

# **PS Depositional Environments of Organic-Rich Calcareous Shale in the Western Anticosti Basin: the Upper Ordovician Macasty Formation, Quebec, Canada\***

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## **Abstract**

The Macasty Formation, equivalent to the Utica shale in the United States and southern Quebec, consists of organic-rich black calcareous shale deposited on top of the shallow water Mingan carbonate platform in a foreland basin during the Taconic orogeny. The sharp boundary between the two units suggests an abrupt change in the basin configuration. The Macasty shale is composed of very fine-grained quartz, feldspar and clay minerals cemented by calcite (up to 45%). We examined the entire section of the Macasty shale (~ 80 m in thickness) in drill hole LGPL on Anticosti Island. The compositions including the mineralogy and major and minor element abundance did not show any significant changes during the deposition of the shale. The siliciclastic components were primarily supplied from granitic rocks of the Grenville province after extensive weathering. These components were deposited in anoxic environments that allowed the accumulation of redox-sensitive elements and organic matter (up to 8 % TOC), and the reduction of marine sulfate to sulfide (0.7 to 1.6 wt% S). The organic matter has  $\delta^{13}\text{C}_{\text{PDB}}$  values ranging from -29 to -23 ‰, which are similar to those of Ordovician sedimentary rocks in other areas. Sulphur isotope compositions for disseminated fine-grained pyrite range from -11 to +1 ‰, which suggest the deposition in a basin with a slightly restricted supply of open ocean water. The sulfide concentrated chalcophile elements, such as As (up to 13 ppm), Cu (up to 61 ppm), Mo (up to 179 ppm) and Pb (up to 39 ppm). The organic matter was responsible for the reduction of soluble  $\text{U}^{6+}$  to  $\text{U}^{4+}$  to be fixed in the sediments, leading to high U/Th ratios (up to 3.5) in organic-rich shale. The abundant calcite in the shale shows  $\delta^{13}\text{C}$  values from -2.8 -to +1.0 ‰ and  $\delta^{18}\text{O}_{\text{PDB}}$  from -8.6 to -2 ‰. Combined with the finely crystalline texture of calcite, it is interpreted to have been precipitated at temperatures from 40 to 55 °C after the deposition of the siliciclastic material and organics, but before any significant compaction. The introduction of this slightly oxidizing diagenetic solution was accompanied by the crystallization of coarse-grained pyrite with variably high  $\delta^{34}\text{S}$  values from - 3 to +28 ‰.



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### Abstract

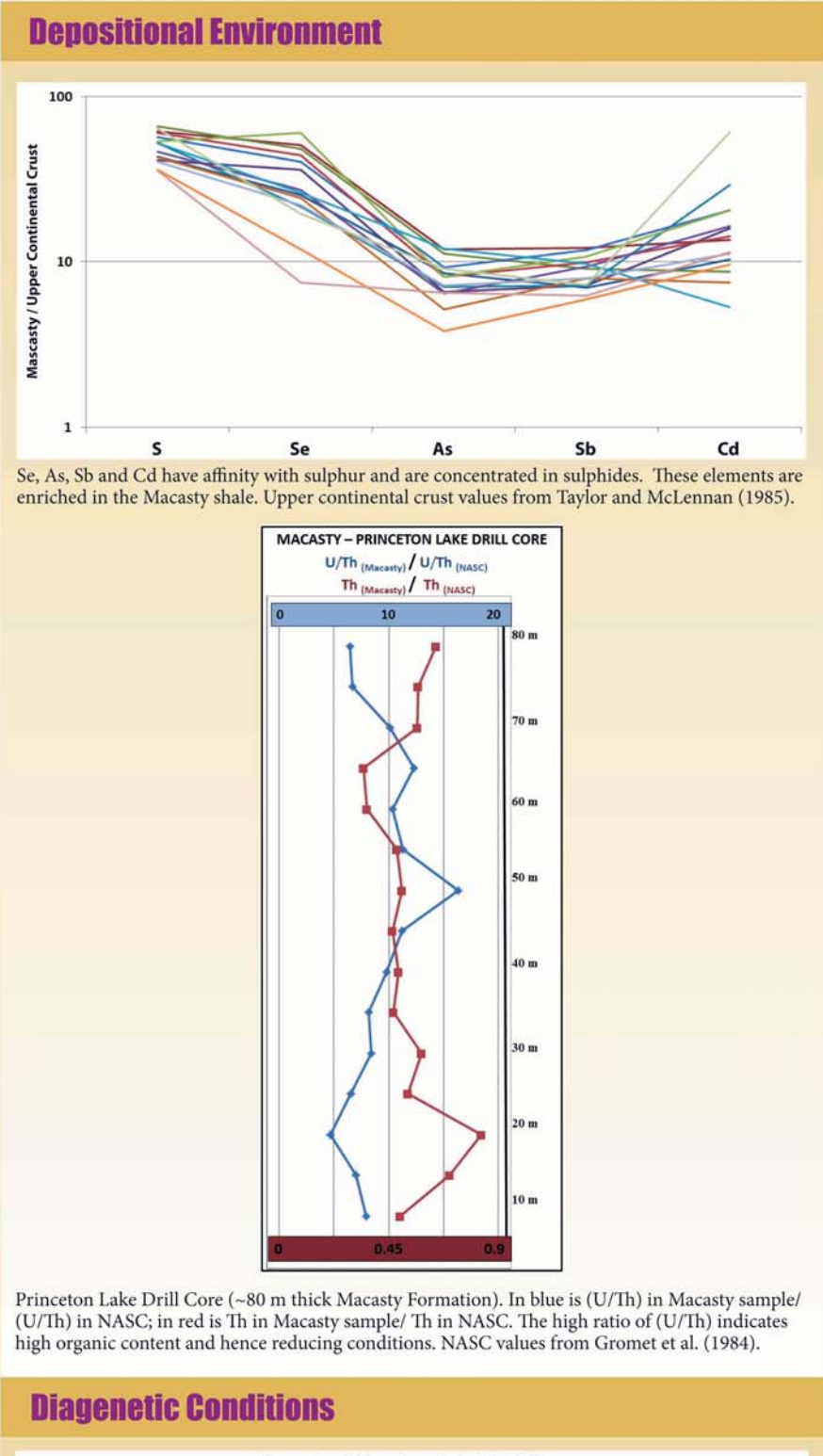
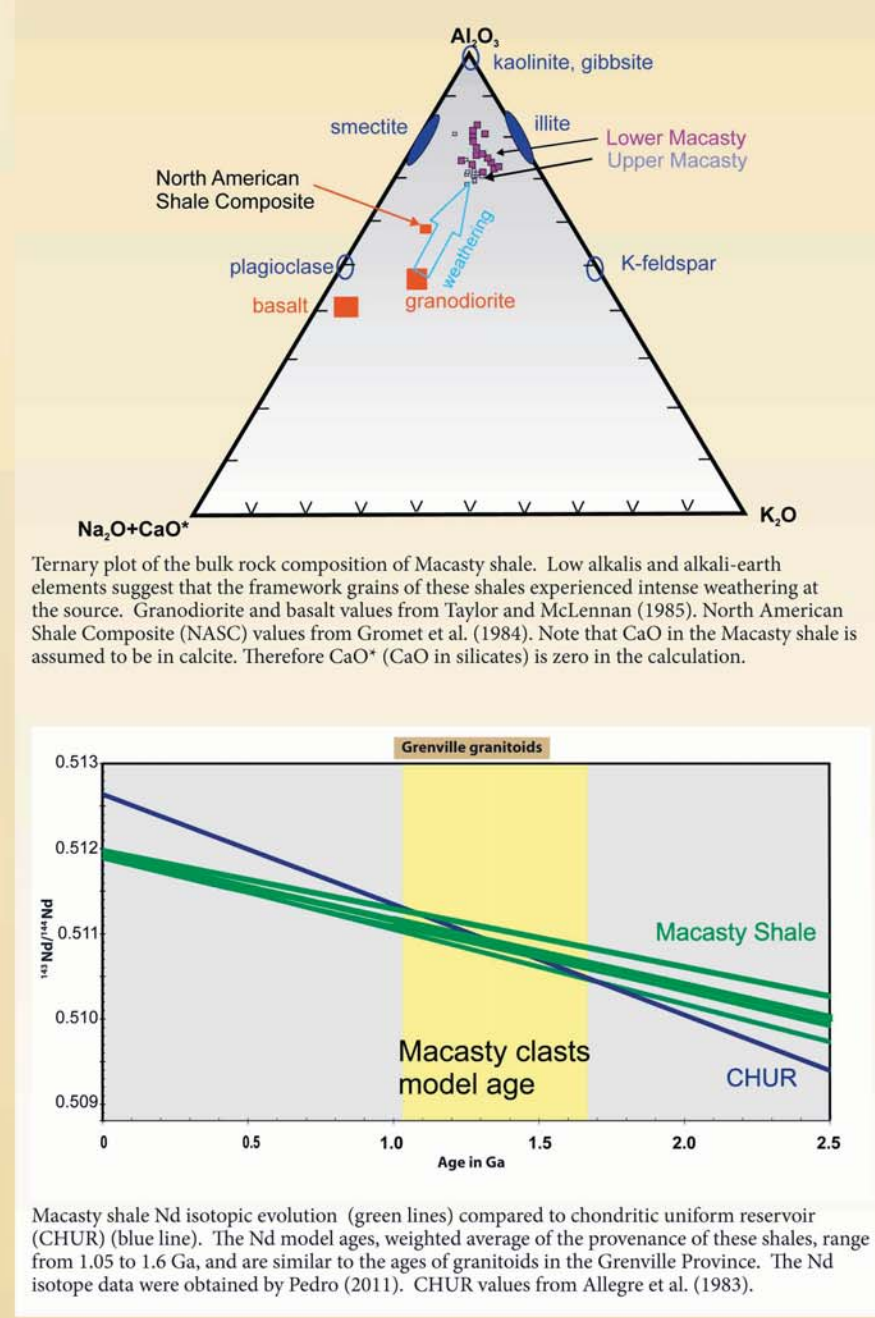
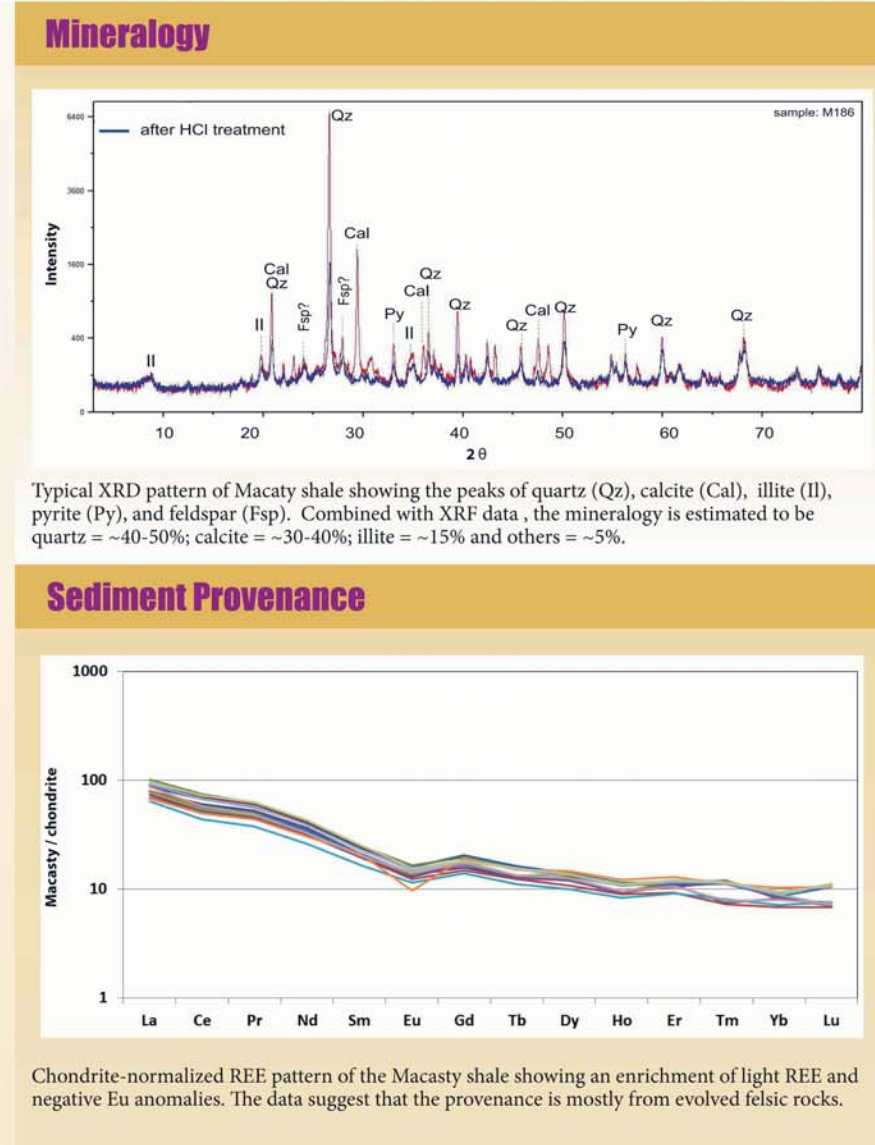
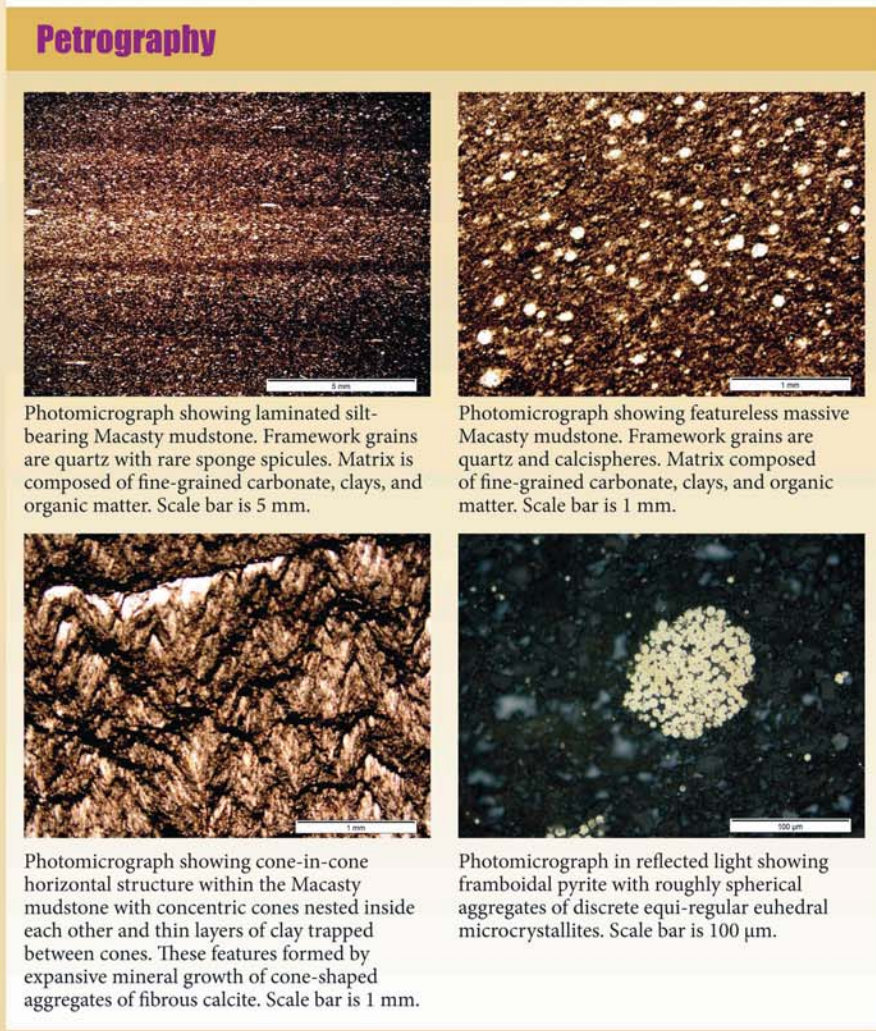
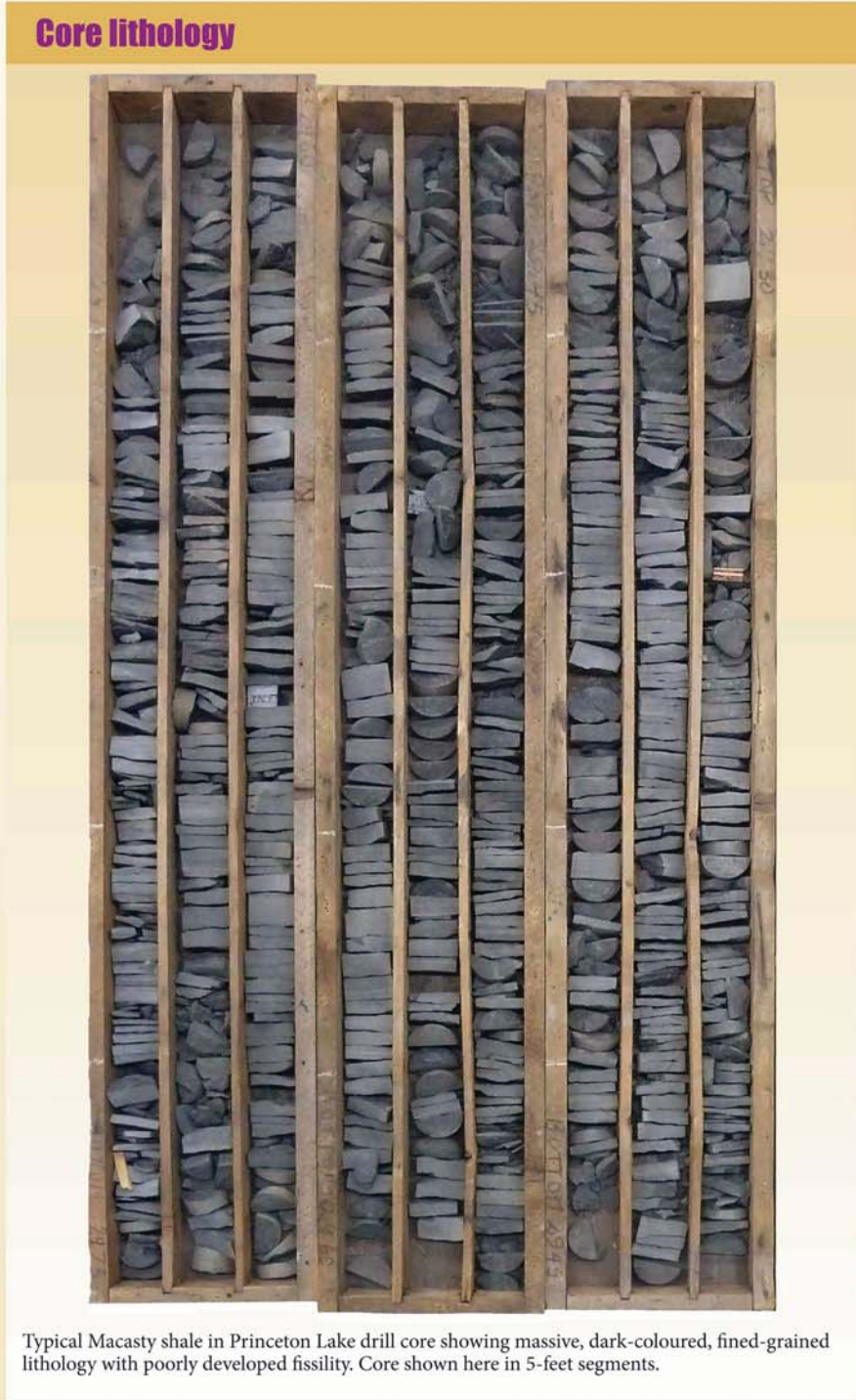
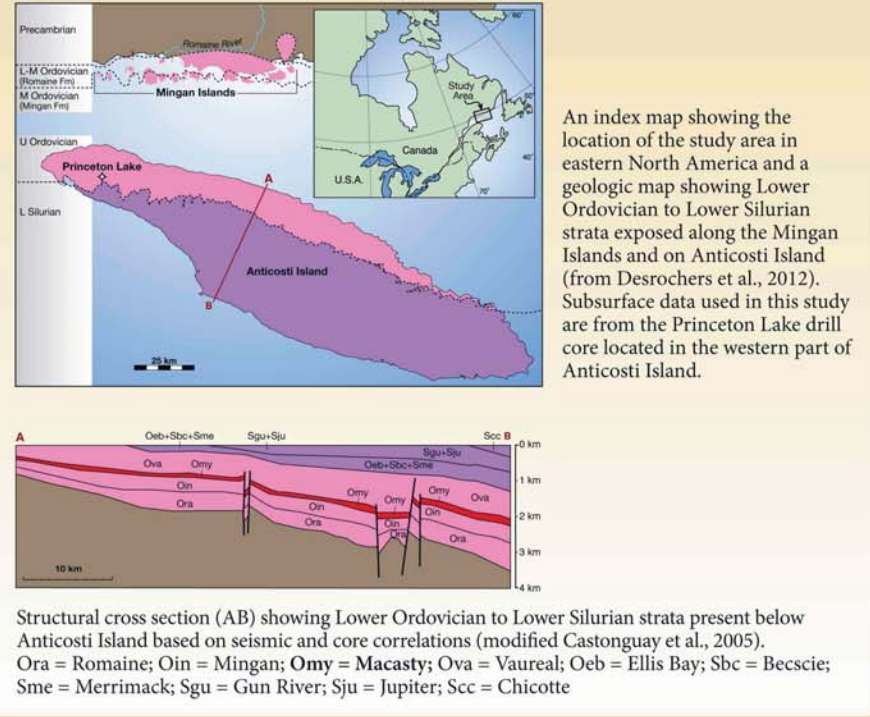
The Macasty Formation, equivalent to the Utica shale in the US and southern Quebec, consists of organic-rich black calcareous shale deposited unconformably on top of the shallow water Mingan carbonate platform in a foreland basin during the Taconic orogeny. The sharp boundary between the two units suggests an abrupt change in the basin configuration. The Macasty shale is composed of very fine-grained quartz, feldspar and clay minerals cemented by calcite (up to 45%). We examined the entire section of the Macasty shale (~80 m in thickness) in Princeton Lake drill core on Anticosti Island. The compositions including the mineralogy and major and minor element abundance did not show any significant changes during the deposition of the shale. The siliciclastic components were primarily supplied from granitic rocks of the Grenville province after extensive weathering. These components were deposited in anoxic environments that allowed the accumulation of redox-sensitive elements and organic matter (up to 8 % TOC), and the reduction of marine sulphate to sulphide (0.7 to 1.6 wt % S). The organic matter has  $\delta^{13}\text{C}_{\text{org}}$  values ranging from -29 to -23 ‰, which are similar to those of Ordovician sedimentary rocks in other areas. Sulphur isotope compositions for disseminated fine-grained pyrite range from +14 to +27 ‰, which suggest the deposition in a basin with a slightly restricted supply of open ocean water. The sulphide concentrated chalcophile elements, such as As (up to 13 ppm), Cu (up to 61 ppm), Mo (up to 179 ppm) and Pb (up to 39 ppm). The organic matter was responsible for the reduction of soluble  $\text{U}^{6+}$  to  $\text{U}^{4+}$  to be fixed in the sediments, leading to high U/Th ratios (up to 3.5) in organic-rich shale. The abundant calcite in the shale shows  $\delta^{13}\text{C}$  values from -2.8 to +1.0 ‰ and  $\delta^{18}\text{O}_{\text{org}}$  from -8.6 to -2 ‰. Combined with the finely crystalline texture of calcite, it precipitated at temperatures from 40 to 55 °C after the deposition of the siliciclastic material and organics, but before any significant compaction. The introduction of this slightly oxidizing diagenetic solution was accompanied by the crystallization of coarse-grained pyrite with variably high  $\delta^{34}\text{S}$  values from -3 to +28 ‰.

### Anticosti Basin

The Anticosti Basin represents the eastern segment of the St. Lawrence platform. The basin is bounded on the north by Precambrian Grenville Province and to the southeast and southwest by thrust terranes of the Appalachian orogen. The western Anticosti Basin is mostly concealed beneath the waters of the northern part of the Gulf of St. Lawrence and its adjacent estuary, but rises to the surface to form bedrock along the Mingan Islands and on Anticosti Island. There, preserved Lower Ordovician to Lower Silurian strata recorded a transition from a passive-margin setting to a tectonically active foreland basin to a post-Taconic successor basin. The foreland basin was related to the emplacement of Taconic thrust sheets farther to the south over the northern part of the Gaspé Peninsula and over parts of the Goult St. Lawrence (Pinet et al., 2008). The subsequent post-Taconic successor basin was affected by minor Acadian tectonic stresses (Bordet et al., 2010).

### Macasty Formation (Princeton Lake Drill Core)

Earlier petrography and Rock-Eval analysis showed that Upper Ordovician Macasty Formation contains Type II organic matter (TOC, up to 7.1 %; HI, up to 485 mg HC/g; Bertrand, 1987) and has significant potential for oil production. In a more recent study by Petrolia (2013), the shale displayed consistently high TOC (average 4.0 wt%) across the entire thickness (~80 m) of the formation and the values are within the oil window.



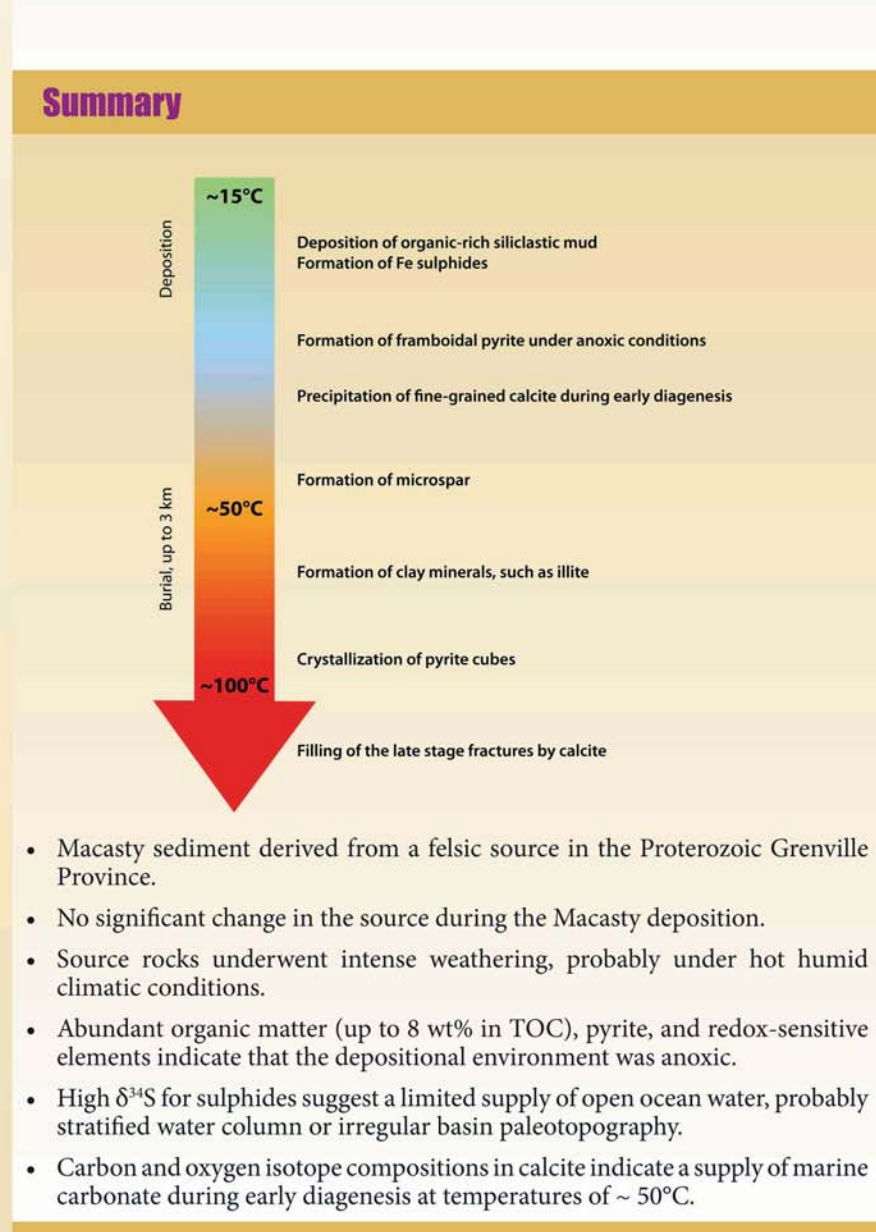
### Discussion

The framework grains of the Macasty shale are composed of very fine-grained quartz, clay minerals, and feldspars. Abundant post-depositional calcite is also present in the Macasty shale; resulting into a more brittle lithology.

The major elements, when compared with the NASC, show a typical signature of shales, but higher content of carbonate and phosphate. The REE show a slight depletion, when compared to NASC, and no significant enrichment or depletion, when compared to the upper crust, but an enrichment of light REE and negative Eu anomalies, when normalized to chondrites, indicating a felsic provenance. Based on its location and tectonic setting, our data suggest a sediment provenance mainly from granitic rocks of the Grenville Province. The Macasty samples show considerable depletion in  $\text{Na}_2\text{O}$  and  $\text{K}_2\text{O}$  content when compared to the upper continental crust indicating that the source was highly weathered.

Se, As, Sb and Cd show high concentrations, when compared to the upper continental crust, being likely incorporated in pyrite. The high U/Th ratios (up to 16), when compared to NASC, indicate anoxic depositional conditions.

The  $\delta^{13}\text{C}_{\text{org}}$  isotope values of the calcite are close to 0 ‰ indicating that calcite was precipitated from marine waters. Their  $\delta^{18}\text{O}_{\text{org}}$  values are ~ -6 ‰ suggesting at low-medium temperature after some burial or incursion of meteoric water.



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