Organic Matter Characterization of the Upper Ordovician Utica and Lorraine Shales, Southern Quebec, Canada*

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Abstract

In the eastern Canada, significant industry interest has recently focused on the Upper Ordovician black shales in southern Quebec and Anticosti Island that is the Utica and Lorraine shales and Macasty Shale, respectively. For the Utica Shale, extensive testing through high pressure hydraulic fracturing has shown that the calcareous shales of the Utica have the capacity to release significant volumes of natural gas. The present study reports the organic matter characterization of core samples of the Upper Ordovician Utica and Lorraine shales in southwestern Quebec. Samples are from deep Utica and near surface samples of both the Utica and Lorraine shales.

Sample lithology varying from shale to fine-grained siltstone has present TOC ranging from 0.08 to 2.25%. The current TOC content of samples represents only the remaining 92-98% of the residual carbon in the sample. The Tmax values obtained from the Rock-Eval analysis appear to be unreliable for theses over-mature samples due to low S2 values. The major organic matter constituents are matrix and migrated bitumen and pyrobitumen (for over-mature samples of Utica) and chitinozoan skeleton particles. The reflectance has been measured on matrix and solid bitumen and chitinozoan skeletons. There is a strong agreement between bitumen reflectance and chitinozoan reflectance when they are converted to vitrinite reflectance. The results show that

the samples from the deeper parts of Utica Shale have equivalent VRo of 2.1% and are in the dry gas zone while shallower samples of Utica and Lorraine show equivalent VRo of 1.1% and are in the oil-liquid gas window. This is in agreement with Rock-Eval data, and the reported well production. Organic matter comprises up to 4.7% in volume of total rock. A portion of organic matter in samples may generate porosity, such as matrix pyrobitumen, which is likely resulting from the formation of gas by secondary cracking of bitumen compounds. Porous matrix solid bitumen appears to be formed during migration and dissemination of bitumen into the porous clay fraction of the rock. This is often associated with significant bacterial sulfate reduction possible in the early generation and migration of bitumen. Based on organic petrology and Rock-Eval data it seems that the organic-lean siltstone facies of the Utica Shale in this area act as a reservoir, and bitumen migrated from organic-rich intervals within Utica Shale or overlying strata.

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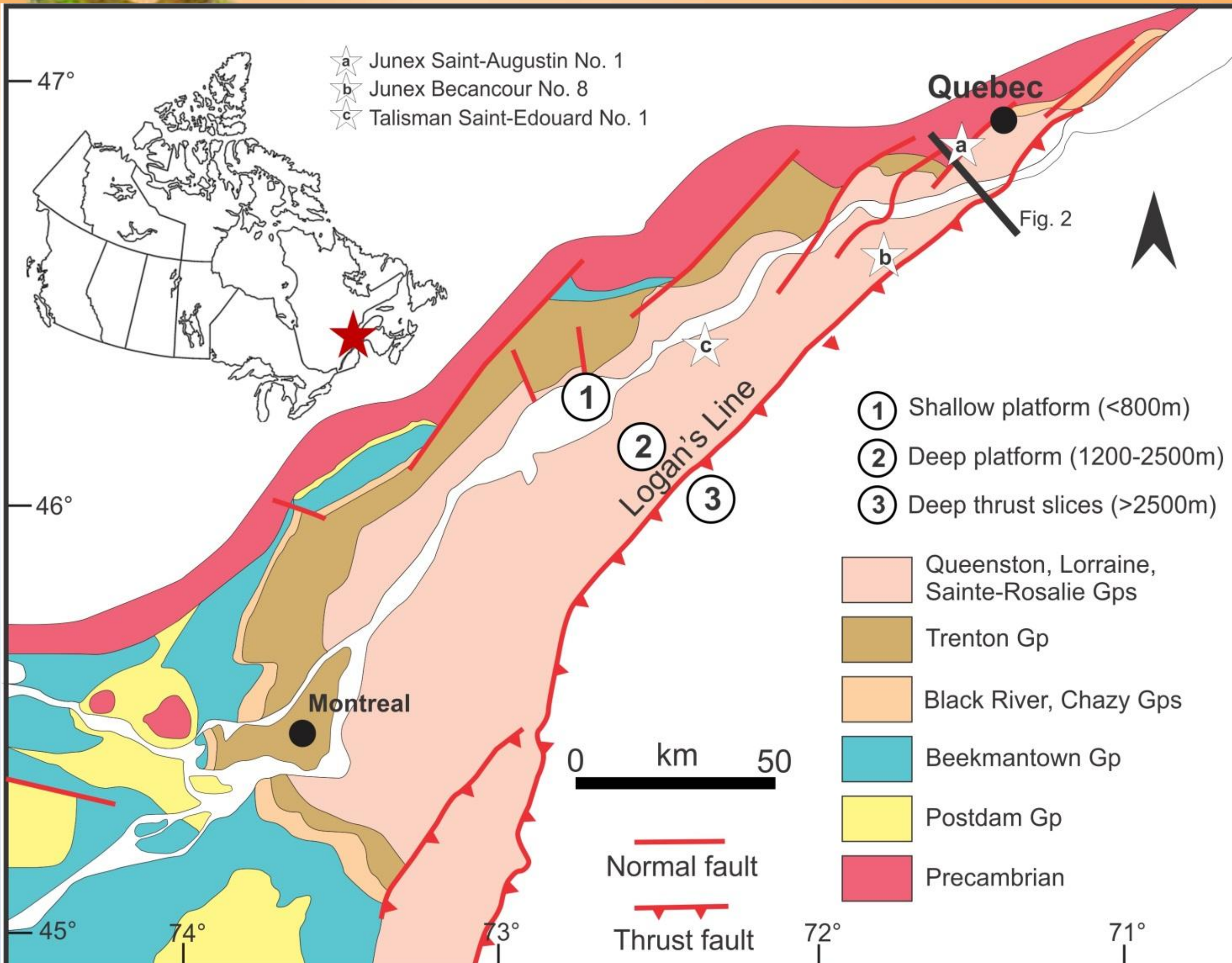
Background

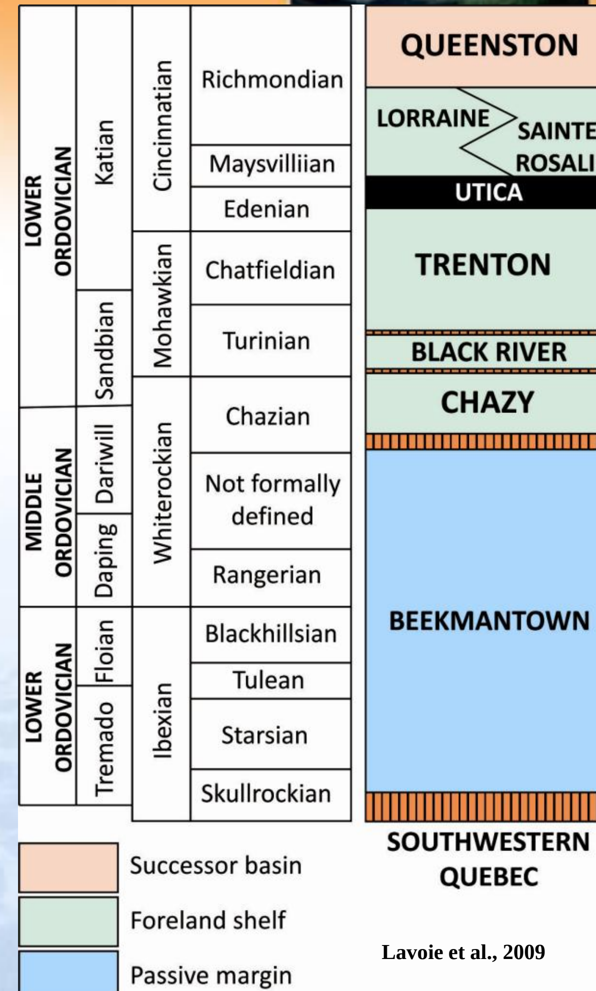
- The early phases of petroleum exploration drilling in the St. Lawrence Platform in southern Quebec occurred in the 1950s to 1970s. Shale gas exploration began from 2006 in southern Quebec.

- Significant industry interest has focused on the Ordovician Utica Shale in southern Quebec.

- This study is part of Shale Reservoir Characterization project of Geoscience for New Energy Supply (GNES) program of Geological Survey of Canada.
  The **GNES** program aims to develop standard best practice methodologies for assessing unconventional petroleum resources.

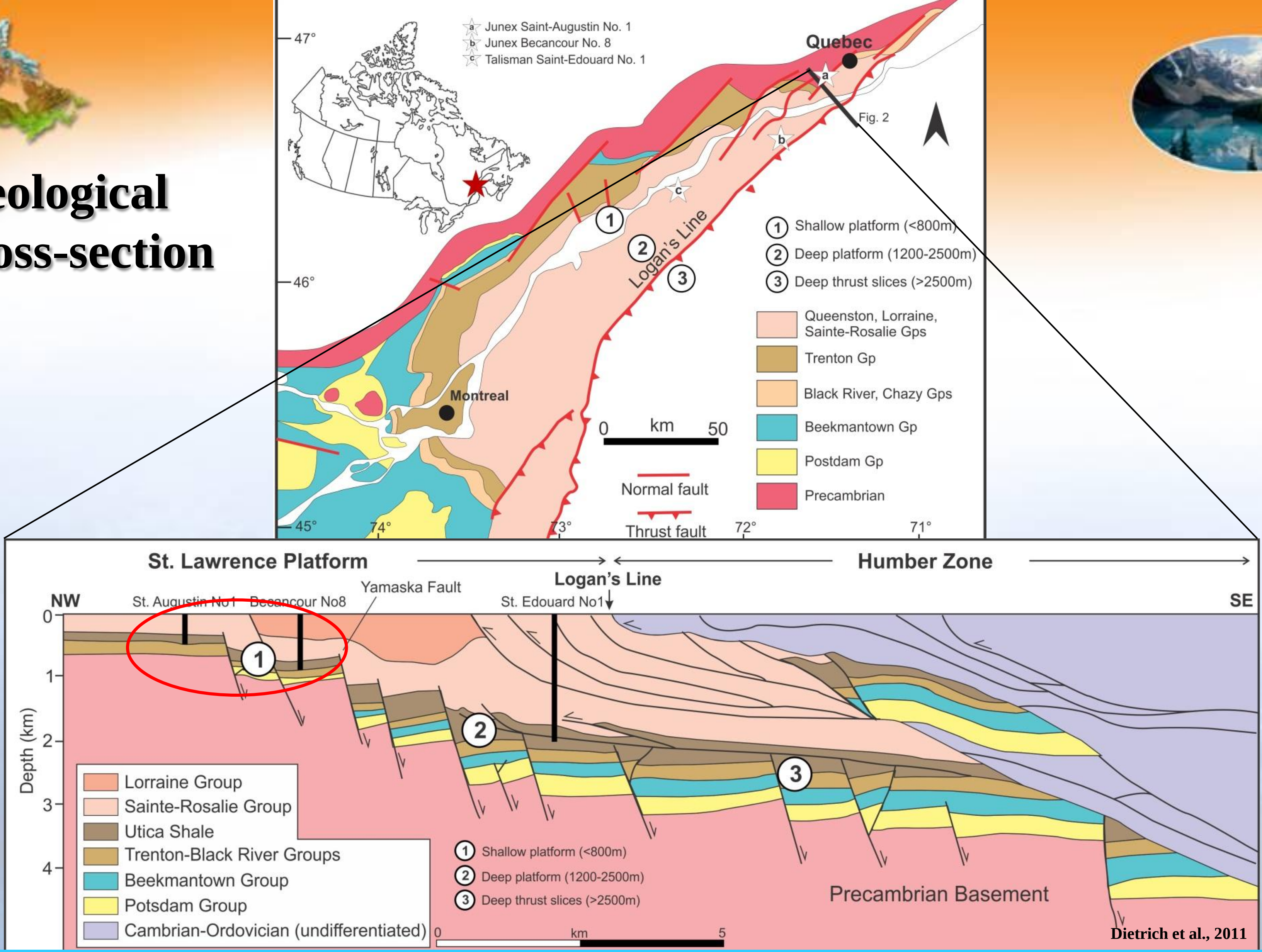
Geological framework





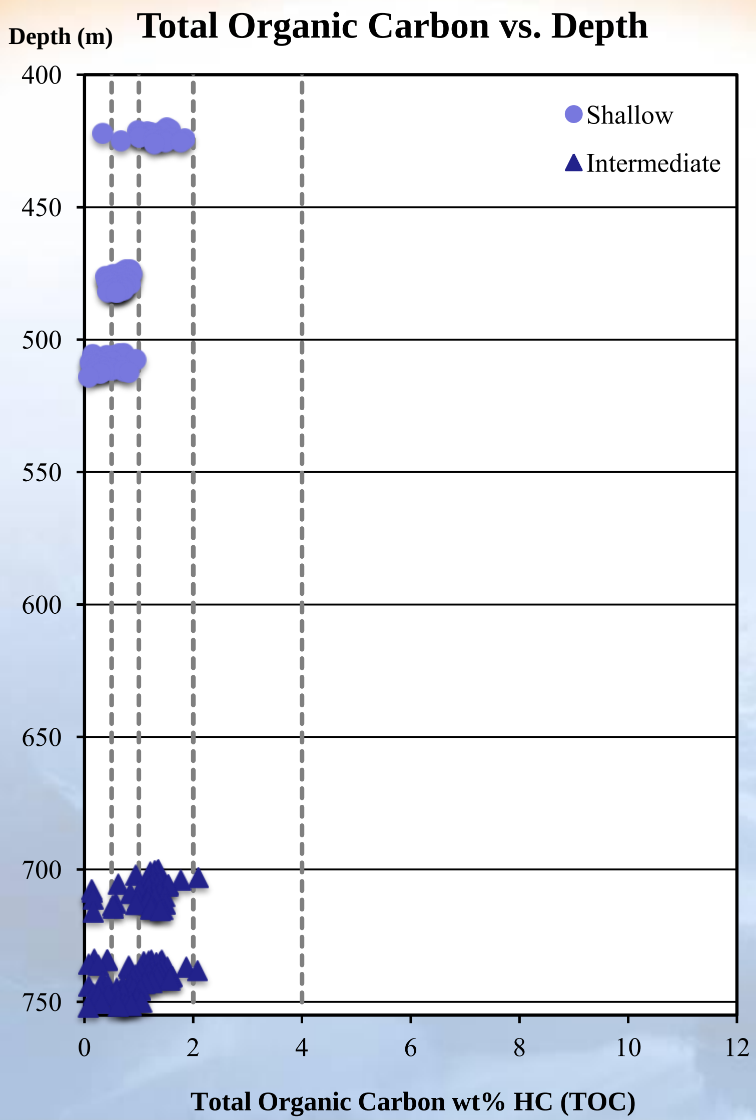
•The St. Lawrence Platform is autochthonous Lower–Middle Paleozoic sedimentary cover of the northeastern American craton.
•The Ordovician deep-marine, thick clastic succession of Utica and Lorraine shales in southern Quebec overlies the predominantly shallow marine carbonate facies of the Cambrian-Ordovician St. Lawrence Platform.
•The Ordovician Utica Shale (50 to 300 m thick) and Lorraine Shale (500 to 2000 m thick) are found in southern Quebec between Montreal and Quebec City.

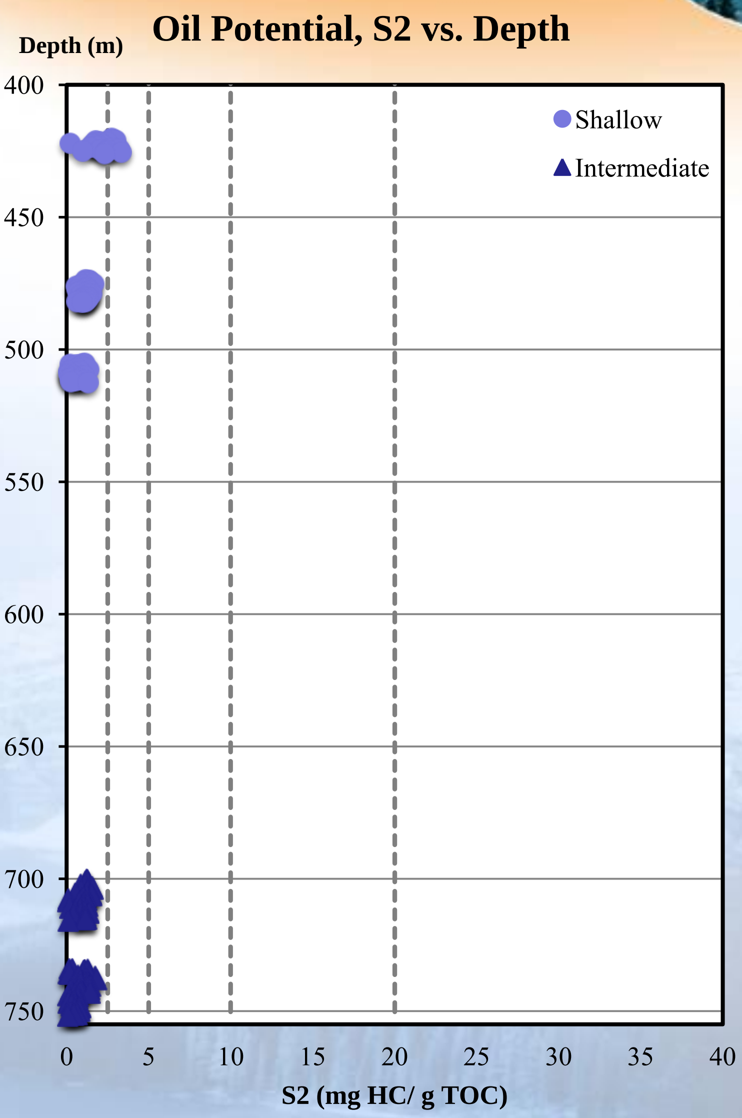
Geological cross-section



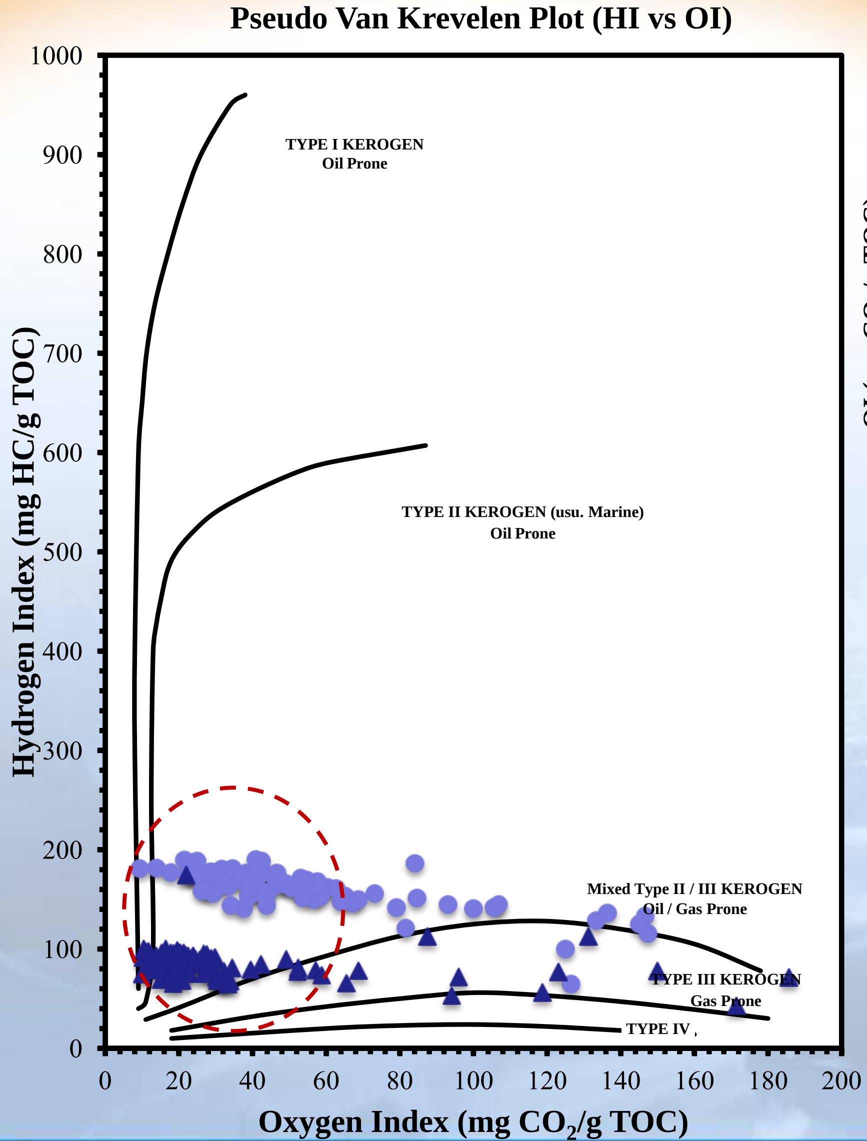
- Utica Shale is progressively thicker and deeper from NW to SE and is also remobilized and imbricate in thrust stacks beneath the St. Lawrence Platform.
- Deep Utica samples obtained from Talisman Saint Edouard No1 well at depth of 2000m and shallow Utica samples obtained from Junex Saint Augustin from a depth of 400m.
- Total number of 300 samples collected from study cores from Utica and Lorraine shales.

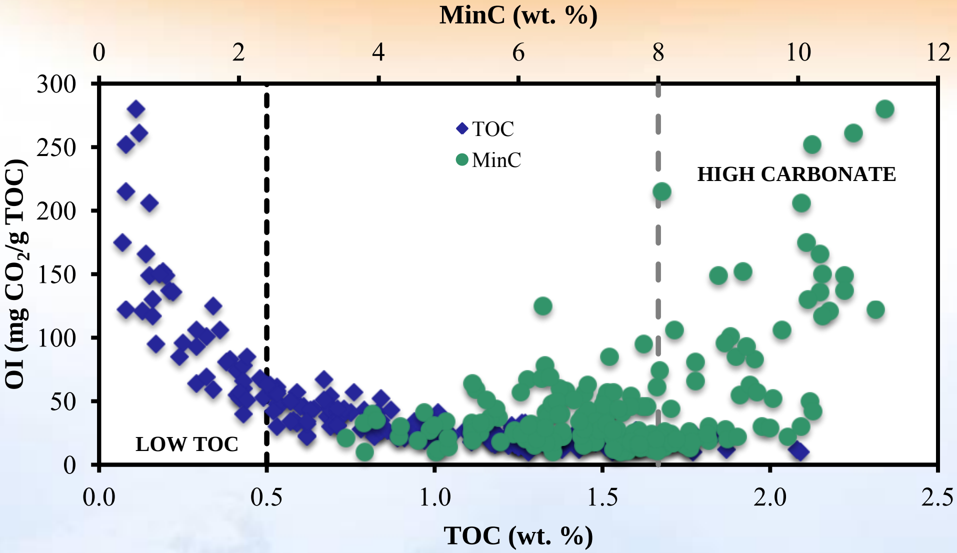
TOC and S2 (Shallow, Intermediate)

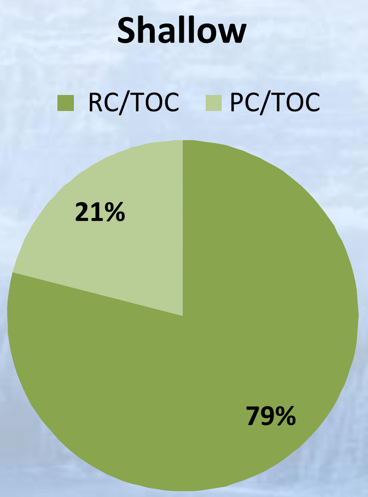


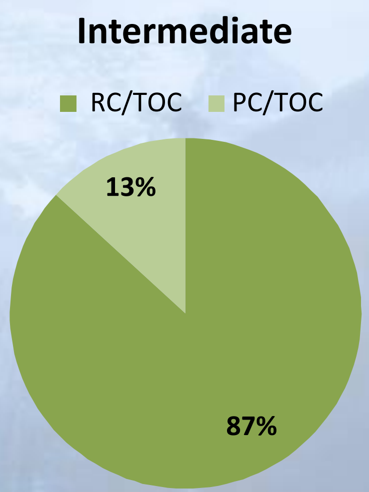


Kerogen type (Shallow, Intermediate)

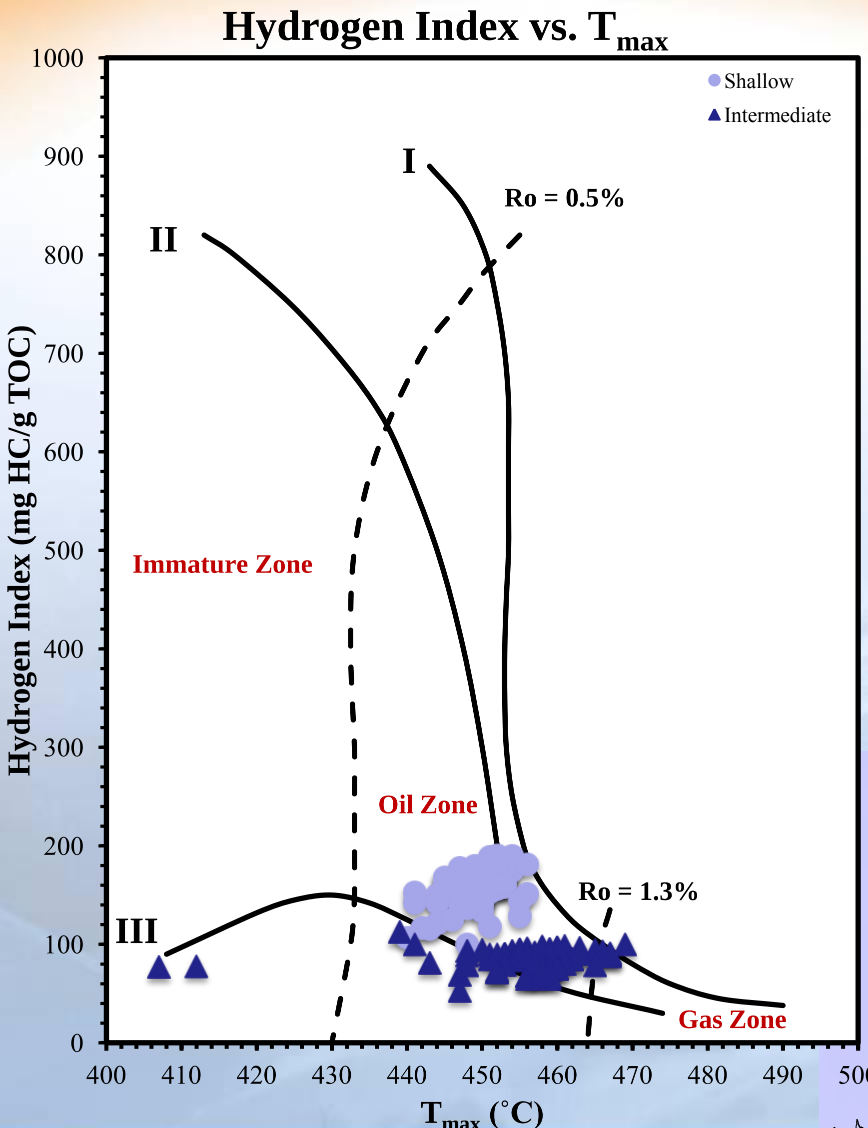


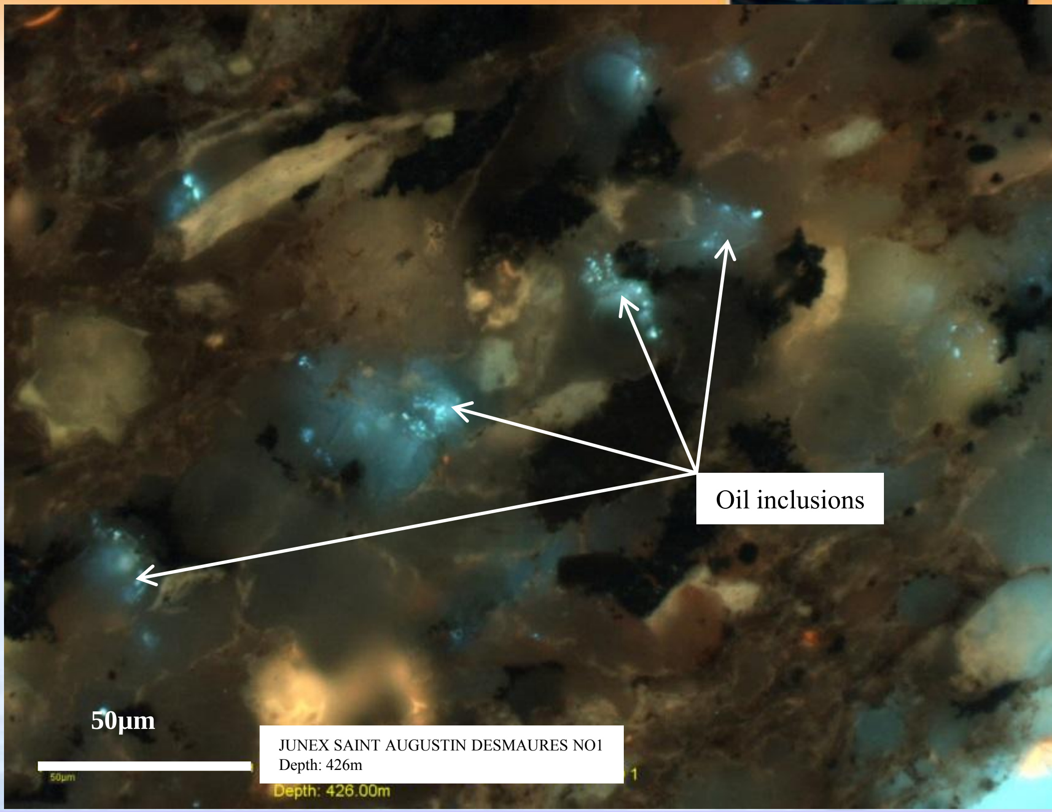


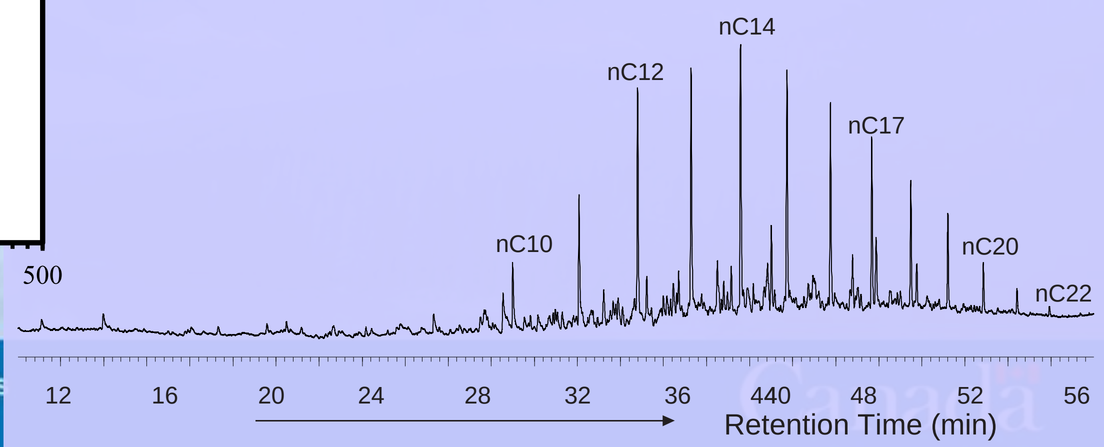




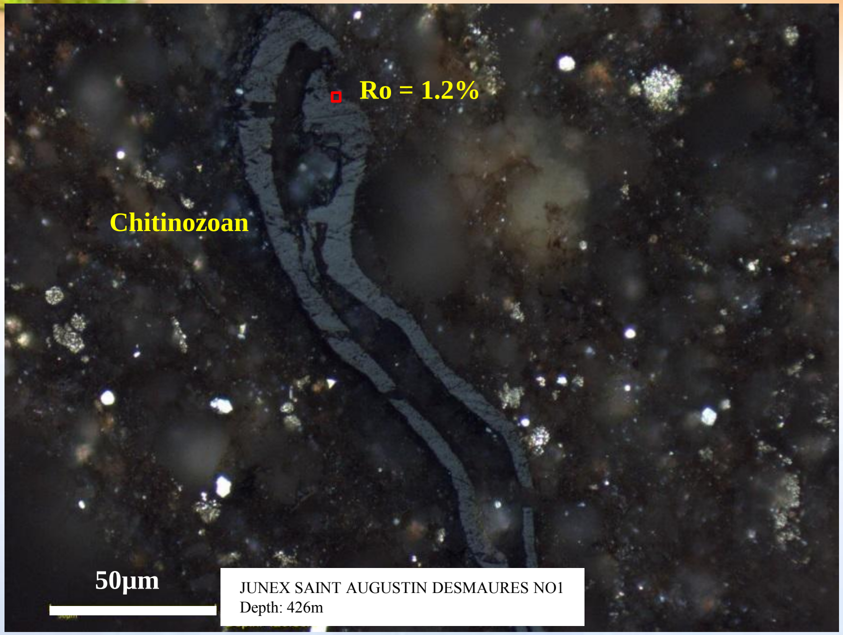
Thermal maturity (Shallow, Intermediate)

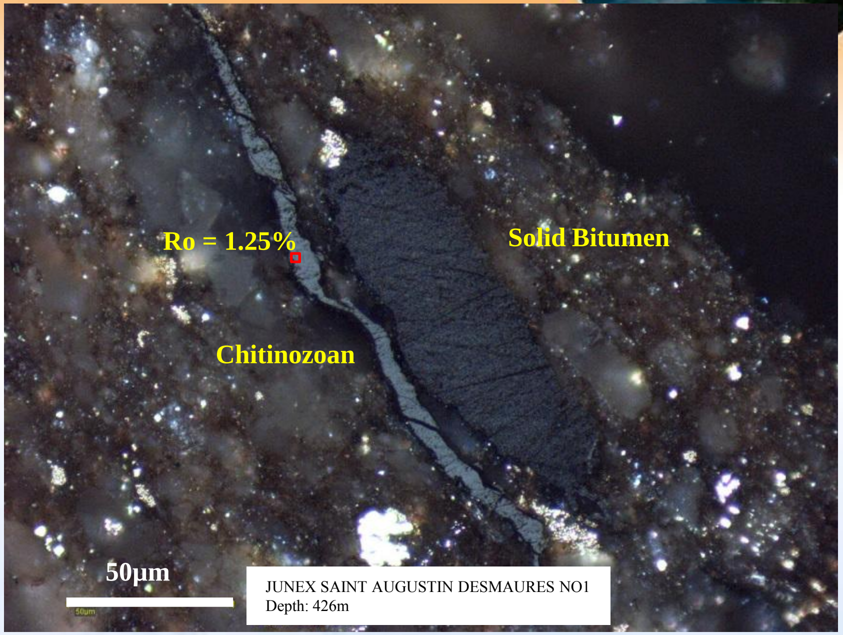


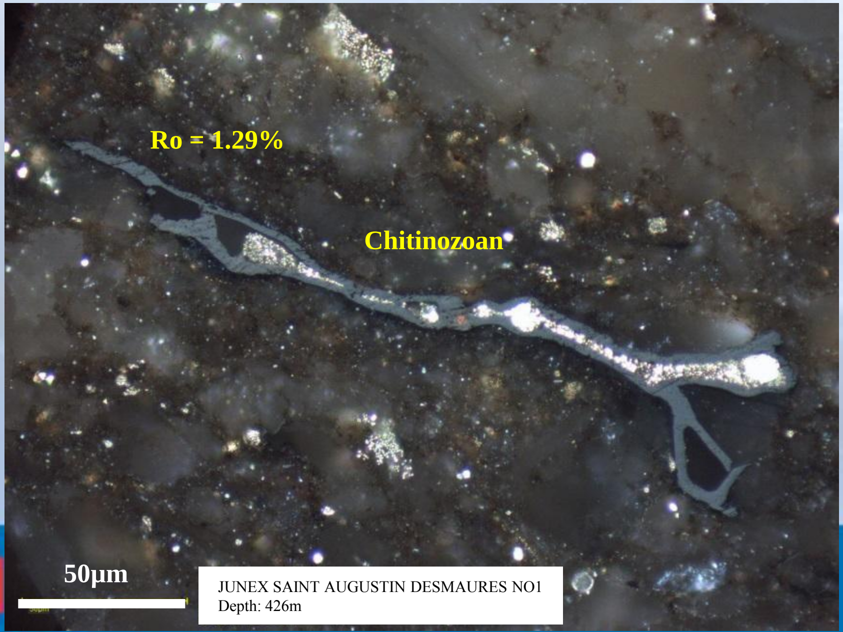


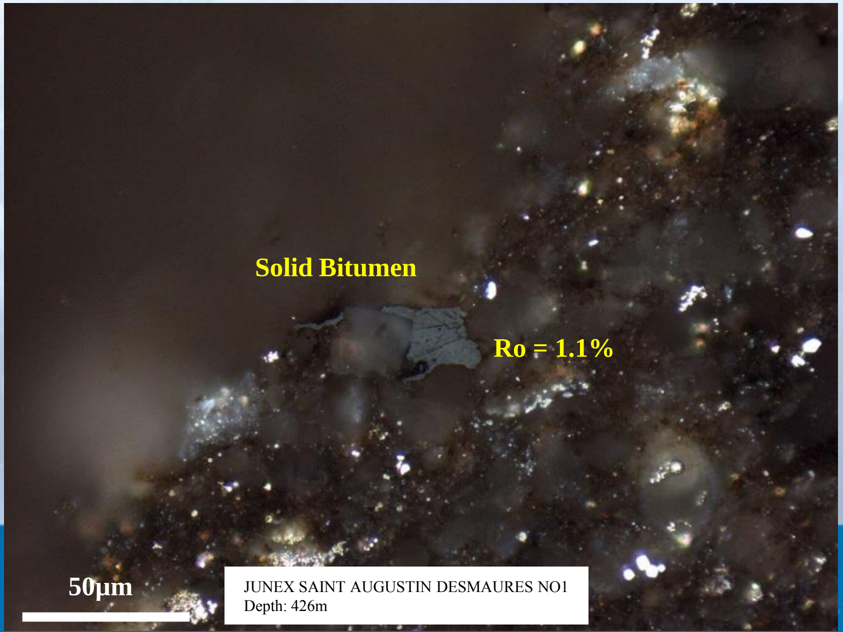


Maceral types (Shallow, Intermediate)

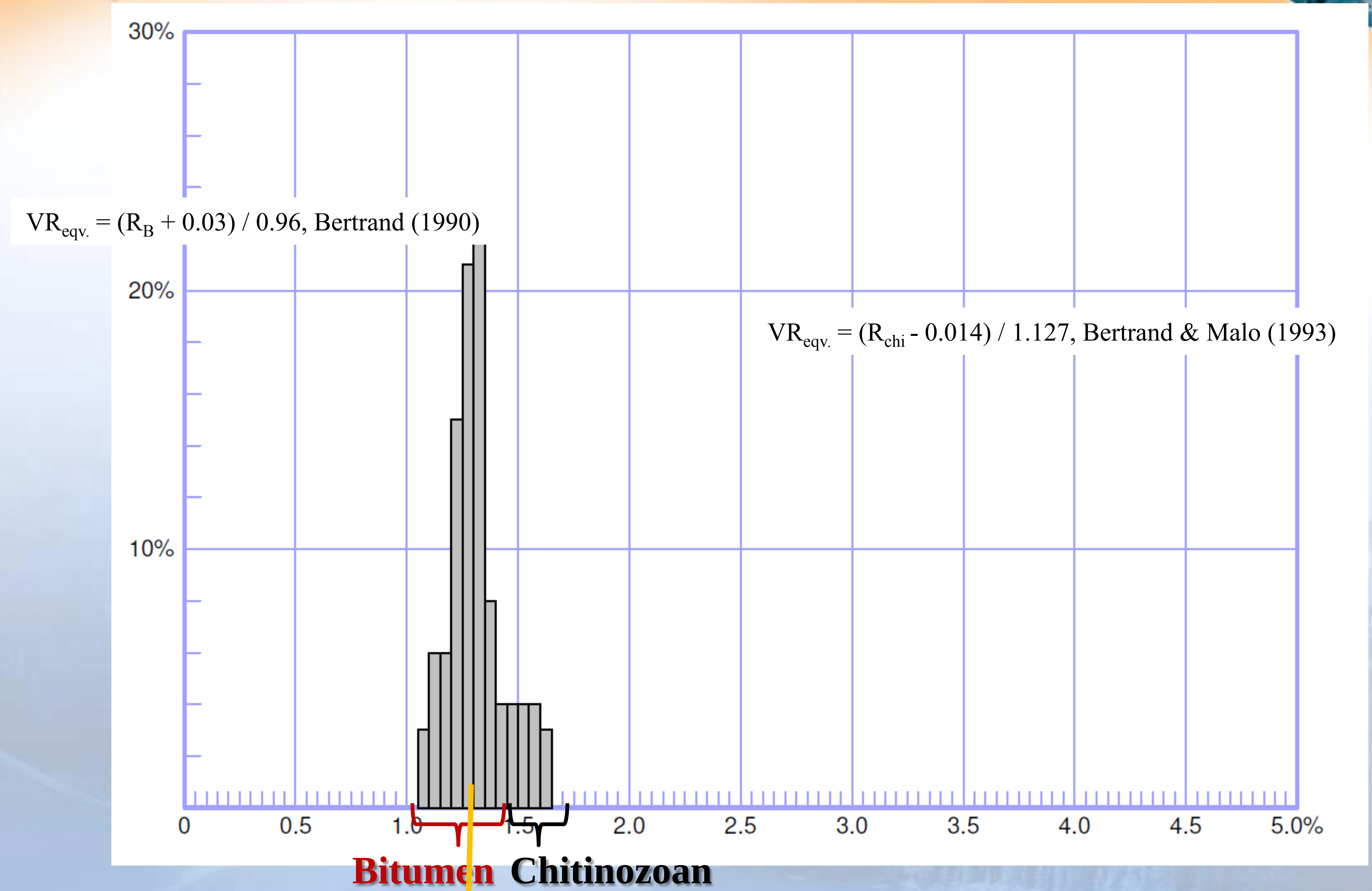






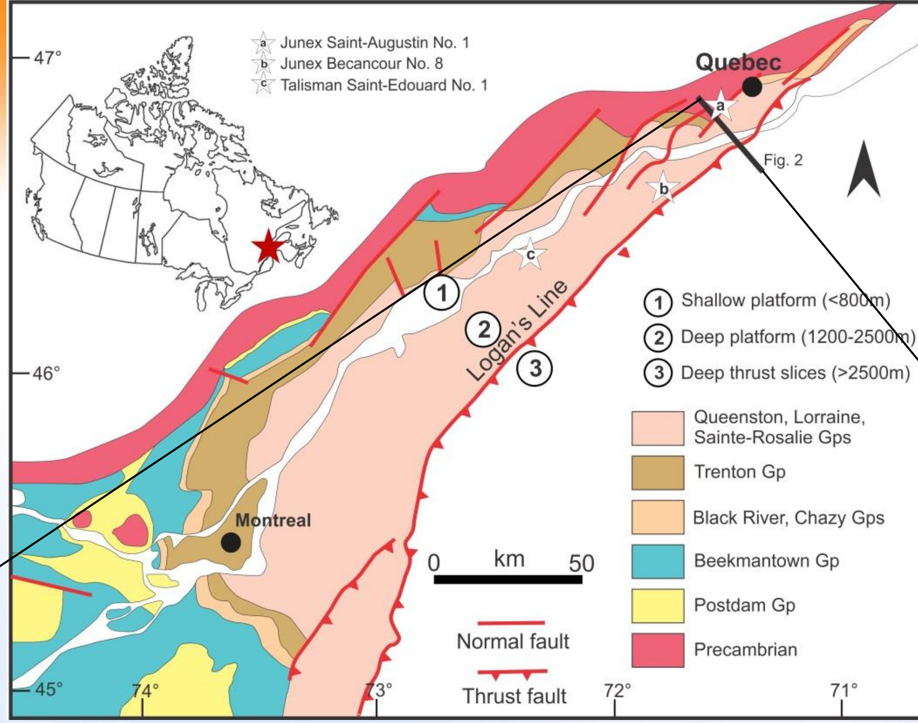


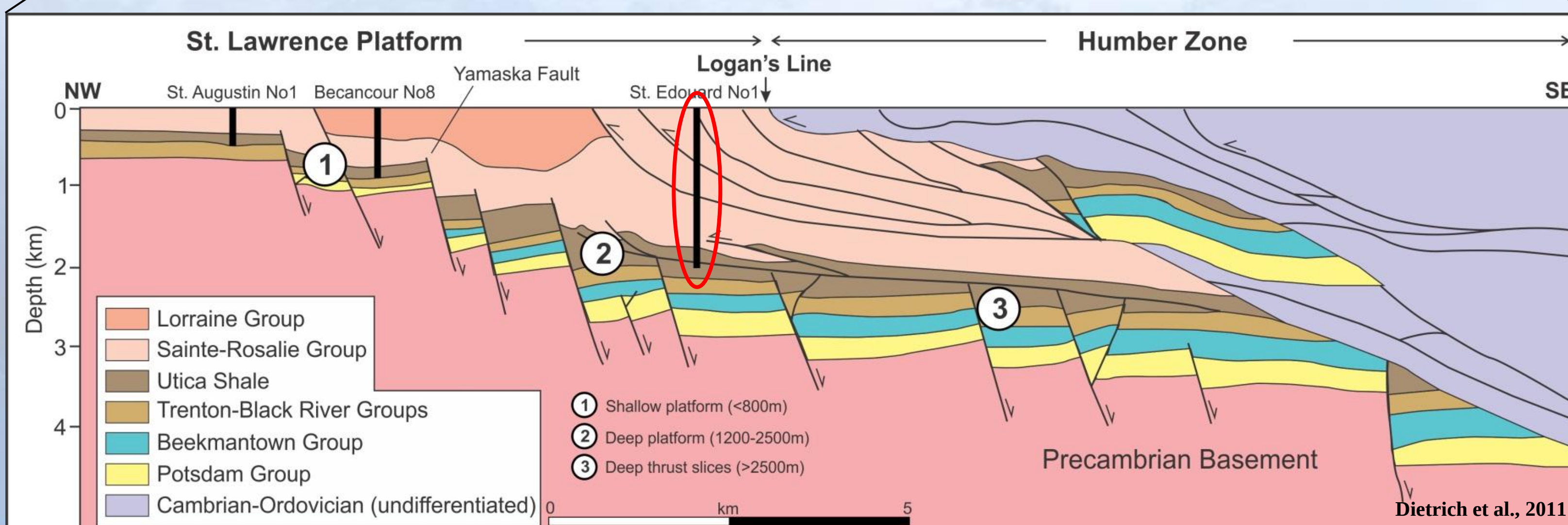
Reflectance measurements (Shallow, Intermediate)



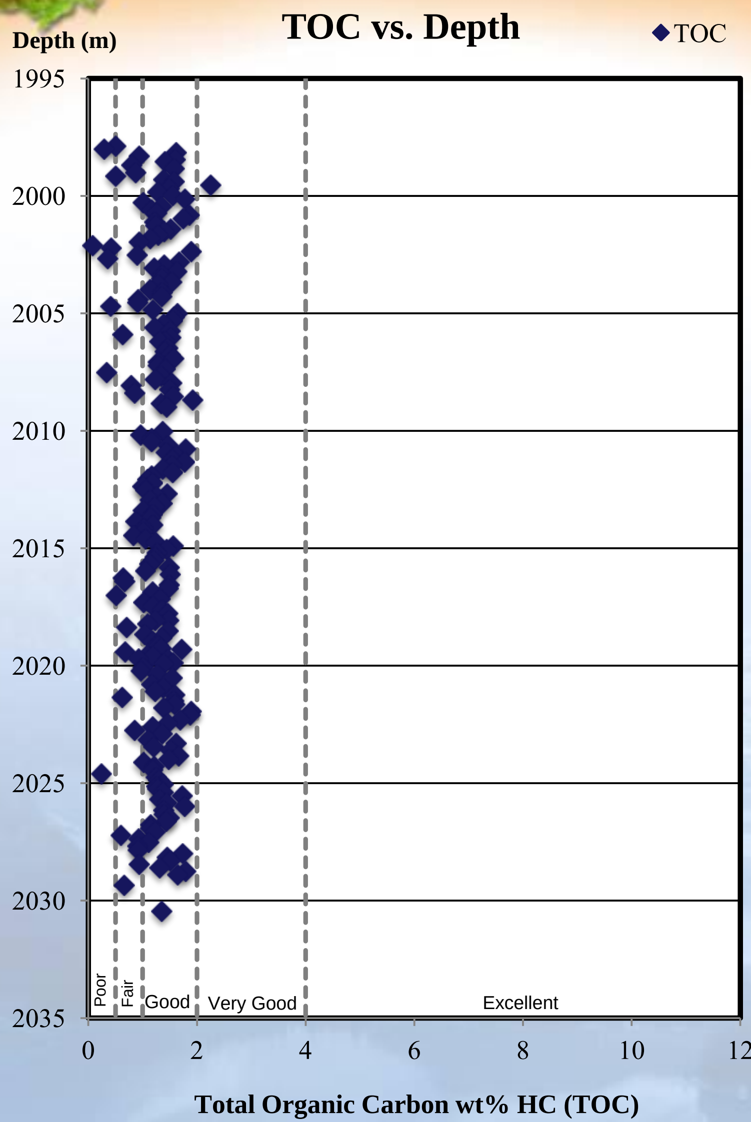
VR_{eqv} = 1.2%

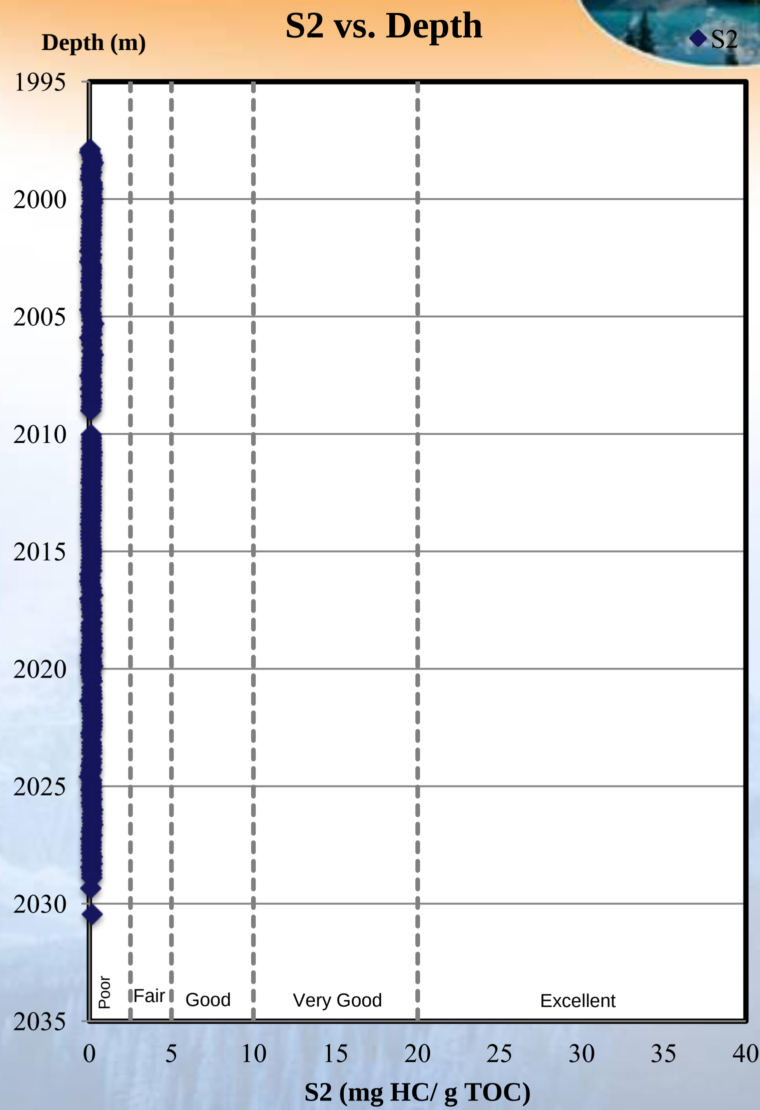
Geological cross-section





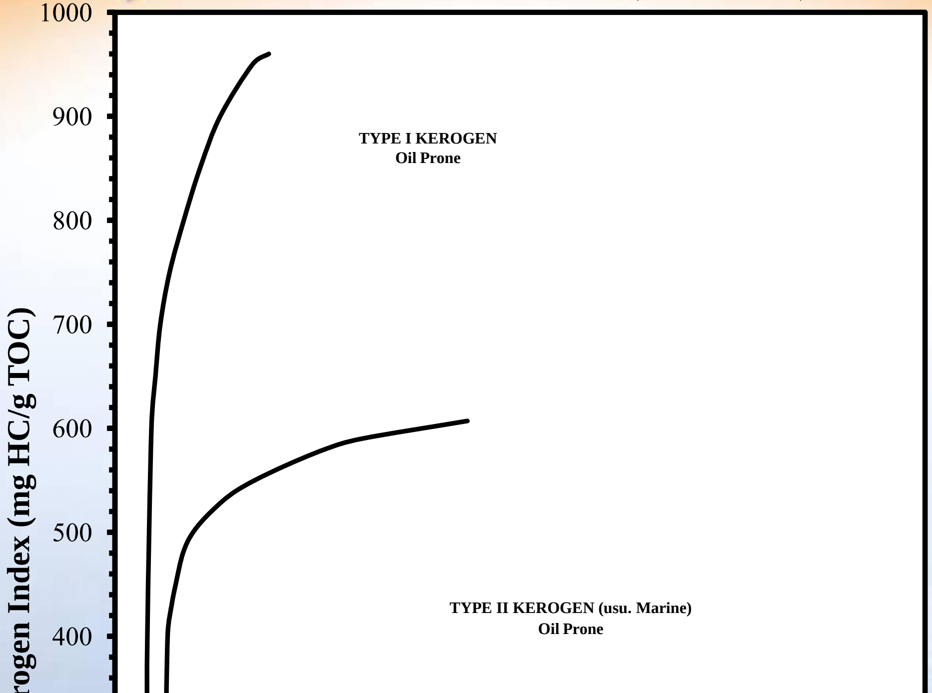
TOC and S2 (Deep Utica)



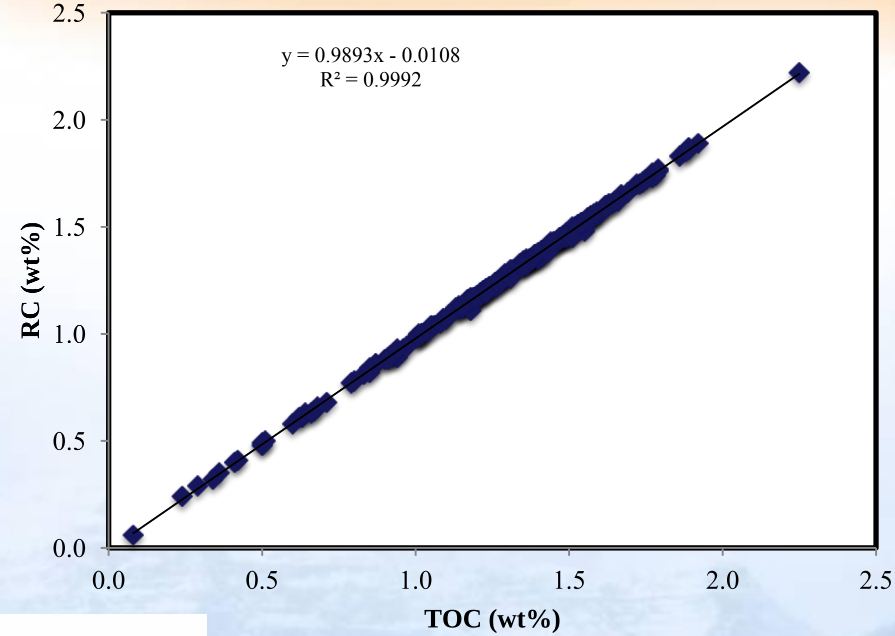


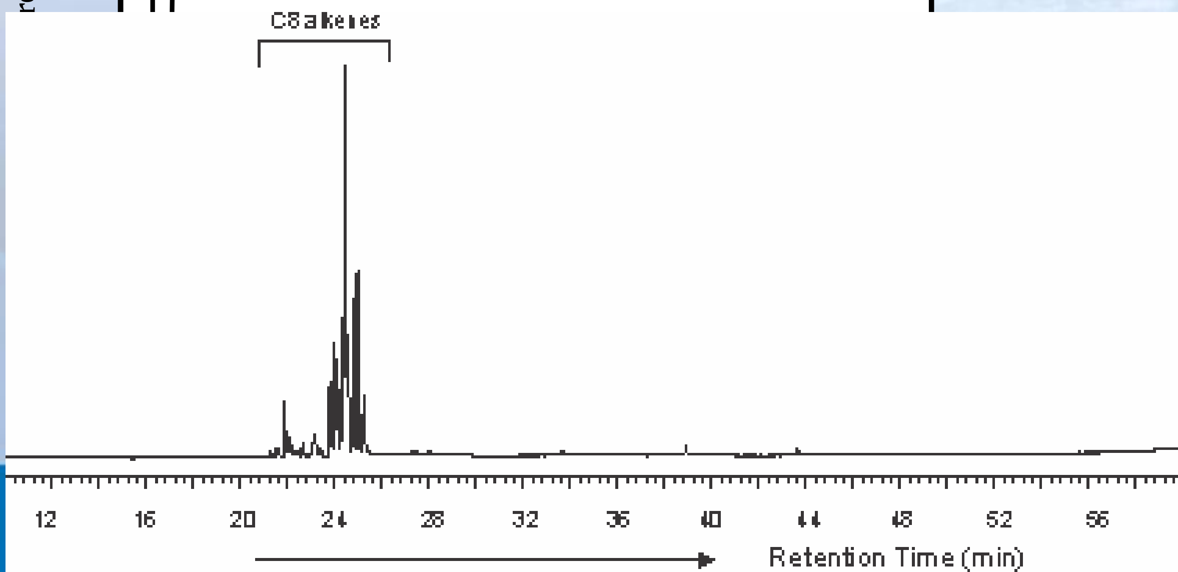
Kerogen type (Deep Utica)

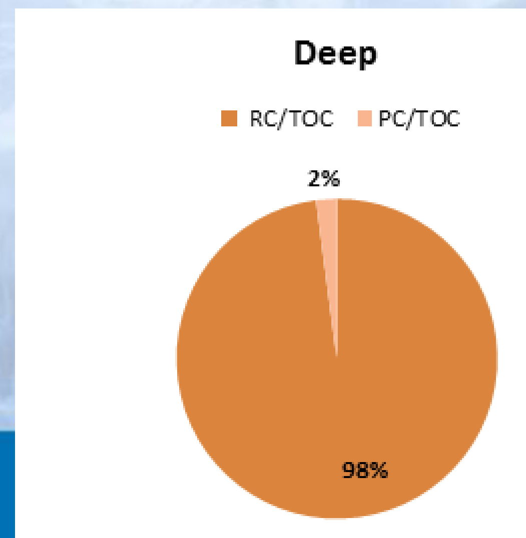
Pseudo Van Krevelen Plot (HI vs OI)



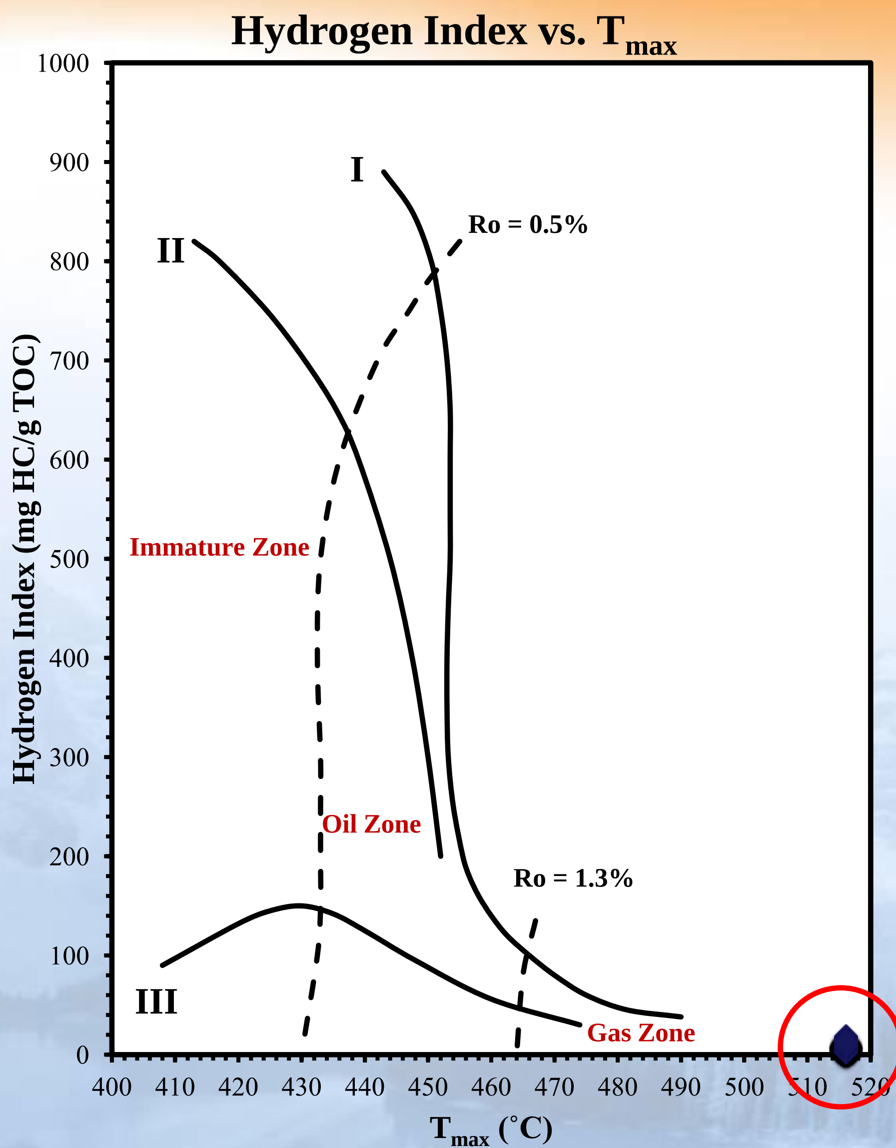
RC vs. TOC





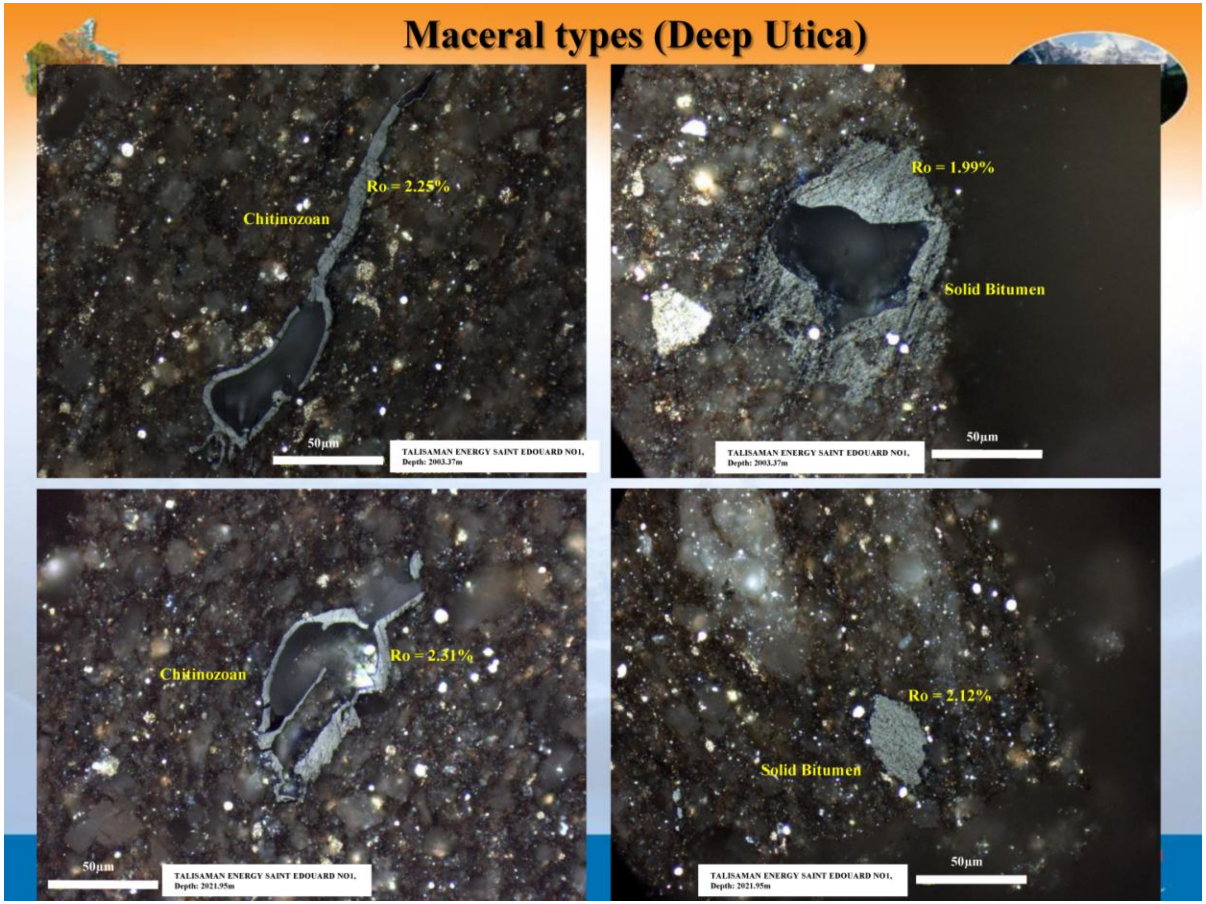


Thermal maturity level (Deep Utica)



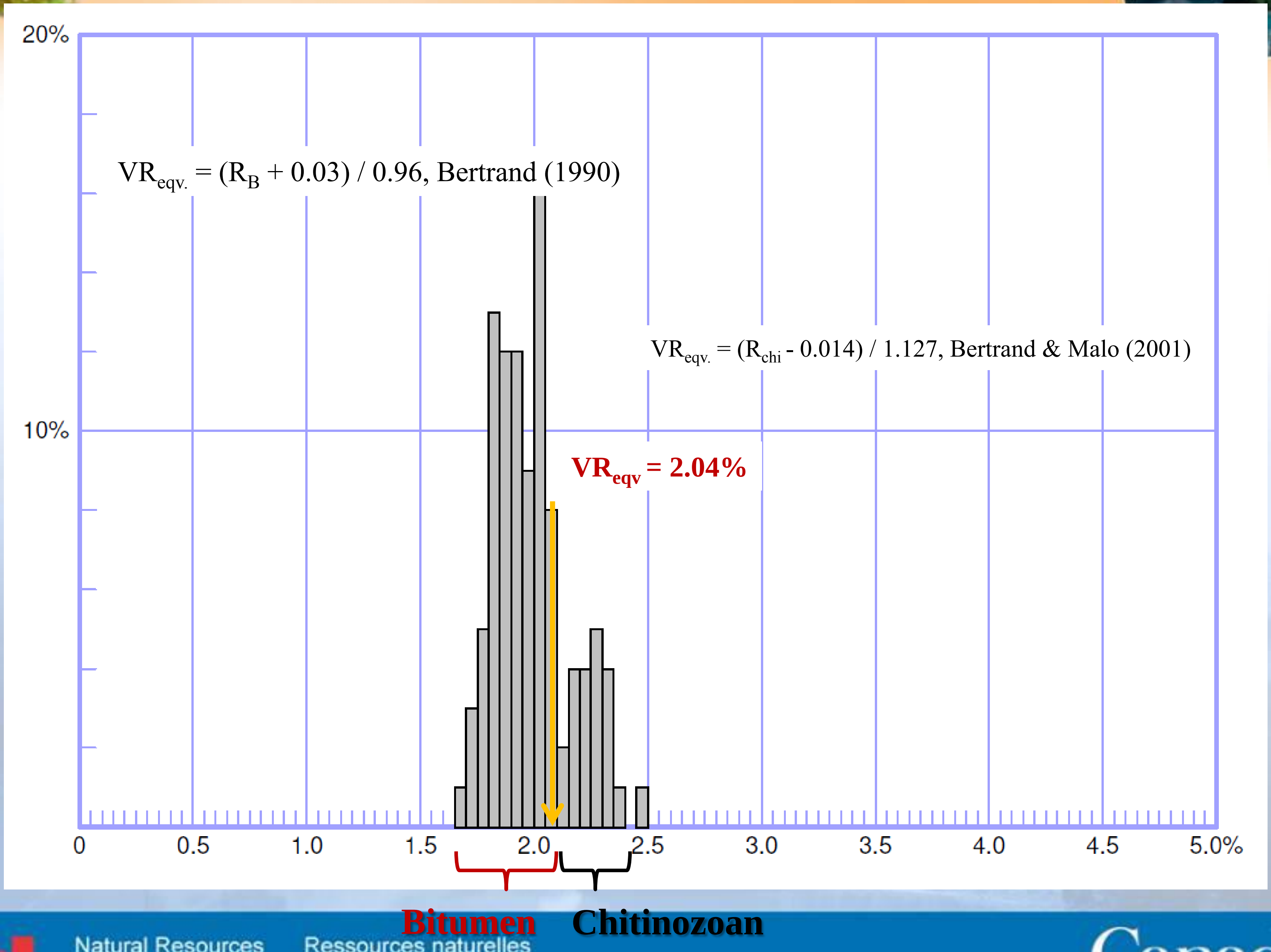
Converted T_{max} based on VR_o

$T_{max} = (VR_o + 7.16)/0.018$; (Jarvie, 2001)

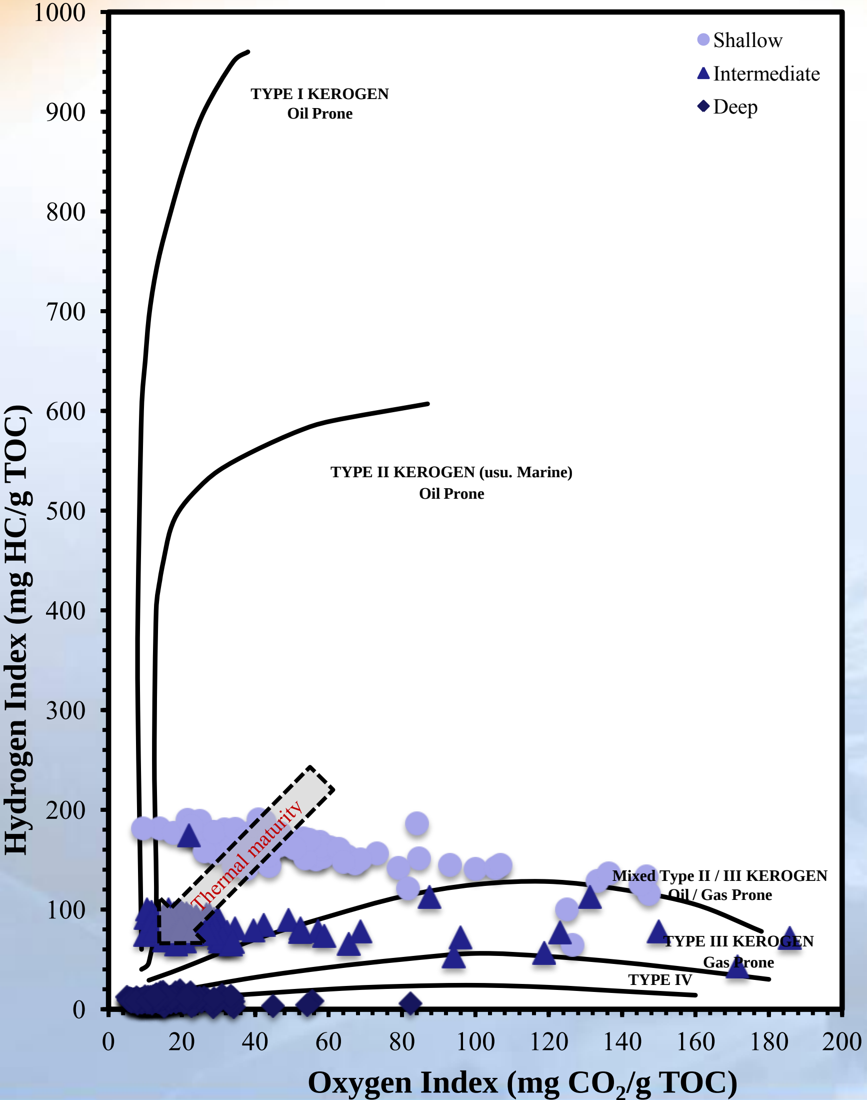


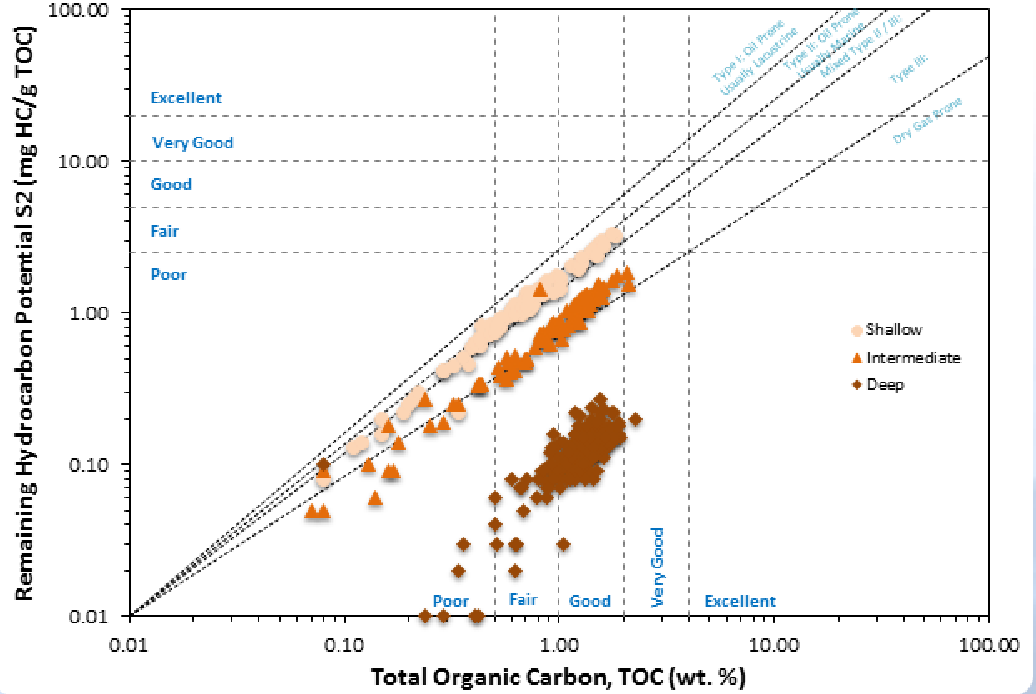
Presenter's notes: Reflectance measurements of organic matter dispersed in sedimentary rocks, e.g. vitrinite particles, are a widely used and robust thermal maturity indicator. Vitrinite is derived from partly decomposed and thermally matured ligno-cellulosic tissues of higher land plants, which appeared after the Late Silurian when the first vascular plants evolved. In the absence of vitrinite in Lower Paleozoic rocks, reflectance measurements have been carried out on zooclasts (graptolites, chitinozoans, and scolecodonts) and other organic particles (bitumen and vitrinite-like particles). Chitinozoans are organic wall pelagic or nektonic-pelagic invertebrates which emerged in Tremadocian (Early Ordovician).

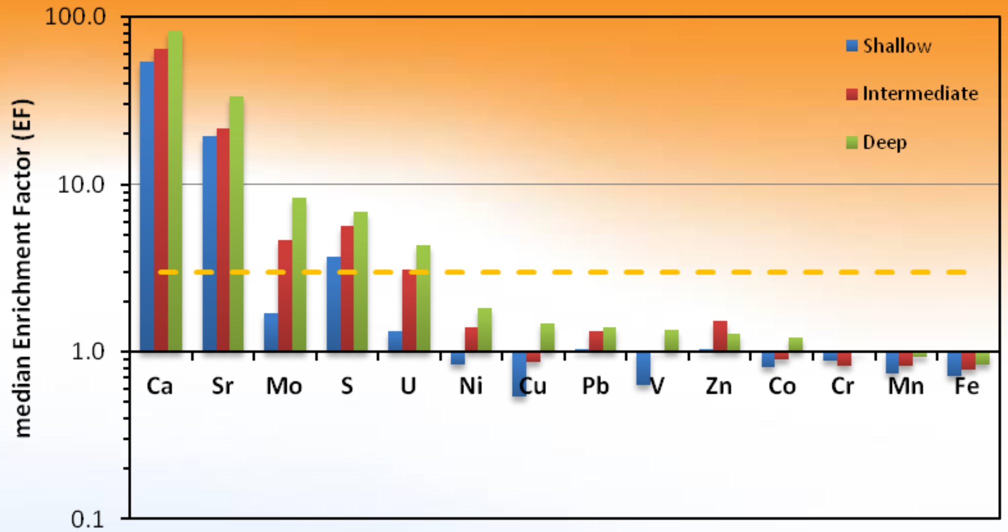
Reflectance measurements (Deep Utica)



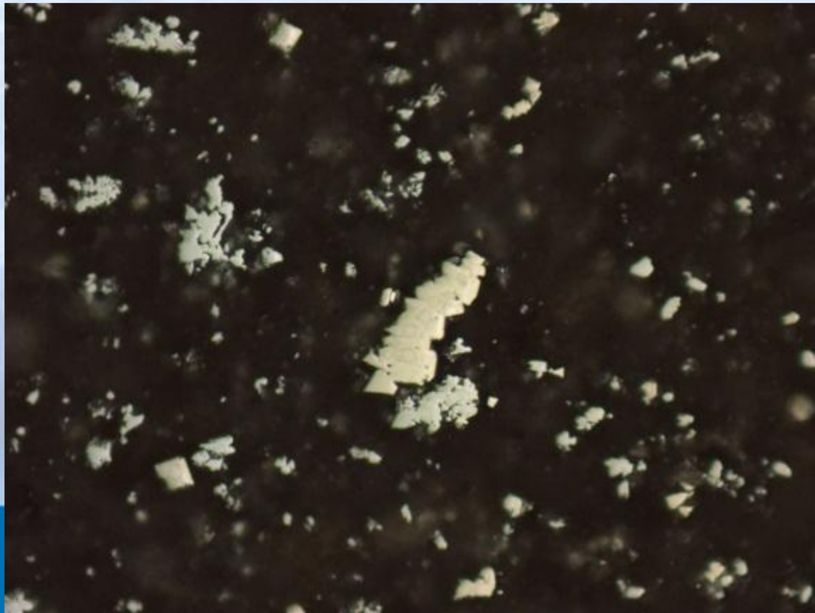
Thermal maturity with depth

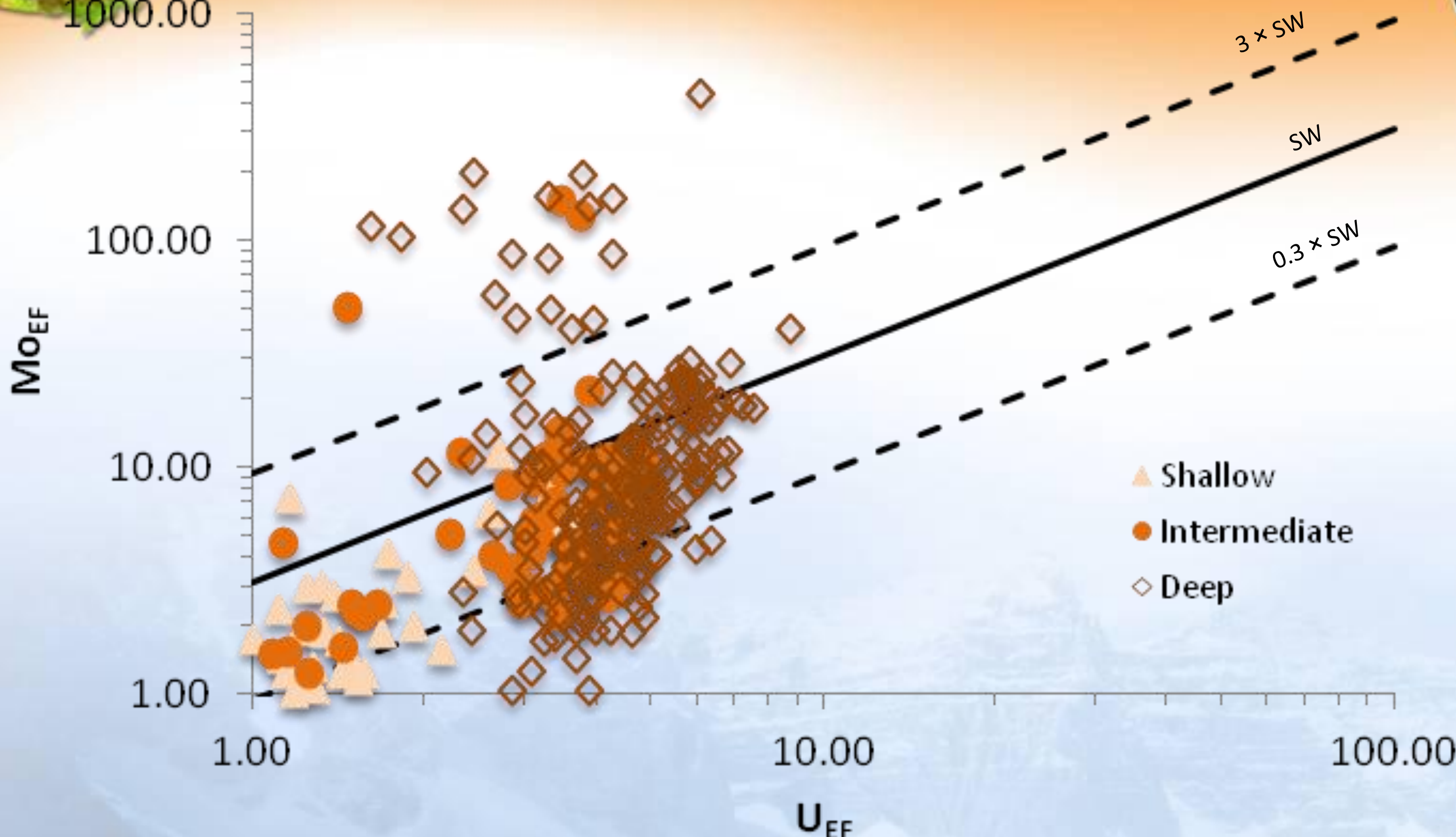






- Utica Shale is a calcareous shale with significantly enriched Ca and Sr.
- Mo and U (paleo-redox proxies)shows significant enrichment in deep and intermediate samples, but not shallow samples.
- Although all samples show significant sulfur enrichment however low Fe content resulting in low pyrite content of samples.
- Pyrite framboids mainly formed in the vicinity or internal parts of chitinozoan where BSR provide necessary sulfur for pyrite formation. In the deep Utica samples however TSR caused all pyrites recrystallize.

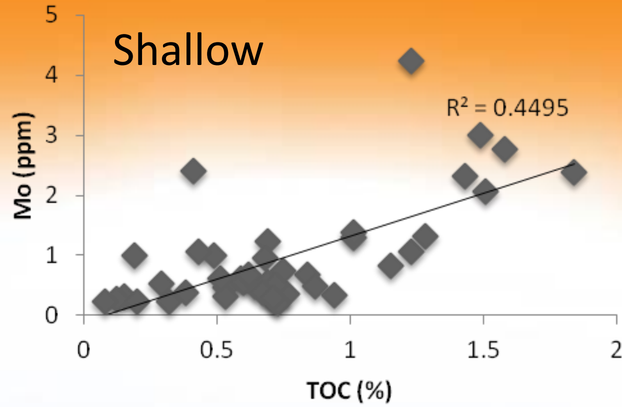




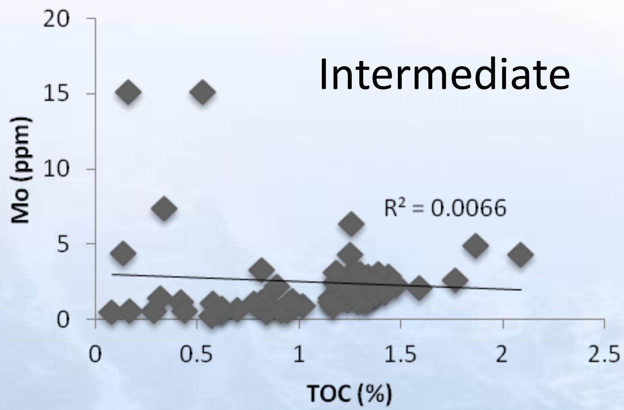
•Mo_{EF} versus U_{EF} commonly shows paleo-redox of sedimentary environments.
•Shallow Utica samples show low Mo and U enrichments (less than seawater) suggesting a suboxic environment
•Deep Utica samples with higher Mo and U enrichments suggests an oxygen deficient to partly euxinic environment.

Conclusions

- The key components of the maceral assemblage in the Utica Shale samples are consisting primary Type II marine kerogen (i.e., chitinozoan, liptinite, liptodetrinite) and the remaining is migrated bitumen.
- Bitumen in the rock are accumulated in larger intergranular pores and/or dispersed within the clay matrix.
- Deep Utica samples are in the dry gas window while the less buried samples from the same unit is in the other two wells are in the oil generation window.
- There is no further hydrocarbon generation for deep Utica samples, while the shallow and intermediate Utica samples still have some potential for hydrocarbon generation.
- Low TOC content and high carbonate content dramatically affect the OI values.
- Vitrinite reflectance equivalent from measurements of bitumen and chitinozoan reflectance strongly correlates.

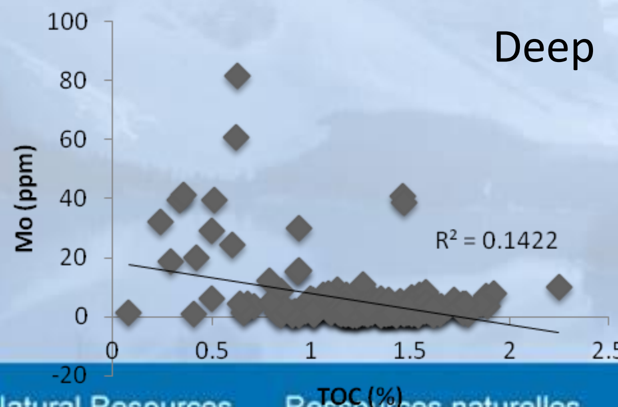


In shallow samples Mo shows a good correlation with TOC, while deeper samples have no significant or negative correlations specifically with higher Mo concentrations. It probably reflect the source/reservoir intervals in the Utica Shale. In intervals with good correlation between Mo and TOC, organic matter is mainly primary organic matter while organic matter in intervals with no or negative correlation organic matter mainly continue of migrated bitumen.



For intermediate samples if we eliminate samples with Mo > 4, TOC and Mo show a good correlation (lower right graph), but it is not the case for deep Utica.

As shown on the graphs with increasing in depth Mo concentration increased as well.



Intermediate, Mo < 4ppm