Organic and Inorganic Petrographic Analysis of the "Nordegg" (Gordondale) Member of the Fernie Formation, Western Canada Sedimentary Basin, West Central Alberta*

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Abstract

The Gordondale ("Nordegg") Member of the Fernie Formation is a shale oil-prone formation that is the target of much unconventional exploration in the Western Canada Sedimentary Basin (WCSB). It is a tight (low permeability and porosity) organic-rich source rock characterized by fine-grained, fossil-rich, phosphatic, calcareous mudstones, deposited as a shelf facies in the Lower Jurassic. This study highlights the detailed organic and inorganic characteristics of the Gordondale, the nature of association of organic matter and mineral matter, and the implications for the hydrocarbon potential and reservoir quality.

Samples were collected from a 30 m core. Scanning electron microscopy (SEM) with energy dispersive x-ray (EDX) mapping, and optical petrography using white and ultraviolet reflected light microscopy were utilized for this study. Preliminary results indicate that the samples are rich in organic material with up to 13 wt. % TOC, and within the oil generation window with eq. VRo of 0.9%. Organic petrology indicates the presence of bitumen, exsudatinite, liptodetrinite, inertinite and zooclast. Bitumen is the dominant organic maceral in the samples. EDX maps indicate the mineralogy consists of calcite, dolomite, quartz, pyrite, apatite and clay minerals – mainly illite and kaolinite. Two main forms of bitumen (matrix and solid) were identified, based on mode of occurrence, maturity and accumulation. Matrix bitumen is fine-grained and invasive. It fills intergranular pore spaces within argillaceous and calcareous fractions. Reflectance and fluorescence measurements on matrix bitumen indicate BRo averaging 0.8%, and a yellow-brown fluorescence. Matrix bitumen is associated with clay mineral aggregates (mainly kaolinite) and apatite nodules. The matrix bitumen and exsudatinite in clay aggregates degrade rapidly and release light hydrocarbons (bright blue fluorescence) after exposure to ultraviolet light. Solid bitumen is solid granular bitumen of larger accumulations that have migrated from the matrix and accumulated within large isolated pore spaces, vacuoles of zooclast, and micro-fractures. It has a measured BRo between 0.8% and 1.1%, and does not fluoresce. Solid bitumen is associated with diagenetic calcites that are likely the bi-product of bacteria sulphate

reduction. Each type of bitumen with their mineral associations could influence the reservoir properties in the Gordondale, with respect to release of hydrocarbons at the micro to nano scale.

References Cited

Asgar-Deen, M., C. Riediger, and R. Hall, 2004, The Gordondale Member: designation of a new member in the Fernie Formation to replace the informal "Nordegg Member" nomenclature of the subsurface of west-central Alberta: Bulletin of Canadian Petroleum Geology, v. 52, p. 201-214.

Boyer, E.W., B.R. Swistock, J. Clark, M. Madden, and D.E. Rizzo, 2011, The impact of Marcellus gas drilling on rural drinking water supplies: The Center for Rural Pennsylvania. Web Accessed November 26, 2014. http://www.rural.palegislature.us/documents/reports/Marcellus_and_drinking_water_2012.pdf.

Bertrand, R., and Malo, M., 2001, Source rock analyses, thermal maturation and hydrocarbon generation in the Siluro-Devonian rocks of the Gaspé Belt basin, Canada. Bulletin of Canadian Petroleum Geology, 49/2, p. 238-261.

Jacob, H., 1989, Classification, structure, genesis and practical importance of natural solid oil bitumen ("migrabitumen"): International Journal of Coal Geology, v. 11, p. 65-79.

Jarvie, D.M., B.L. Claxton, F. Henk, and J.T. Breyer, 2001, Oil and shale gas from the Barnett Shale, Fort Worth Basin, Texas: AAPG Annual Meeting, Program and Abstracts, p. A100.

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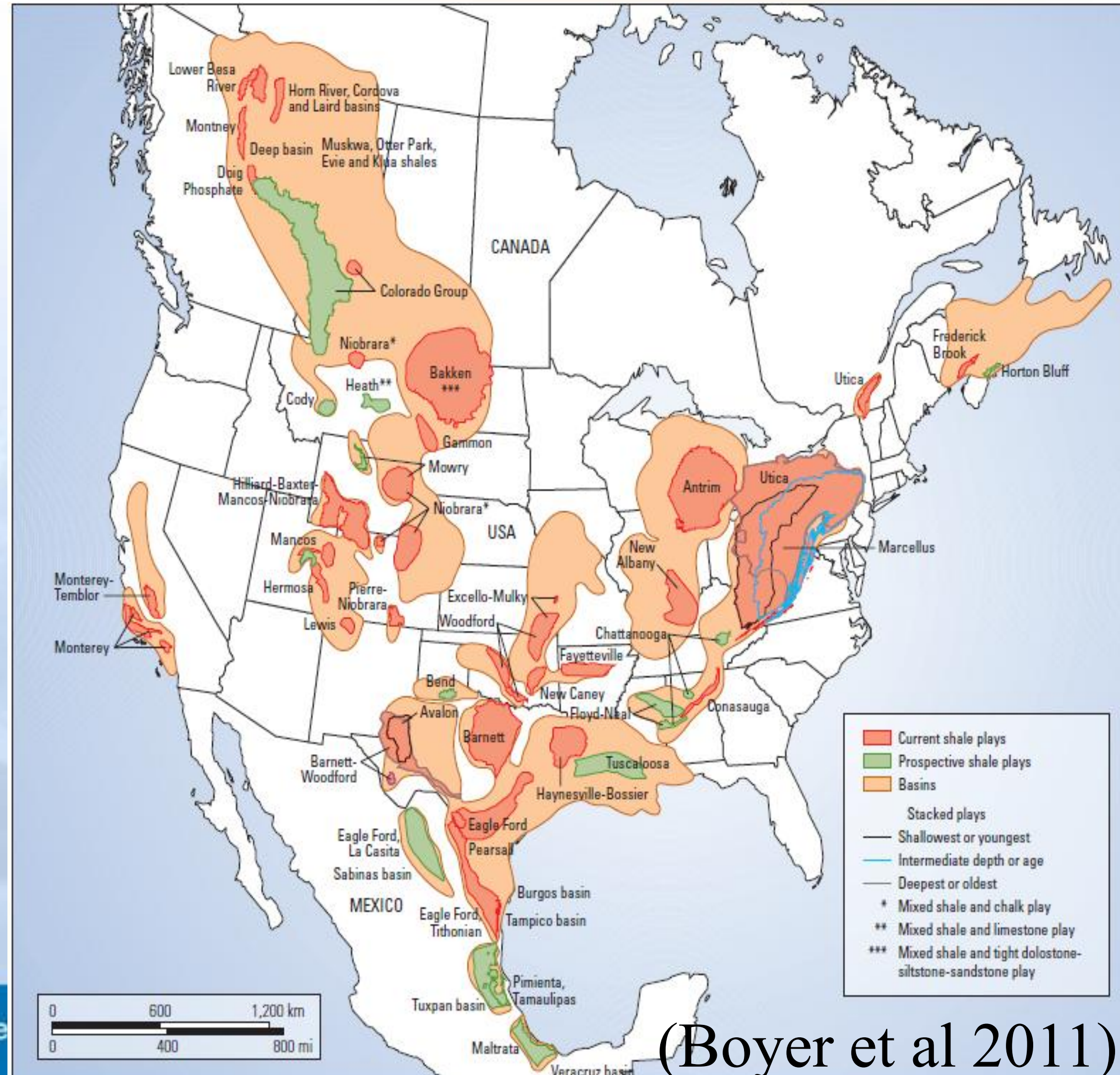
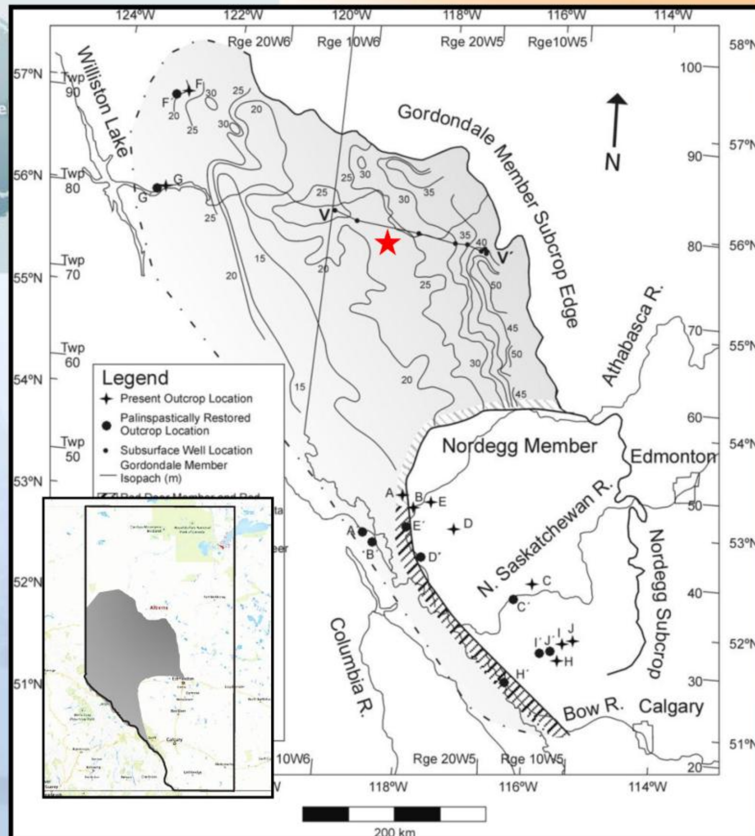
- Why is this important?
  - The Gordondale is one of the richest oil-liquid gas hydrocarbon source rocks in Canada, and is an unconventional petroleum resource target
- What's the ultimate Goal?
  - To improve understanding of the microscale organic matter characteristics of the Gordondale & it's association with inorganic matter & implications for its reservoir characteristics
- What Methods will be applied?
  - Organic geochemistry, Organic petrography & Scanning electron microscopy with energy dispersive x-ray mapping
  - two cores for thesis, only results for the primary core will be presented in this study

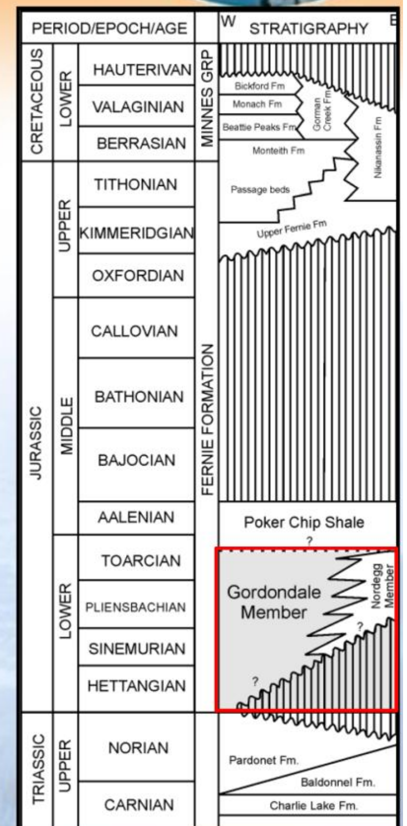


(Boyer et al 2011)

Geological Location & Age



Map showing the areal extent of the Gordondale Member in Grey, and the approximate location of the well studied. Modified from Asgar-Deen et al., 2004.



Age determined based on coccolith & ammonite biostratigraphy. From Hettangian to Toarcian Age (201.6Ma to 176Ma)

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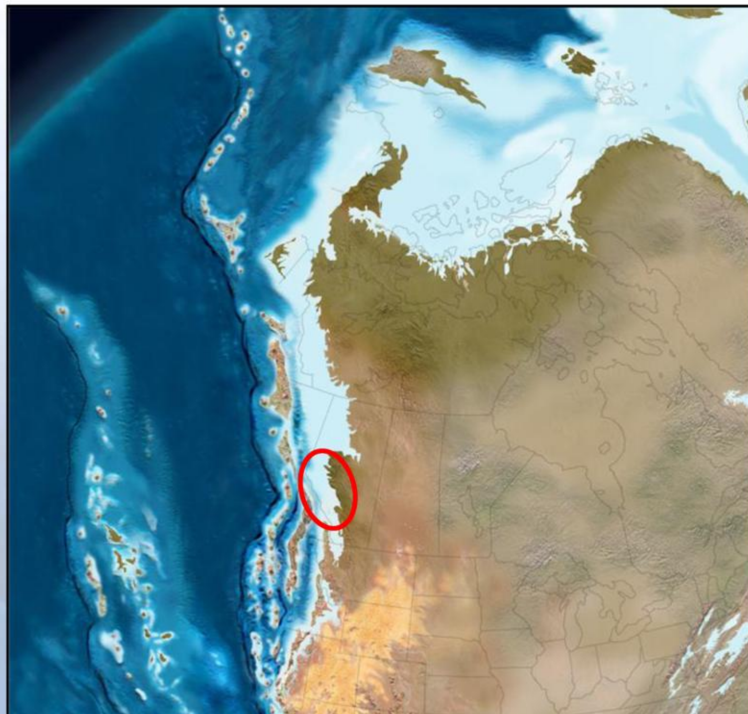
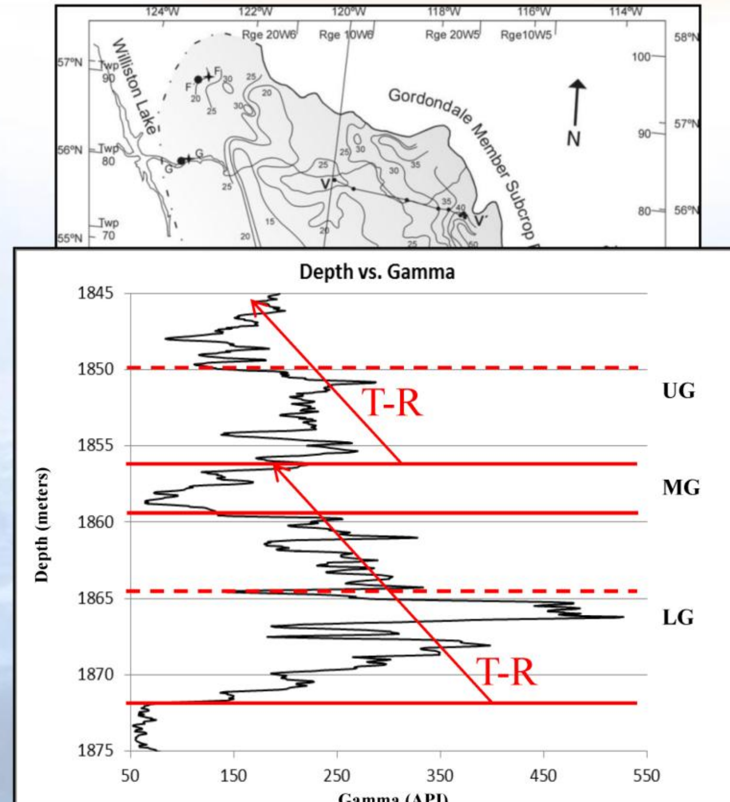
Presenter's notes: Nordegg carbonate platform just south of the Gordondale Basin. The Gordondale is conformably overlain by poker chip shale (seal), and unconformably underlain by Upper Triassic carbonates (Charlie Lake Limestone). The spatial extent of Gordondale is about 400 km in length (NW-SE) and 300 km in width (E-W), so the areal extent is about 120,000 km^2

Paleogeography & Depositional Environment

- Deposited Northwest of a carbonate platform and Terrane accretion west of study area
- Restricted basin conditions, dominantly anoxic, hypersaline.
- In two Transgressive-Regressive cycles

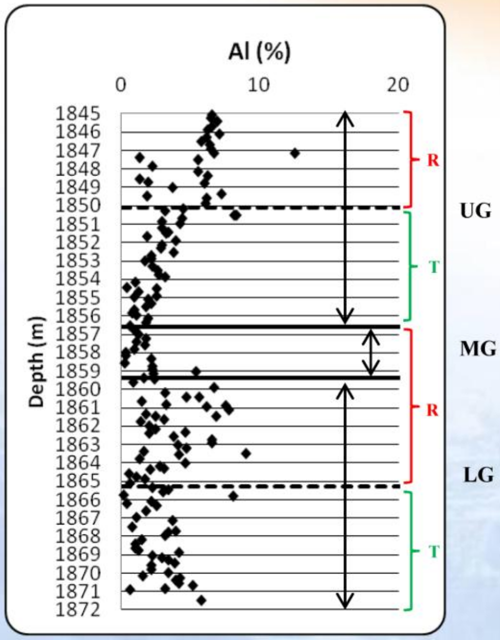


Lower Jurassic (180Ma) Paleogeography of North America. From R. Blakey, ***http://jan.ucc.nau.edu/rcb7/***



Presenter's notes: Restricted basin condition a result of being bound by carbonate platform and terrane accretion to the west. Terrane accretion also sediment source for siliciclatic input to basin during regression.

Detrital Proxies

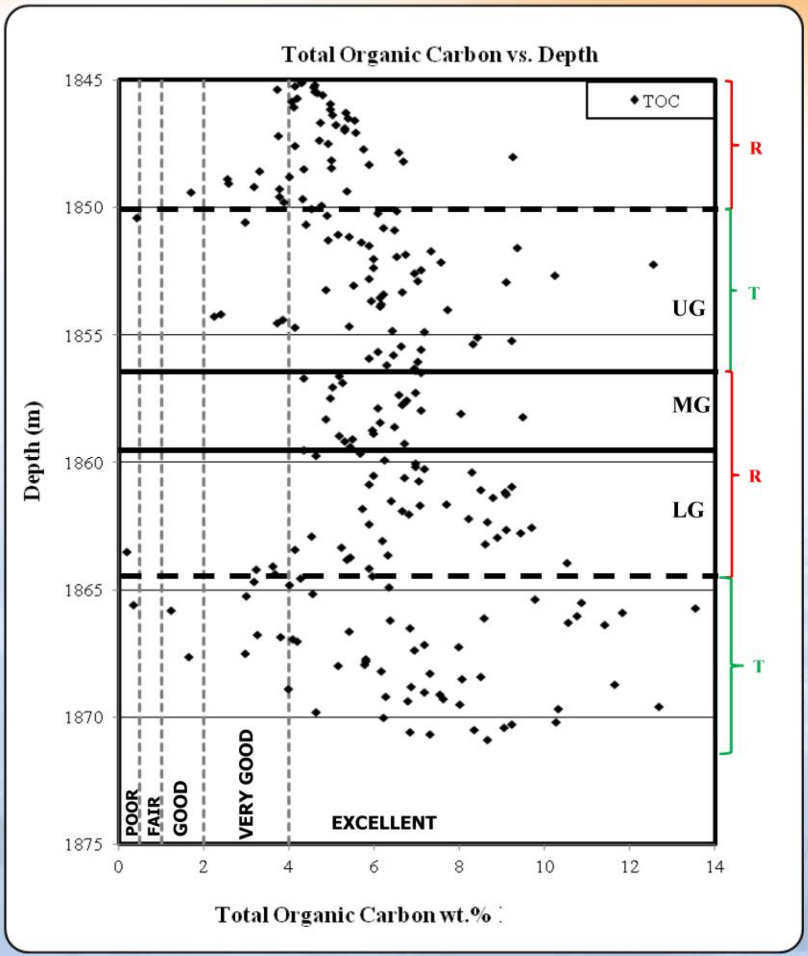


T-R boundary

- Al is a key proxy for detrital input events.
- Transgressive intervals = higher water depths, low sedimentation rate & anoxia = better organic matter preservation.
- Regressive intervals = higher sediment input into the basin = more detrital (argillaceous) sediment deposited in the basin, TOC dilution

Presenter's notes: Low siliciclastic input in middle Gordondale – 1st regression, so sediments dominantly composed of bioclastic carbonate grains, e.g coccoliths and foraminifers from suspension fallout, some replaced radiolarians too – low dilution of TOC due to limited detrital input.

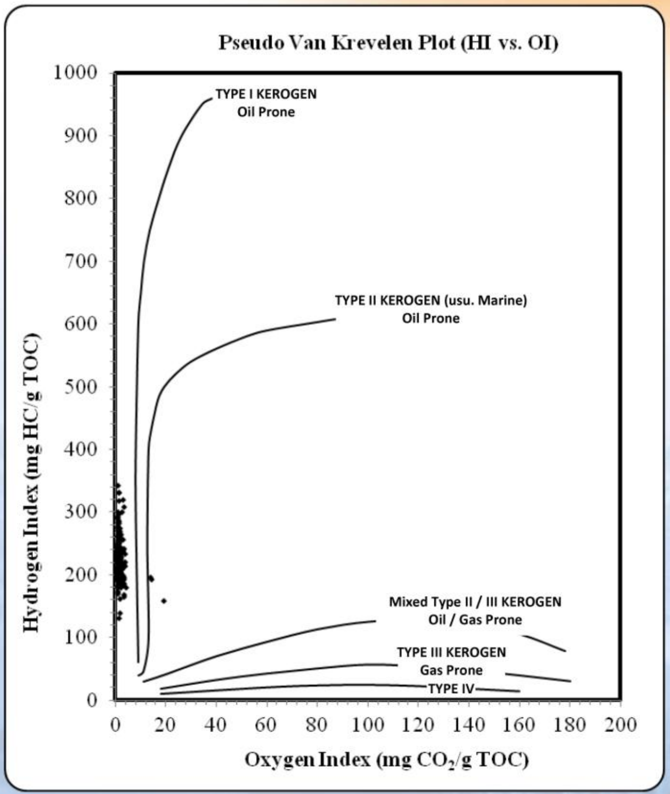
Rock-Eval 6 – TOC



- Higher TOC (10+ wt.%) during Transgressive intervals
- Average TOC – 6 wt.%, including the middle silty unit
- Overall TOC in Gordondale is excellent!

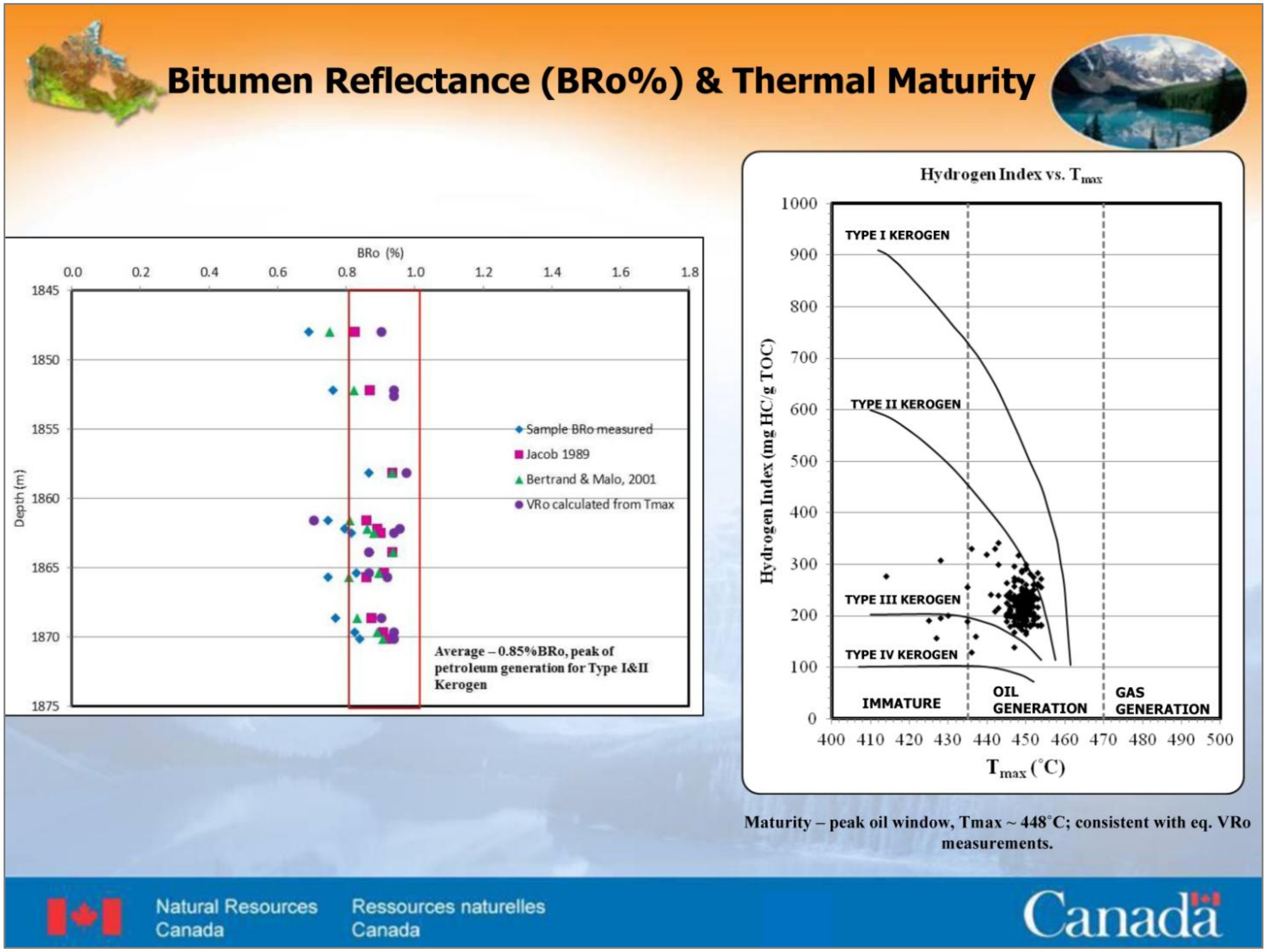
Presenter's notes: Through both regressive and transgressive cycles, TOC remains excellent. This is because the nature of the restricted basin, which provided great opportunity for nutrient input, primary productivity, and excellent preservation.

Rock-Eval 6 – Kerogen Quality



Type I & Type II Kerogen – Marine sourced Kerogen, based on the thermal evolution curves. These Kerogen types will likely produce oil upon maturation.

Presenter's notes: Pseudo Van Krevelen diagram tells us the type and quality of the HC's that the Kerogen type is able to generate upon reaching maturity HI/OI is used to distinguish the source of the OM, Marine OM produce mostly oil while terrestrial OM produce mostly gas. Over mature Marine OM can also produce gas. In late stages of oil generation (over-mature), the TOC content, Hydrogen Index and hence HC potential drop significantly.



Presenter's notes: Reflectance of the bitumen was measured and it was converted to eq.VRo using Jacobs and Bertrands-Malos's equations. Also the Tmax values measured in pyrolysis were converted to eq. Vro and all these values are plotted. Narrow range of values, with average of 0.85BRo. Measurement error as oxidized OM – inertinites and not bitumen was measured in one of samples, in that sample Tmax fairly consistent with other samples, so error was in reflectance measurements.

$\%VRo = (\%BRo+0.03)/0.96$ (Bertrand & Malo, 2001)

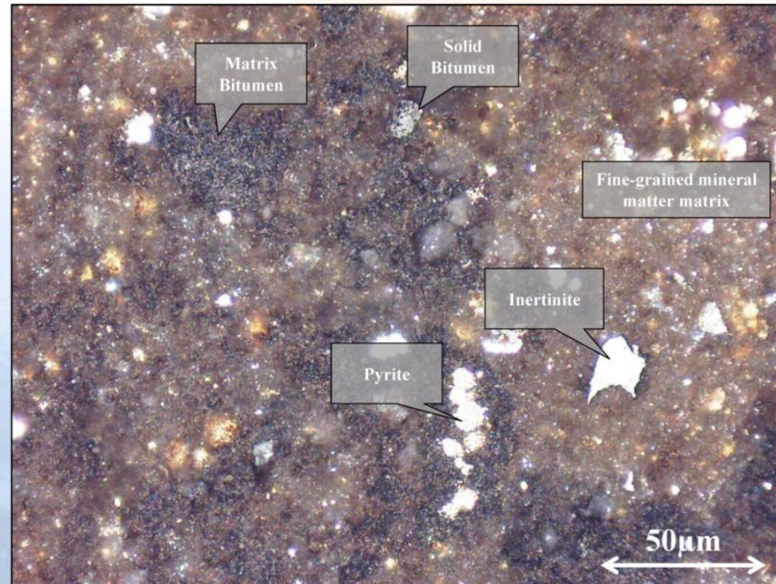
$\%VRo = 0.618 * \%BRo+0.40$ (Jacob, 1989)

$\%VRo = (0.0180) * (Tmax) - 7.16$ (Jarvie et al. 2001)

Organic Petrography - organic matter type

- Dominant organic matter – Bitumen, sulphur rich (1.5 to 7.1 wt%)
- Two modes of accumulation:
  a) Fine grained dispersed bitumen – matrix bitumen

  b) Molding, pore & fracture filling bitumen – solid bitumen
- This distinction is solely based on accumulation



Reflected white light photomicrograph

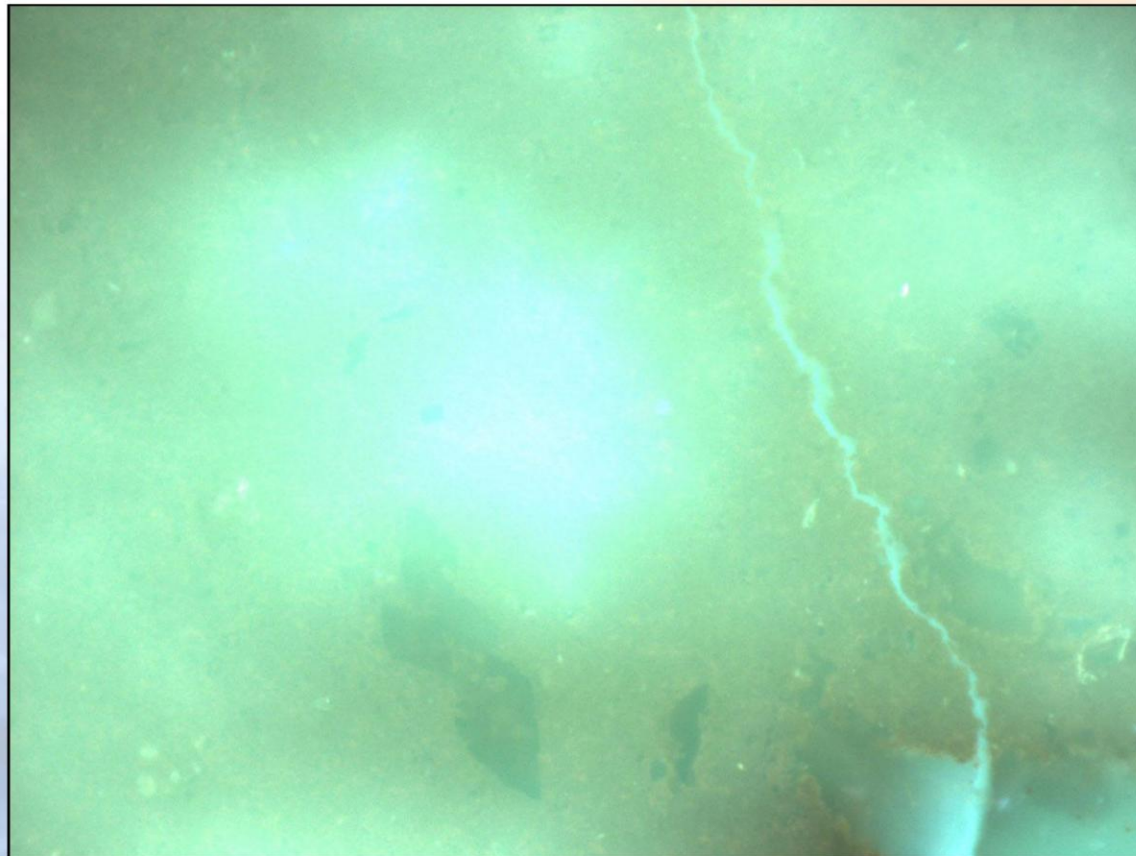
Presenter's notes: Some Type I are sulphur enriched kerogen – Total sulphur values range from 1.5 to 7.1% by weight - The Nordegg HC's were generated early at lower thermal maturities.

OM bits in Gordondale consist of mostly bitumen – 90% and smaller amounts of:

- Exsudatinite (a microscopic solid bitumen that is a by-product of *in situ* hydrocarbon generation)
- Inertinite
- Liptodetrinite
- Zooclasts (zooinertinites)
  - Algae remains
  - Alginite

Volatilization of HC's after exposure to high power fluorescent light

Time – [illegible]s



- Blue-green fluorescing volatile & free hydrocarbons

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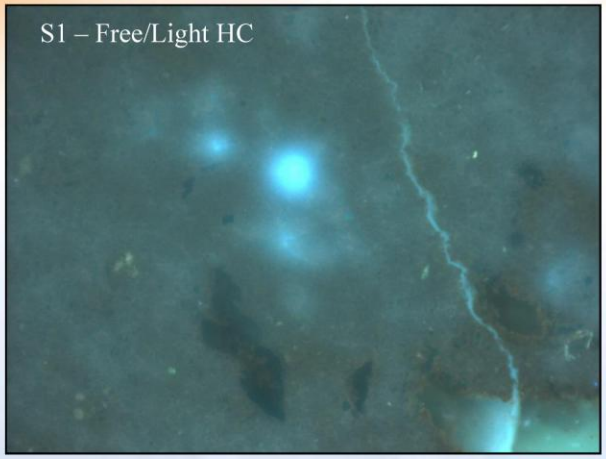
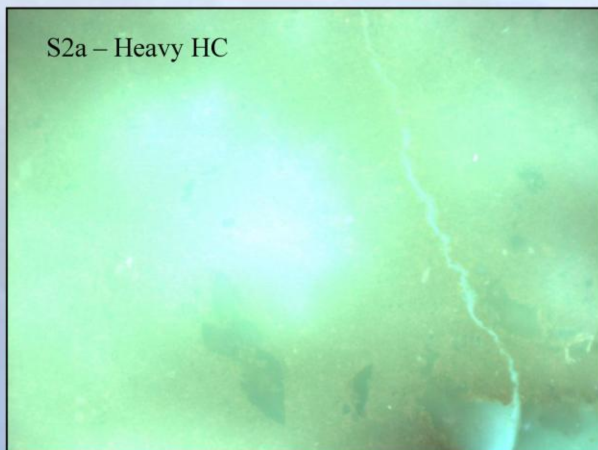
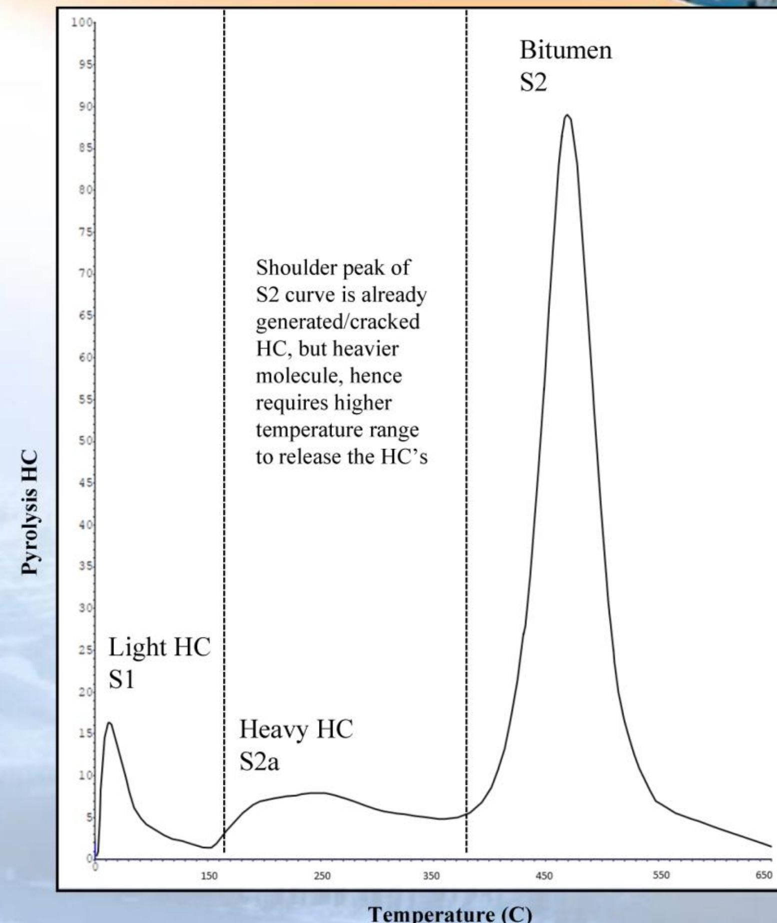
Presenter's notes: Increased exposure to UV light breaking down to solid Bitumen and release of HC's.

Light & Heavy Hydrocarbons S1 & S2a

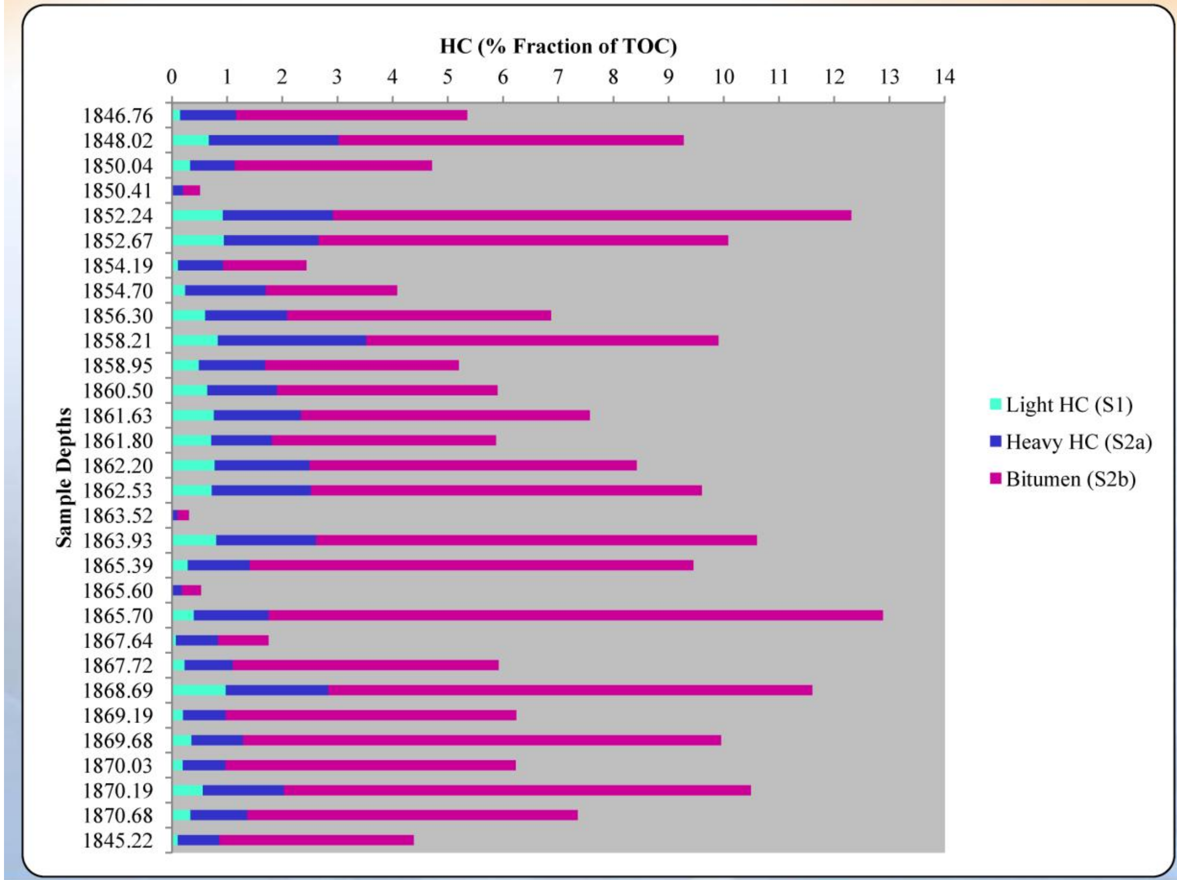






Presenter's notes: FID (Flame Ionization Detector) - detector signal. At lower end of exposure already see HC already sitting in sample, at higher ends of exposure, get release of more HC's likely heavier, there is no direct proof that the UV light simulates the temperature ranges needed to release these 3 types of HC, as per the diagram on the right, because UV light is used under room temperature.

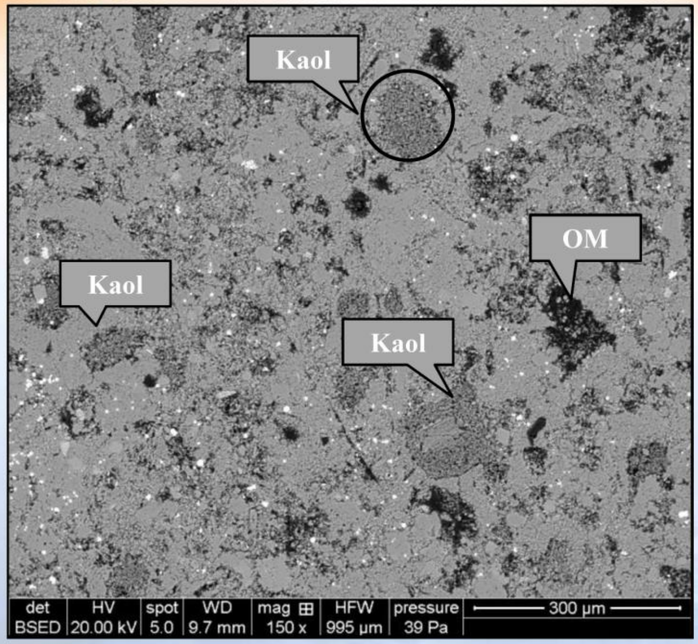
HC's & Bitumen distribution in TOC

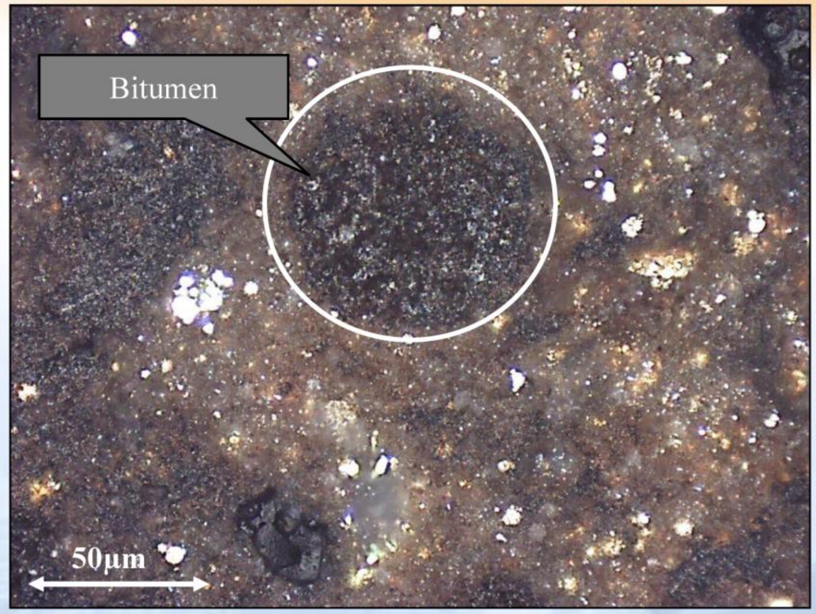


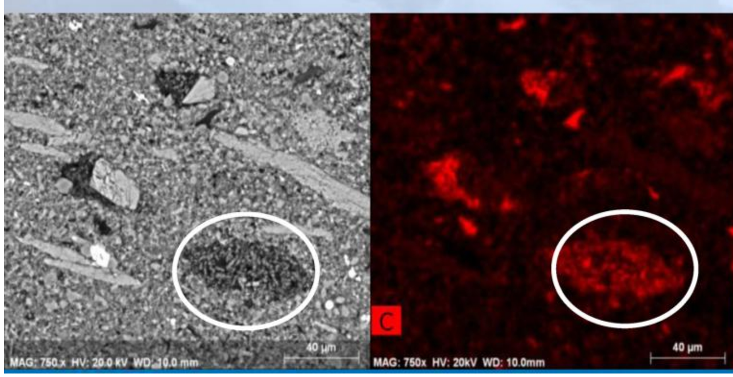
- A large amount ~ 70% of the current organic matter component of the Gordondale is Bitumen, which still has secondary generation potential

Presenter's notes: So far, 3 components of HC's in sample TOC, their relative abundance is 70% for Bitumen, and ~20% for heavier HC's and 10% for light hydrocarbons. There is still a good remaining HC potential in Gordondale – the bitumen that has secondary generation capabilities.

- Bitumen dispersed in kaolinite clay aggregates, within argillaceous (detrital) matrix





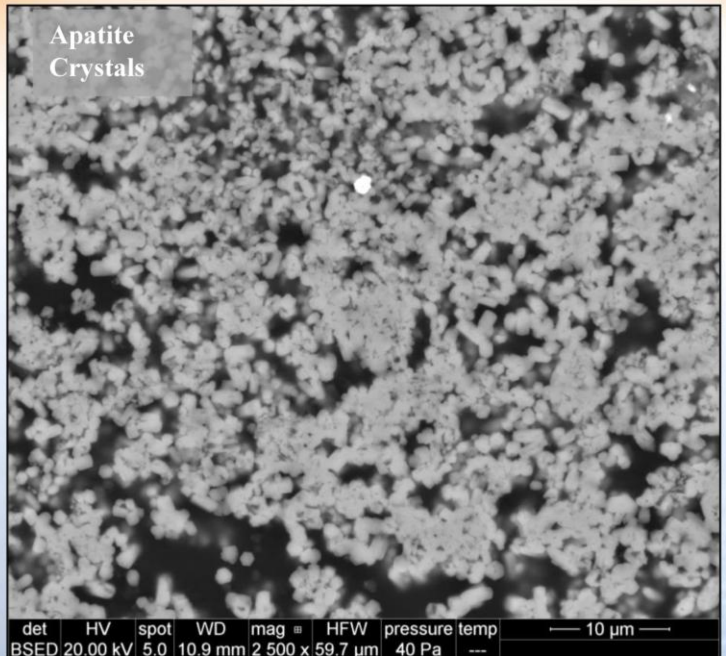


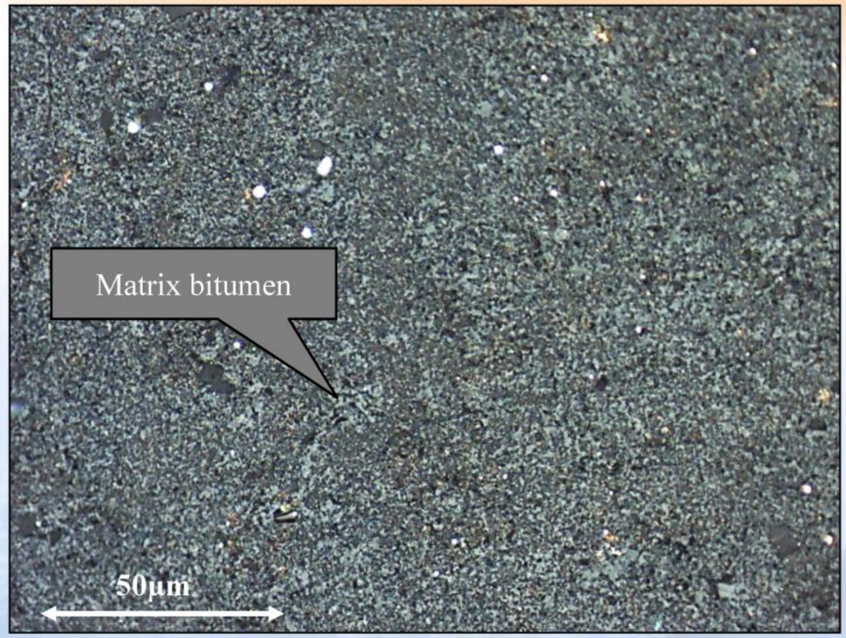
- Argillaceous mudstone
- TOC – 9.27%
- Inter particle porosity in Kaolinite aggregates are bitumen filled

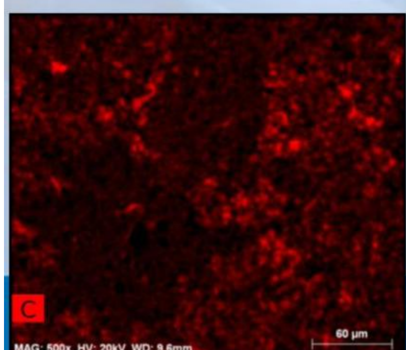
Canada

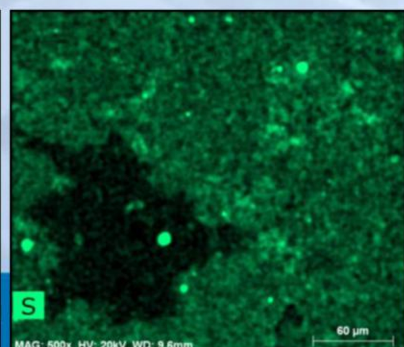
Presenter's notes: Dolomite in matrix, argillaceous (clay rich) matrix with detrital Qtz – siliciclastic input TOC concentrated in Kaol hosts. Regressive intervals not typically rich but where TOC is high, likely associated with Kaolinite aggregates. Sample is mature.

- Bitumen dispersed in re-worked micro-crystalline Ca-P pellets & lenses (Apatite)





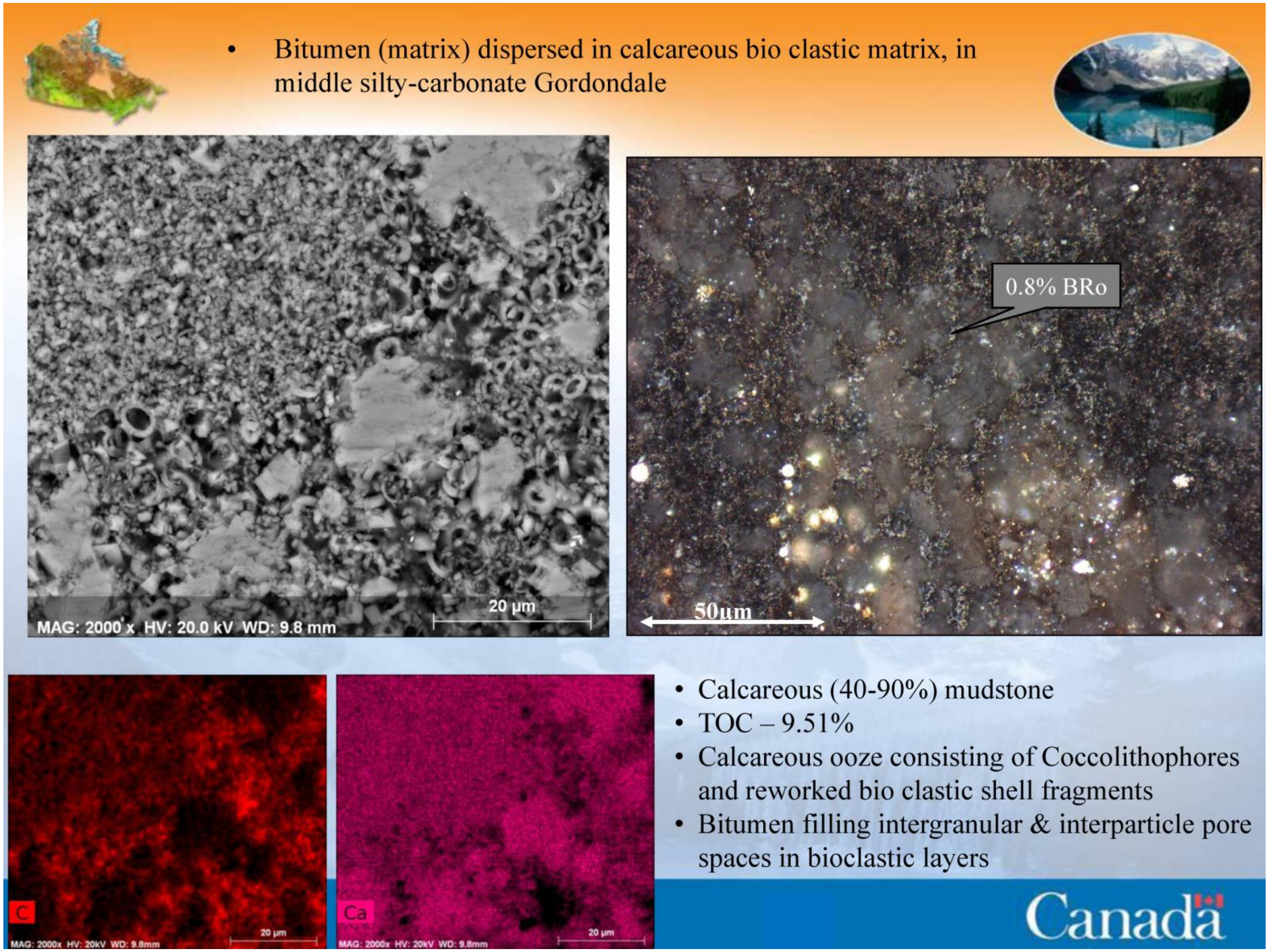




- Phosphatic, moderately calcareous mudstone
- TOC – 12.55%
- Intercrytalline porosity within apatite crystals is bitumen filled

Canada

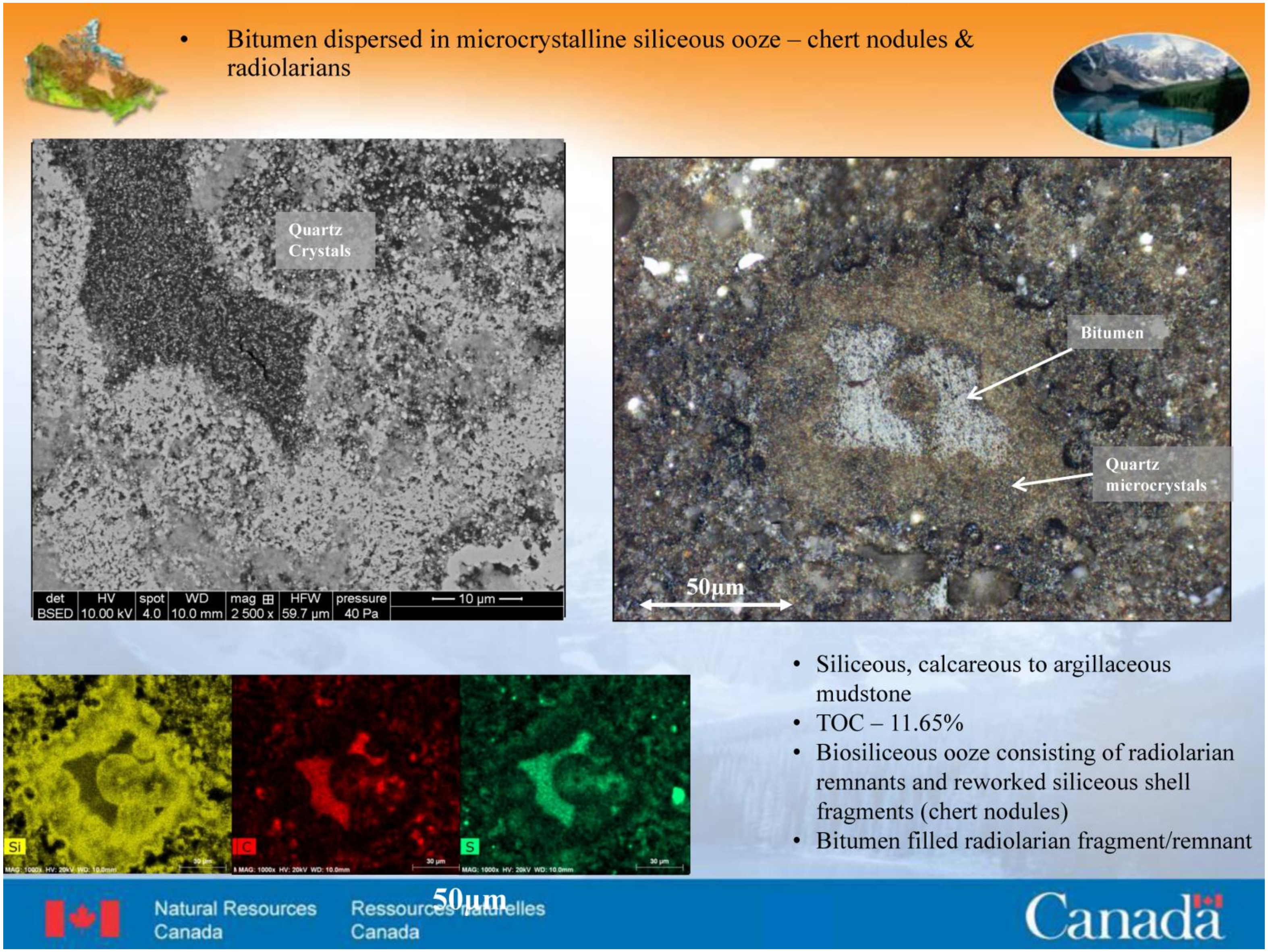
Presenter's notes: Clay-rich matrix in some areas – makes sense as this is the bottom of the T cycle, so sample is around the boundary between transgression and regression. Reworked phosphate nodules because it also contains detrital calcite, quartz, pyrite framboids, coccolith remains, etc. All grey is bitumen – sample completely saturated with Bitumen. High TOC – transgressive interval. Mature.



Presenter’s notes: The matrix consists of aggregates of coccolith remnants in an organic and argillaceous matrix. Quartz appears as detrital grains concentrated within lenses and laminae in the rock matrix – as evident from Si. Most calcite present in fine-grained matrix or as whole and fragmented coccoliths. Calcite is also present as bioclasts (bivalves, replaced radiolarians – or are they rounded micronodules? and foraminifera). Bedding distorted/deflected around micronodules, indicates a detrital origin for the calcite nodules. Not typically TOC rich but when it is, it is more concentrated in the more porous bioclastic carbonates. *(Presenter’s notes continued on next slide)*

(Presenter's notes continued from previous slide)

Biogenic ooze, also called biogenic sediment, any pelagic sediment that contains more than 30 percent skeletal material. These sediments can be made up of either carbonate (or calcareous) ooze or siliceous ooze. The skeletal material in carbonate oozes is calcium carbonate usually in the form of the mineral calcite but sometimes aragonite. The most common contributors to the skeletal debris are such microorganisms as foraminiferans and coccoliths, microscopic carbonate plates that coat certain species of marine algae and protozoa. The distribution of biogenic oozes depends mainly on the supply of skeletal material, dissolution of the skeletons, and dilution by other sediment types, such as turbidites or clays.



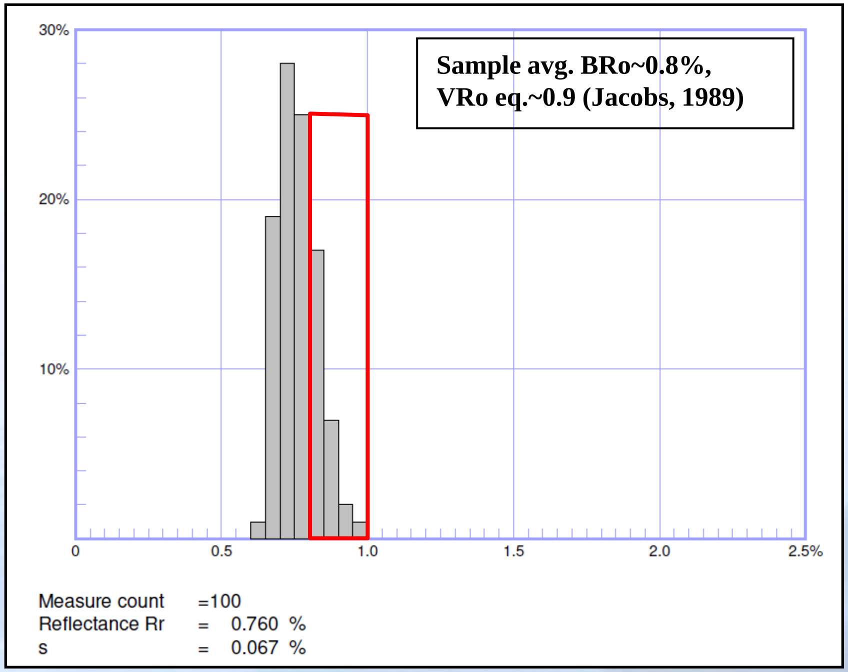
Presenter's notes:Siliceous ooze which is composed of chert nodules and replaced radiolarian fragments. Siliceous ooze is a soft siliceous pelagic sediment that covers large areas of the deep ocean floor. Siliceous oozes consist predominantly of the remains of microscopic sea creatures, mostly those of diatoms and radiolarians. Sometimes siliceous oozes also contain silicoflagellates and the spicules of sponges.
(Presenter's notes continued on next slide)

(Presenter's notes continued from previous slide)

Radiolarians are marine protists that also construct microscopic shells composed of opaline silica and are distant relatives of the foraminifera. Siliceous ooze accumulates on the ocean floor where the bottom waters are close to saturation with respect to silica, and the opaline remains of either diatoms, radiolarians, silicoflagellates, and sponge spicules, or combinations of these are rapidly buried. These conditions exist within areas of high biological productivity associated with volcanic islands and nutrient-rich upwelling zones.

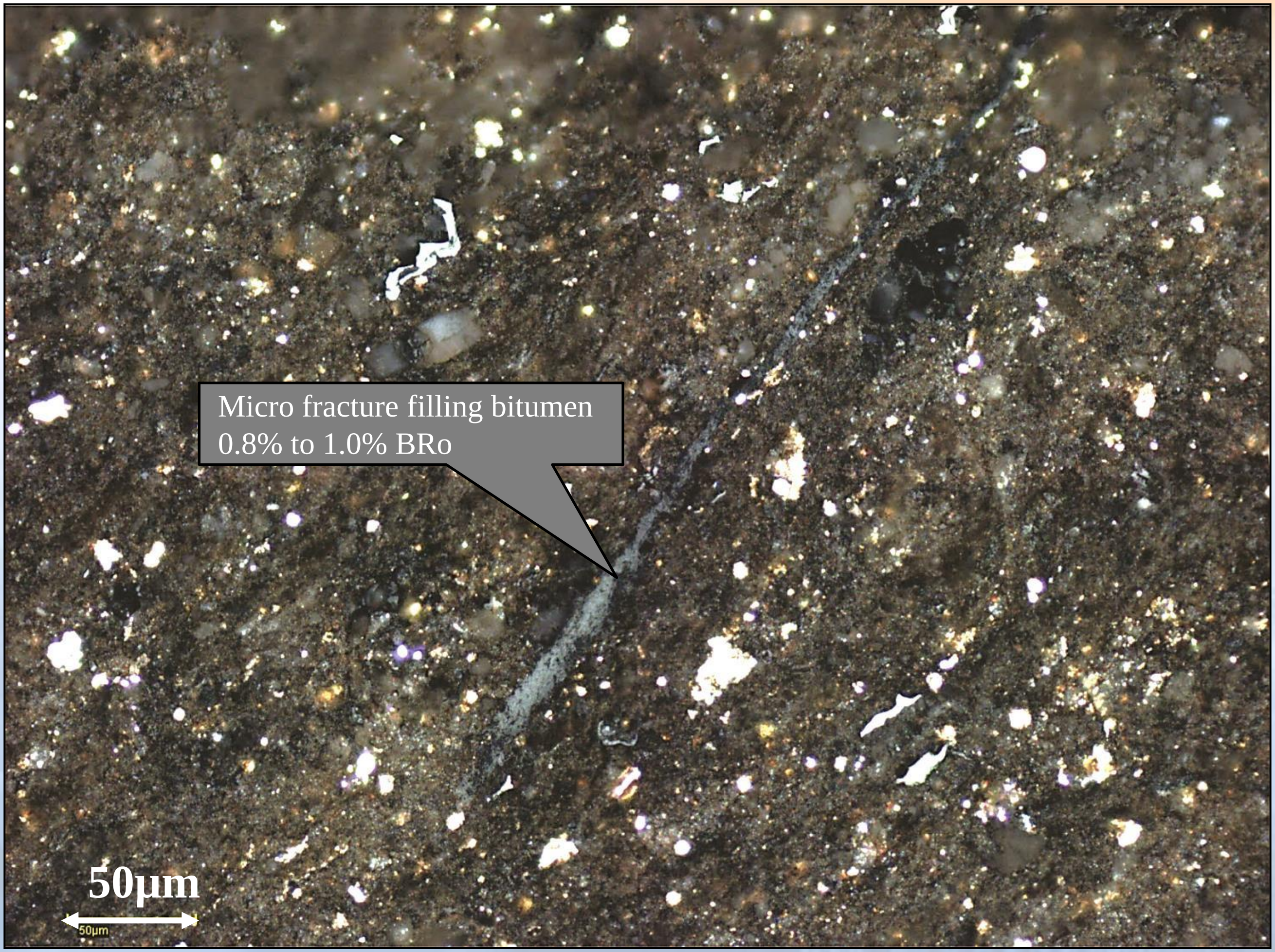
The entire particle was a radiolarian with hard silica shell . It was then replaced by microcrystalline quartz from outside towards core of the radiolarian. The space left out inside is filled with bitumen. Reworked and replaced (recrystallized) radiolarians – now either carbonate nodules or siliceous (chert) nodules. Biosiliceous sediment – highly productive water column. Sulphur rich bitumen.

Solid Bitumen – lump accumulations



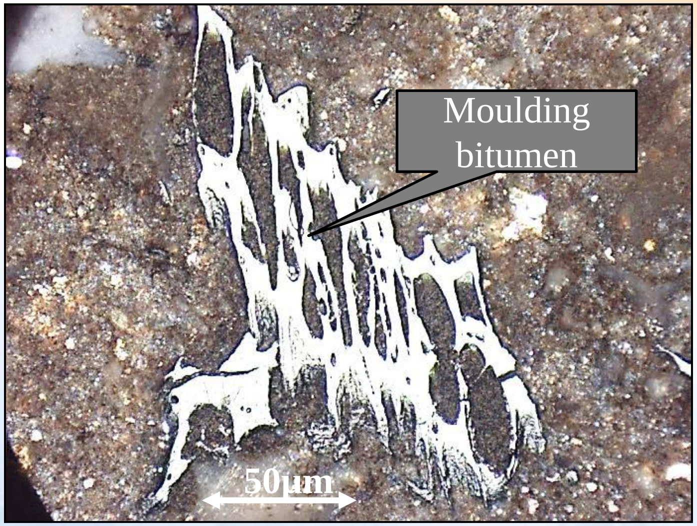
- Surfaces span 10's of microns in size & it has a compact, non-dispersive texture.
- Appears to concentrate in large pores and fractures in matrix and in particles.
- Reflectance of bitumen ranges from 0.8% to 1.0 BRo%.
- Good measurable surfaces, easy to measure with spot size of 3µm.

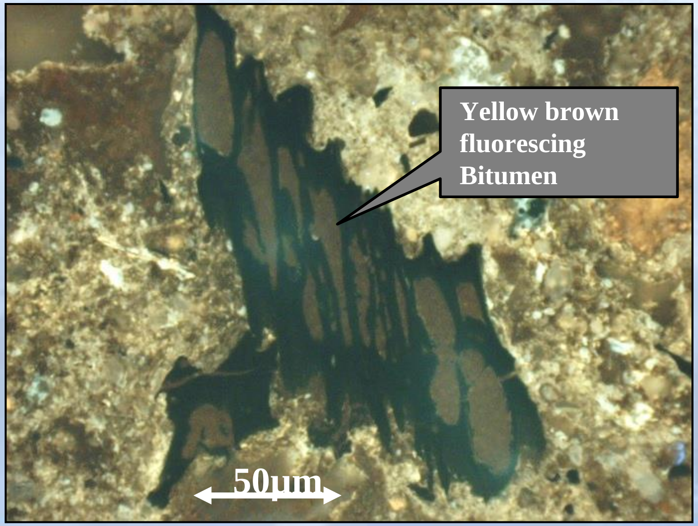
- Micro - Fracture filling solid bitumen



- Migration of initial generated oil through micro fractures, where they were subsequently converted to bitumen in later stages of maturation

- Pore filling solid bitumen - accumulation within pores of microfossil remnants (e.g. Foraminifera, bivalves, belemnites, fish bones) & vacuoles of other organic macerals (inertinite)





- Bitumen filled Fusinite maceral (woody terrestrial)

Conclusions

- Predominant organic matter – Bitumen
- There is a wide range of varying accumulation modes along depth, representation of depositional and mineralogical controls
- Matrix and Solid bitumen accumulations ~ average 0.8% BRo – Oil Window, correlates with Tmax Values of ~ 448^{o} C
- There is ongoing conversion of bitumen to volatile hydrocarbons in the study area. Release of volatile HC's results in re-opening of existing pore spaces initially filled with bitumen.
- Integration of SEM and Organic petrography helps to understand the mineral and organic matter relationships

Acknowledgements

- Geological Survey of Canada
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- IFFAEM Lab, Department of Geoscience
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