In situ SIMS Oxygen Isotope Analyses Reveals a Continuous 300 Ma History of Carbonate Cementation and Dolomitization in the middle Bakken

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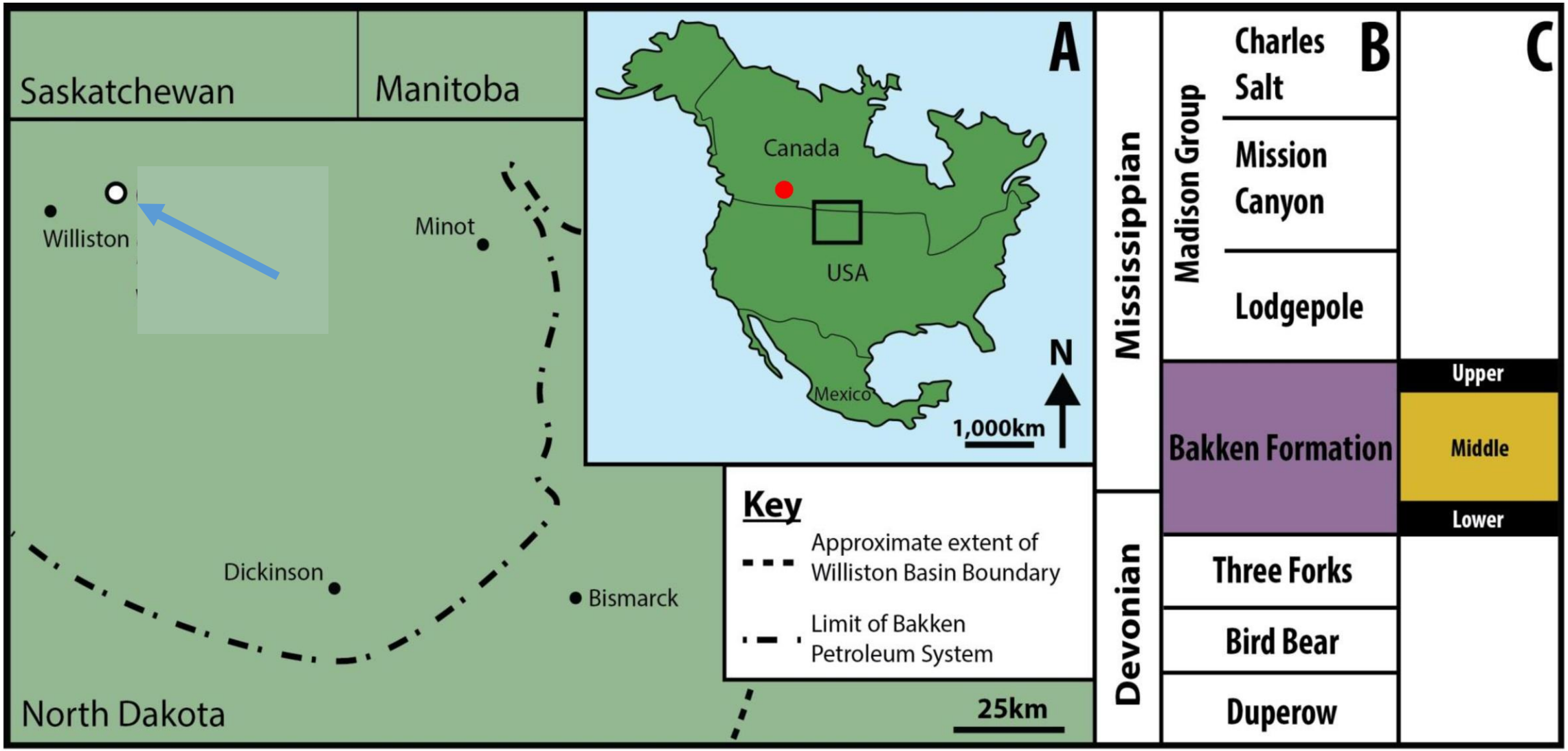
Outline

- Middle Bakken: Reservoir Quality
- *In Situ* Oxygen Isotopes using Secondary Ion Mass Spectrometry
    - Temperature/timing of calcite and dolomite formation?
    - Continuous or punctuated diagenesis?
    - Dolomite: primary cement or dolomitization of calcite?
    - Closed or open geochemical system?
- Petrophysics

Williston Basin



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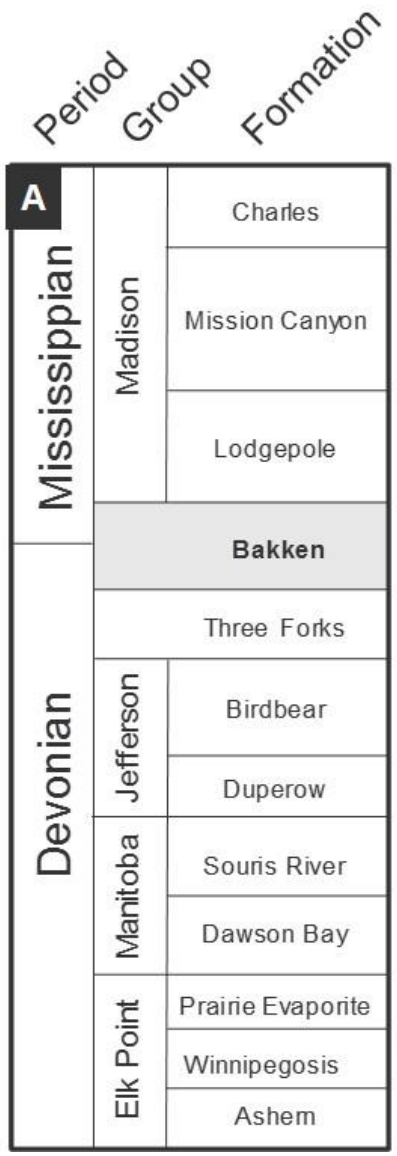
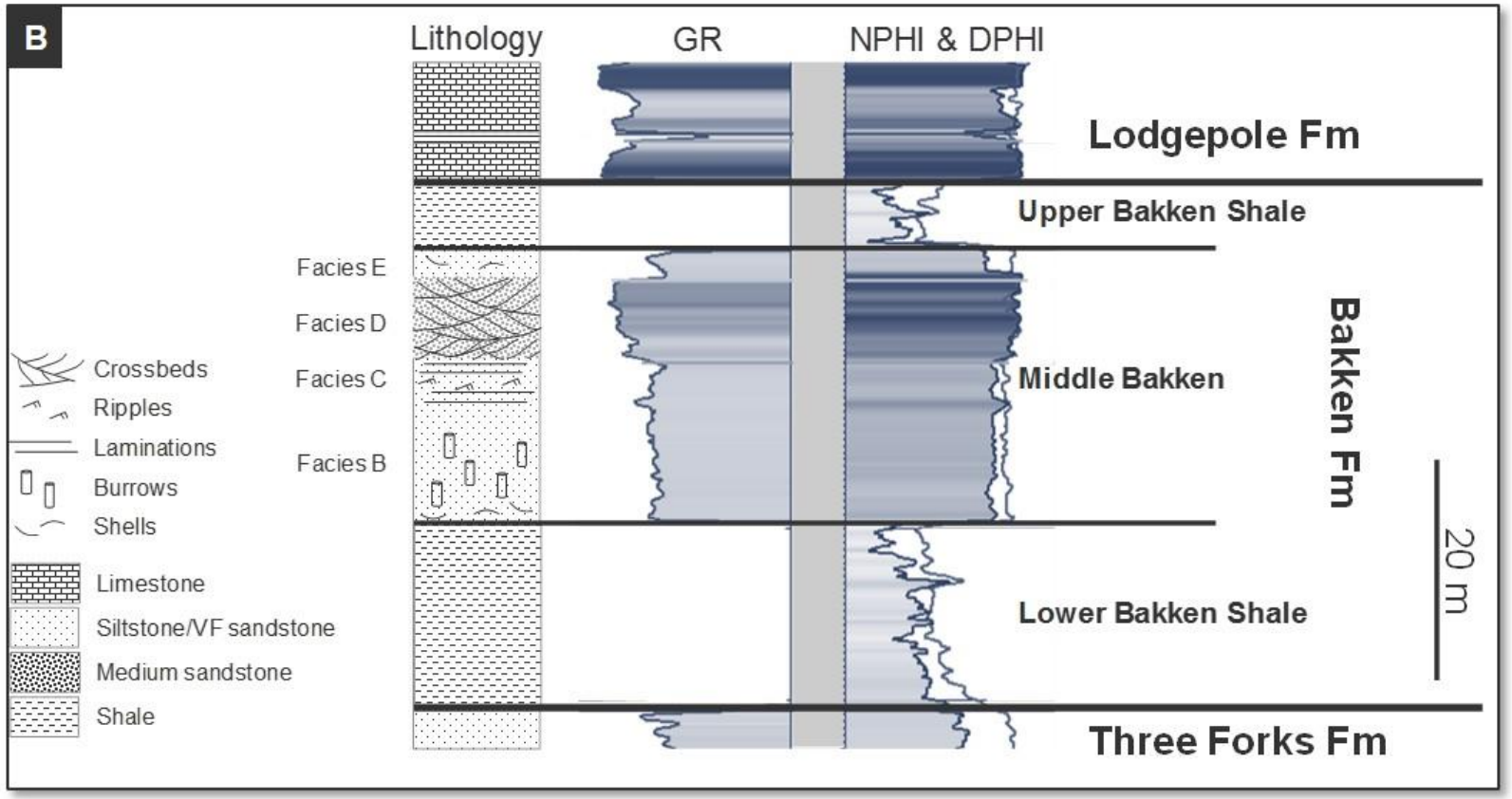
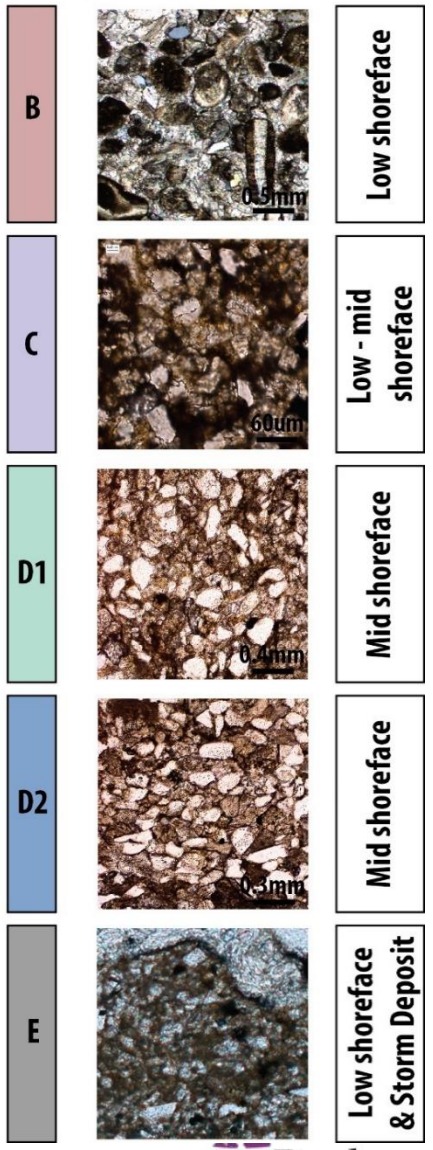
Bakken Formation







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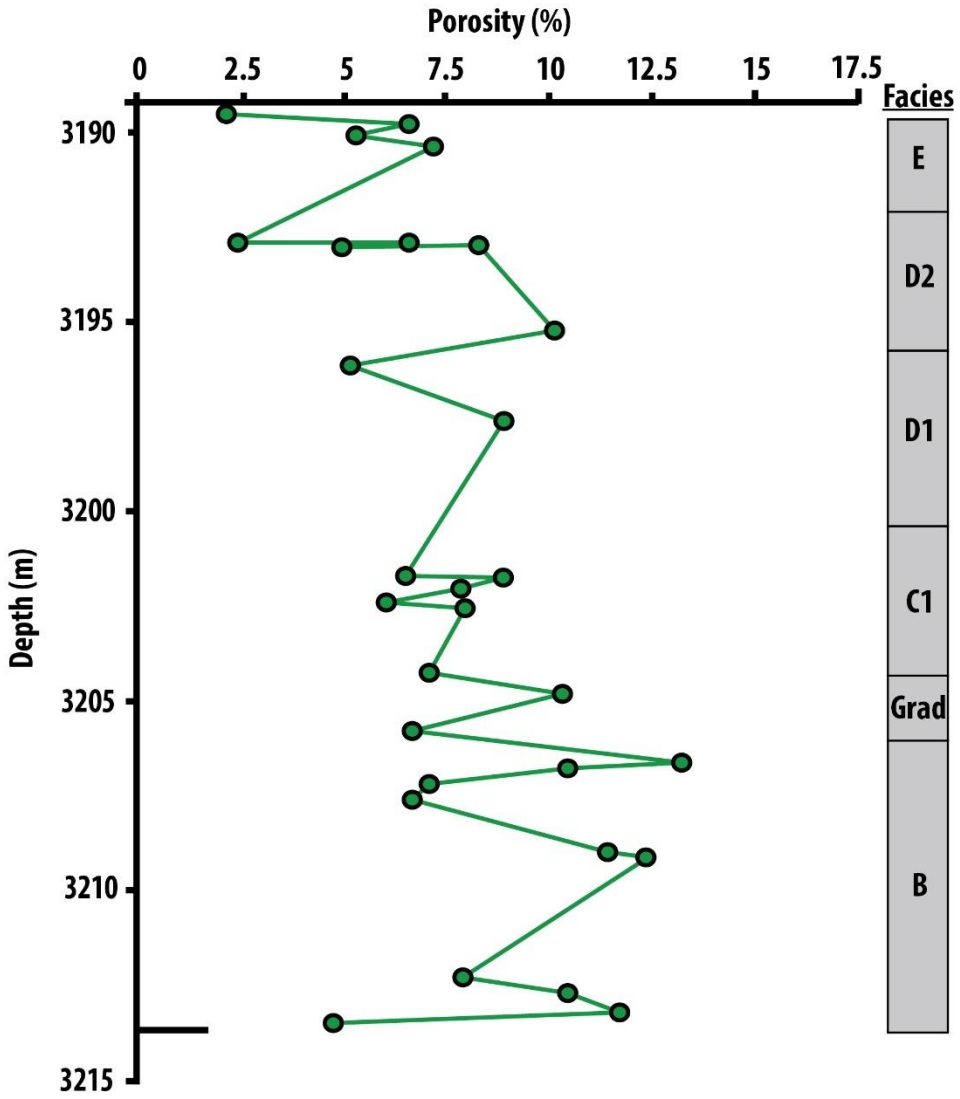
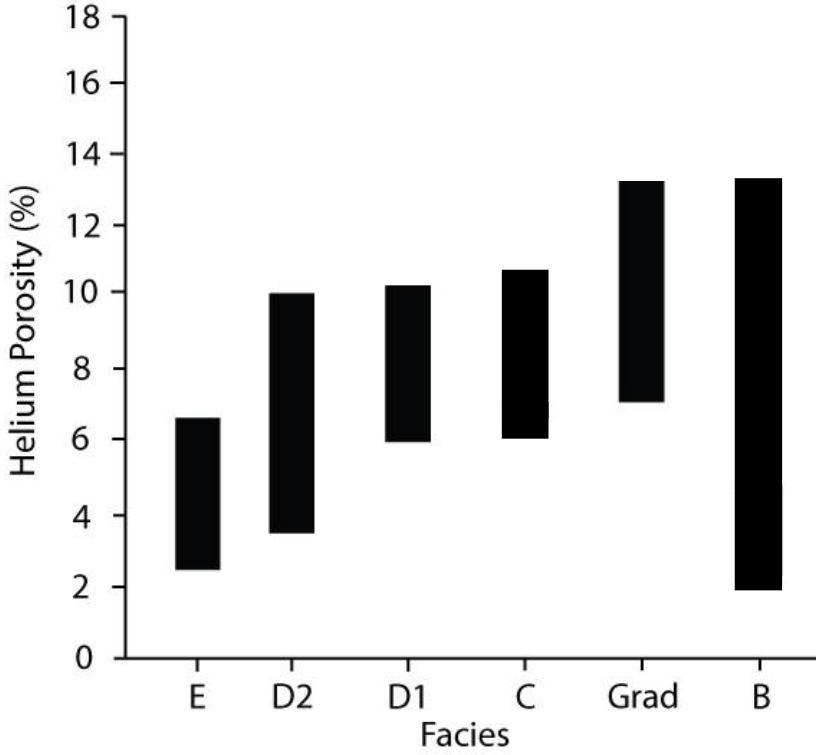
Middle Bakken: Porosity





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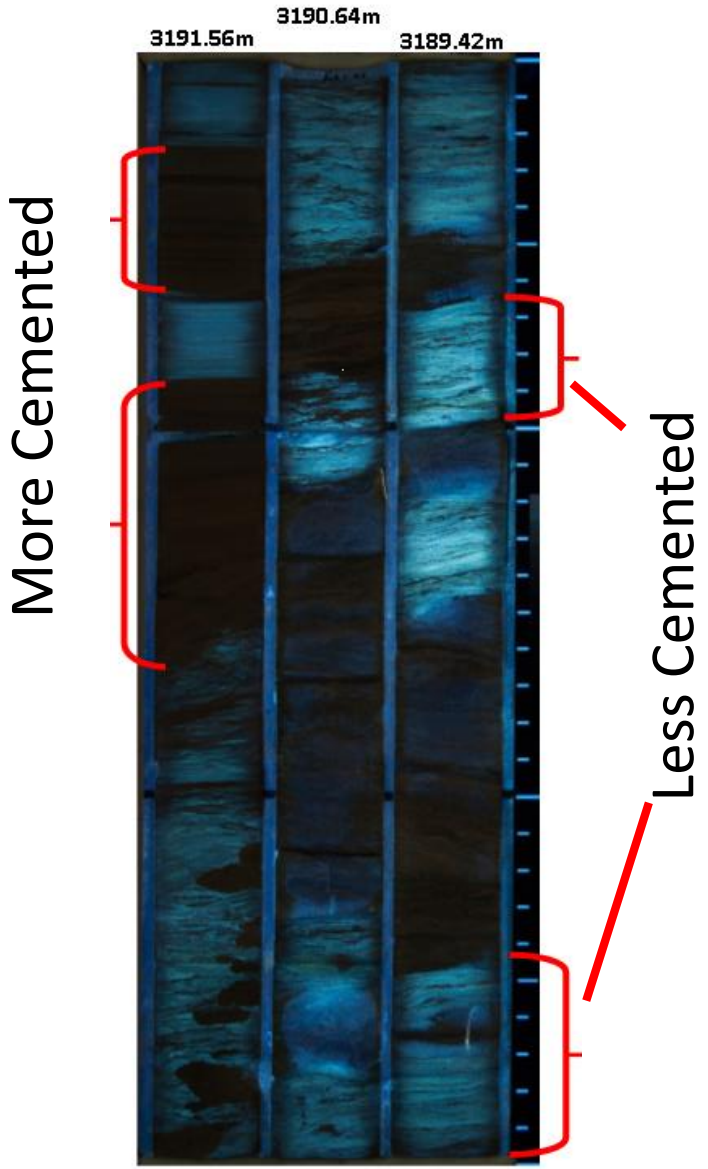
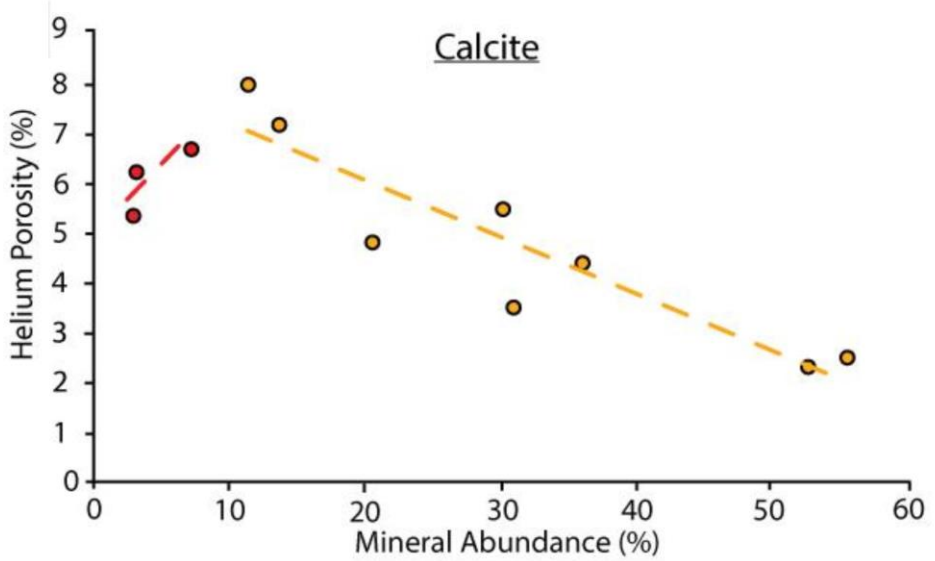
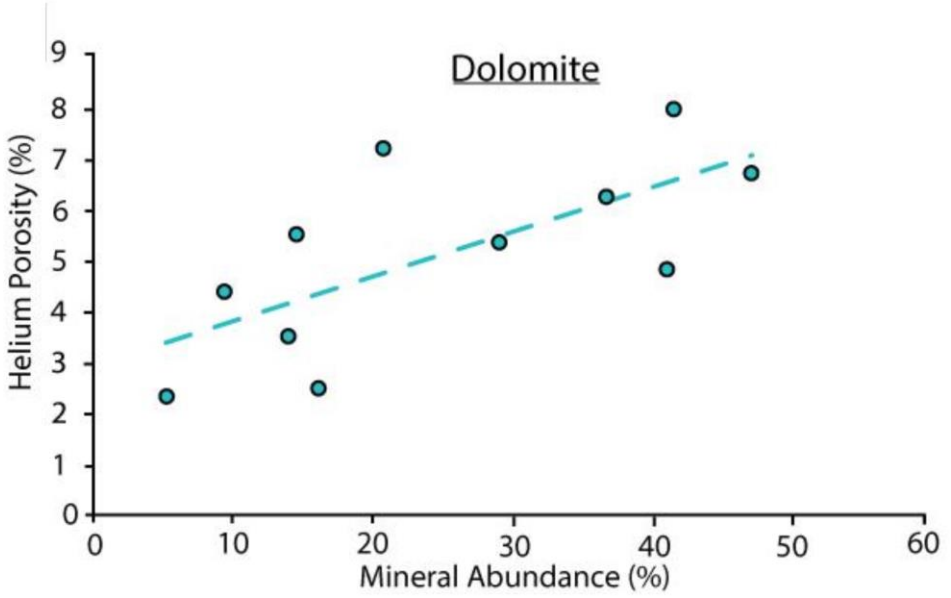
Calcite and Dolomite Define Bakken Reservoir Quality







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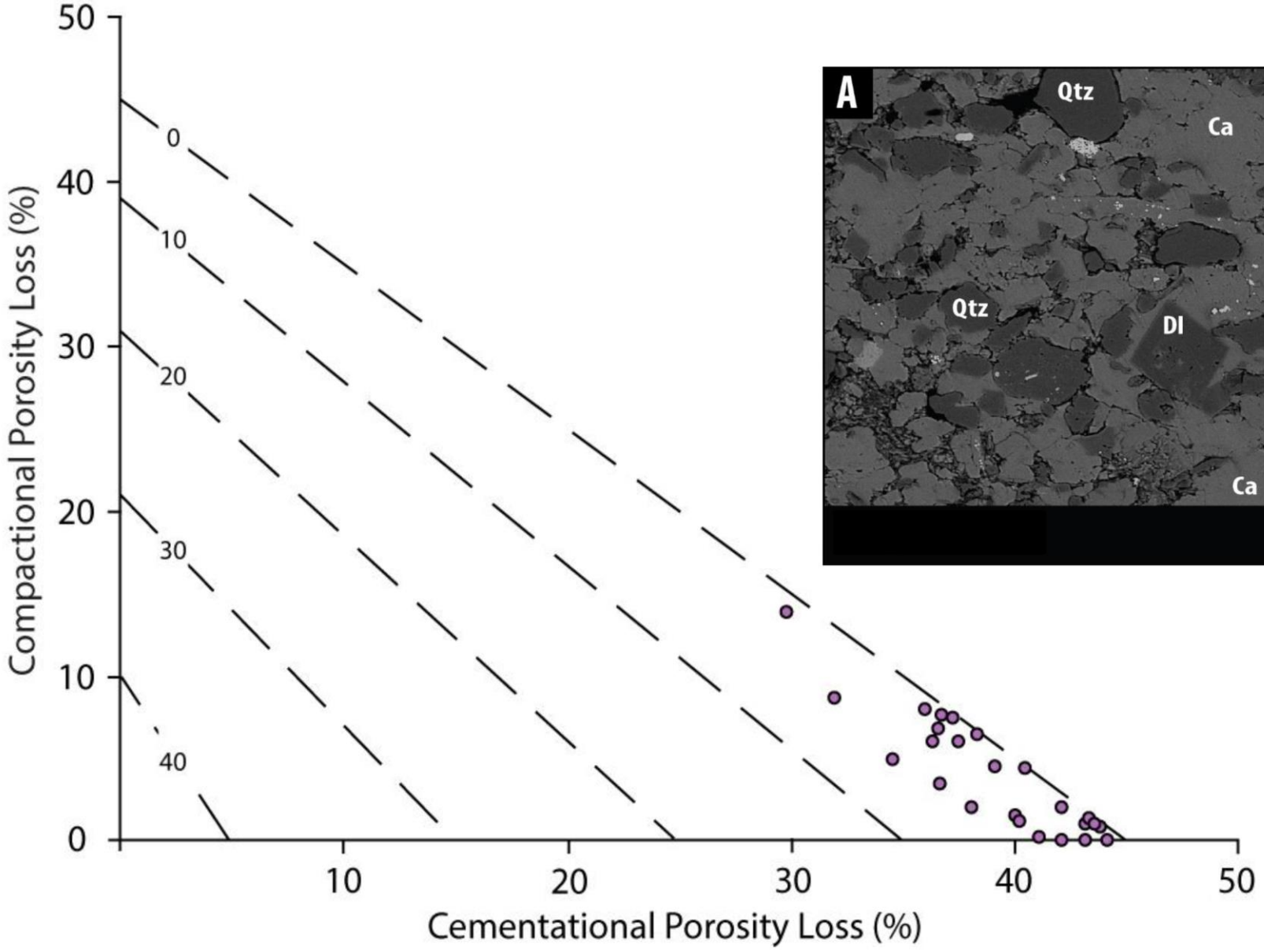
Calcite Cement is Early



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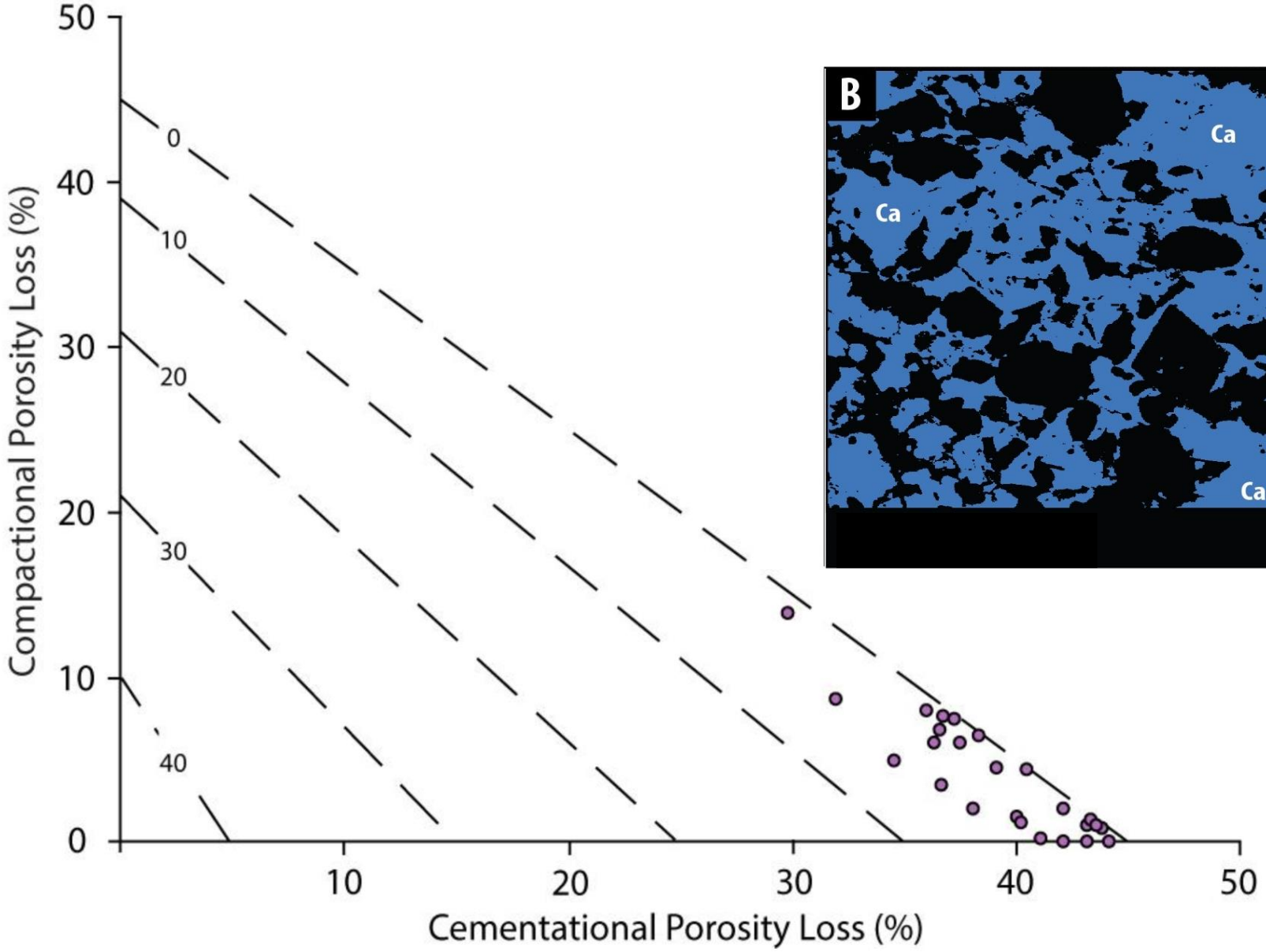
Early Calcite



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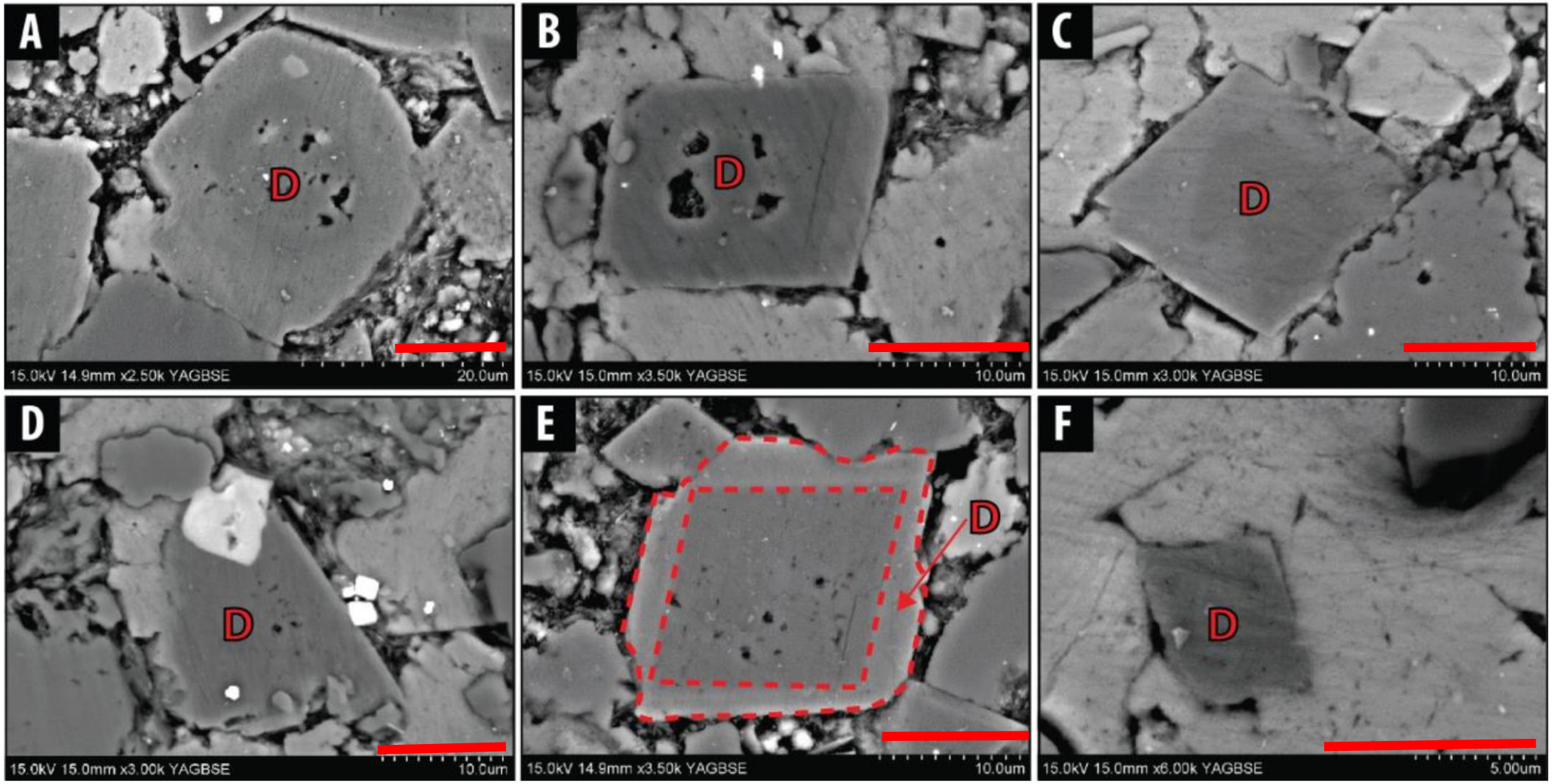
5 – 50 Micron Dolomite Crystals



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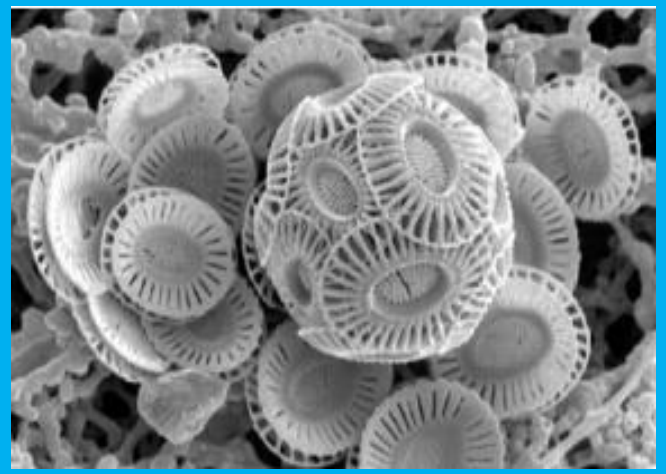
Oxygen Isotopes Preserve Information about Fluid and Temperature

$\delta^{18}O_{water}$ = 0‰



$\delta^{18}O_{mineral} \neq$ 0‰

$\delta^{18}O_{mineral}$ depends on:
$\delta^{18}O_{water}$
Temperature

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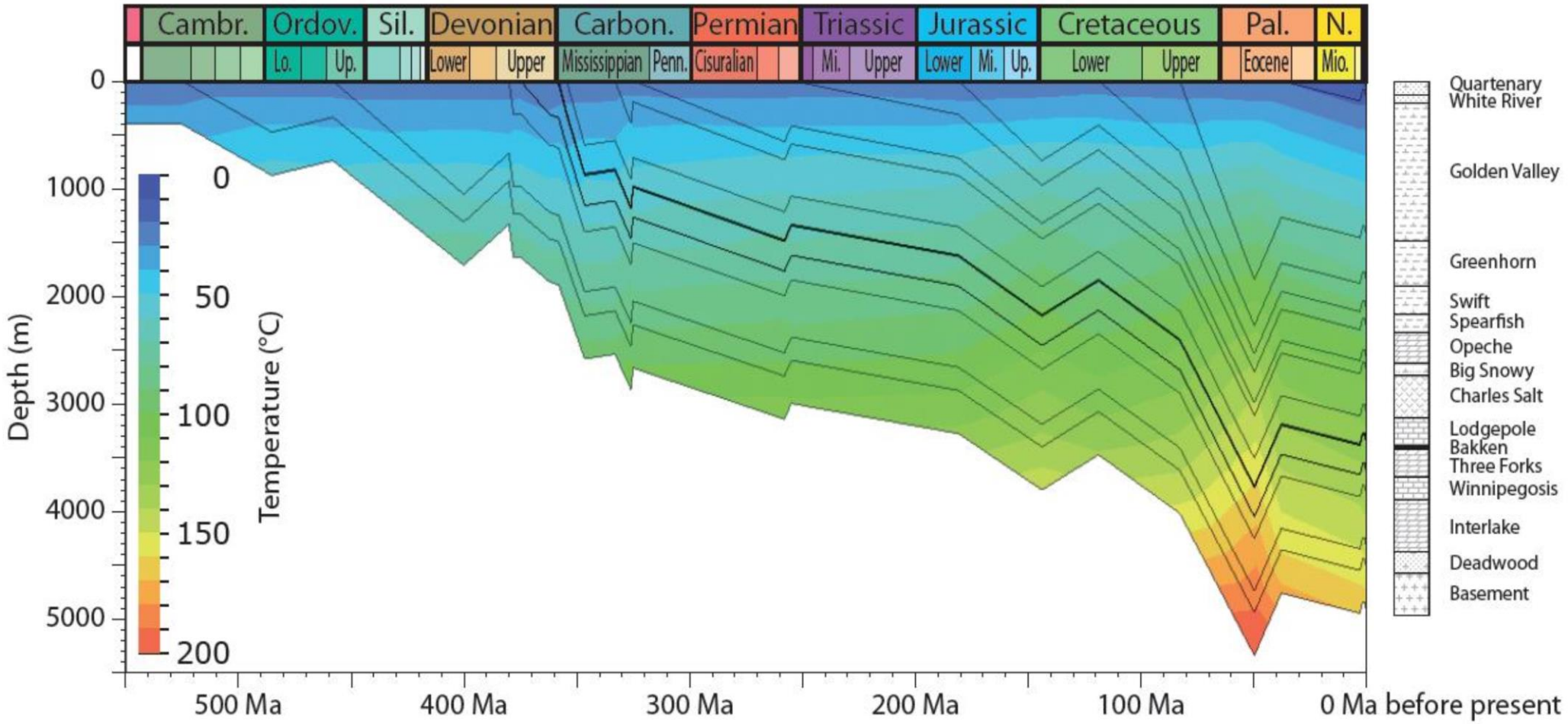
IF We Know $\delta^{18}O_{H2O}$:
We Know Precipitation Temperature(s) and Time(s)



Kuhn et al. (2012)

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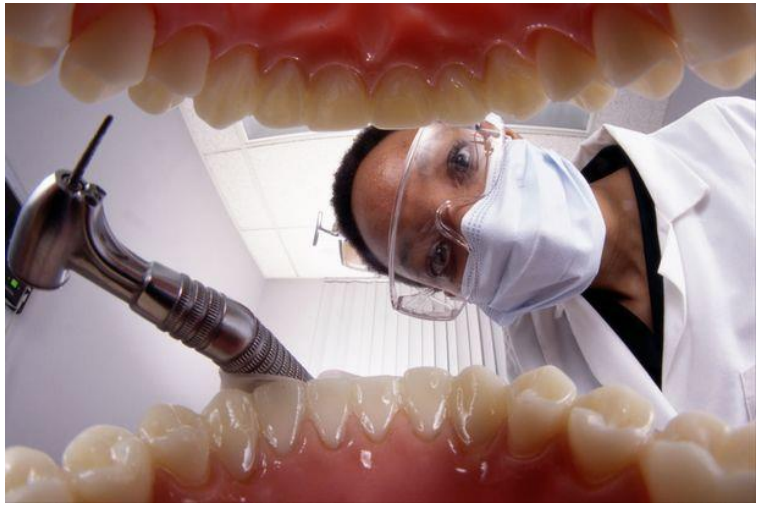
Conventional Analytical Techniques Analyse Mixed Phases

- Dental drill



- Selective leaching

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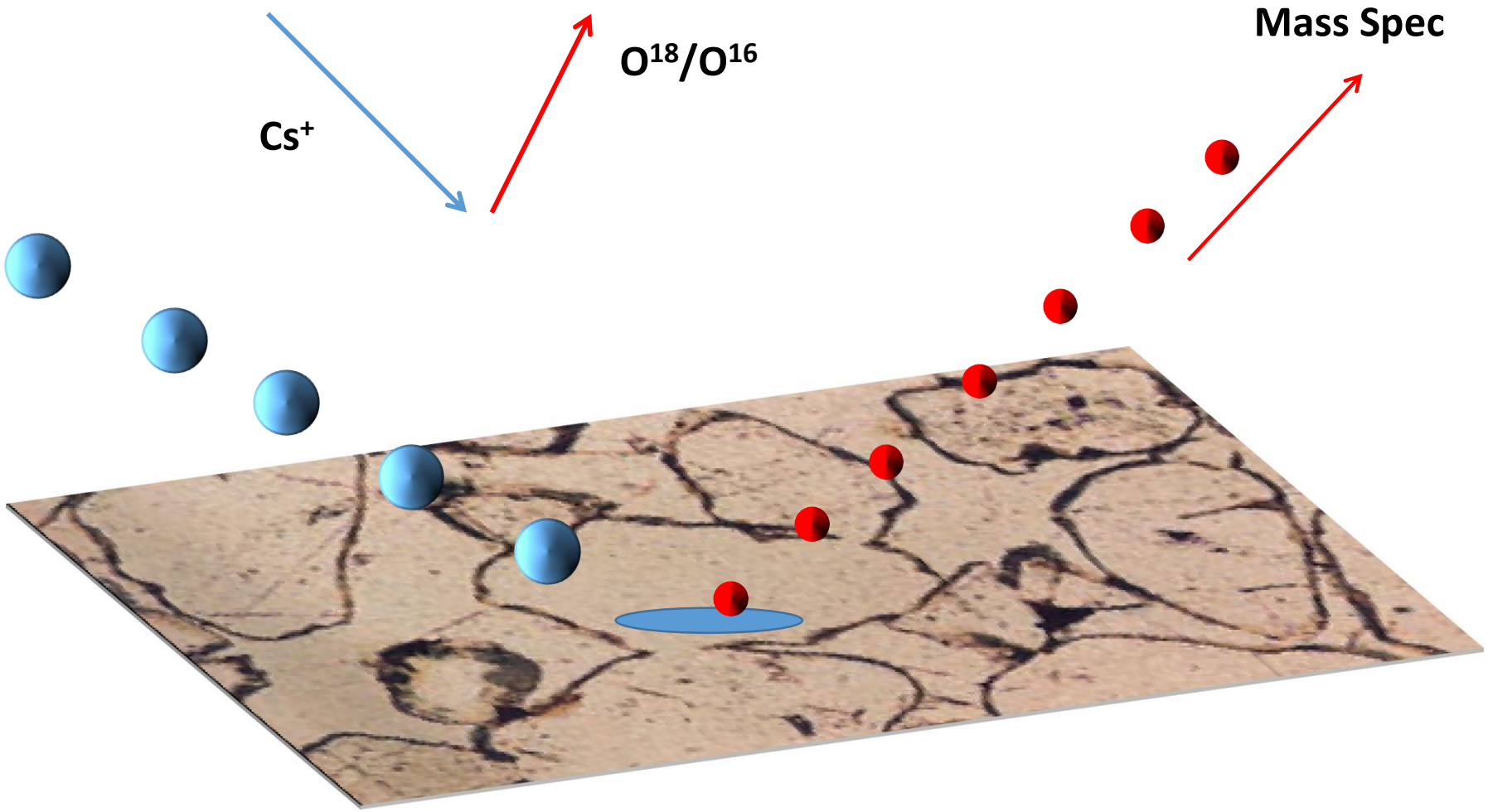
Determining $\delta^{18}O_{(Carbonate)}$

Secondary Ion Mass Spectroscopy



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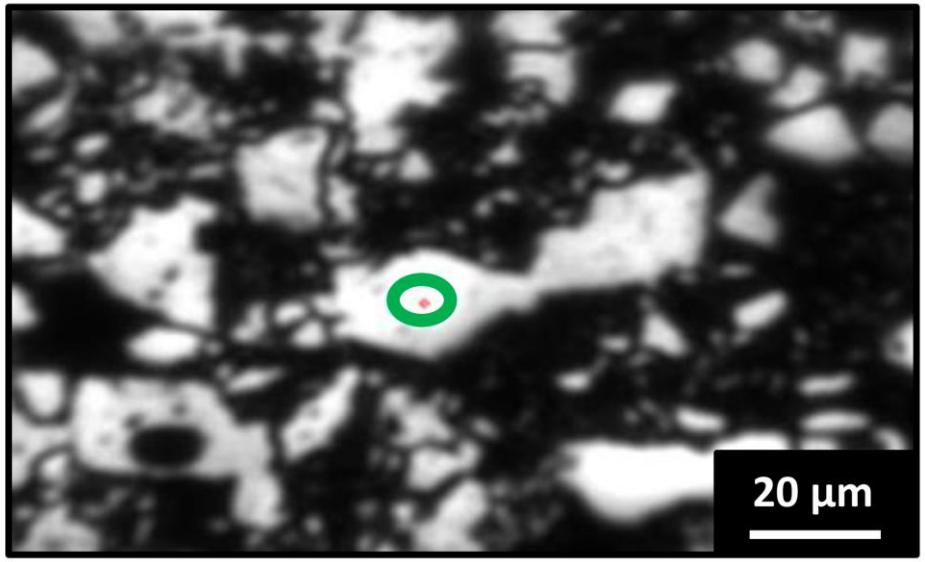
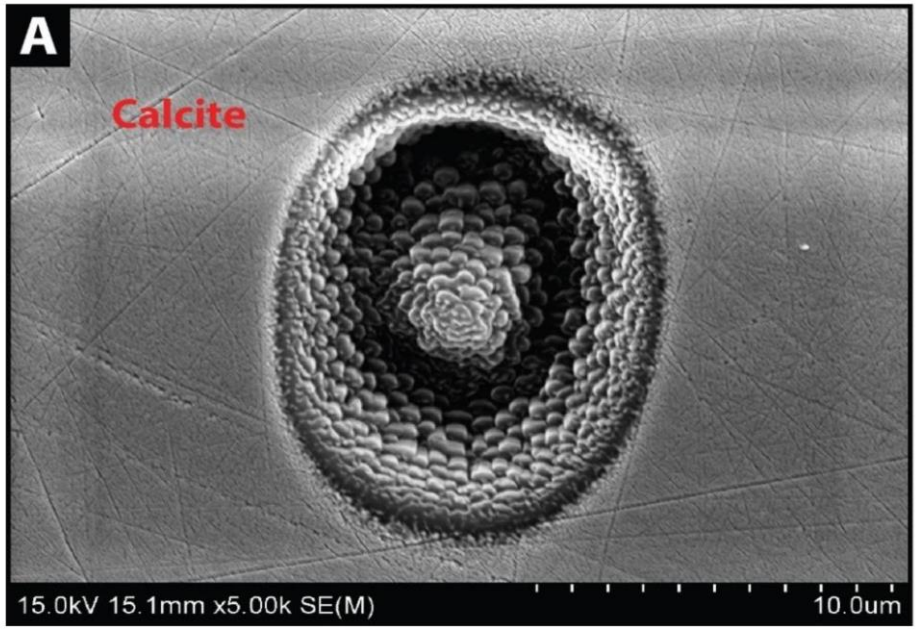
Example SIMS Pit





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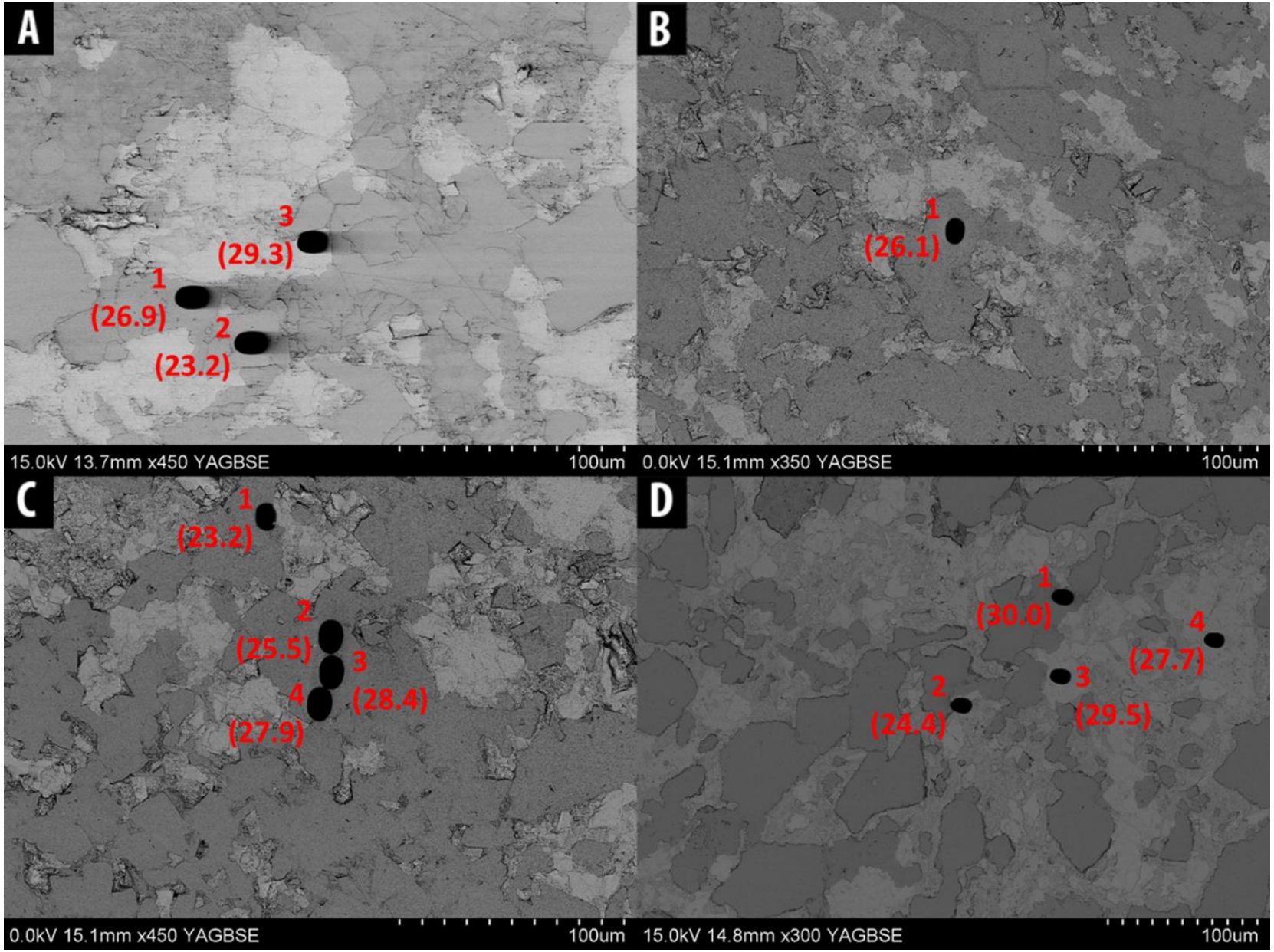
$\delta^{18}O$ of Calcite and Dolomite



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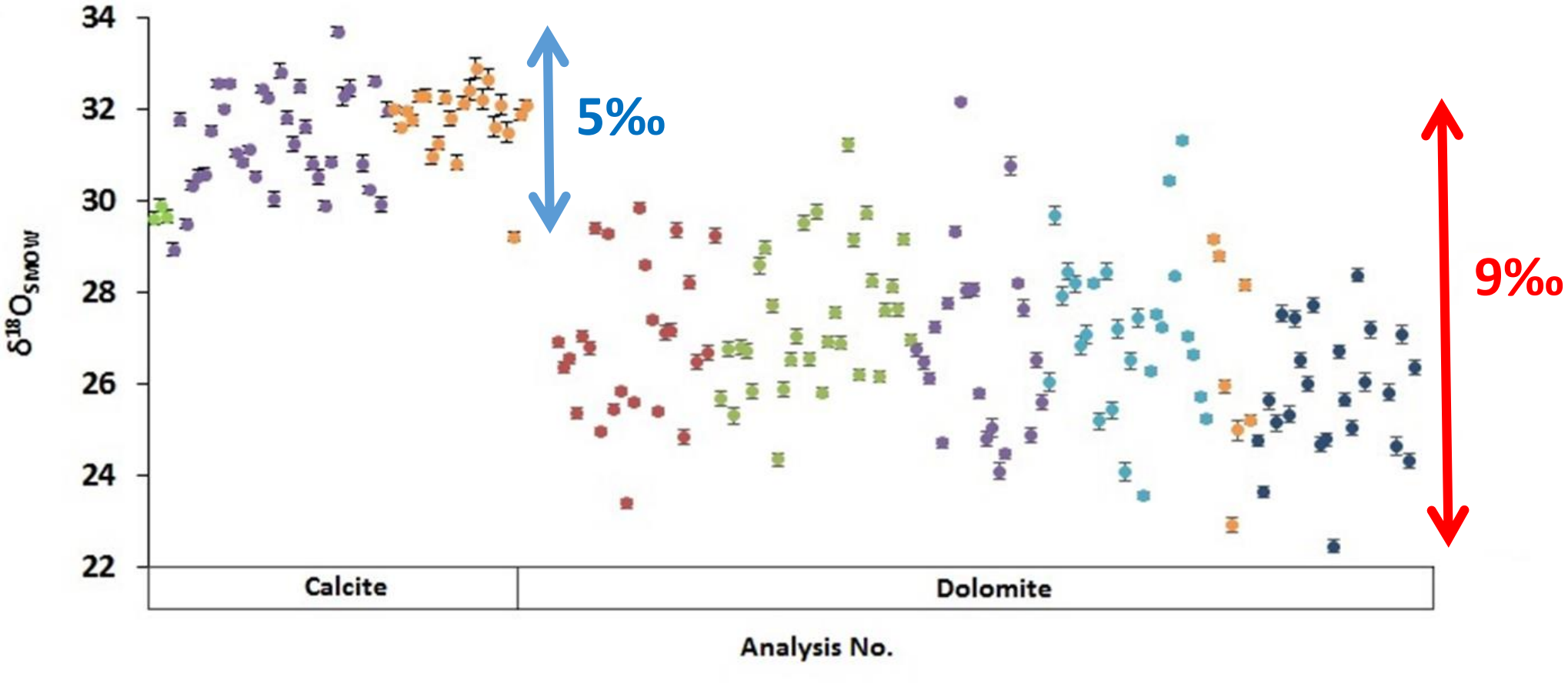
5 – 9 ‰ $\delta^{18}O$ Range Over 5 Millimetres



Colours represent sample/facies

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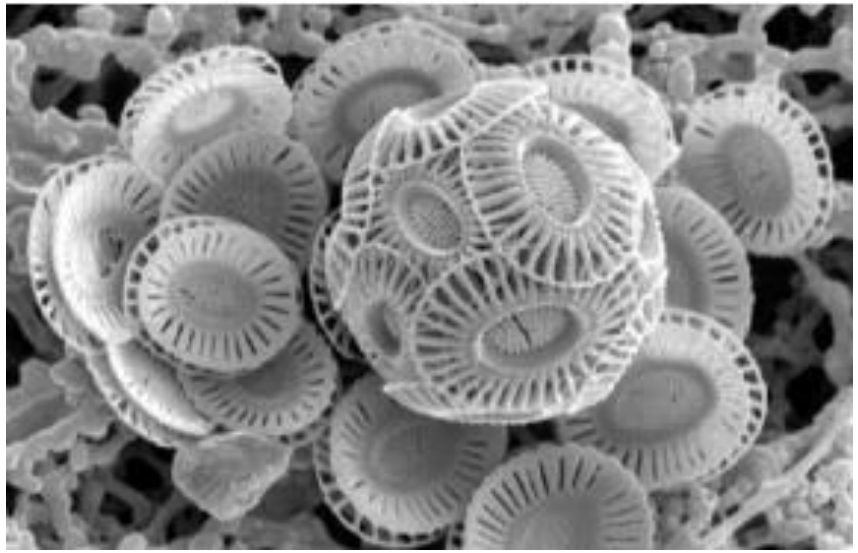
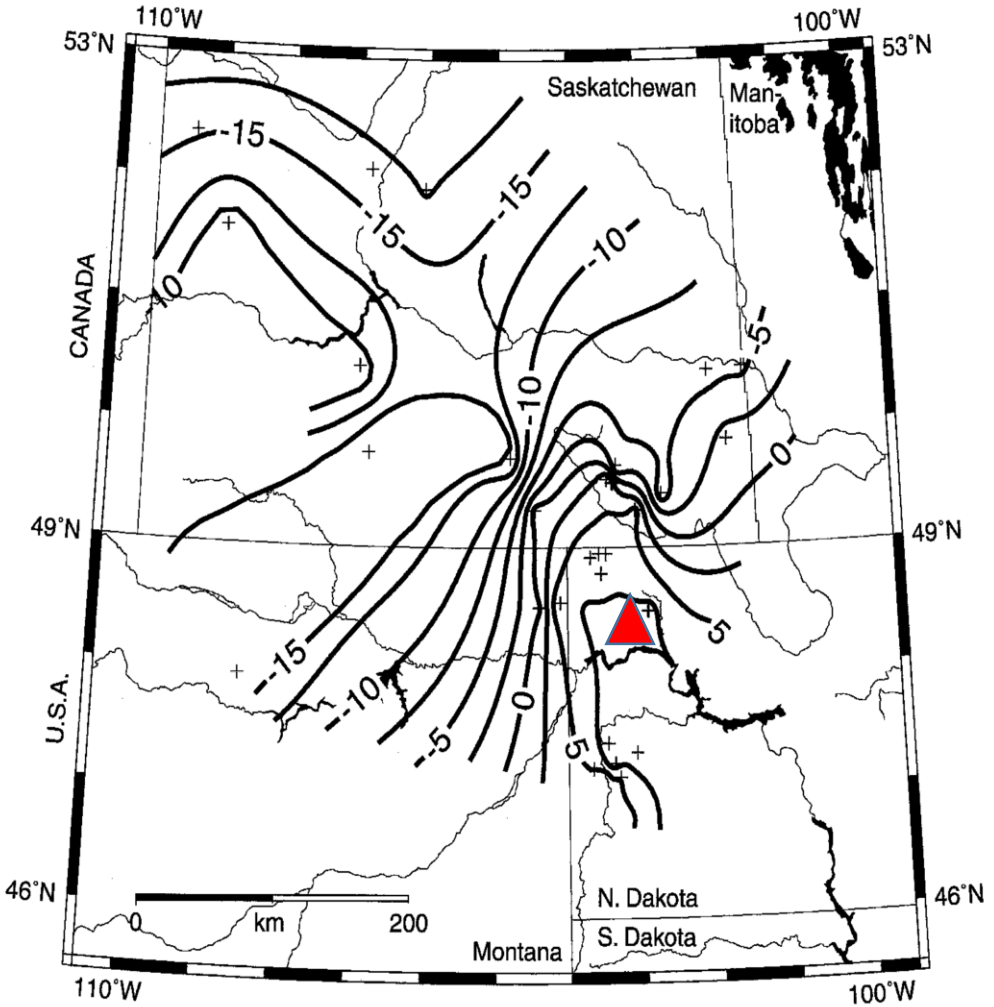
Precipitation Temperatures Require $\delta^{18}O_{H20}$

$\delta^{18}O_{mineral}$ depends on:

- $\delta^{18}O_{water}$
- Temperature



$\delta^{18}O$ of = -1.5‰ for Late Devonian seawater



Rostron & Holmden (2003)

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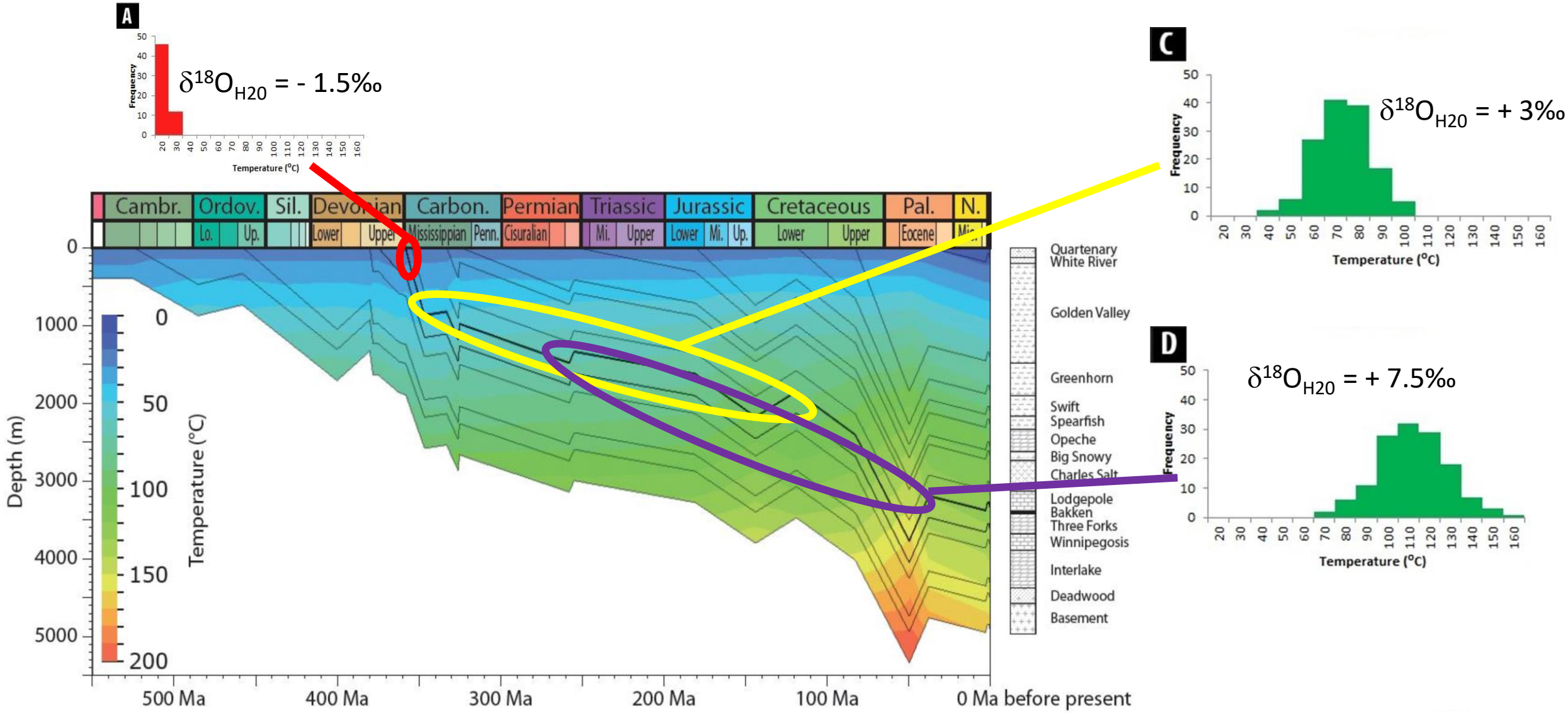
300 Ma Cementation and Dolomitization History



Kuhn et al. (2012)

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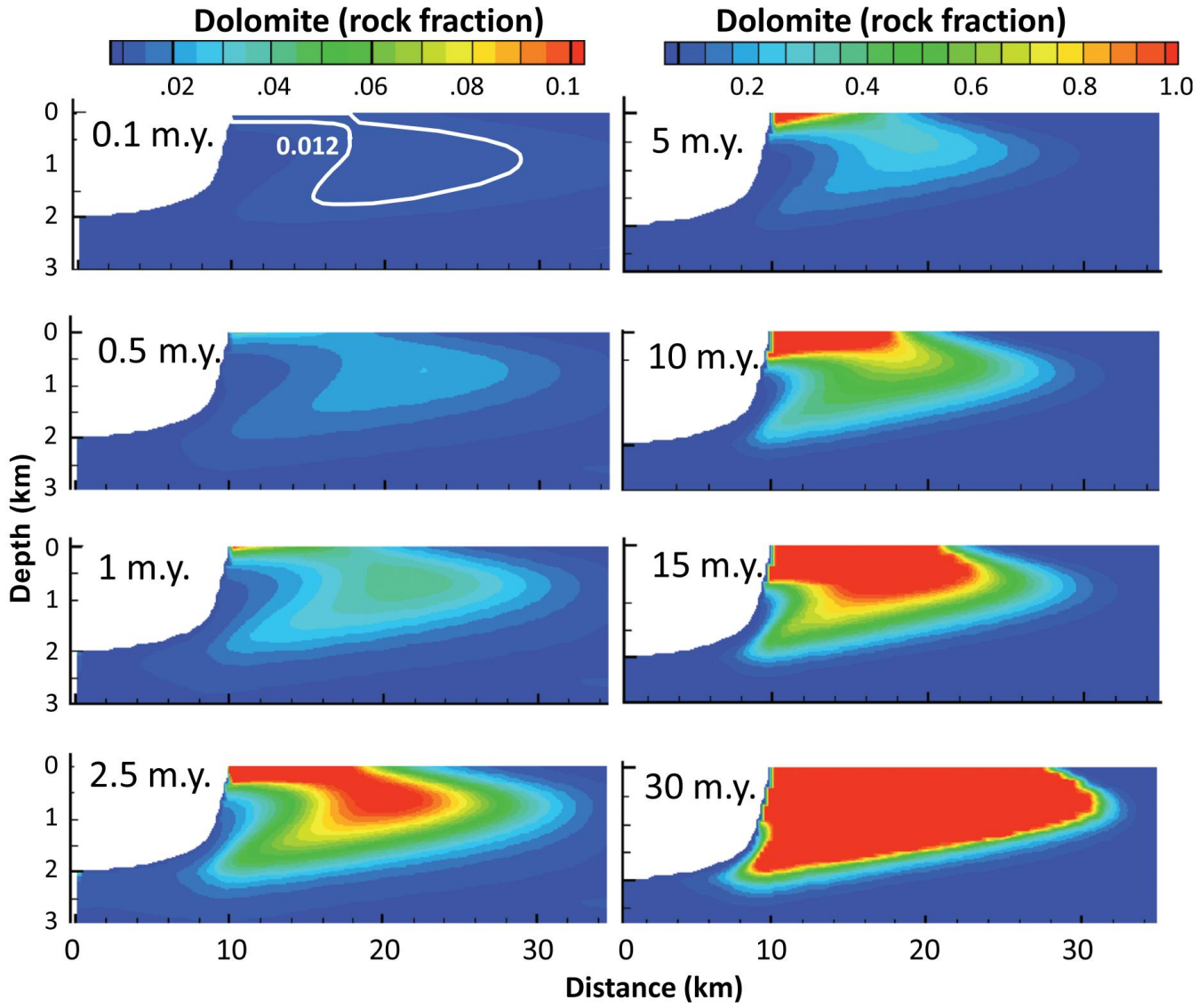
Kinetics: Dolomitization of Platform Carbonate by Geothermal Convection



Whitaker and Xiao (2010)

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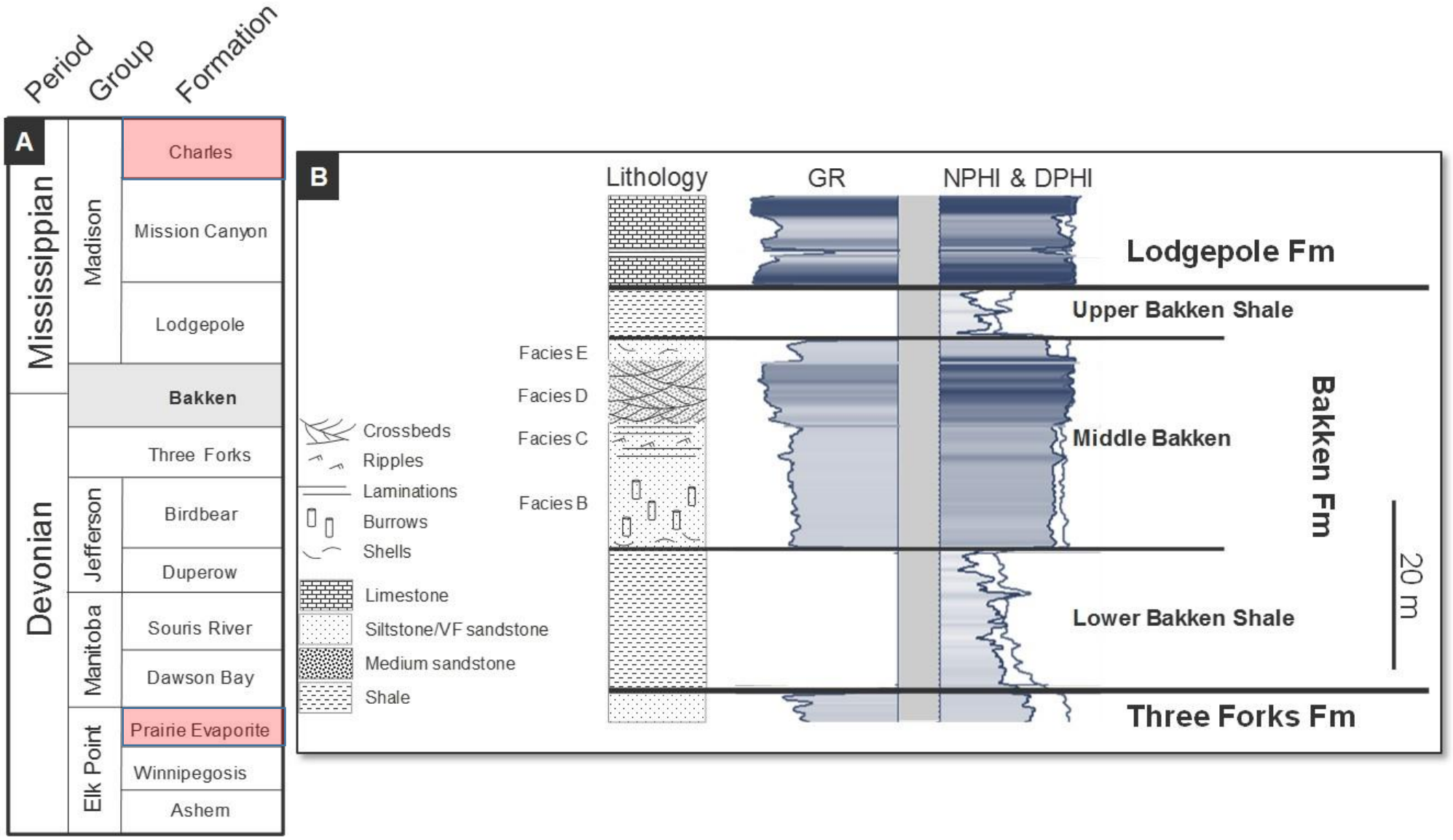
Dolomitising Fluids



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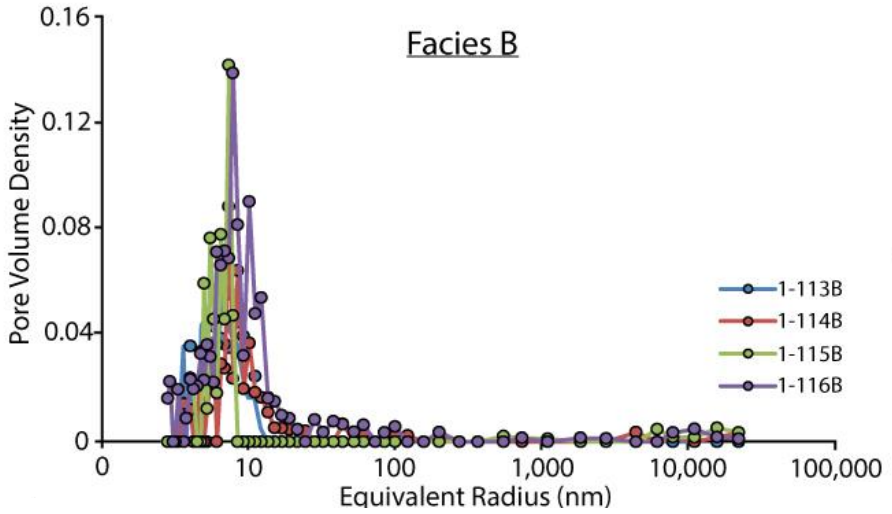
Cementation: Summary

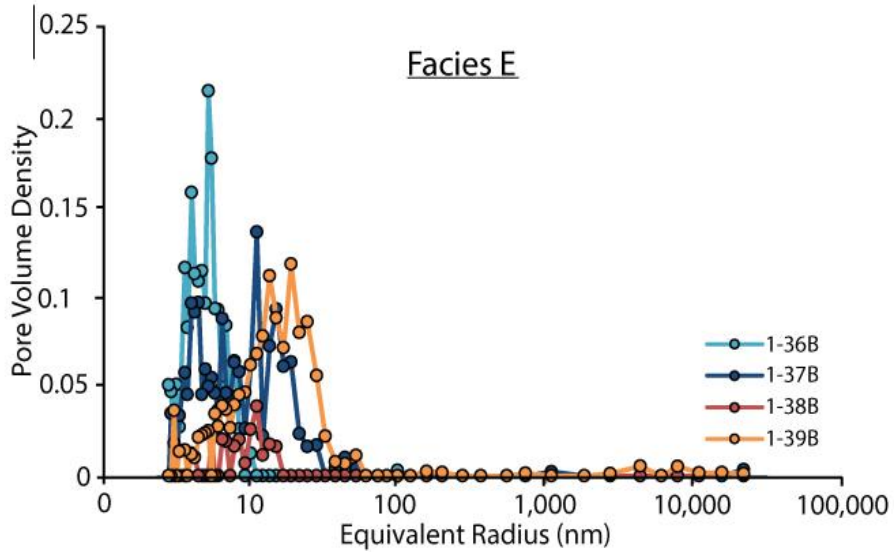
- Oxygen isotopic variations as great on millimetre scale as metre scale
- Many previous studies will have yielded smudged isotopic/diagenetic histories
- Dolomitisation: ultra-slow process in very sluggish flow systems /almost closed chemical systems

Petrophysical Implications

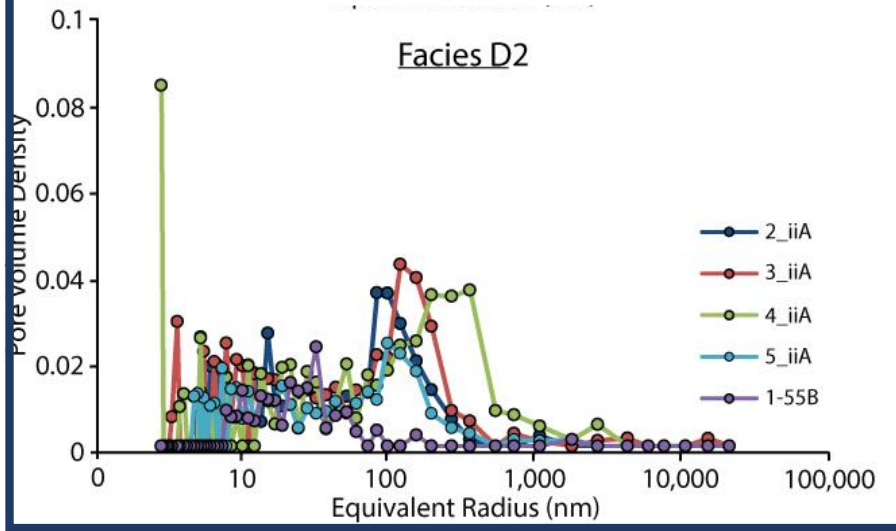
Pore Size and Estimated Permeabilities

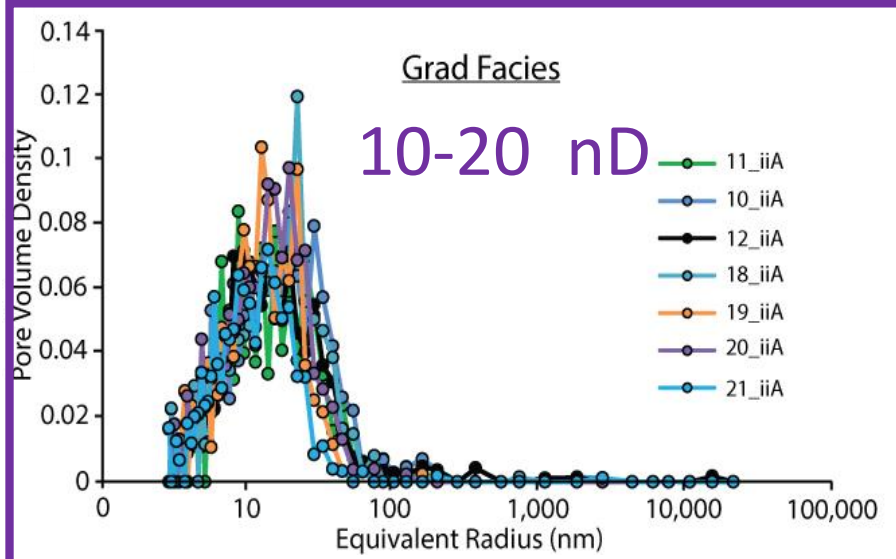
< 10 nD





x00 nD





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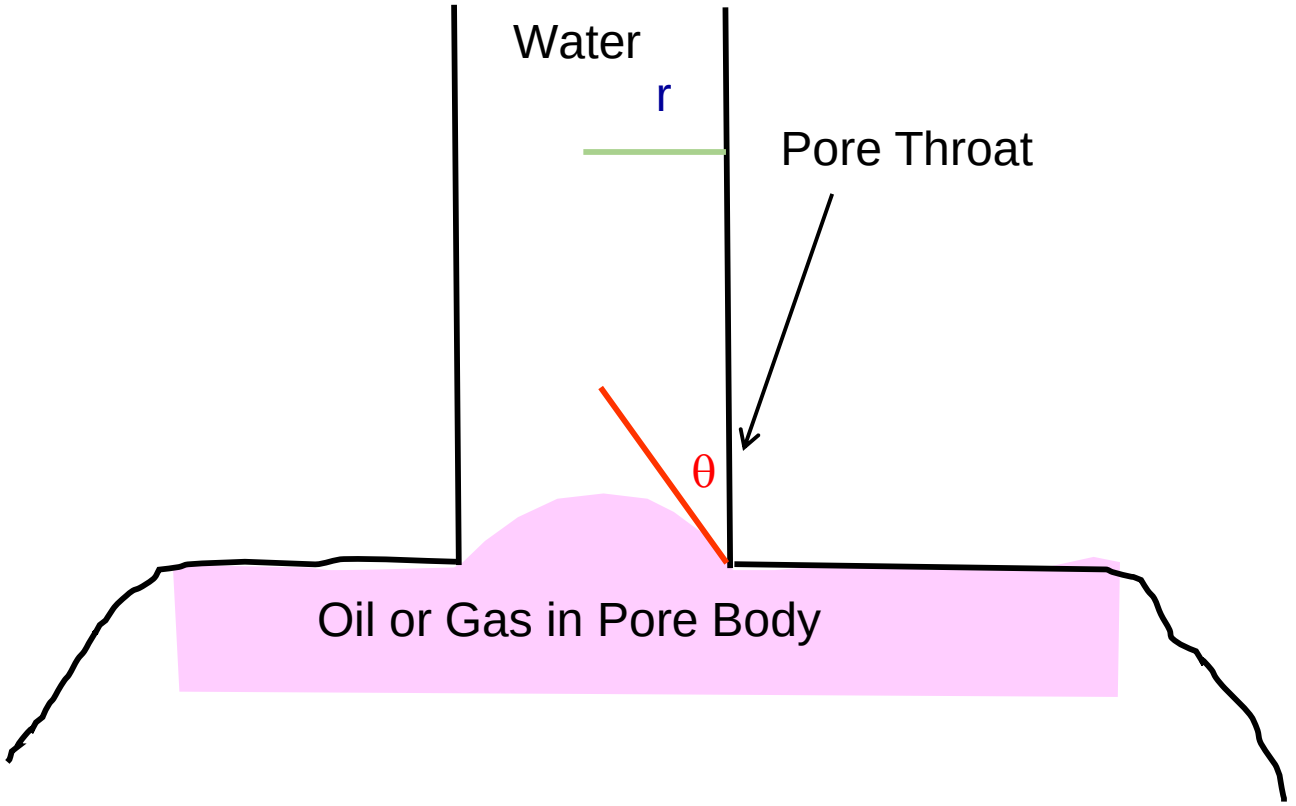
Displacement (Capillary Entry) Pressure

Capillary Entry Pressure =

$$CEP = P_d = \frac{2\sigma\cos\theta}{r}$$

σ = interfacial tension (N/m)
θ = contact angle between oil, water and solid
r = pore radius



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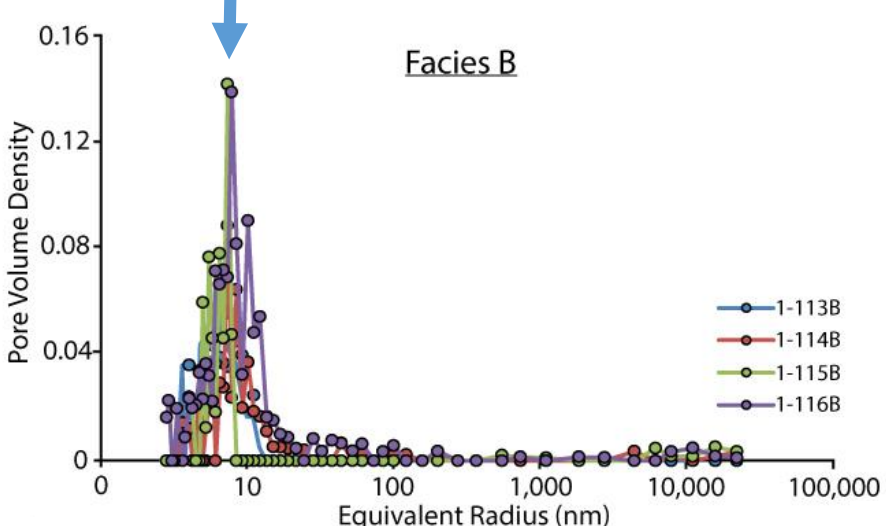
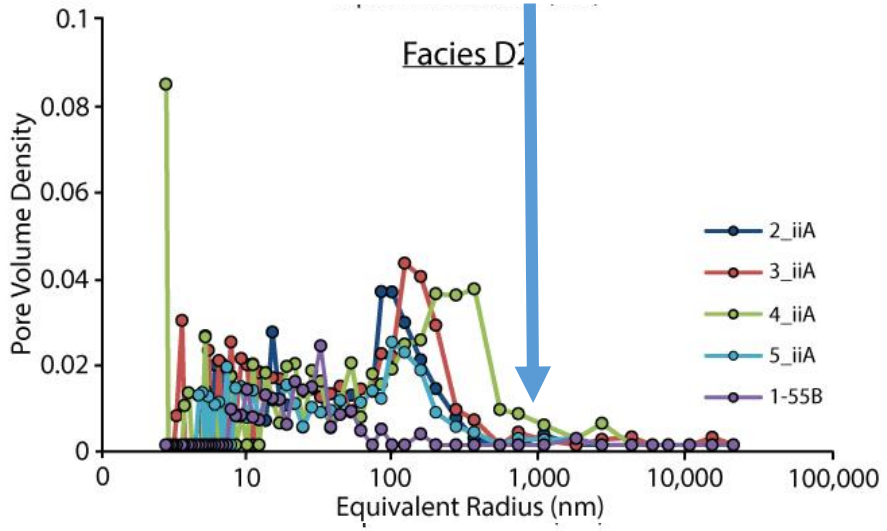
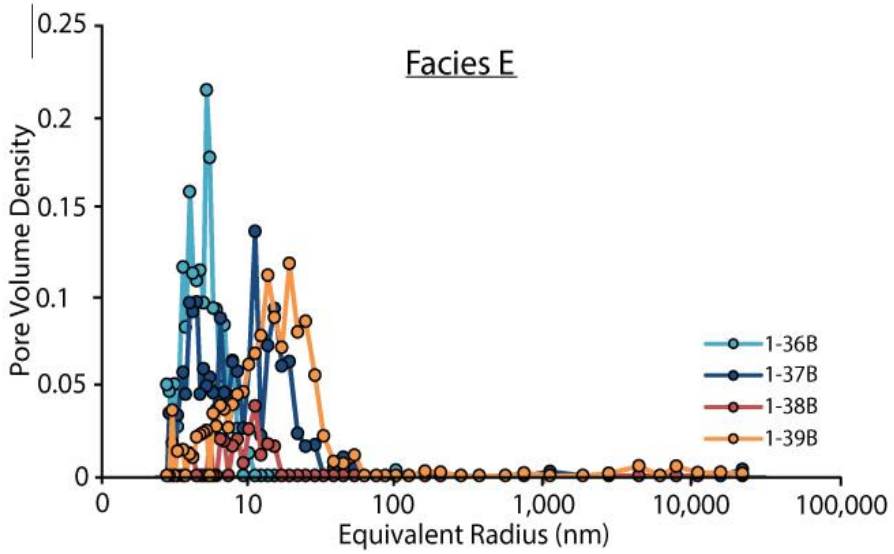
How Did The Middle Bakken Fill?

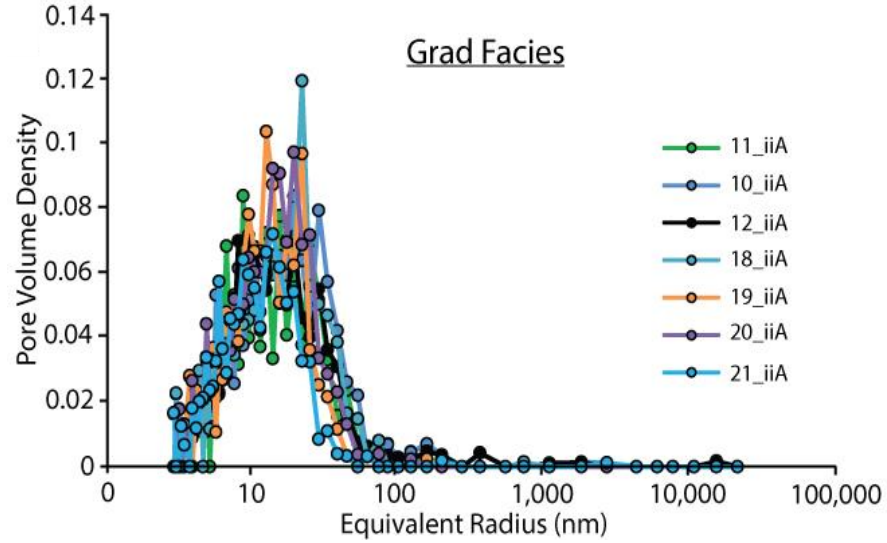
CEP = 7MPa = 2200m oil column

0.07MPa = 22m oil column









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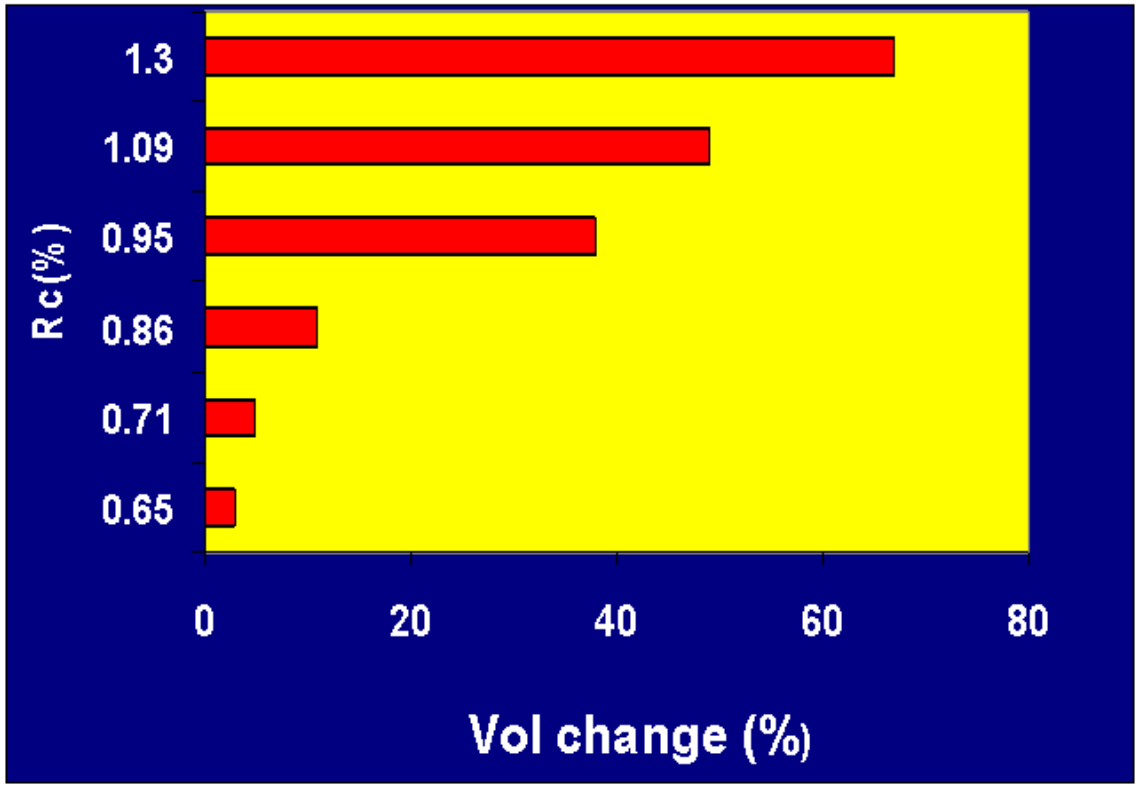
Petroleum Generation: Volume Change

Increasing

Maturity



Simplistic closed-system calculations, without compaction:
10-17 MPa increase in pressure to mid oil window
30-40 MPa in late oil window
50 MPa+ in early gas window

Okiongbo (2004)

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Wetting State: Oil and Water on Oil-wet Leaf

$$P_{cap} = \frac{2\sigma}{r}\cos\theta$$

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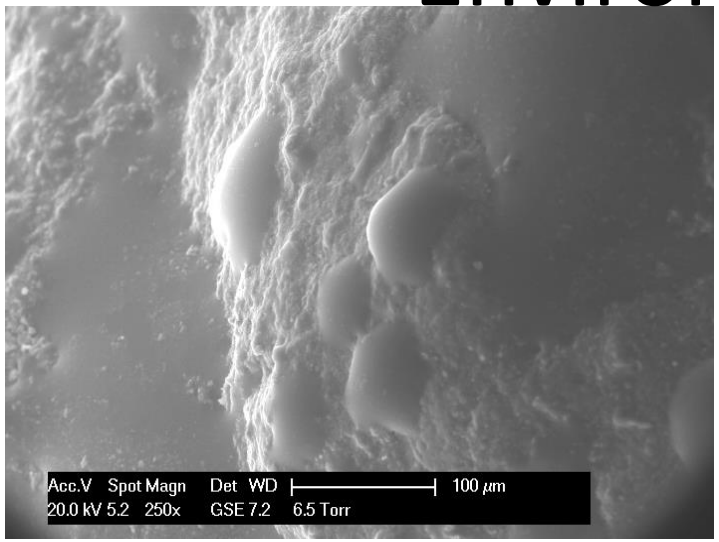
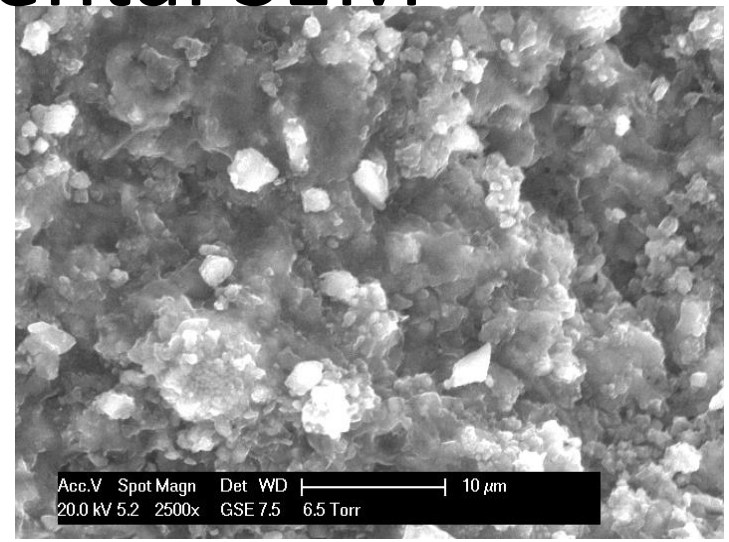
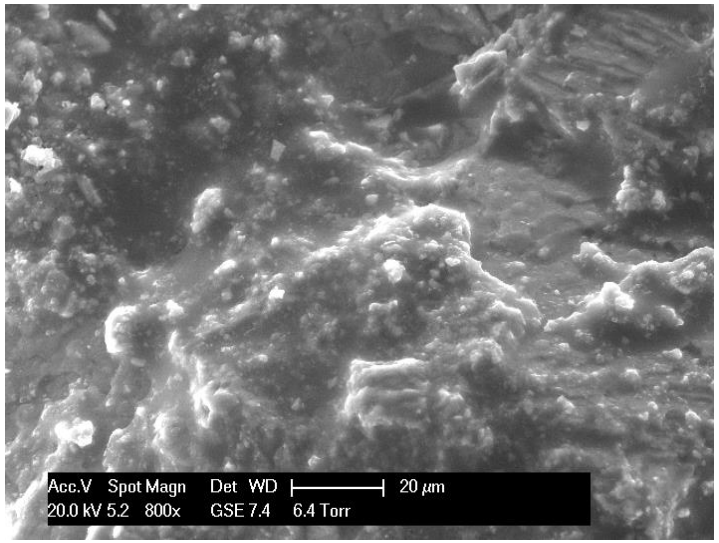
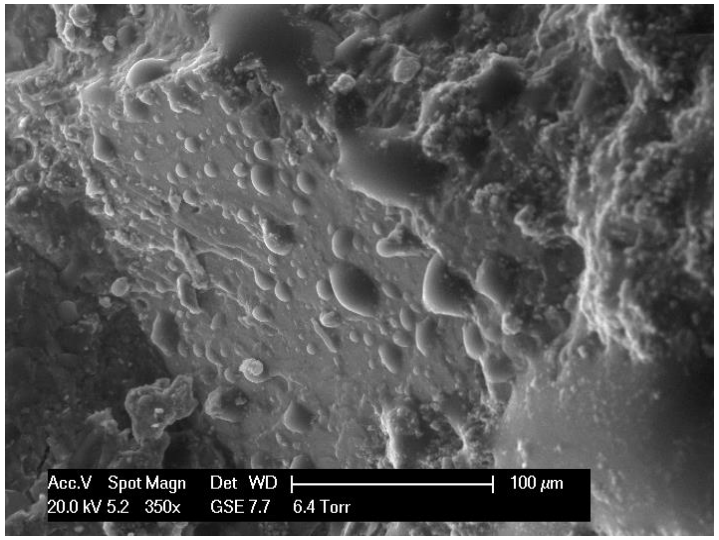
Wetting State of Tight Oil Carbonate: Environmental SEM









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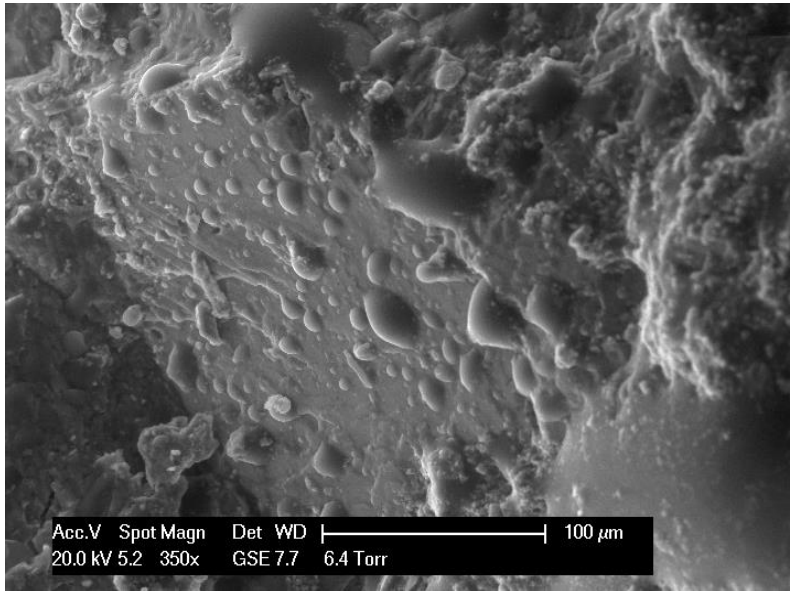
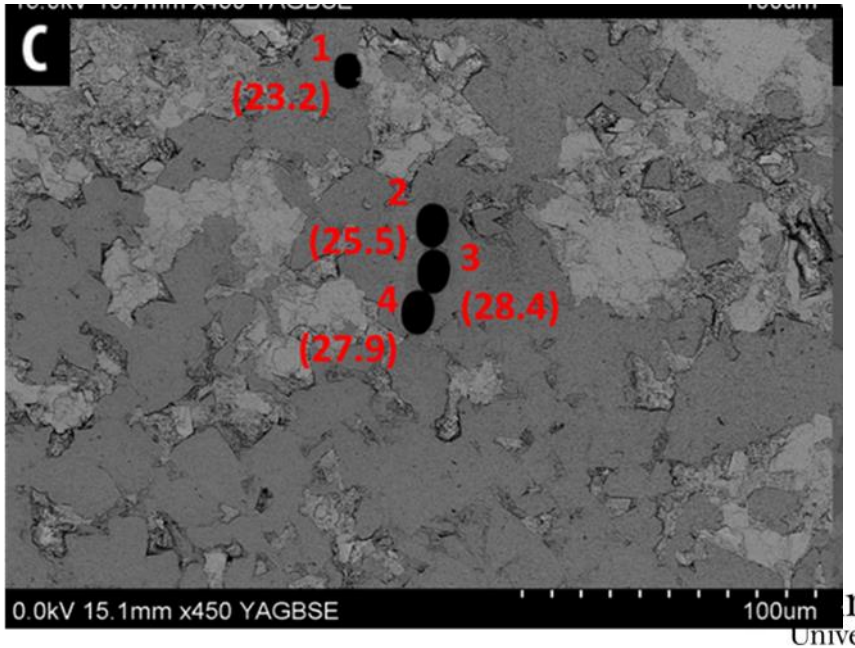
Comments & Questions?





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