Dolomitization, platform collapse, and reservoir development in Ordovician carbonates of Anticosti Island, Gulf of St. Lawrence

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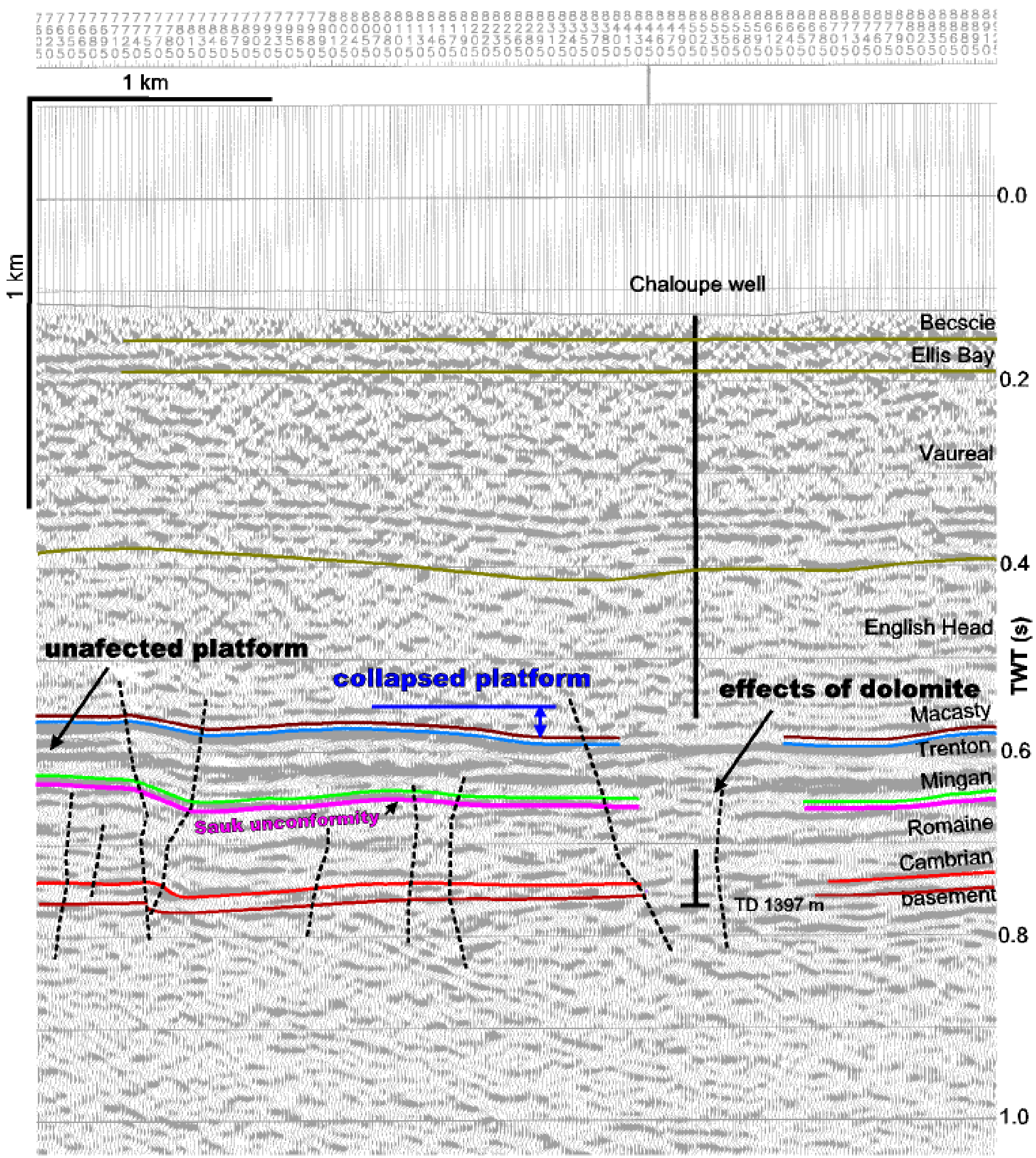
Recent drilling on Anticosti Island has encountered widespread hydrothermal dolomitization in Ordovician carbonate platform rocks, locally enhancing reservoir development and quality. Large fracture systems and platform collapse are associated with the dolomitization, and reservoirs developed in this manner can now be mapped seismically (Figure 1).

Early hydrocarbon exploration on Anticosti Island was undertaken in the 1960-70's by companies such as Imperial Oil, ARCO, and Soquip, where a total of eight wells were drilled, covering a very large region. Despite a lack of success in those wells, recent interest in the region has been renewed from encouraging results in Ordovician carbonates of southwest Newfoundland (e.g. Port aux Port #1 well). Hence a new round of exploration was undertaken on Anticosti, beginning in earnest in 1997, through a farmout taken by Shell Canada Limited and Encal Energy Limited from Corridor Resources. Five wells and some 400 km of seismic fulfilled the requirements.

Ordovician-Silurian miogeoclinal carbonate rocks underlie Anticosti Island and much of the northern Gulf of St. Lawrence. The subsurface stratigraphic framework established by SOQUIP is adopted here. Correlative units extend into the St.Lawrence Lowlands and further to the southwest into the Michigan Basin as well as into New York state. The stratigraphy may be extended even further through the U.S mid-continent down into southwest Texas, as part of the western rim of the ancient Iapetus Ocean. On Anticosti Island, in ascending stratigraphic order above the Grenville basement potential reservoir rocks include lower Ordovician shallow marine to peritidal dolomites of the Romaine Formation, sandy carbonates of the Mingan Formation, and open marine limestone of the middle Ordovician Trenton Formation. Structurally, units dip moderately to the south-southwest in a broad regional monocline in front of the Apalachian thrust belt. On Anticosti Island the Jupiter fault is a large steep structure running northwest-southeast diagonally through the island, with the downdropped block on the southwestern side of the fault. Subsidiary faults have also been mapped, and like the Jupiter fault are attributed to crustal flexure well in front of the Taconic deformation belt.

Exploration play-types which apply to Anticosti Island include the Albion-Scipio (Michigan) and Ellenberger (Texas) analogues, for reservoir units in the Trenton and Romaine formations respectively. Similarities are also recognized with hydrothermal dolomite plays in northern Alberta and British Columbia. On Anticosti, faults, fractures, and secondary hydrothermal dolomitization have generated porosity in both the Trenton limestones and Romaine dolomites. Primary facies-controlled porosity and secondary dolomite leaching (possibly karsting) are recorded in the Romaine Formation. The Macasty shale is an organic-rich source rock which is positioned directly above the Trenton Formation, and passes from a sub-mature state, to within the oil and gas windows with increasing depth across the island toward the southwest. Hydrocarbon shows in some wells and fluid inclusion data indicate a charged system.

Figure 1. LINE 203 Shell-Encal-Corridor Anticosti Chaloupe well, shows effects of dolomitization on seismic character, including sag of top Trenton reflector and disruption of internal seismic marker.



Five wells were drilled on Anticosti Island, to depths ranging from 1375-2785 m. The Jupiter and Roliff wells were drilled in the summer of 1998 in the central region of Anticosti Island. The wells targetted structural closure on the upthrown and downthrown blocks straddling the Jupiter fault. Zones of interest included the Trentom/Black River, Mingan, and Romaine formations. Extensive hydrothermal dolomitization was encountered in the Romaine Formation in both wells. Numerous porous intervals were found, though permeability is invariably low apparently due to pore throat closure from over-dolomitization.

In 1999 three relatively shallow wells were drilled on the eastern side of Anticosti Island in order to explore three different play concepts. The Chaloupe well was drilled into a zone of fractured Trenton Formation rocks where the seismic signature is characterized by sag along the upper contact of the Formation and an internal chaotic aspect, reflecting the fractured and dolomitized nature of the unit here. At 1070 m in the middle Trenton a 70 m thick zone of highly permeable fracture porosity was encountered. Loss of circulation on the order of 270 m^3 mud while drilling through1070-1260 m depth caused significant drilling problems. Dynamic losses peaked at 5 m^3/hr. A 40 m thick porous interval was also encountered at the top of the Romaine Formation where the gas log recorded 2000 parts above background of methane. The drill stem test (DST) in this lower zone showed saline formation water flowing from reservoir with excellent permeability.

Bulk fluid inclusion analysis was performed on samples from cuttings, in 5 m sample intervals for the Trenton, Mingan, and Romaine Formations, in eight wells on Anticosti Island. Hydrocarbons trapped in inclusions are abundant and widespread indicating paleocharge. Furthermore the distribution of hydrocarbons in inclusions closely matches the burial profile for the Anticosti platform: Deep wells drilled into the gas window where the Macasty source rock has a VR > 1.2 contain gas-rich inclusions, whereas shallower wells contain oil-rich inclusions in the less mature sectors of the island (Figure 2).

From the standpoint of characterizing the seismic data, the Chaloupe well makes an important contribution by showing that abrupt chaotic discontinuities in the otherwise regular reflective nature of the Trenton represent permeable dolomitized fracture zones with good reservoir qualities. Numerous such zones can now be recognized from the seismic data in this region, providing other targets and potential opportunities.

Presently, the opportunity exists for a company to step in and rejuvenate activity on the island through farmin. In view of the success enjoyed in similar settings (e.g. Trenton play in New York state or Ladyfern in Alberta), this opportunity represents a high risk but potentially high reward play.

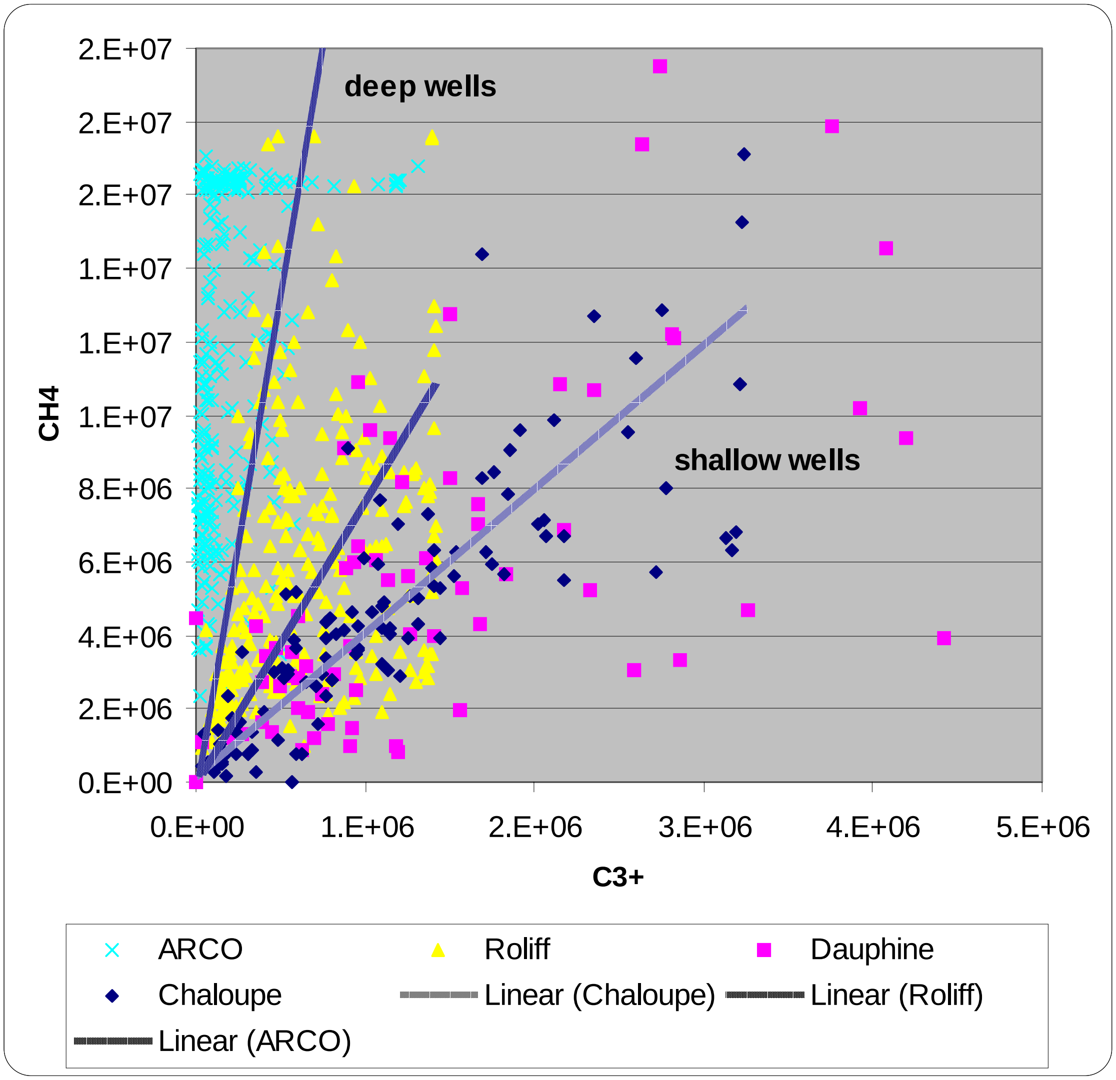
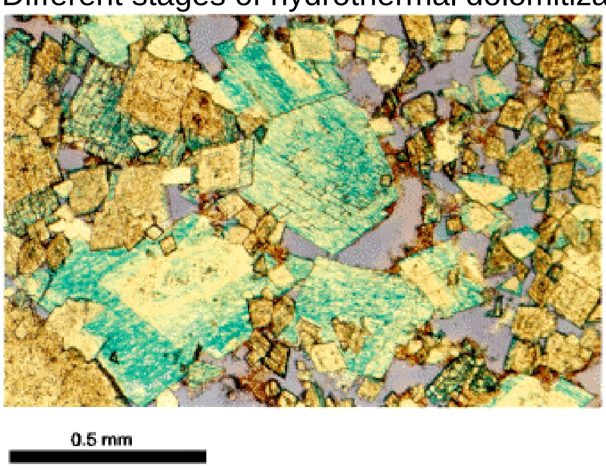


Figure 2. Bulk fluid inclusion analyses from cuttings for wells on Anticosti Island, indicating tendency of deep wells to be gas prone and shallow wells to be oil prone. Samples collected from Romaine, Mingan, and Trenton formations.

Reservoir and dolomitization

From petrographic observations made on sidewall cores several stages of dolomitization affecting the Romaine, Mingan, and Trenton formations are recognized. Dolomite dissolution is also an important feature. Also, the post-Romaine unconformity (Sauk) can be recognized in the sub-surface of Anticosti Island based on petrographic and well log evidence, and may have enhanced reservoir properties in the upper portions of the Romaine Formation immediately below the unconformity. Three broad stages of dolomitization can be defined, comprising 1) early dolomicritic and fine grained dolomite in peritidal facies; 2) later medium grained xenotopic or "sucrosic" idiotopic dolomite rhombs precipitated during stages of diagenesis on the platform; and 3) latest fracture controlled hydrothermal Fe-rich saddle dolomite, developed late in the history of the platform likely after significant burial. Dolomite dissolution (dedolomitization) affects the middle stage of diagenetic dolomite, particularly in the Chaloupe and Carleton Point wells and at the QIT quarry to the north on the mainland (Figure 3). Dolomite rhombs with dissolved cores are a distinct textural feature. Porosity-permeability measurements from plugs indicates that dedolomitization significantly improves permeability (Figure 4). Primary porosity is locally facies related, such as in oolitic shoals in the middle Romaine Formation in the Oil River and Princeton Lake wells, or where sucrosic dolomite cements fine grained dolomite clasts from intertidal breccias in the upper Romaine Formation (e.g. Carleton Point well). Vugs and fractures are associated with late hydrothermal saddle dolomite, however effective porosity ranges from good to poor where pore throats have been cemented shut. Hydrothermal dolomitization is intensely developed and widespread in the Romaine Formation and is recorded in all five Shell-Encal wells, whereas dolomitization in the Trenton is less intense and recorded only in the three eastern wells (Chaloupe, Saumon, Dauphine). Different stages of hydrothermal dolomitization appear likely.



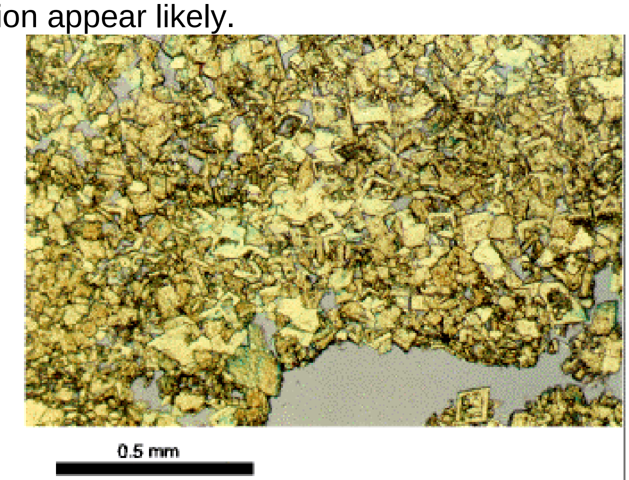


Figure 3. Left-hand photomicrograph shows coarse grained iron rich blue-stained saddle dolomite and vuggy porosity related to hydrothermal circulation in Romaine Formation. Right-hand image shows dissolved cores of altered dolomites (de-dolomitization) and vuggy porosity from the Romaine Formation.

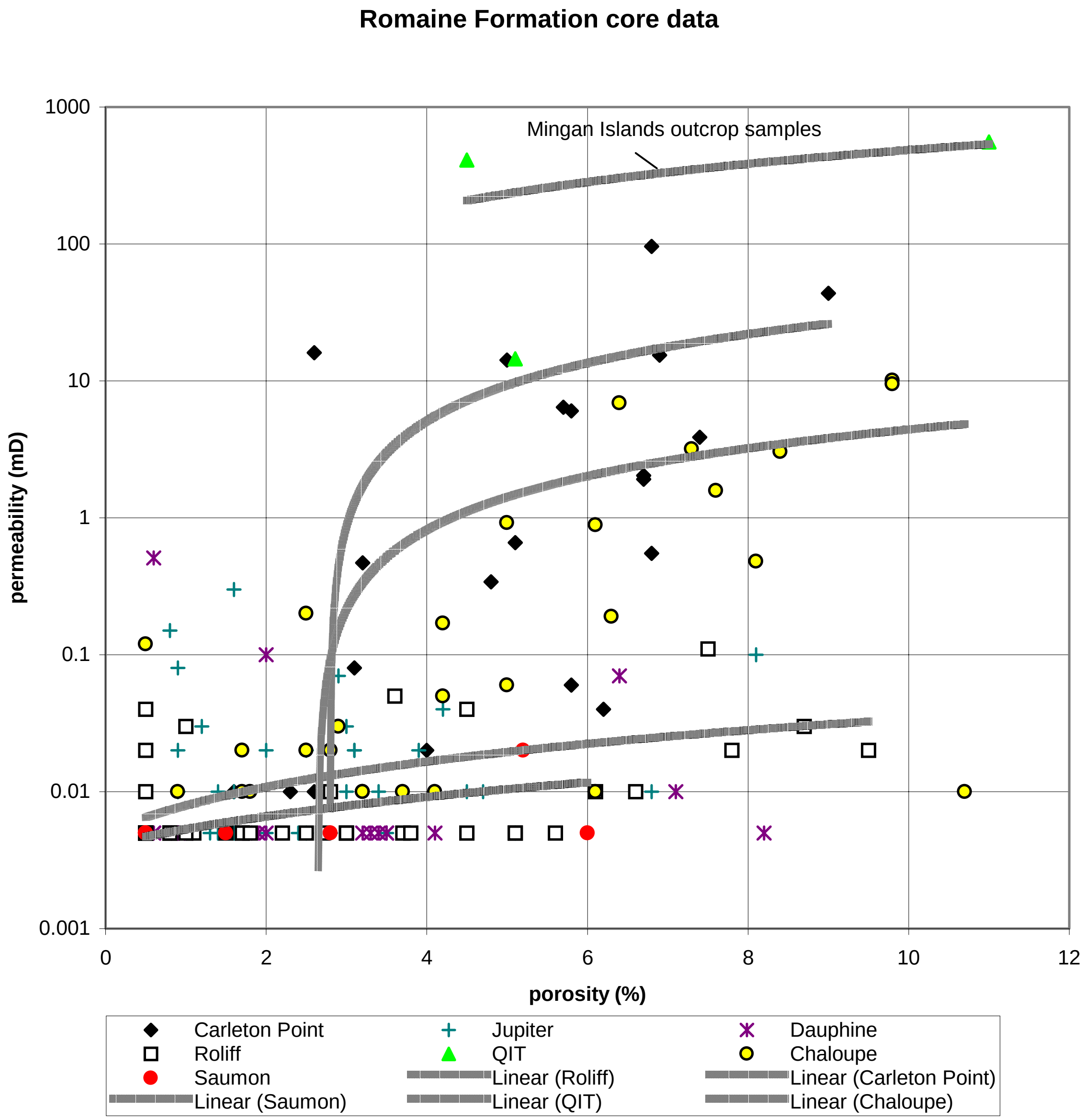


Figure 4. Sidewall core porosity-permeability data demonstrating enhanced permeability within Romaine Formation rocks affected by dolomite dissolution (de-dolomitization) such as at Carleton Point, Chaloupe, and QIT quarry (Mingan Islands); other samples do not show evidence of de-dolomitization and have corresponding low-permeabilities.