The Oil and Gas Plays of Ontario

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The oil and gas industry in Ontario has had a long and storied history since the first commercial well was dug at Oil Springs in 1858. Today, the Ontario industry remains small but profitable with total cumulative production of over 86 million barrels of oil and nearly 1.3 trillion cubic feet (tcf) of natural gas from rocks ranging from Cambrian to Devonian in age (Table 1). While oil and gas exploration and production has declined in recent years, part of this is due to the fevered activity in the north-eastern USA and western Canada drawing investment dollars, exploration personnel and equipment away from Ontario. With inflated costs and a slowdown in activity in western Canada, investors should find Ontario attractive with high producer netbacks, low royalties and leasing costs, convenient access to exploration data, low transportation costs, easy road access and numerous untested prospects in five classic petroleum plays.

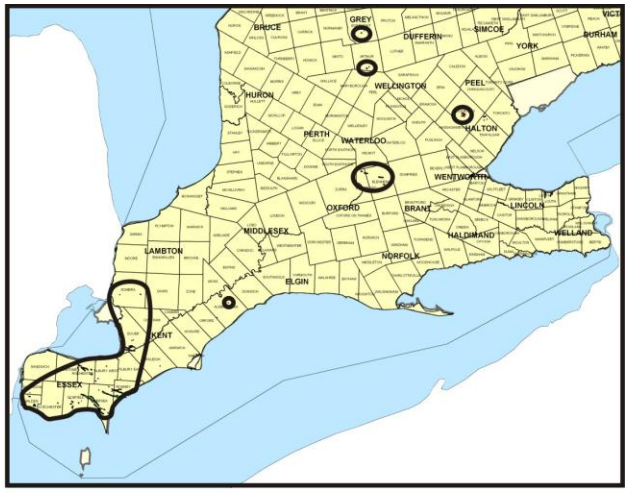
Interval	Cumulative Production through 2006			
	OIL (m^3)	OIL (bbls)	GAS (x1000 m^3)	bcf
DEV	7,035,308	44,250,756	0	0
SAL	2,285,983	14,378,400	22,806,196	805.4
CLI	7,520	47,304	11,055,927	390.4
ORD	3,536,097	22,241,382	1,134,633	40.1
CAM	828,475	5,210,955	844,943	29.8
Total	**13,693,383**	**86,128,797**	**35,841,700**	**1,265.7**

Table 1. Cumulative Oil and Gas Production in Ontario

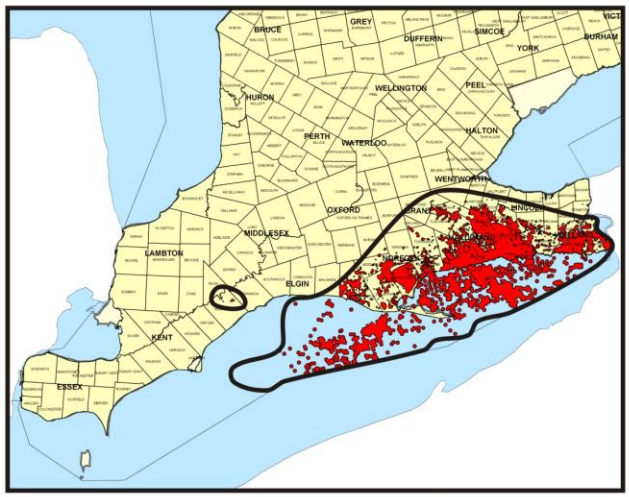
The plays

All of Ontario's oil and gas discoveries and production to date are found in southern Ontario in Paleozoic rocks of the Michigan and Appalachian basins. Commercial quantities of oil and gas have been discovered at several stratigraphic intervals and comprise 5 principal plays: CAM – structural and stratigraphic traps in Cambrian sandstones and sandy dolomites; ORD – hydrothermal dolomite reservoirs in middle Ordovician limestones; CLI – stratigraphic traps in lower Silurian sandstones and associated carbonates; SAL – reefs and structural traps in middle Silurian carbonates; and DEV – structural traps in Devonian fractured, dolomitized carbonates and sandstones (Figures 1 and 2).

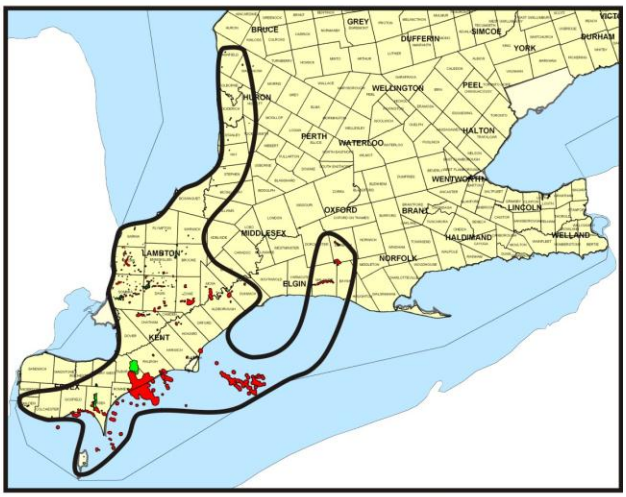
Cambrian Play



Ordovician Play



Silurian - Sandstone Play



Silurian - Salina - Guelph Play

Devonian Play

Figure 1. Approximate boundaries of principal oil and gas producing areas (past and current) in southwestern Ontario, with counties shown for reference.

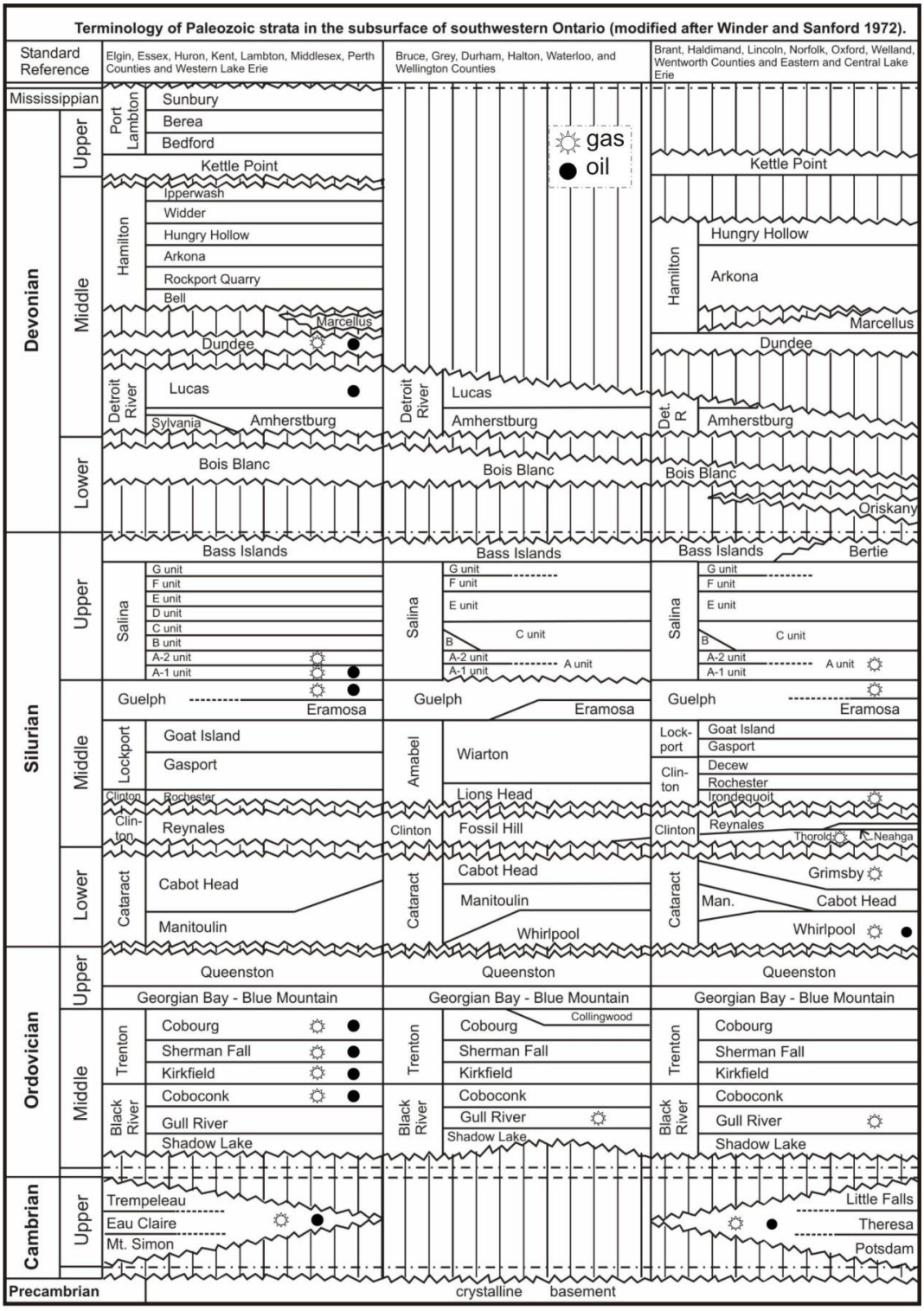


Figure 2. Subsurface stratigraphy of southwestern Ontario (Armstrong and Carter, 2006).

Cambrian Play (CAM)

The sedimentary rocks of the Michigan and Appalachian basins in southern Ontario are separated by a ridge known as the Algonquin Arch. During late Cambrian time most of Ontario was covered by warm shallow seas which deposited sandstone, limestone/dolomite and sandy limestones and dolostones over

all of southern Ontario, including the arch. However, much of the Cambrian and Lower Ordovician sediments were subsequently eroded away during early Ordovician time leaving the crest of the arch almost completely bare of Cambrian sedimentary rocks. Focus of exploration of the Cambrian plays is therefore restricted to the basins bordering the arch, with all of Ontario's Cambrian production to date occurring from rocks in the Appalachian Basin (Figure 3).

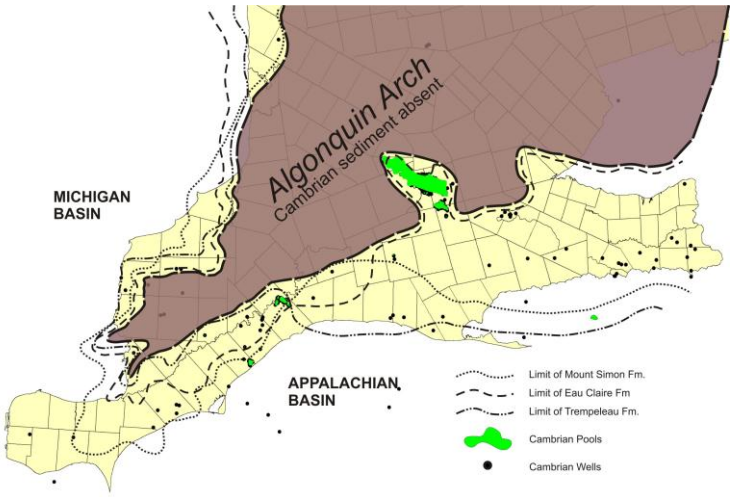


Figure 3. Subcrop limits of Cambrian sandstones in Ontario. Modified from Trevail, 1990.

Cambrian reservoirs occur as (1) structural traps associated with faulting and, (2) stratigraphic traps along the Cambrian sub-crop edge (Figure 4). Structural traps occur where fault blocks of porous and permeable Cambrian sandstones and sandy dolostones are juxtaposed against the overlying less permeable Ordovician shales and limestones. Stratigraphic traps occur where Cambrian sedimentary rocks are truncated or pinch out up-dip along both sides of the arch in the Michigan and Appalachian basins. Overlying Middle Ordovician shales and limestones provide a cap rock.

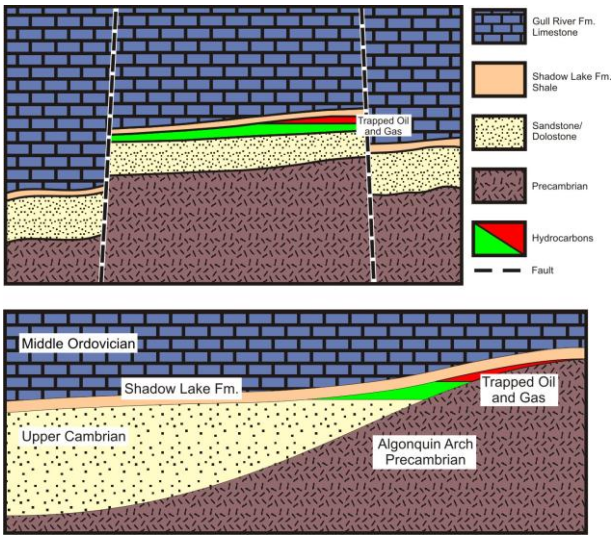


Figure 4. Trapping styles in Cambrian sandstones. Top, structural trap associated with faulting. Bottom, pinch-out style trap along Algonquin Arch. Modified from Bailey Geological Services Ltd. and Cochrane, 1984.

Discovered pool sizes range up to a maximum of 1.8 million barrels of oil and 31 bcf of natural gas at depths ranging from 700 to 1200 metres. A total of only 1050 wells have been drilled to test Cambrian targets to the end of 2007 in a prospective area of 48,000 km^2. Of the 22 Cambrian pools discovered in southern Ontario since 1923, 11 are still active.

There is still considerable potential for the Cambrian in Ontario. Bailey Geological Services Ltd and Cochrane (1984) estimated the potential reserves in the stratigraphic pinch-out type play to be 180 bcf of gas and 19.1 million barrels of oil, and for the structural play, 42 bcf of gas and 112.3 million barrels of oil. However, by the end of 2006, only 5.2 million barrels of oil and 30 bcf of gas had been produced from both play types combined. Although the Michigan side of the arch has not produced any commercial quantities of oil or gas, favourable trapping conditions exist. Exploration strategies need to incorporate mapping of the Cambrian erosional limit to assist in locating future prospects. A recent study also suggests that some of the sandstones mapped as Cambrian in the pinch-out play are actually a sandy facies of the Middle Ordovician Shadow Lake Formation. More oil and gas may be trapped in isolated lenses of Shadow Lake sands preserved in depressions on the crest of the Algonquin Arch, and would constitute a new play type.

Ordovician Play (ORD)

The Ordovician play in Ontario is a continuation of the prolific Trenton-Black River Group hydrothermal dolomite play of Ohio, Indiana, Pennsylvania, West Virginia, Michigan and New York. The play has seen production of more than 485 million barrels of oil and 1 tcf of gas from Ohio and Indiana and more than 146 million barrels of oil and 275 tcf of gas in Michigan, most notably from the Albion-Scipio field. In New York State, the Trenton-Black River Group has produced over 154 bcf of gas since 1995 and accounted for 80% of the state's gas production in 2005.

Ordovician gas was first discovered in the late 1800's and was in commercial production at the turn of the century. Successful application of seismic techniques by Ontario-based exploration companies in the early 1980's led to a string of new discoveries and rejuvenated this play. A recent reassessment of Trenton-Black River oil and gas reserves (Golder Associates, 2005) estimated total potential reserves of 281 bcf of gas and 39.7 million barrels of oil in Ontario. The report was highly favourable for continued exploration because 85% of the gas volume and 43% of the oil volume has yet to be discovered.

Oil and gas in these pools are trapped in Middle Ordovician carbonates of the Trenton and Black River Groups where the regional limestones have been dolomitized and fractured adjacent to vertical wrench faults (Figure 5). The faults are believed to have provided a conduit for movement of hydrothermal waters which subsequently altered the limestone to porous and permeable dolostone in the immediate vicinity of the faults. The resulting linear hydrothermal dolomite reservoirs reach up to 14 kilometres in length and several hundred metres in width. The marine shales of the overlying Blue Mountain Formation provide a vertical cap to the reservoirs with unaltered limestones limiting their lateral extents. Porosities and permeabilities can vary widely, both laterally and vertically, resulting in pods and sweet spots of enhanced porosity and permeability.

Discovered pool sizes in Ontario range up to a maximum of 6.1 million barrels of oil and 14 bcf of natural gas at an average depth of 800 to 850 metres. Approximately 1150 wells have been drilled to date to test Ordovician targets in a prospective area of over 130,000 km^2. Most of the recently drilled

wells have been horizontal. Several long-reach horizontal wells have been drilled since 1998 to exploit extensions of the pools beneath Lake Erie. Drilling for oil from wells located on the lake is not permitted.

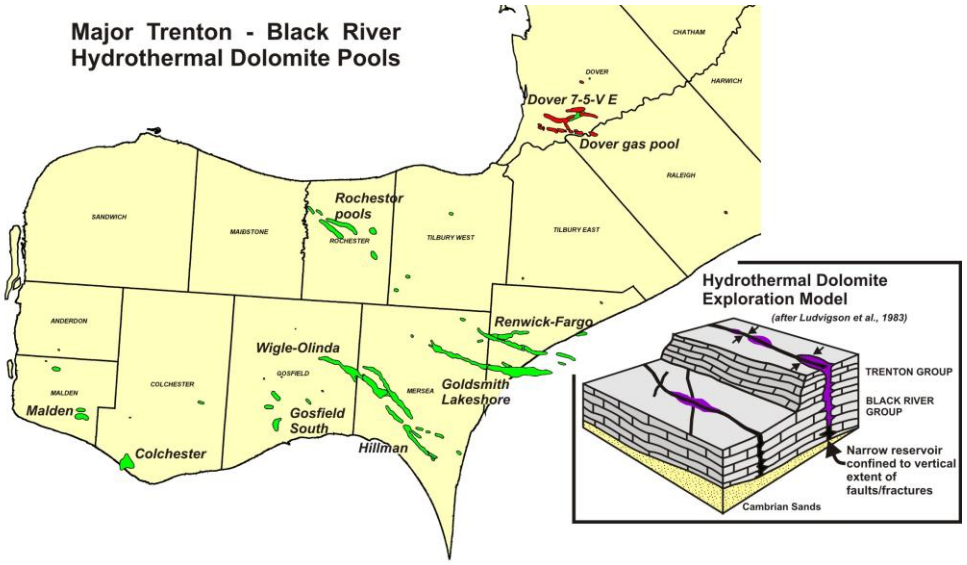


Figure 5. Trenton-Black River hydrothermal dolomite pools and exploration model. Modified from Golder Associates (2005).

Current exploration methods focus on 2D and 3D seismic. Typically a subtle but resolvable structural depression over the dolomitized zone can be seen in the seismic section, as well as vertical displacement of the underlying Precambrian crystalline basement rocks and a change in the seismic character occurring at the boundary between the highly porous dolomite and the unaltered limestone.

Silurian Sandstone Play (CLI)

Gas-prone sandstones of Lower to early Middle Silurian age constitute the oldest Silurian strata in southern Ontario. They underlie an extensive area beneath the Niagara peninsula and eastern and central Lake Erie (Figure 6), extending south through Pennsylvania, Ohio and New York, and into northern Kentucky. The sandstones have been a historically important source of natural gas production since gas was first discovered in Welland Township in 1889. By the end of 2006, 236 bcf of gas had been produced on-shore and 152 bcf had been produced from beneath Lake Erie, with all of the Lake Erie production coming since the early 1960s.

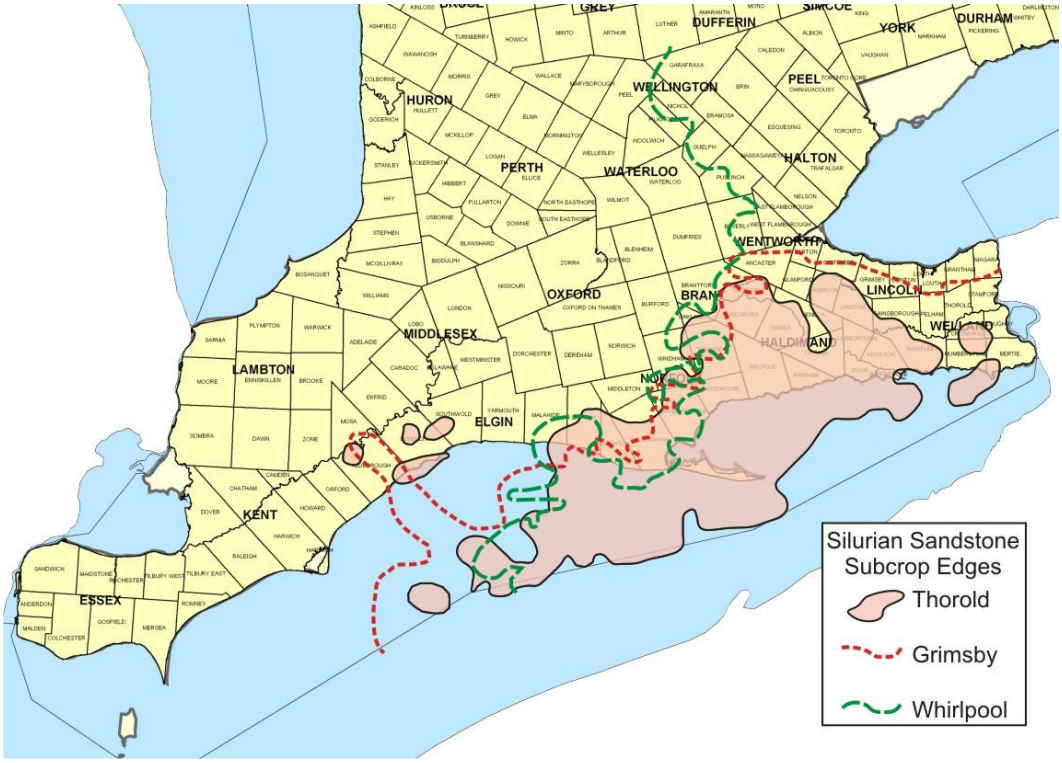


Figure 6. Silurian sandstone Subcrop edges in Ontario.
Modified from Bailey Geological Services and Cochrane, 1986.

During early Silurian time large amounts of sand, silt and clay were eroded from highlands to the south and were deposited into the Appalachian Basin. Sediment grain sizes fine to the northwest into Ontario. Sand deposition was restricted to the Appalachian side of the Algonquin Arch. Within this wedge of clastic sediments porous sands are generally confined to the Whirlpool Formation and the Grimsby and Thorold formations of the Clinton and Cataract Groups. They occur as extensive regional blankets and in channels and bars. Natural gas occurs wherever there is good porosity development, making this a classic continuous distribution style of play.

The continuous nature of the reservoir makes it impractical to define pool boundaries and size with any confidence. Average depth of the reservoirs ranges from as little as 150 metres up to 500 metres. Gross pay thickness varies from a few metres to several tens of metres in several pay zones, with some production occurring from the immediately overlying carbonates of the Irondequoit and Reynales formations (Figure 7).

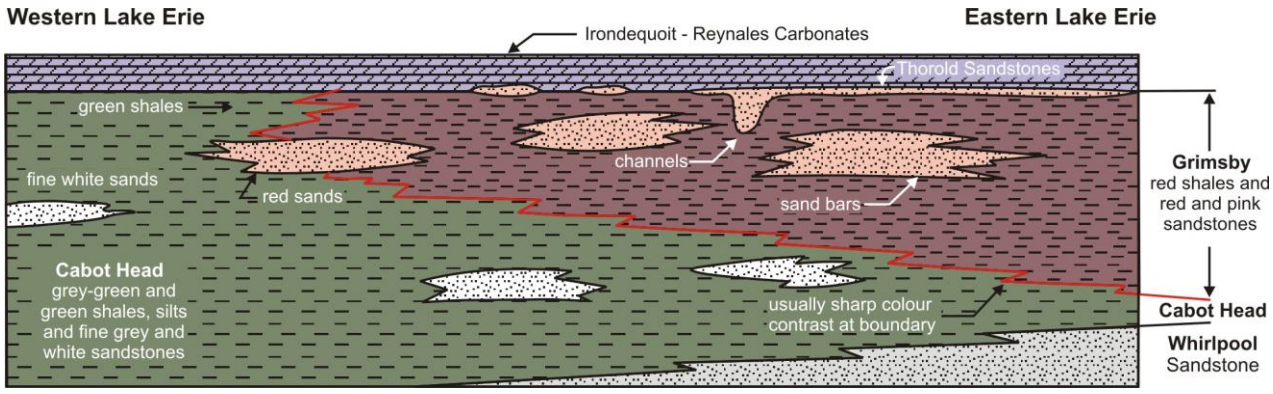


Figure 7. Conceptual cross-section through the Cabot Head-Grimsby strata of eastern Lake Erie showing lateral facies changes. Modified from Bailey Geological Services and Cochrane, 1985

The Silurian sandstone play is a mature play, but exploration and development drilling is continuing in areas not previously drilled. Bailey Geological Services Ltd. and Cochrane estimated proven recoverable gas reserves of 260 bcf from Lake Erie of which 106 bcf of gas is yet to be produced.

Silurian Carbonate Play (SAL)

The late Middle to Upper Silurian saw a return to warm equatorial seas over what is now southern Ontario and Michigan. These conditions were ideal for the formation of barrier and patch reef complexes in the warm shallow waters of the Ontario Platform, and for the formation of towering pinnacle reefs in the deeper waters sloping into the Michigan Basin (Figure 8). In Ontario, these reefal carbonates are known as the Guelph Formation, while in Michigan they are known as the Niagaran. The Guelph reefs were subsequently buried by carbonates, evaporites and minor shales of the Upper Silurian Salina Group (Figure 9). Hydrocarbon reservoirs occur within the Guelph Formation reefs and the A-1 Carbonate and A-2 Carbonate units of the Salina Group.

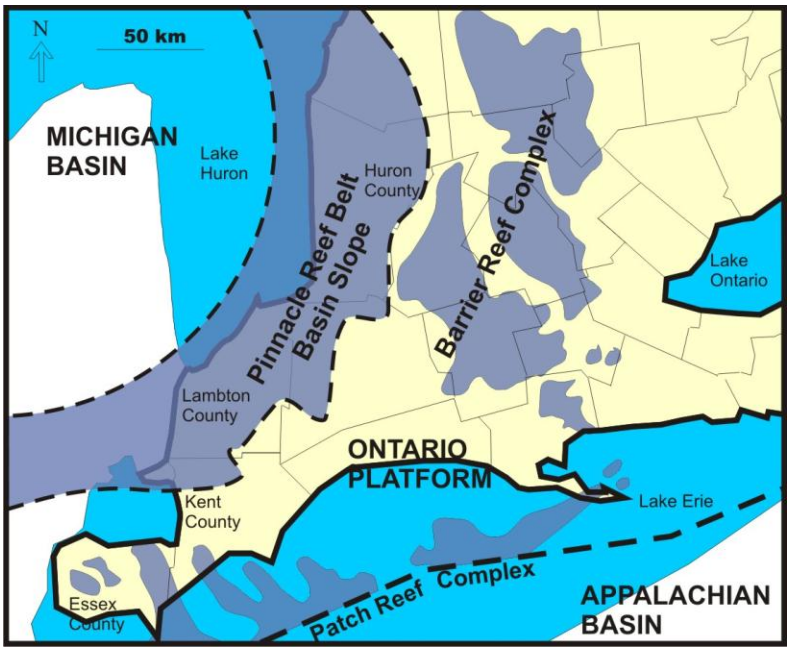


Figure 8. Reef belts in Ontario. Modified from Coniglio et al., 2003.

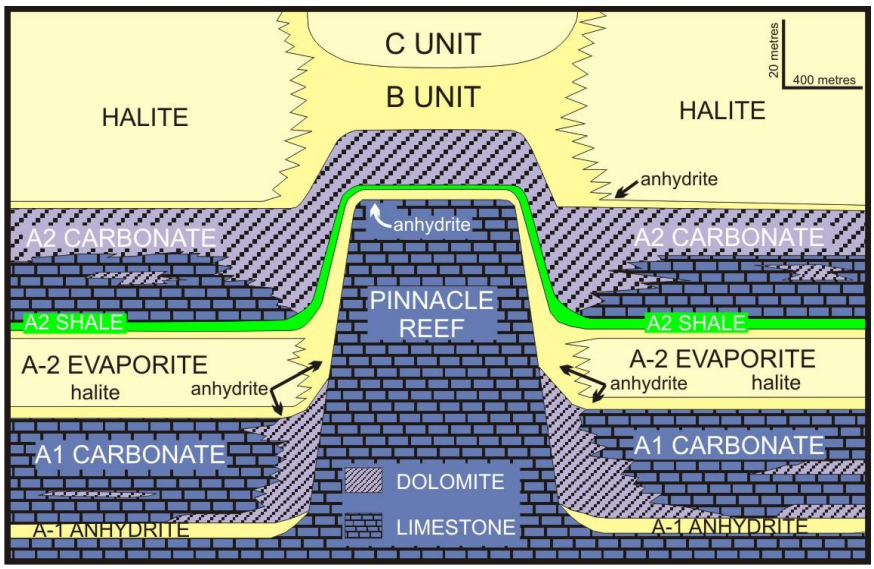


Figure 9. Schematic summary of lower Salina Group units overlying and adjacent to Guelph Formation pinnacle reefs in Lambton County. Modified from Carter et al, 1994.

Within the Guelph Formation, three distinct reef types are seen. Pinnacle reefs are reef buildups greater than 50 metres in height and extend through the subsequent deposition of A-1 carbonate. They occur in the pinnacle reef belt running through Lambton, Huron and Bruce counties. Incipient reefs are less than 50 metres in height and occur in the same reef belt. Patch reefs also exhibit less than 50 metres of buildup but underlie very large geographic areas. Most of these reefs have been dolomitized. Oil and gas reservoirs occur within all three reef types and are sealed by impermeable anhydrites and carbonates of the overlying Salina A-2 and A-1 units.

Hydrocarbons also occur in dolomitized sections of the Salina A-1 and A-2 Carbonate units where porosity is developed and a trapping mechanism exists. Hydrocarbon traps most commonly occur on the upthrown side of regional faults and in structural drapes over reef buildups in the underlying Guelph Formation.

Discovered pool sizes range up to a maximum of 280 bcf of natural gas in the patch reefs. Pinnacle reefs may contain up to 42 bcf of natural gas and 1.6 million barrels of oil. Depths range from 300 to 700 metres. Thirty pinnacle reefs have been converted to natural gas storage with total working gas volume of 243 bcf of natural gas. Approximately 5000 wells have been drilled to date to test targets in these middle Silurian carbonate rocks.

This is a mature play with opportunities for further discoveries both on and offshore. There is potential for conversion of additional reefs for use as natural gas storage reservoirs. While early exploration methods focused on gravity anomalies to locate pinnacle reefs, both 2D and 3D seismic have become far more important in combination with careful study of drill cuttings samples to identify reef proximity indicators. Careful mapping of dolomitization patterns and thickness of the A-1 Carbonate Unit may also provide a useful guide to undiscovered pinnacle reefs.

Devonian Play (DEV)
In 1858 James Miller Williams dug the first commercial oil well in North America into shallow Middle Devonian carbonate rocks at Oil Springs, Ontario. After 150 years, oil is still produced from this area. By the end of 2006, total cumulative oil production from the Middle Devonian totalled more than 44.3 million barrels and oil continues to be produced from six active pools.

Oil production from Devonian rocks is confined to the Lucas and Dundee Formations and a sandy facies of the Lucas locally referred to as the Columbus. Only minor gas production has been reported from the Devonian carbonates of Ontario, but there may be potential for shale gas in overlying black shales. The Devonian rocks are restricted to the western portion of southwestern Ontario. Reservoirs consist of fractured, microporous limestones, dolomitic siliciclastics, sand-rich limestones and fractured limestones with no associated matrix porosity. All of the Devonian oil pools are located on structural domes which are the result of differential dissolution of salt beds in the underlying Salina Group (Figure 10).

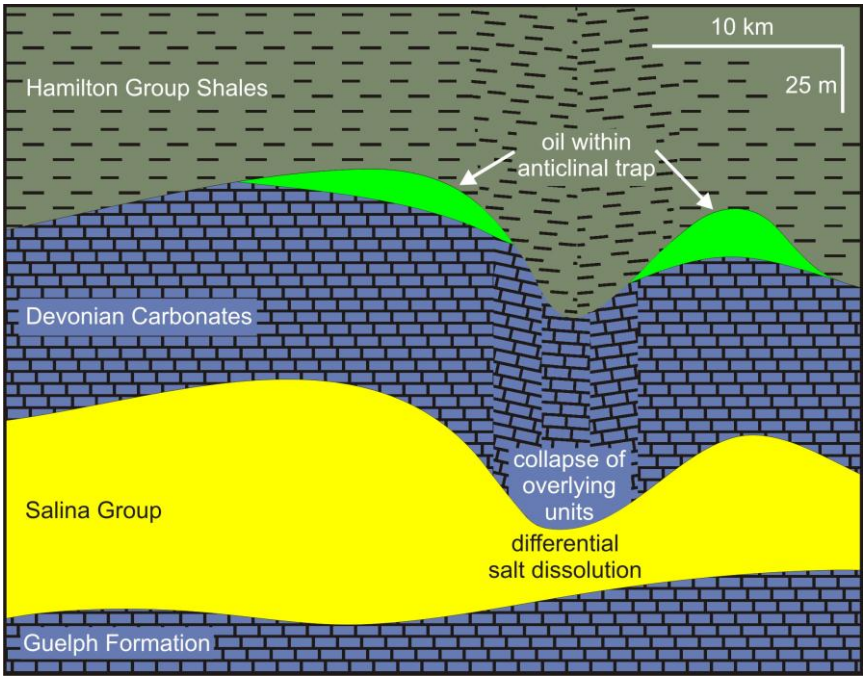


Figure 10. Conceptual model of Devonian structural traps formed by differential salt dissolution in the Salina Group.

Discovered pool sizes range up to a maximum of 18.4 million barrels of oil at depths not exceeding 150 metres. Secondary recovery methods have proven very effective in extending the life of these older pools. Water injection in the Rodney Pool resulted in a 232% increase in daily production and 55% recovery of original in-place oil.

The Devonian oil reservoirs are a mature play and only two small pools have been discovered since the 1949 discovery of the Rodney Pool in the Columbus sands. This may be due more to a lack of modern exploration effort specifically targeting Devonian reservoirs rather than a lack of targets. The shallow depth and potentially large pool size make this play worthy of further investigation, despite its long

history of exploitation. Detailed mapping and interpretation of subsurface structures will be key in locating these targets.

For More Information

Armstrong, D.K., and Carter. T.R. 2006. An updated guide to the subsurface Paleozoic stratigraphy of southern Ontario, Ontario Geological Survey, Open File Report 6191, 214 p.

Bailey Geological Services and Cochrane, R.O., 1984-1990. Evaluation of the conventional and potential oil and gas reserves of Ontario; Ontario Geological Survey, Open File Reports 5498, 5499, 5555, 5578, 5722.

Carter, T.R., Trevail, R.A., and Smith, L., 1994. Core workshop: Niagaran reef and inter-reef relationships in the subsurface of southwestern Ontario; Geological Association of Canada 1994 Annual Meeting, Waterloo, Ontario, Field Trip A5 Guidebook, 37 p.

Golder Associates, 2005. Hydrocarbon resource assessment of the Trenton-Black River hydrothermal dolomite play in Ontario, Ontario Oil, Gas and Salt Resources Library, 35 p., 27 figures, 8 tables, 11 cross-sections, 7 pool maps, 4 appendices.

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