source rocks. Fluvial and deltaic sandstones have a good production record and combined stratigraphic tectonic-salt seals and traps are multiple.

Introduction

Over the last 10 years, the Geological Survey of Canada and its regional partners have generated hydrocarbon systems data in the Cambrian to Permian successions of eastern Canada (Figure 1). Historic and actual producing fields suggest that all the elements for economic hydrocarbon systems were met.

Geological Framework

Paleozoic basins in eastern Canada were formed at the break-up of the Rodinia in late Neoproterozoic. In Paleozoic time, the continental margin of Laurentia experienced multiple episodes of compressive tectonic events part of a *circa* 350 Ma Wilson's cycle that ended in Late Paleozoic in the formation of Pangea. Three main tectonic events are used to recognize major hydrocarbon systems, all characterized by specific source rocks, reservoirs, traps and production history. These events are: 1) the Late Ordovician Taconian Orogeny, 2) the Middle Devonian Acadian Orogeny and 3) the Carboniferous-Permian Alleghenian Orogeny.

Hydrocarbon Systems in the Cambrian-Ordovician – Taconian System

In the Canadian Appalachians, Rock Eval analyses identify potential source shales in Lower Ordovician passive margin (TOC: 10.4%, HI: 759; Type II), in Middle Ordovician deep ocean basin (TOC: 10.7%, HI: 266, Type I-II) and in Upper Ordovician foreland basin (TOC: 14%, HI: 633, Type II). 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 correlates with Upper Ordovician foreland basin black shales.

Best reservoirs are Ordovician hydrothermal dolomites (HTD) in Lower Ordovician passive margin and in the Middle/Upper Ordovician foreland basin successions. The HTD formed in shallow burial from circulation of high-pressure, warm (135-150°C) and saline (16 to 20 wt% $NaCl_{equi}$) fluids along transtensional faults rooted in basement (high $^{87}Sr/^{86}Sr$). Secondary potential reservoirs consist of nearshore and fluvial sands, and thick successions of turbidites and slope channel-fill sands.

The carbonate and clastics reservoirs are involved in stratigraphic and tectono-diagenetic traps in the St. Lawrence Platform and in foothill-style traps at the Appalachian structural front. Maturation for the Cambrian-Ordovician successions indicates that most of the area is prone for preservation of gas with some sectors still prone for oil (Newfoundland, Anticosti and Quebec City area) (Figure 2)

Hydrocarbon Systems in the Silurian-Devonian – Acadian System

Rock-Eval analyses identify fair to poor source rocks in the Acadian system; Lower Devonian foreland basin shaly limestone (TOC: 4%, HI: 225, Type II-III) and thin Lower Devonian coals. Analyses indicate that oil in Lower Devonian reservoirs in Gaspé can best be tied with either Middle or Upper Ordovician shales.

Production occurs in the Lower Devonian sandstones and hydrothermal dolomites (HTD). The Lower Devonian sandstones are highly porous and form interesting shallow targets. The Lower Devonian HTD formed at proximity of significant fracture network that is a prerequisite for enhanced permeability and economic potential. Other targets consist of Lower Silurian well washed and locally bitumen-impregnated nearshore sands and Lower Silurian to lowermost Devonian HTD. These HTD are of demonstrated shallow burial origin. The carbonate hosts are dissected by faults that were active at the Early Silurian onset of the Acadian foreland basin. The faults were efficient conduits for episodic high-pressure migration of high temperature (180-225°C) and very saline (18 to 26 wt% $NaCl_{equi}$) fluids.

The pre-Devonian successions are part of a major compressive envelope that formed in the early stage of the Acadian Orogeny (the Silurian "Salinic"). As seen on seismic, the succession is characterized by Foothill-style structures; a significant number of seismic anomalies and bright spots are observed in the untested Silurian potential reservoirs. The Devonian (HTD and clastic) reservoirs are involved in large synclines and tight faulted anticlines that formed during the Acadian Orogeny. Maturation data for the Silurian-Devonian domain indicates both oil and gas potential (Figure 3).

Hydrocarbon Systems in the Carboniferous-Permian – Alleghenian Systems

The Carboniferous to Permian succession in eastern Canada is divided into latest Devonian to end Mississippian (lower Alleghenian) and Pennsylvanian to Permian (upper Alleghenian) hydrocarbon systems based on regional unconformities and very distinctive hydrocarbon source rocks (Figure 4).

The Lower Alleghenian System

Rock-Eval analyses confirm the source rock potential of Tournaisian lacustrine shales (TOC up to 30%, Type I and II). These rocks geochemically correlate with the oil seeps that are regionally found in the Lower Carboniferous sandstones. These source rocks are interbedded with the gas bearing sandstones at the McCully field in New Brunswick (1 Tcf in place). An alternative fair source rock is the TOC-rich deep marine Viséan limestone, although this unit is of very limited thickness.

Current (McCully) and past (Stoney Creek) production is from low permeability Tournaisian sandstones interbedded with the lacustrine source rocks. These sandstones comprise coarse (proximal) to fine (distal) alluvial fan facies, cyclic channel-fill and deltaic sandstones. Secondary targets consist of hydrothermally altered carbonate mounds and reefs of Viséan age.

The clastic and potential carbonate reservoirs are involved in number of stratigraphic, tectonic and salt traps. Major salt deposits of Viséan age form a significant domain in the southern segment of the Gulf of St. Lawrence. Detailed onshore maturation maps of the lower Alleghenian system in southern New Brunswick indicate that location of gas fields correlates with thermal anomalies in the sedimentary succession.

The Upper Alleghenian System

The Pennsylvanian succession is characterized by thick coal measures some of which are currently being evaluated for coal-bed methane. These coal beds have significant potential for gas source.

The potential reservoirs consist of various sandstone units. These are fluvial to deltaic in origin with good porosity and permeability values. A significant sandstone reservoir was drilled in the late 1970s, the East Point E-49 well offshore PEI, tested at 5 mmcf/d with in place reserves of 77 Bcf. These sandstones are regionally distributed over the entire Alleghenian domain although efficient net pay zones are highly variable from one locality to the other. This Pennsylvanian sandstone-dominated interval is overlain by a thick Upper Pennsylvanian mudstone-dominated succession that an efficient cap unit, at least locally (e.g., the East Point and other wells with significant gas shows). Porous and permeable Permian eolian sandstones top the Alleghenian succession, unfortunately without any known seal.

Stratigraphic and tectonic traps are proposed in the upper Alleghenian system (Figure 5). Major exploration tectonic plays/targets are currently being evaluated by the industry. The giant “Old Harry” structure in the middle part of the Gulf of St. Lawrence is the largest 4-way Paleozoic structures of eastern Canada; it consists of Pennsylvanian sands and coal measures with significant seismic anomalies and natural seeps.

Conclusions

Three major hydrocarbon systems have been recognized in the Paleozoic rocks of eastern Canada, all differ with regard of source rocks, reservoirs and traps and seals. The Taconian system has multiple potential source rocks; hydrothermal dolomites are huge producers in the USA and tectono-diagenetic traps are common. The Acadian system is likely feed from the Ordovician source rocks, both clastics and hydrothermal dolomites are producing, Foothill-style traps have the greatest potential. The Alleghenian systems are characterized by excellent lacustrine and coal measures for source rocks. Fluvial and deltaic sandstones have a good production record and combined stratigraphic tectonic-salt seals and traps are multiple.

Reference Cited

Dietrich, J.R., and P.S. Giles, 2005, Petroleum systems in the Carboniferous Magdalen basin, Gulf of St. Lawrence, Eastern Canada: Geological Association of Canada, Annual meeting, Halifax, Nova Scotia, Canada, p. 44.

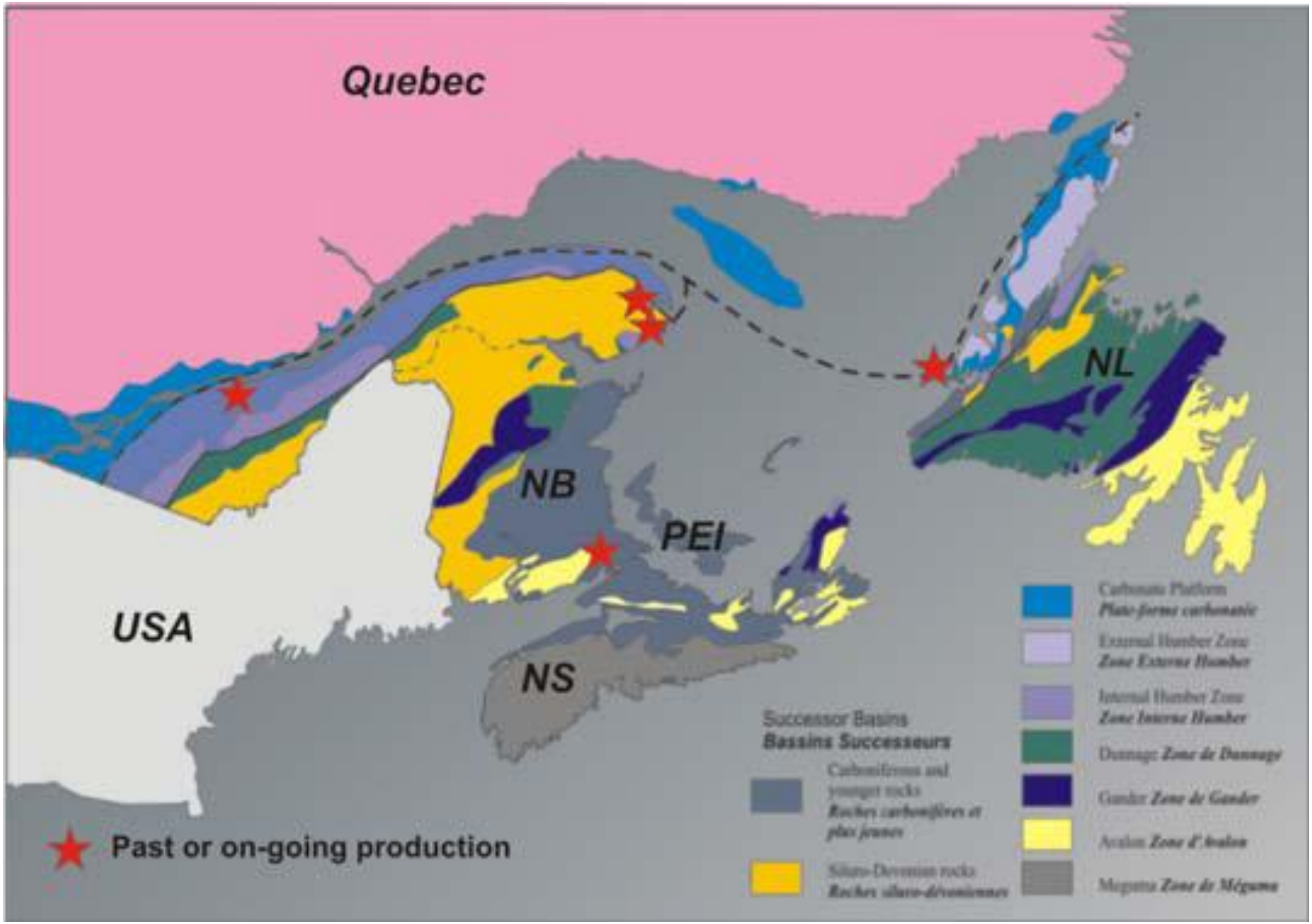

Figure 1. Hydrocarbon systems in the Cambrian to Permian successions of eastern Canada.

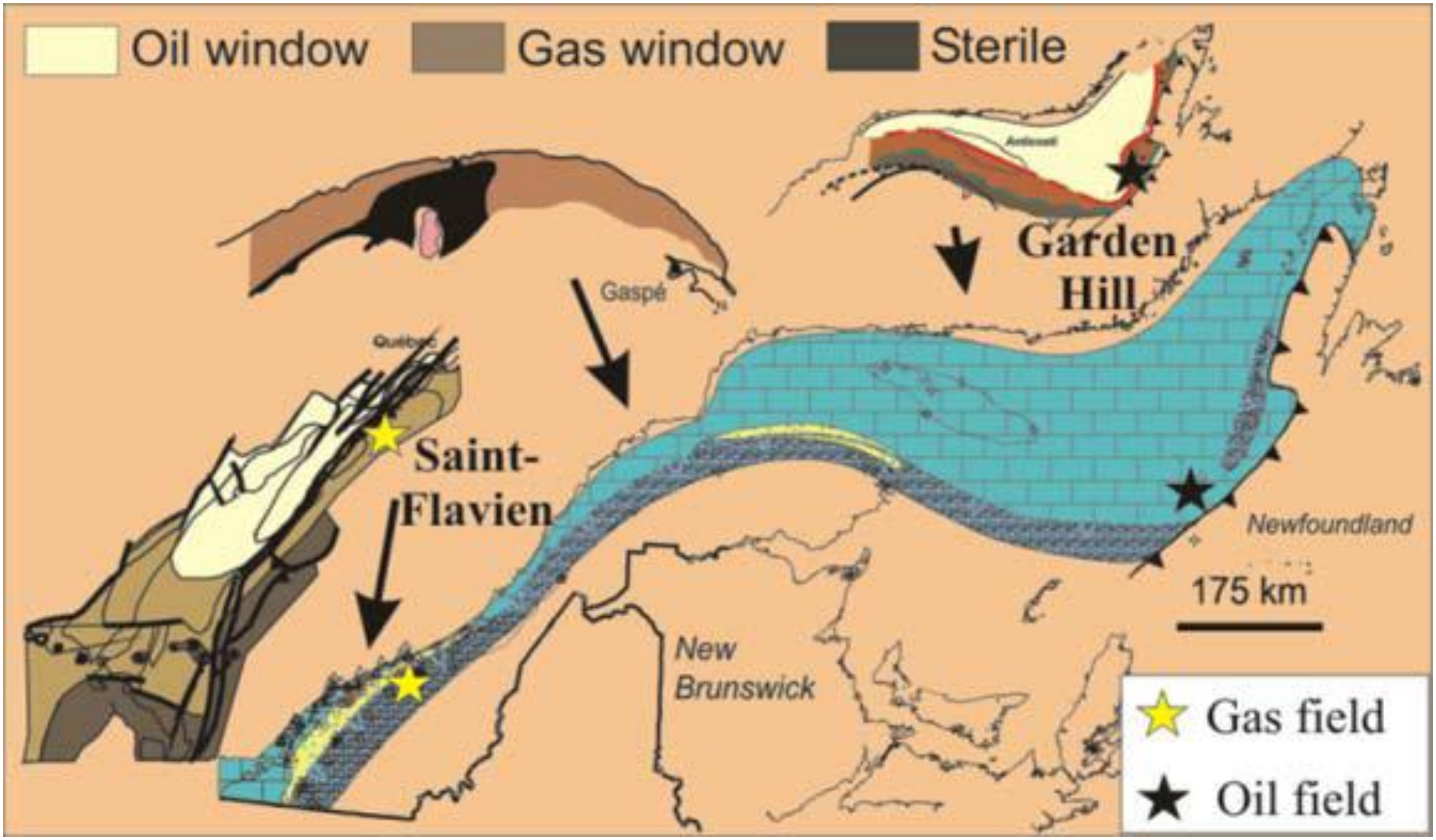

Figure 2. Oil and gas prone preservation areas within the Cambrian-Ordovician successions at the Appalachian structural front.

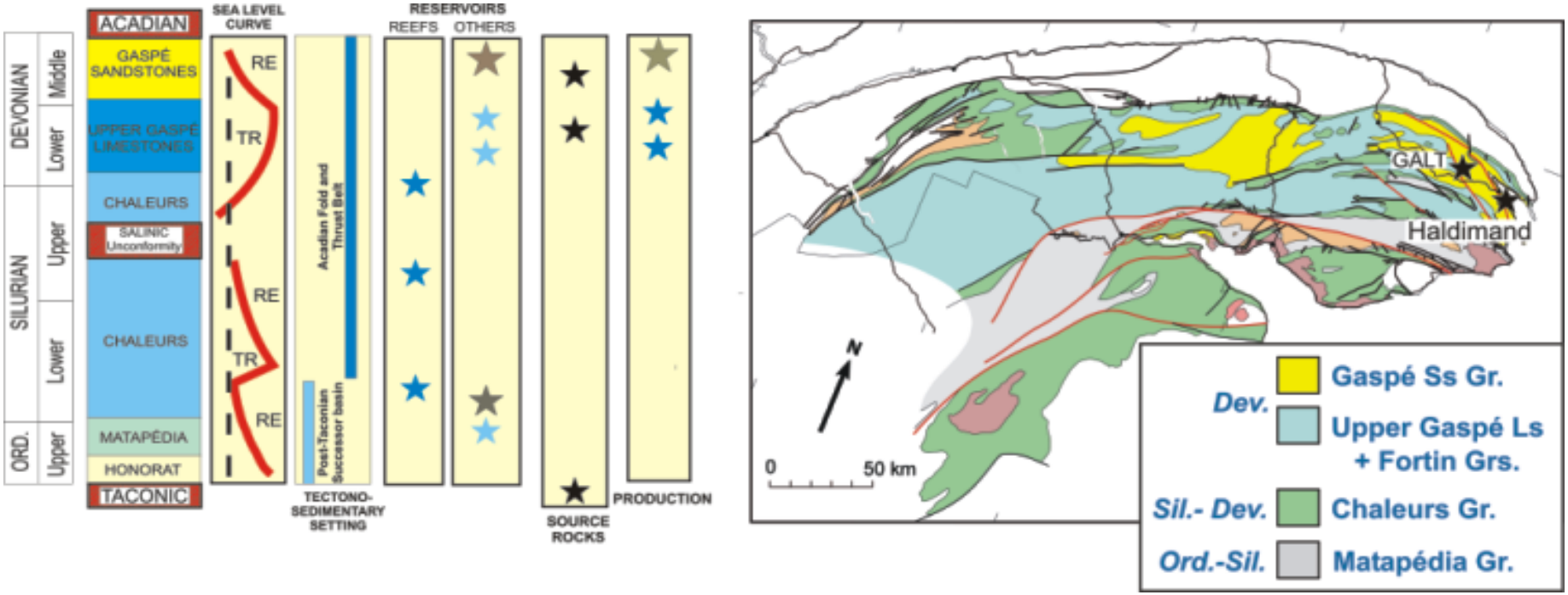

Figure 3. Maturation data for the Silurian-Devonian domain indicates both oil and gas potential.

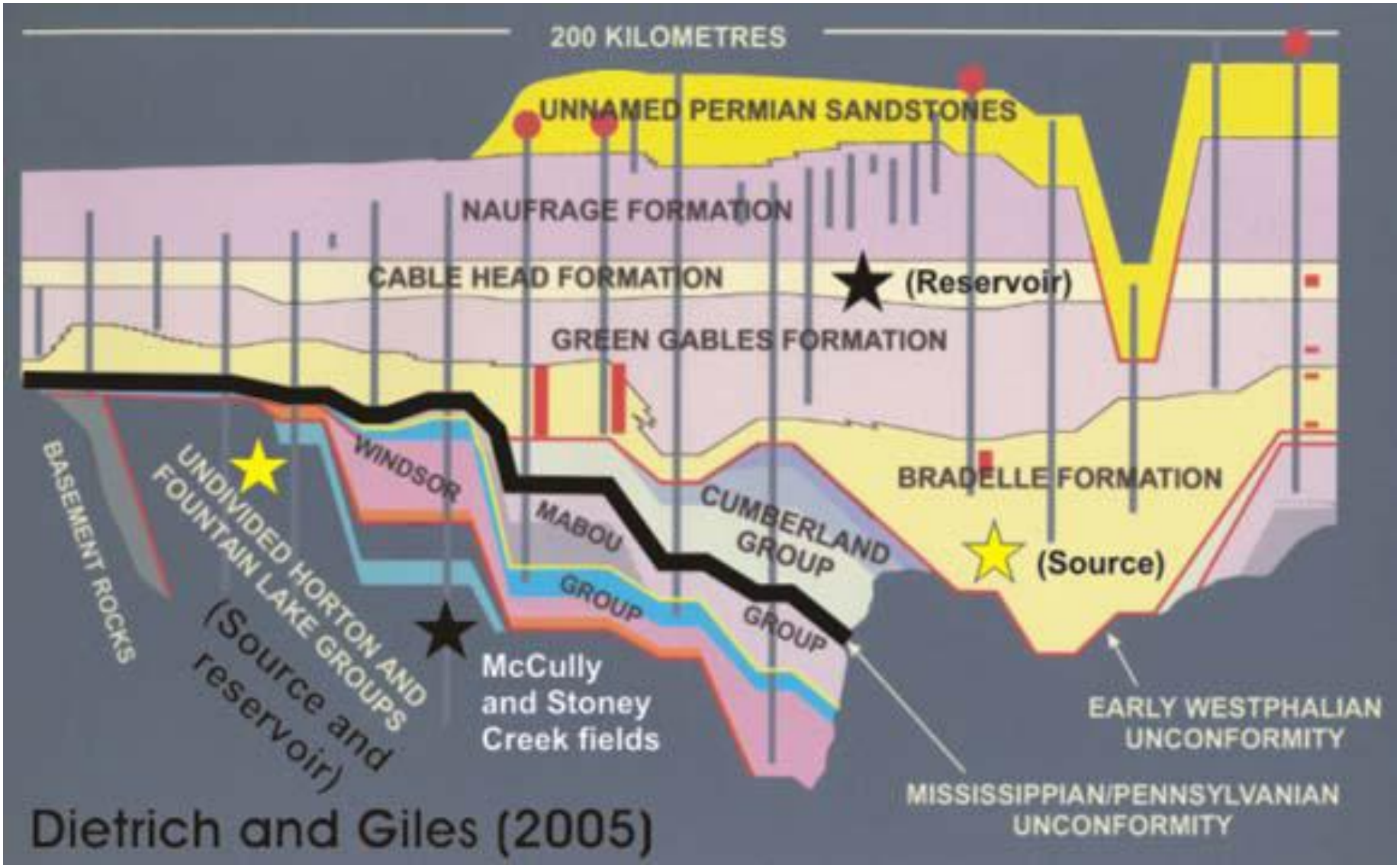

Figure 4. The Carboniferous to Permian succession in eastern Canada.

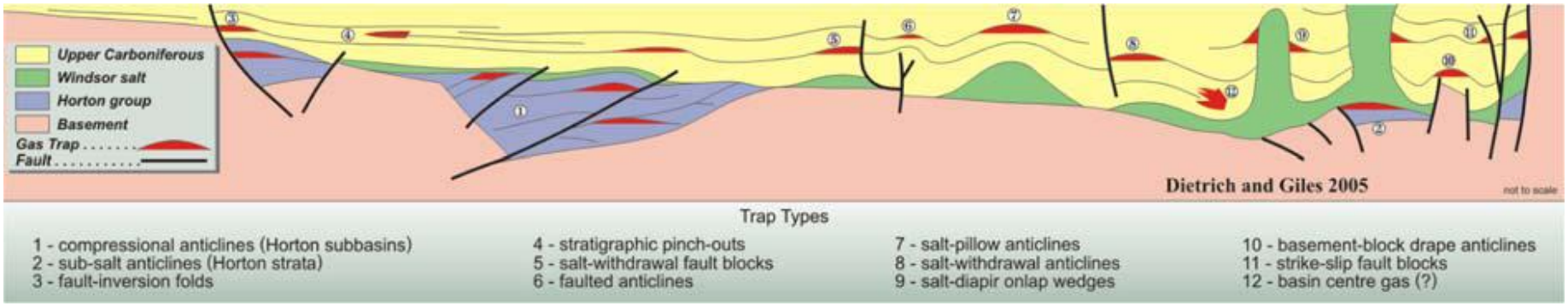

Figure 5. Stratigraphic and tectonic traps proposed in the upper Alleghenian system.