Microfracture Characterization in the Lower Vaca Muerta Formation, Neuquén Basin, Argentina*

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Abstract

The Vaca Muerta Formation in the Neuquén Basin, Argentina, is an emerging resource play containing shale oil and gas in Late Jurassic to Early Cretaceous foreland basin strata. Like many black shales, it is characterized by the presence of abundant bedding-parallel microfractures within the organic-rich matrix. Sub-vertical fractures are also observed across the studied section, adding complexity to characterization of the mudrocks. The Lower Vaca Muerta is composed of alternating mudstones-wackestones, bioclastic siltstones, carbonate mudstones, and bentonite facies. The mudstone-wackestone facies is characterized by an impermeable, wavy, clay-rich matrix that encompasses the kerogen grains. The concept of bedding-parallel microfracturing has been related to thermal maturation of kerogen in organic-rich black shales. Within the oil maturation window, overpressure at the Lower Vaca Muerta interval is correlated with significant total organic content values (up to 10 wt%). These conditions eventually dominate the mechanical behavior of the formation. Observed microfractures are filled or partially filled with calcite cement. Thus carbon and oxygen stable isotope chemostratigraphy together with thin-section petrography aid in establishing the paragenetic sequence, and ultimately identify the origin of the aqueous and hydrocarbon fluids. In addition, microfractures may have the potential to contribute to overall effective permeability of the matrix depending on their length, aperture orientation, and connectivity to larger fractures. Thus, microfracture characterization and their relation to facies is key for identifying the sweet spots for future production.

Selected References

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June 1st, 2015

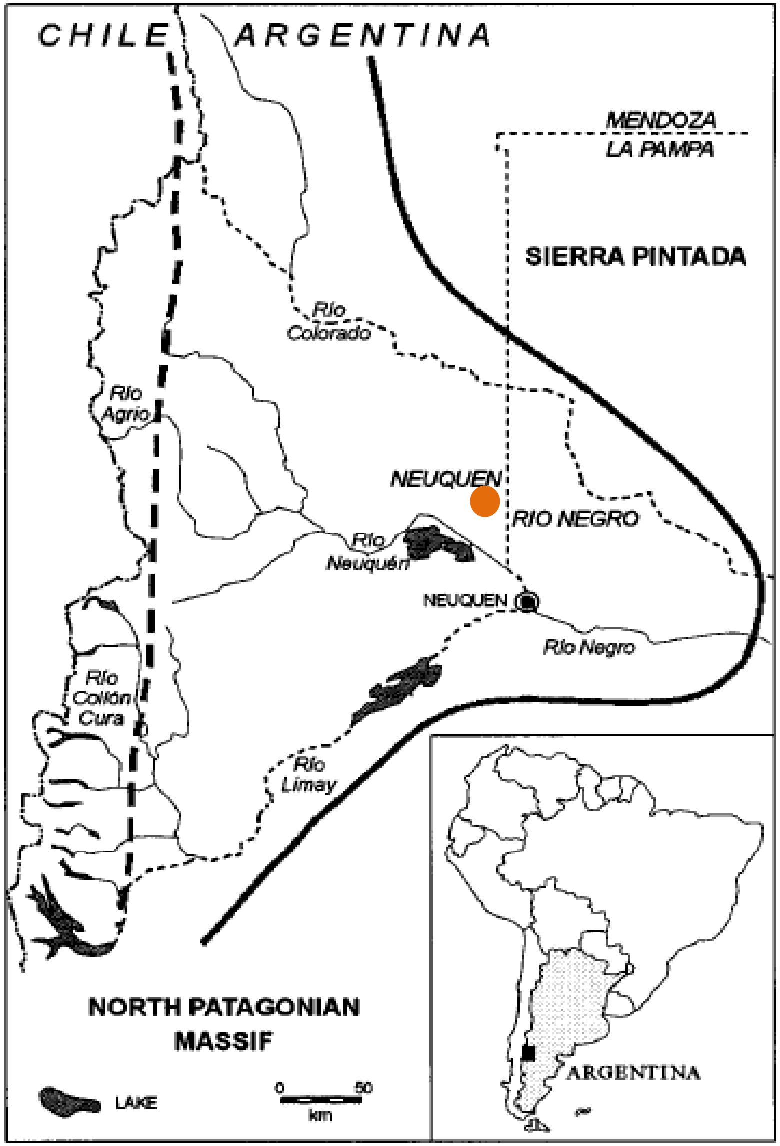
CSM Vaca Muerta Consortium

Outline

- The Neuquén Basin
- Stress Evolution
- Burial History
- Fracture Quantification and Description
- C & O Stable Isotopes
- Conclusion

1. The Neuquén Basin

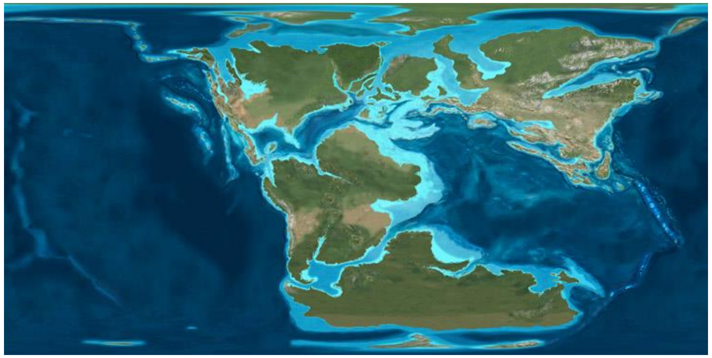
The Neuquén Basin



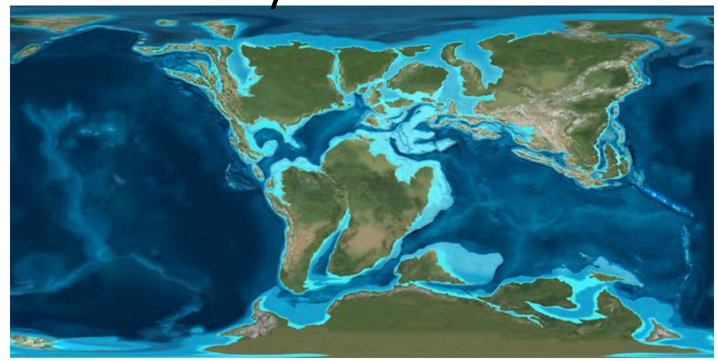
(Modified from Vergani et al., 1995)

Vaca Muerta Fm.

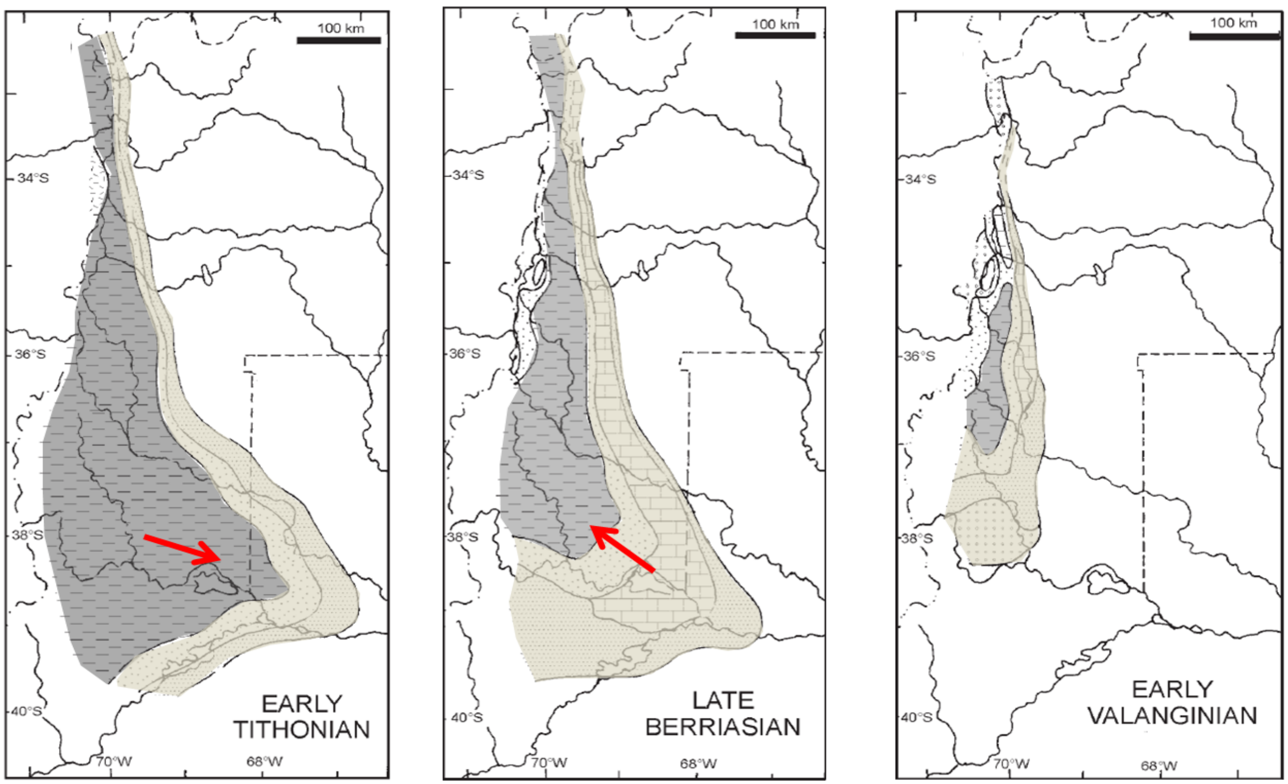
Late Jurassic



Early Cretaceous



2nd order cycle

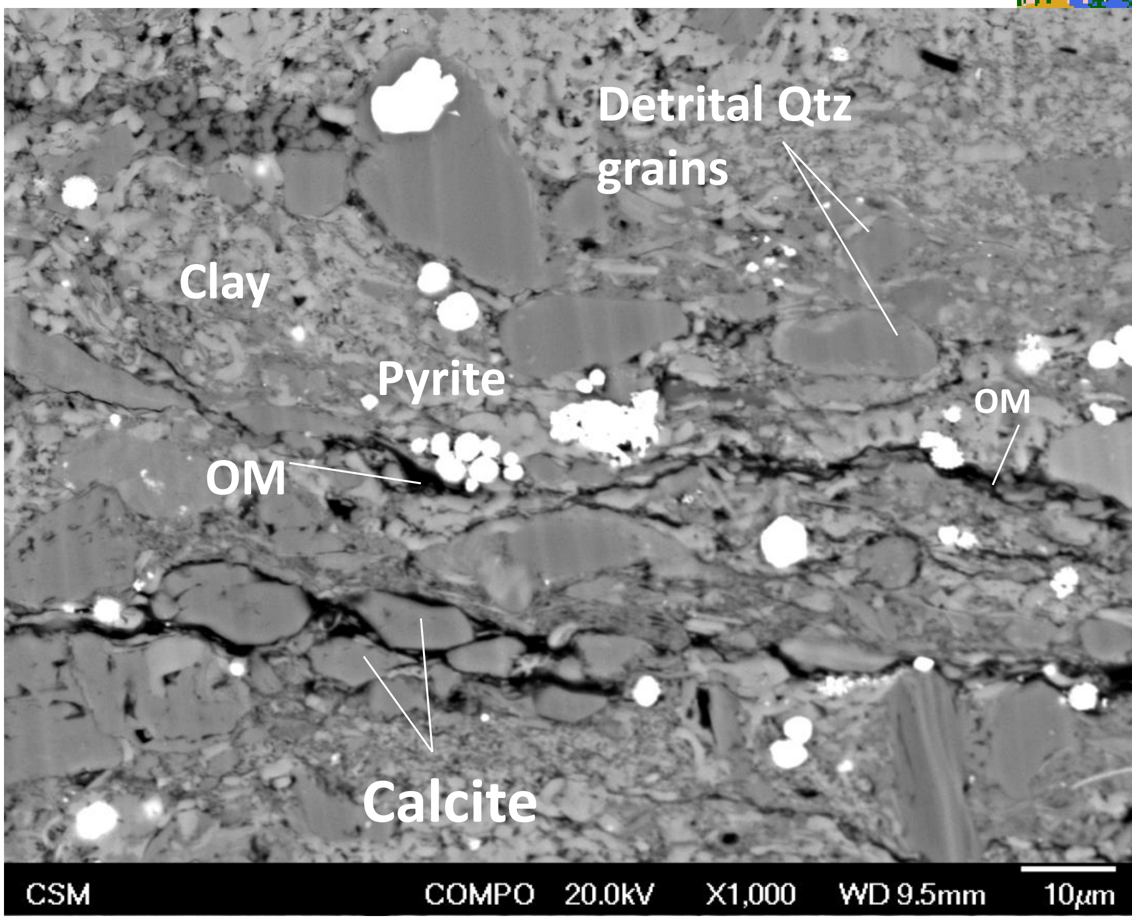


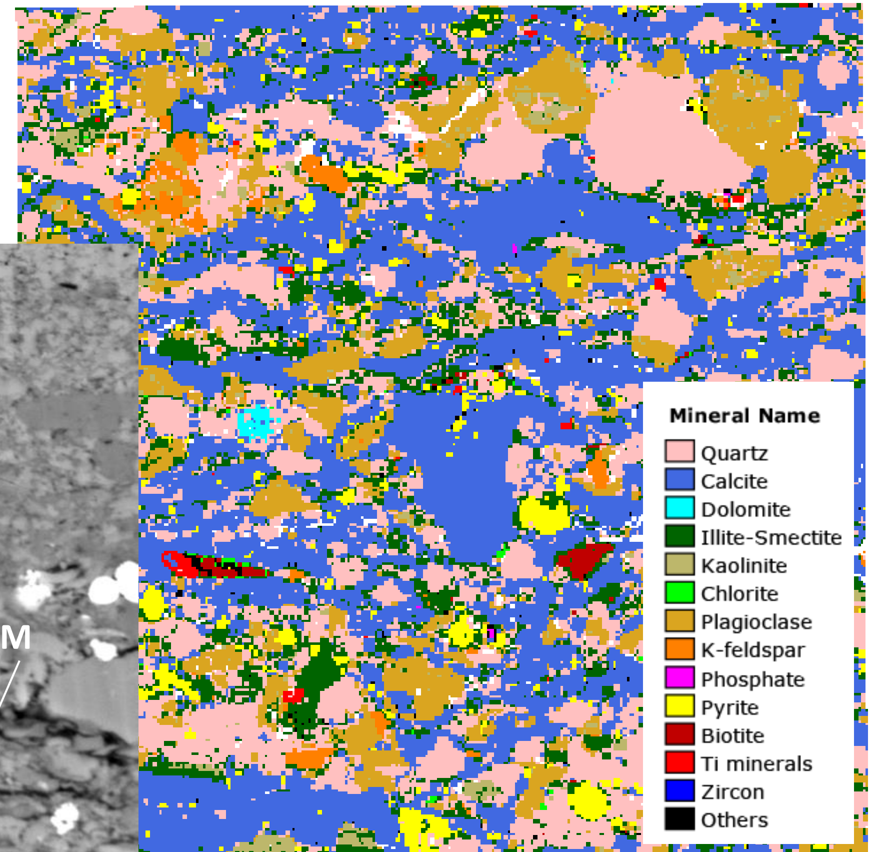
Basinal clastics and carbonates

Platform carbonates and shallow marine (near–shore) clastics

(Modified from Aguirre-Urreta, 2001)

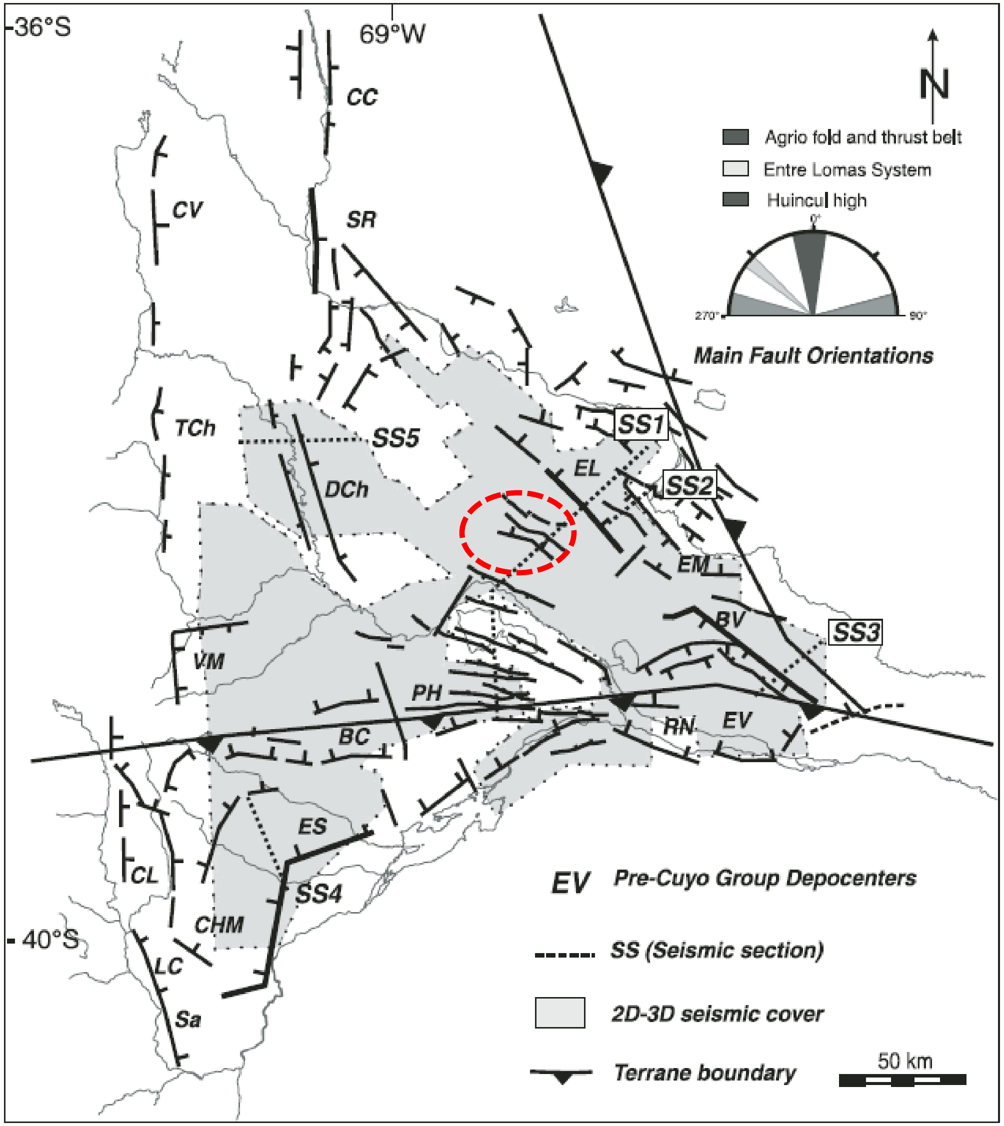
Lower Vaca Muerta Fm.





2. Stress Evolution in the Basin

Stress Evolution in the Basin

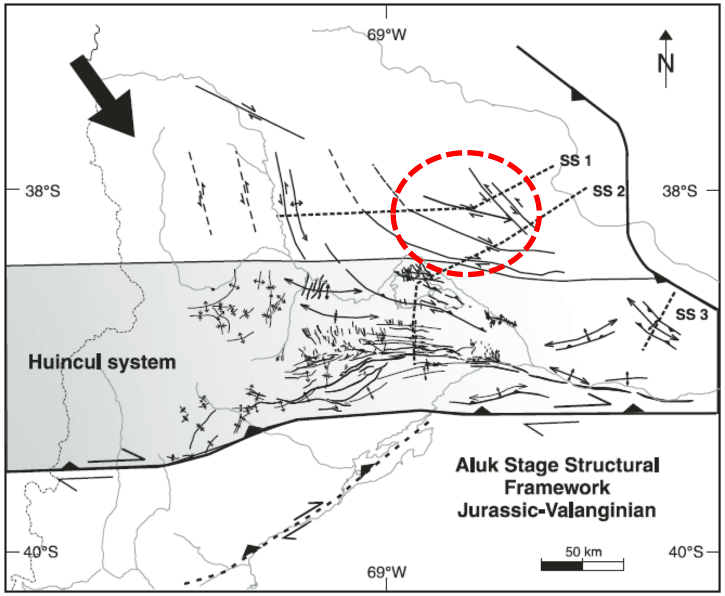


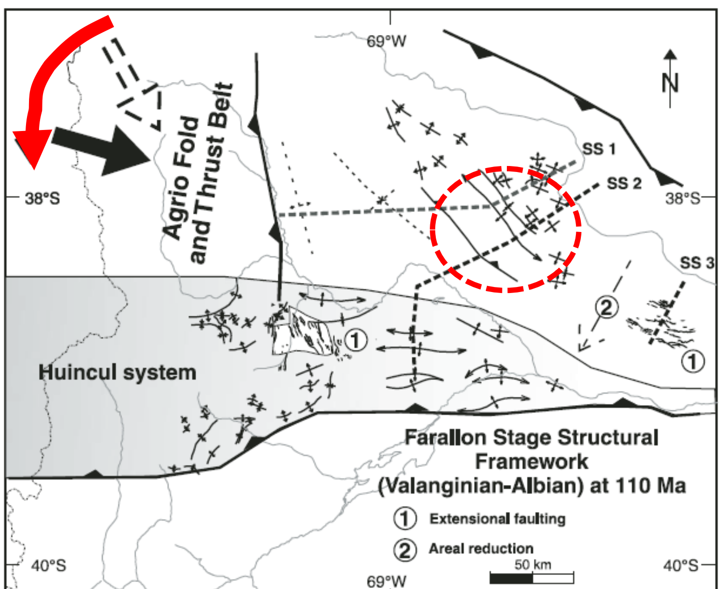
Extensional faults and major depocenters in the embayment

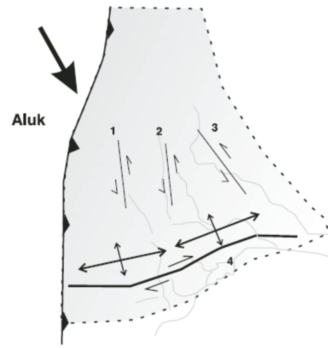
Pre-Cuyo group half-grabens have three main orientations

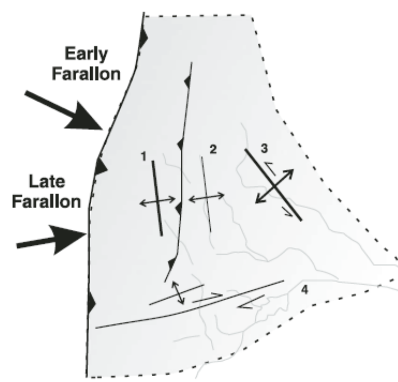
After Mosquera and Ramos 2006

Stress Evolution in the Basin







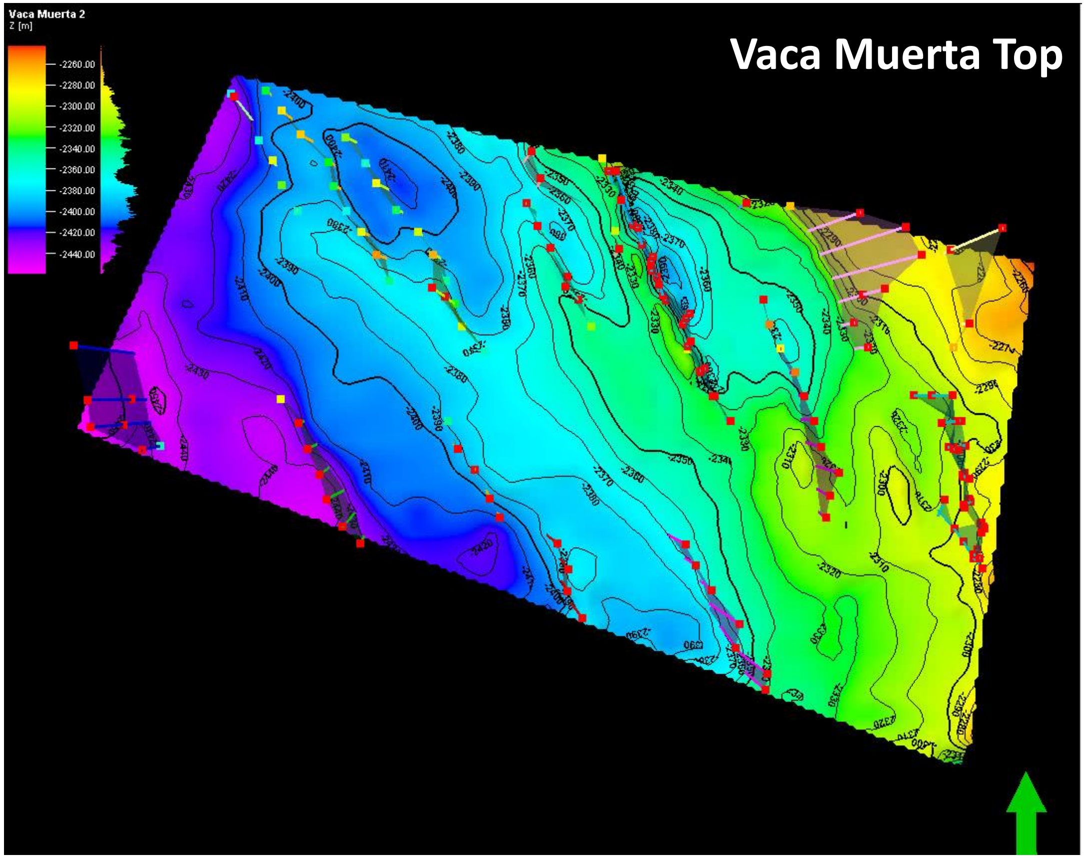


- Rotation of the convergence vector from N40°W to almost orthogonal between the Pacific plates and South America occurred during the **mid-Cretaceous**
- **Miocene**: more orthogonal vector (compression)
- **Pliocene**: widespread extension

After Mosquera and Ramos 2006

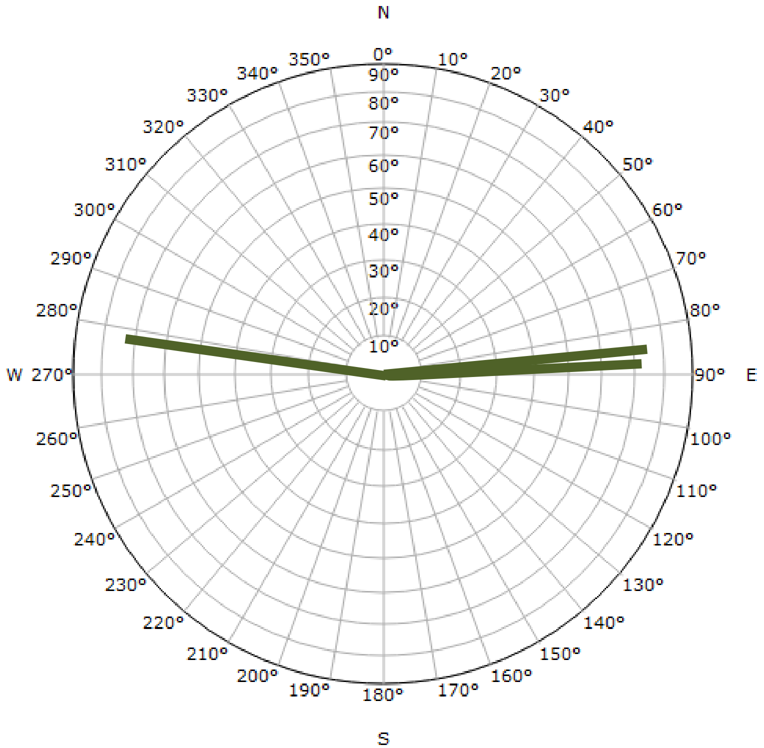
Fault and Fracture Strikes

NW-SE Fault Strike



(Modified after Franklin, 2015)

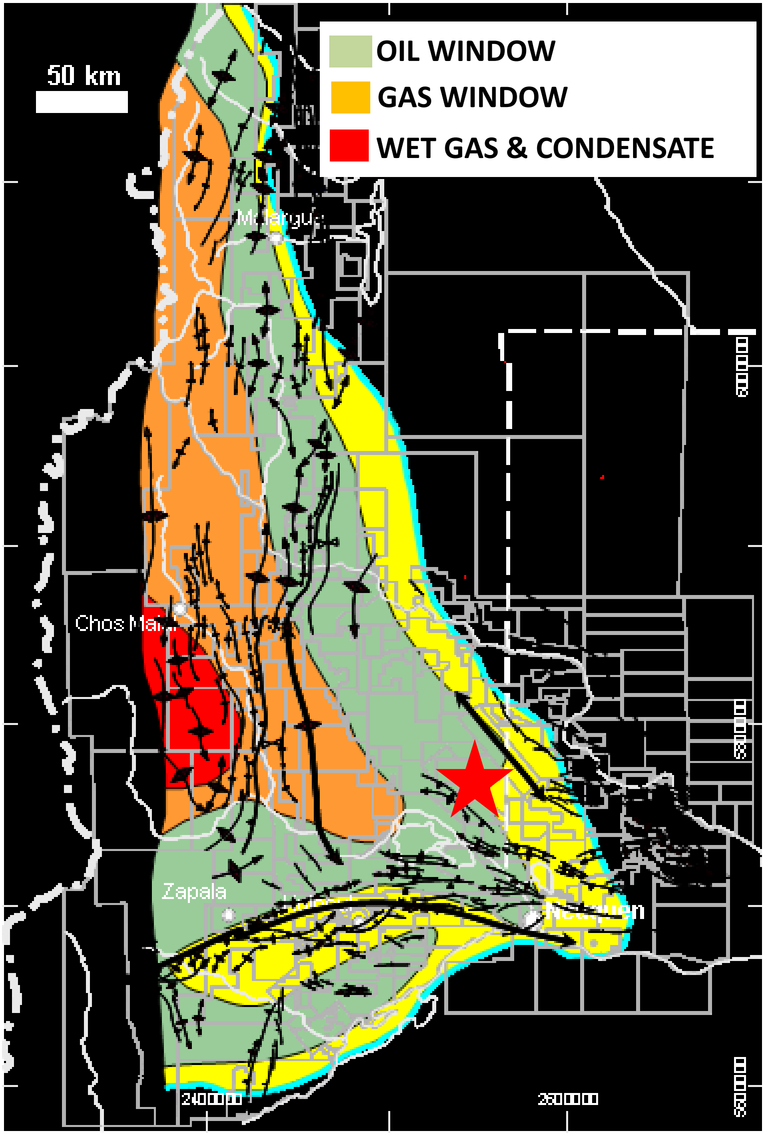
Sub-Vertical Fracture Strike



Log depth	Dip	Azimuth
3098.736	72.47 N	87.81
3099.045	76.27 N	85.72
3117.548	71.96 N	278.39

3. Burial History

Vaca Muerta Maturity Map

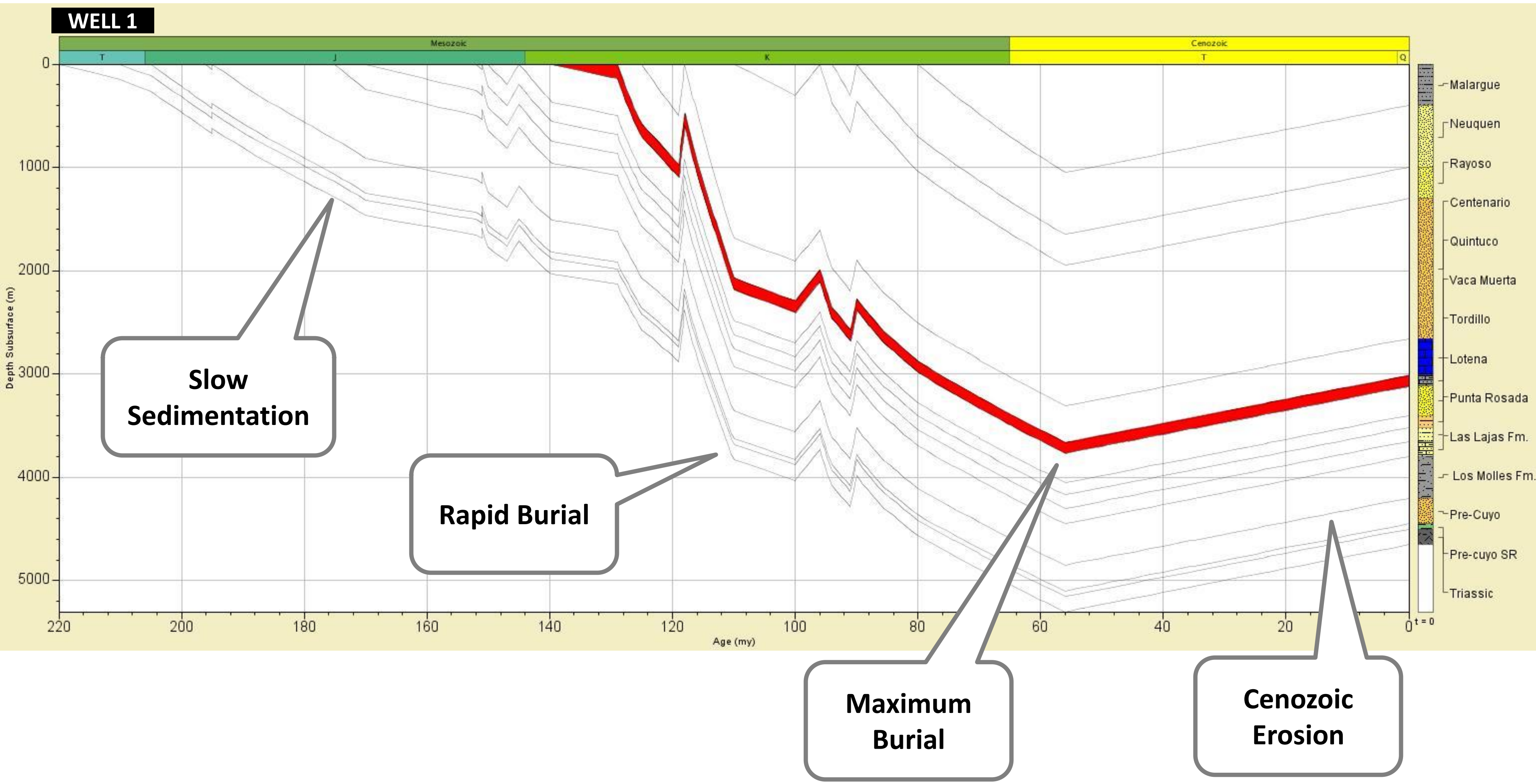


(Modified after Legarreta & Villar, 2011)

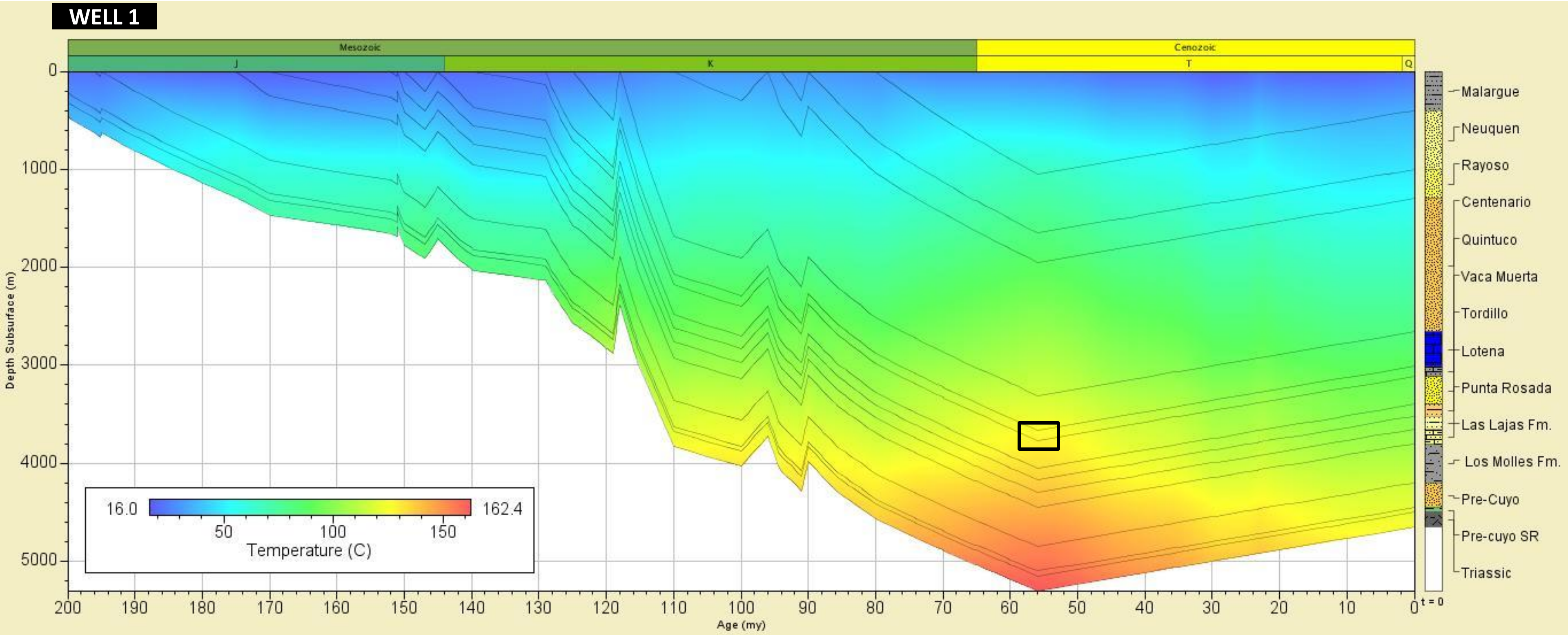
Kerogen Type: I/II

Ro: 0.8 %

Burial History

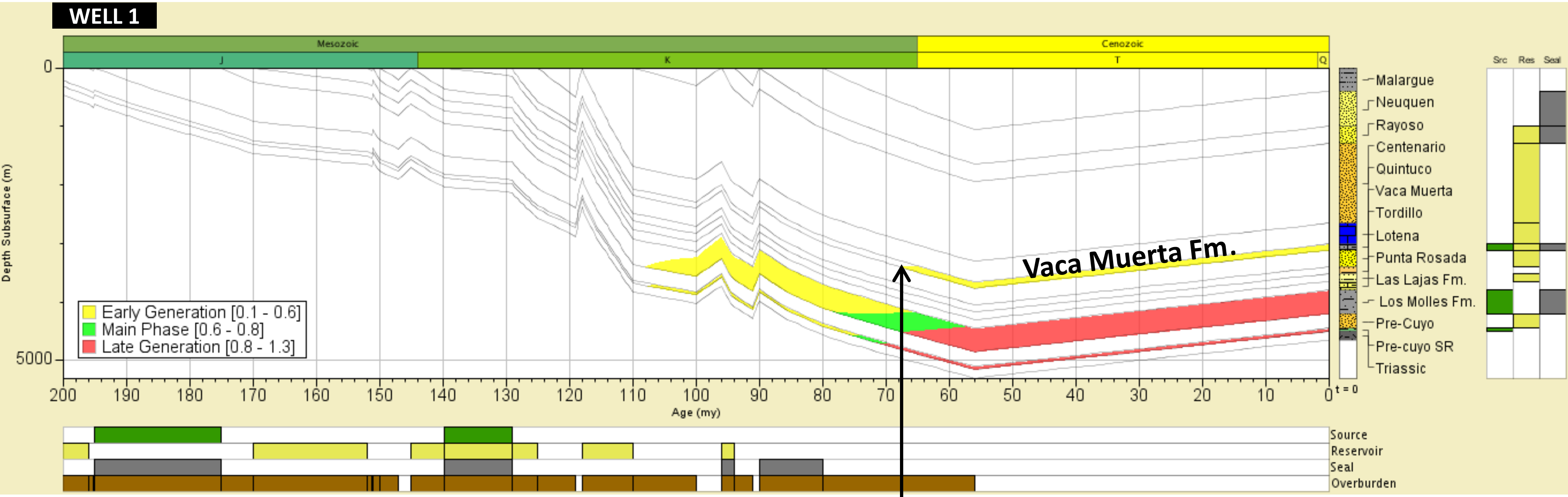


Thermal History



Modelled Vaca Muerta T_{max} 125 °C

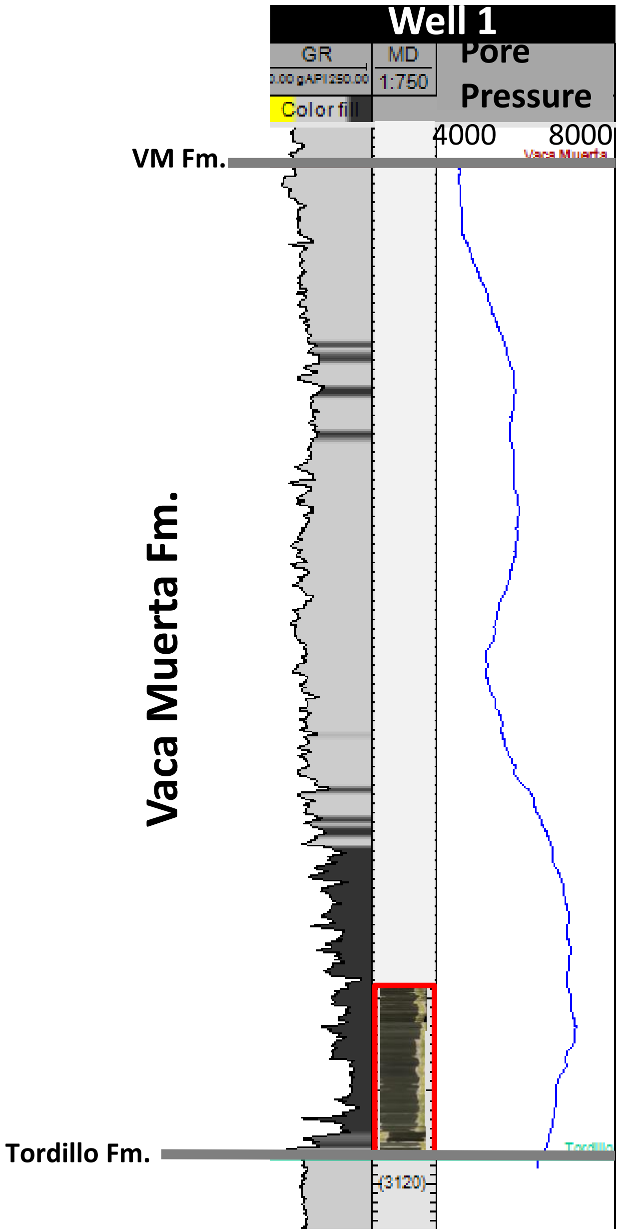
Kinetics



Early oil window @ 68 my

4. Fracture Quantification and Description

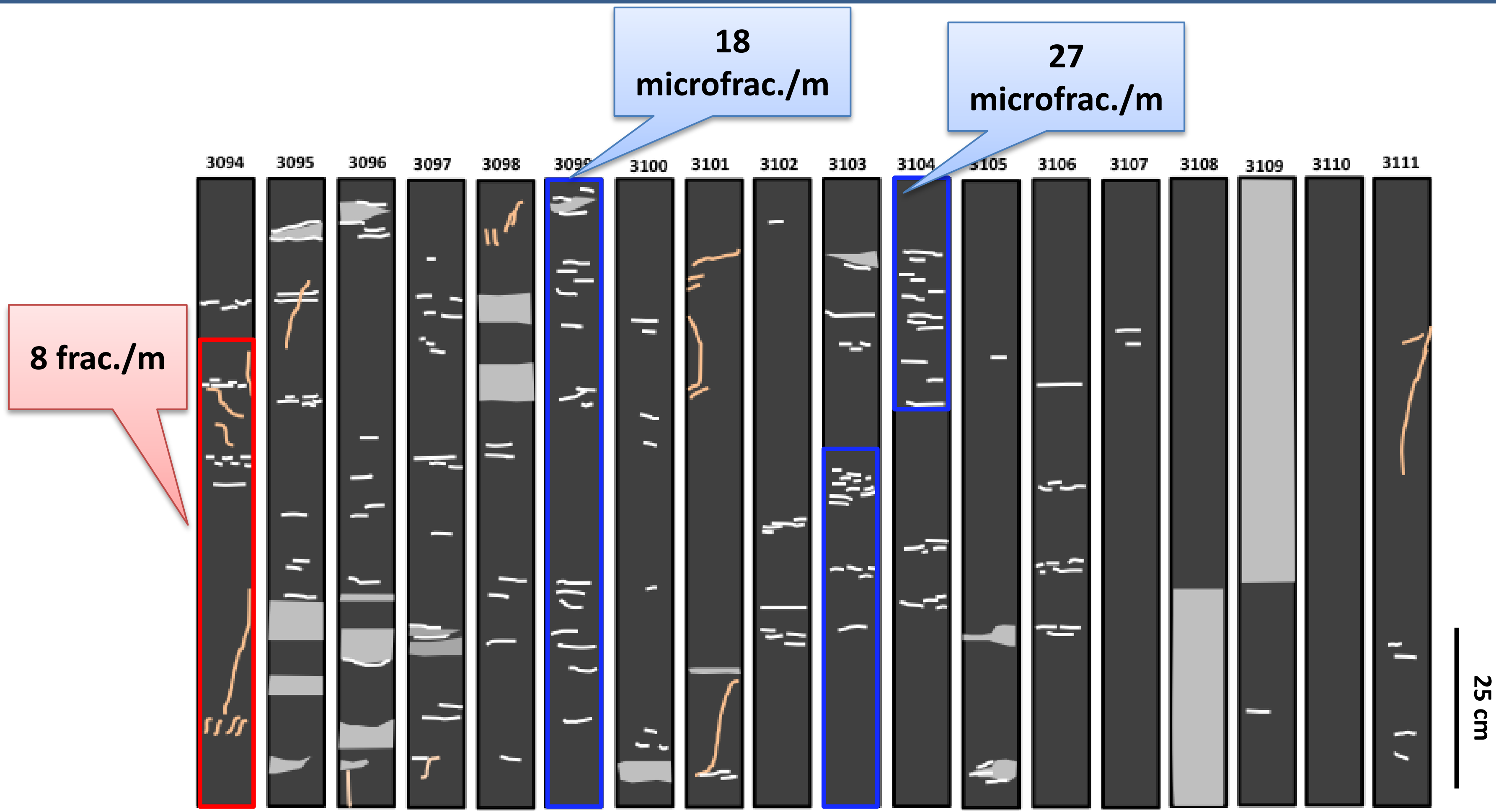
Well 1



18m core from Lower Vaca Muerta Fm.

Significant overpressure

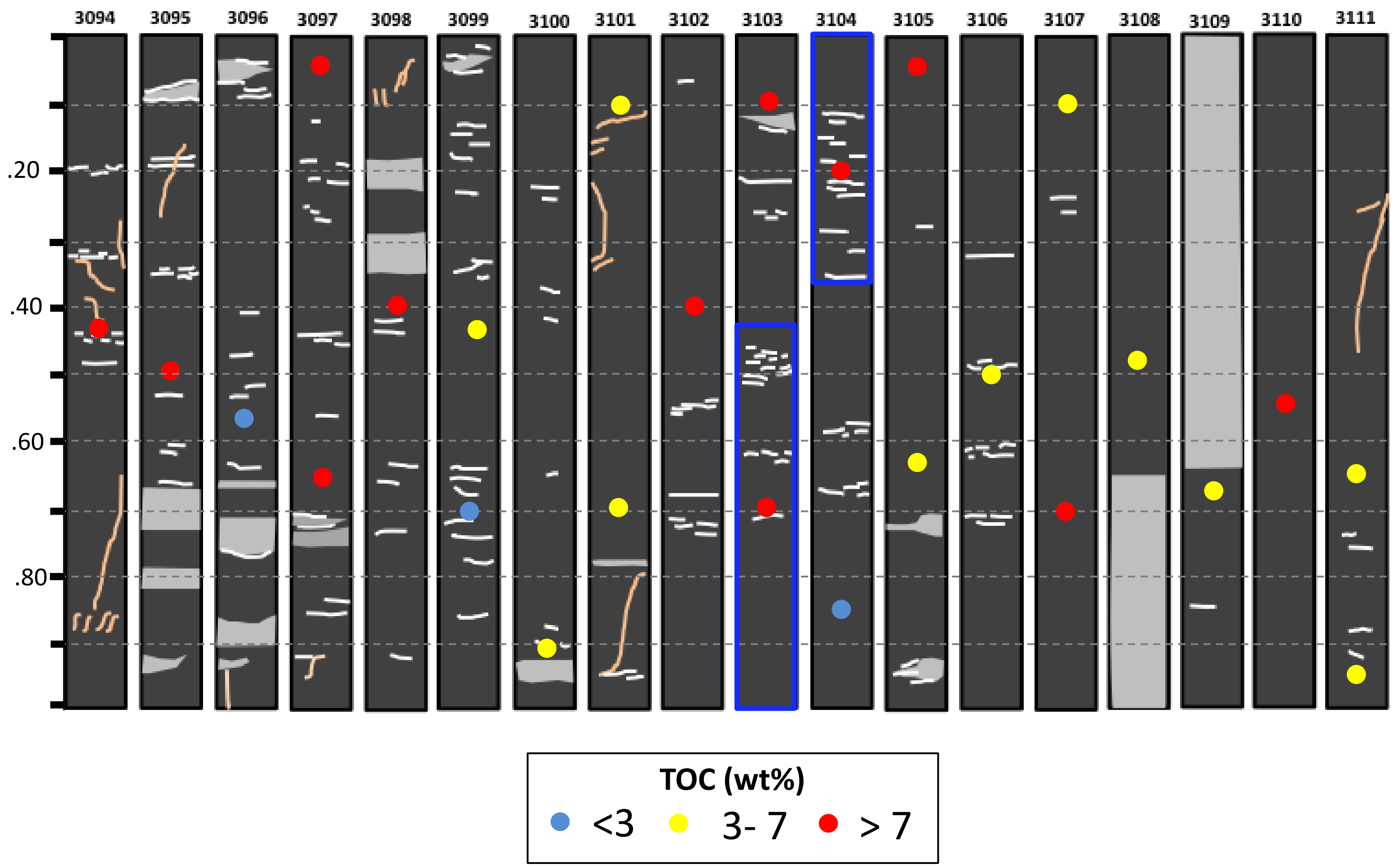
(Micro)Fracture Quantification



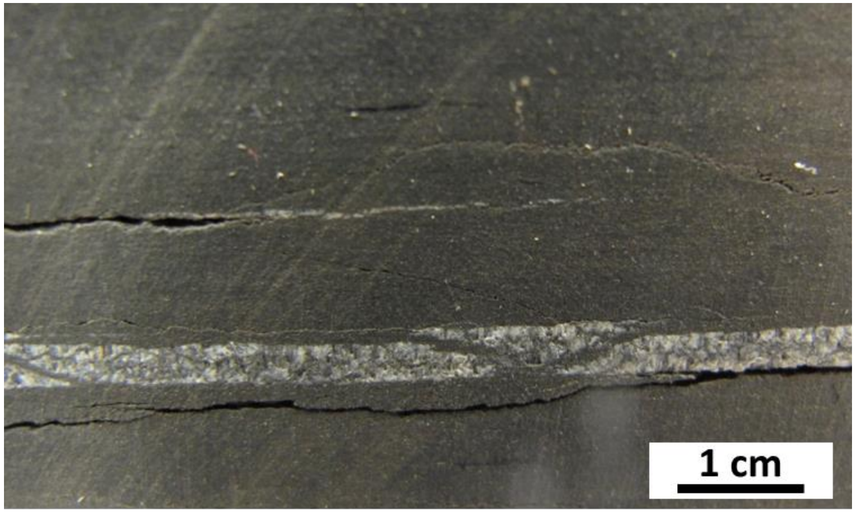
155 Horizontal calcite-filled microfractures (Microfracture Density: 8.61 Microfrac./m)

22 Sub-vertical calcite-filled fractures (Fracture Density: 1.22 Frac./m)

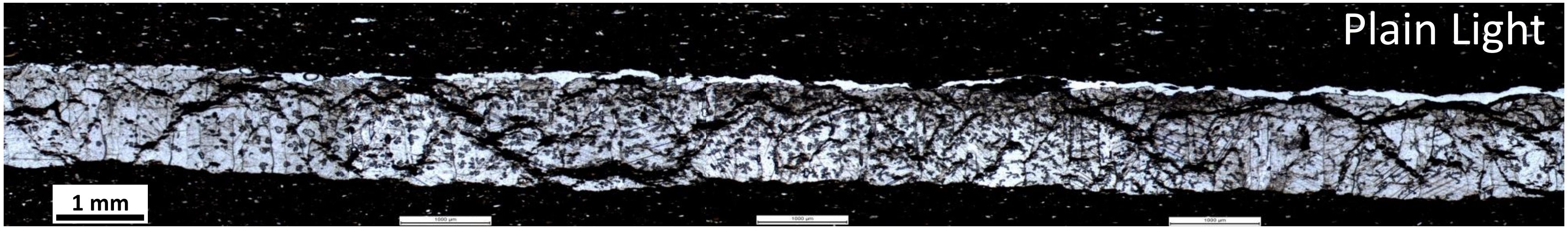
TOC & (Micro)fractures

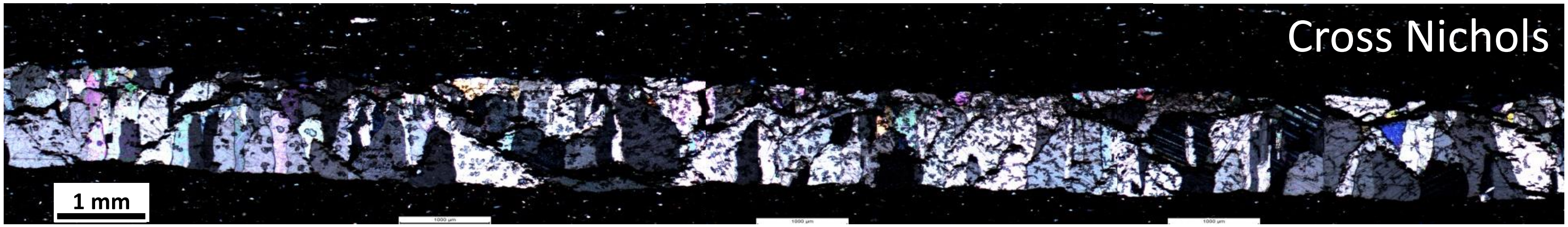


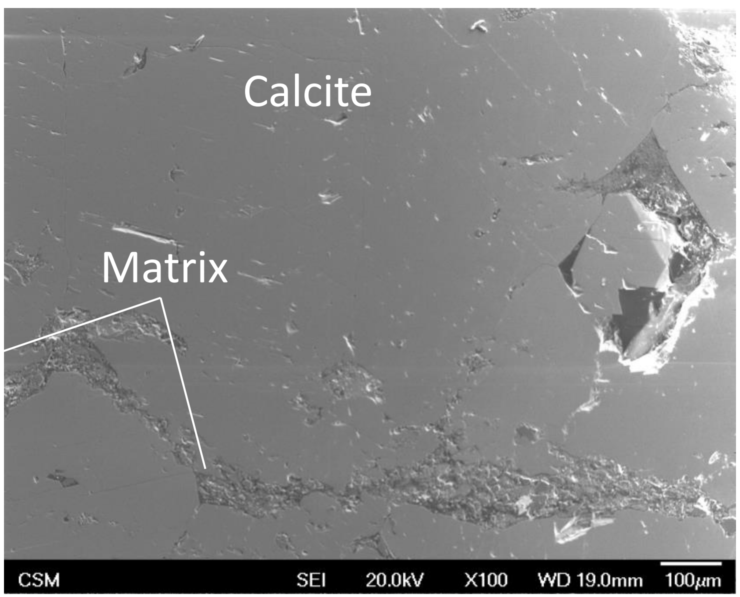
1. Horizontal Microfractures - Core

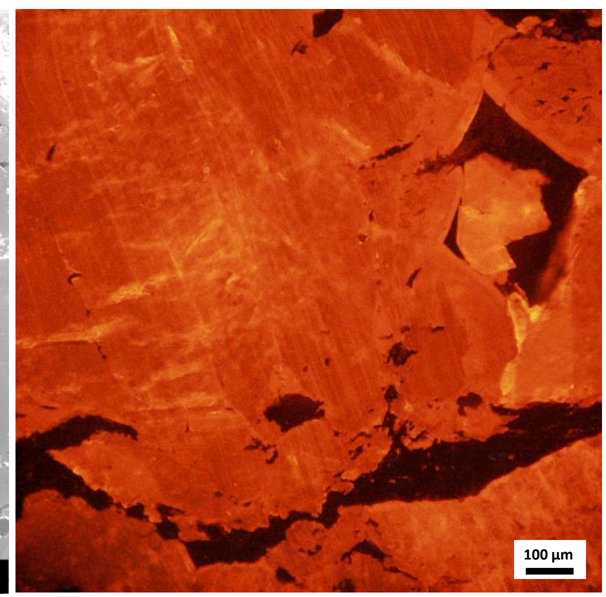


Horizontal Microfracture - TS

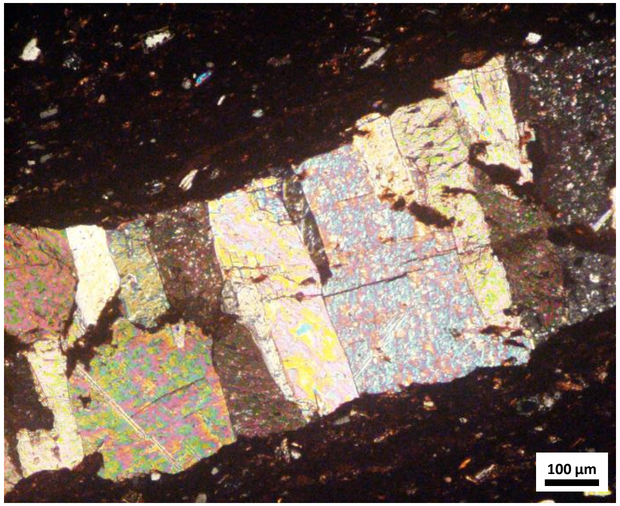


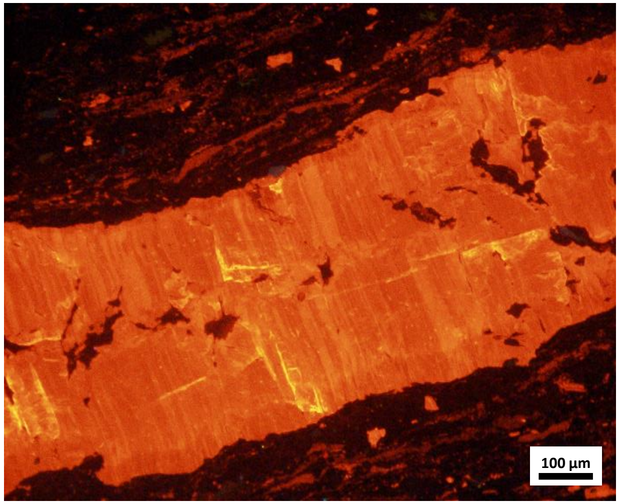


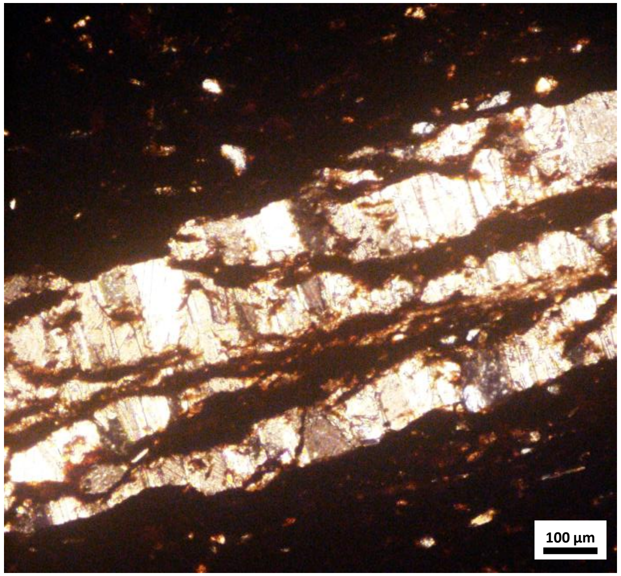


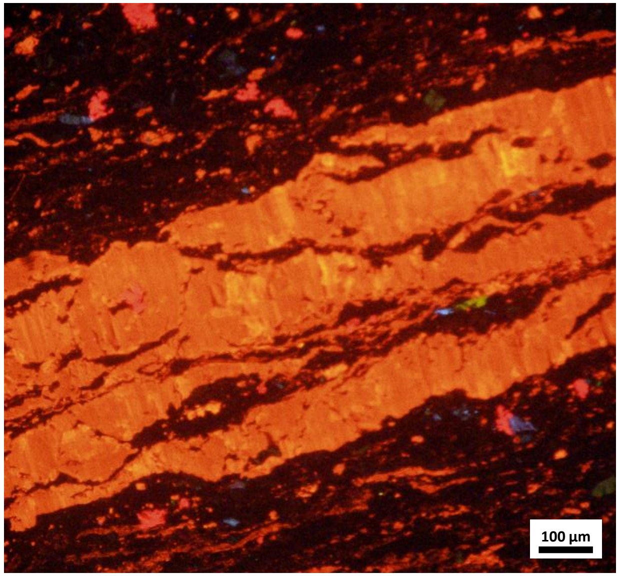


Horizontal Microfracture



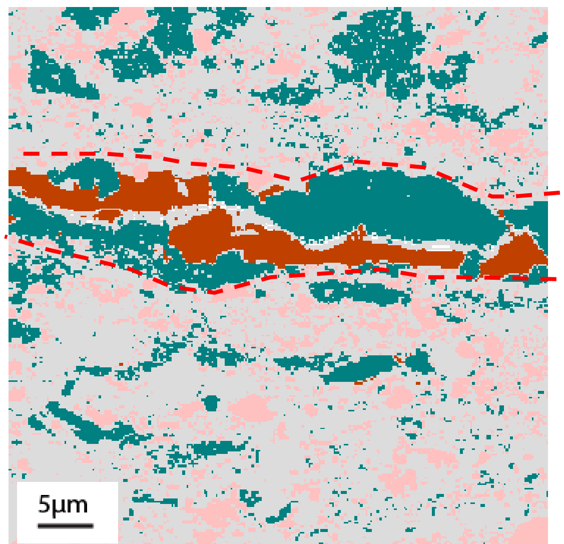






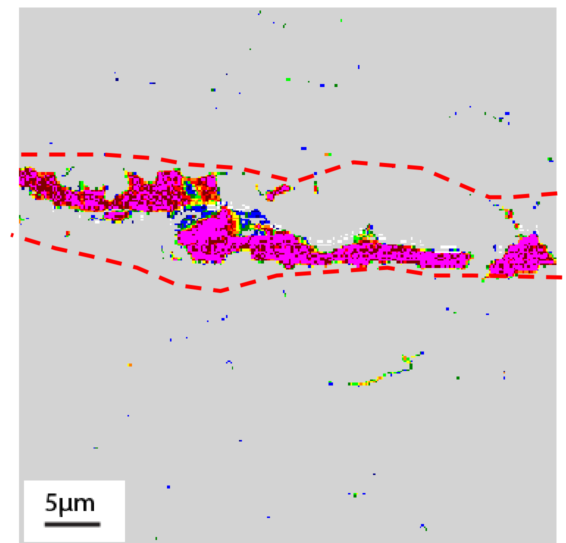
Horizontal Microfractures

OM Map



Mineral Name	Area%
Organic Matter	5.27
Calcite	20.64
Quartz	15.97
Others	58.12

Carbon Map

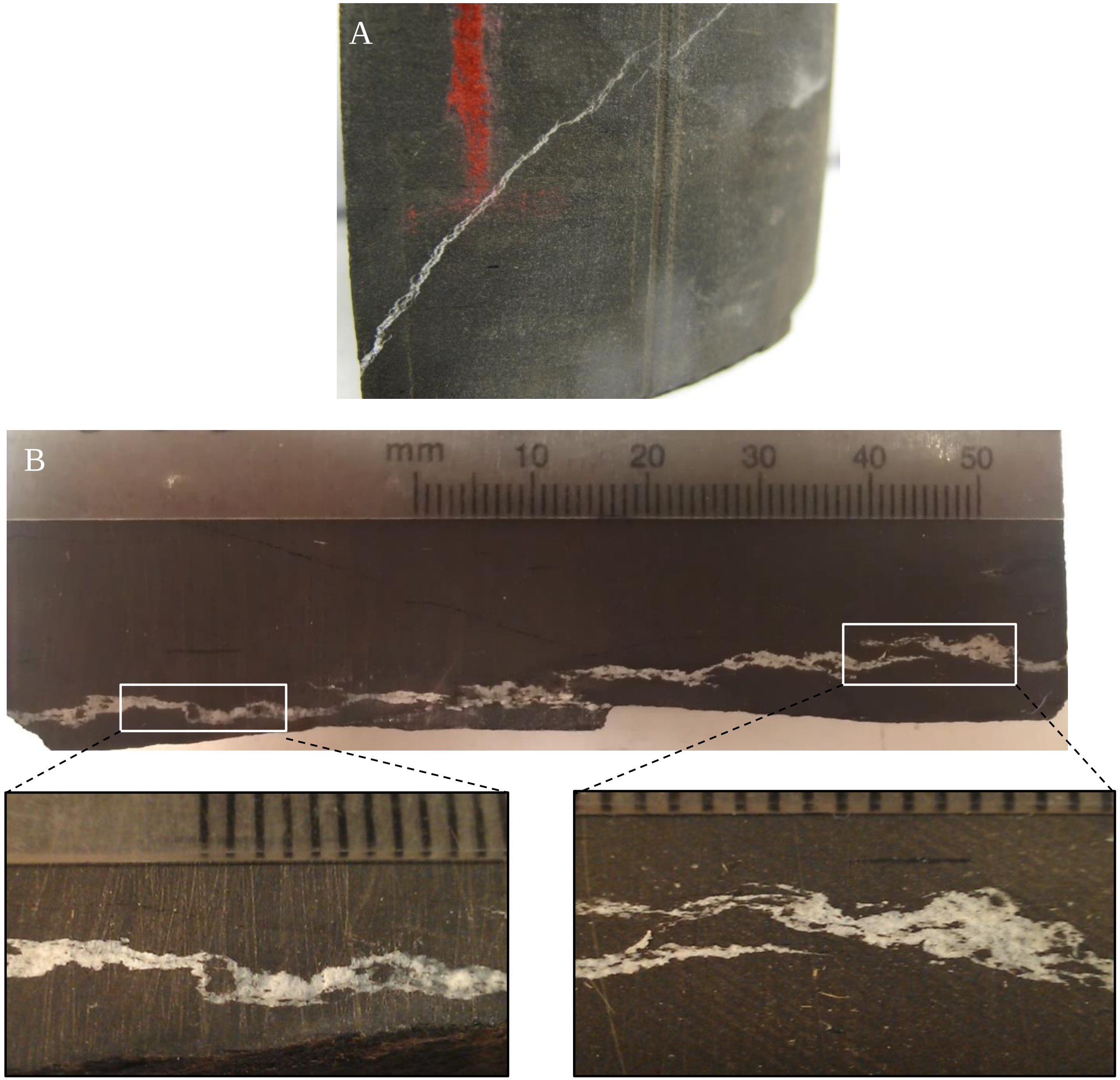


Mineral Name

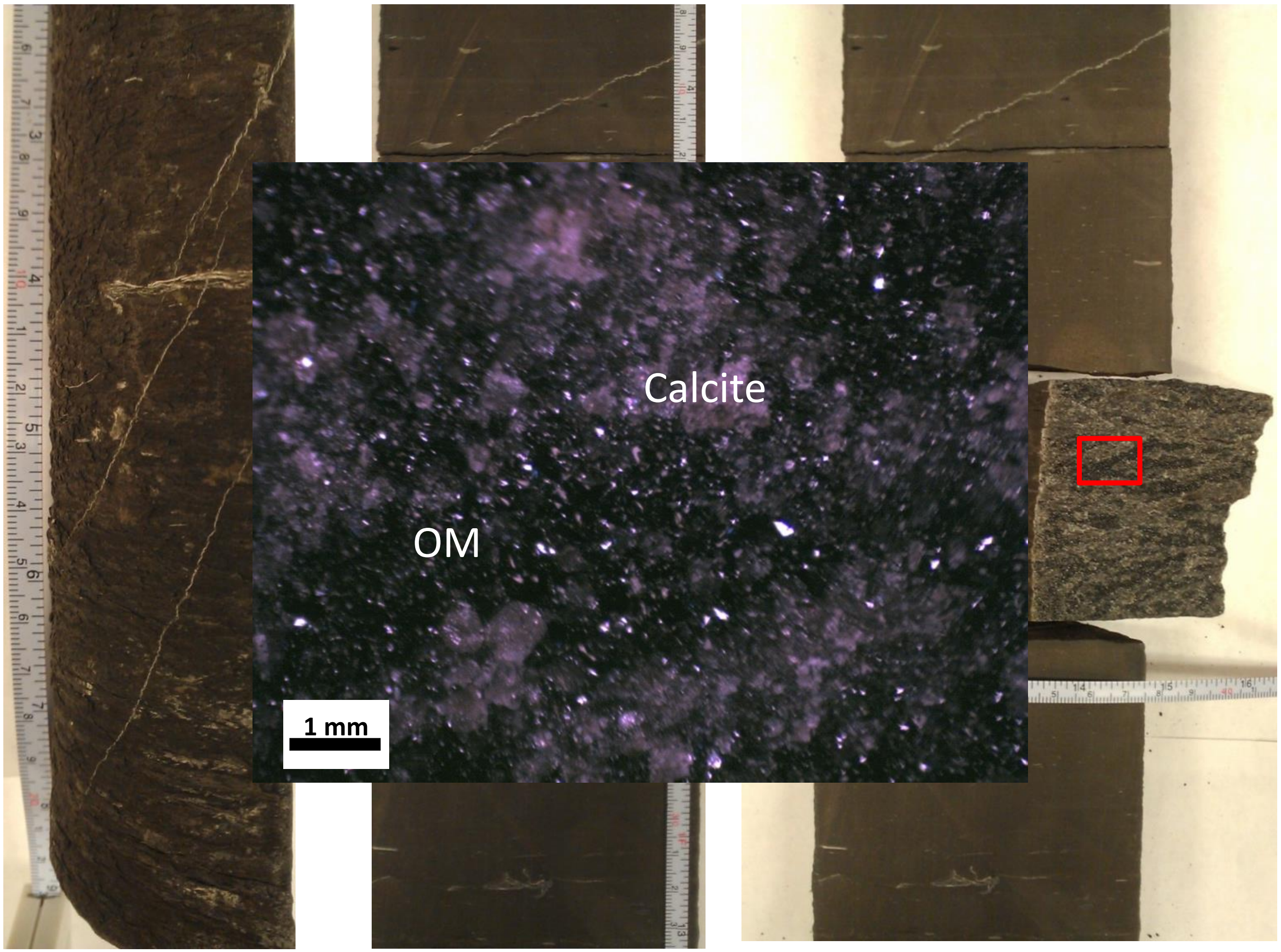
- C:<10%
- C:10-15%
- C:15-20%
- C:20-25%
- C:25-30%
- C:30-35%
- C:35-40%
- C:40-45%
- C:>45%-100
- Others

Fracture Boundary

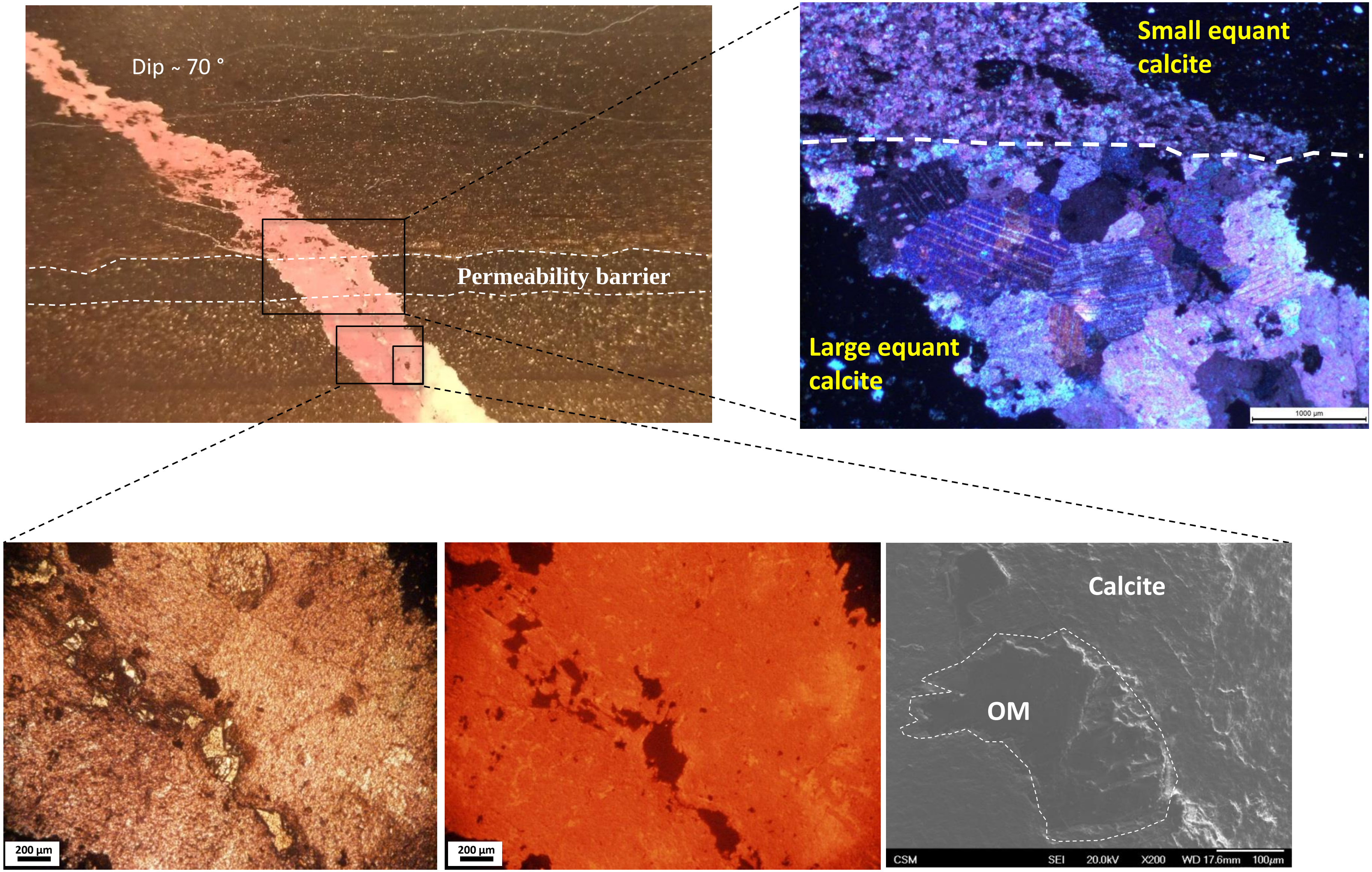
2. Sub-Vertical Fractures -Core



Sub-Vertical Fractures - Core

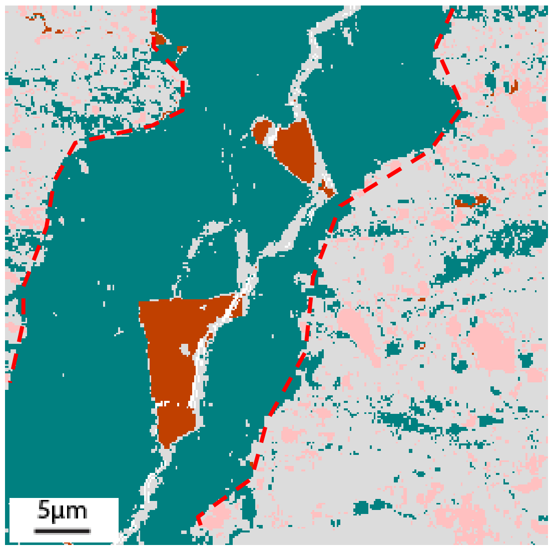


Sub-Vertical Fractures - TS



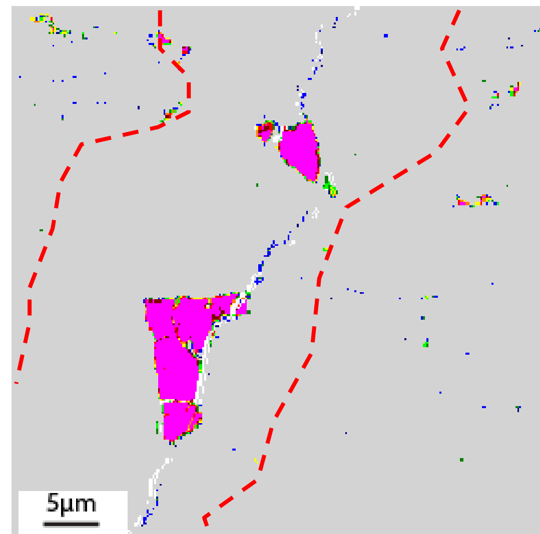
Sub-Vertical Fractures

OM Map



Mineral Name	Area%
Organic Matter	3.48
Calcite	49.83
Quartz	6.86
Others	39.84

Carbon Map



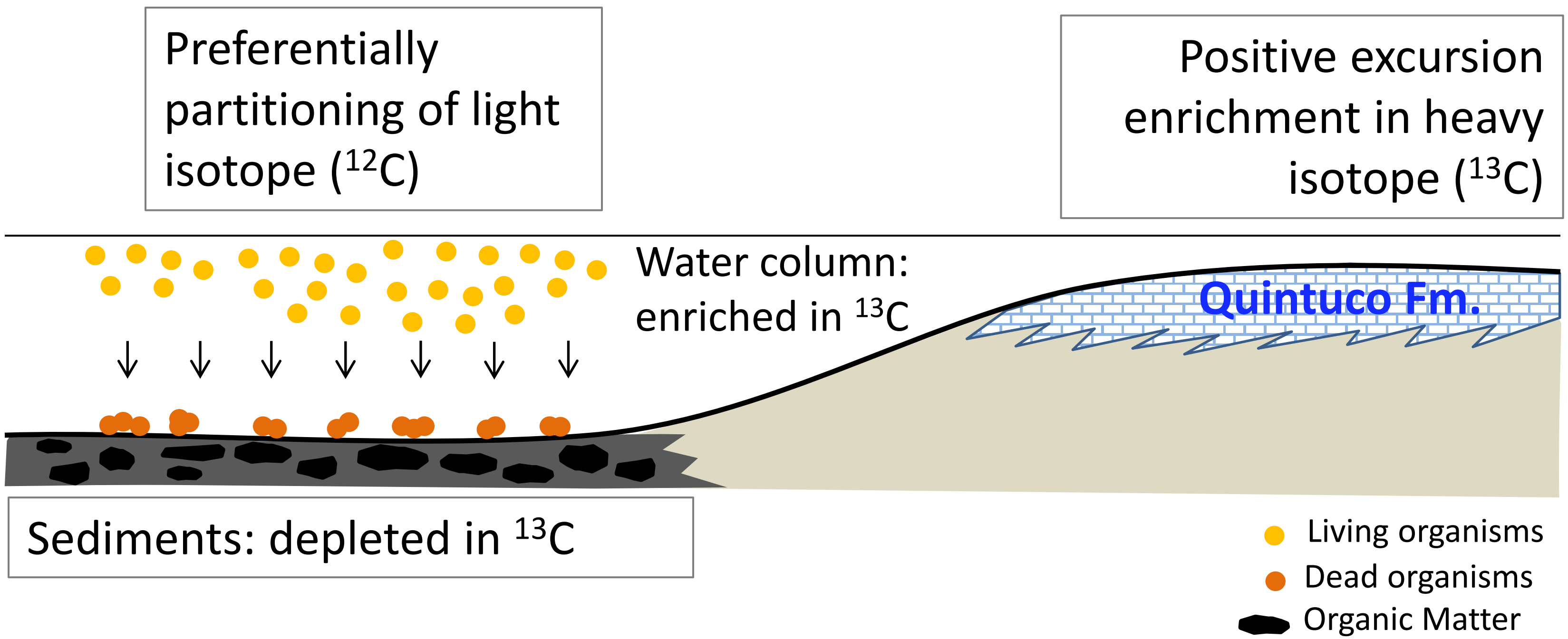
Mineral Name

- C:<10%
- C:10-15%
- C:15-20%
- C:20-25%
- C:25-30%
- C:30-35%
- C:35-40%
- C:40-45%
- C:>45%-100
- Others

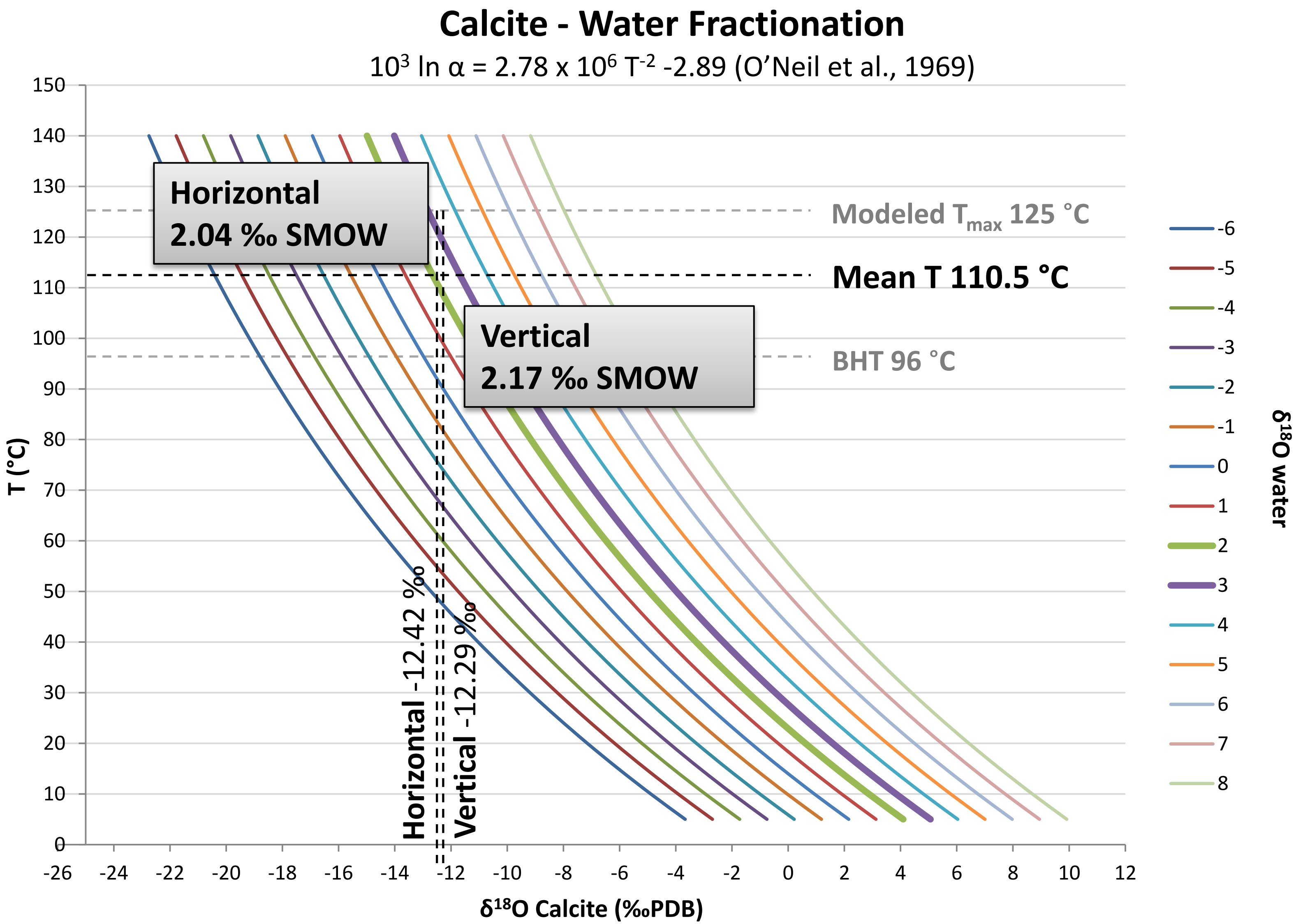
5. C and O Stable Isotope

$\delta^{13}C$ Stable Isotope

Productivity Increase

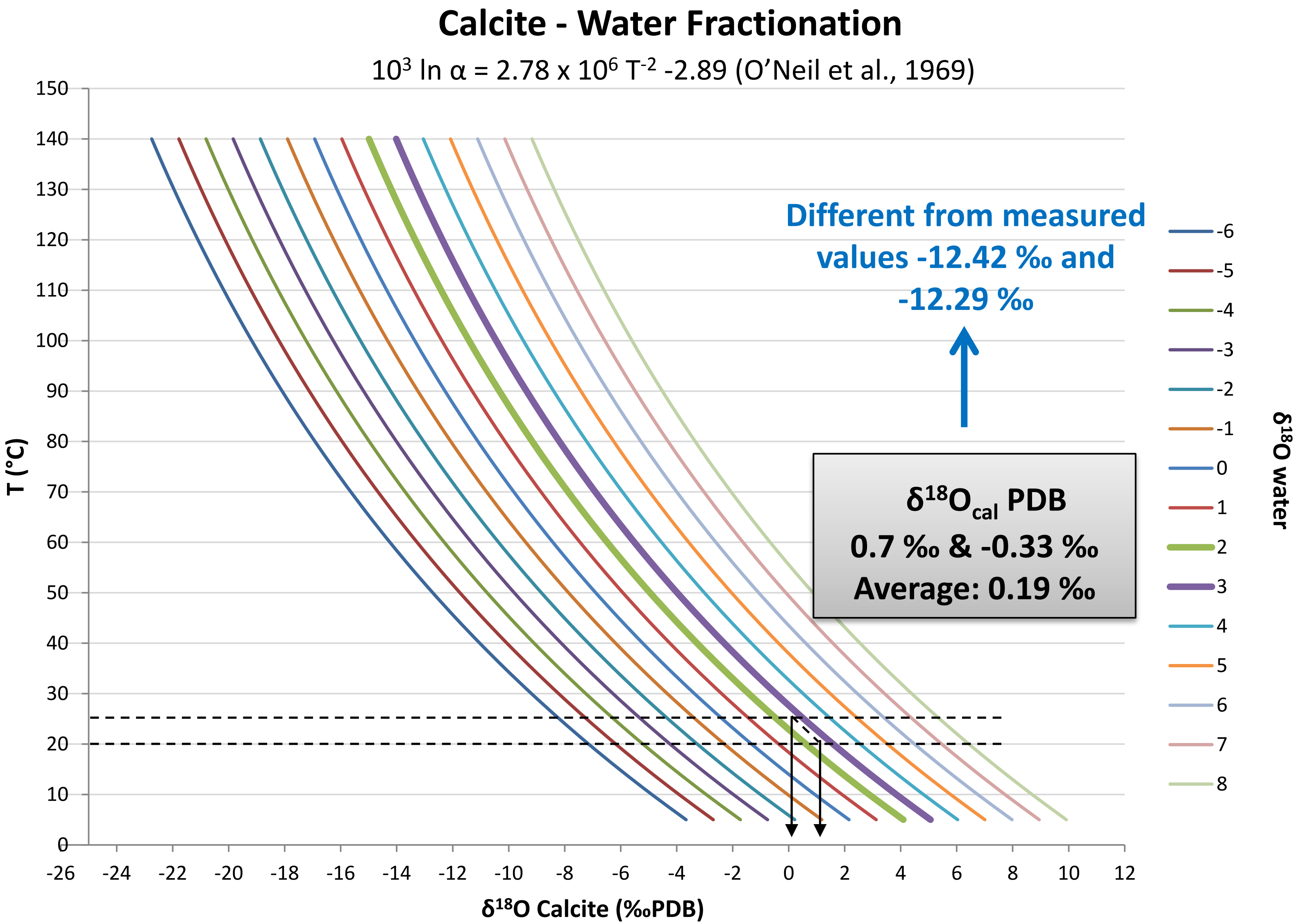


Mean Water Composition



Average $\delta^{18}O$ water 2.11 ‰ SMOW

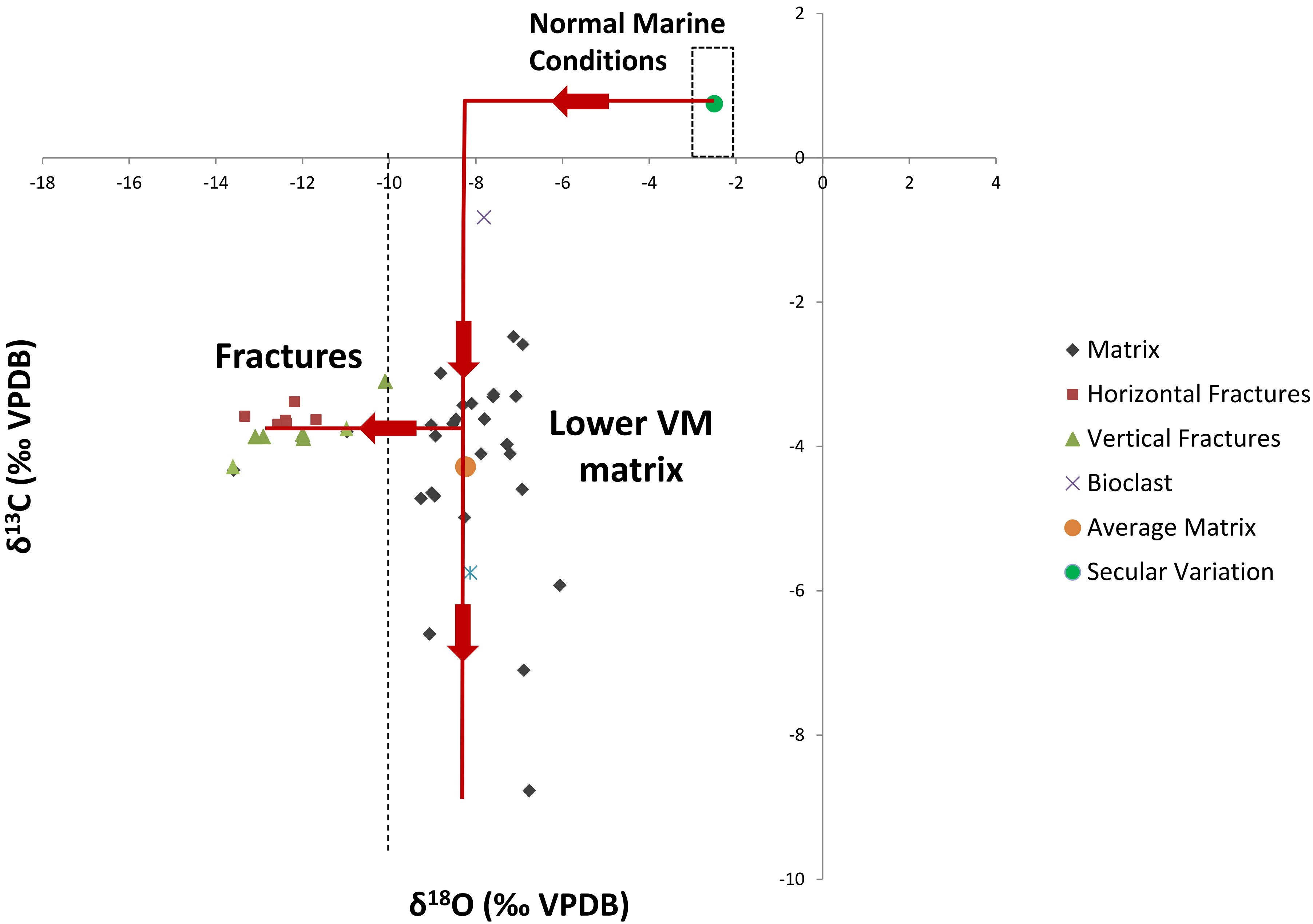
Calcite in Eq. with Water



Surface Temperature range for calcite precipitation: 20-25 °C

Average $\delta^{18}O$ water 2.11 ‰ SMOW

Isotope Data



Conclusions

Cement type

- Sub-vertical: equant calcite
- Horizontal: equant and fibrous
- OM present in both types of fractures (Qemscan)
- Precipitation deep in the burial, reducing environment with significant Mn2+ and Fe2+ (CL)

Stress regime and fractures

- Strike of sub-vertical fractures on the core almost perpendicular to regional trend

Basin modeling

- Modeled T_{max} 125 °C
- Onset of HC generation in Late Cretaceous (68 m.y.)

Isotopes

- Calcite for horizontal and vertical fractures precipitated from same fluid
- Calcite extremely diagenetically altered with burial
- Depleted C values, inherited from the matrix

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