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Geological Survey of Canada
Scientific Presentation 145

Diagenetic fluid flow and hydrocarbon migration in the Montney Formation, British Columbia: fluid inclusion and stable isotope evidence

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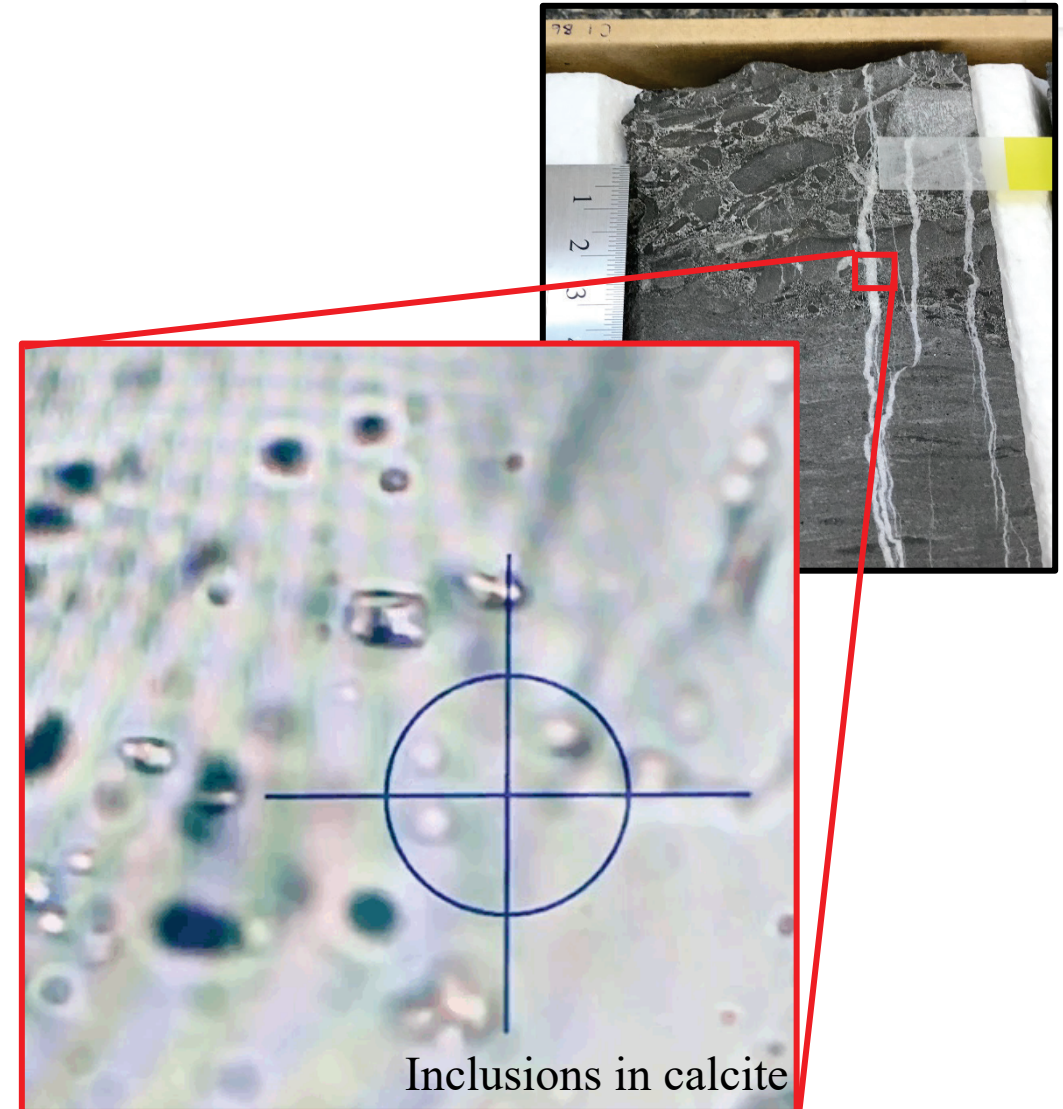
Traditional Territorial Acknowledgement

I acknowledge that I am working on the traditional territories of the people of the Treaty 7 region in Southern Alberta. These are the Tsuut'ina First Nation, the Stoney Nakoda First Nation (including people of the Chiniki, Bearpaw, and Wesley), and the Blackfoot Confederacy (which includes people of the Siksika, Kainai, and Piikani). This region is also home to Métis Nation of Alberta, Region III.



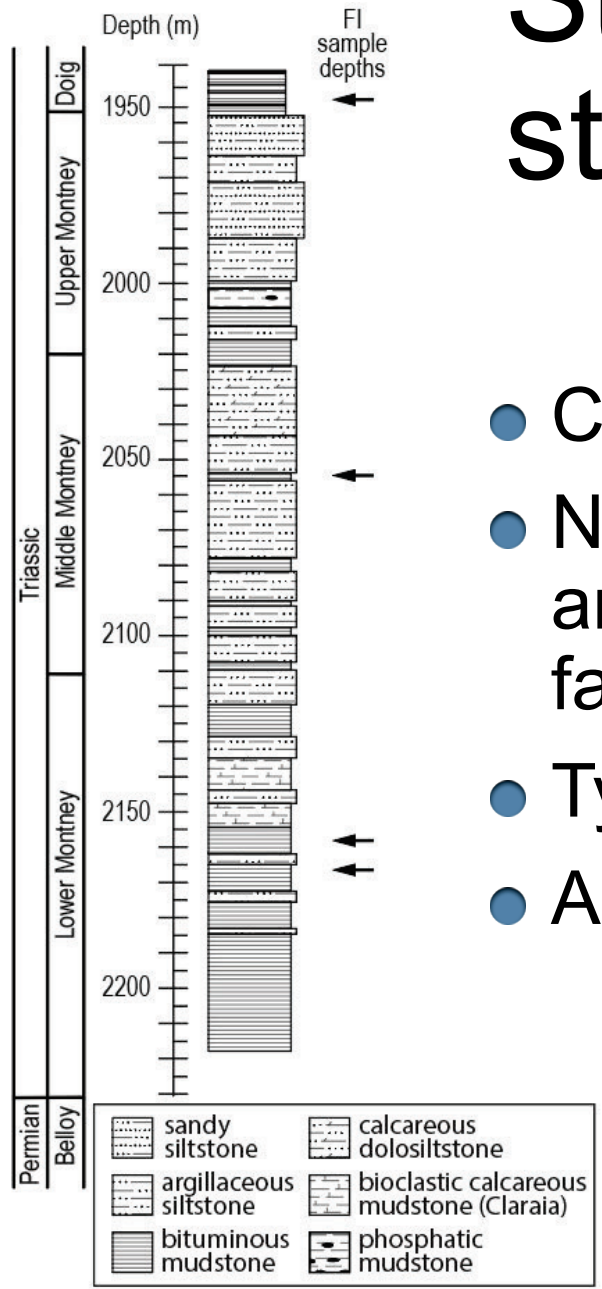
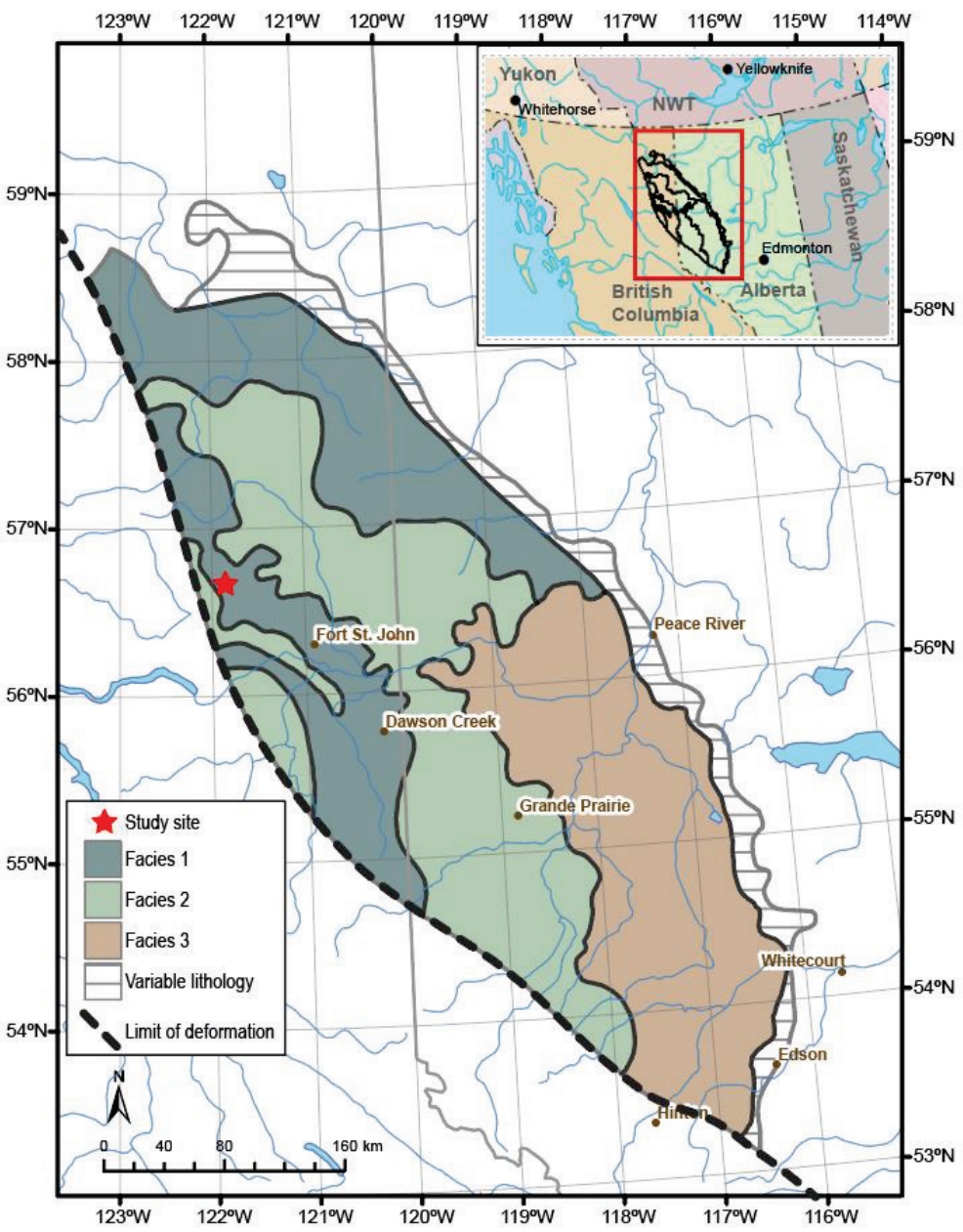
Project objectives

- Pressure-temperature conditions at the time of fracture formation
 - Implications for the timing of entrapment
- Isotope composition of fracture fill
 - Implications for fluid source
- Characteristics of the system during fracture formation
 - Pressure-temperature: open vs. closed system
 - Hydrocarbon migration/maturation history



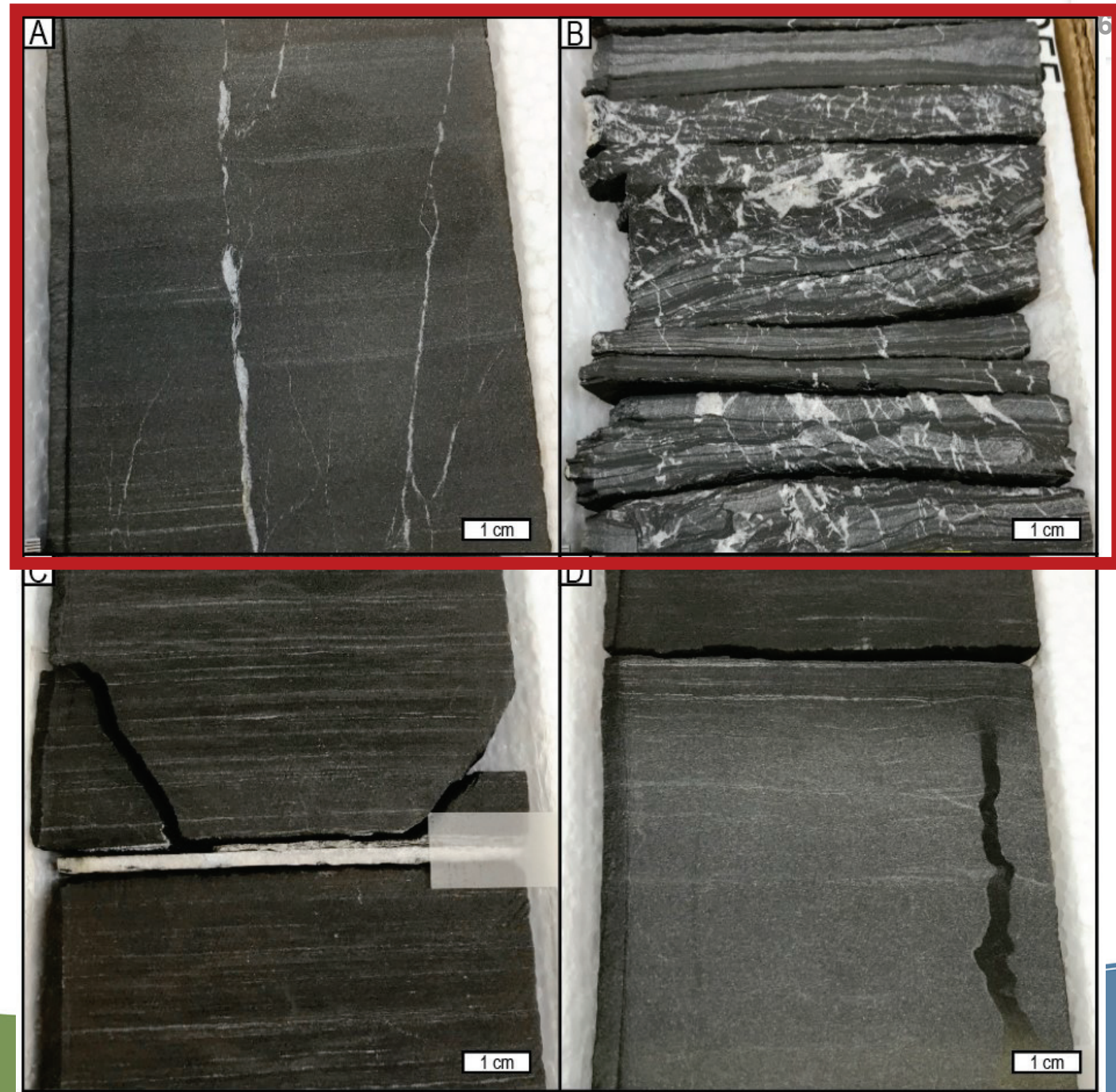
Study site and stratigraphy

- Close to full Montney core
- Near deformation front and several regional scale faults
- Typical Montney lithology
- Abundant fractures

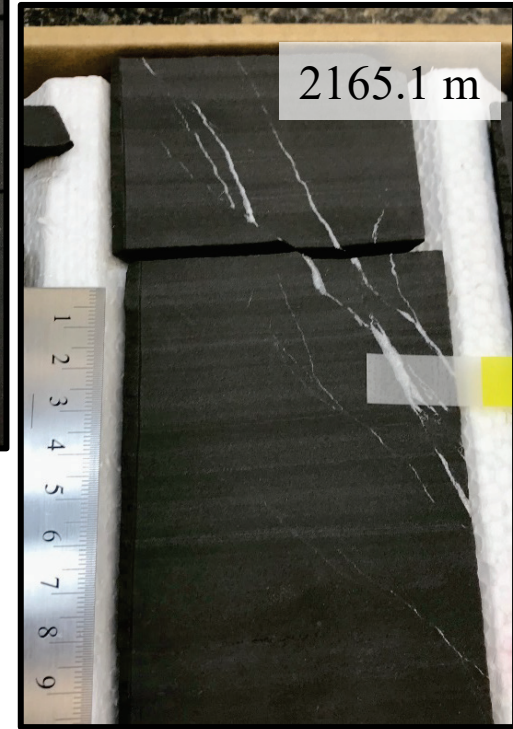
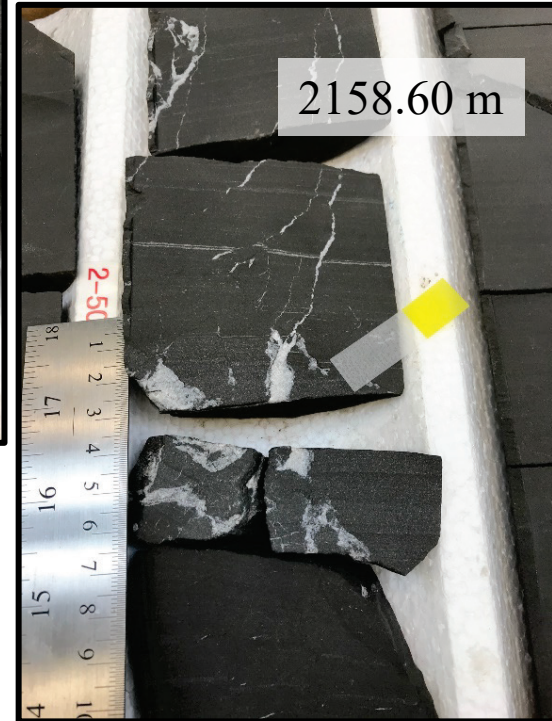
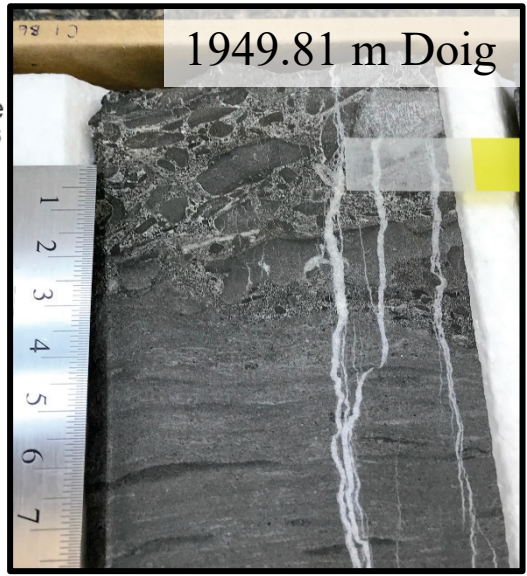
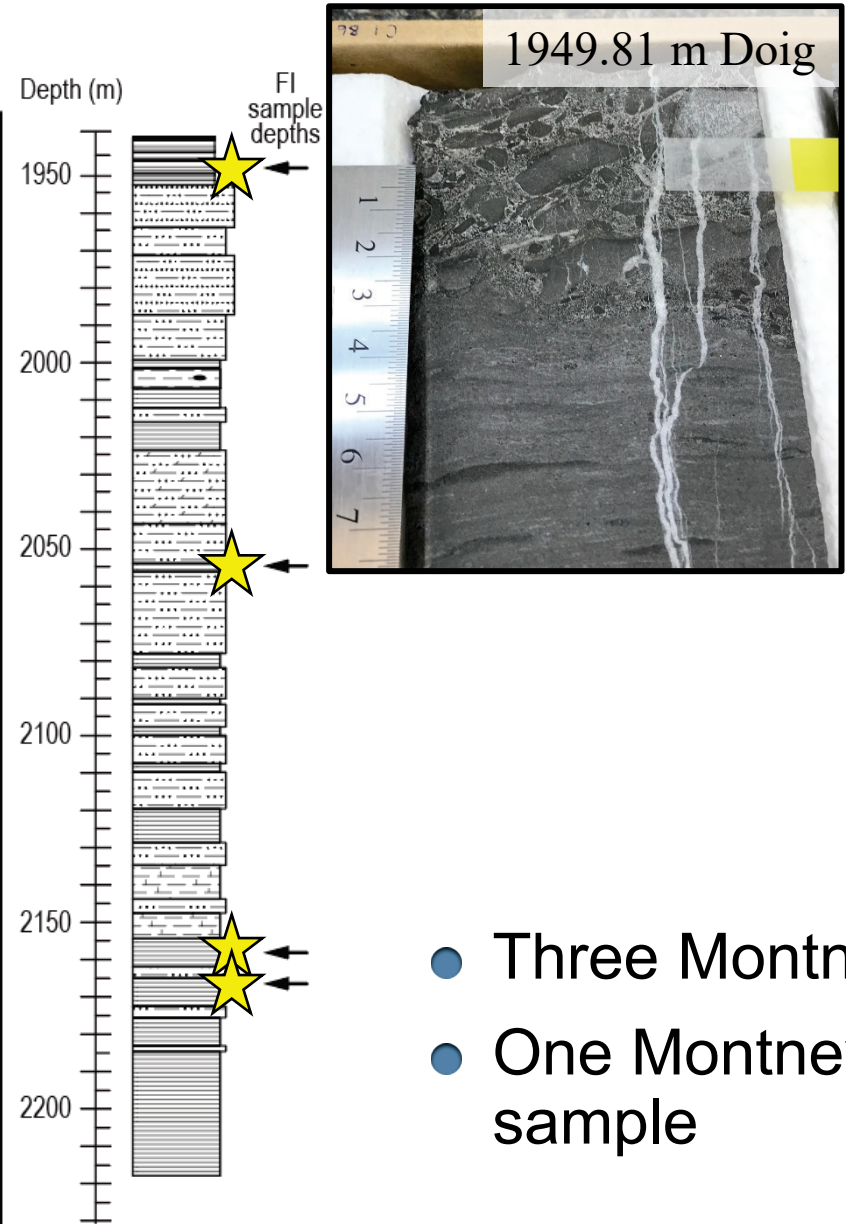


Fracture types

- Vertical fractures (hydraulic tension fractures)
 - Minimal displacement
- Brecciated zones
 - Complex fracturing
- Horizontal, bedding-plane parallel fractures (beefs)
 - Fine grained
- Sediment filled features



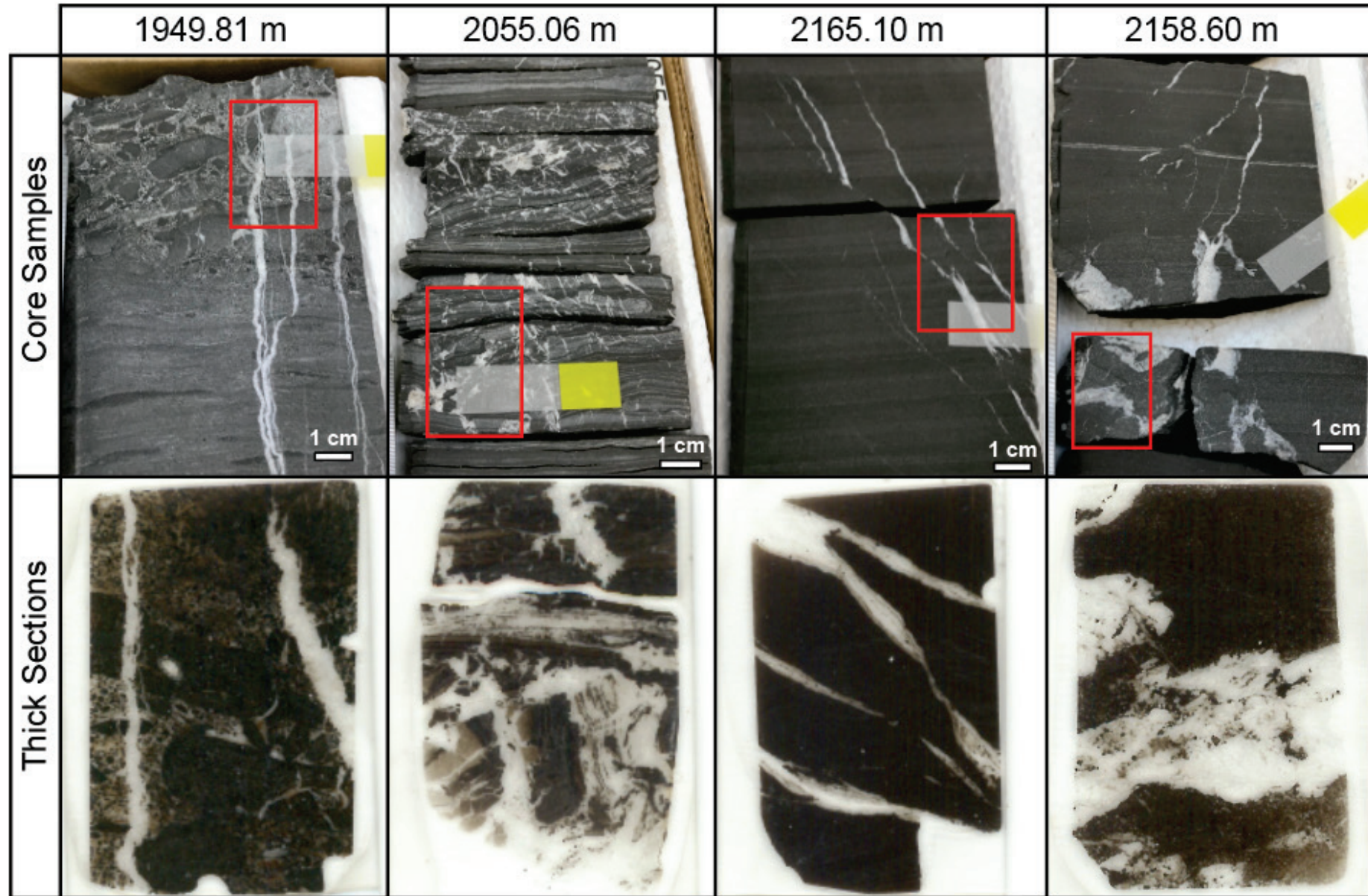
Fluid inclusion sample locations



- Three Montney samples
- One Montney-Doig boundary sample

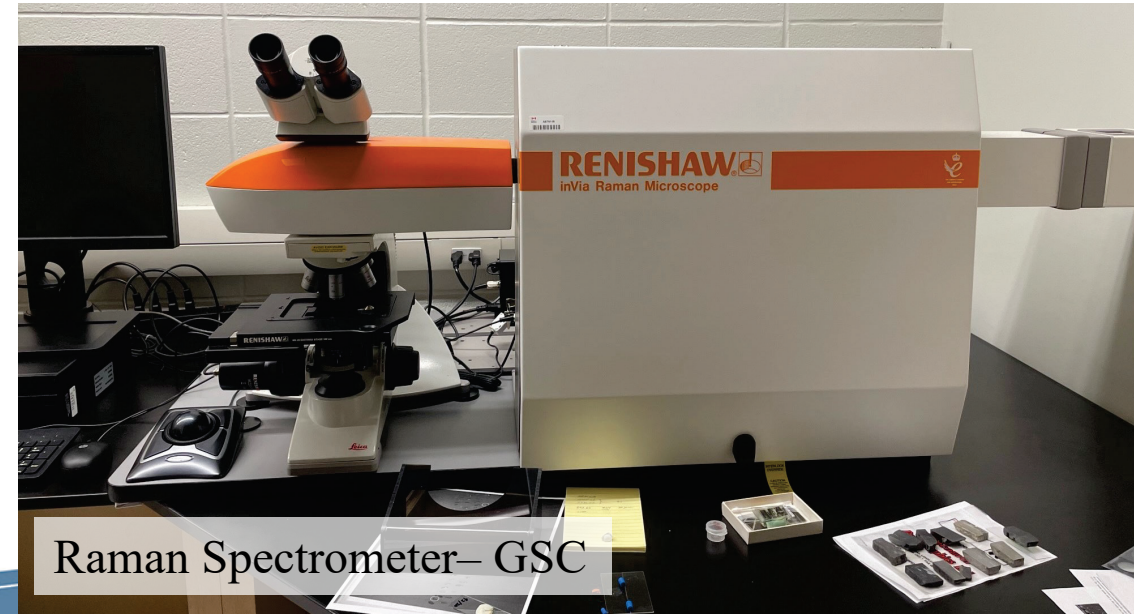
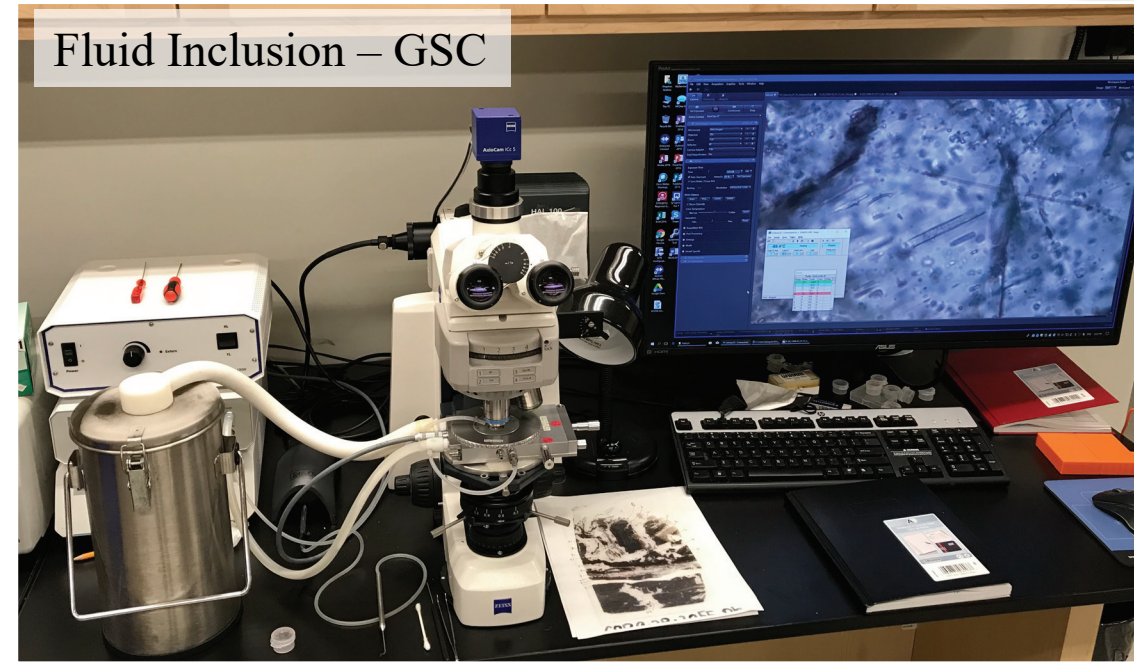
Samples

- Only vertical fractures and a brecciated zone were sampled
- All fractures blocky calcite filled
- Abundant fluid inclusions in all samples



Methods

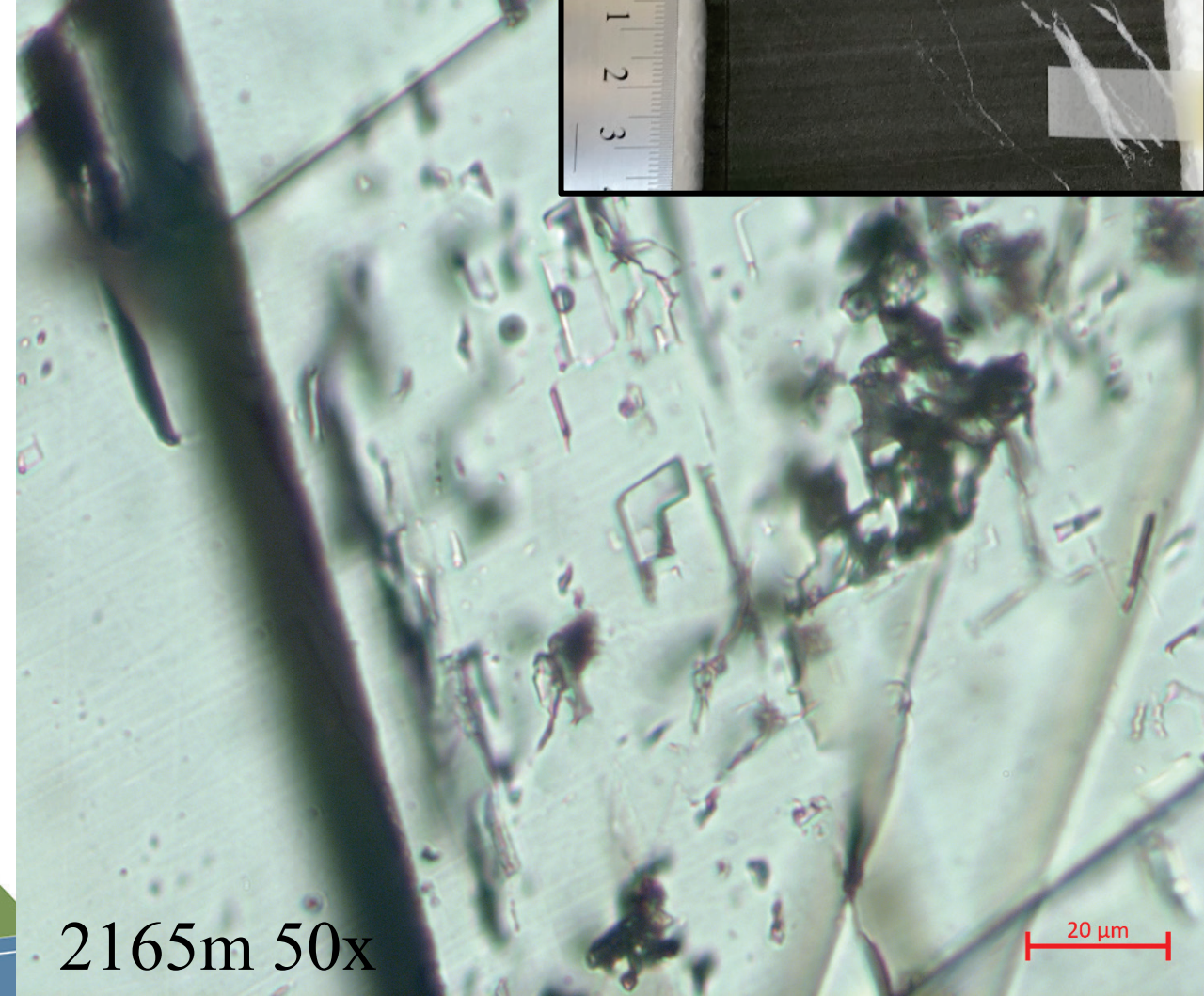
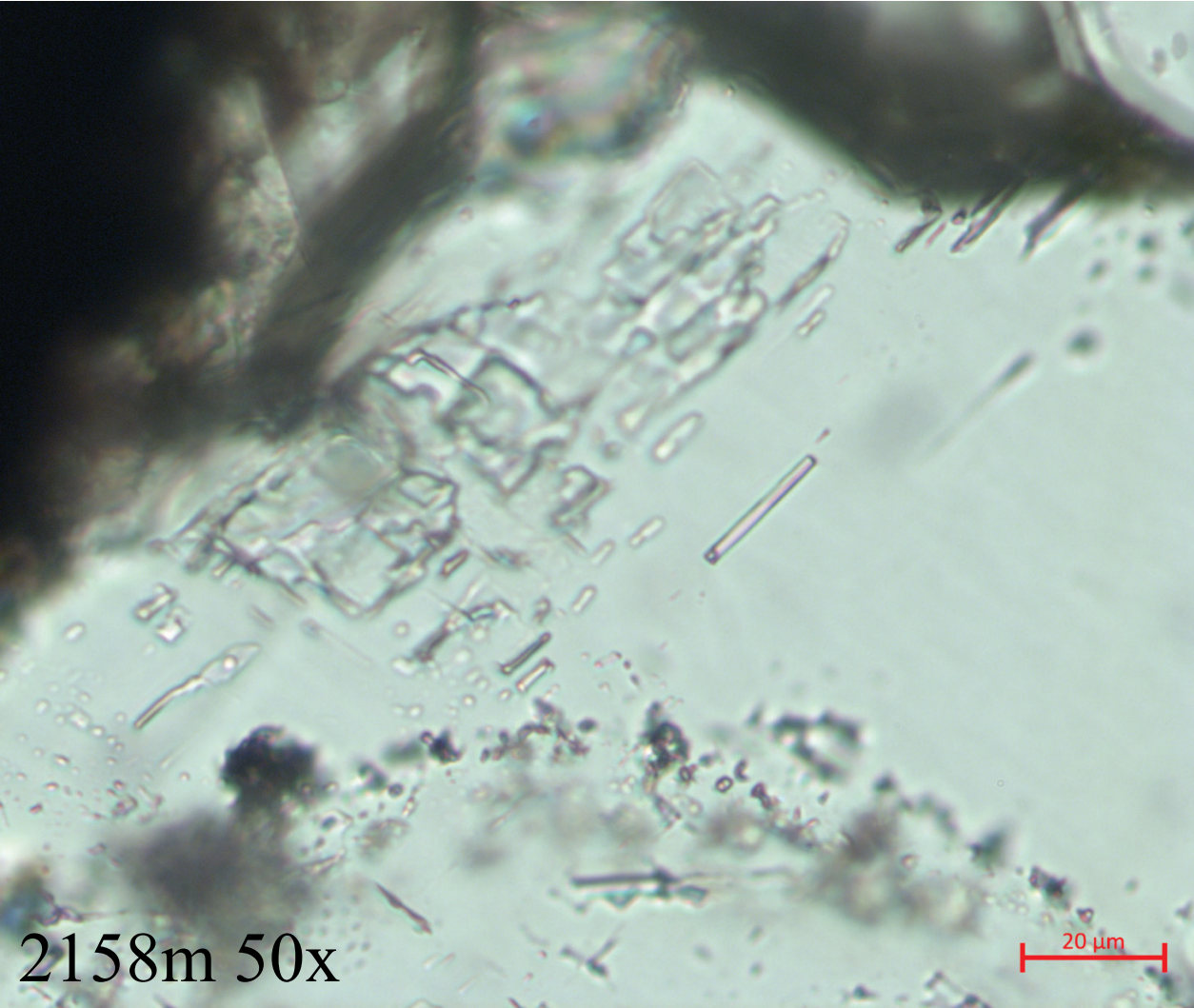
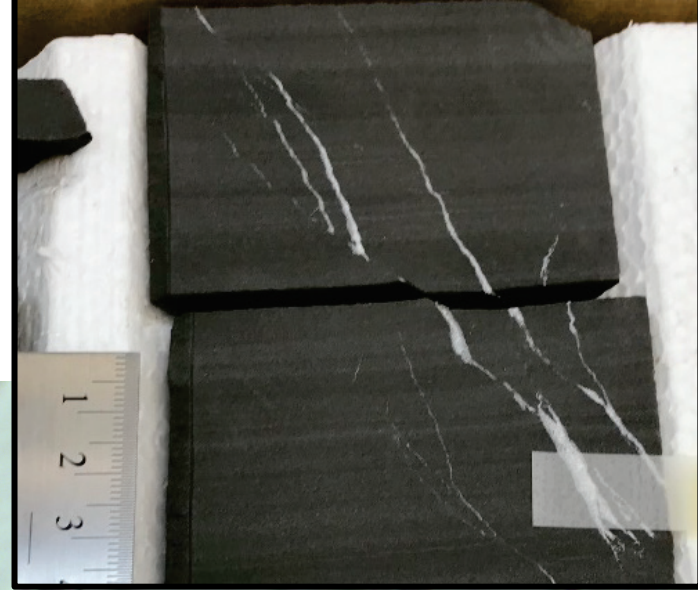
- Petrography (visible and UV light)
- Fluid inclusion microthermometry (Th, Tm, Te)
- Raman Spectroscopy
- Stable isotope geochemistry ($\delta^{13}\text{C}$ & $\delta^{18}\text{O}$)



Aqueous fluid inclusions

- **Primary** Inclusions:

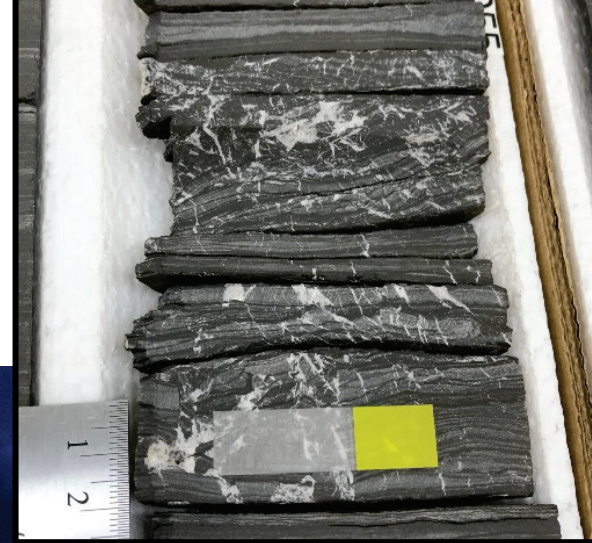
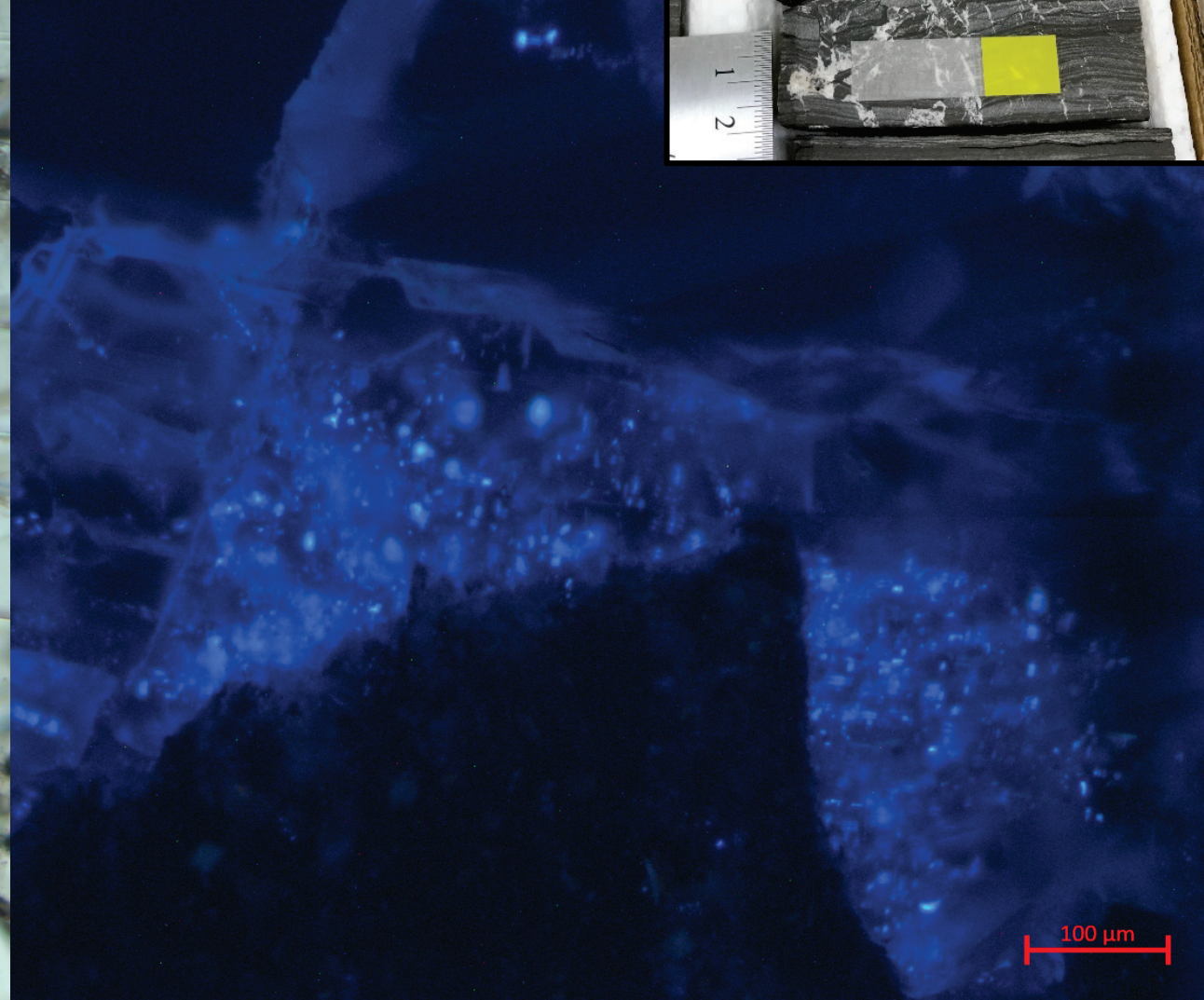
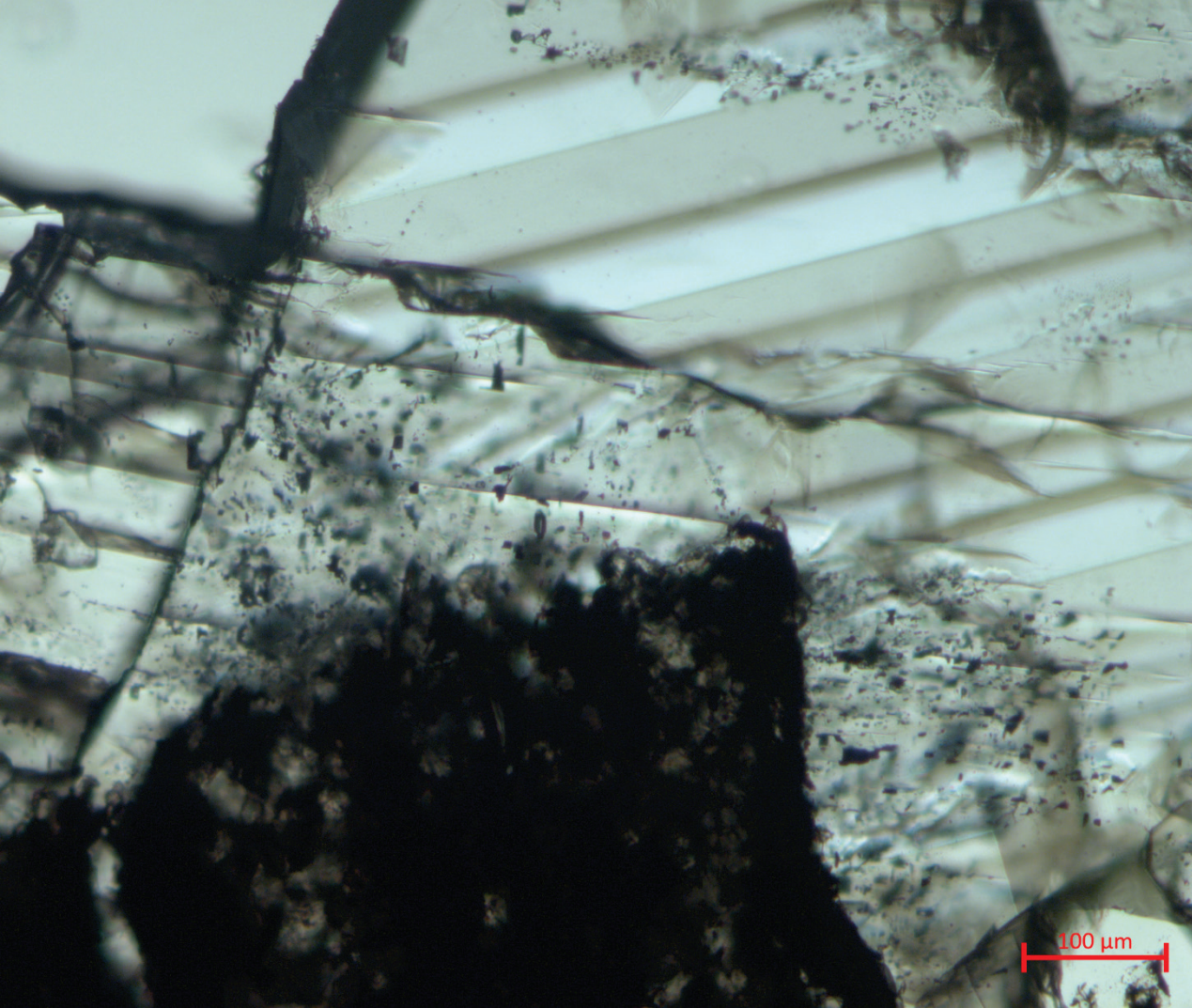
- Large, two phase, typically negative crystal shape, along growth margins and in cores, pre-date petroleum inclusions



Petroleum inclusions

- **Primary Inclusions:**

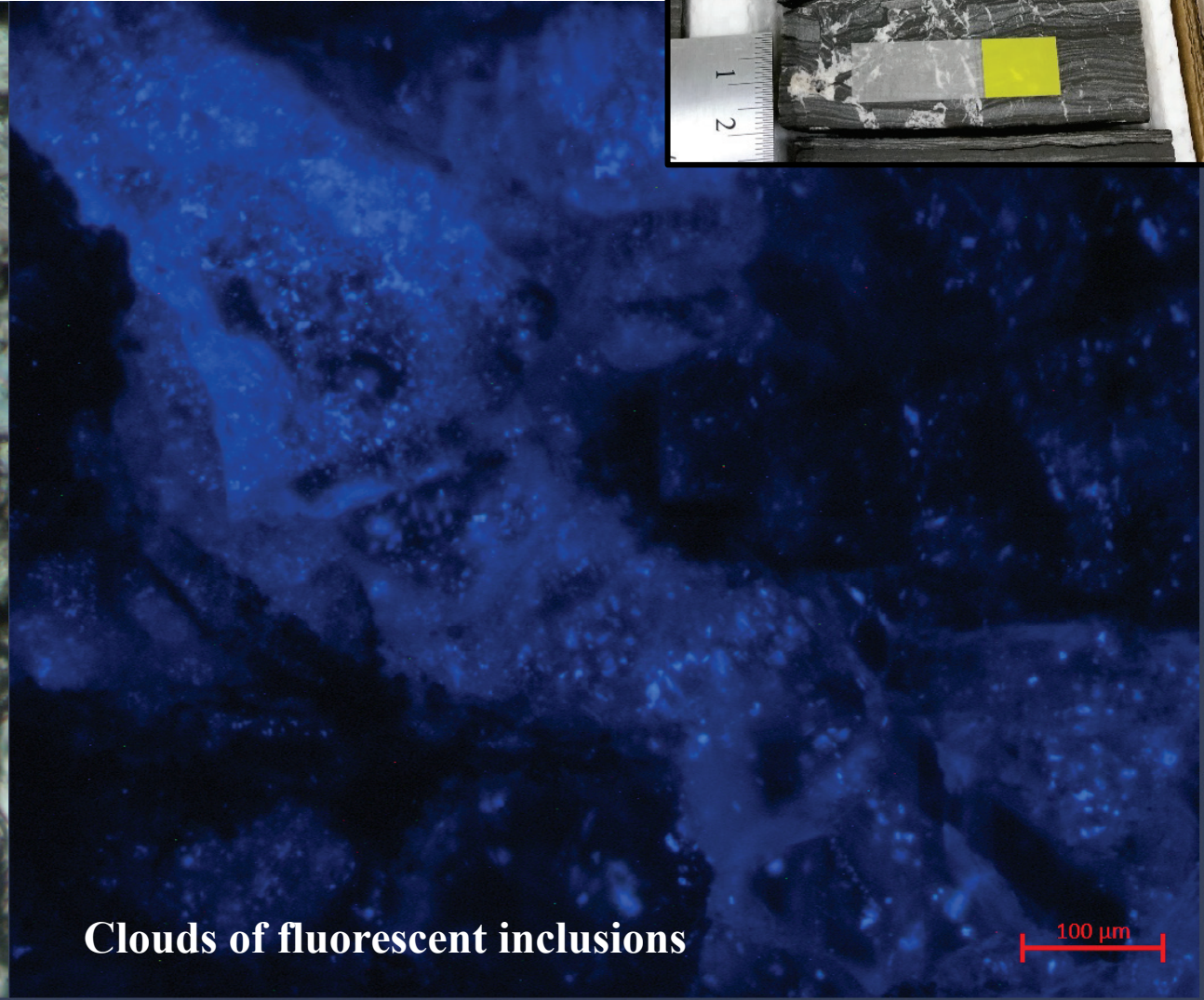
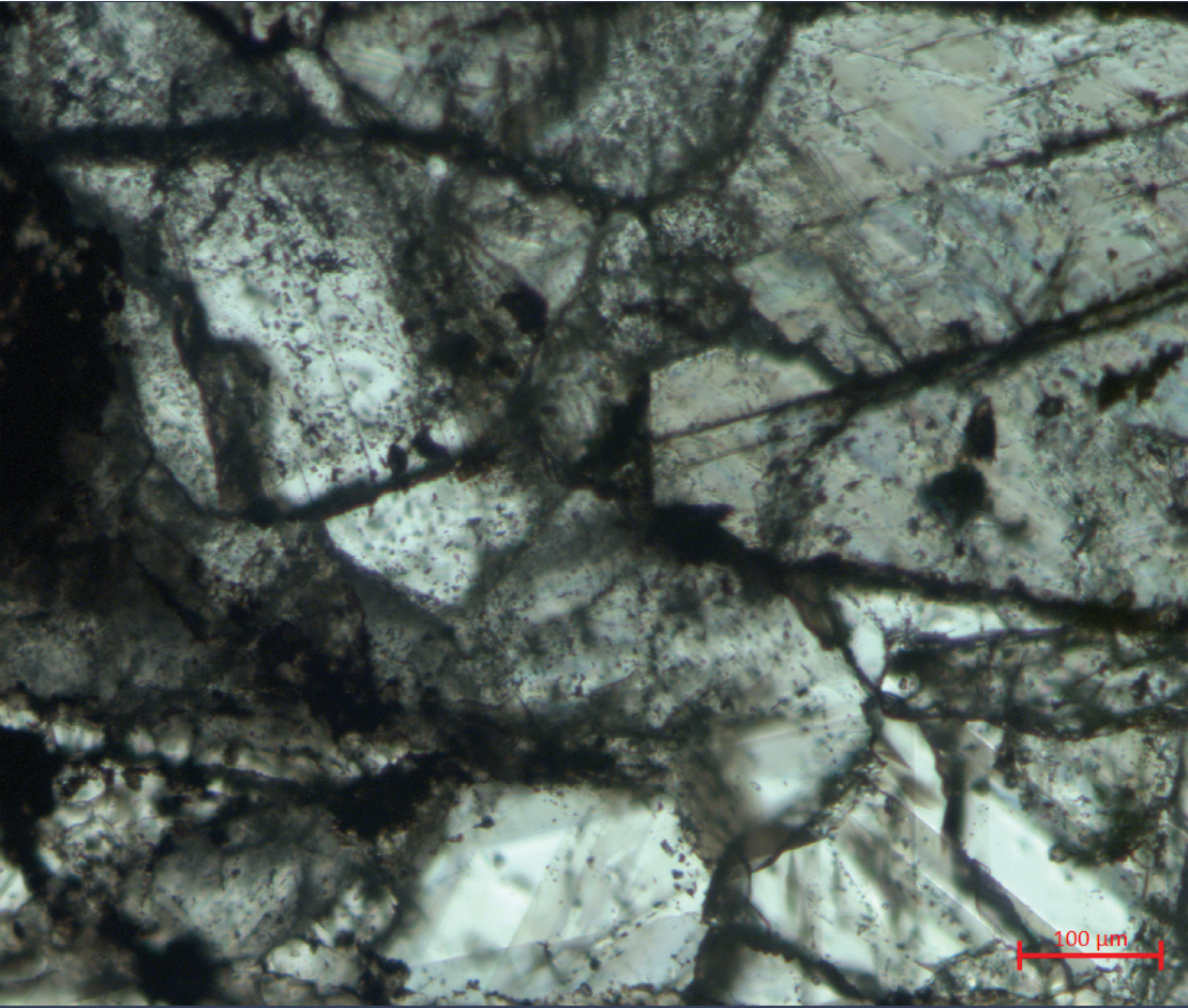
- Typically two-phase, ellipsoidal, **evidence of maturation of hydrocarbons from host rock**, clouds of inclusions within cores of crystals



Petroleum inclusions

- **Primary Inclusions:**

- Typically two-phase, ellipsoidal, evidence of maturation of hydrocarbons from host rock, **clouds of inclusions within cores of crystals**

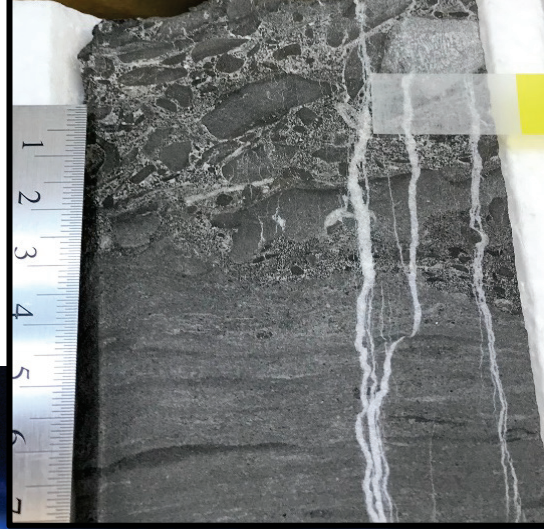
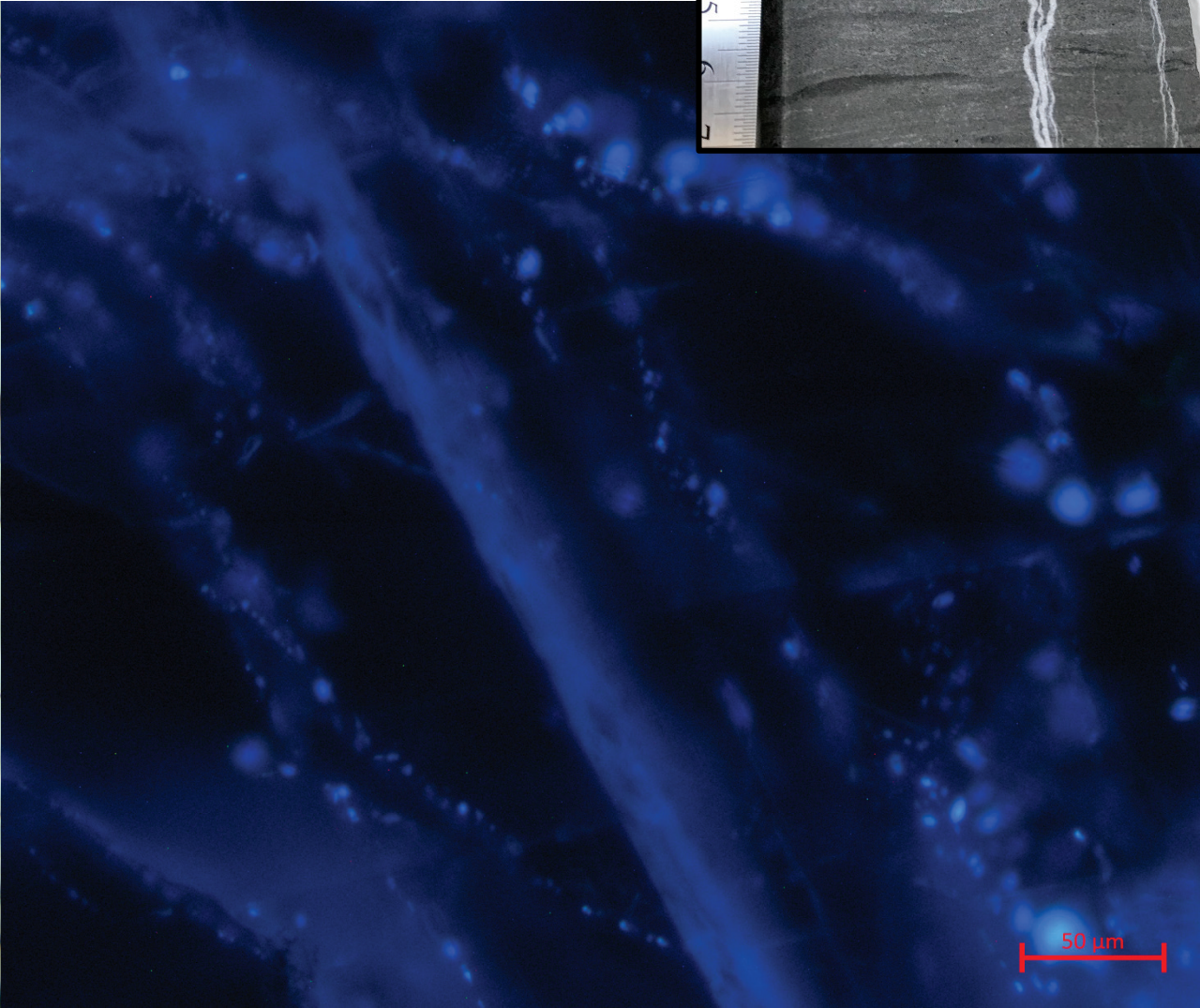
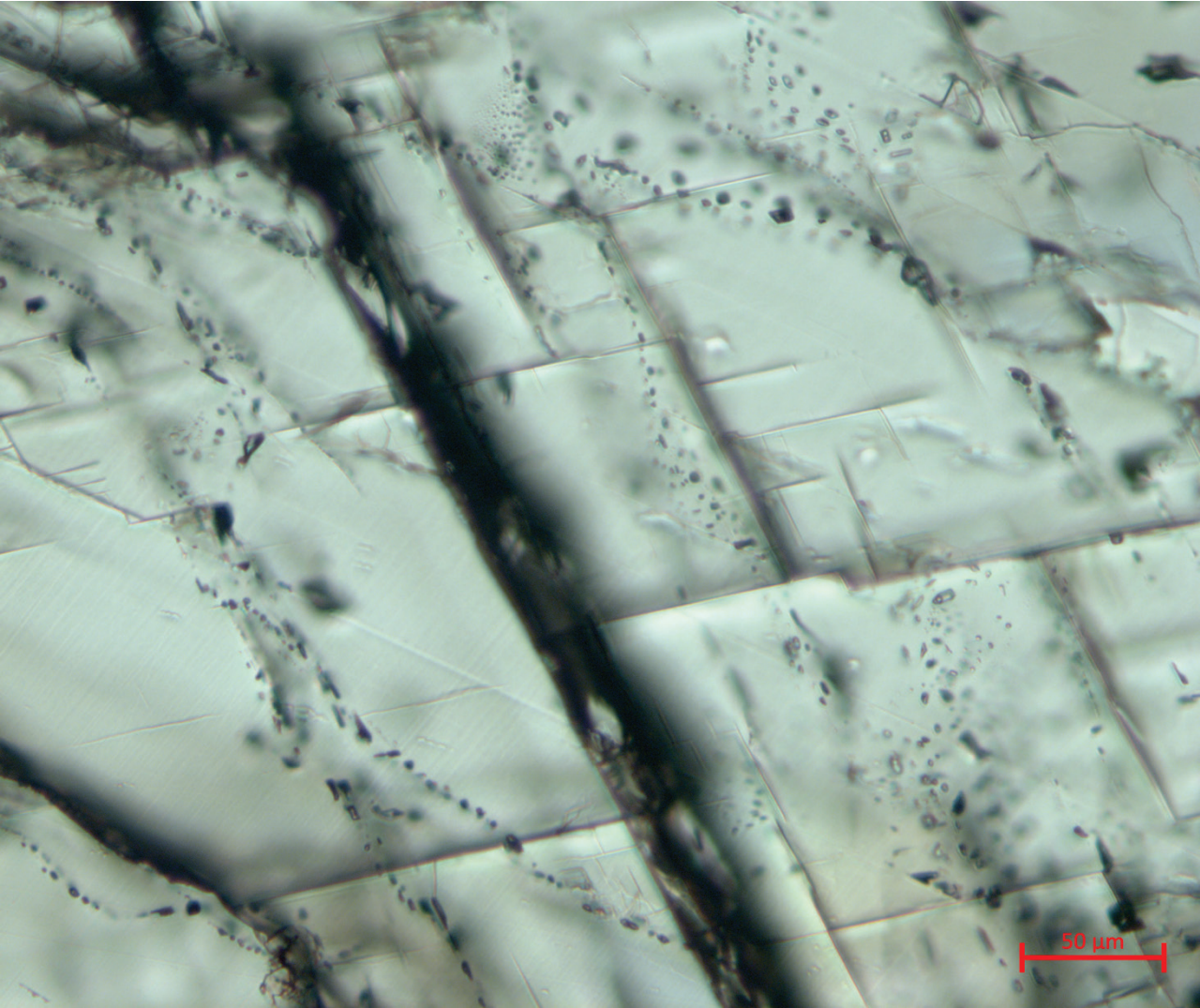


Clouds of fluorescent inclusions

Petroleum inclusions

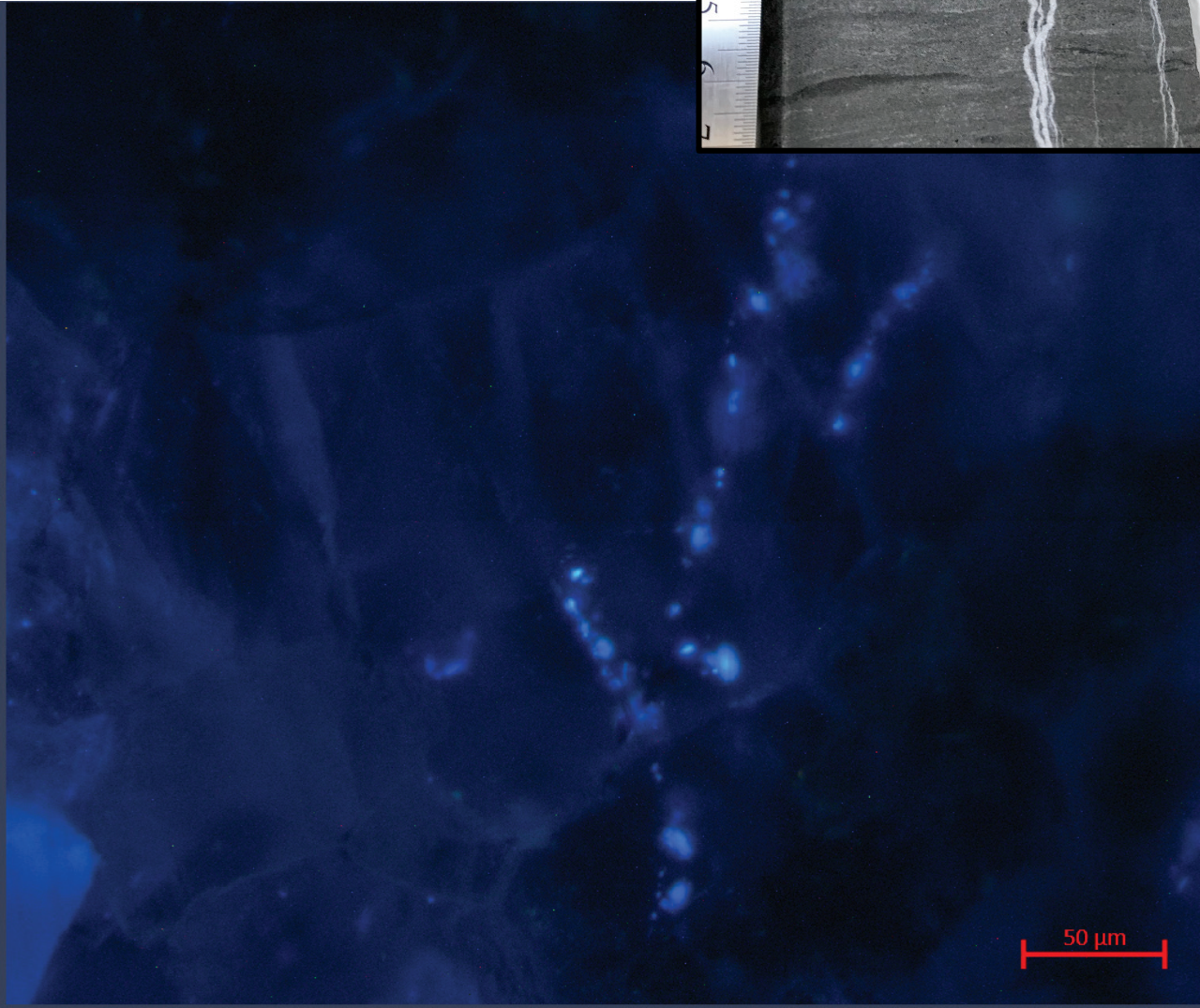
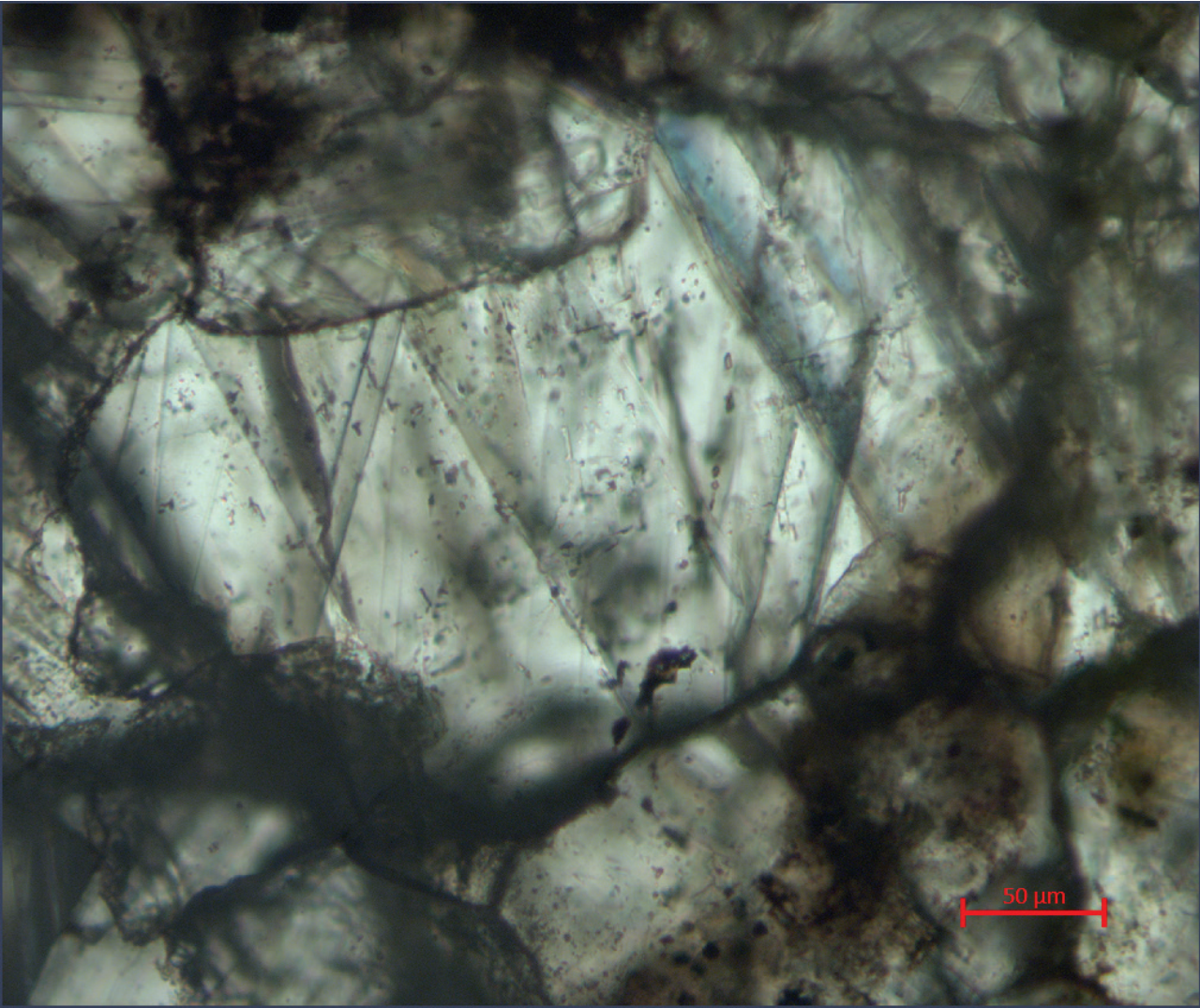
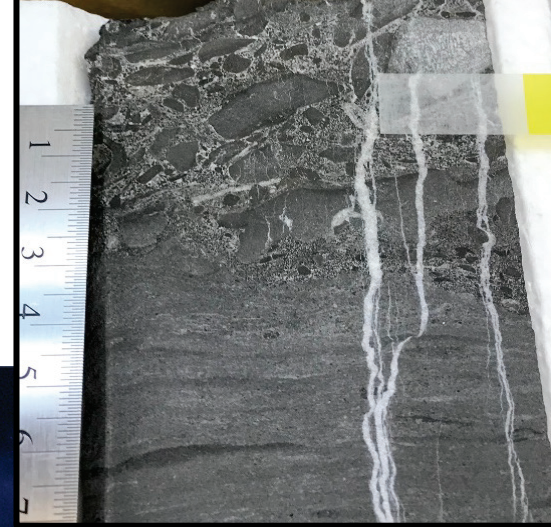
- **Secondary** Inclusions:

- Typically two-phase, ellipsoidal, **along healed cracks**, cleavage planes, post-date aqueous inclusions

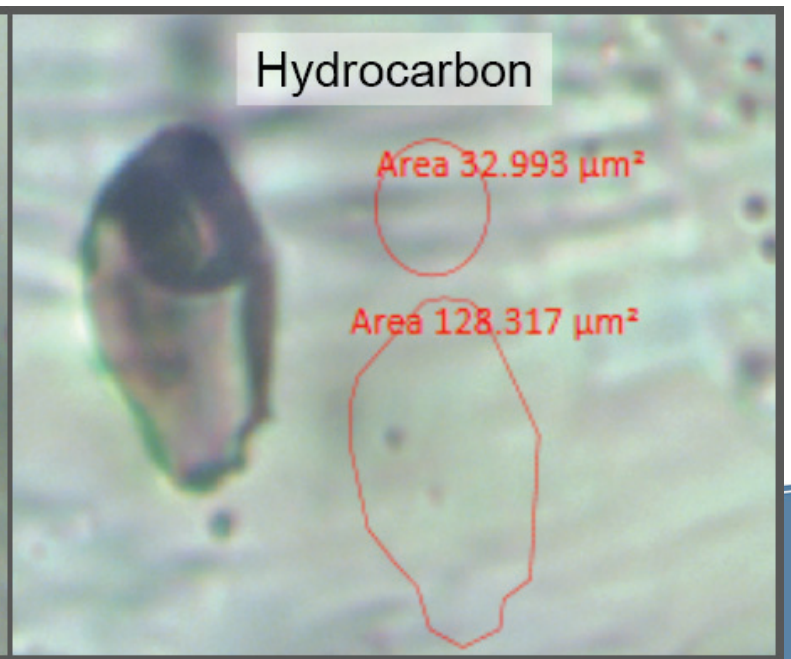
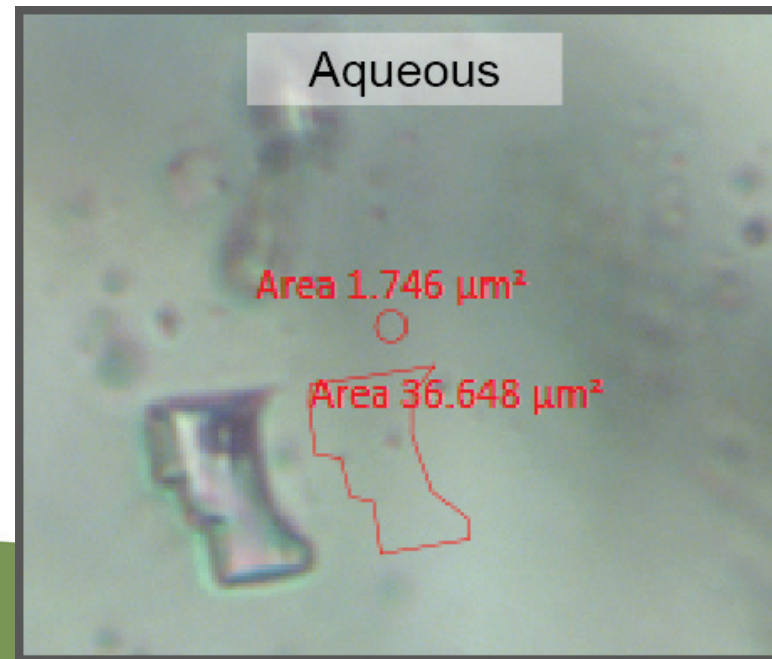
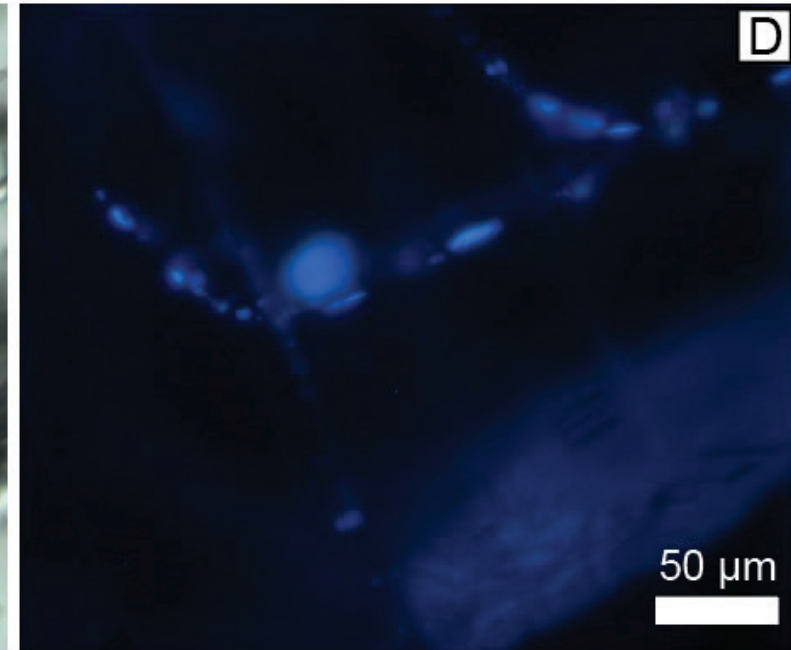
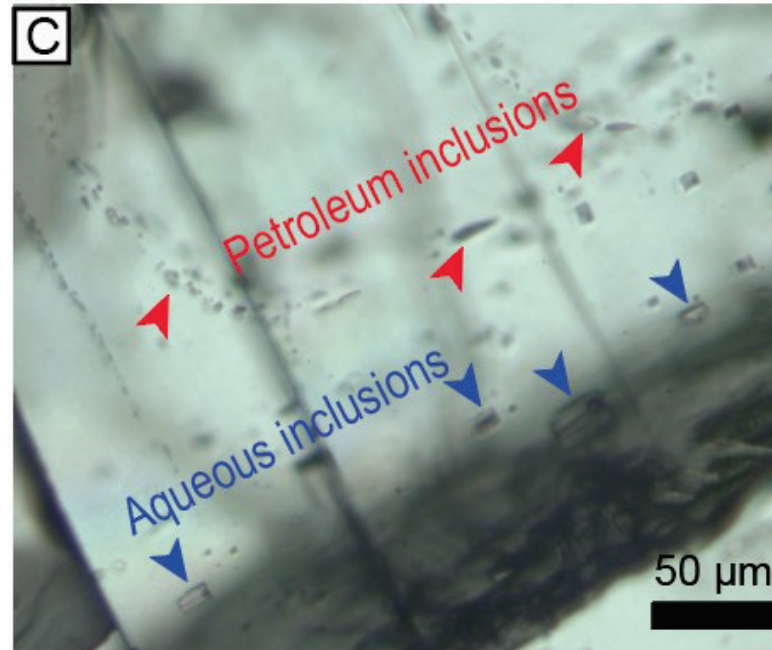


Petroleum inclusions

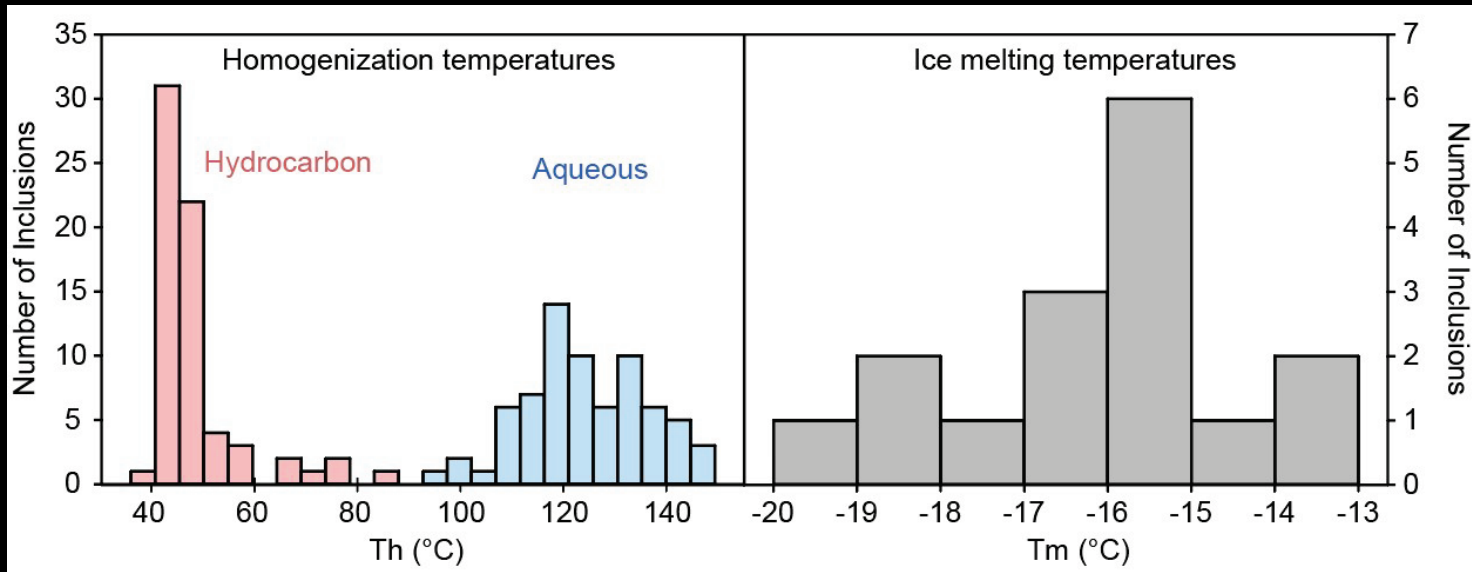
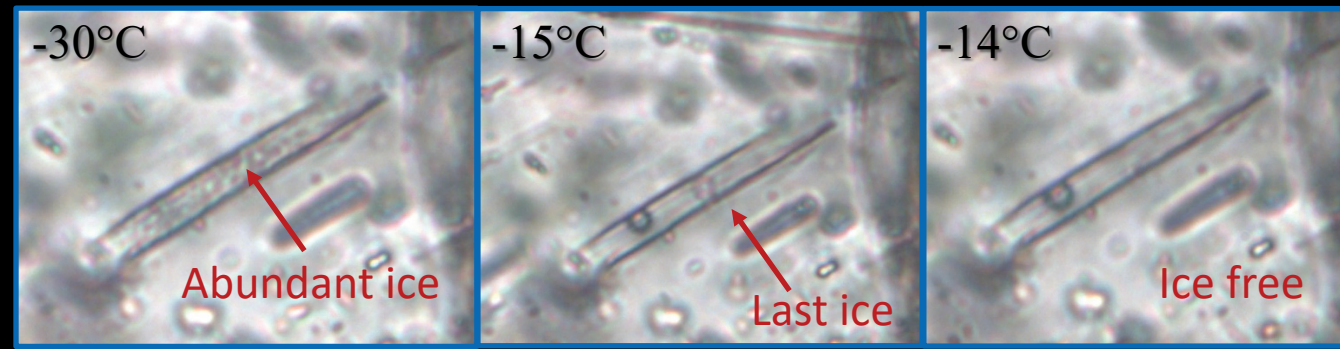
- **Secondary** inclusions:
 - Typically two-phase, ellipsoidal, along healed cracks, **cleavage planes**, post-date aqueous inclusions



- Aqueous and petroleum inclusions are co-occurring but not in the same FIA: **not co-genetic**
- Consistent blue-white fluorescence (452 nm):
 - **Single generation**
 - Gas-rich condensate / Volatile-rich Oil
- Room temperature vapor measurements
 - Average vapor fraction in HC FI measured = 0.21
 - Average vapor fraction in aqueous FI measured = 0.045
predicted = 0.051



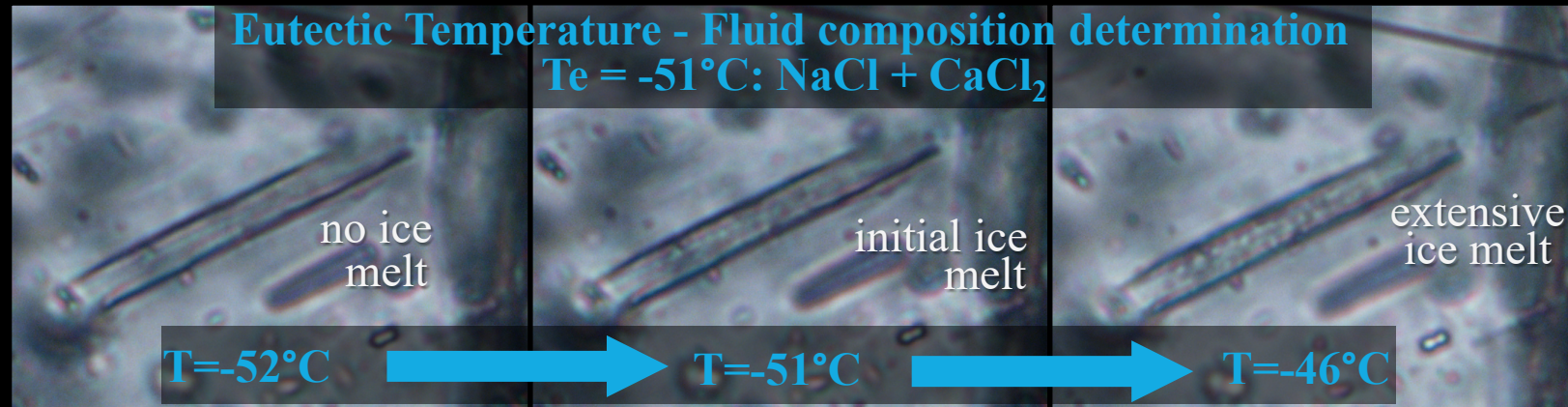
Fluid inclusion microthermometry



- Average homogenization temperature **Aqueous = 124°C Petroleum = 45°C**
- Average salinity is 19.0 wt% NaCl equiv. (n=16)
 - The same as Gasparrini et al. (2021)
- Average Te = -51°C
- NaCl-CaCl₂ fluid composition
- No significant down core variability

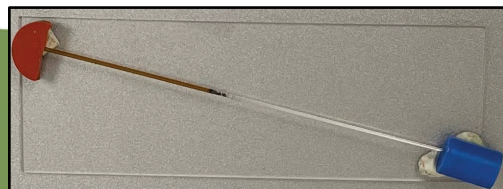
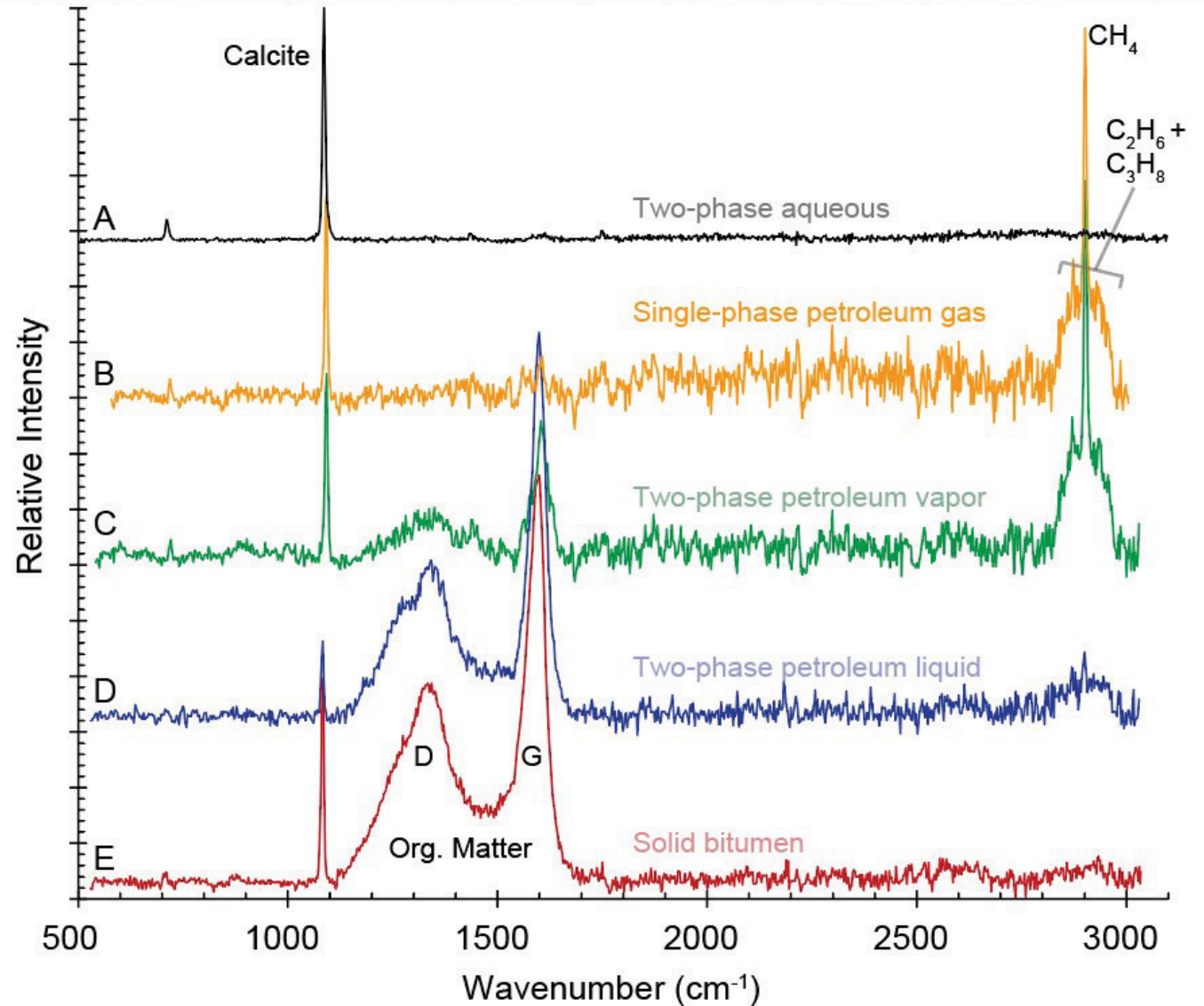
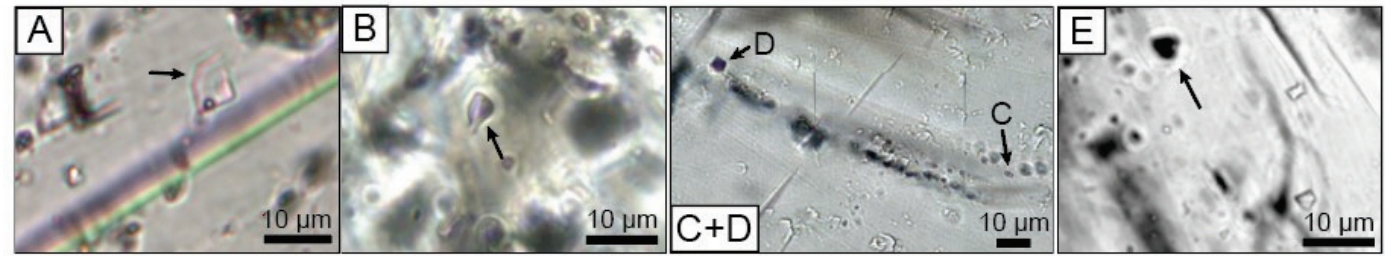
First ice melting (Te) –

- NaCl -21.2°C
- CaCl₂ -49.8°C
- NaCl-KCl -22.9°C
- **NaCl-CaCl₂ -52.0°C**

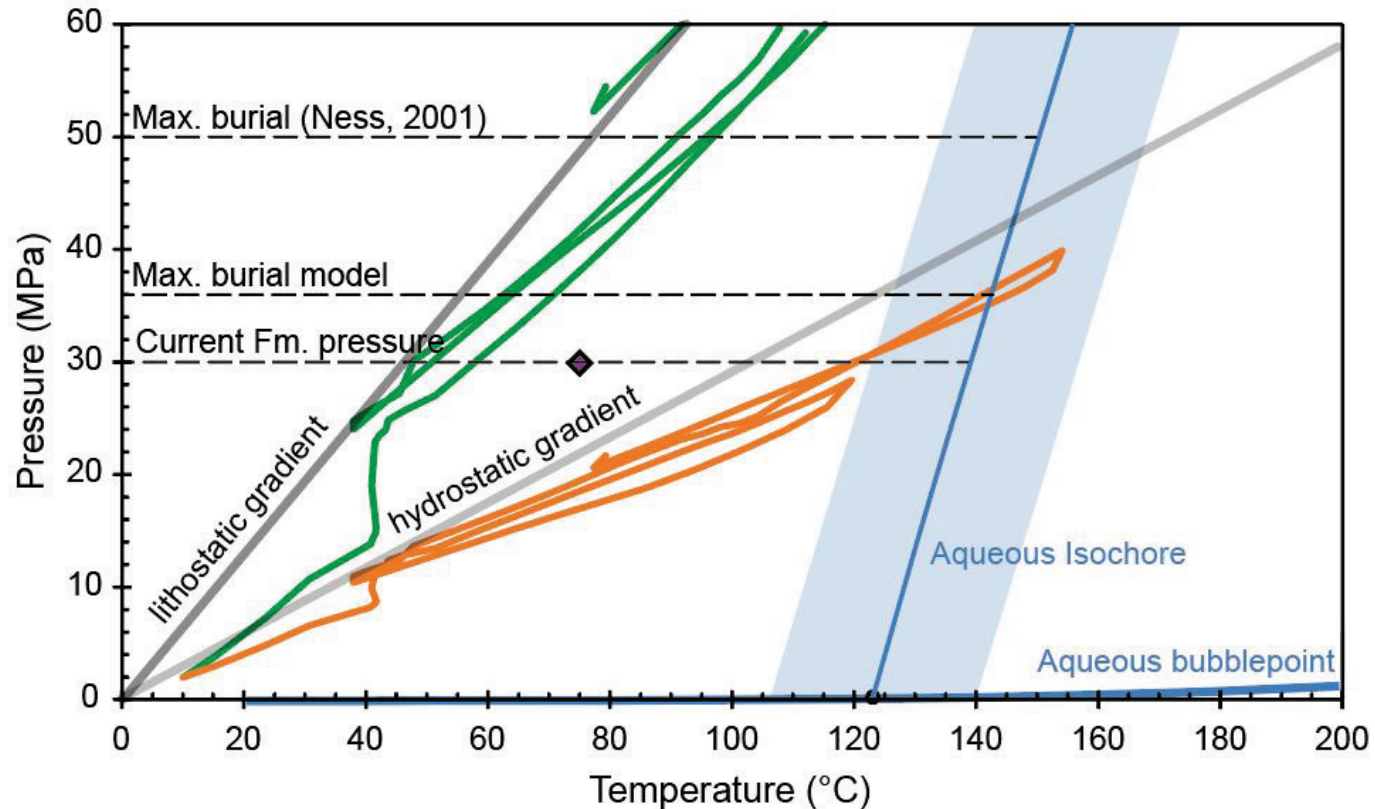


Raman Spectroscopy

- Aqueous inclusions have no hydrocarbons present
- Gas inclusions are rich in methane, ethane, etc.
- Vapor of two-phase similar composition to single phase gas
- Consistency – single generation
- Bathochromic shift of CH_4 band 2905 cm^{-1} vs. 2917 cm^{-1}
 - High density CH_4



Aqueous inclusions modeling

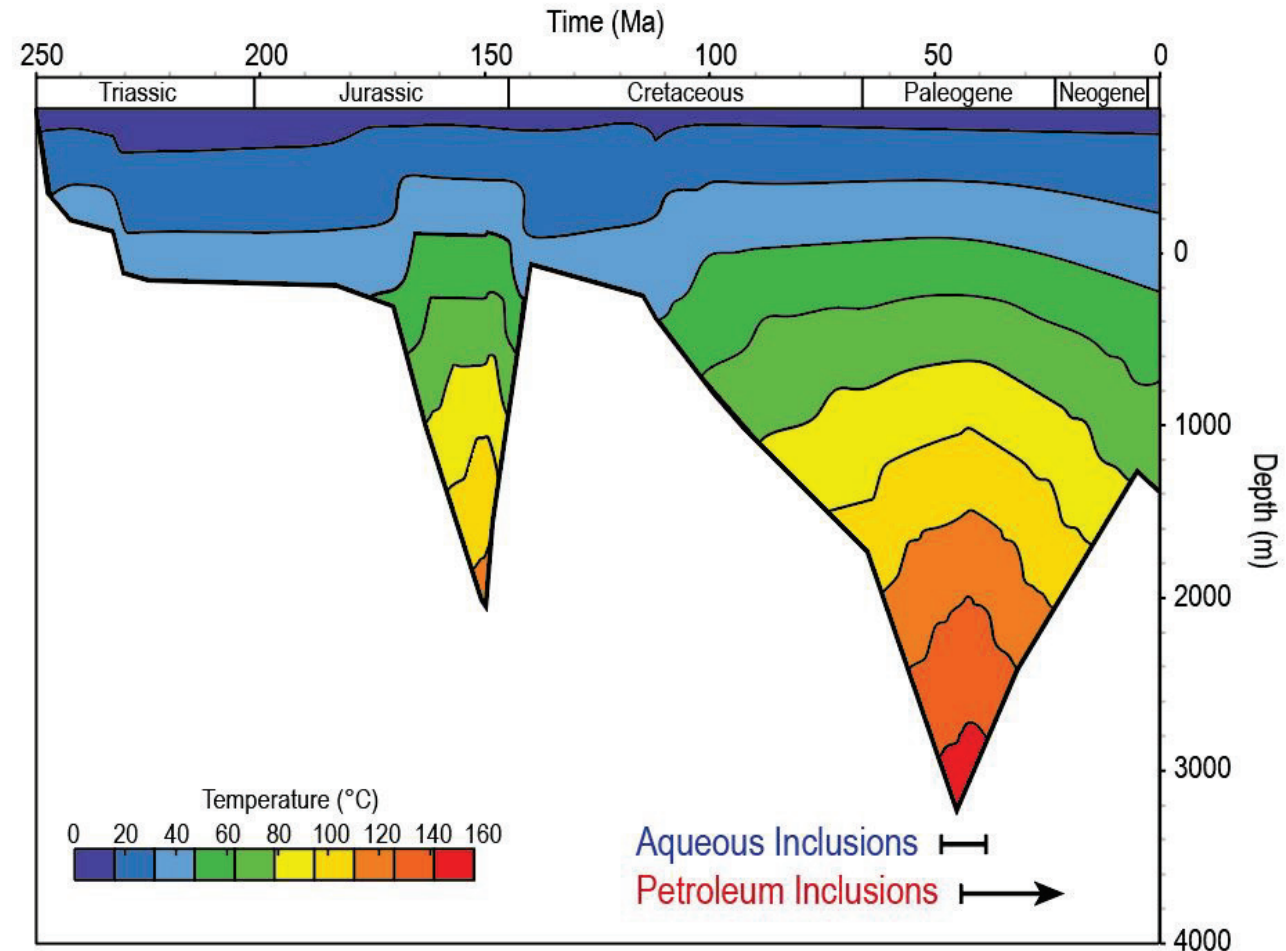


- Average Th of 124°C
- salinity of 19.6% NaCl equiv.
- Intersection of hydrostatic gradient with fluid inclusion isochore results in a minimum entrapment temperature of 142°C



Timing of entrapment

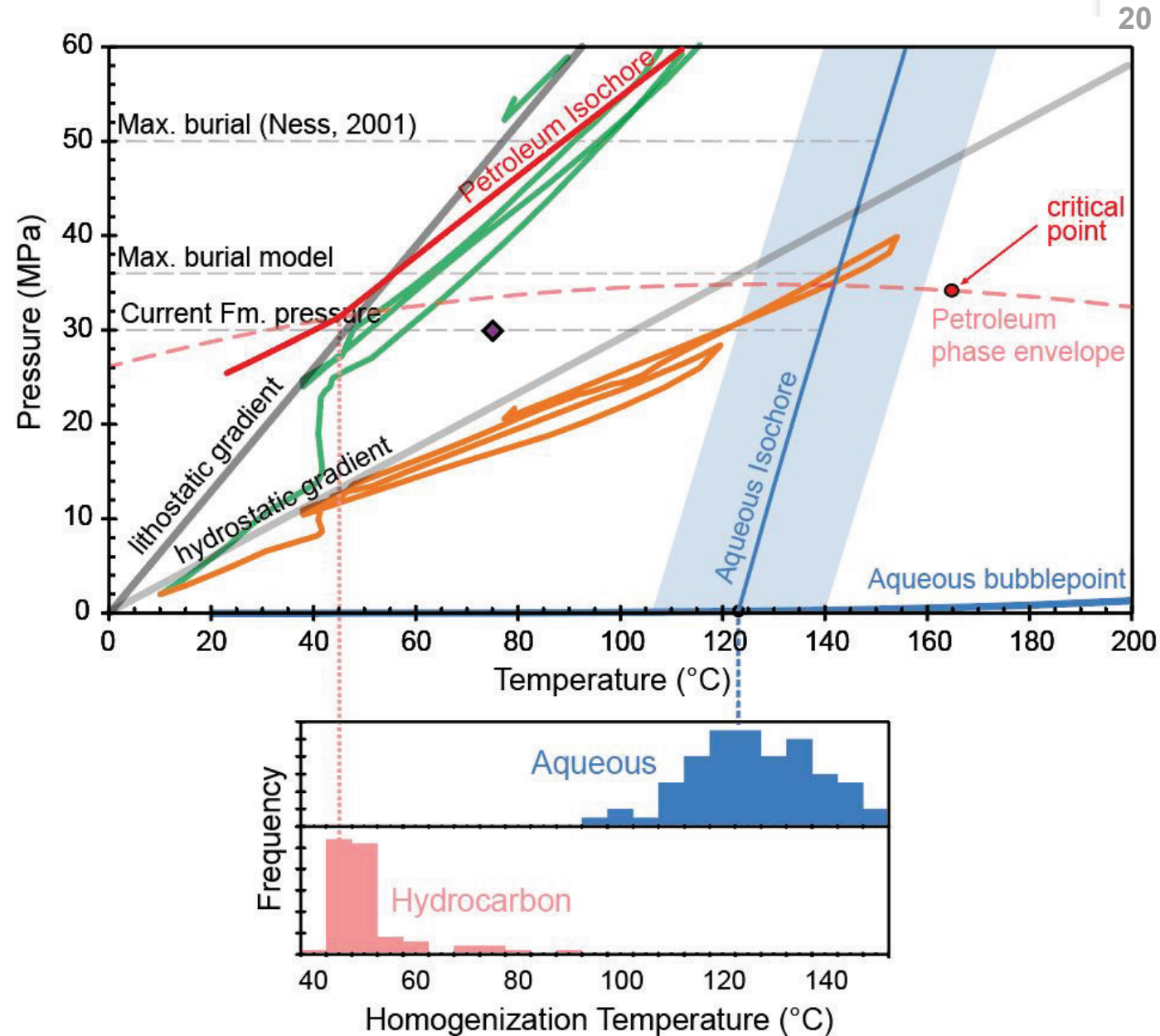
- Burial-Temperature history of well indicates temperatures in excess of 142°C only occurred during the Laramide orogeny (~ 50 Ma)
- Therefore vertical fractures likely formed as a result of this tectonic activity



Burial history by A. Mort

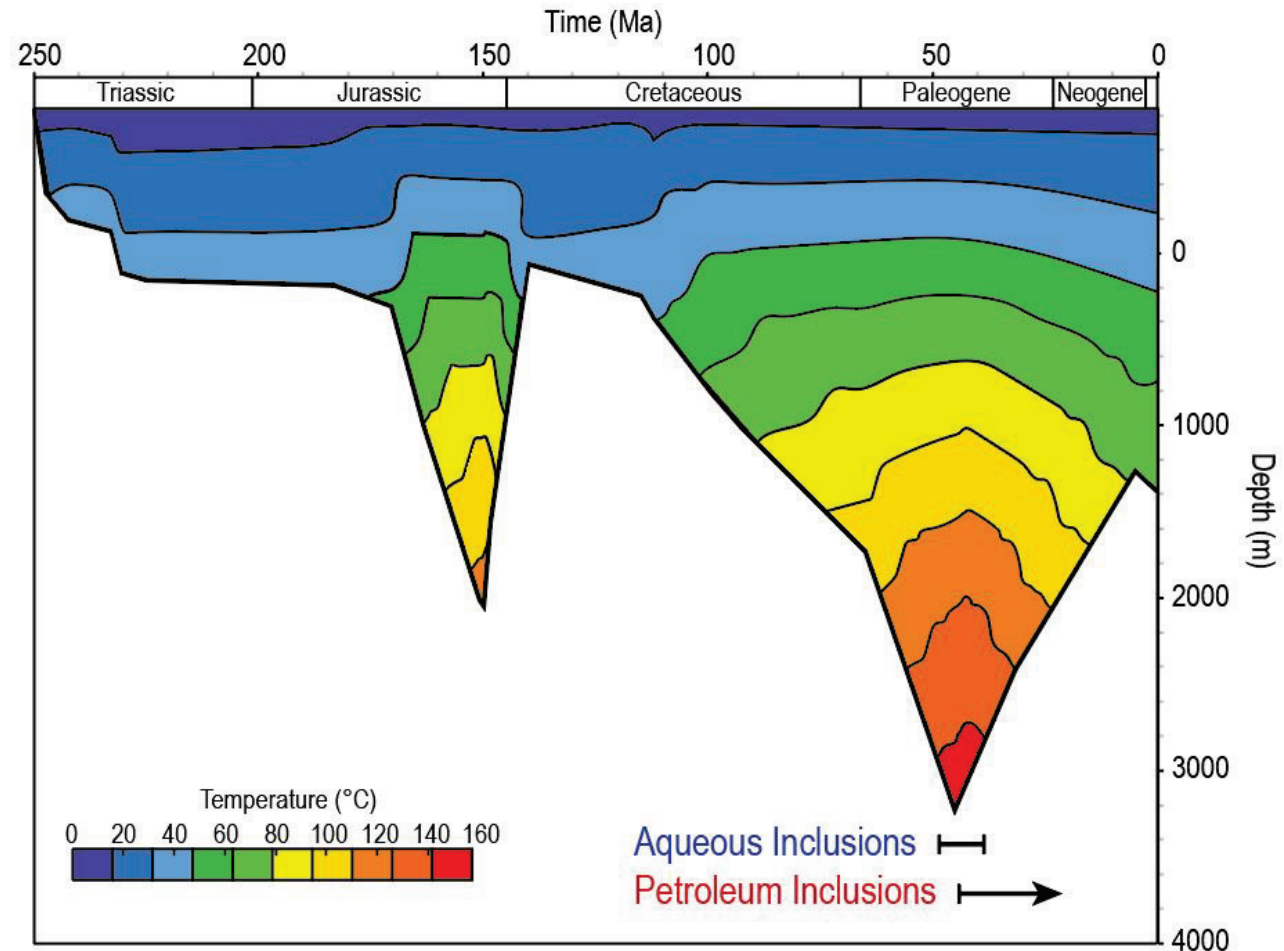
Petroleum inclusion modeling

- Recombined fluid composition used to model petroleum phase envelope
- Petroleum isochore modeled with PVTsim
- Petroleum isochore is near or in excess of lithostatic pressure
- Overpressure resulting from thermal maturation of hydrocarbons



Timing of entrapment

- Petroleum inclusions post-date aqueous inclusions
- Formed at pressures approaching or in excess of lithostatic pressure
 - Max burial or during proceeding uplift
- Primary petroleum inclusions formed first followed by migration and reactivation of fractures (secondary inclusions)
- Similar origin or event



Modelling $\delta^{18}\text{O}$ composition of parent fluids

Temperature of calcite formation from Th of FI



Measure $\delta^{18}\text{O}$ of calcite



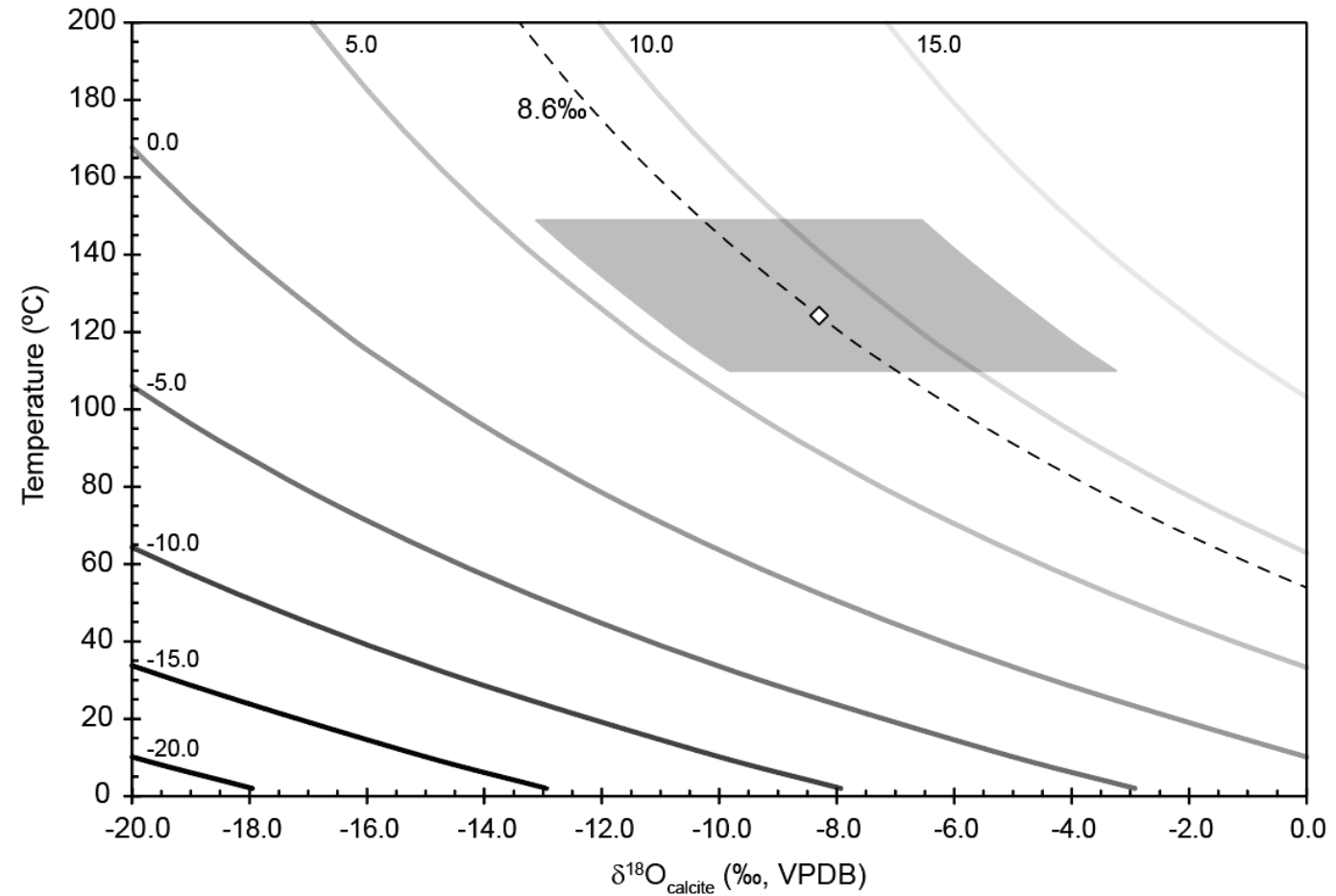
$$1000 \ln \alpha (\text{CdCO}_3\text{-H}_2\text{O}) = 2.76(10^6 T^{-2}) - 3.96$$

Kim and O'Neil, 1997

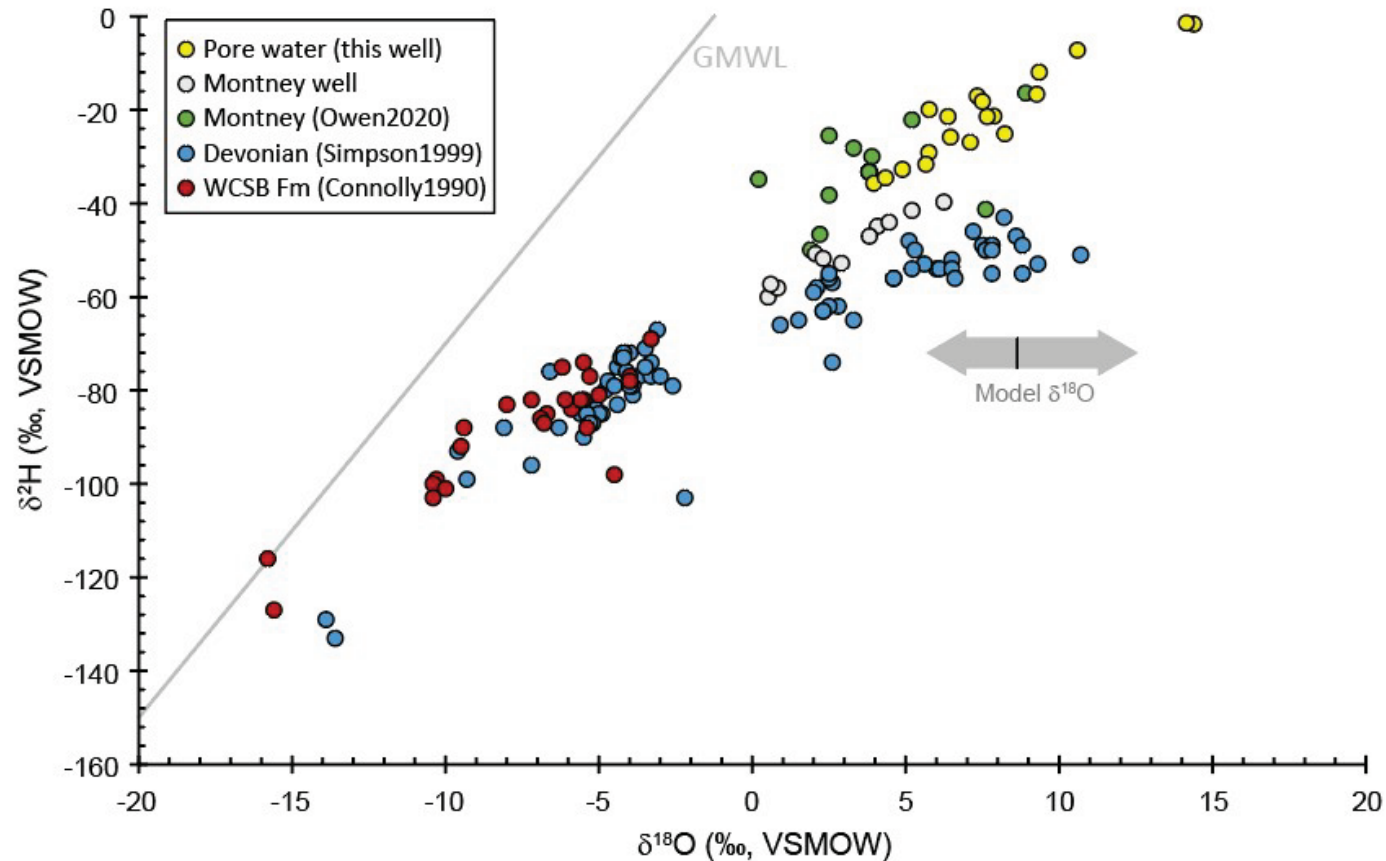


Calculate $\delta^{18}\text{O}$ of paleowater

- Average values give water $\delta^{18}\text{O}$ composition of +8.6‰
- Brine-type composition, not original Triassic seawater



WCSB Formation water

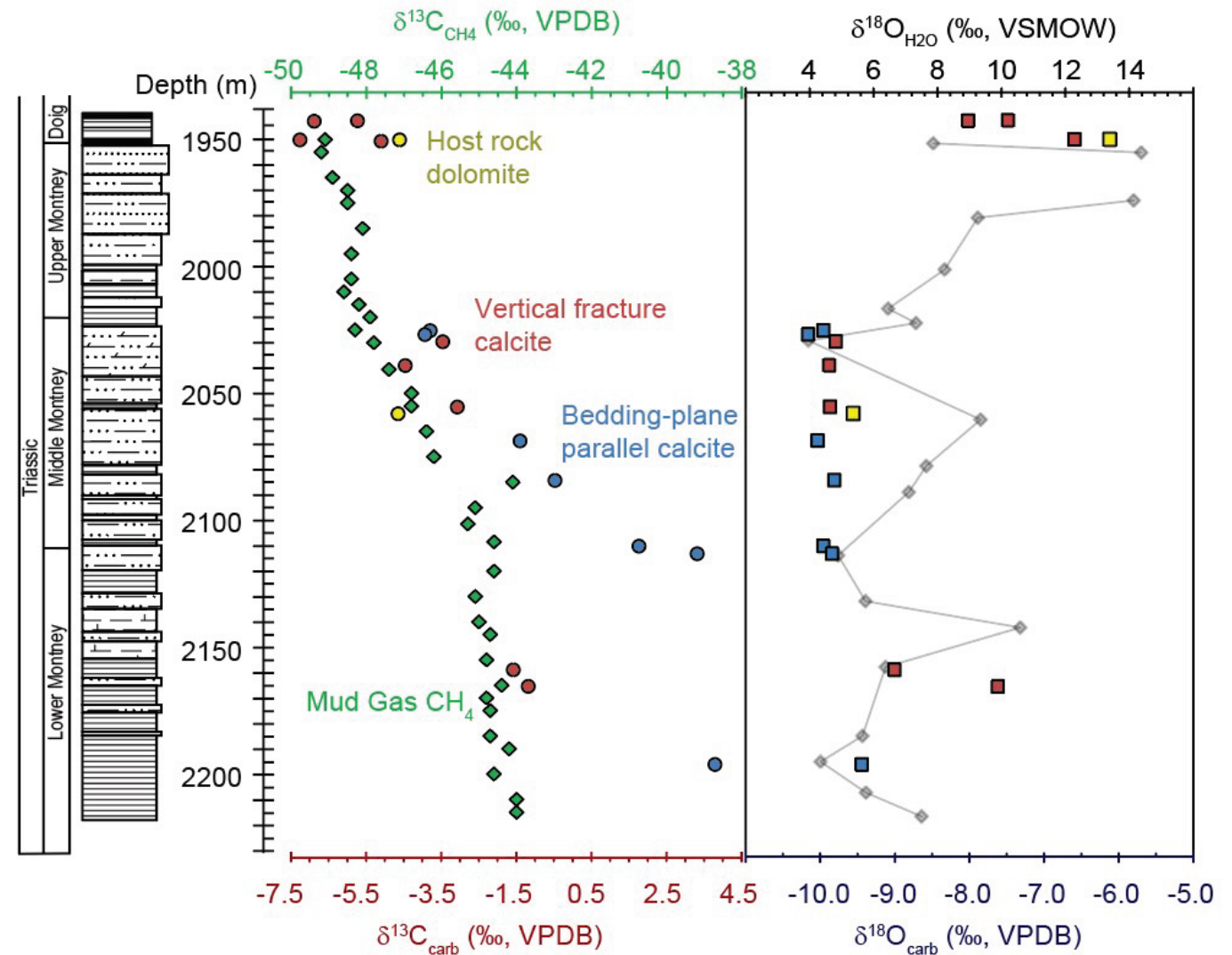


- Modeled $\delta^{18}\text{O}$ of parent fluids correlated well with **modern pore waters**
- These fluids are in $\delta^{18}\text{O}$ equilibrium
- Indicates fracture filling calcite is locally derived
- Suggests minimal fluid flow and closed system like behavior



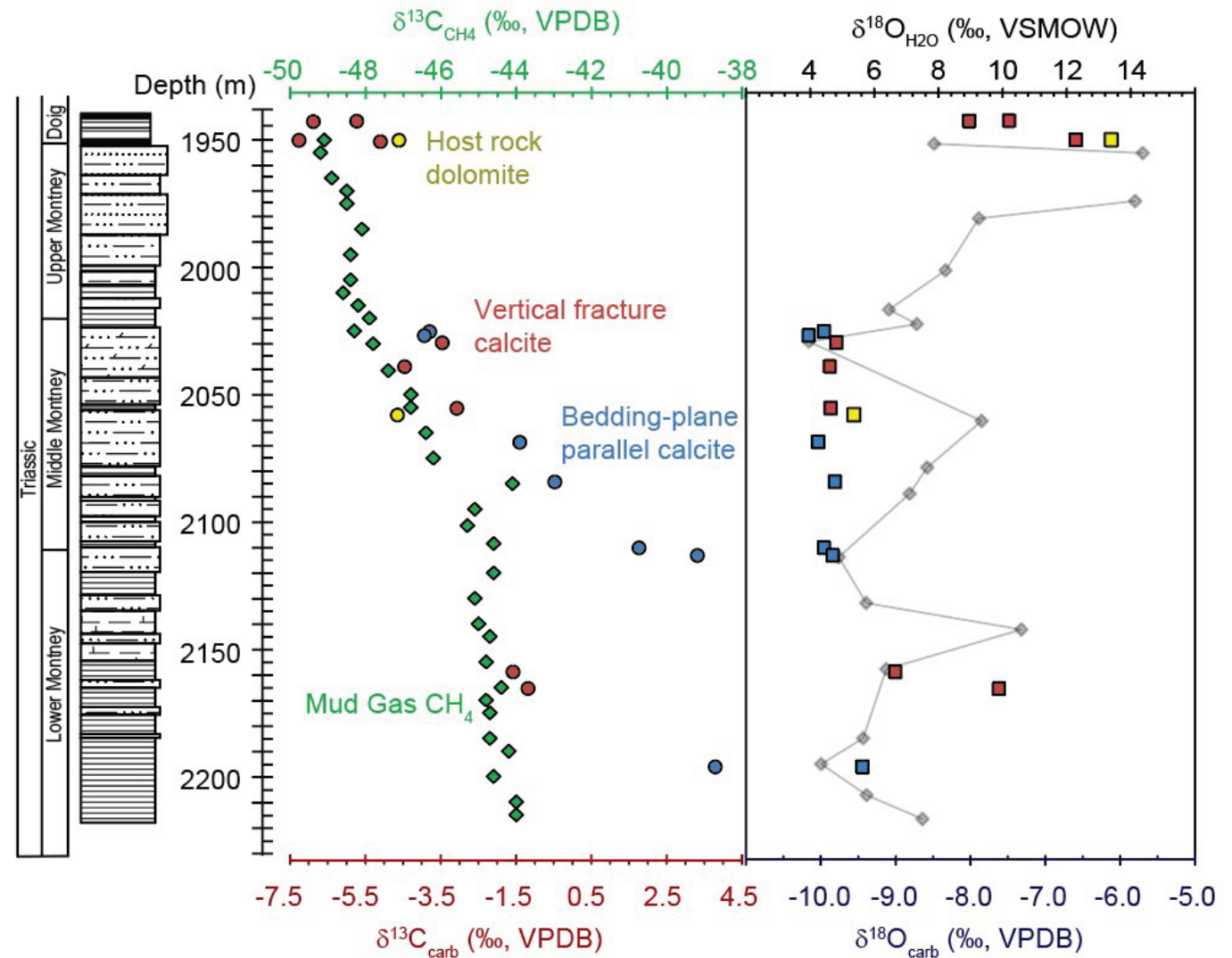
Isotope stratigraphy

- $\delta^{18}\text{O}$ values of vertical, horizontal and host rock (dolomite) are all similar
- Downhole variability in $\delta^{18}\text{O}$ of fracture calcite is consistent with pore water $\delta^{18}\text{O}$
- Further evidence of locally sourced carbonate



Isotope stratigraphy

- Both **vertical** and **horizontal** fracture calcite $\delta^{13}\text{C}$ values increase with depth similar to **mud gas CH_4** $\delta^{13}\text{C}$
- Horizontal fracture calcite has greater deviation and therefore different carbon source
 - Associated with CO_2 - CH_4 equilibrium effects related to thermal maturation of hydrocarbons
- Horizontal fractures post-date thermal degradation of hydrocarbons



Conclusions

- Core has several types of calcite filled fractures
 - Vertical, horizontal (beefs), brecciated zones
- Abundant fluid inclusions
 - Aqueous, petroleum-bearing
- **Aqueous inclusions:**
 - Formed from brine with CaCl_2
 - Trapping temperature of $\sim 142^\circ\text{C}$
 - Timing of entrapment: max burial, Laramide
 - Closed system (tight) with locally sourced parent fluids
- **Petroleum inclusions:**
 - Post-date aqueous inclusions
 - Formed at pressures approaching or in excess of lithostatic pressure
 - Related to thermal degradation of hydrocarbons
 - Associated with brecciated zones and beef formation
 - Timing of entrapment: max burial or during proceeding uplift
- All fractures developed in a short time period close to maximum burial



Project Partners



Geological Survey of Canada

Andy Mort



University of Windsor

Iain Samson



University of Calgary

Bernhard Mayer
Stephen Taylor
Veith Becker

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Evidence of Hydrocarbon Generation and Overpressure Development in an Unconventional Reservoir Using Fluid Inclusion and Stable Isotope Analysis From the Early Triassic, Western Canadian Sedimentary Basin

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