Reservoir Characteristics & Geological Controls on Permeability of the Triassic Doig-Montney Shales of NEBC

- Comparison with the Devonian Horn River Shale

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Presentation Outline

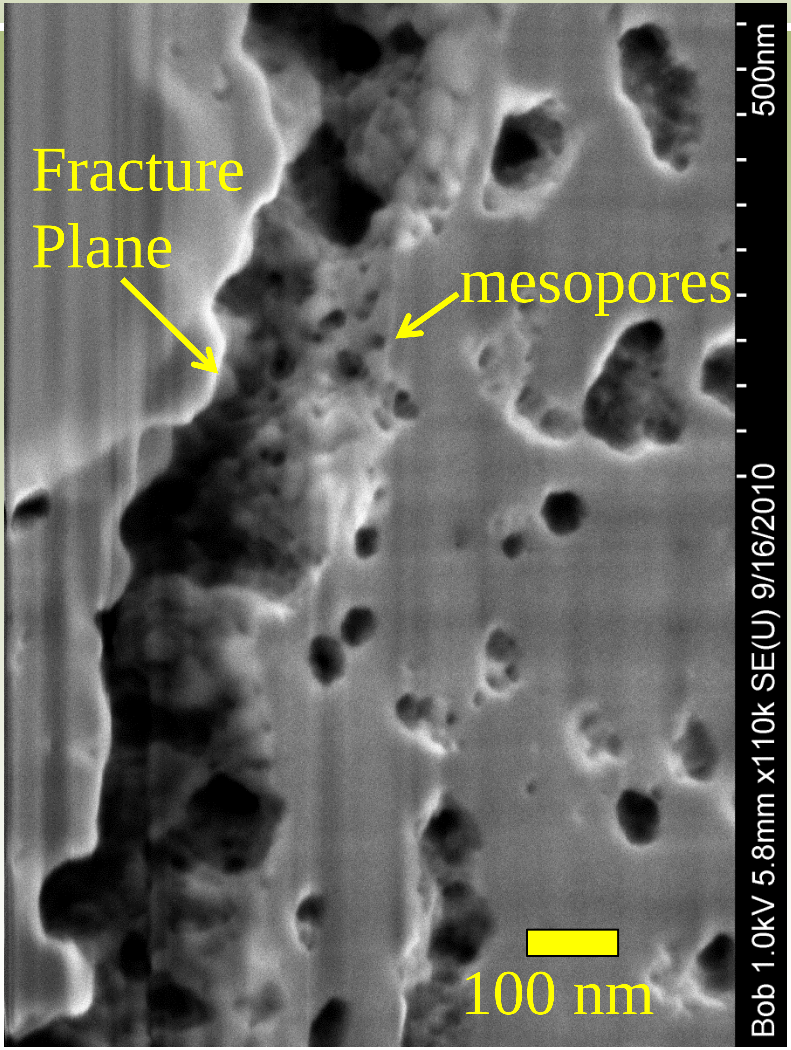
- Introduction
- Triassic Rocks
  - Mineralogy, texture and fabric
  - Organic geochemistry
  - Porosity distribution
  - Geological controls on pore size distribution & K
- Comparison between Triassic and Devonian Rocks
  - Mineralogy, fabric versus K
  - PSD versus K
- Pore Models and Conclusions

Introduction

- Large TCF gas-in-place estimates for unconventional reservoirs
- What controls the fluid flow?
  - Fracture porosity is important BUT so is matrix flow
- Porosity models include
  - Dual porosity model
    - Coal – micropores (<2nm)[1] & cleat fractures (Lu and Connell, 2007)
  - Triple porosity model (Wei & Zhang, 2010)
    - Coal and shale reservoirs
    - Micropores, mesopores[1] and macropores (>50nm)[1]

[1] International Union of Pure and Applied Chemistry (IUPAC) pore classification (Rouquerol et al., 1994).

Introduction: street-map-pore analogy



Woodford Shale:
FE-SEM micrograph

Google Maps 2012.

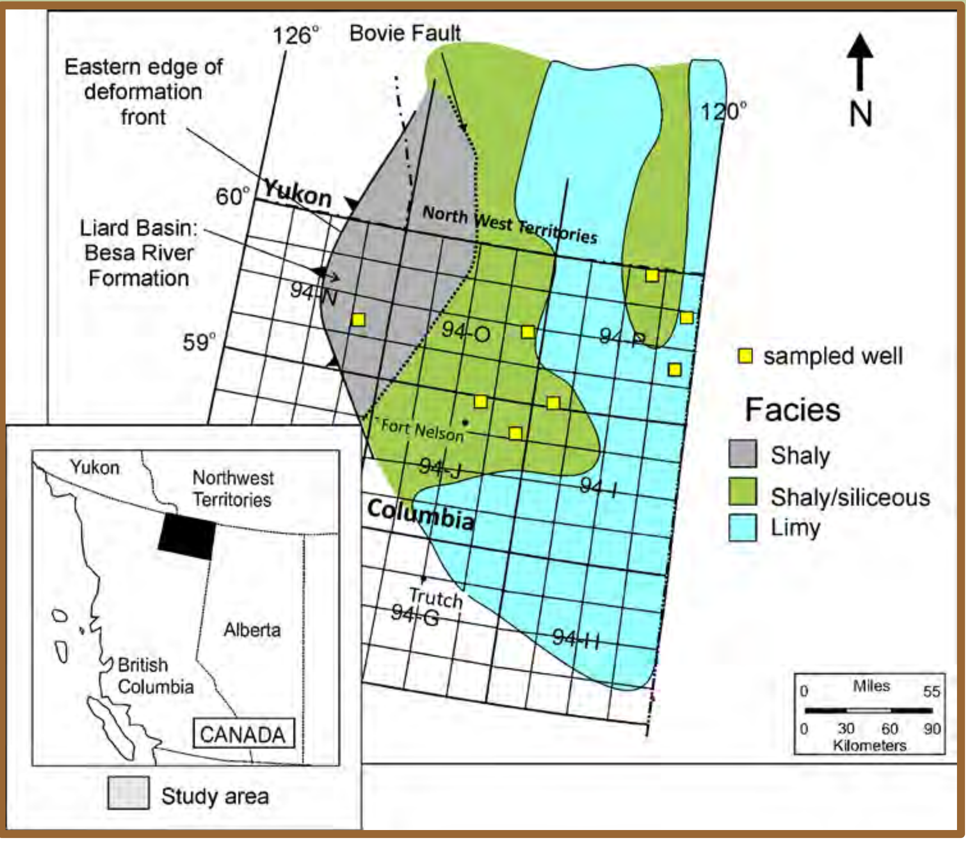
Geological Setting Summary

- Triassic Montney-Doig-Halfway Fms
  - Westward thickening, siliciclastic prograding wedge in a passive margin setting (Edwards et al., 1994; Davies 1997; Walsh et al., 2006; Dixon, 2009a and b).
  - 2 of 3 T-R cycles

- Devonian Horn River Basin Fms
  - Reef-dominated shale basin (Kent, 1994)
  - Shales & carbonates deposited within a embayments (shale rich) & salients (carbonate platforms) due to faulting & unconformity development (Morrow et al., 2002).

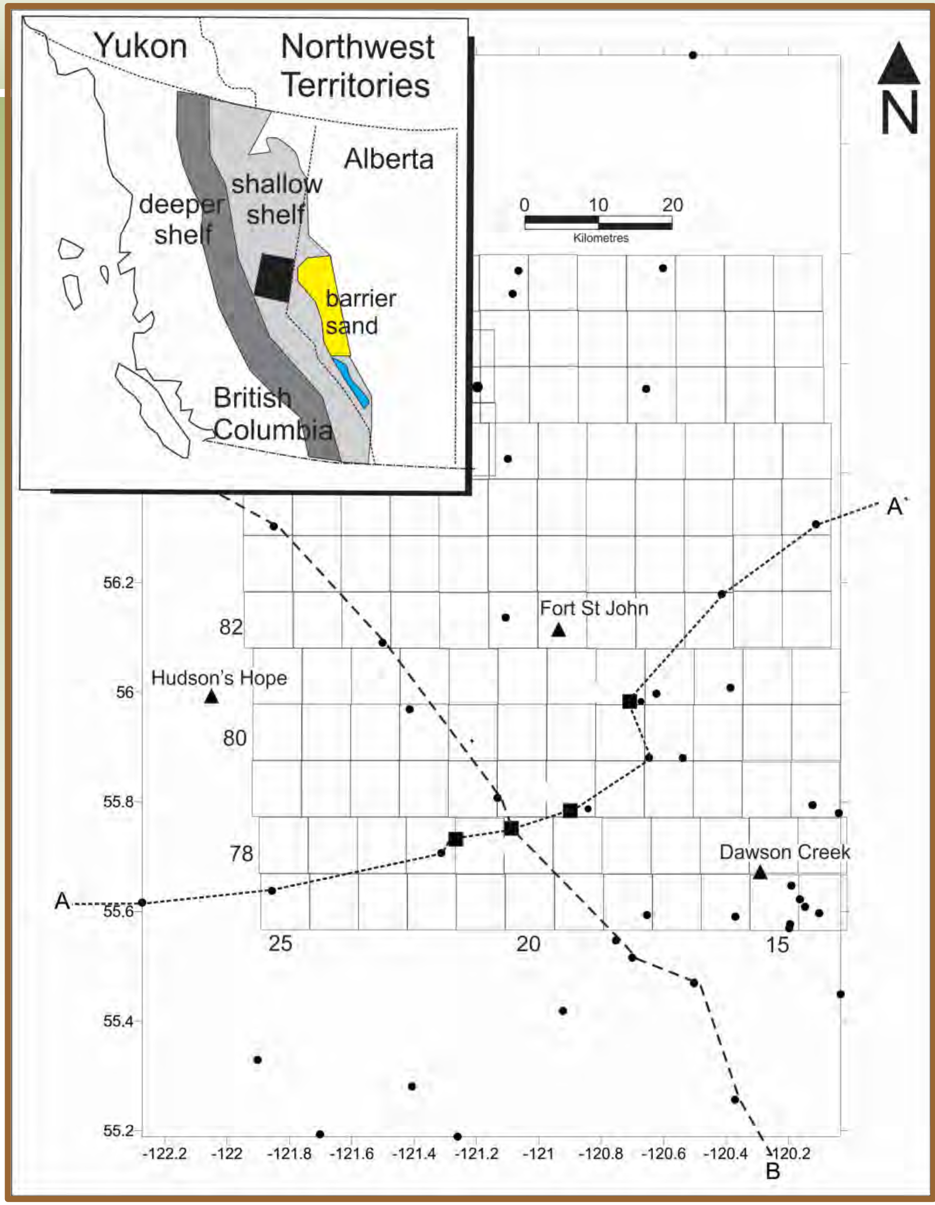
Study Areas

Devonian Shale - Liard (LB) and Horn River (HRB) Basins



Facies from Ross (2008) PhD Thesis, UBC.

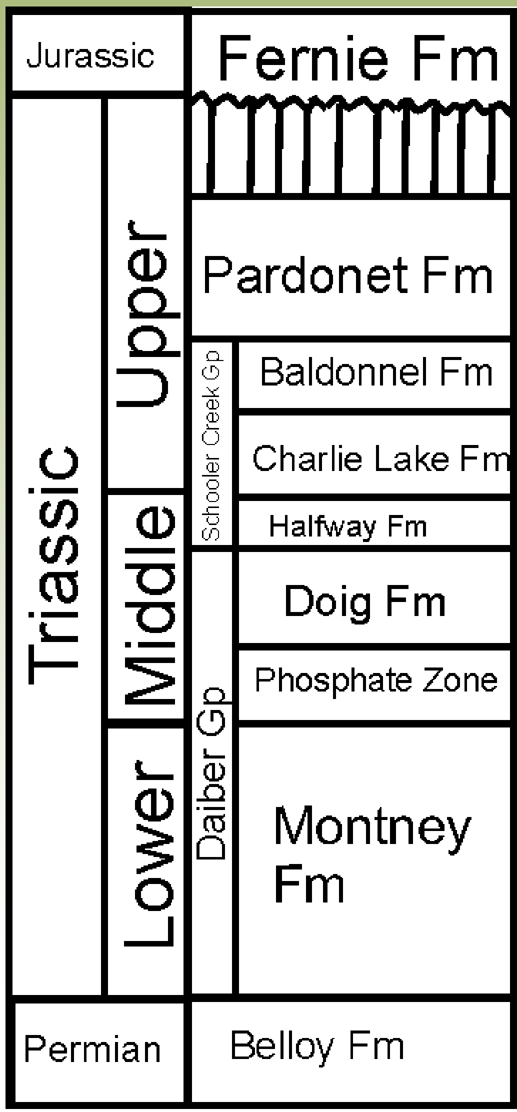
Triassic Doig-Montney Shales



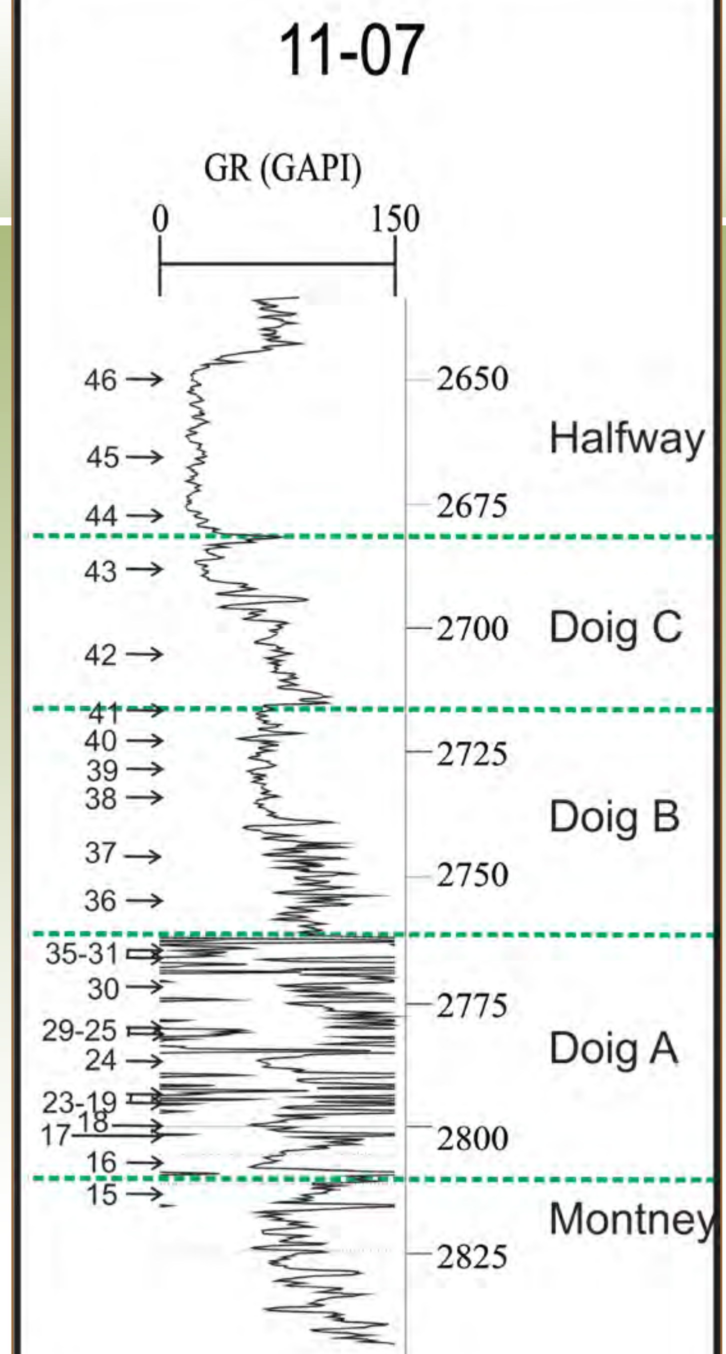
Palaeogeog. by Kent (1994)

Stratigraphy - Triassic

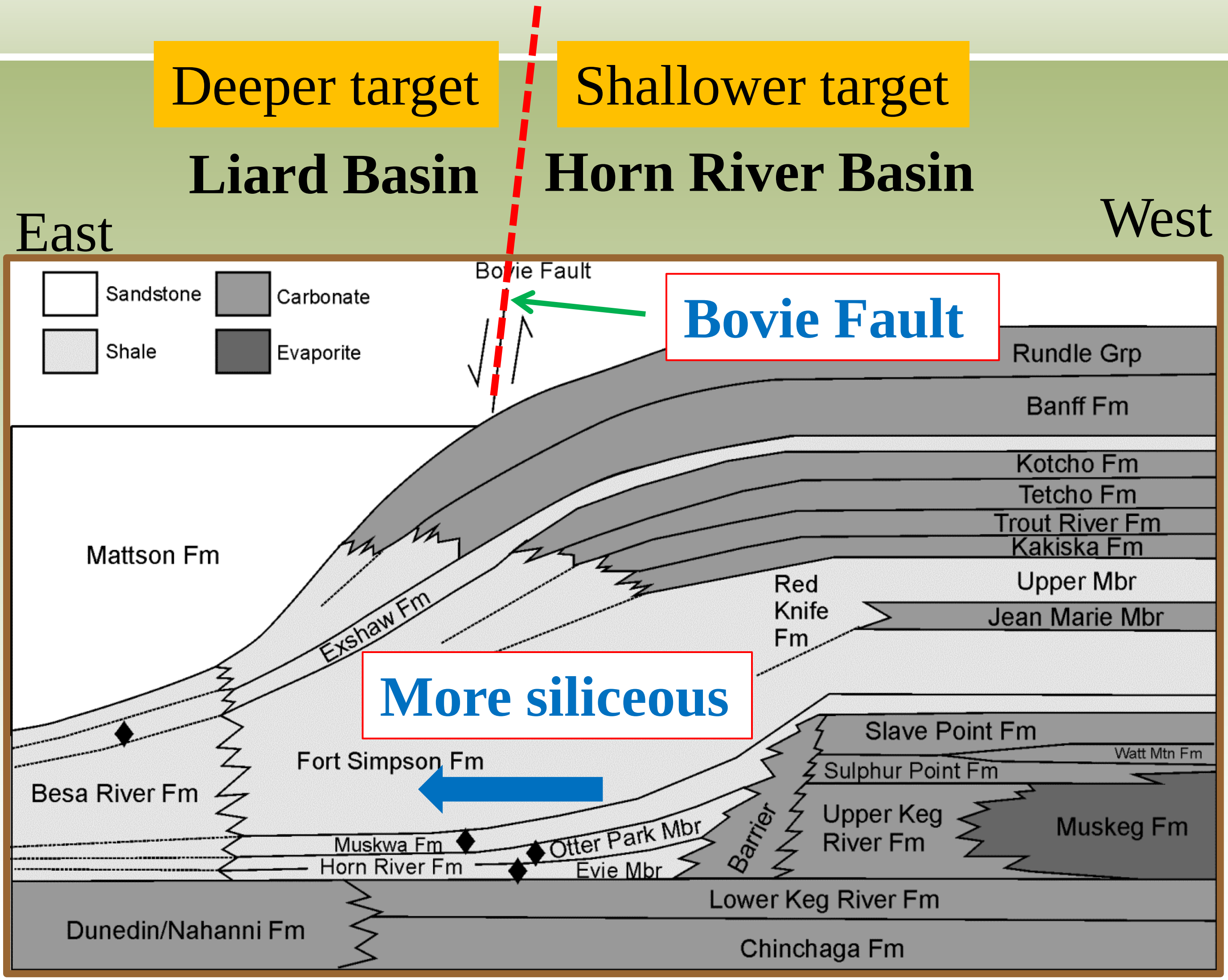
DOIG-MONTNEY SHALES

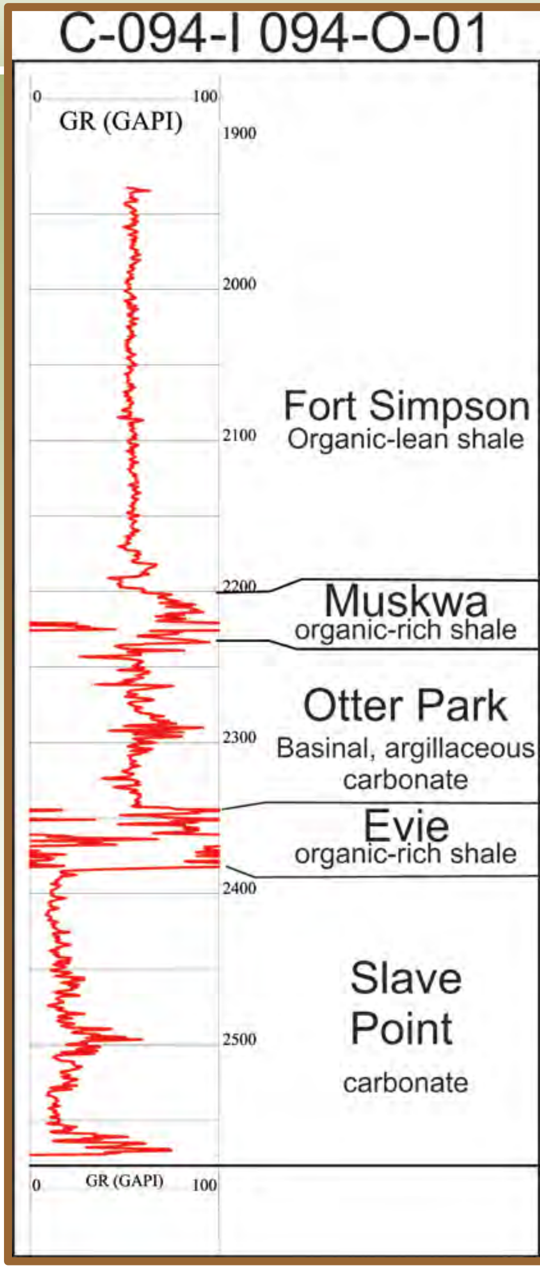


2.5 cm



Stratigraphy - Devonian





Ferri et al., (2011)

Geological parameters studied

- Mineralogy – XRD & Rietveld, EDX + petrology
- TOC Content – Rock Eval II + organic petrology
- Porosity – He Pycnometry & Hg Porosimetry
- Pore Size Distribution (PSD) – Hg porosimetry

& low P gas adsorption analyses

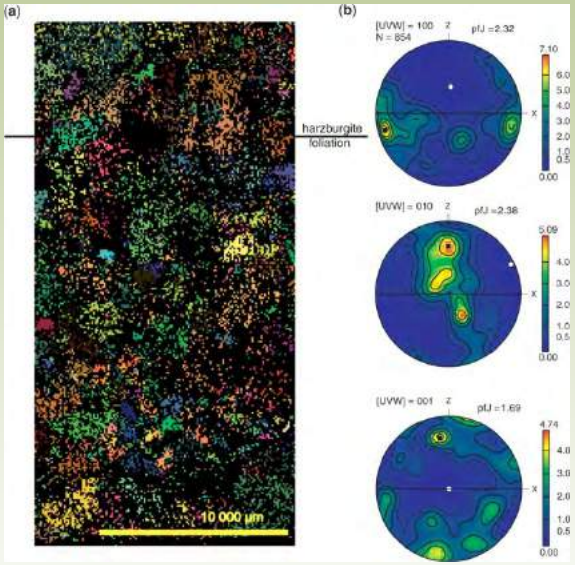
- Matrix Permeability – pulse decay permeameter
- Texture and fabric – qualitative, thin sections

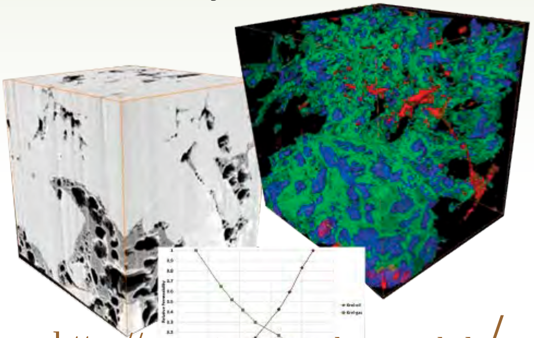
& back scatter electron microscopy (BSEM)

  - Future use of EBSD analysis

EBSD

Boudier et al, (2009)



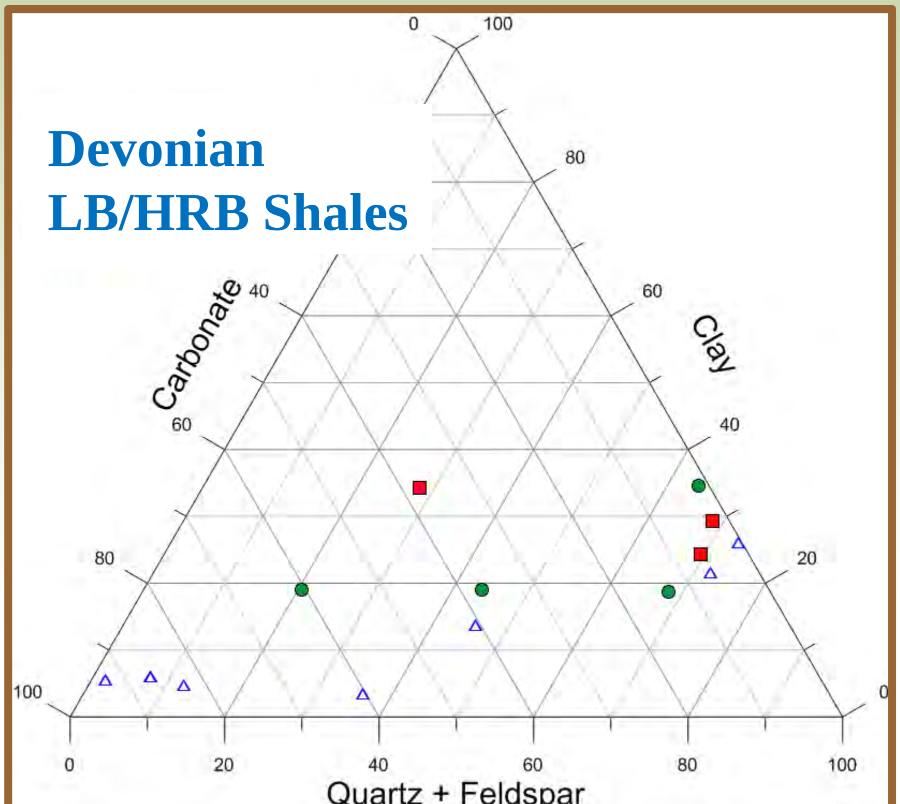


http://www.ingrainrocks.com/shale/

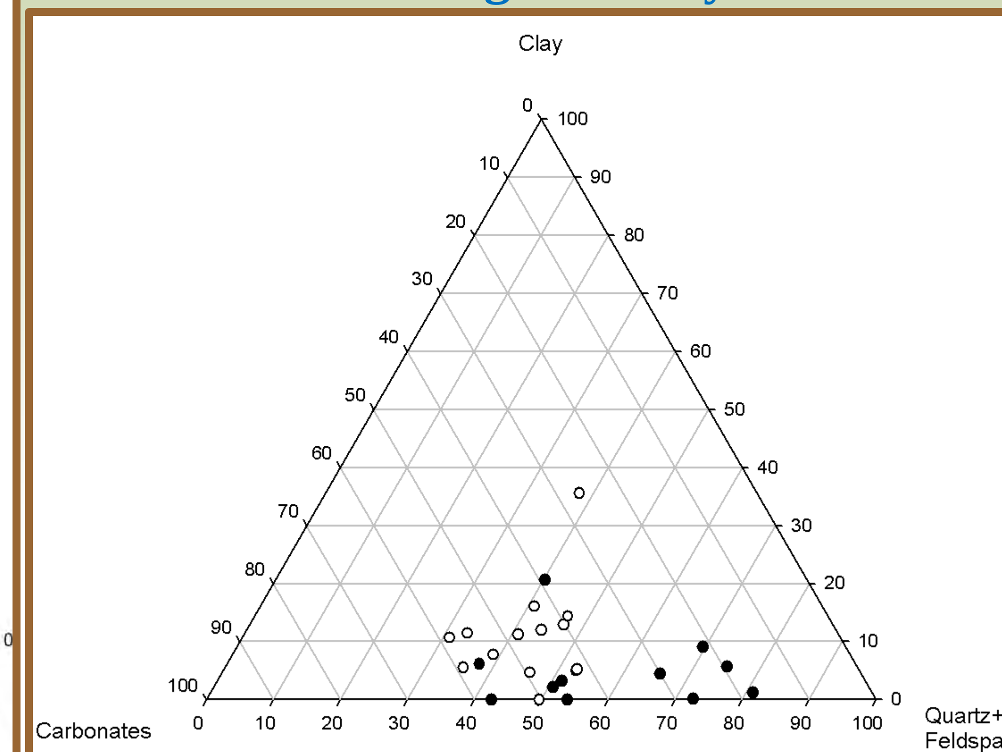
Mineralogy

- Poor to moderate clay in both Devonian and Triassic rocks
- Vary between high and low quartz, carbonates (feldspar is important Triassic)

Devonian LB/HRB Shales



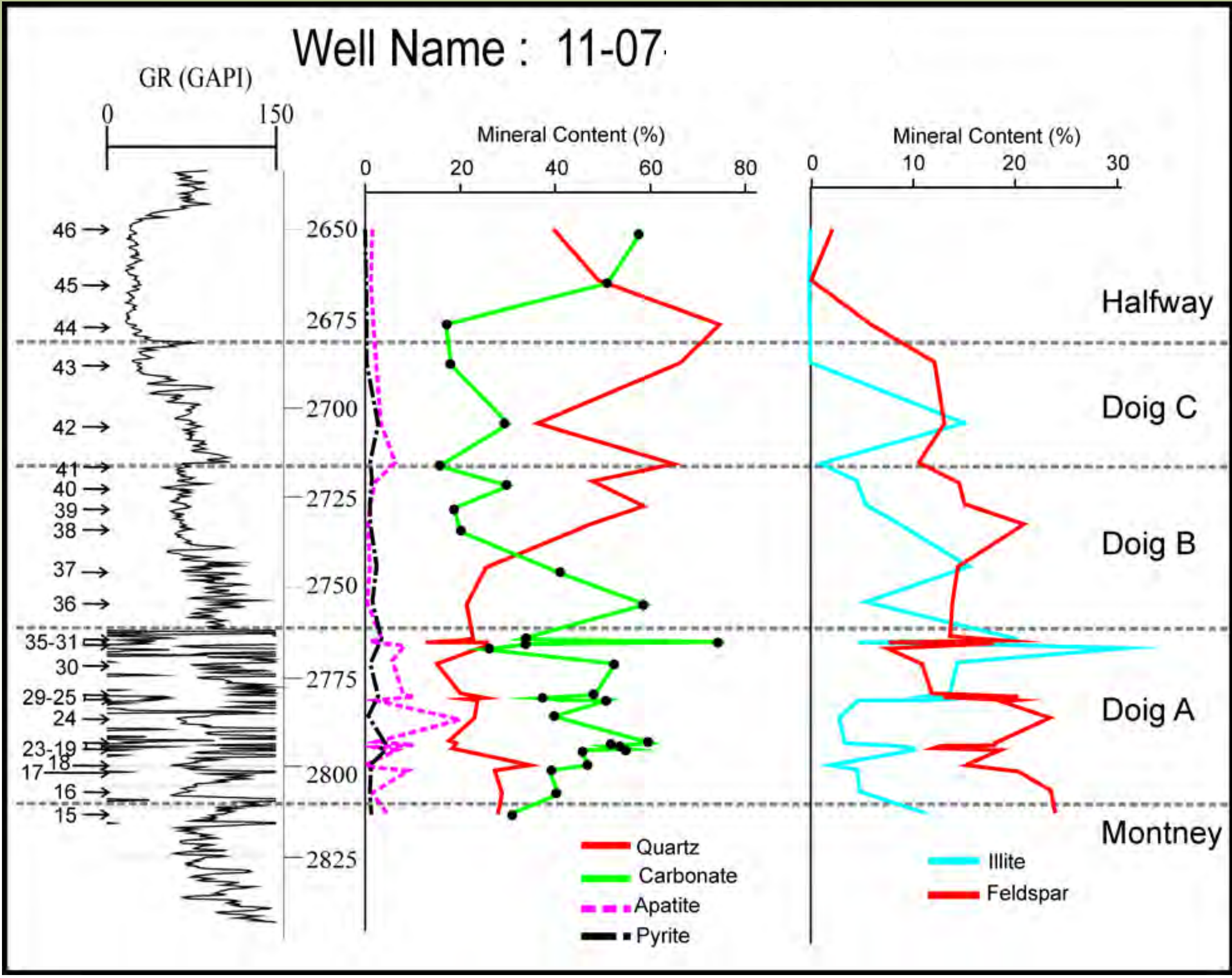
Triassic Doig/Montney Shales



Mineralogy, Texture & Fabric of Triassic shales

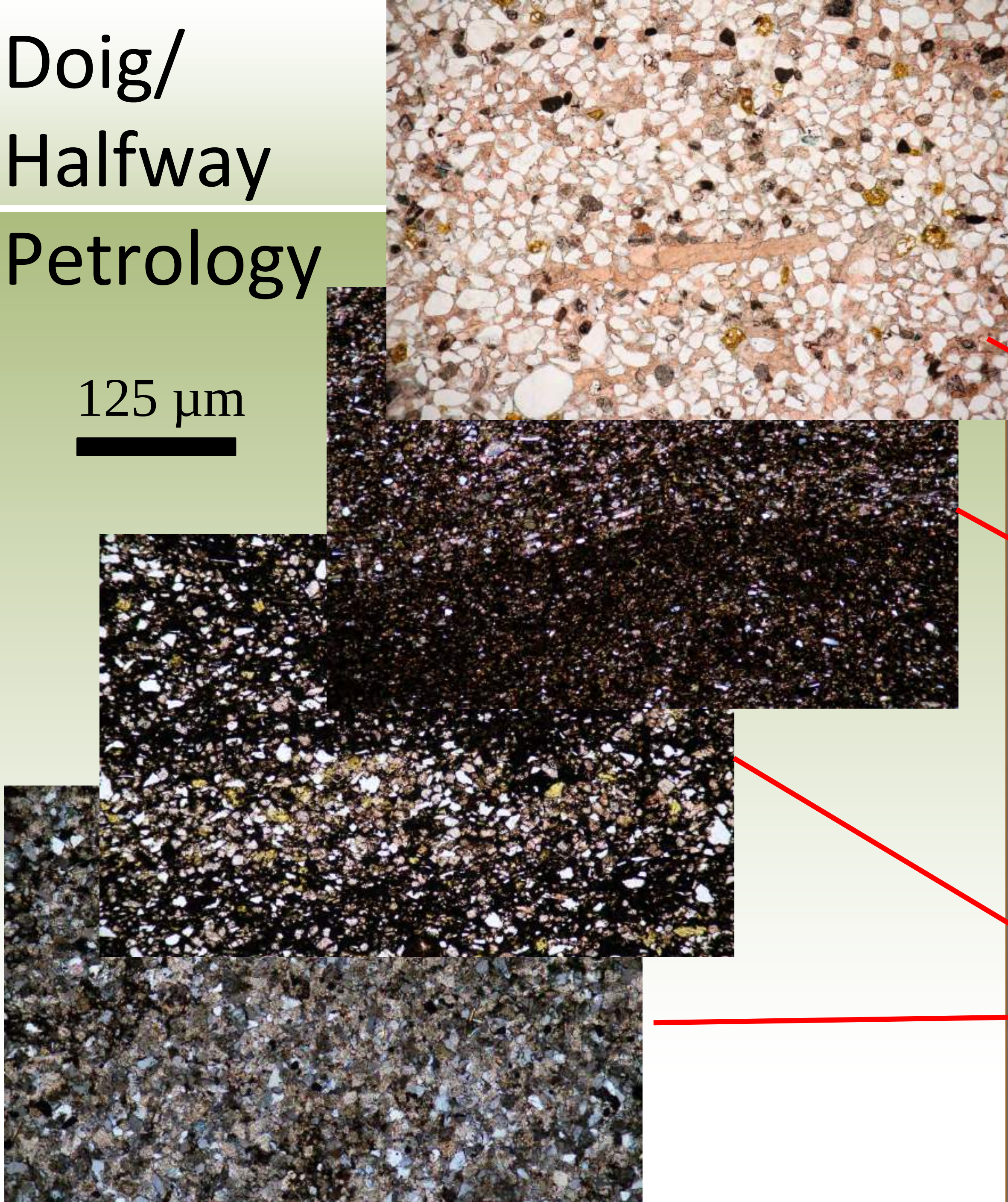
Doig Mineralogical Trends

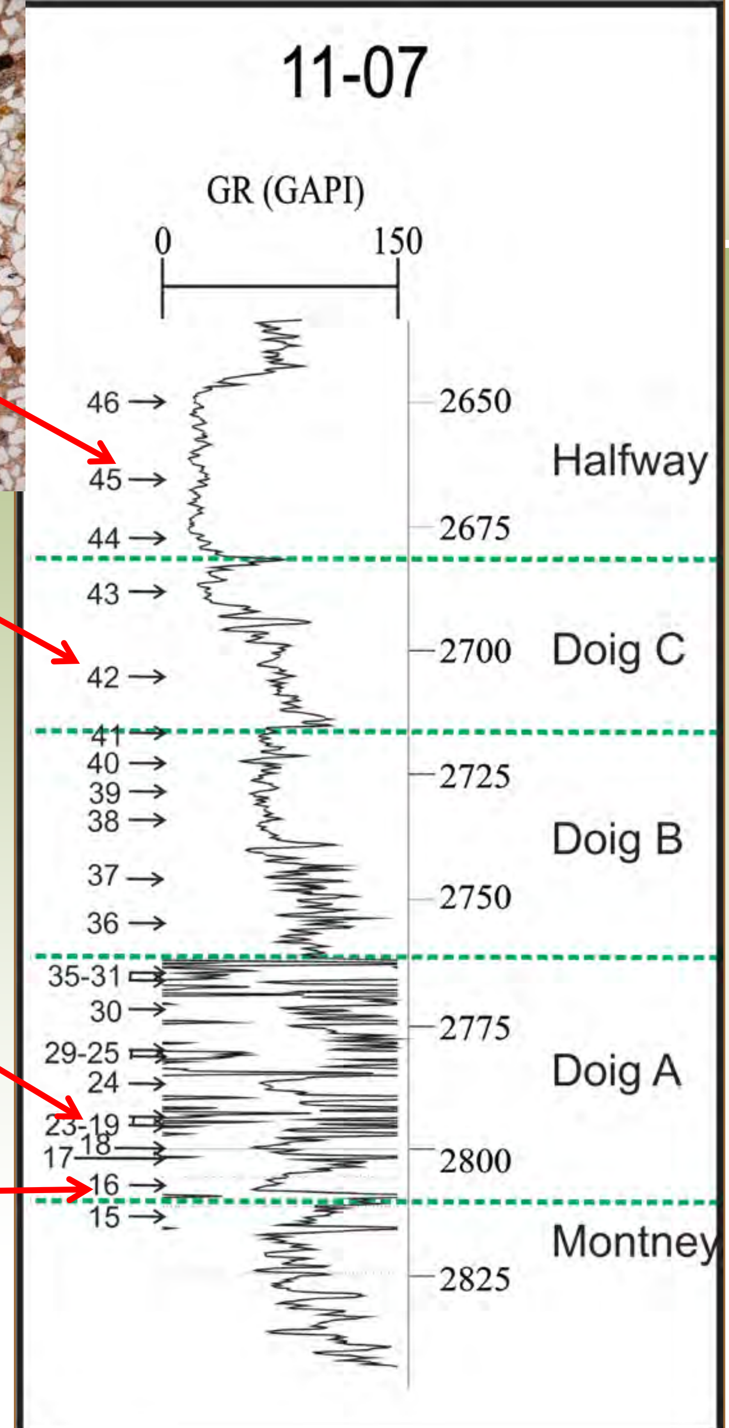
- Doig A (Phosphate Zone) is carbonate rich; highly variable mineralogy
- Quartz increases upwards
- Clay conc. in finer sections
- Feldspars conc. in Doig A and B
- Apatite highest in Doig A



Doig/ Halfway Petrology

125 µm

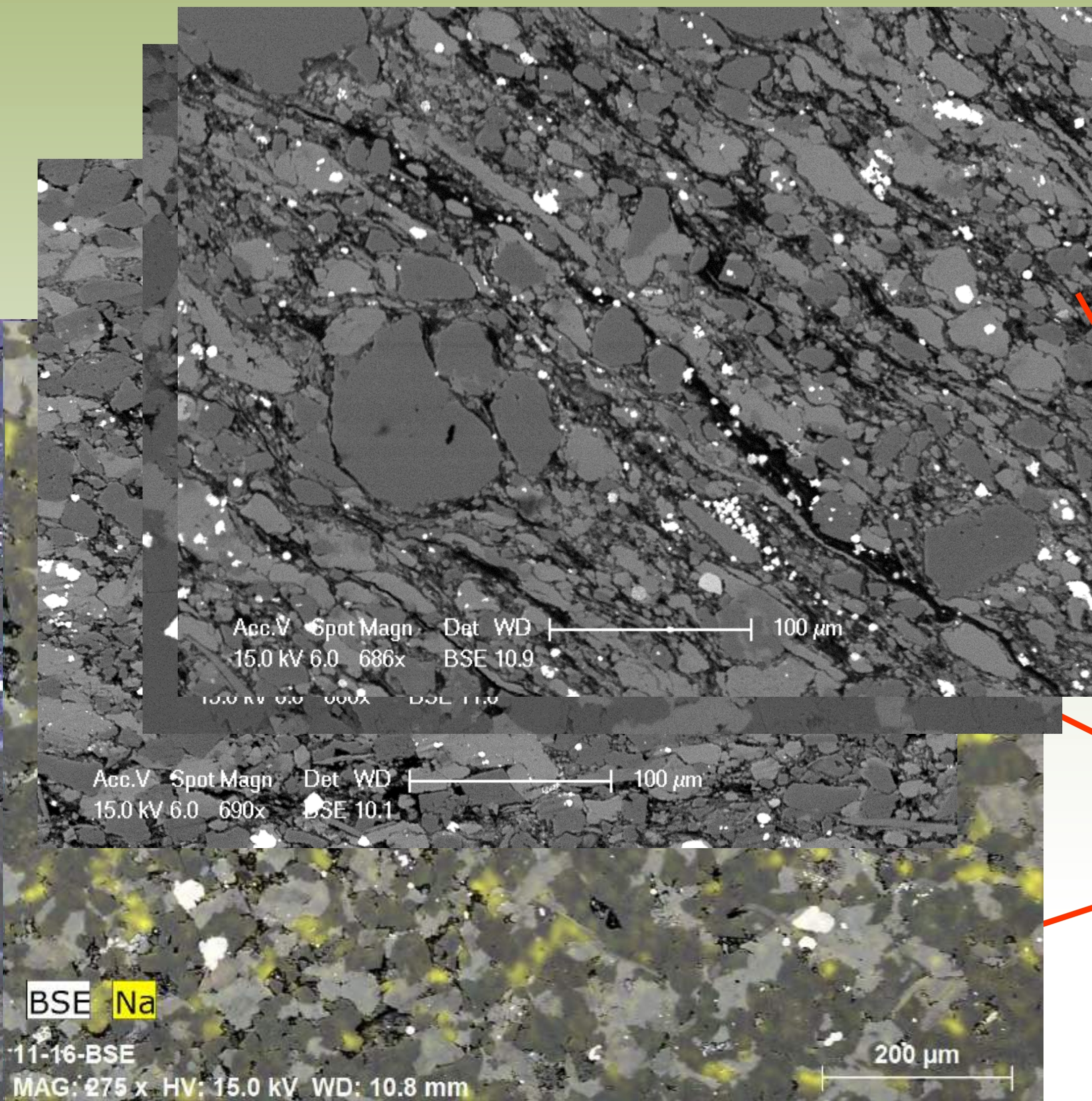


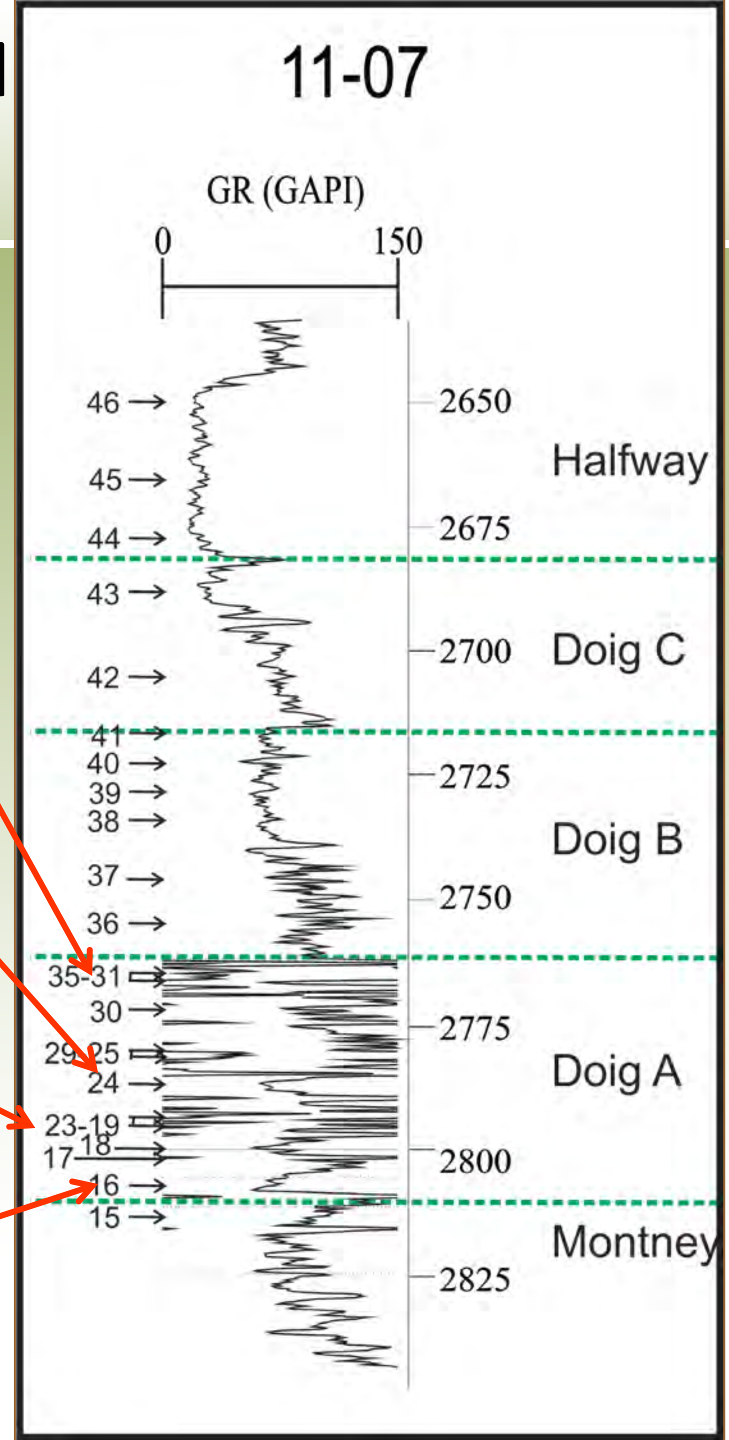


Doig "A" Textural Analysis – BSEM

Darker mins = quartz+dolomite

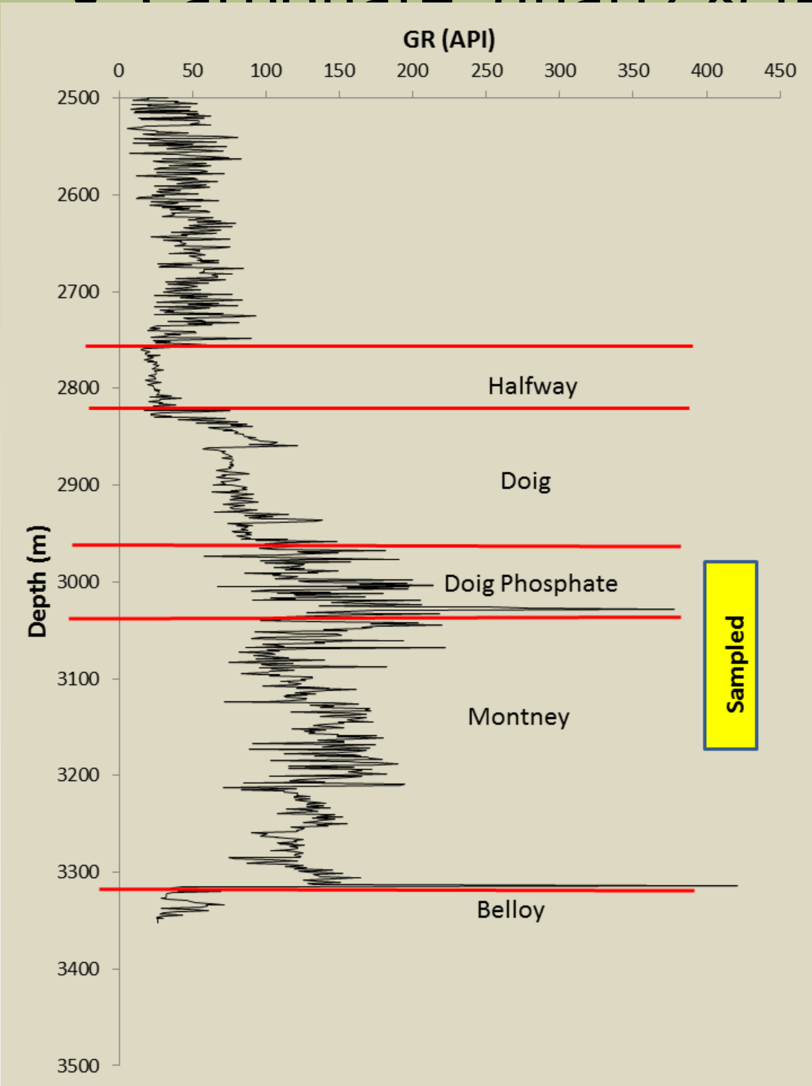
Lighter mins = calcite+feldspar+muscovite

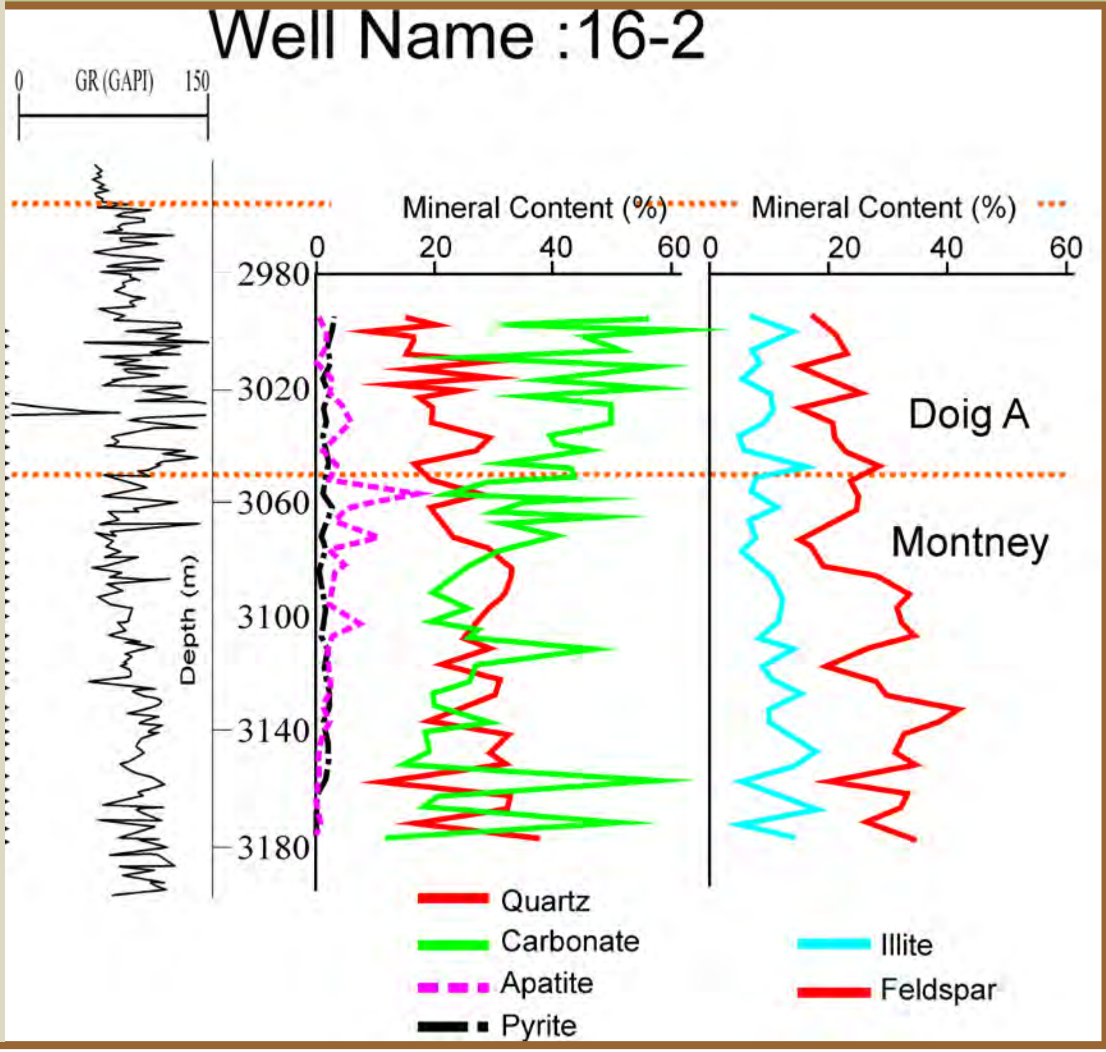




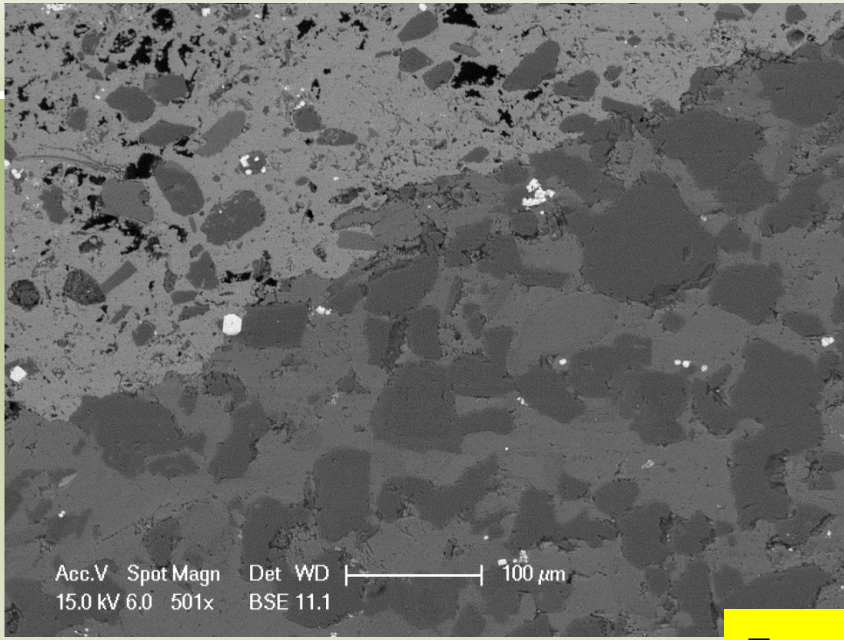
Montney Mineralogical Trends

- Carbonate, quartz & feldspar are significant

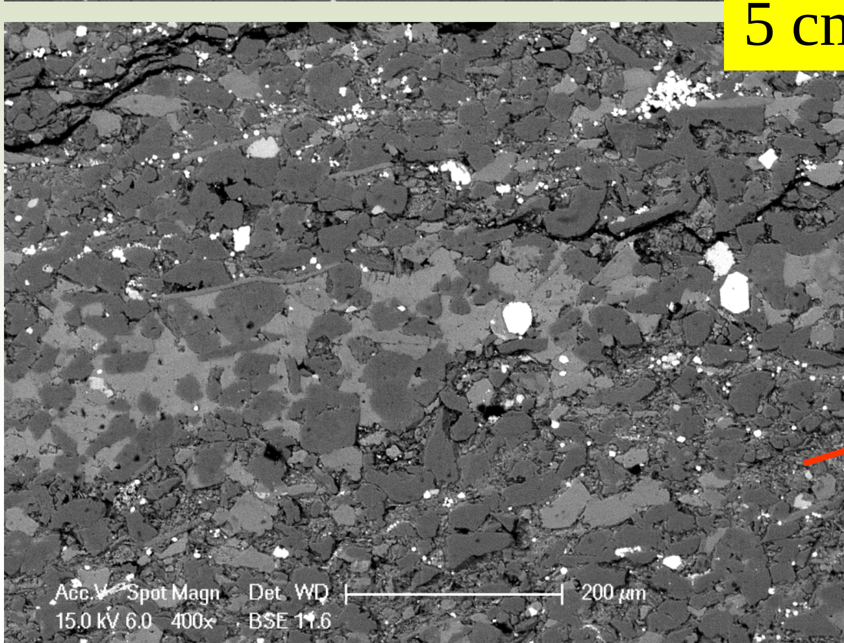


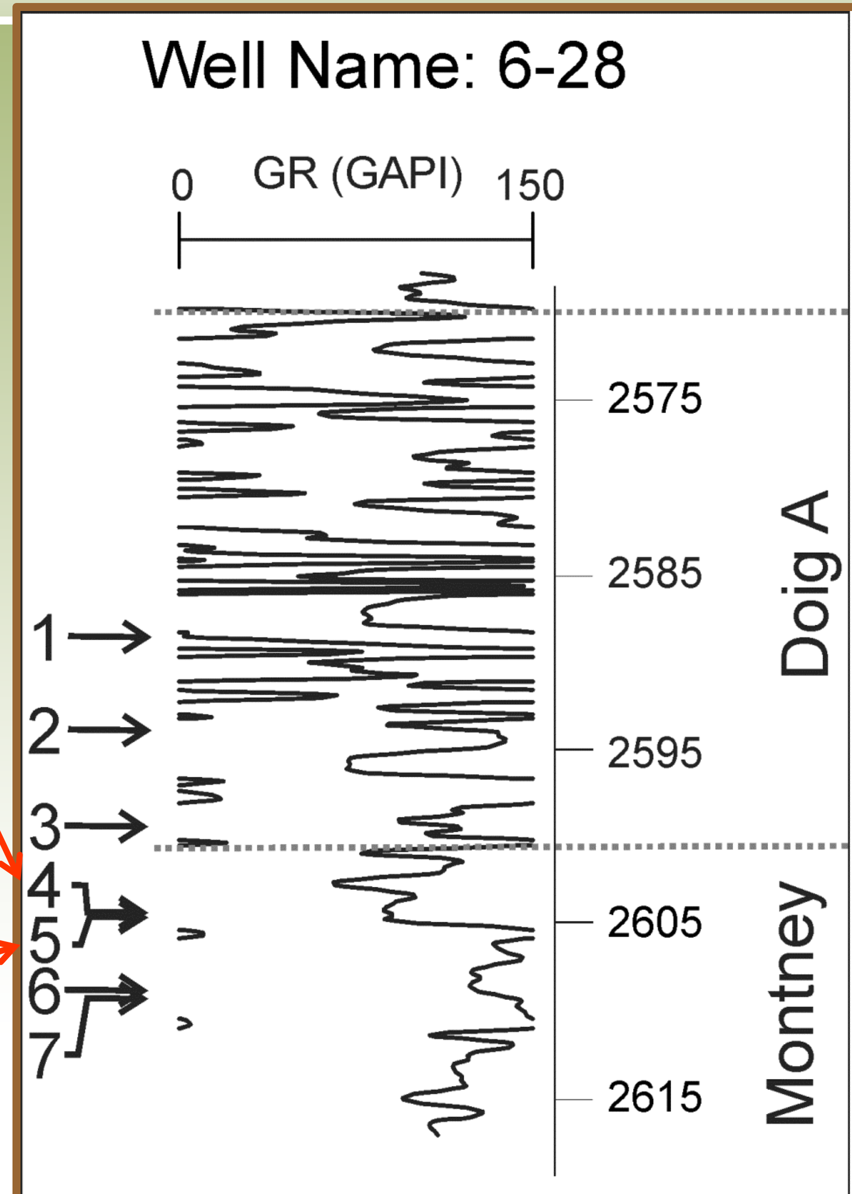


Montney Textural Analysis - BSEM



5 cm apart

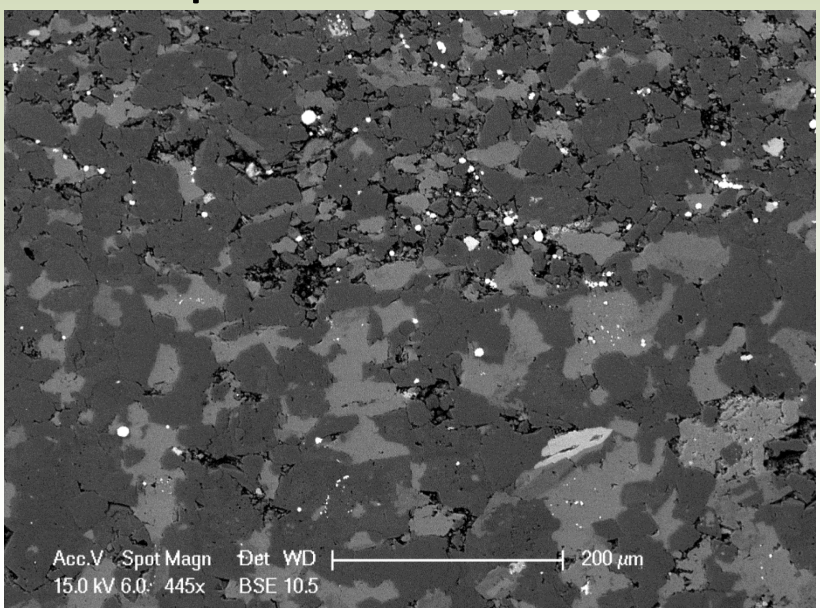




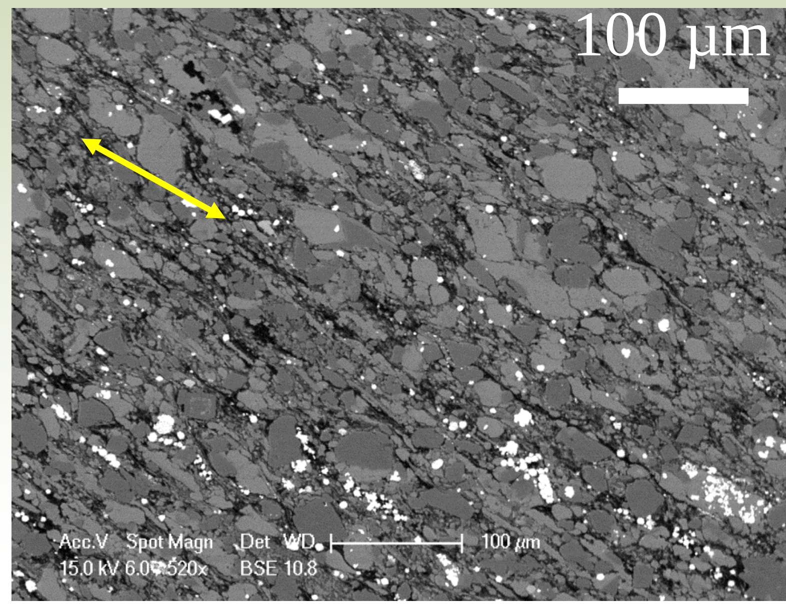
Fabric – Degree of anisotropy

- qualitative measurement of the degree of crystal/clast alignment
- Controlled by mineralogy & paragenesis
  - Clay-rich samples are more anisotropic than quartz & carbonate rich samples

Bedding ↔ Direction



Mod Qtz/$CaCO_3$ Isotropic;11-7-16



Anisotropic;11-7-34
Mod clay/qtz/$CaCO_3$

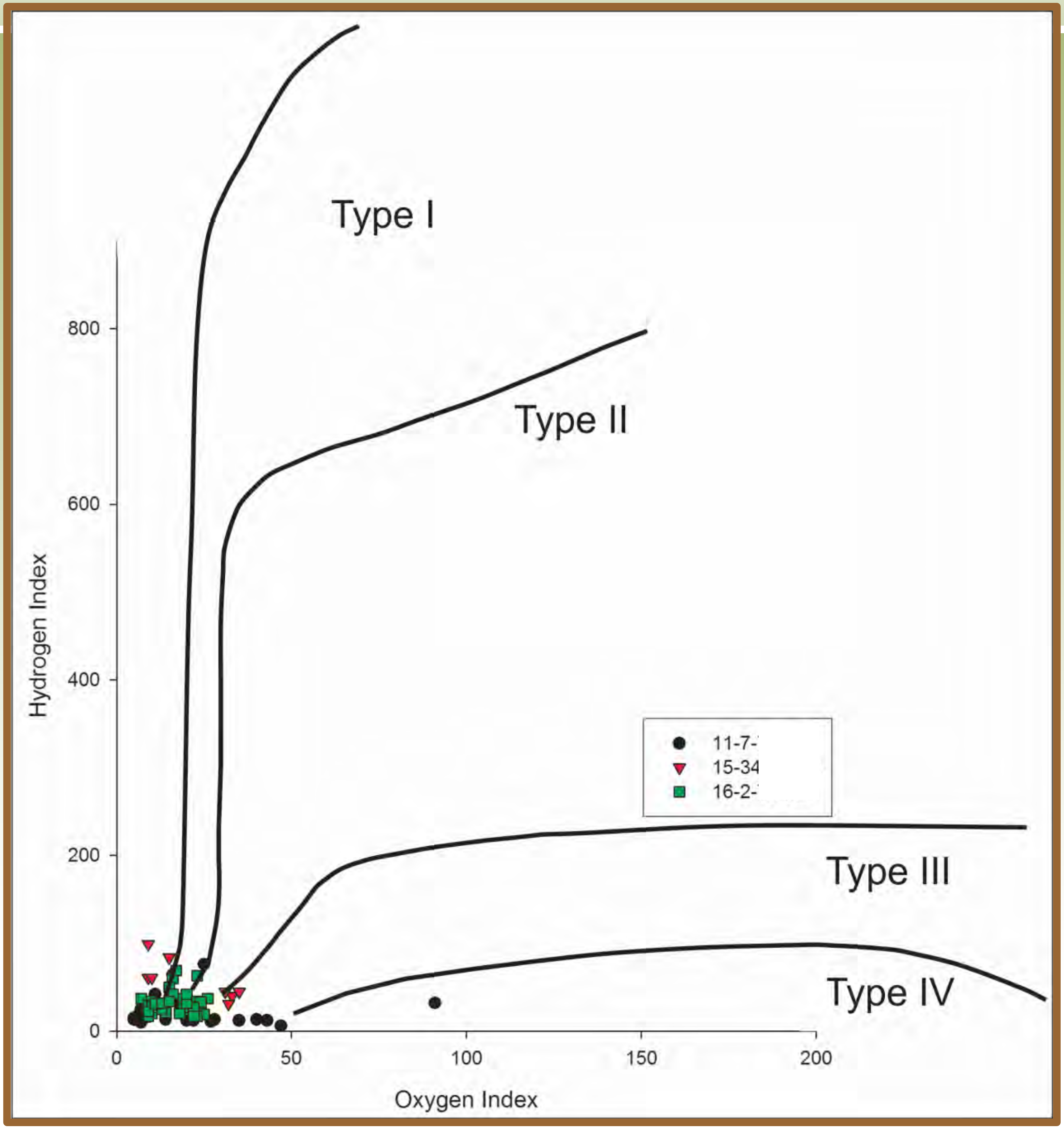
Mineralogy, fabric & texture summary

- 3 coarsening upward packages for Montney-Doig-Halfway
- Mineralogy, texture & fabric varies significantly within the Doig A (phosphate zone) and in parts of the Montney
- Higher carbonate or higher quartz contents reduce gamma log response
- Carbonate in the form of cement or detrital grains
- Apatite locally important coating grains, cement or nodule

Organic geochemistry of Triassic Shales

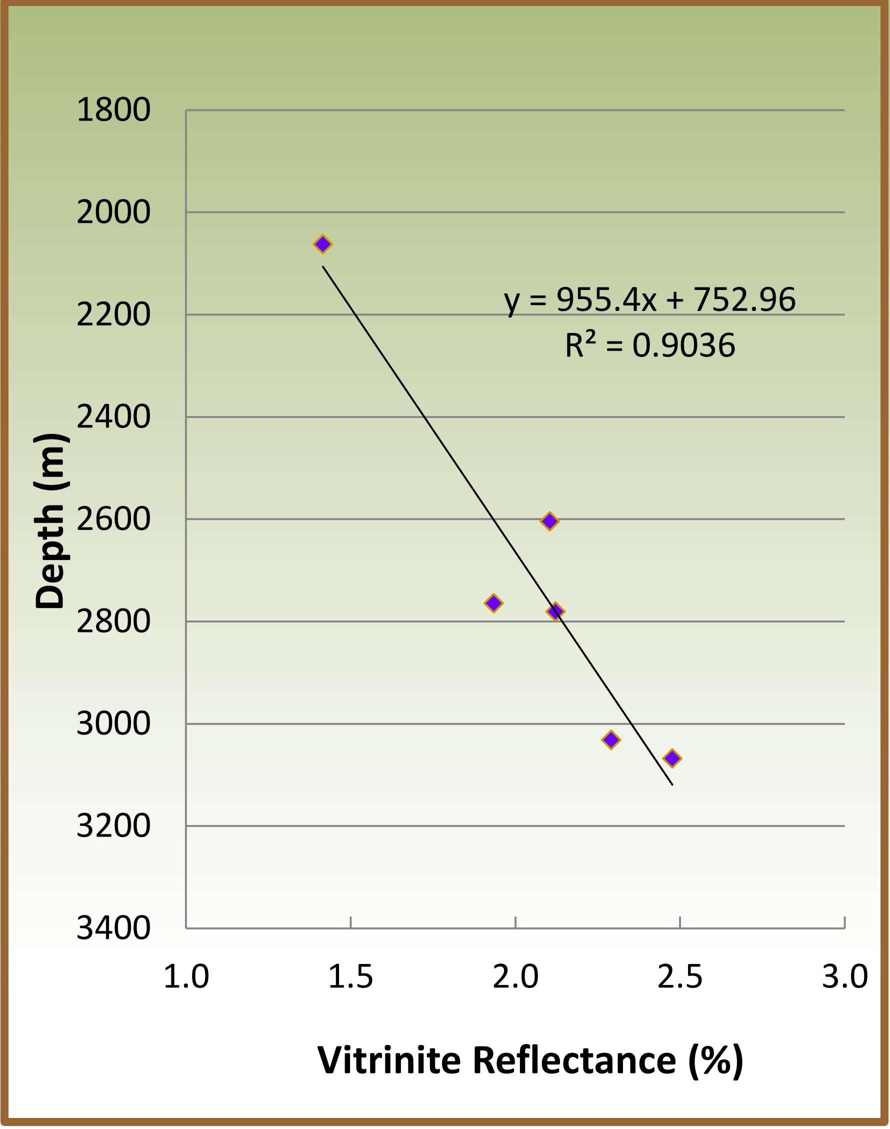
Organic Geochemistry of Doig Shale

- Kerogen is carbon rich
- Reflectance & T_{max} indicate maturity is beyond oil window
- Majority have low HI and OI; due to either primary kerogen type &/or maturity



Tmax, Reflectance & HCs generation

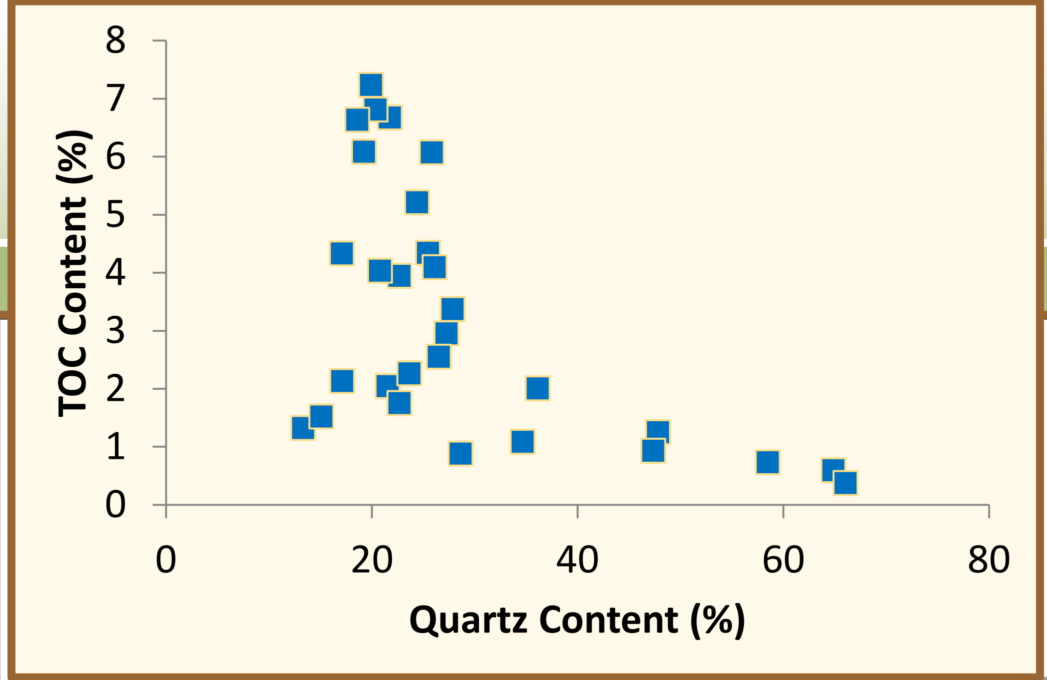
- Averaged pyrobitumen equivalent* %Ro is 2.058 (dry gas)
- S2 peak too low for most sample for Tmax value
- Tmax = 457°C; wet to dry gas generation

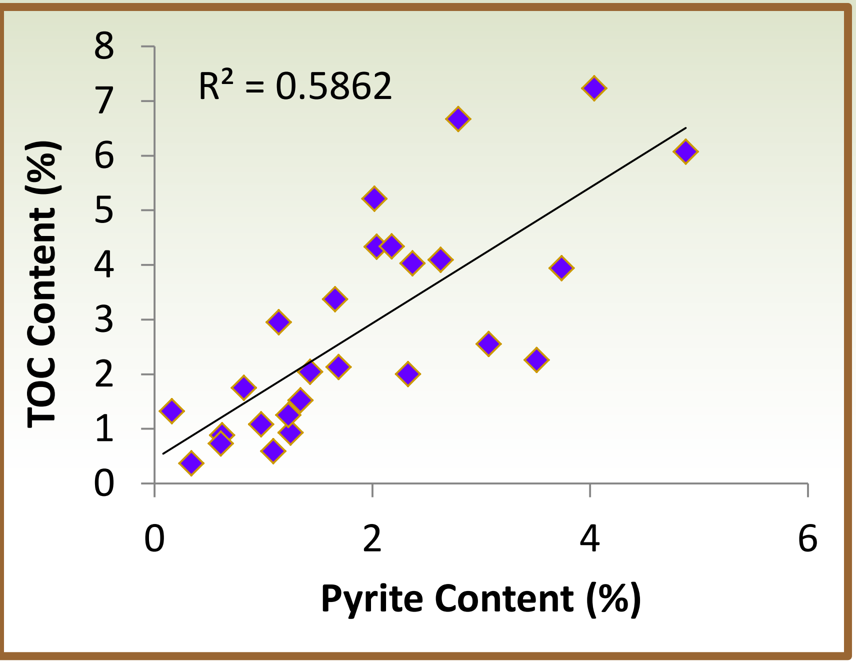


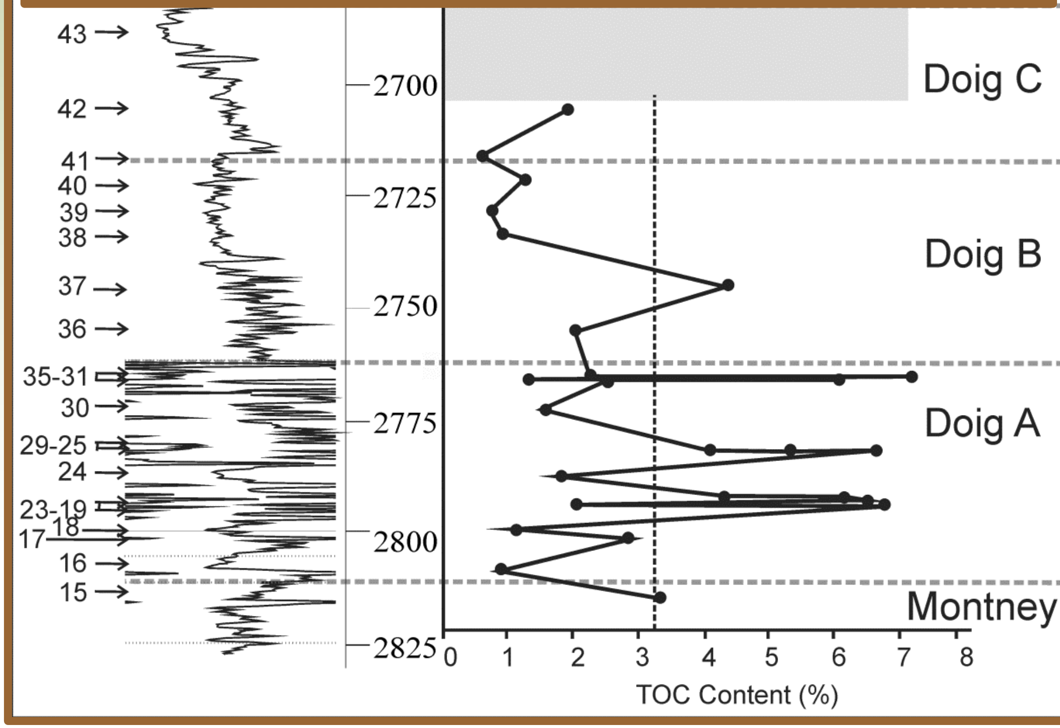
*Schoenherr et al. (2007)

Doig TOC Distribution

- Large, abrupt TOC changes in Doig A
  - Sampling resolution
  - Primary deposition
    - TOC vs pyrite & quartz

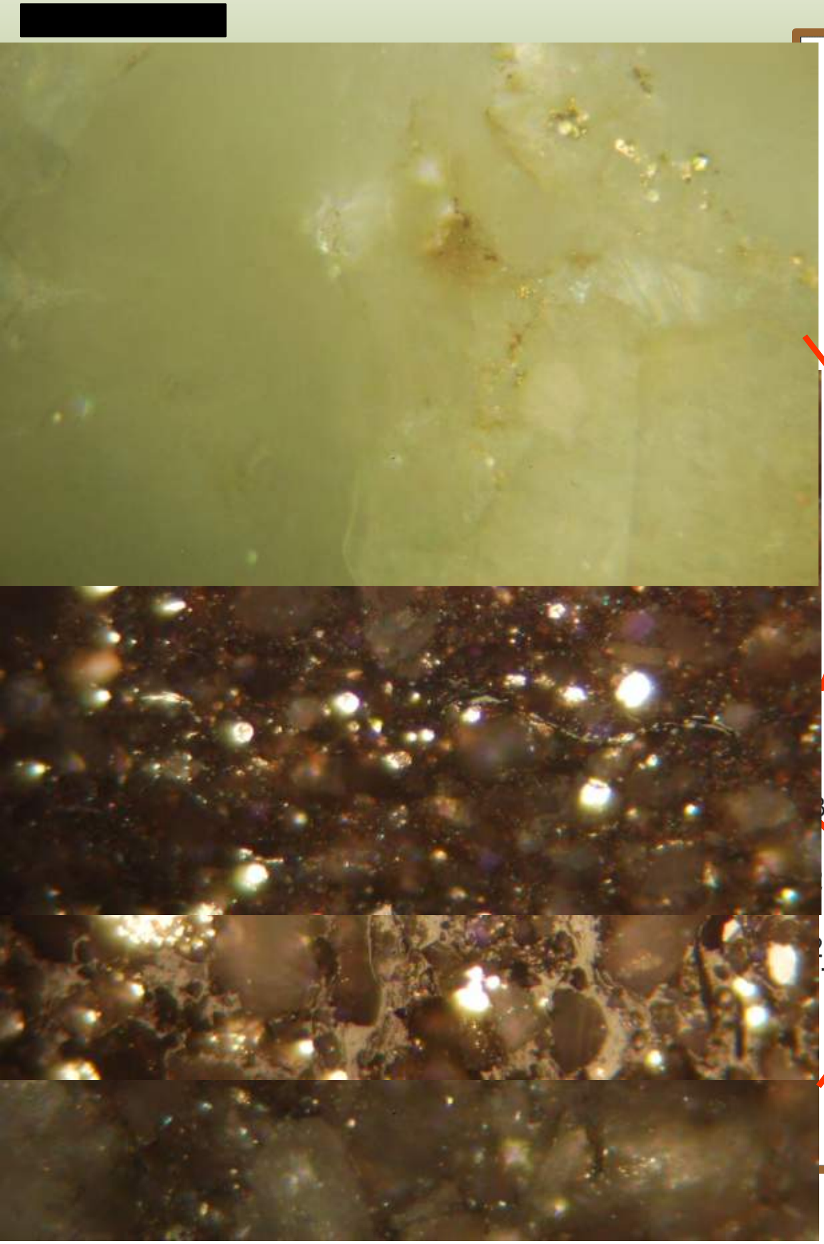


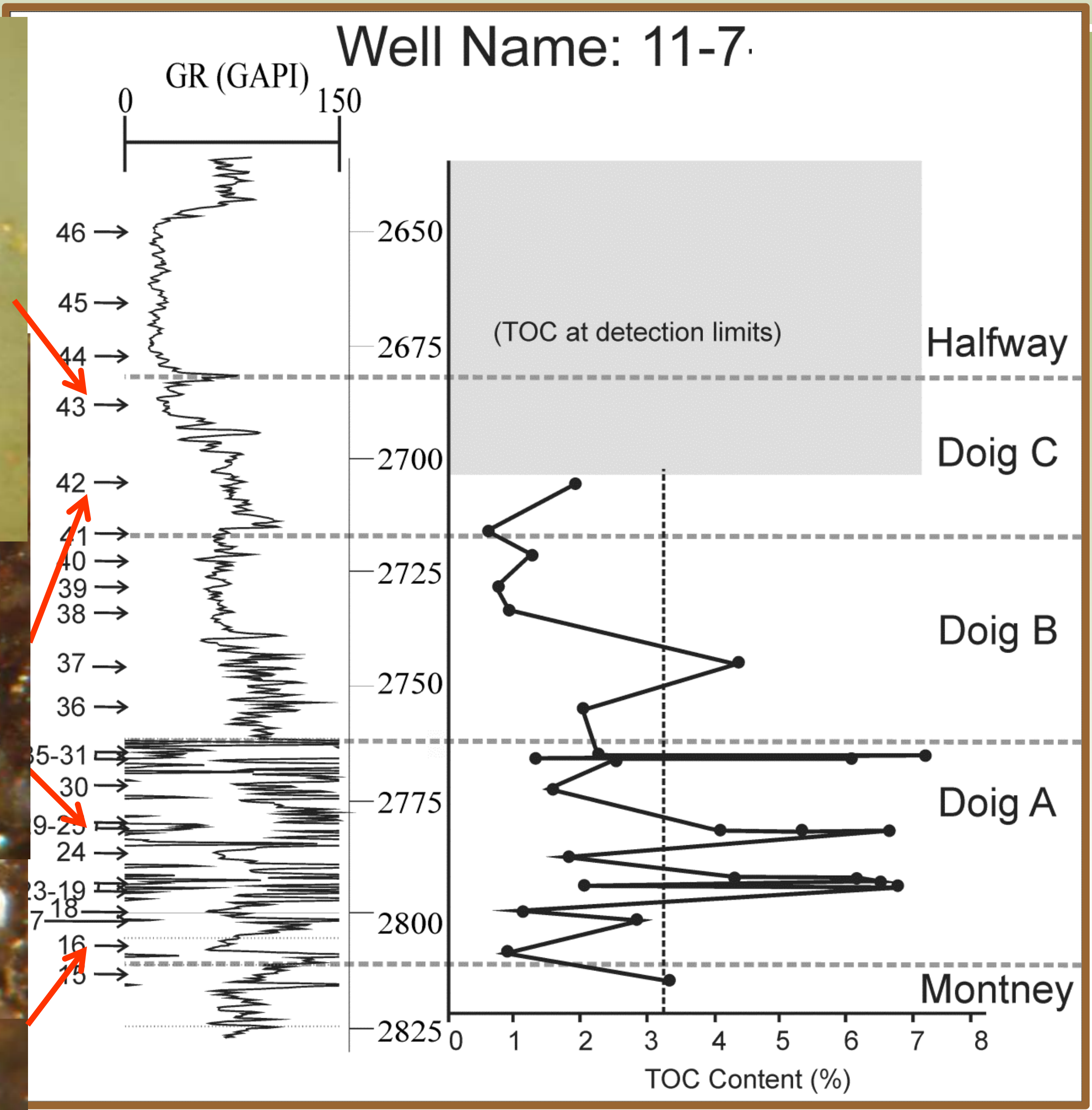




Doig Organic Petrology

41 µm





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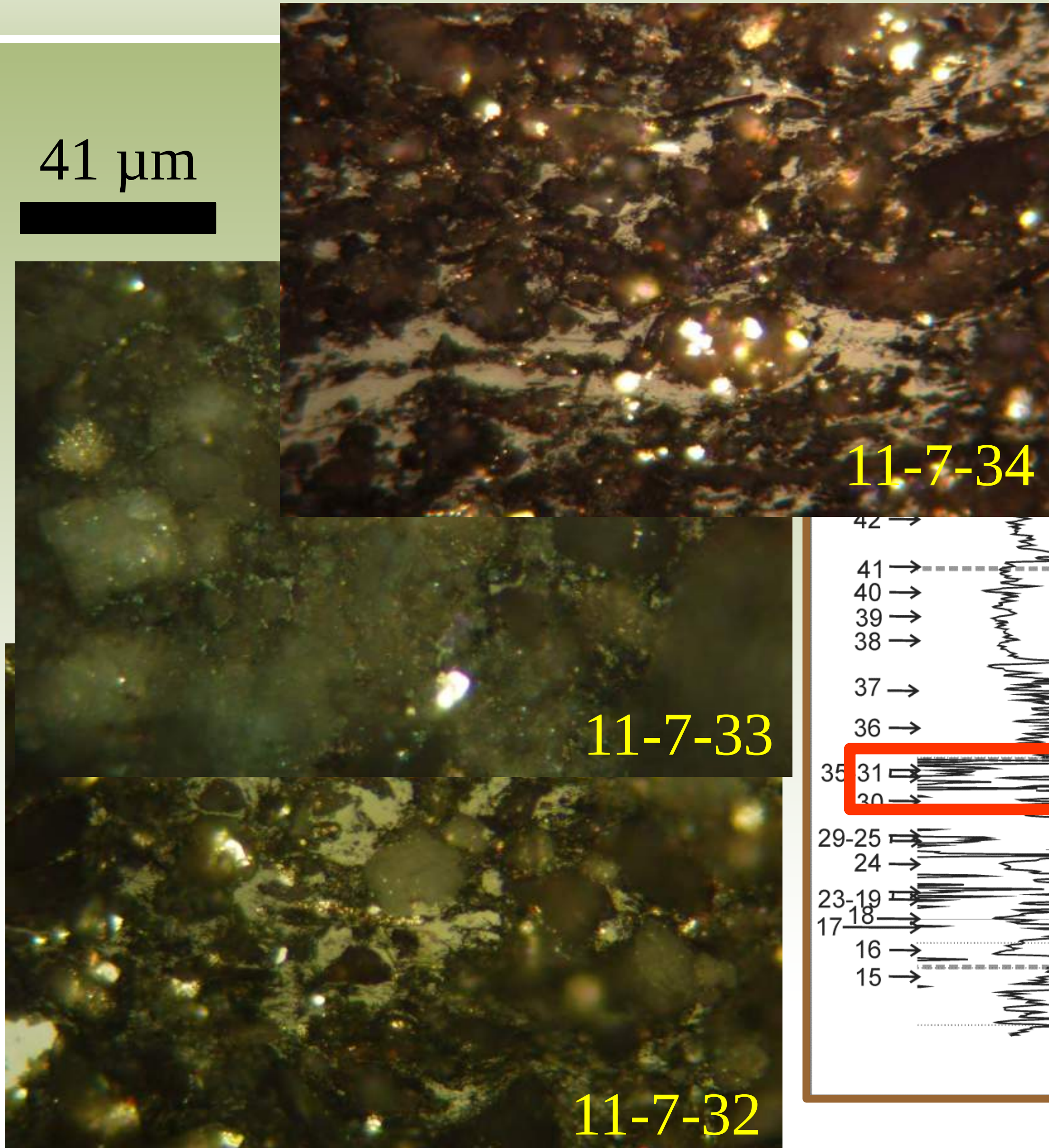
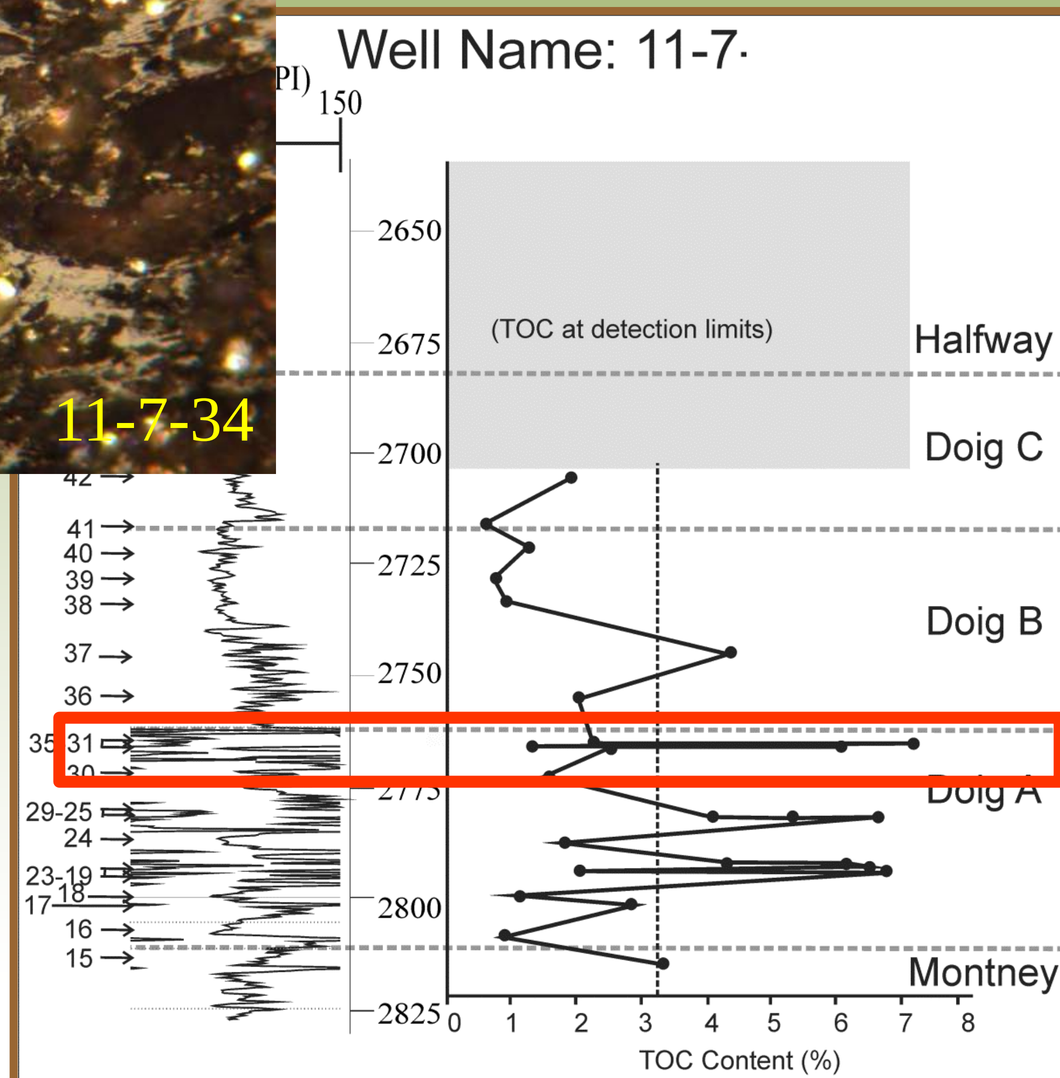
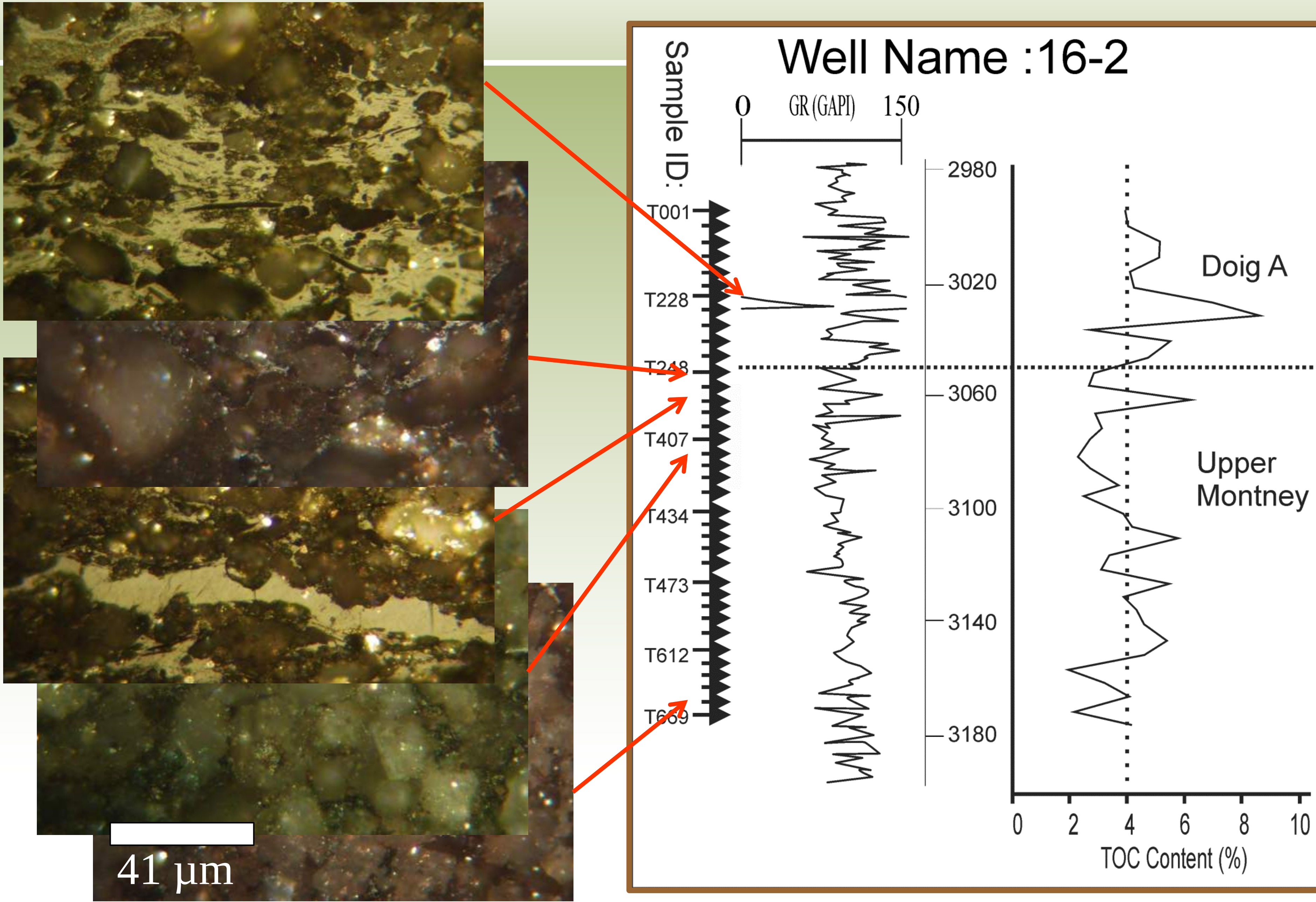


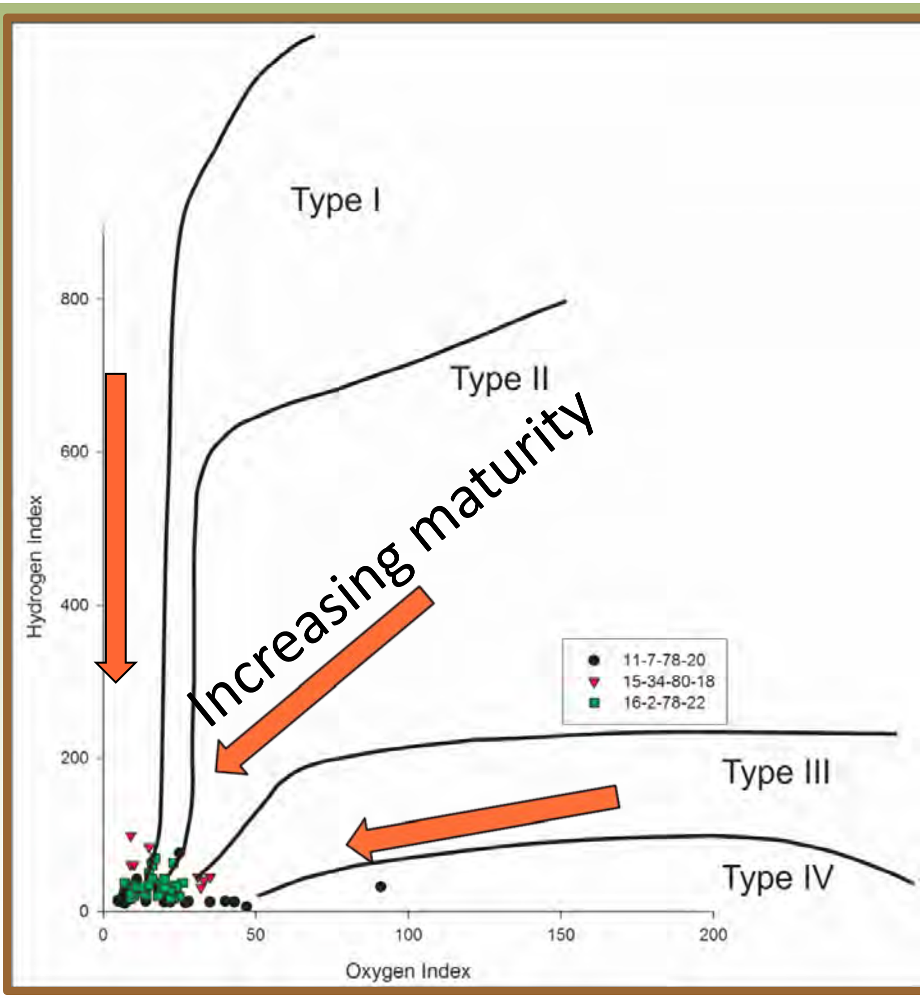


Montney Organic Petrology

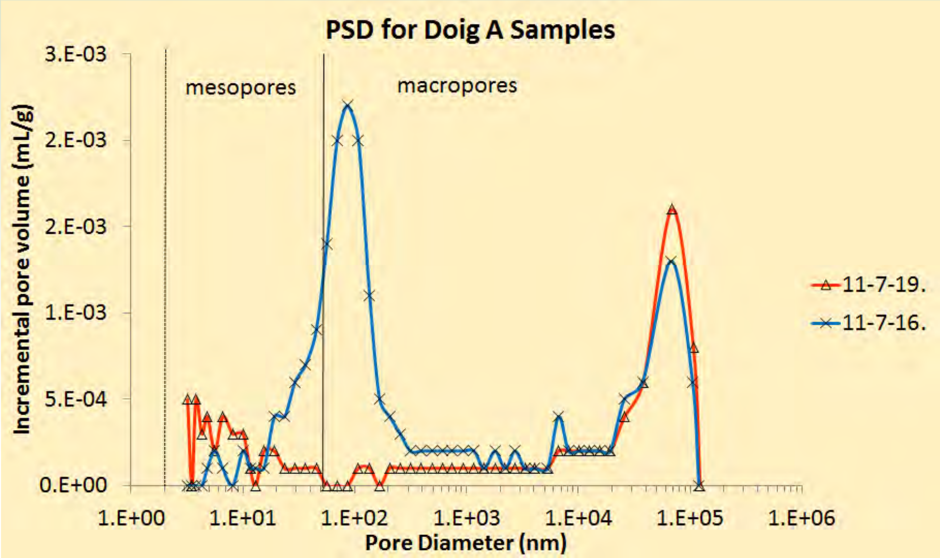


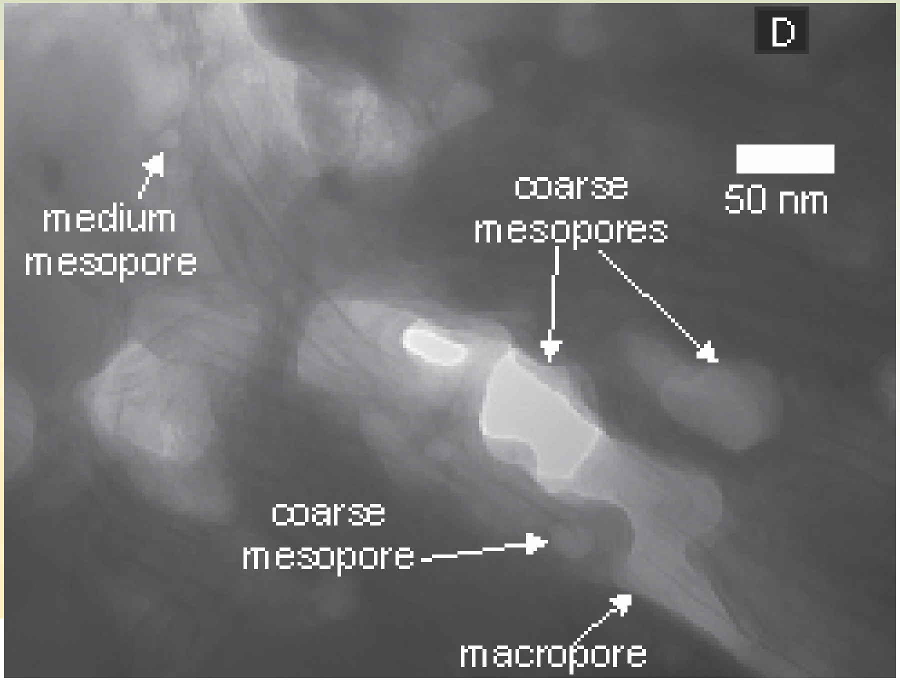
HC generation summary

- From observations, kerogen has been converted to bitumen (oil)
  - Flow textures
  - Oil migration (Riediger et al., 1990)
- Inefficient oil migration resulted in secondary cracking of remaining bitumen to pyrobitumen
  - No fluorescence
  - degassing (macro) pores
  - Increasing TOC maturity = increasing micropores & storage of methane (Chalmers & Bustin, 2008)



Porosity Distribution of Triassic Rocks





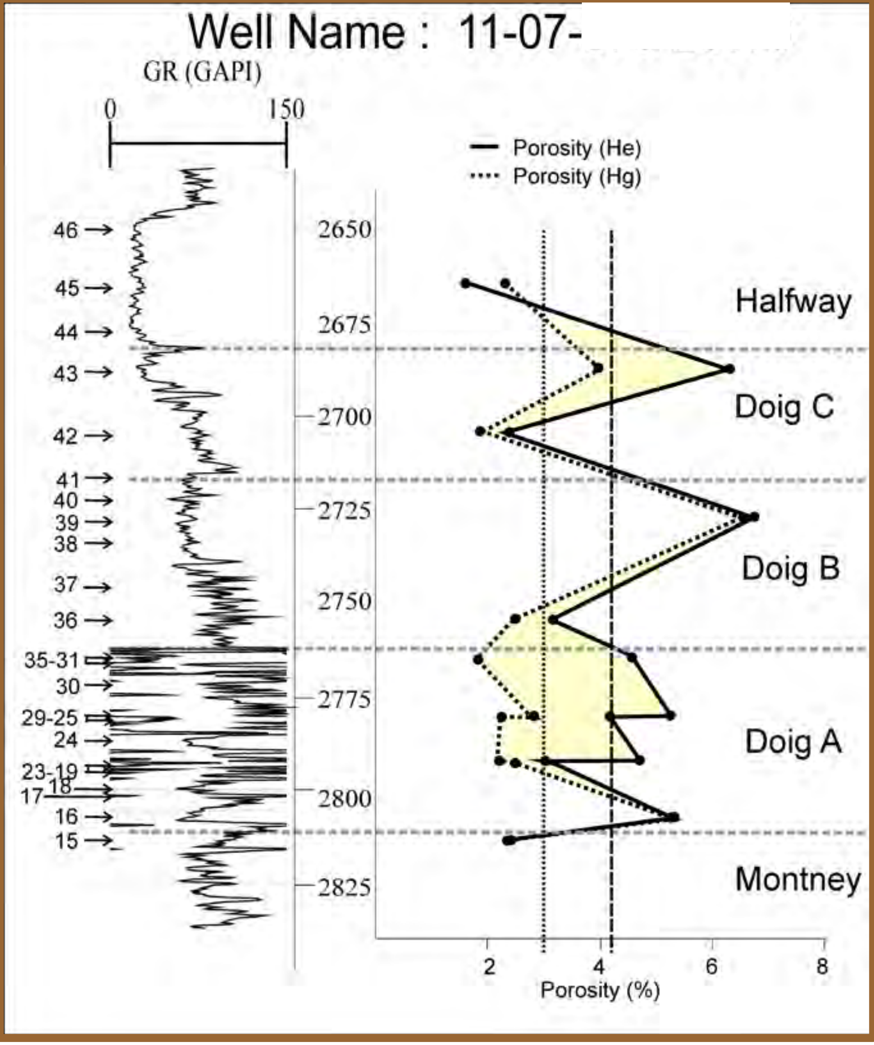
Porosity Measurements

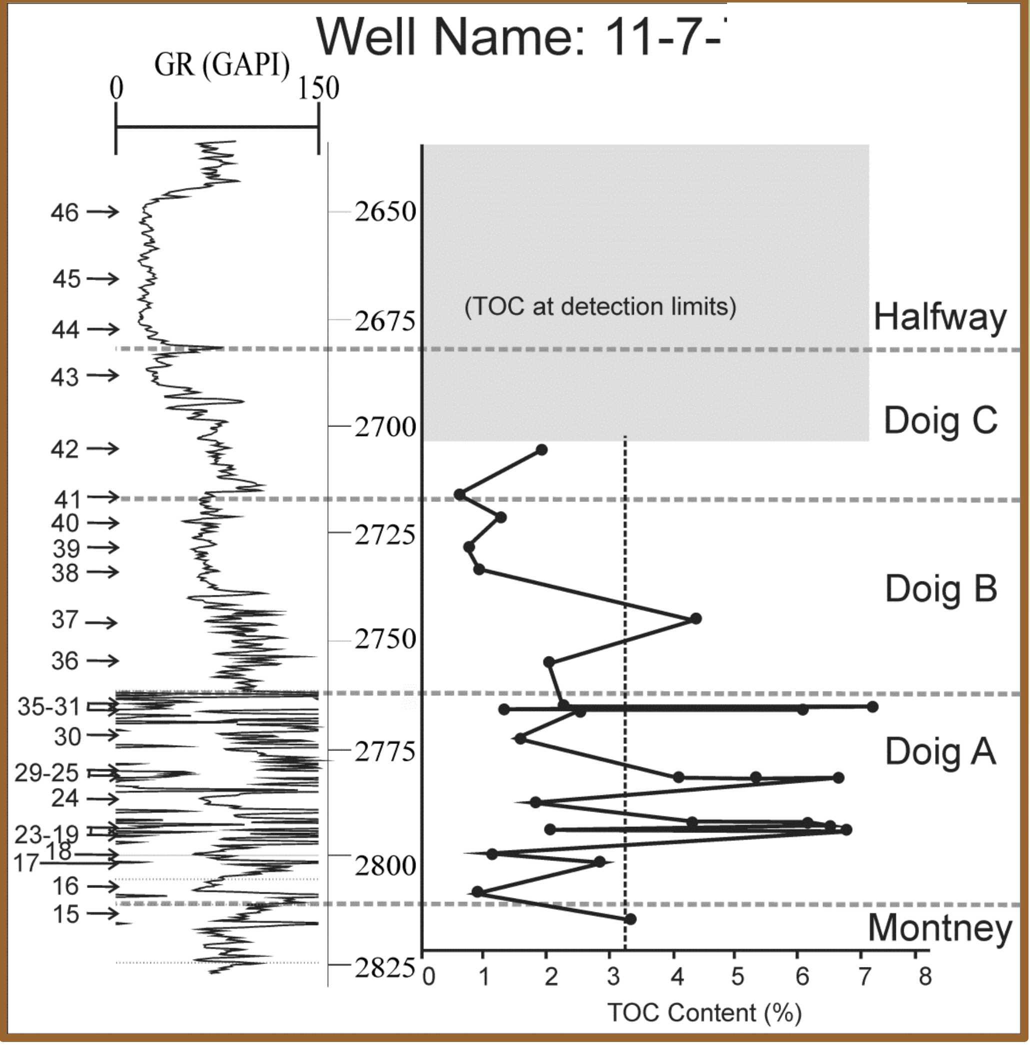
- 2 porosity methods
  - Hg Porosimetry – measures greater than 3 nm
  - He pycnometry – measures greater than 0.26 nm

- Any difference between measurements highlights pore sizes between **0.26 – 3.0 nm** (mostly micropores)

Porosity distribution

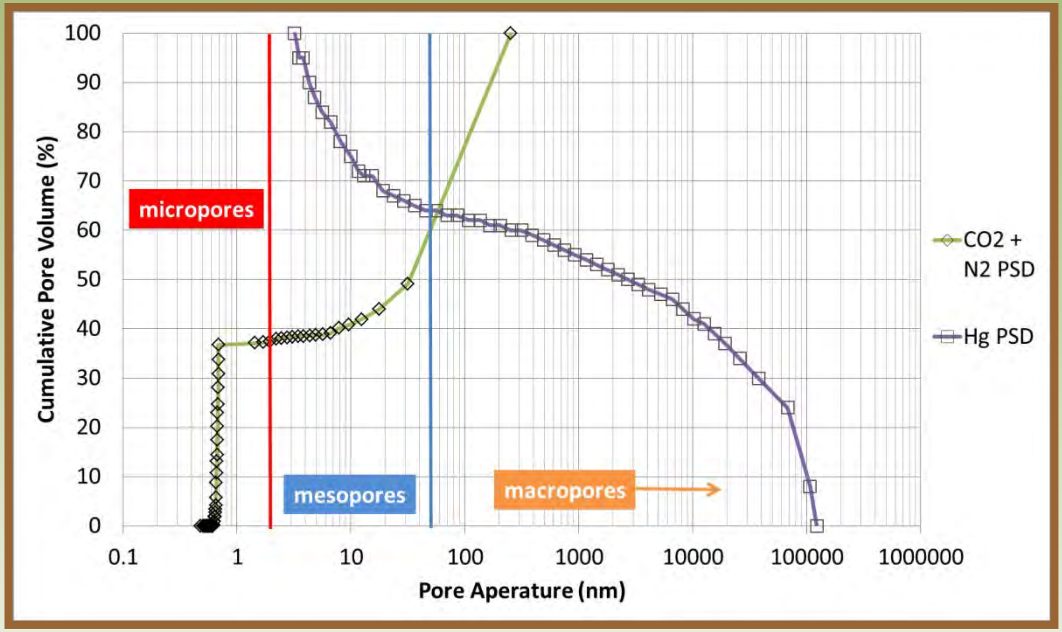
Measured difference between porosity methods is 3 to 0.3 nm





Geological Controls on Pore Size Distribution & Permeability for Triassic Rocks

Geological Controls on Pore Size Distribution (PSD)

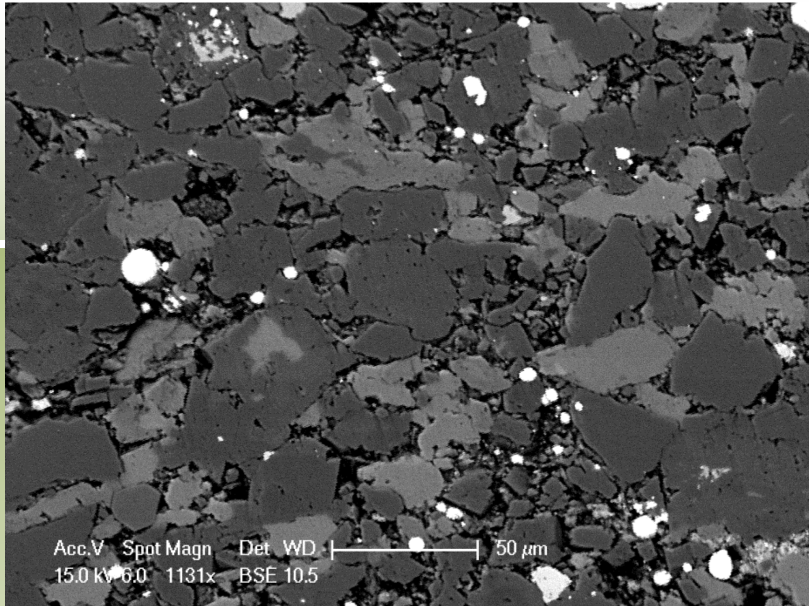


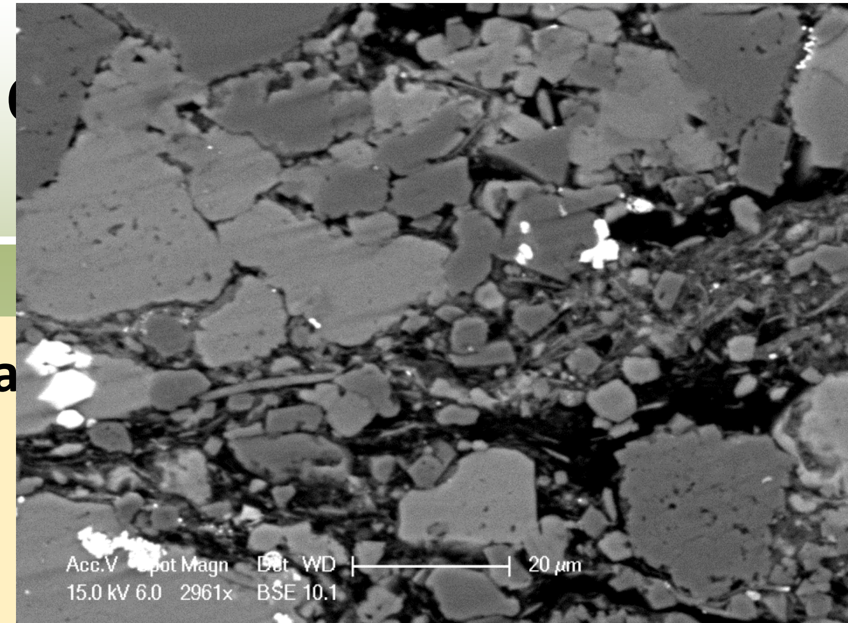
- Combination of:
  - Mineralogy
  - TOC content
  - Texture and fabric
    - Degree of anisotropy

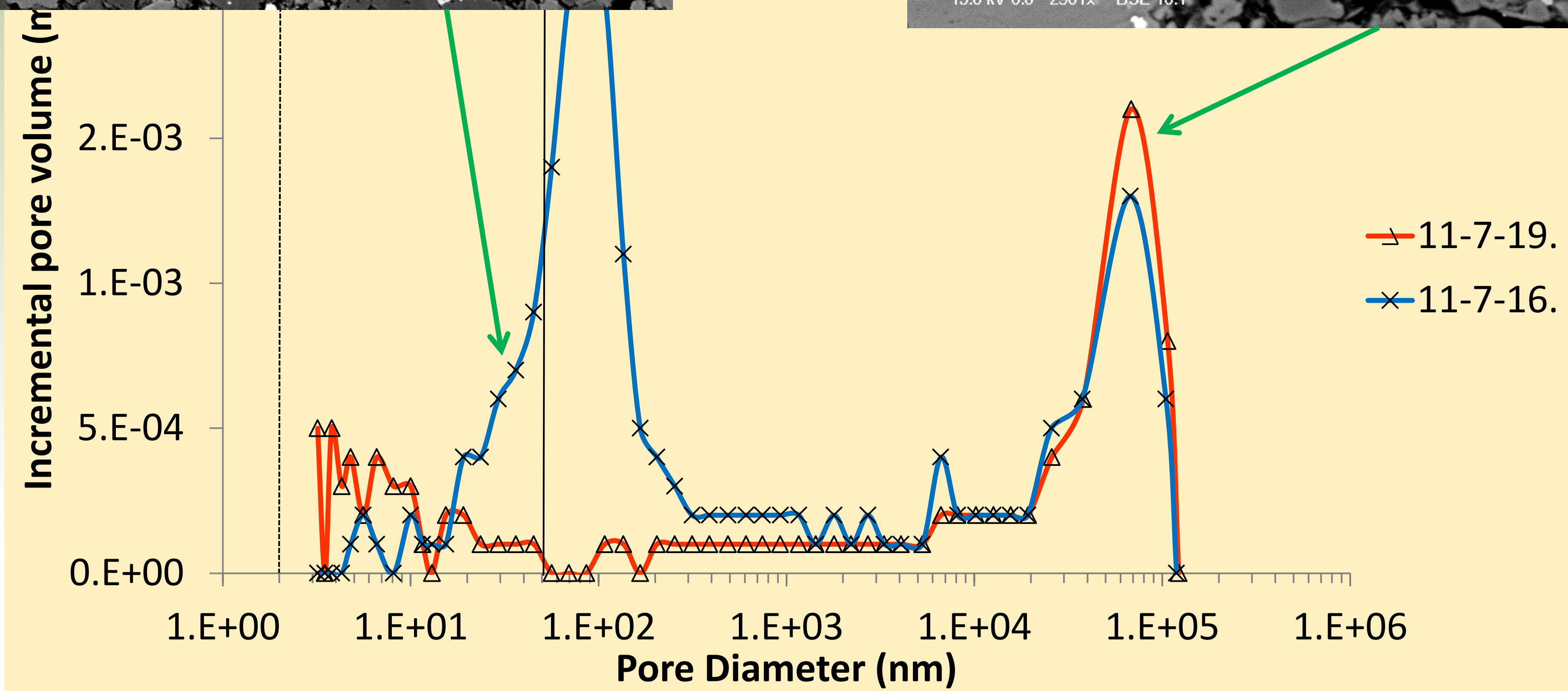
...on by p...

...or Doig A Sa...

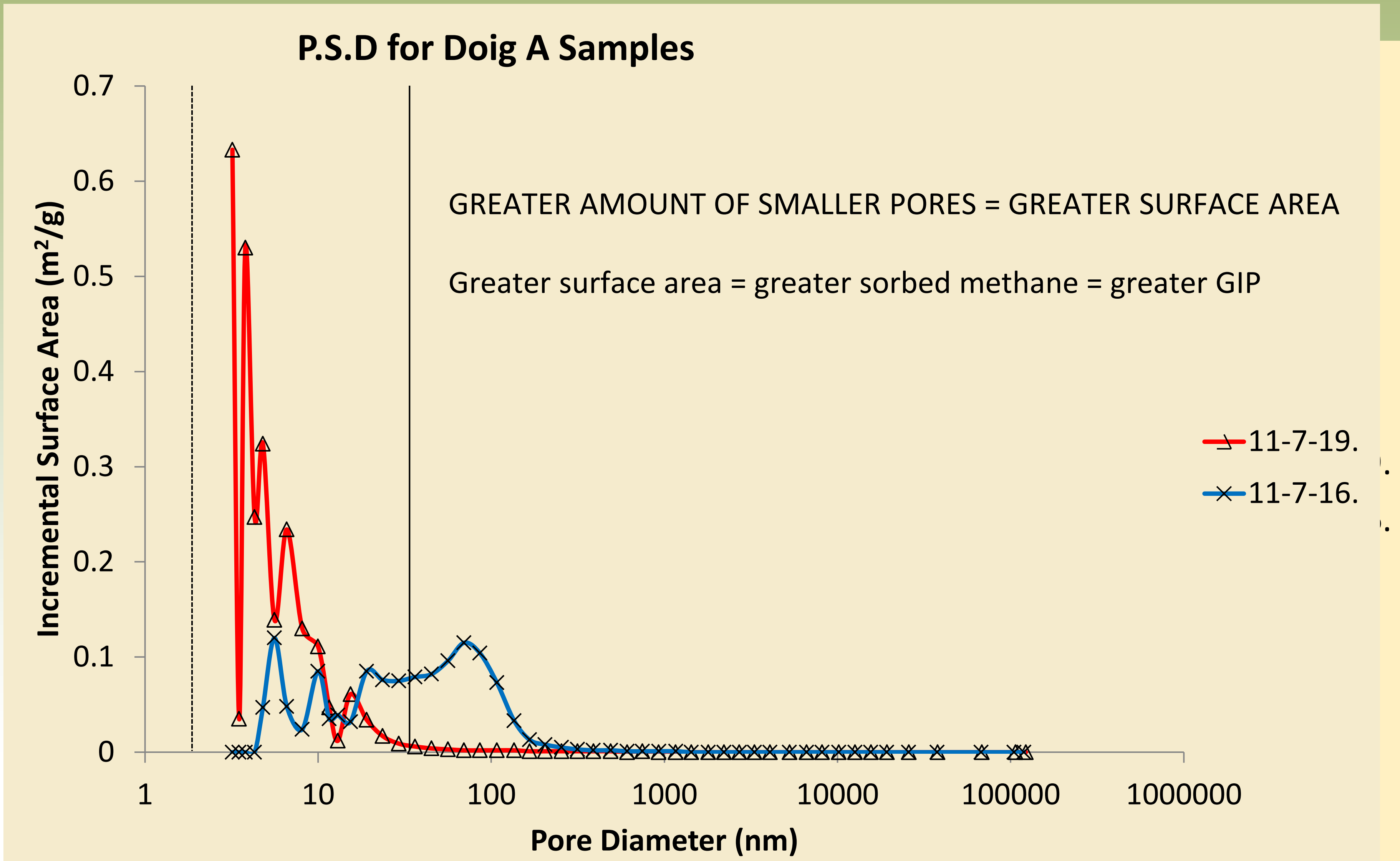
...macropores





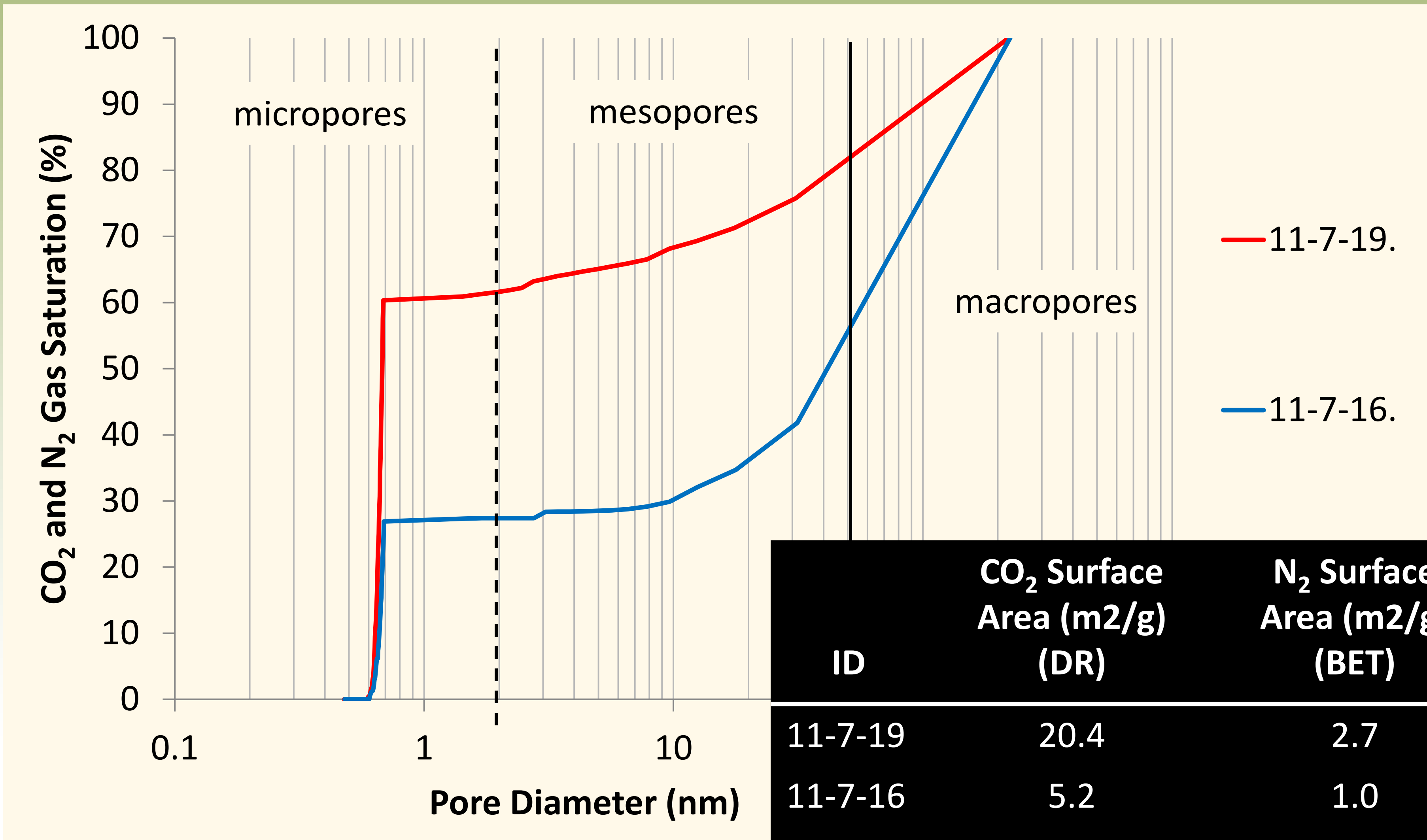


Why are mesopores & micropores important?



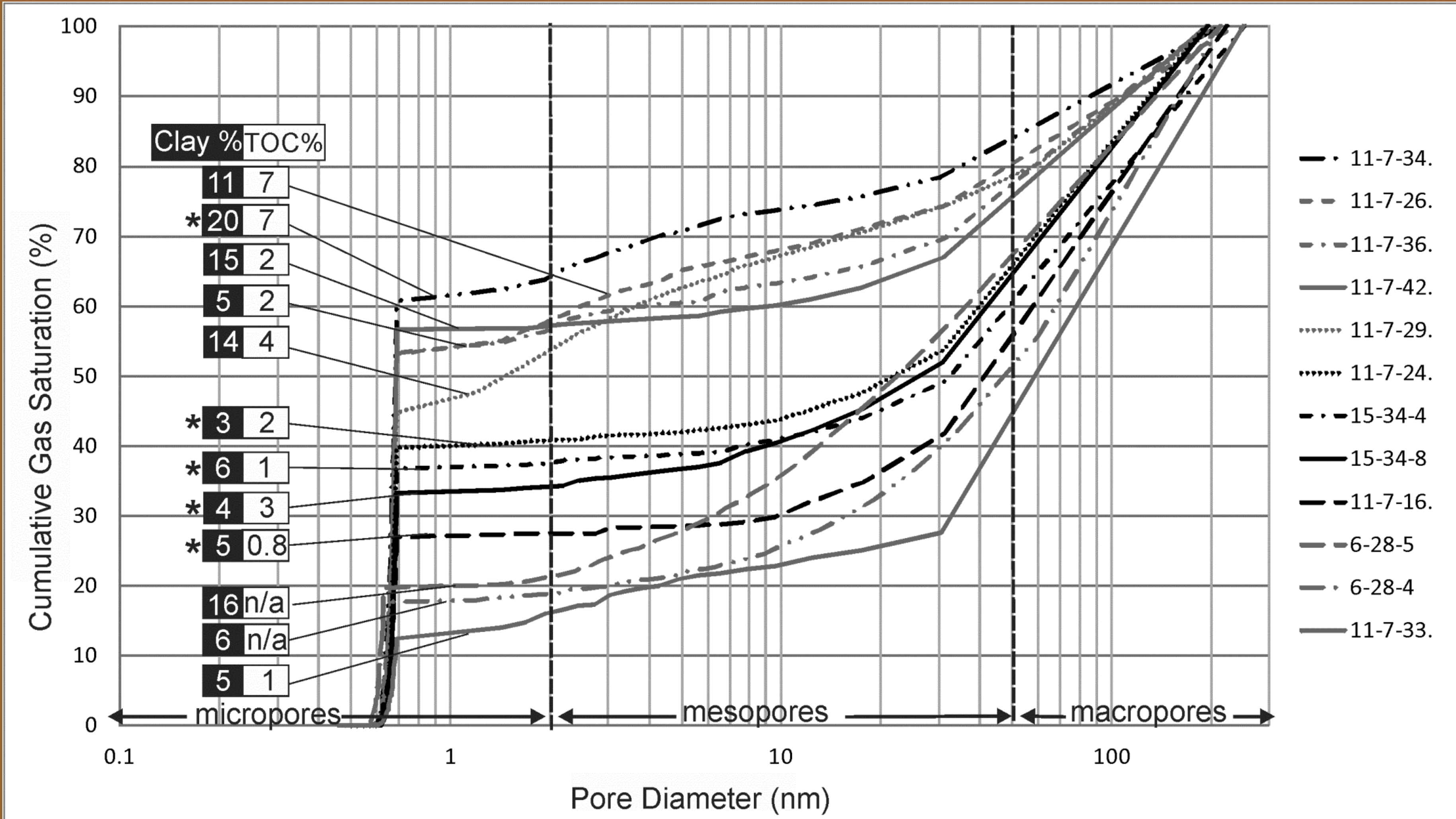
Why are mesopores & micropores important?

- Surface area/storage sites important for continuous HC reservoirs



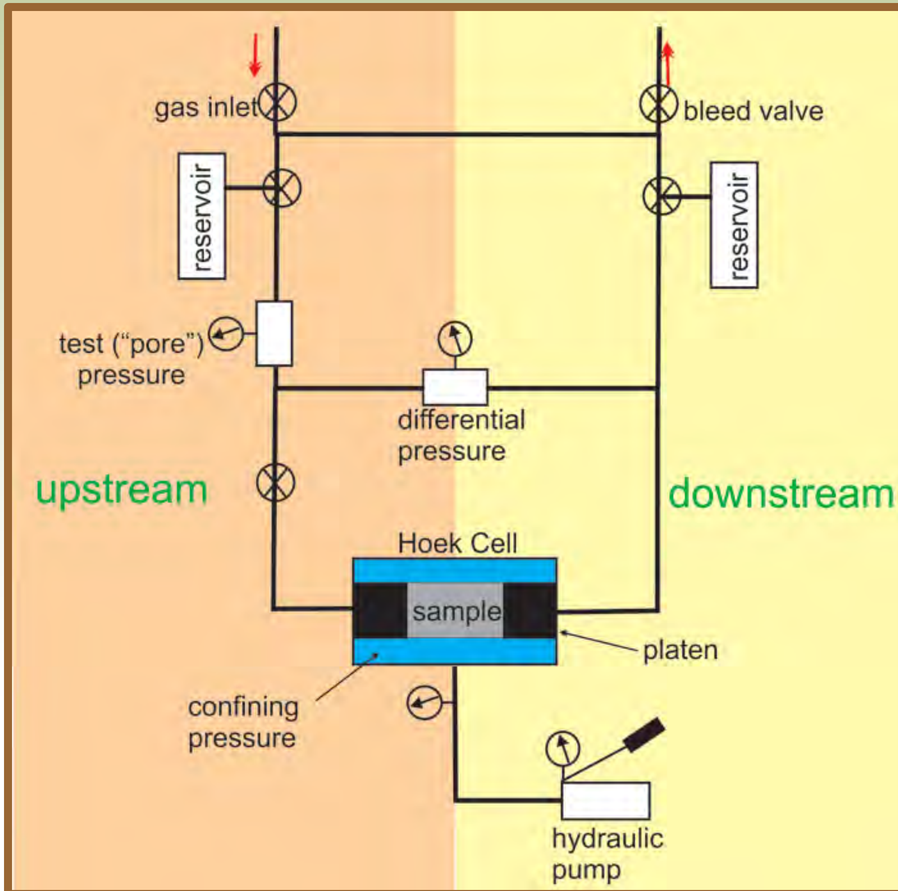
ID	CO_2 Surface Area (m2/g) (DR)	N_2 Surface Area (m2/g) (BET)
11-7-19	20.4	2.7
11-7-16	5.2	1.0

PSD and Clay + TOC Contents



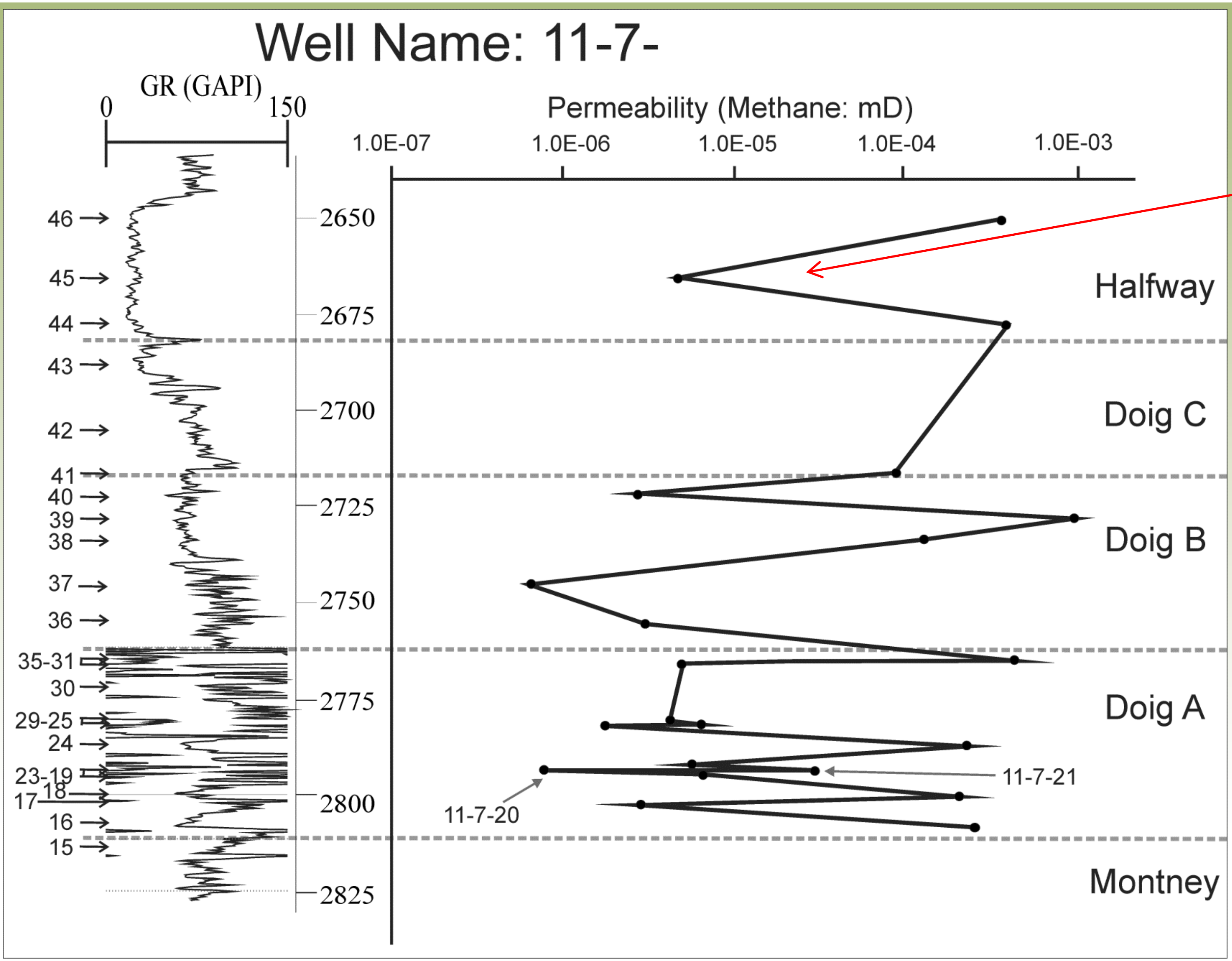
Matrix permeability

- No visible fractures in core & partially submerged in alcohol after analyses
- Confined to 4000 PSI (28 MPa)
- Pore P = 500 PSI
- Methane gas used
  - Corrected for sorption
    - Cui et al., 2009*



* Geofluids, vol. 9, p 208-223, 2009.

Down-hole profile of K



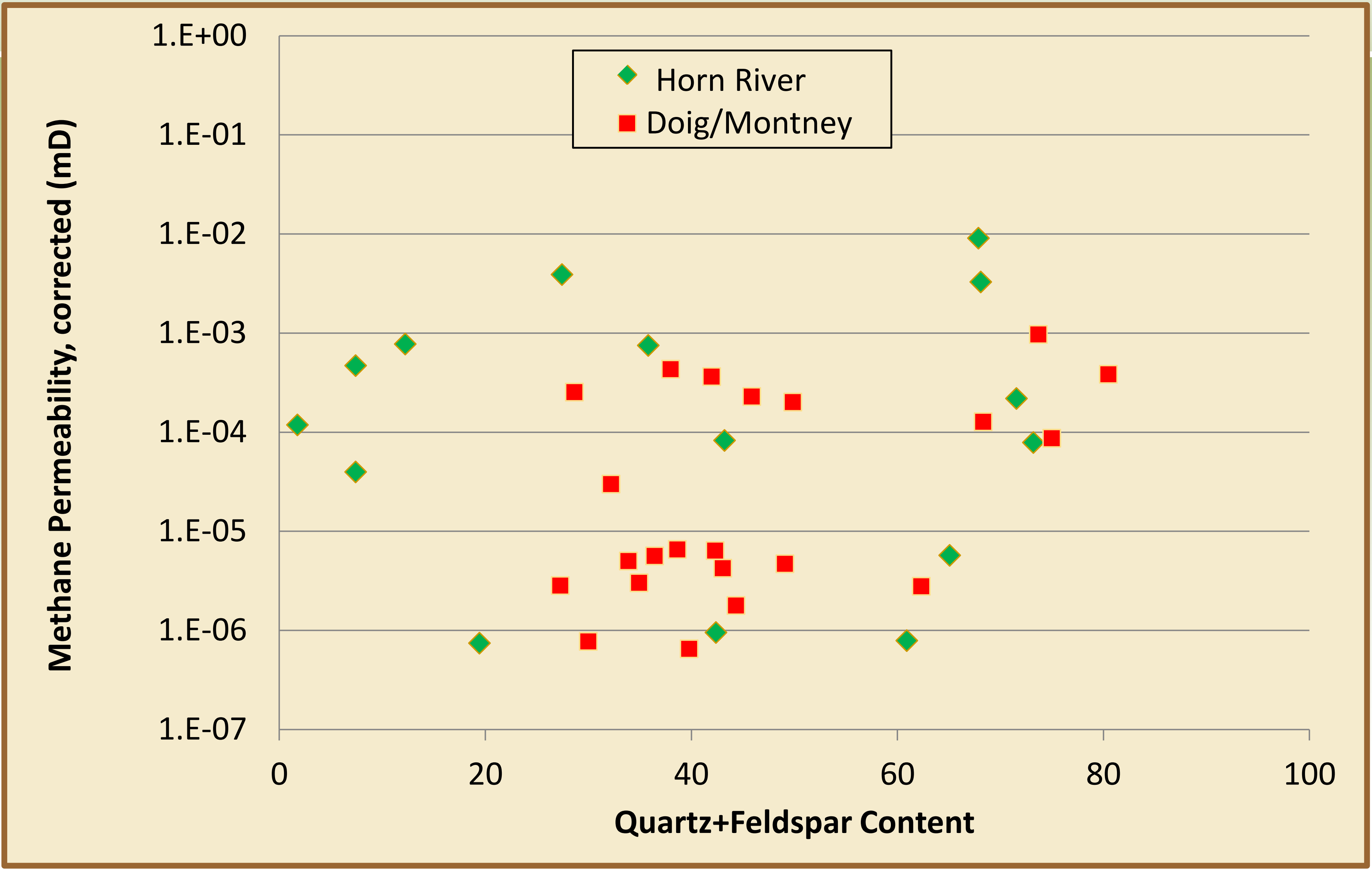
Low K due to calcite cement

Highly Variable K

Mineralogy & fabric vs Permeability

for Triassic and Devonian Rocks

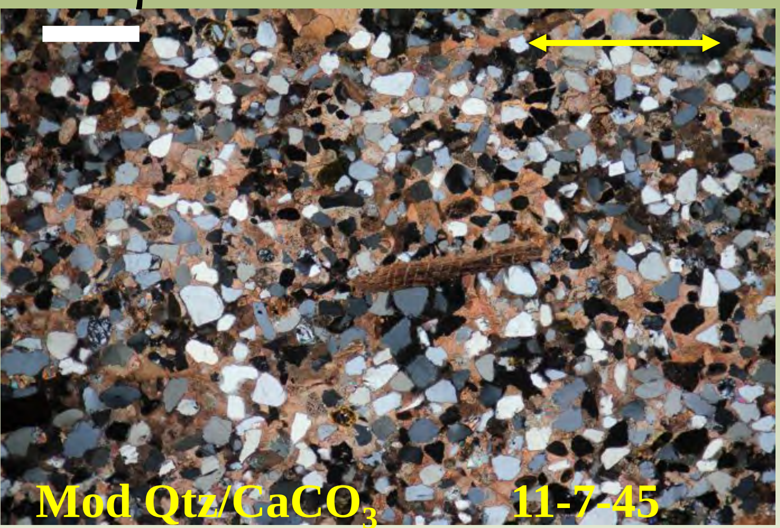
Variability of Matrix Permeability



Comparing High & Low K – Triassic

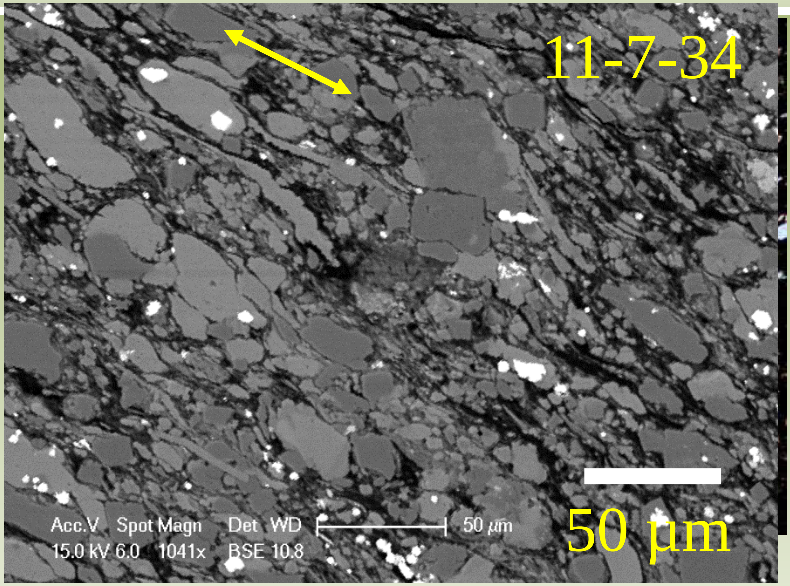
Low K (< 1E-5 mD)

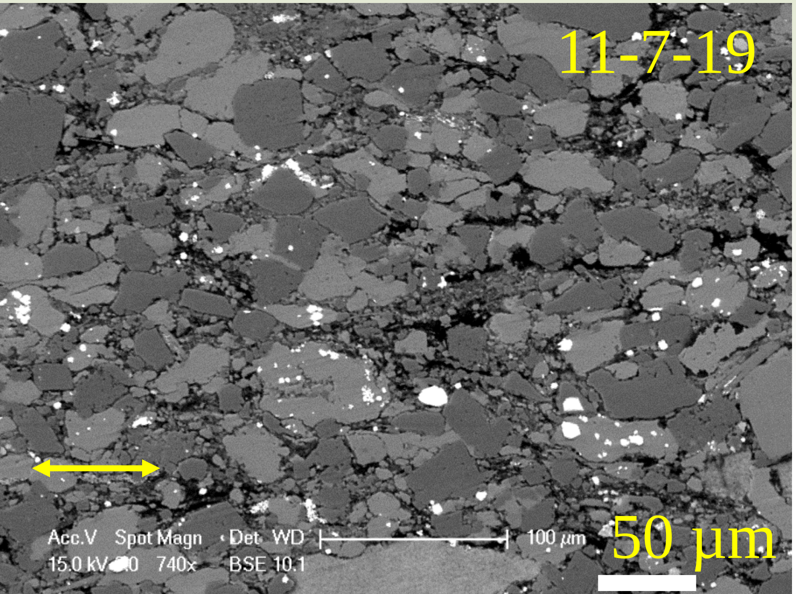
500 µm



Bedding Direction

High K (>1E-04 mD)

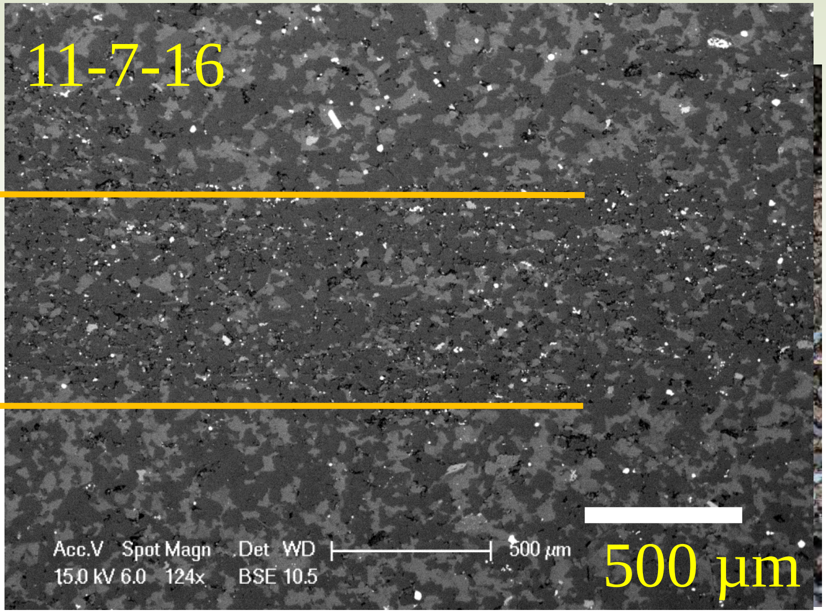




Calcite cemented

less cemented

Calcite cemented

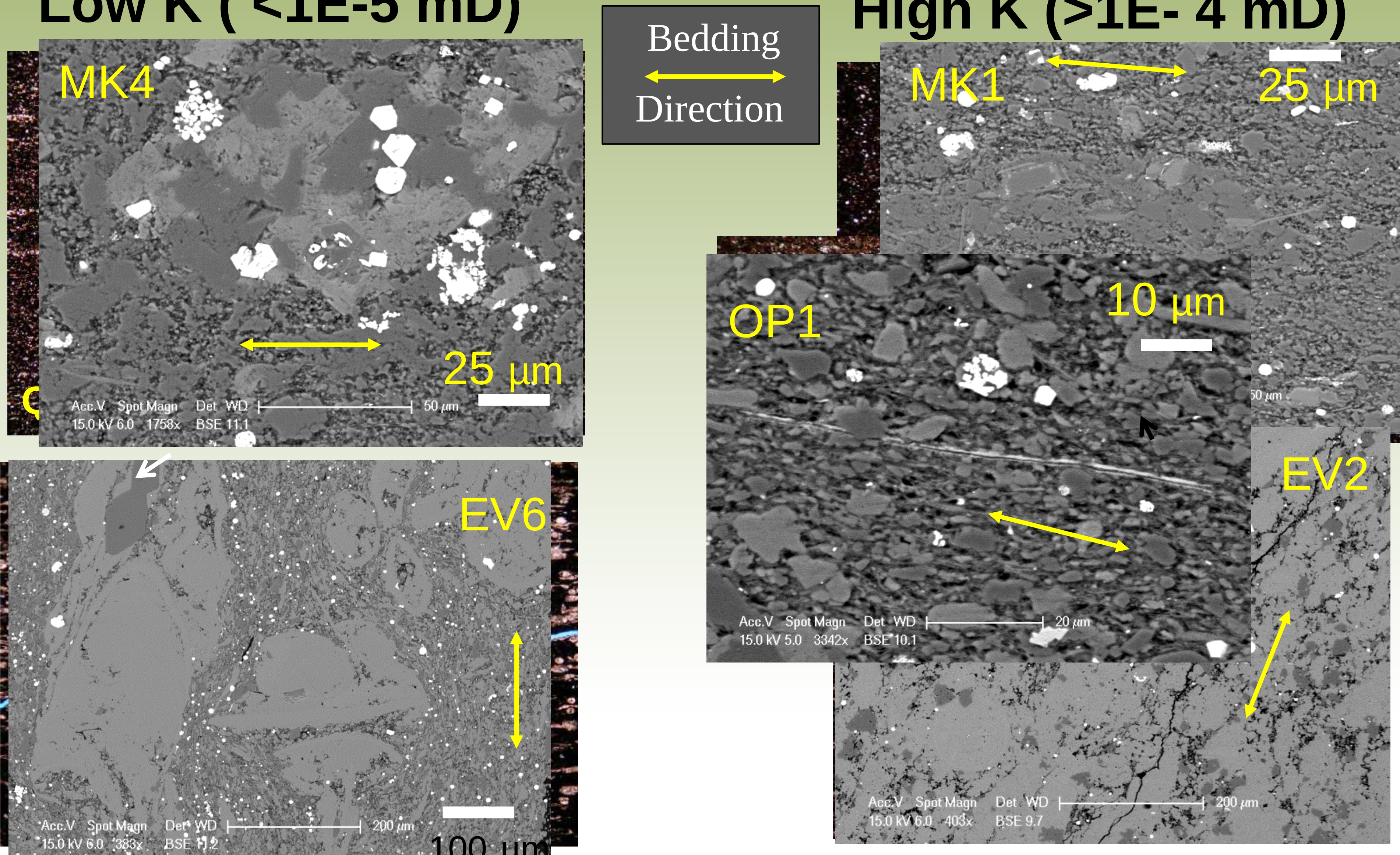


Comparing High & Low K – Devonian

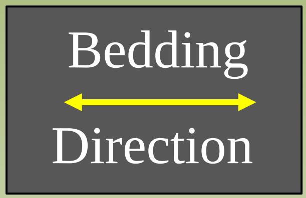
- Mineralogy is not the sole cause of permeability differences

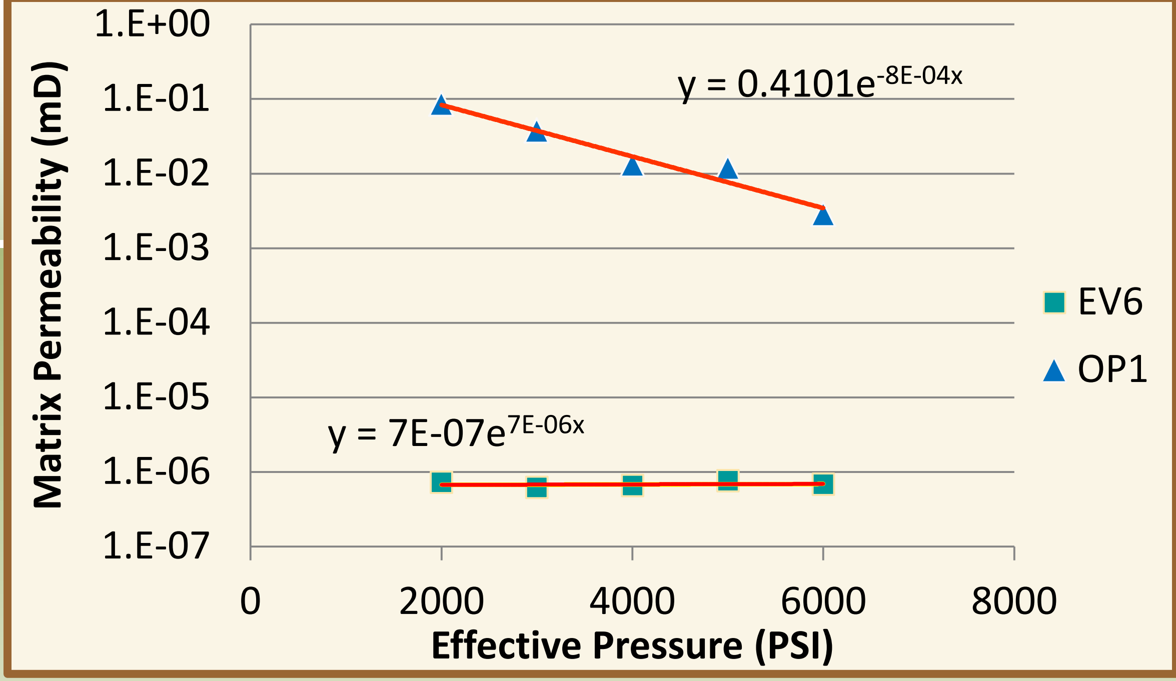
Low K (<1E-5 mD)

High K (>1E- 4 mD)

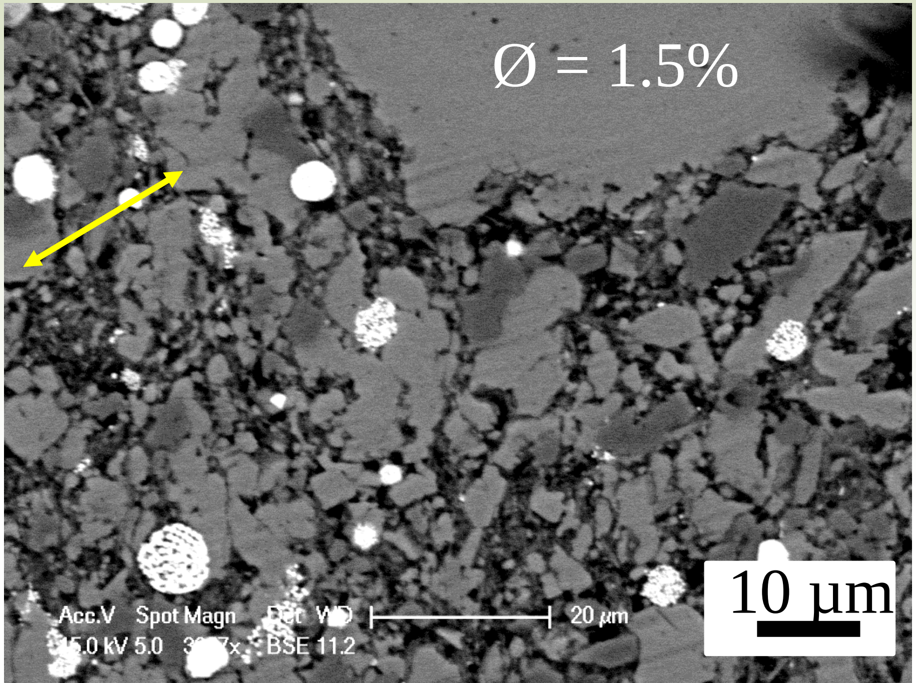


Mineralogy, fabric vs K Sensitivity

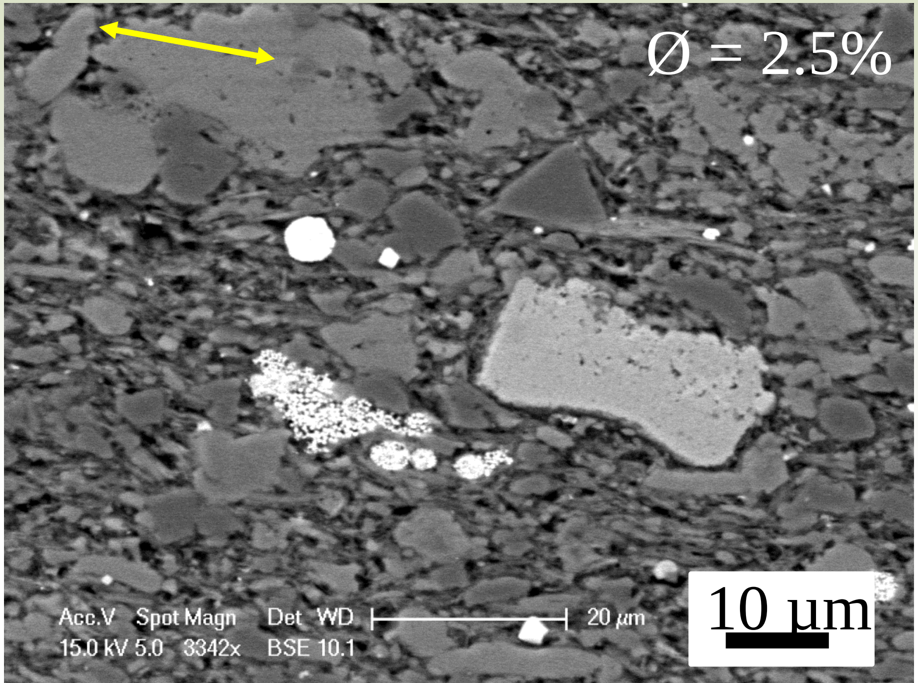




EV6: isotropic, carbonate rich, less sensitive

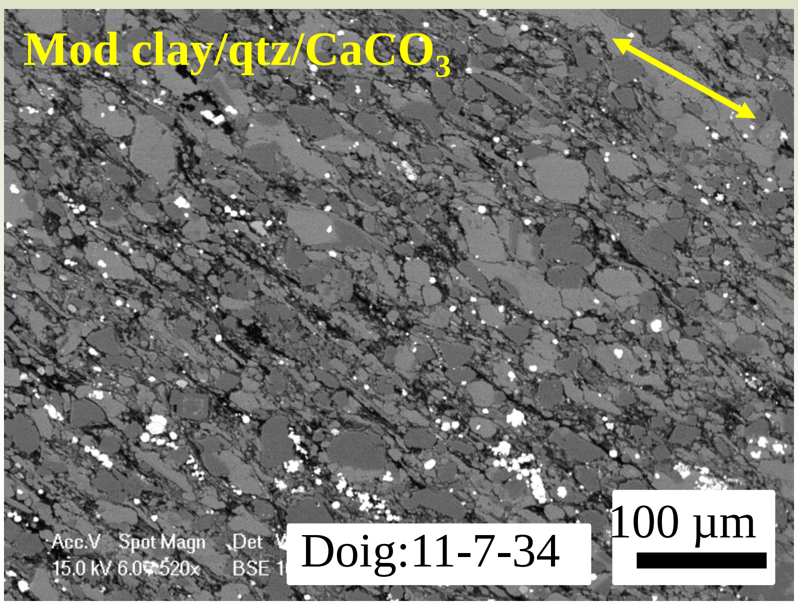


OP1: anisotropic, clay rich, sensitive



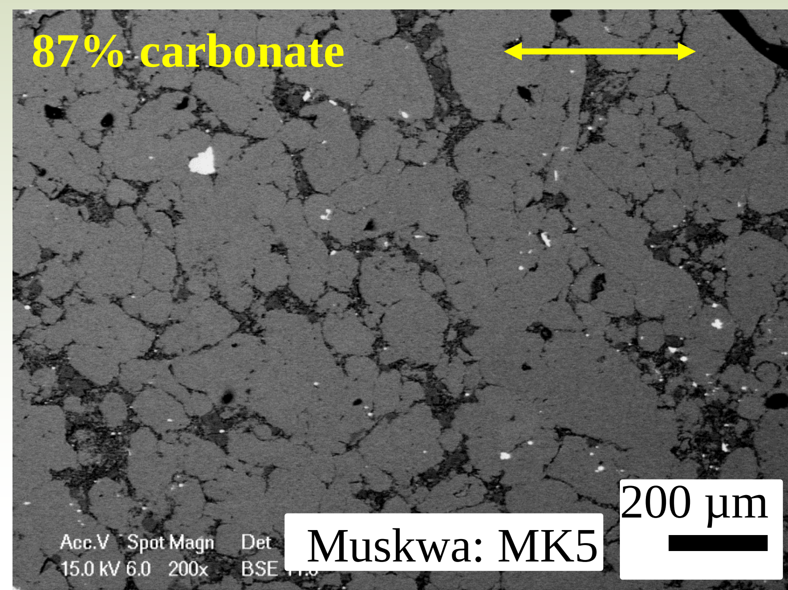
Fabric vs K - summary

- Anisotropic
  - Greater content of clay, kerogen, long axis of elliptical clasts parallel with lamination
  - High K
  - K more sensitive to varying E.P.



- Isotropic
  - High proportion of equant grains – calcite or quartz
  - High or low K
  - Less sensitive

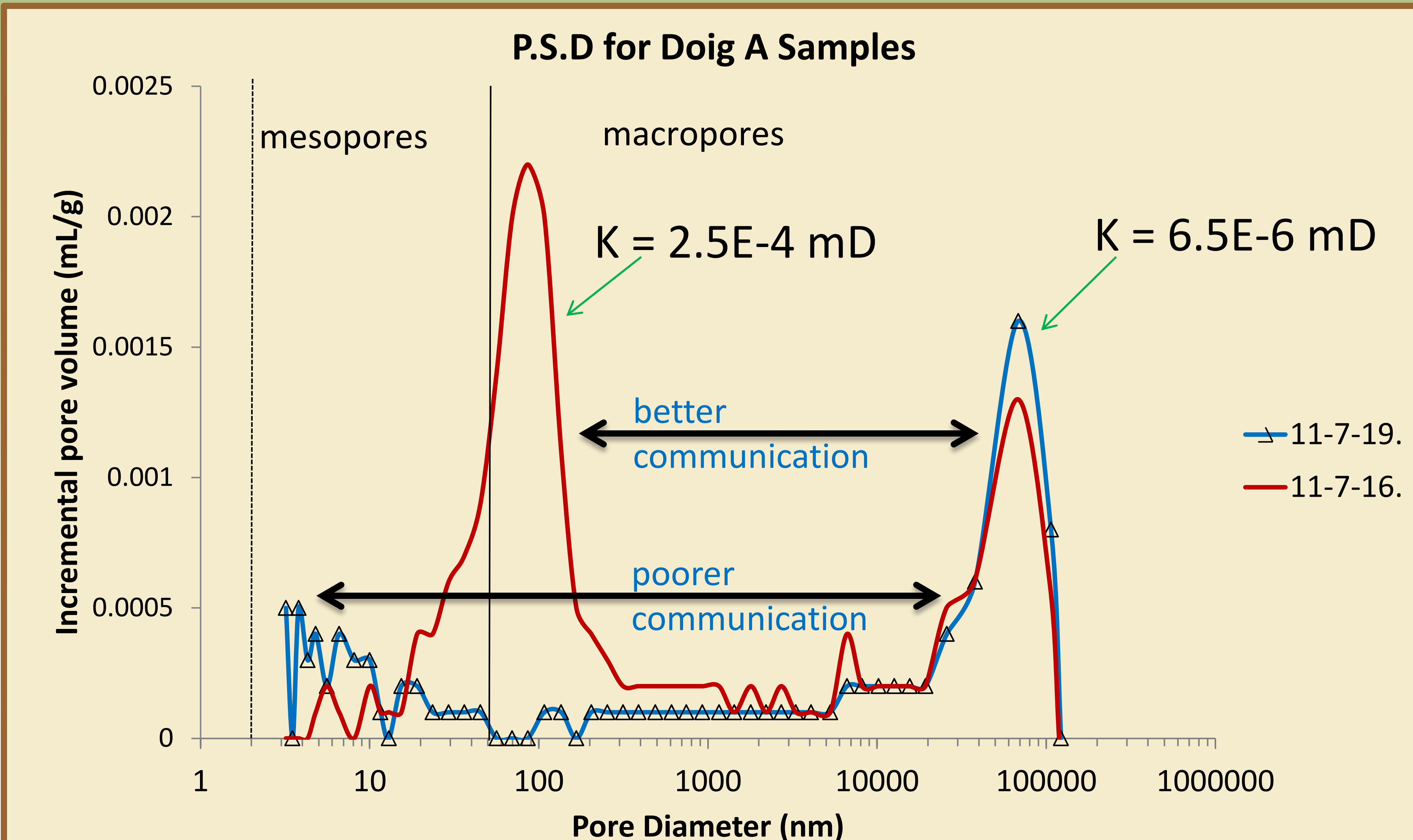
Bedding
Direction



PSD vs Permeability

Hg intrusion curves and K

- PSD by incremental pore volume



PSD by Gas Adsorption

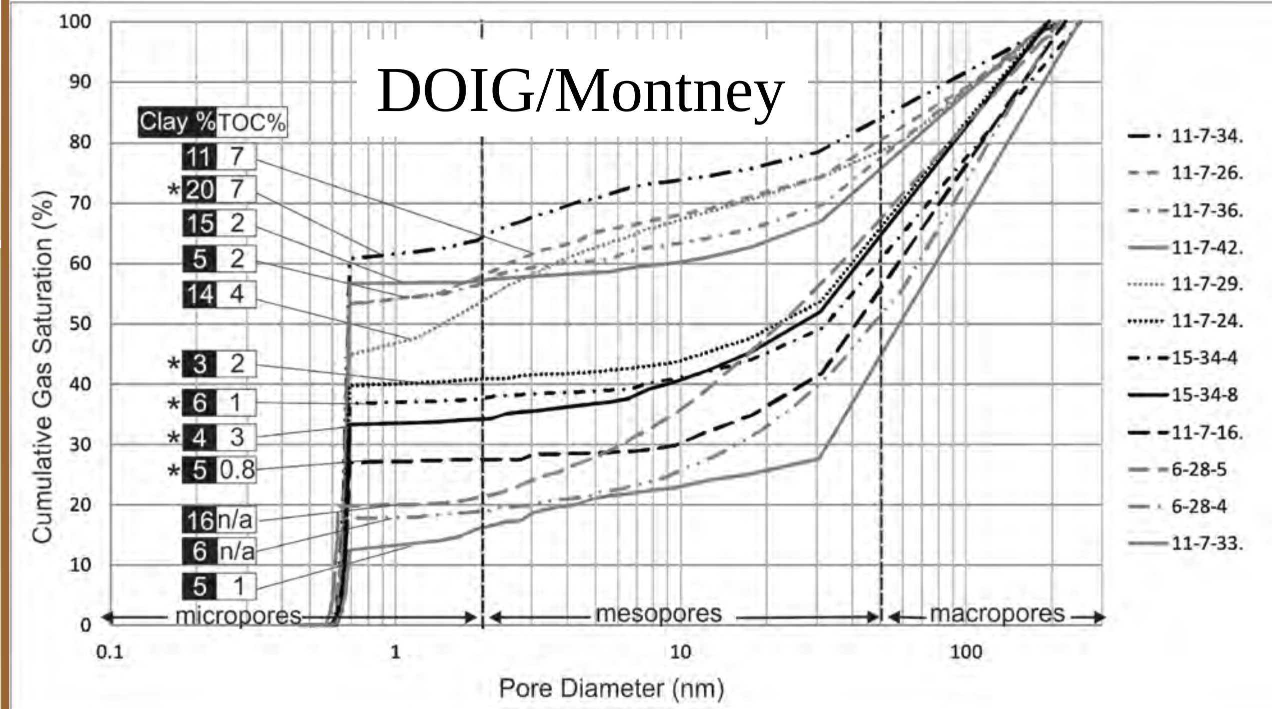
* = high K

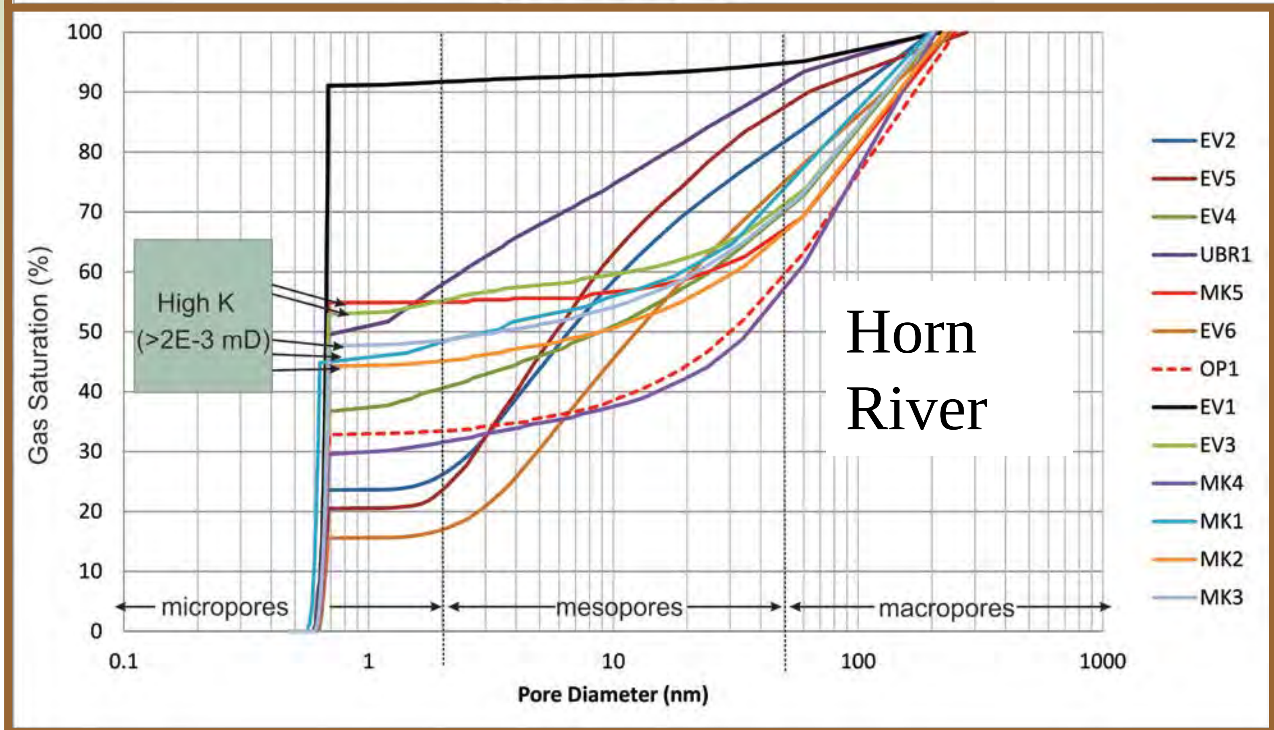
Higher K samples have similar ratio & shape

Ratio of
Micro-, meso-, macropore:

Doig	38: 22: 40
HRB	45: 25: 30

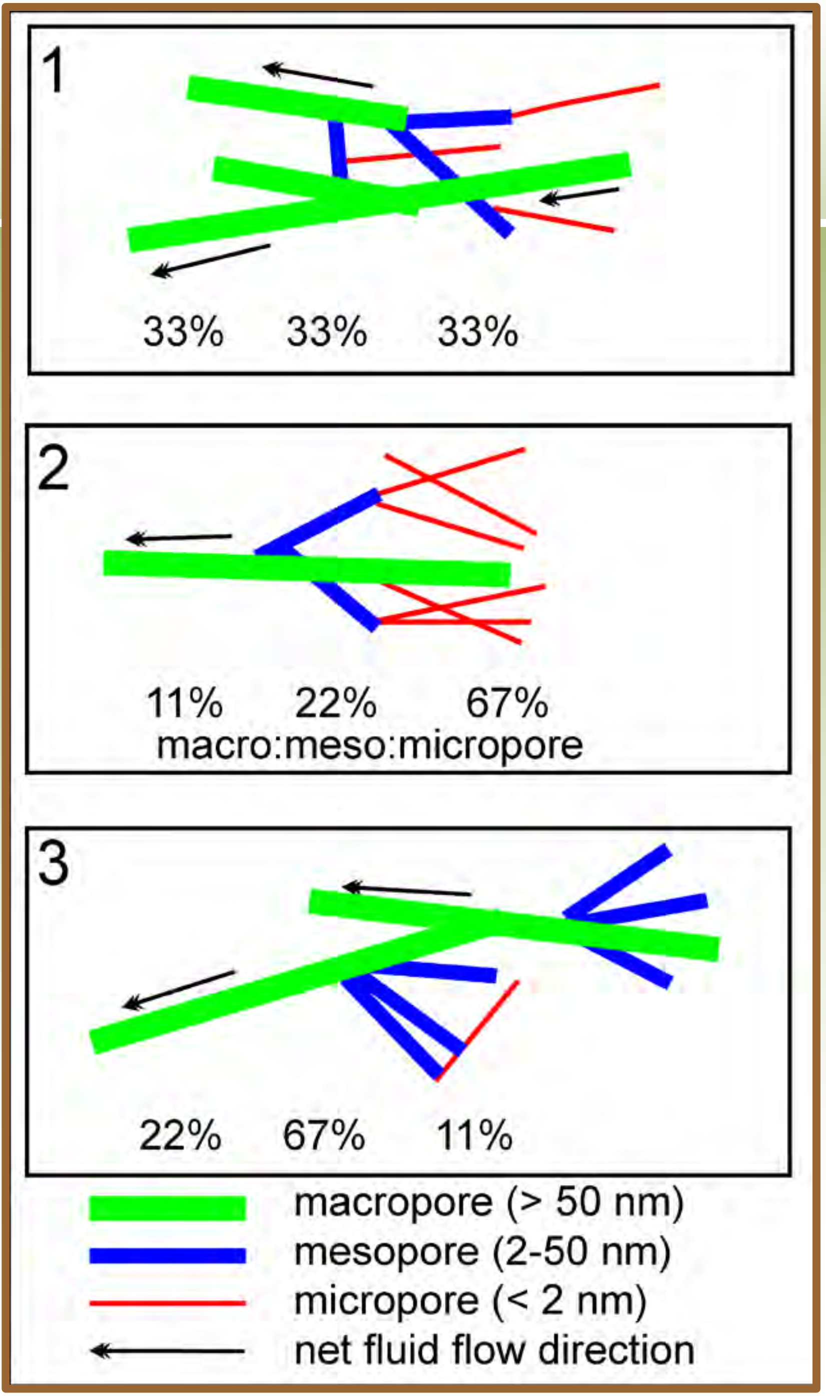
Balanced ratio





Pore Model

- Moderate, more balanced ratio of pore sizes (model #1)
  - Increases connectedness & flow
  - Greatest surface area is within micropores
    - Surface area stores HCs



Conclusions: Controls on Matrix Permeability

- PSD controls permeability
- PSD
  - Mineralogy
  - TOC content
  - Texture
  - Fabric and degree of anisotropy

Google Maps 2012.

Conclusions

- Triassic rocks show small scaled heterogeneity in TOC and mineralogy and PSD
  - Increases the reservoir's complexity with respect to storage of methane and permeability
- Kerogen (TOC) distribution due to deposition & conversion of bitumen to pyrobitumen has produced gas & storage site within reservoir

- Although Devonian rocks differ from Triassic rocks, higher K values have similar PSD
  - More balanced ratios of micro-, meso and macropores

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- "Your name here"

- "Geological Controls on Permeability of the Devonian Horn River Shales"
  - In review, International Journal of Coal Geology, special issue of gas shales
- "Geological Controls on Permeability of Triassic Doig/Montney Shales"
  - In review, Journal of Marine and Petroleum Geology