

# **A Regional Diagenetic and Petrophysical Model for the Montney Formation, Western Canada Sedimentary Basin\***

**Noga Vaisblat<sup>1</sup>, Nicholas B. Harris<sup>1</sup>, Vincent Crombez<sup>2</sup>, Tristan Euzen<sup>3</sup>, Marta Gasparrini<sup>2</sup>, and Sebastien Rohais<sup>2</sup>**

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## **Abstract**

The Lower Triassic Montney Formation of the Western Canadian Sedimentary Basin is a world-class unconventional resource of gas, gas condensate and oil. Although commonly described as a shale, it is a siltstone over most of its subcrop, which presents complications for understanding and predicting petrophysical properties and hydrocarbon distribution. Petrophysical properties are functions of rock fabric, mineralogy and diagenetic processes, which in turn depend on sediment provenance, depositional environment, the pressure and temperature history, and fluid flow. In this study we are building a basin-wide petrophysical assessment of the Montney Formation, related to mineralogy and diagenesis and correlated with a sequence stratigraphic model. Datasets include mineralogical analyses from QEMSCAN and XRD, whole rock geochemical analyses by ICP-MS/ ICP-EAS, petrographic analysis from thin-section investigation with optical and cathodoluminescence microscope, and SEM imaging and pore system characterization. The Montney paragenetic sequence includes both pore-occluding and porosity-enhancing events. Pore-occluding events include precipitation of cements (quartz, feldspar, calcite and several generations of dolomite), mineral replacement (dolomite replacing silicate grains and gypsum replacing carbonates), and precipitation of authigenic phases in open pore space (pyrite and different types of clay). Pore-enhancing events include dissolution of different phases (feldspar, quartz and carbonate bioclaststic grains). Mapping mineralogy and diagenesis throughout the basin and incorporating this information, together with well logs, into GAMLS software (Geologic Analysis via Maximum Likelihood System) enabled us to generate a lithological model of the Montney that was fine-tuned against core logs. From the calibrated model, we calculated porosity and water-saturation profiles for selected wells and compared these results with porosity data obtained in the lab. This study is the first attempt at understanding pore systems of the Montney Formation on a regional scale and within the sequence stratigraphic boundaries. Our results provide a platform for modeling basin-scale fluid flow and predicting hydrocarbon distribution in the Montney.

## **Selected Reference**

Blakey, R., 2011, Colorado Plateau Geosystems, North American Paleogeographic Maps, Early Triassic (245 Ma): Website accessed September 6, 2015, <http://www2.nau.edu/rcb7/namTr245.jpg>.



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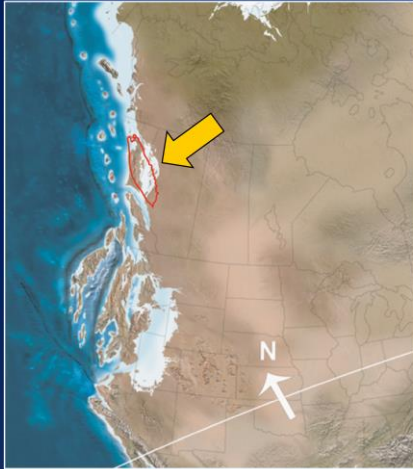
<sup>1</sup> University of Alberta

<sup>2</sup> IFP Energies nouvelles

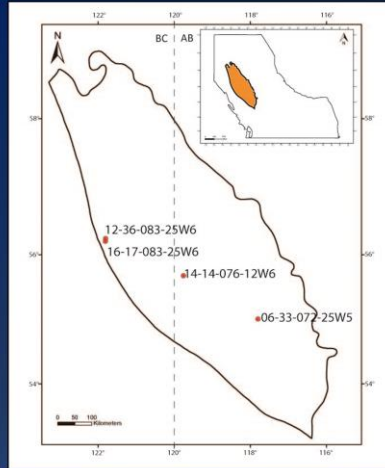
<sup>3</sup> IFP Canada

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# The Montney Formation

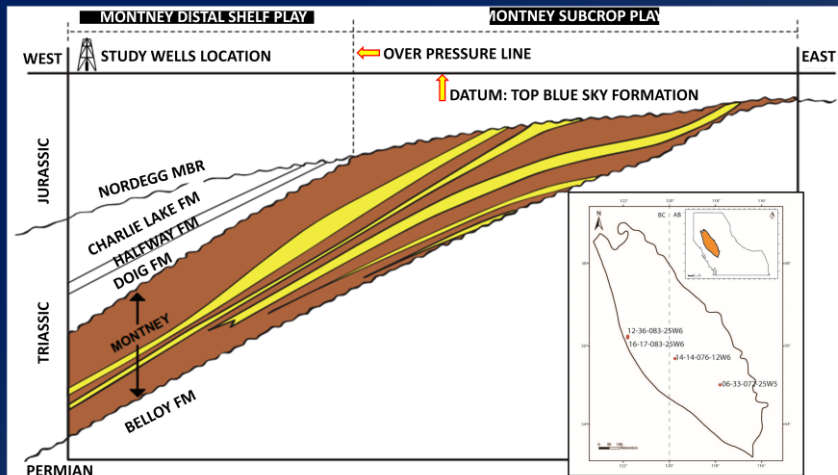


Blakey 2011; <http://www2.nau.edu/rcb7/namTr245.jpg>



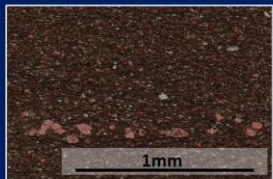
Presenter's notes: The Montney is a Lower Triassic siltstone formation that was deposited on the western margins of Pangea in shallow marine settings. On the Isopach map on the right the Montney is thickening westward and eroded to a zero edge on the eastern side by a major unconformity. All data presented will follow the cross section of those 4 wells. Samples are either from core chips (16-17 well) or cutting samples— all other wells.

# The Montney Formation

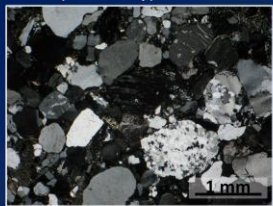


Low et al. (2011).

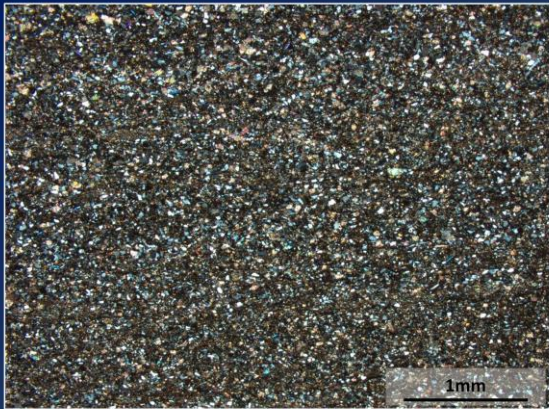
# Montney Siltstone



Shale (Duvernay)



Sandstone  
(Torridon, Scotland)

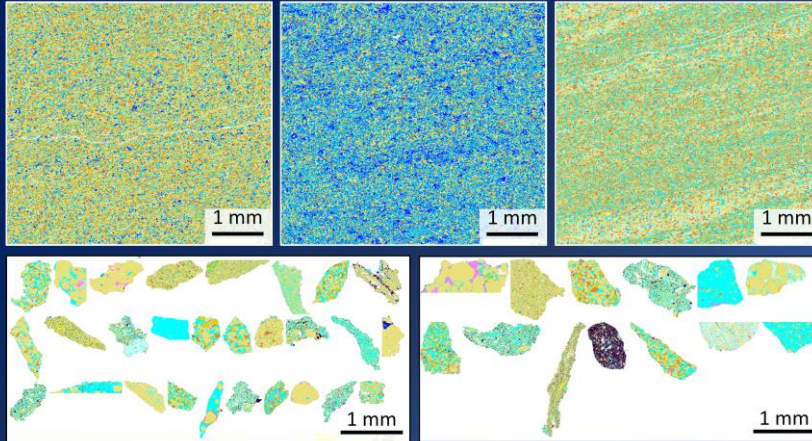


Siltstone (Montney)

Presenter's notes: The Montney, though considered a shale play, is actually siltstone reservoir. We know a lot about how a sandstone reservoir behaves, and in the past years we developed a good understanding of shale-reservoir processes. However, we do not know much about siltstone reservoirs. How would a siltstone reservoir differ from a shale or a sandstone?

## Rock Composition - QEMSCAN

- Backscattered Electron Microscope
- Energy Dispersive X-Ray Spectroscopy

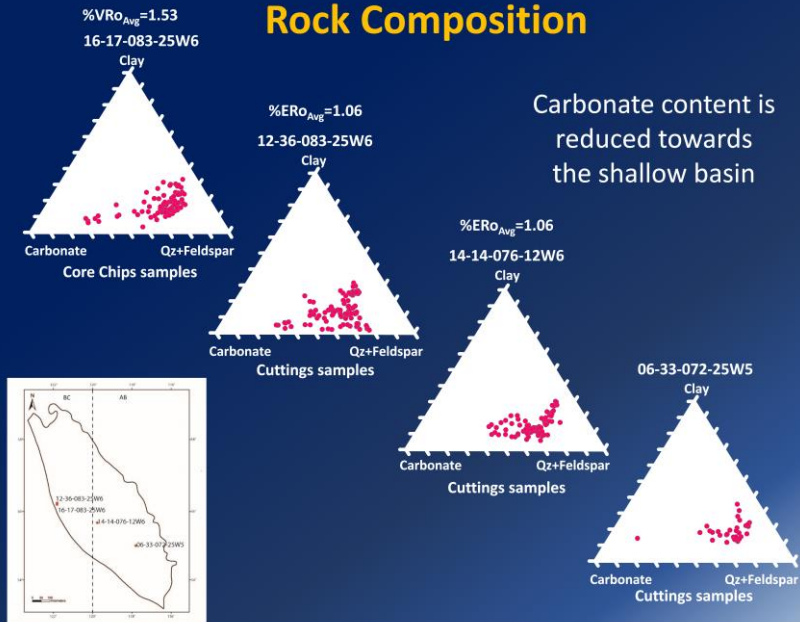


Presenter's notes: This is where technology is important; we use QEMSCAN to get precise mineralogy of core and cutting samples. Major advantage is the ability to distinguish micas from clays which can not be done by XRD.



# Rock Composition

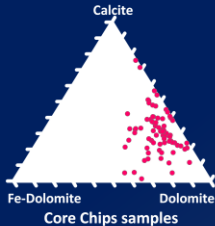
Carbonate content is reduced towards the shallow basin



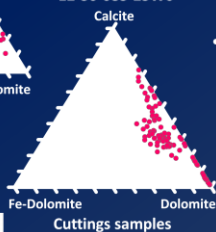
Presenter's notes: The bulk mineralogy plots for the 4 wells show a decrease in the total carbonate content towards the shallow part of the basin.

# Diagenetic Trends - Carbonates

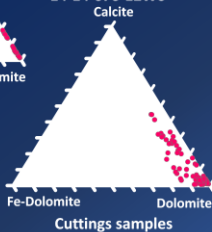
16-17-083-25W6



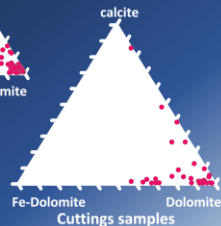
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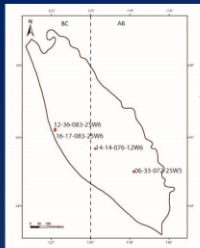
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06-33-072-25W5

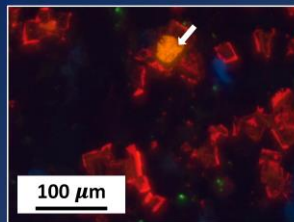
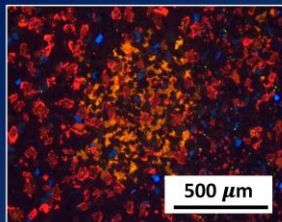
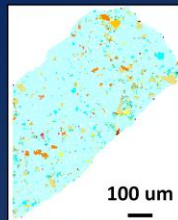
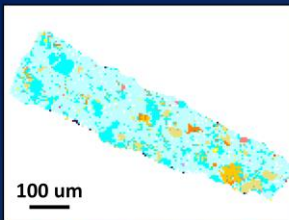
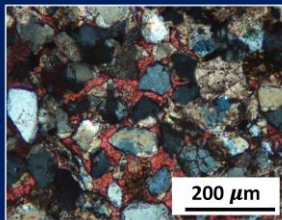


- Dolomite shows wide range (20-100%); quantity slightly increases towards the shallow basin
- Calcite content is slightly reduced towards the shallow basin
- Fe-dolomite content fluctuates



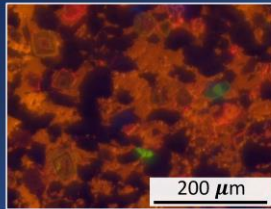
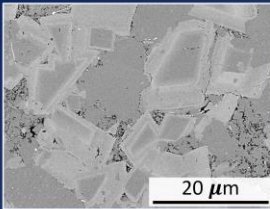
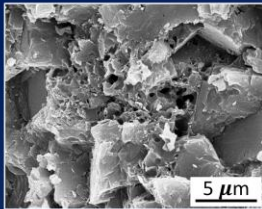
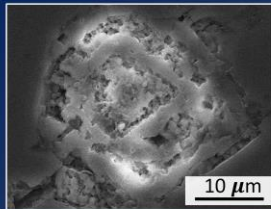
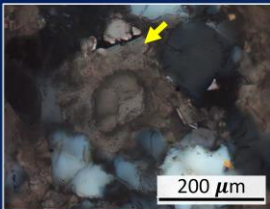
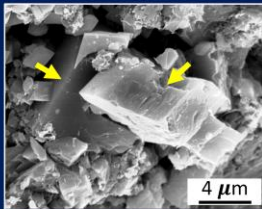


## Calcite

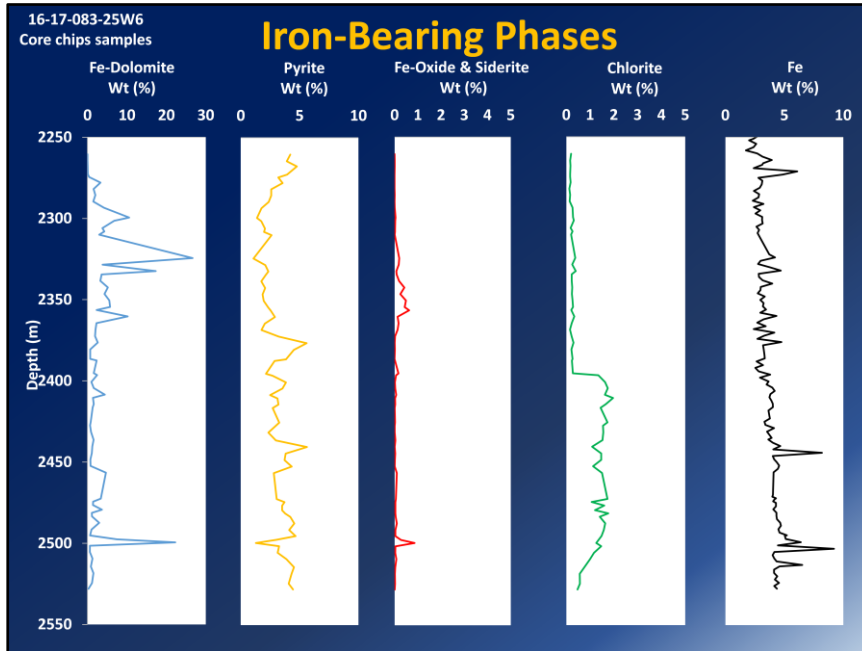


- Almost no detrital calcite was found. When present almost always found as nucleus for later dolomite growth
- Poikilotopic cement and overgrowth around dolomitic grain cores
- Possibly late diagenetic phase

## Dolomite

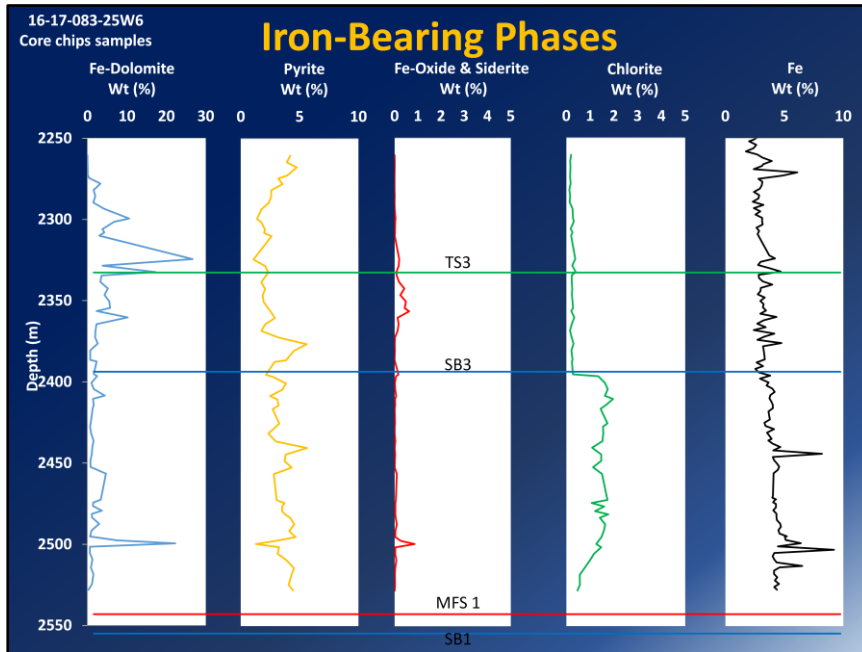


- Dolomite is present as detrital grains, authigenic crystals and overgrowth rims
- At least 2 generations of dolomite exist - possibly more.
- Dolomite dissolution is common
- Fe-Dolomite is visible in SEM by lighter colour



Presenter's notes: Deep wells (only one is presented; the others look very similar but the relations between minerals are more blurred (to be explained subsequently)). Negative correlation between Fe dolomite and pyrite. This means that as long as there is sulfide- pyrite being precipitated, and when sulfide is no longer present, iron is incorporated into the carbonate. Very low oxide content. A small increase at the bottom of the section with low pyrite and high Fe-dolomite (high Fe in the water, low S [Fe is not the limiting factor?]). Chlorite content increases towards the bottom of the well. Chlorite requires volcanic origin-- sediment source dependent-- less dependent on the amount of Fe in the system and the oxygen fugacity.

Middle and shallow wells- the pyrite to Fe-dolomite negative correlation is not everywhere kept, probably because there is some mixing in the samples (both are cutting samples). Lower concentrations of Fe-dolomite. Will be harder to conclude about minerals precipitation processes and water or sediment conditions from these samples as the relations between the phases are not straightforward because of the mixing.



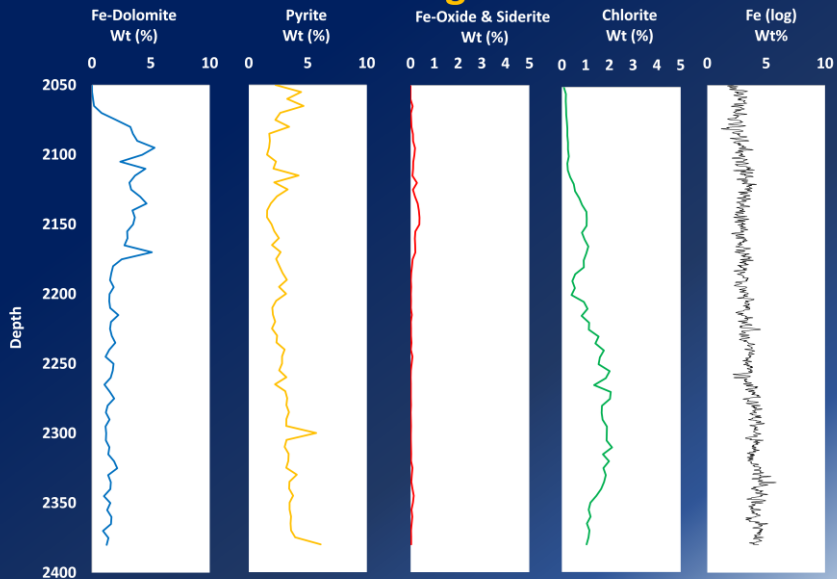
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12-36-083-25W6

Cuttings samples

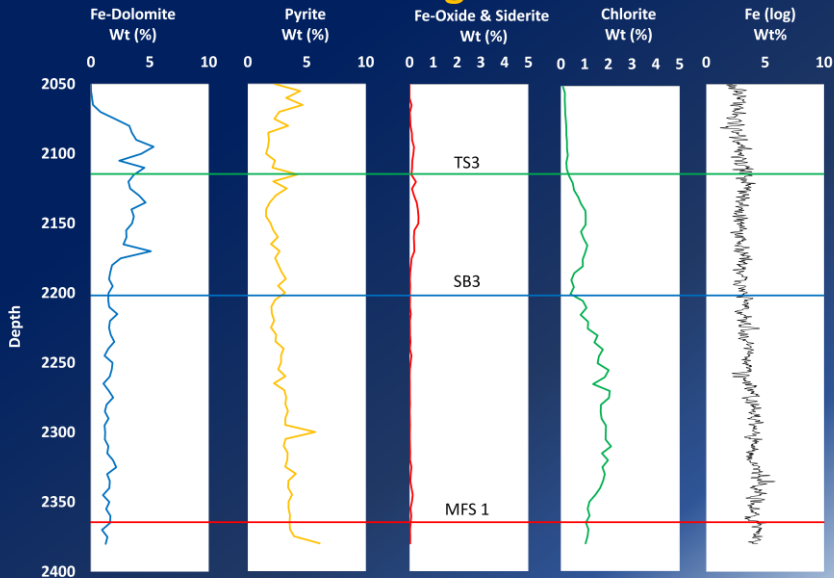
## Iron-Bearing Phases

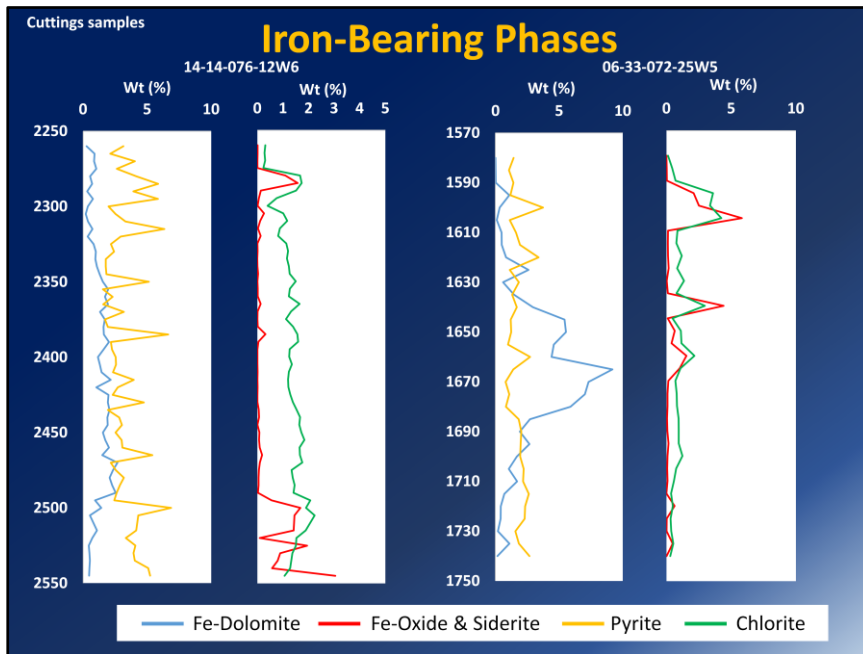


12-36-083-25W6

Cuttings samples

## Iron-Bearing Phases

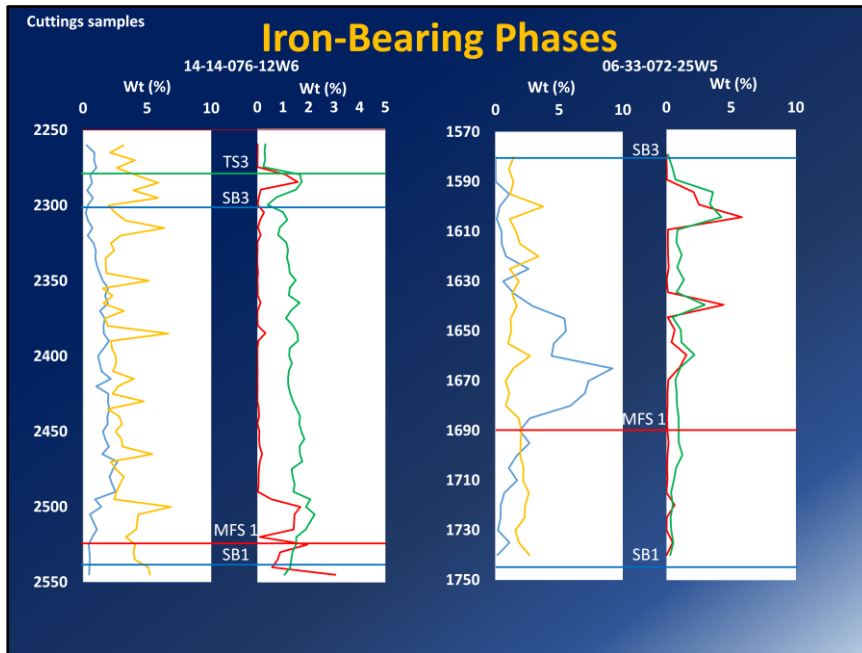




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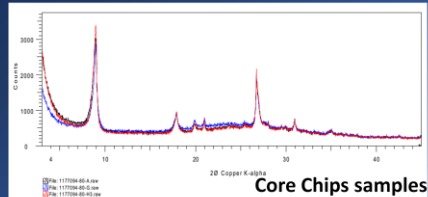
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# Clays

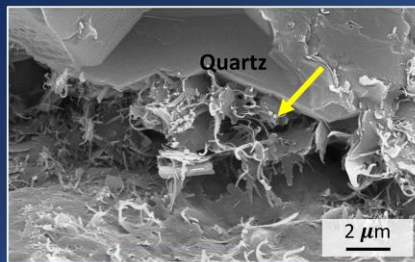
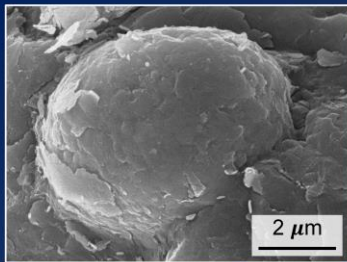
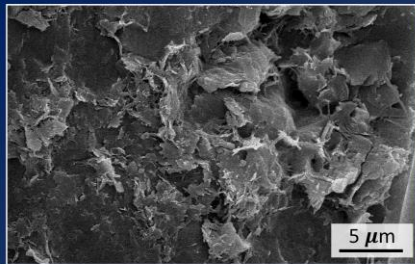
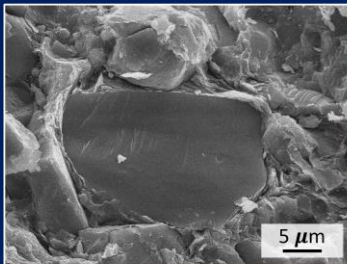
The Montney is considered to have very low clay content

Our results show:

- wide range of 1.6 - 32% clay content (average of 14%)
- Illite and MLIS are most abundant (up to 100%)
- 5% Expendable MLIS in the deep part of the basin
- Lesser amounts of chlorite, kaolinite

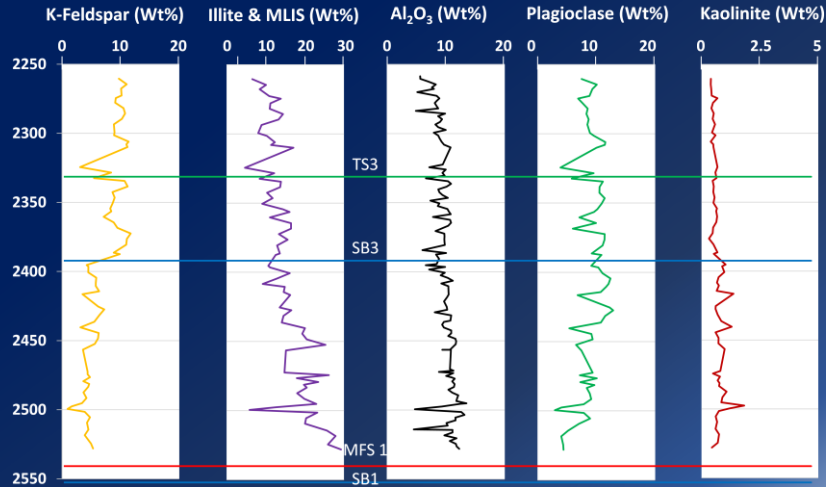


## Detrital & Diagenetic Clay



16-17-083-25W6

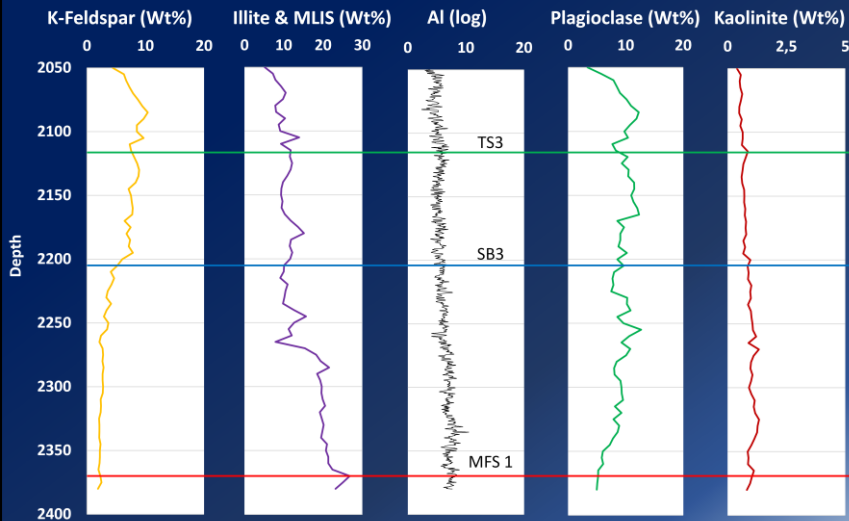
## Diagenetic Trends - Clay



- Constant Al content (Al does not leave the system)
- Partitioning of Al between clays and feldspars varies (diagenetic effect? paleoclimate? depositional? )

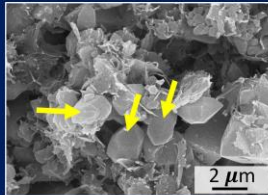
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## Diagenetic Trends - Clay

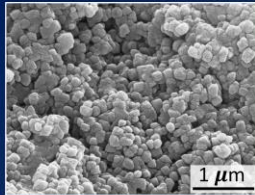


- Mixing of cuttings in the well blur trends

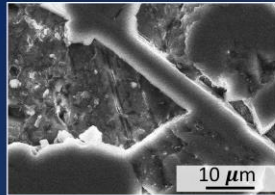
## Diagenetic Trends - Quartz



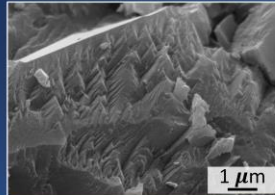
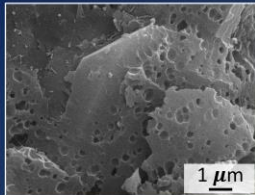
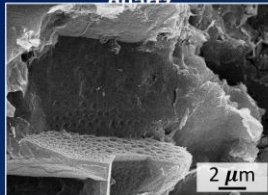
Microcrystalline  
quartz



Opaline silica

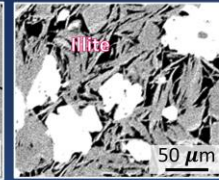
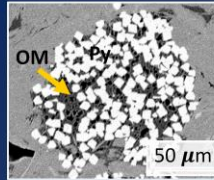
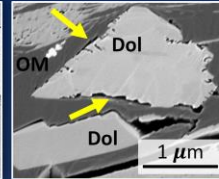
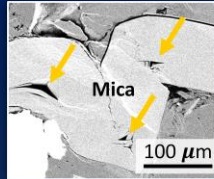
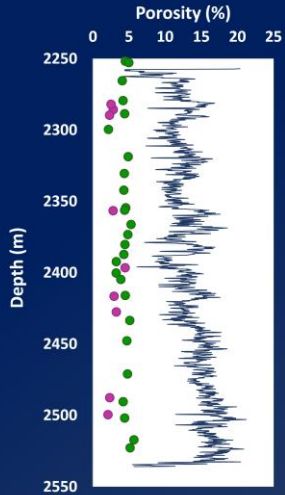


Quartz cement

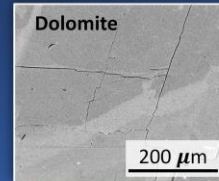


Quartz dissolution

# Porosity



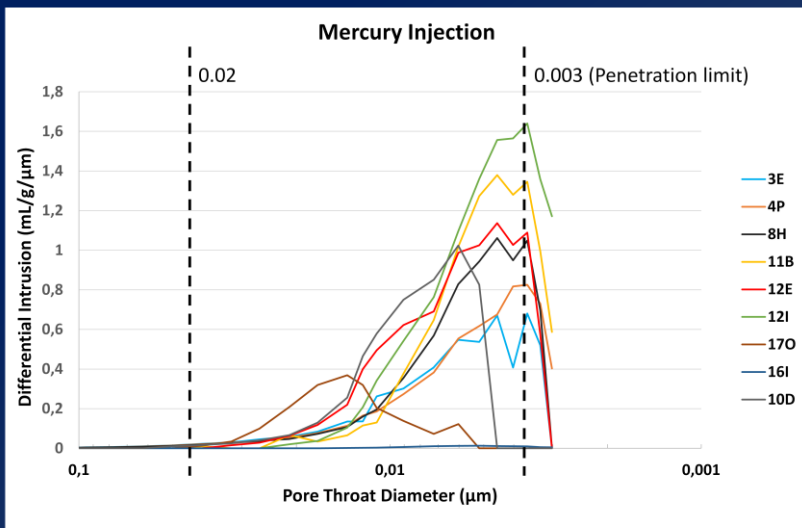
● Hg Injection Porosity  
● He Porosity  
— Neutron Porosity



- Not all porosity is effective
- Over-estimation of porosity by log due to abundant clay if the Montney is indeed oil-wet (Wood et al., 2015)

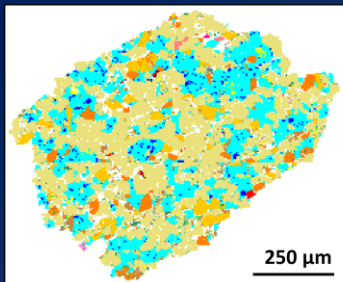


# Porosity

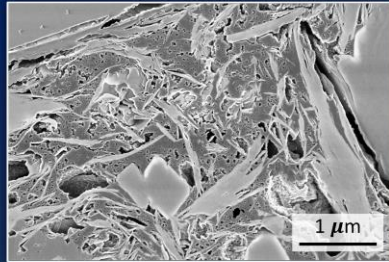
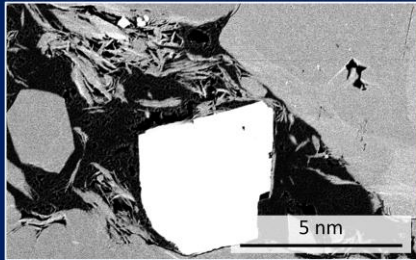


## QEMSCAN Porosity

- QEMSCAN detects pores  $>5\text{ }\mu\text{m}$  (depending on pixel size)
- Porosity is two dimensional - provides estimation only
- Appears as white pixels



## Porosity



Stepwise regression (9 samples):

$$R^2 = 0.987$$

$$\Phi_{(MI)} = 3.996 - 0.108 (\text{Calcite}) - 0.24 (\text{Muscovite}) + 0.58 (\text{Fe Oxide}) + 0.035 (\text{Total Clay})$$

General regression (a subset of 6 samples):

$$R^2 = 1.00$$

$$\Phi_{(MI)} = 5.320 + 2.272 (\text{TOC}) - 0.091 (\text{Quartz}) - 0.843 (\text{K-Feldspar}) - 0.0839 (\text{Plagioclase}) + 0.564 (\text{Muscovite})$$

## QEMSCAN Porosity

DEEP: 12-36-083-25W6: (67 samples)

$$\Phi_{(QS)} = 9.20 - 0.08 (\text{Total Clay}) + 0.49 (\text{TOC}) - 0.52 (\text{Fe Dolomite}) + 0.037 (\text{K-Feldspar}) - 0.12 (\text{Quartz})$$

$$R^2=0.82$$

SHALLOW 06-33-072-25W5: (33 samples)

$$\Phi_{(QS)} = -0.795 + 0.167 (\text{Calcite}) - 0.318 (\text{Fe Dolomite}) + 0.119 (\text{Quartz})$$

$$R^2=0.71$$

## Summary

- Distribution of iron-bearing phases suggest relationships to stratigraphic sequences, overprinted by temperature-controlled reactions such as  $S \rightarrow I$
- Clay-minerals have a complex relationship with feldspar
  - Potassium is released from K-Feldspar to create Illite
  - Sodium is released from plagioclase to create kaolinite (possibly contributing to formation water high salinity)
- Effective porosity (<5%) is controlled mostly by the presence of organic matter

# Thank You

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Dr. Matthew Power

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Dr. Sébastien Rohais

Dr. Korhan Ayranci

Levi Knapp

Tian Dong

Julia McMillan



Geomechanical Reservoir  
Experimental Facility

