Brittle Deformation, Diagenesis and Hydrothermal Alteration –The Recipe for Enhanced Extra-Matrix Permeabilities in Santos Basin Pre-Salt

Rodrigo Corrêa[1], B. Carvalho[1], E. Ukar[2], A. Fall[2], S. Laubach[2], and A. Pestilho[3]

Search and Discovery Article #30685 (2025)**
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[1]Petrobras
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[3]Universidade de São Paulo

Abstract

The Barra Velha Formation is a carbonate unit in Brazil's Santos Basin Pre-salt, notable for its extensive fracturing and karstification. Core sample analyses reveal structures indicative of hydrothermal alteration, often manifested as breccias or veins. These alterations and diagenesis imprints significantly affect well productivity, with dissolution features commonly observed in both image logs and rock samples. However, the understanding of the timing, temperature, age, and geochemical characteristics of the fluids affecting the structural framework remains limited, mainly due to the complex interplay between deformation and fluid migration. This uncertainty presents challenges in developing a comprehensive model that explains the relationship between natural fractures and diagenesis, as well as the preservation of large pores.

This study investigates the textures of brittle structures and how diagenesis and hydrothermal alteration have reshaped the structural framework over time in the Barra Velha Formation, aiming to reconstruct the timeline of diagenetic events and link brittle deformation to hydrothermal processes that impact reservoir quality. To achieve our objectives, we employed an integrated approach to gather data on the cements present in the rocks. We described 110 meters of core samples, focusing on structural features and related diagenesis. We analyzed 31 thin sections through transmitted light petrography, cathodoluminescence, and scanning electron microscopy. Fluid inclusion microthermometry was used to determine precipitation temperatures for quartz and barite cements. The bulk crush leach method assessed halogen compositions in fluid inclusions. Noble gas compositions were analyzed for magmatic influences, while carbon and oxygen isotopes were measured in carbonate cements to evaluate parent fluid composition. U-Pb geochronology provided absolute ages for the carbonate cements.

Our findings elucidate deformation mechanisms affecting the Barra Velha Formation, characterized by multiple brecciation, dissolution, faulting, and fracturing events. Evidence of hydrothermal mineralization includes barite veins, saddle dolomite, breccias, and quartz-filled veins, highlighting the influence of hydrothermal fluids on diagenesis. High salinity fluid inclusions rich in mantle volatiles suggest mixing between deep hydrothermal fluids and evaporitic brines. Mineralized fault zones were dated using U-Pb geochronology to approximately 95 million years ago. We constructed a timeline of diagenetic events and natural fractures, constrained by U-Pb ages. The fracture network underwent several cementation events, especially where fluids ascended through fault damage zones. Open porosity within fractures was

preserved, and intense dissolution created large pores only partially filled by cementation, leaving connected open pores that positively impacts well productivity.

AAPG International Conference & Exhibition

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Ranking of 30 most productive oil wells in Brazilian Pre-salt

Ranking position	Well name	Oil field	Basin	Location	Oil Production (bbl/d)
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How can we find **more "high production" wells?**

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How can we find **more "high production" wells?**

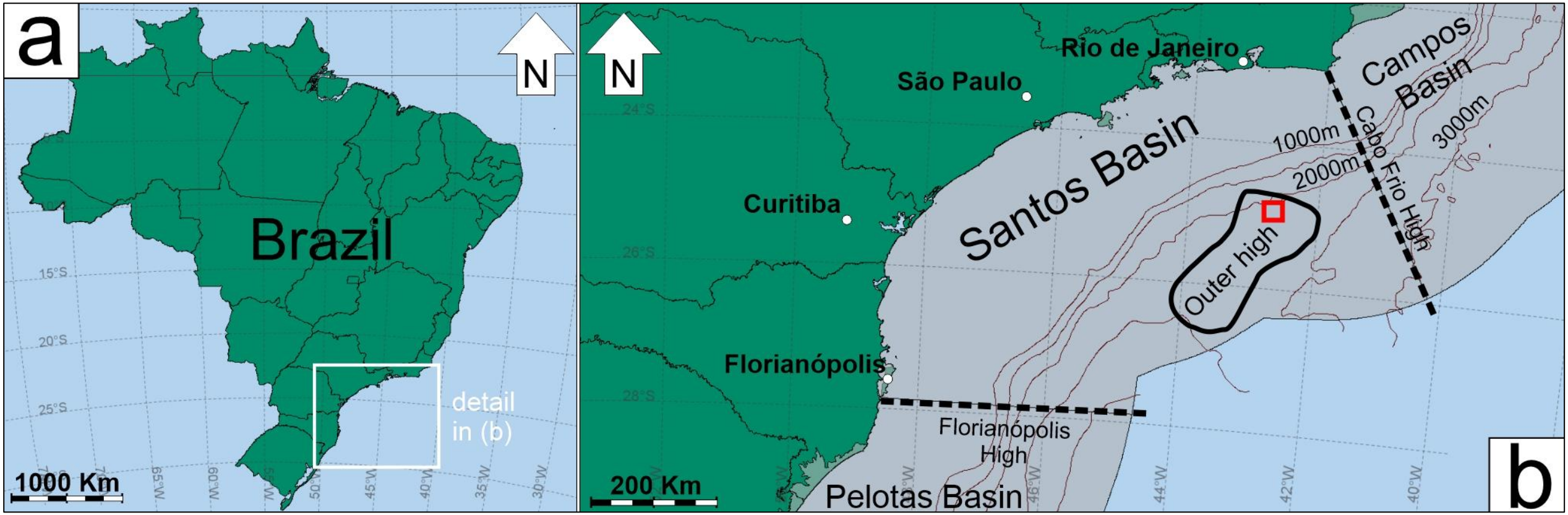
What is the geological recipe for such **high productivity?**

Brazilian national petroleum agency report (June/2025)

Location

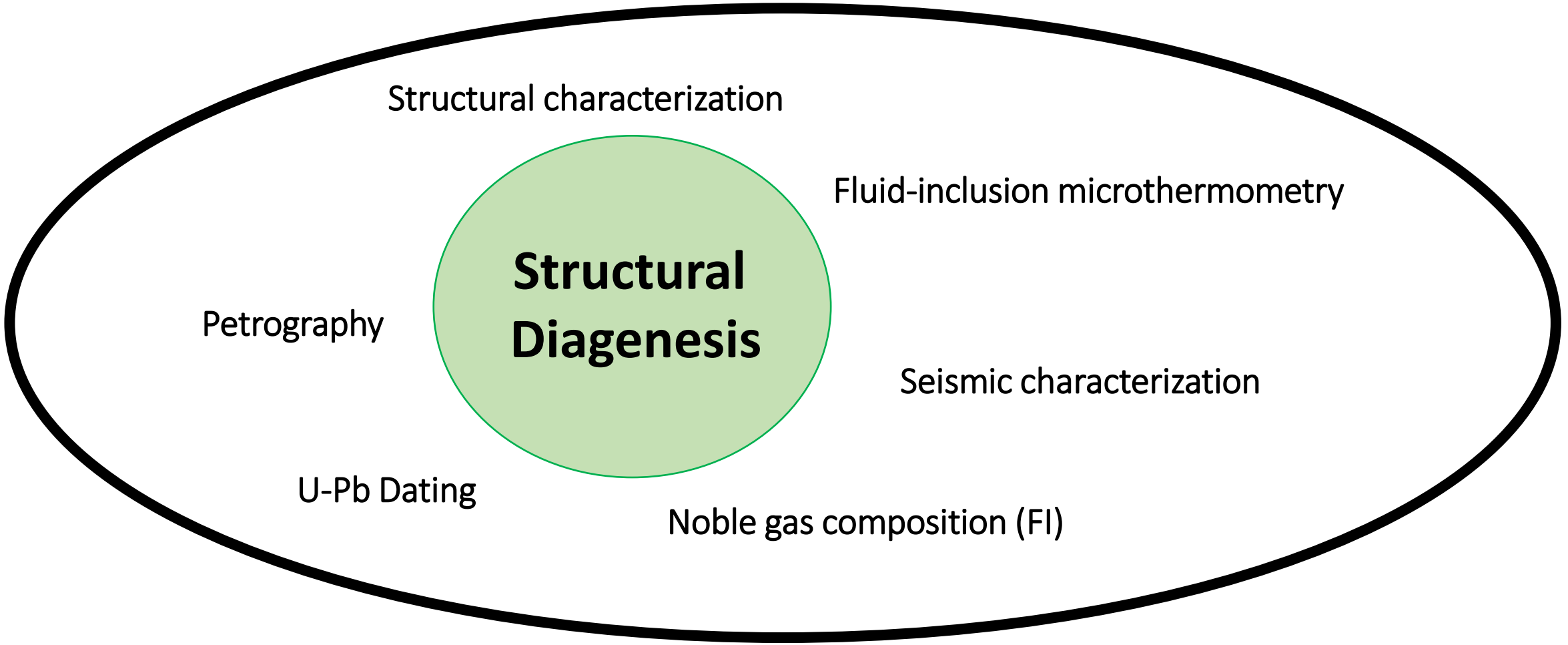
Brazilian Pre-salt Area
- Southeast Atlantic coast
- Santos and Campos Basins
- Carbonate reservoirs

Location

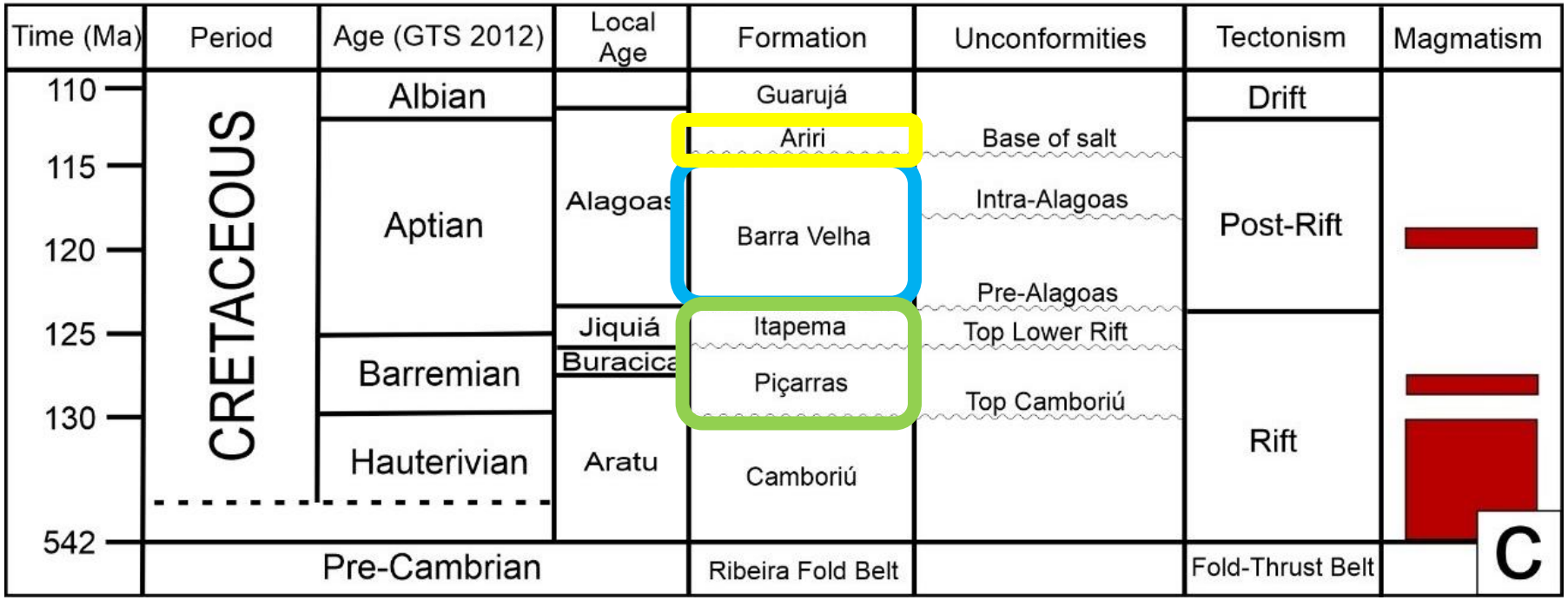


Corrêa et al. 2025

Methodology



Reservoir Characteristics



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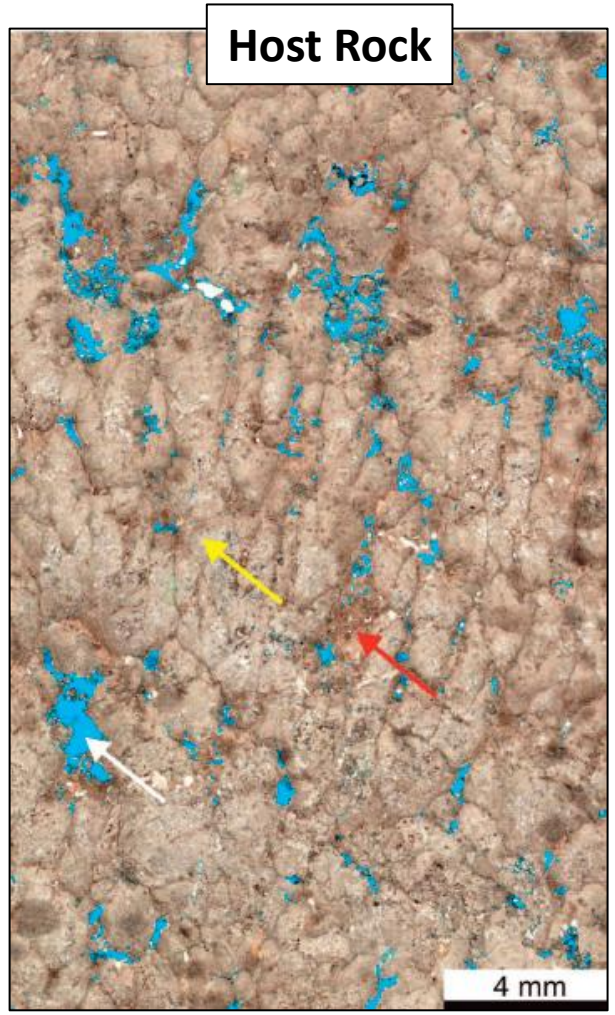
Seal

Reservoir

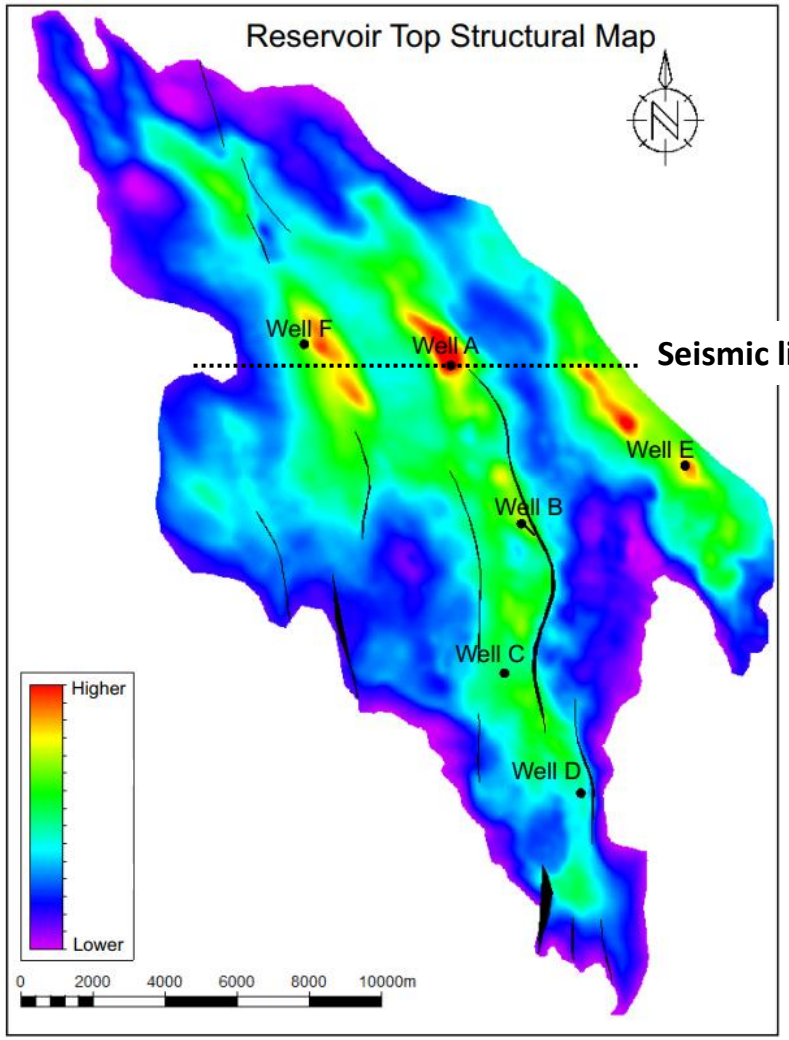
Source

Barra Velha Formation
Age: Aptian
Lithology: Lacustrine Carbonates

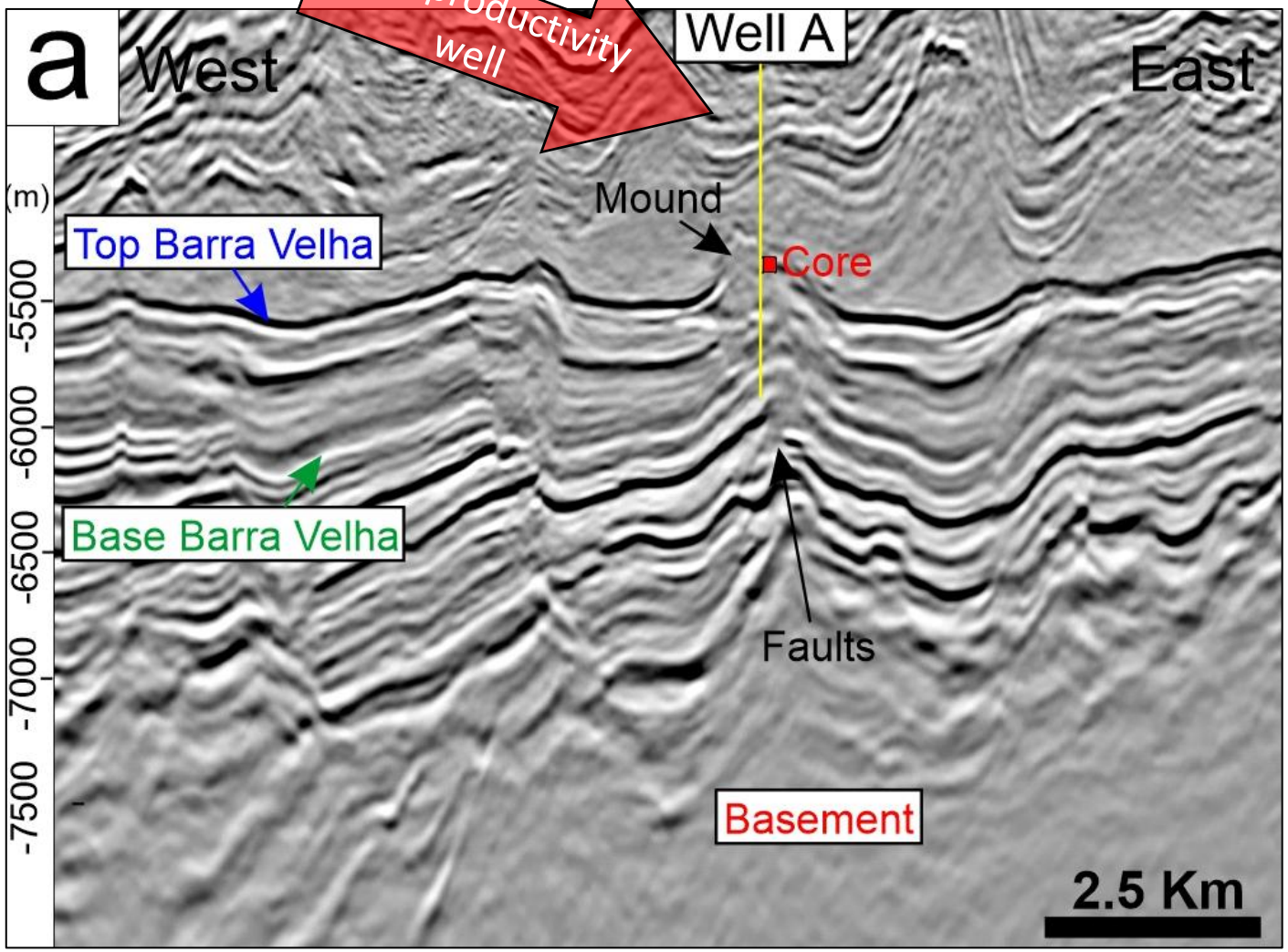


Herlinger et al. 2017

Seismic characteristics



Corrêa et al. 2019



Corrêa et al. 2025

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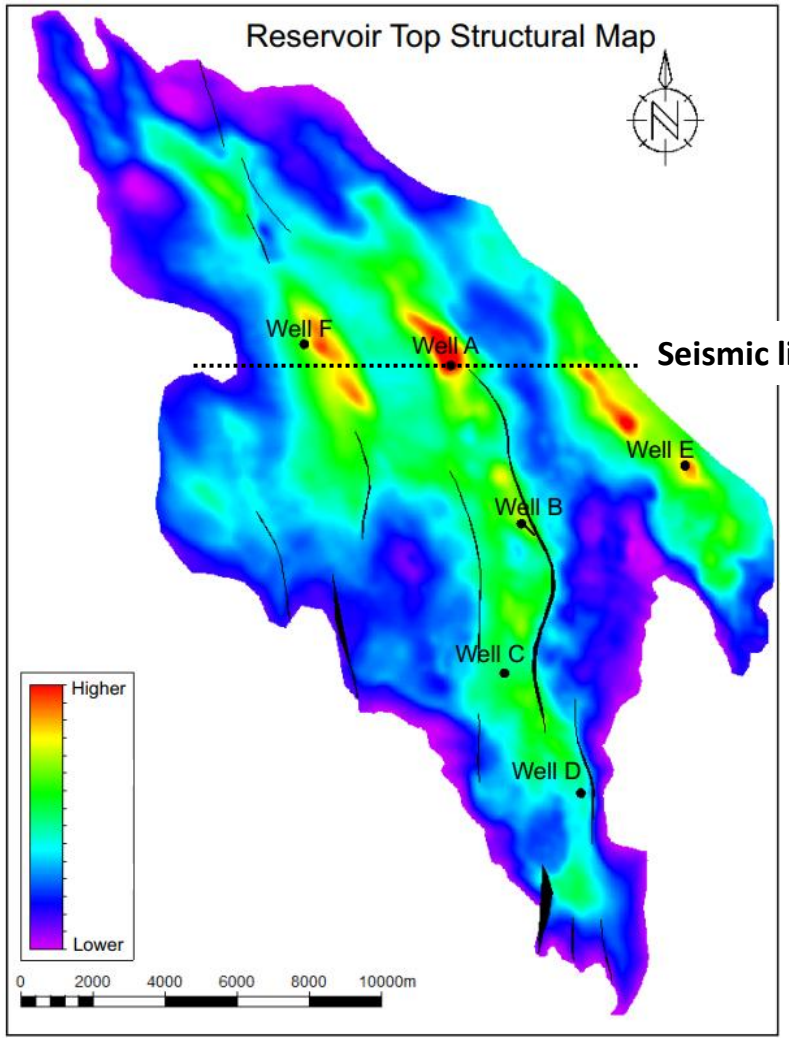

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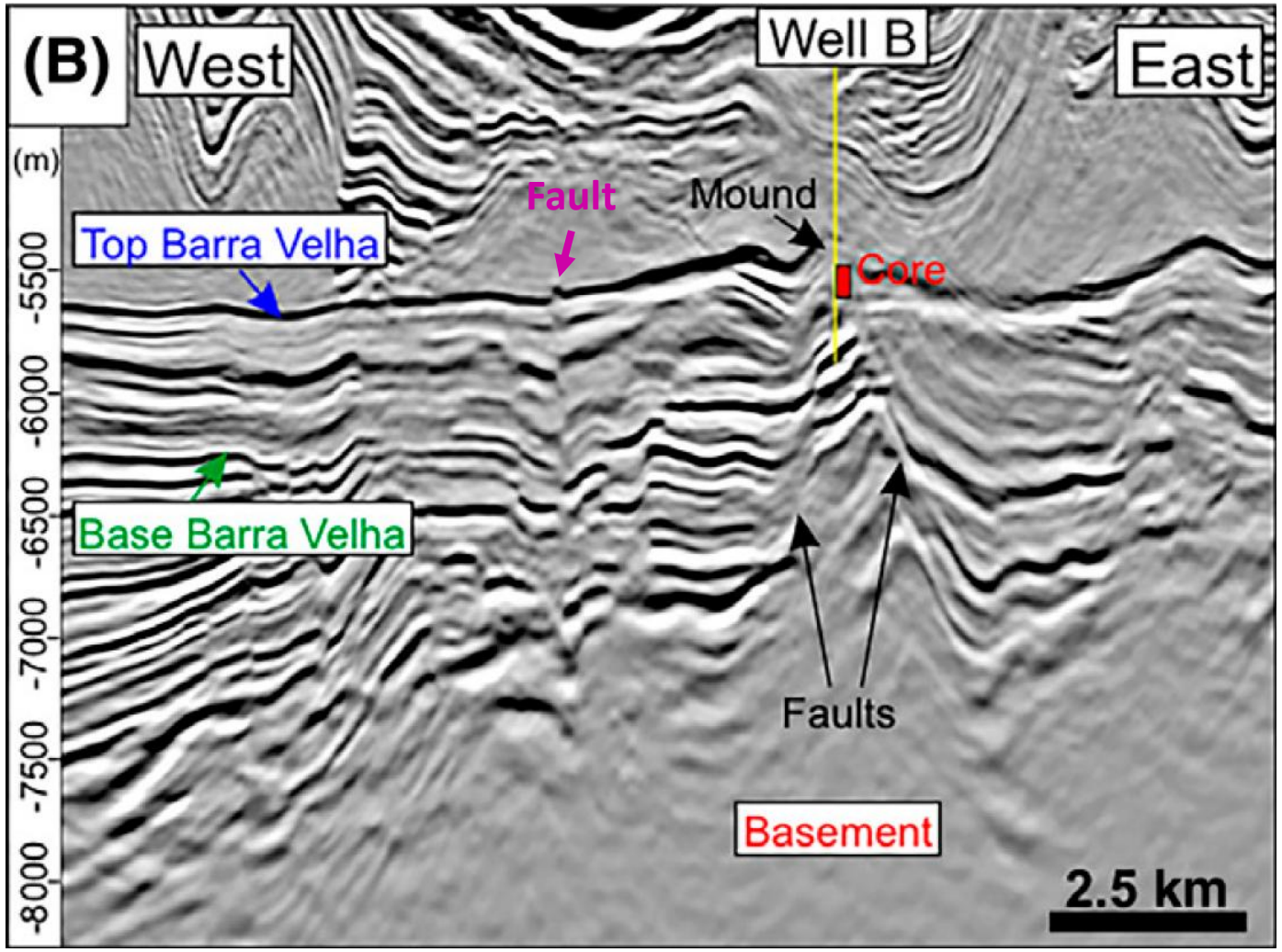

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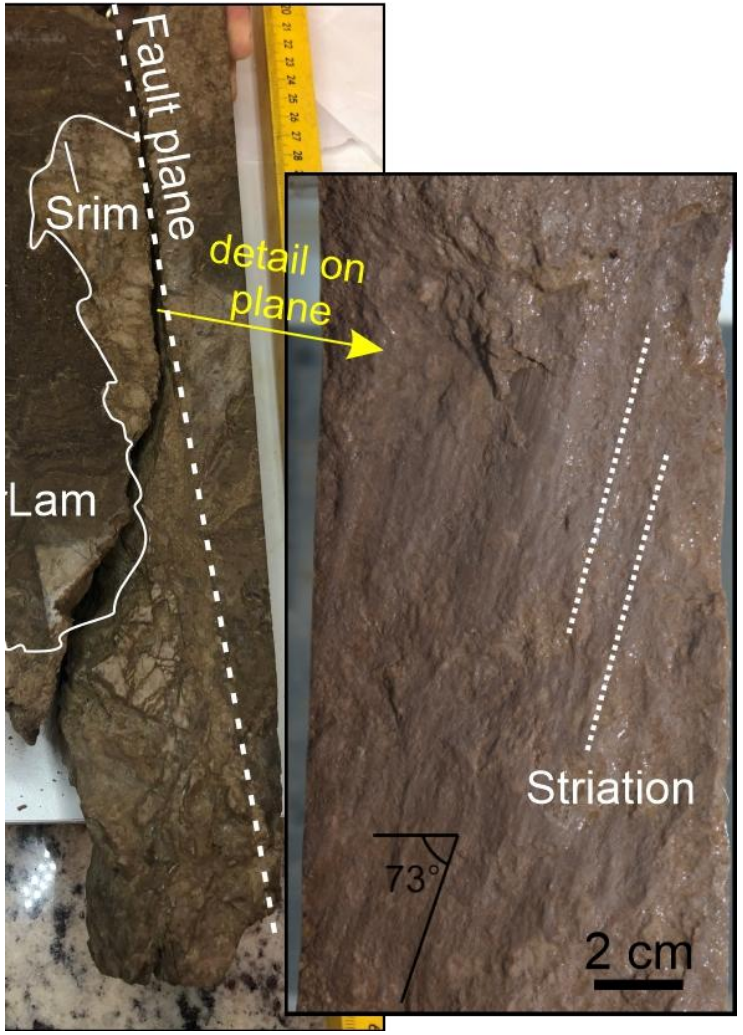
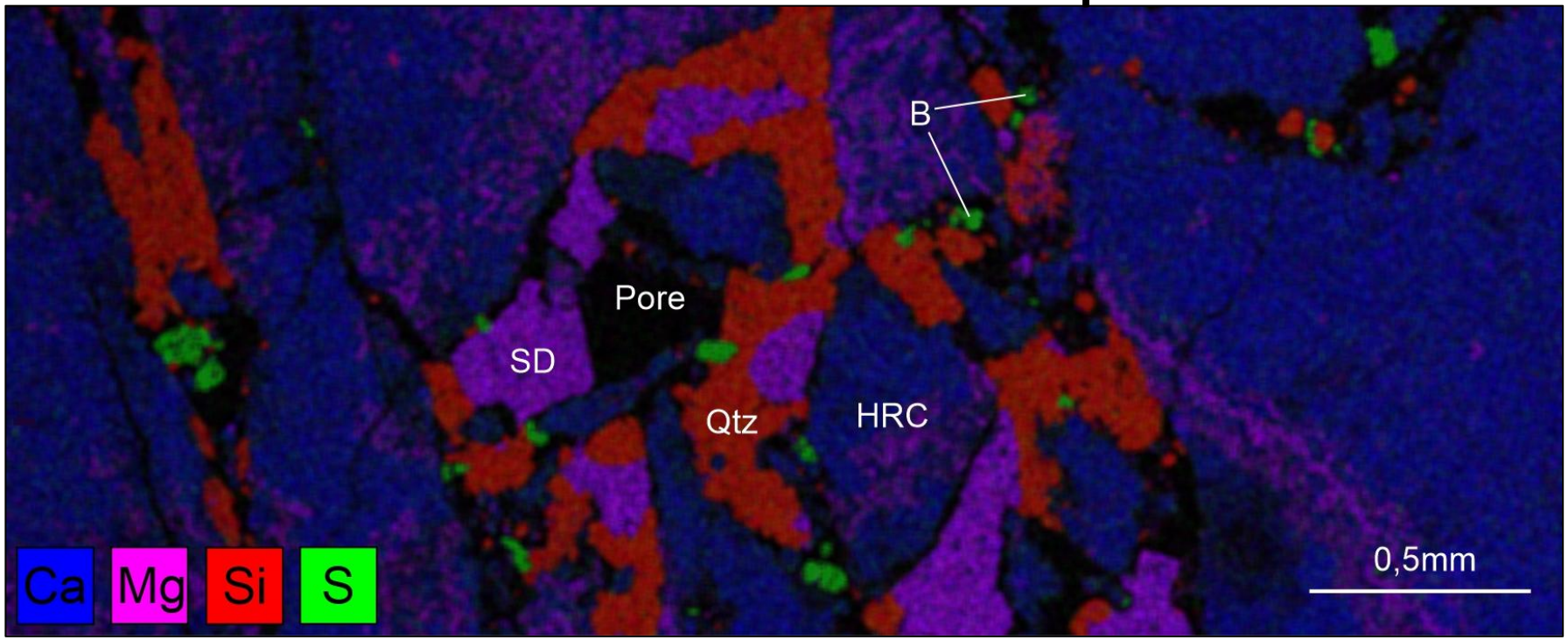
Ingredient Nr.1 - Brittle deformation

Structural characterization

Fault observed on core



SEM-EDS element map



Oblique-normal fault associated with barite, quartz and saddle dolomite

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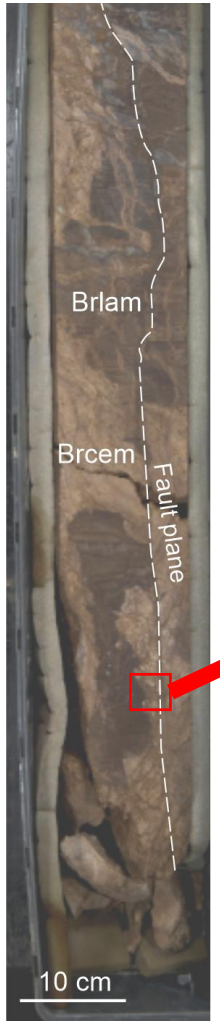
Ingredient Nr.1 - Brittle deformation

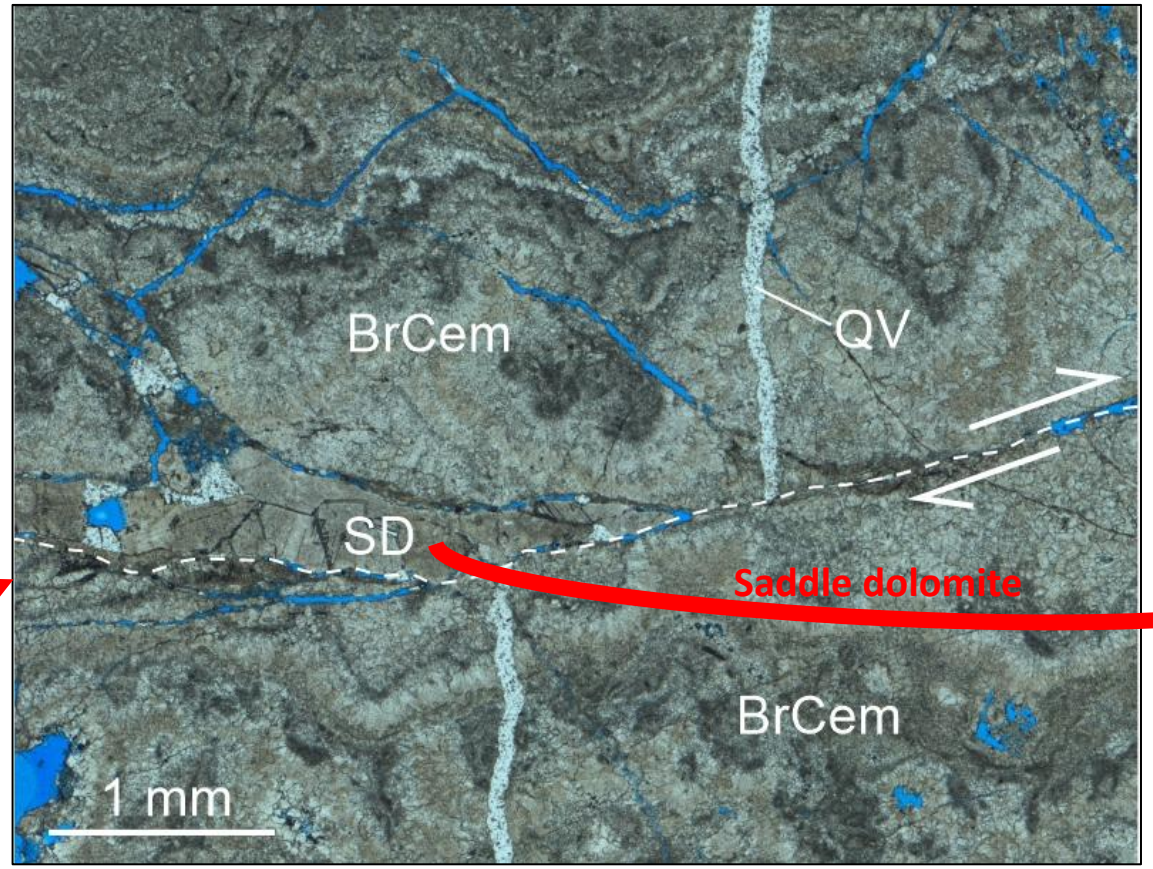
U-Pb Geochronology

Faulted core



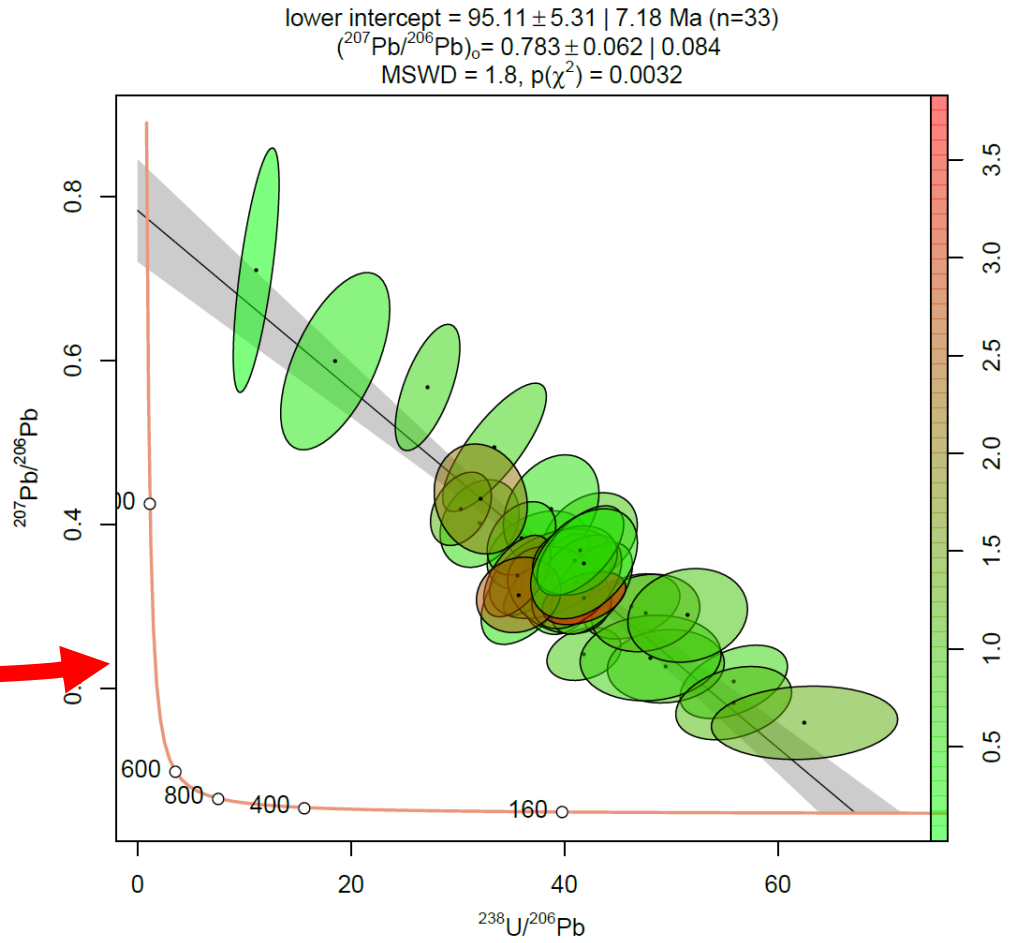
Thin section

Fault breccia mineralized with saddle dolomite



Tera-Wasserburg diagram

U-Pb age estimated @ 95 My



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Ingredient Nr. 2 – Hydrothermal alteration

Vuggy Fractures

Cored fractured-karstified reservoir

Natural fractures

+

Intense karstification

Very high “extra-matrix” permeability

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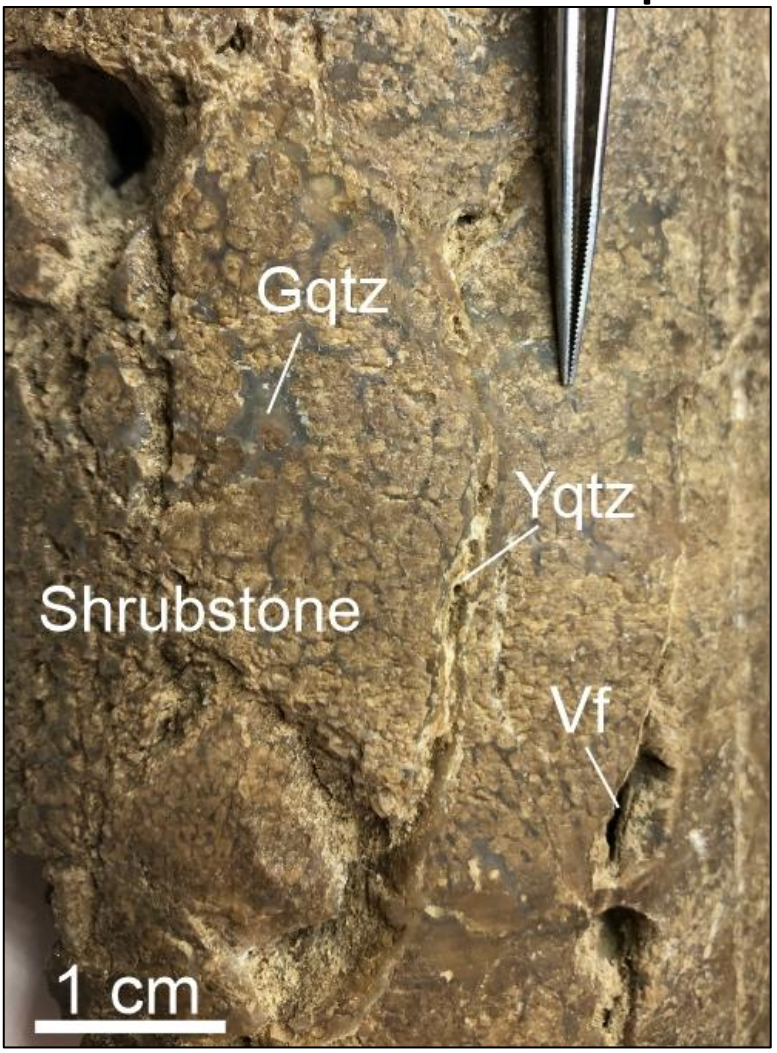
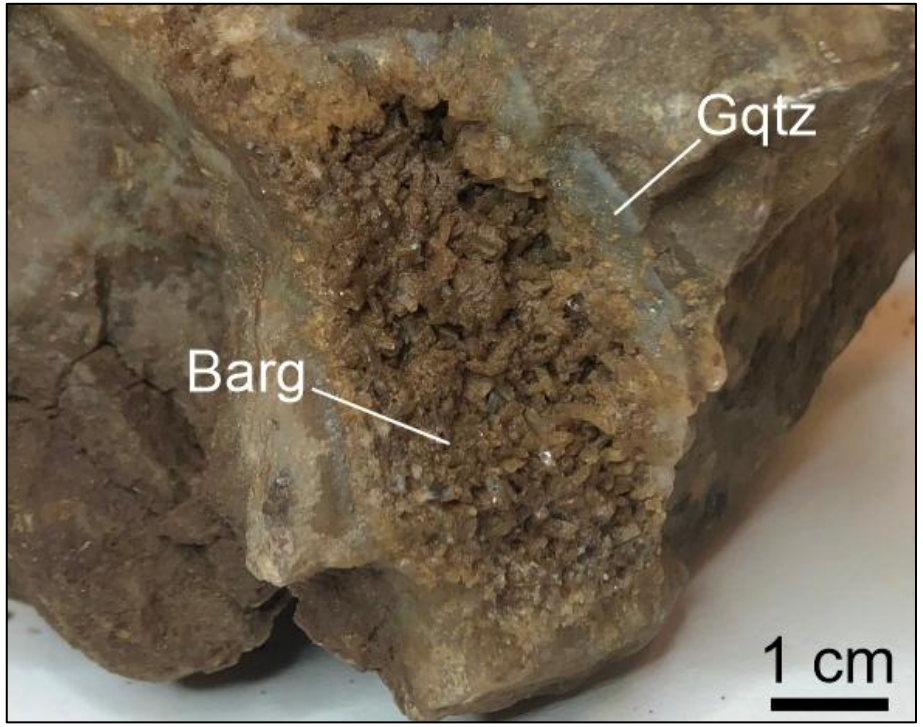
Ingredient Nr. 2 – Hydrothermal alteration

Petrography

Fractures mineralized with quartz

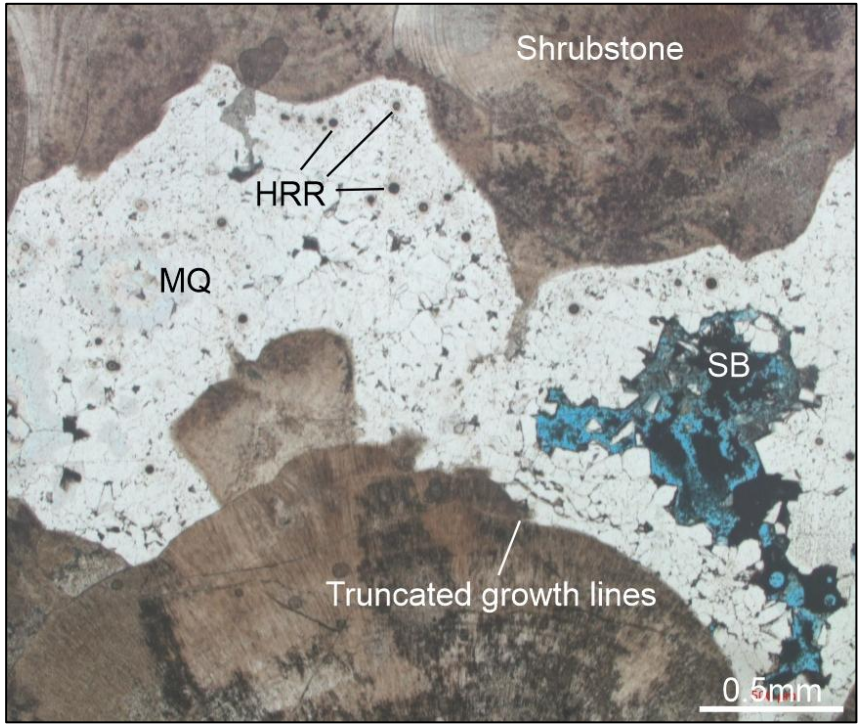


Fractures mineralized with barite



Thin section

vuggy fracture partially filled by quartz and bitumen



Vuggy fractures lined with quartz, barite and bitumen.

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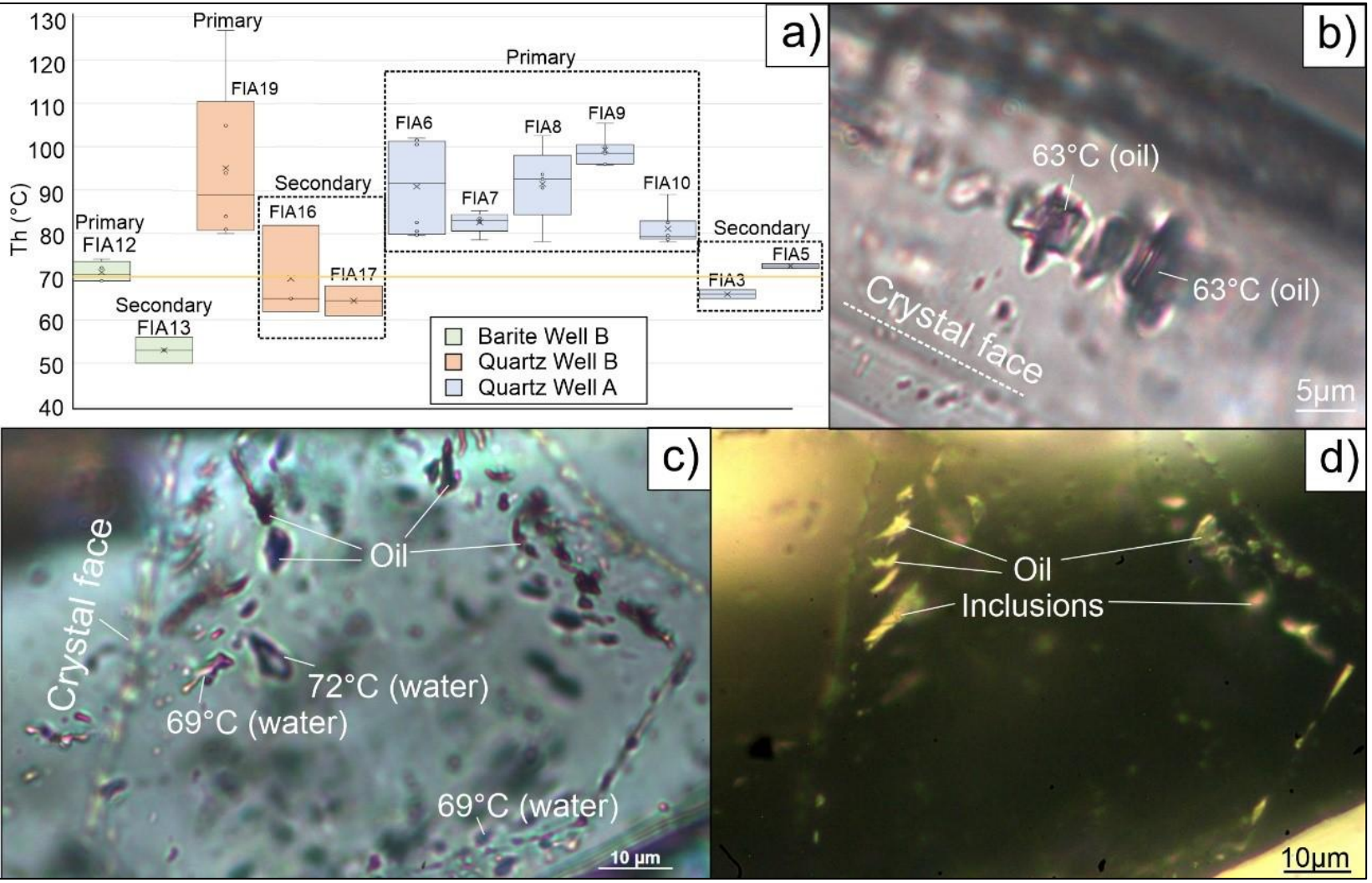
Ingredient Nr. 2 – Hydrothermal alteration

Fluid inclusions

Homogenization temperature plot and fluid inclusion images



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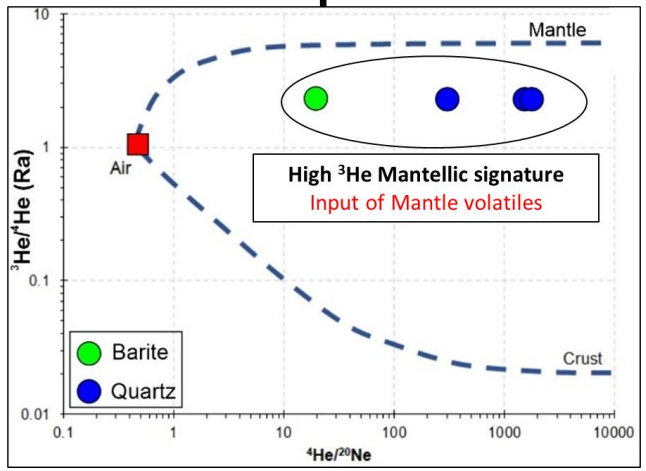
Volatile composition in FI



Temperature:

Blocky Quartz: 80°C – 127°C

Barite: 70°C - 75°C

Salinity:

High Salinity > 20% NaCl eq.

Volatiles:

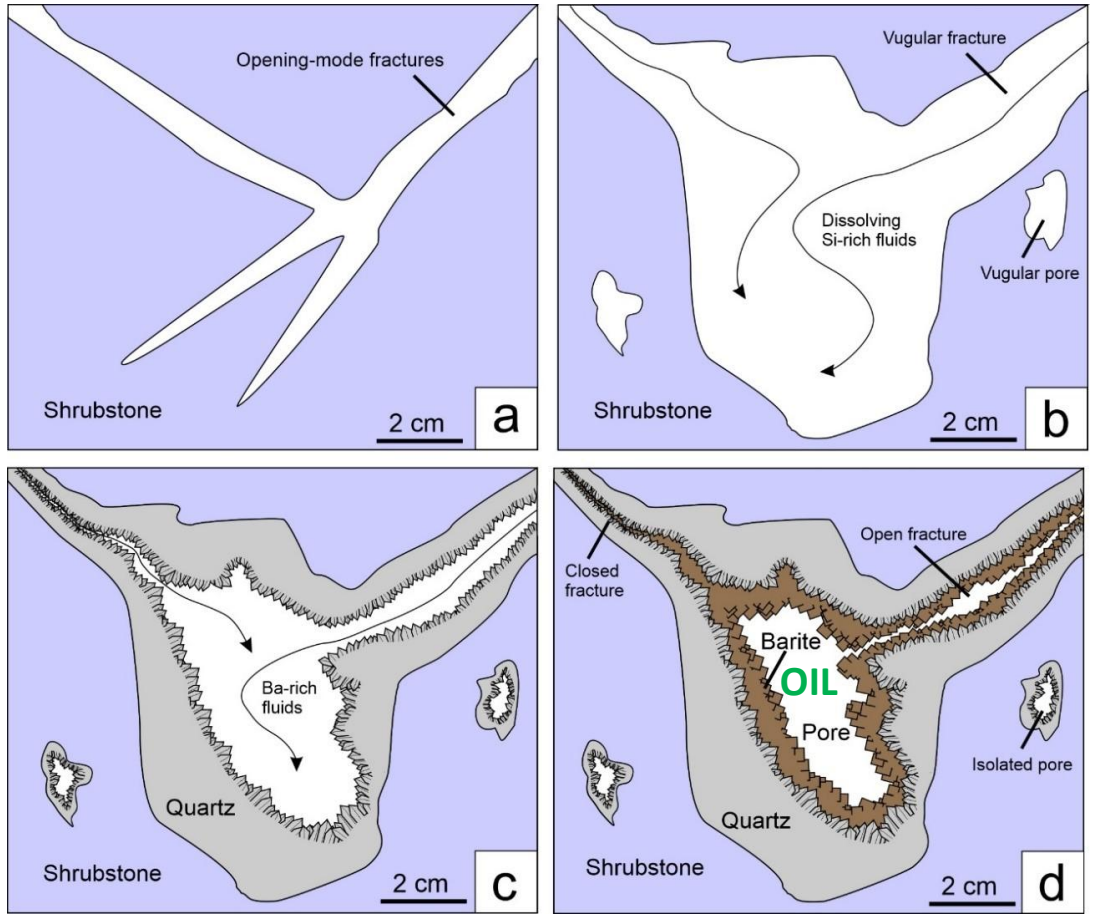
Mantellic signature (High ^{3}He)

Possible CO_2

Homogenization temperatures above reservoir temperature!

Ingredient Nr.3 - Diagenesis

Preservation-Mineralization of large pores



- **Size and inter-connection between cavities plays a major role in preservation.**
- **Proximity to fault zone opens pathways for fluids.**

Possible outcomes:

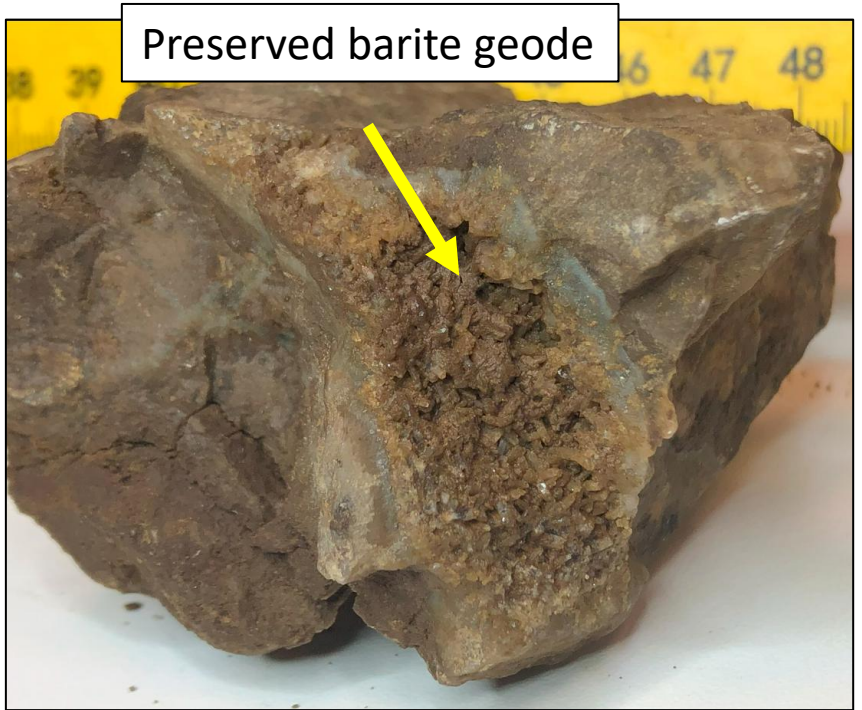
1) Fully cemented vuggy fracture - **Not connected**

2) Partially cemented vuggy fracture (geode) – **Not connected** – **Water filled**

3) **Partially cemented vuggy fracture** – **Connected** – **Oil filled**

High Perm.

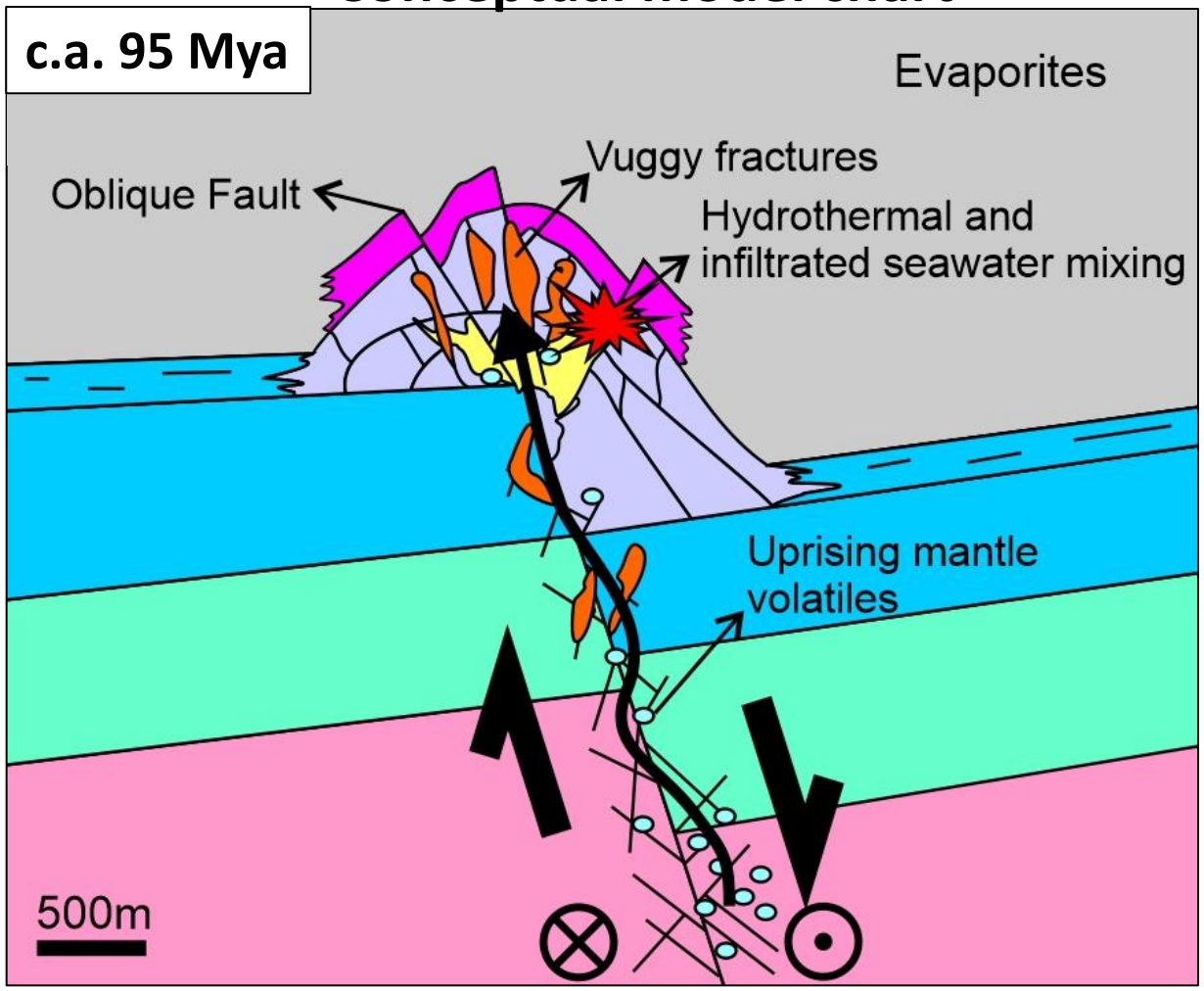
Preserved barite geode



Preserved quartz geode

Conceptual Model – The recipe

Conceptual model chart



- At c.a. 95Mya faults were reactivated
- Interaction with mantle-derived volatiles (Possibly rich in CO2)
- Enhanced dissolution along fault zones
- Dissolution in fractured carbonate mounds
- Mineralization by hydrothermal fluids and later by other basinal fluids

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Contact

Papers related to this talk

Corrêa, R. S. M., Carvalho, B., Ukar, E., Laubach, S. E., Pestilho, A. L., Fall, A., Larson, T., Stockli, D., Stockli, L., Lüders, V., Niedermann, S. & Banks, D. A. (2025). **Brittle deformation and hydrothermal alteration in the Barra Velha Formation, Santos Basin, offshore Brazil**. AAPG Bulletin, 109(4), 545-590.

Corrêa, R., Pereira, C., Cruz, F., Lisboa, S., Junior, M., Souza, V., ... & de Carvalho, B. M. (2019). **Integrated seismic-log-core-test fracture characterization and modelling, Barra Velha Formation, Pre-Salt of Santos Basin**. In 2019 AAPG Annual Convention and Exhibition, San Antonio - Texas.

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