

Clastic Pipe Diagenesis of the Jurassic Carmel Formation, Southern Utah*

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Abstract

Well-exposed clastic pipes that crosscut sabkha sandstones of the Jurassic Carmel Formation in southern Utah preserve multiple stages of diagenesis. Clastic pipes generally coarsen outwards with prominent calcite rhombs 0.2 - 1 cm long occurring in the coarse-grained rinds of the m-scale pipes. The calcite rhombs serve as records of fluid flow relevant to understanding the timing and extent of cementation within pipes, and its effects on connectivity in reservoir sandstones. Numerous dominantly monophasic aqueous fluid inclusions of various sizes with some relatively large (40 µm) inclusions are present within the crystalline rhombs. Salinity measurements from the fluids all had relatively similar values spatially, with a brackish response falling within the 700-1400 ppm range. The monophasic inclusions indicate low formation temperatures likely between 70–80 °C, which signifies burial depths of less than a kilometer. In contrast, results from clay XRD reveal interstratified illite-smectite and kaolinite, which are present in both pipes and the host rock as clay cements. The interstratified illite-smectite has a reicheite ordering number of 1 (R1) and can therefore be termed rectorite, demonstrating at least several kilometers of burial. The clay data suggest a middle, mesodiagenetic phase during burial in contrast to the shallow diagenetic conditions implied from the calcite inclusions. The combinations of diagenetic phases show multiple stages of diagenesis within the clastic pipes as shallow, low temperature fluids moved through the pipes either: 1) pre-burial during early stage eogenesis or 2) after burial during late stage telogenesis. The fluid inclusion analysis indicates a brackish groundwater system with an evaporative component consistent with the sabkha interpretation for the host rock deposits. However, the well-developed crystal rhombs and lack of diagenetic overprinting support a late stage hypothesis. Large-scale sandstone intrusions in deep water systems are commonly targeted because of their potential as long-term fluid conduits in subsurface petroleum explorations. However, this Jurassic study shows that complex diagenesis can occur within clastic pipes, and the diagenesis should be an important consideration in the risk analysis and assessment of fluid history through time.

Selected References

Chan, M.A., J. Gosse, T.E. Cerling, and D.I. Netoff, 2010, Weathering pits in Jurassic Sandstones: Cosmogenic exposure age dating of geomorphic surfaces in Southern Utah: in Carney, S.M., Tabet, D.E, Johnson, C.L., editors, Geology of south-central Utah, Utah Geological Association Publication 39.

- Eruteya, O., N. Waldmann, D. Schalev, and Z. Ben-Avraham, 2015, Intra- to Post-Messinian deep-water gas piping in the Levant Basin, SE Mediterranean: *Marine and Petroleum Geology*, v. 66, p. 246-261.
- Huuse, M., and M. Mickelson, 2004, Eocene sandstone intrusions in the Tampen Spur area (Norwegian North Sea Quad 34) imaged by 3D seismic data: *Marine and Petroleum Geology*, v. 21, p. 141–155.
- Loope, D.B., J.F. Elder, V.A. Zlotnik, R.M. Kettler, and D.T. Pederson, 2013, Jurassic earthquake sequence recorded by multiple generations of sand blows, Zion National Park: *Utah: Geology*, v. 41, p. 1131–1134.

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Dept. Geology & Geophysics

Outline

- Clastic Pipes
- Clastic Pipes in Petroleum Systems
- Research Questions
- Case Study: S. Utah
 - Stratigraphy + Formation
 - Diagenetic Products
- Paragenesis
- Conclusions



Clastic Pipes

- Vertical cylindrical injectites
- Sharp contacts
- 0.10-100 m diameter
- Clastic material
 - Quartz sand
 - Breccia blocks



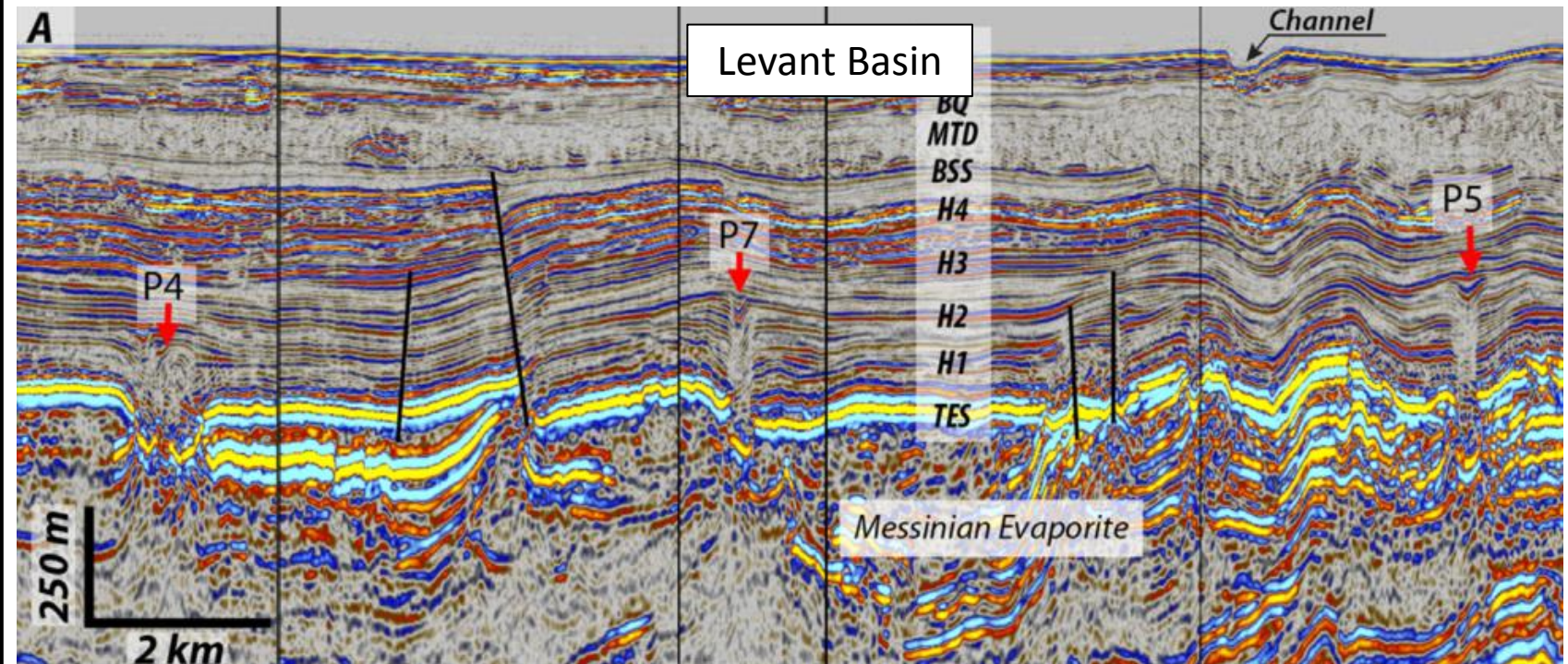
Chan et al, 2010



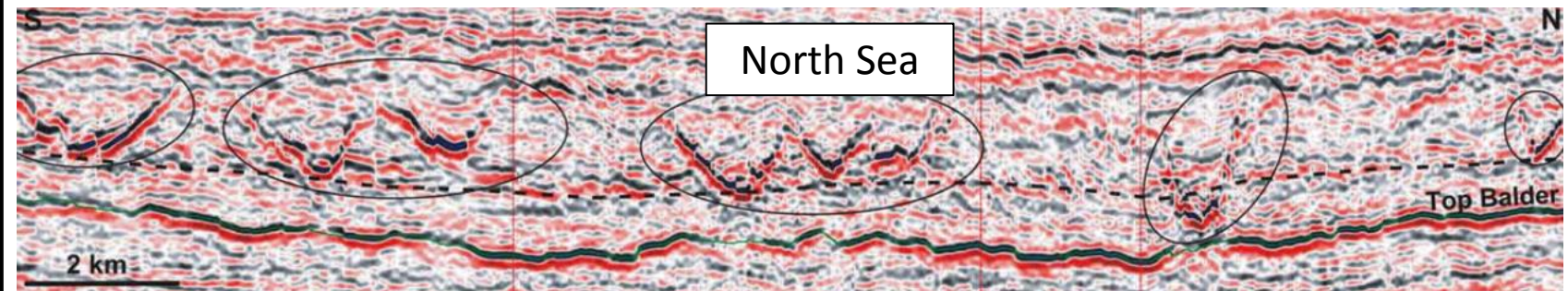
Loope et al, 2013

Clastic Pipes within Petroleum Systems

- Petroleum systems
 - North Sea
- Remobilizes reservoir rock
 - Affects reservoir geometries, volumes
- Act as fluid conduits
 - Bypass baffles and barriers to flow



Eruteya et al, 2015



Huuse and Mickelson, 2004

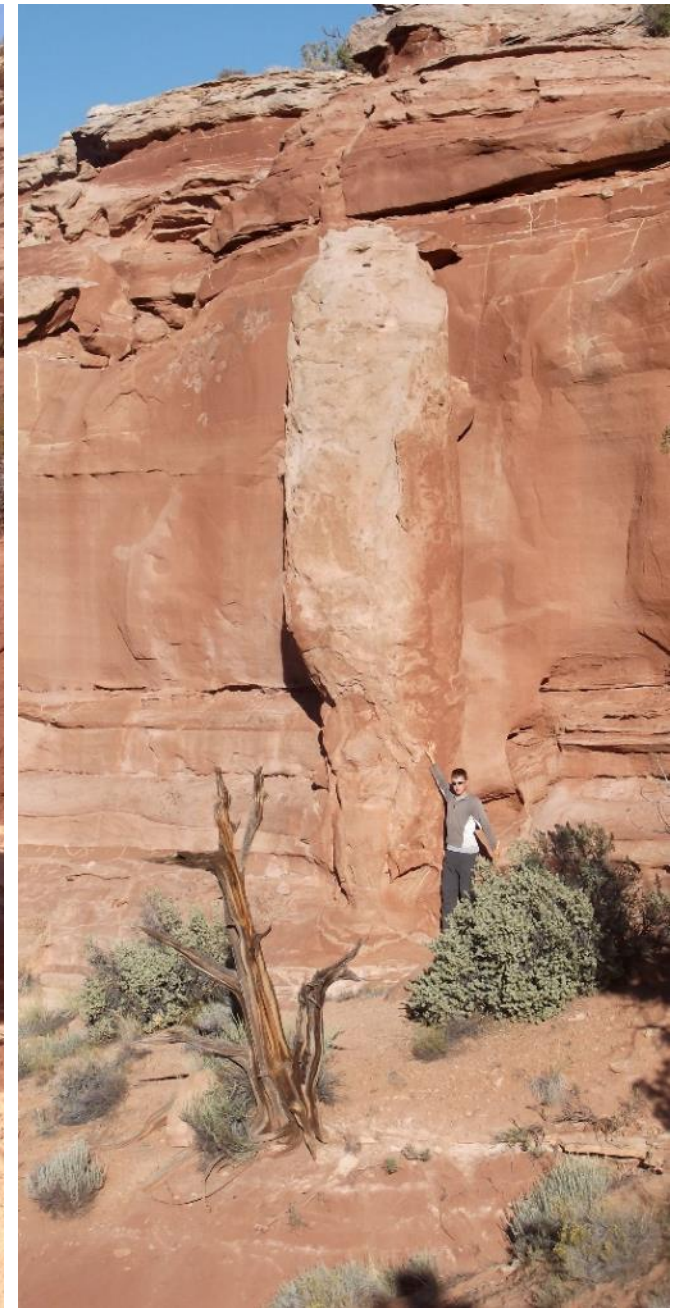
Research Questions

Driving Questions:

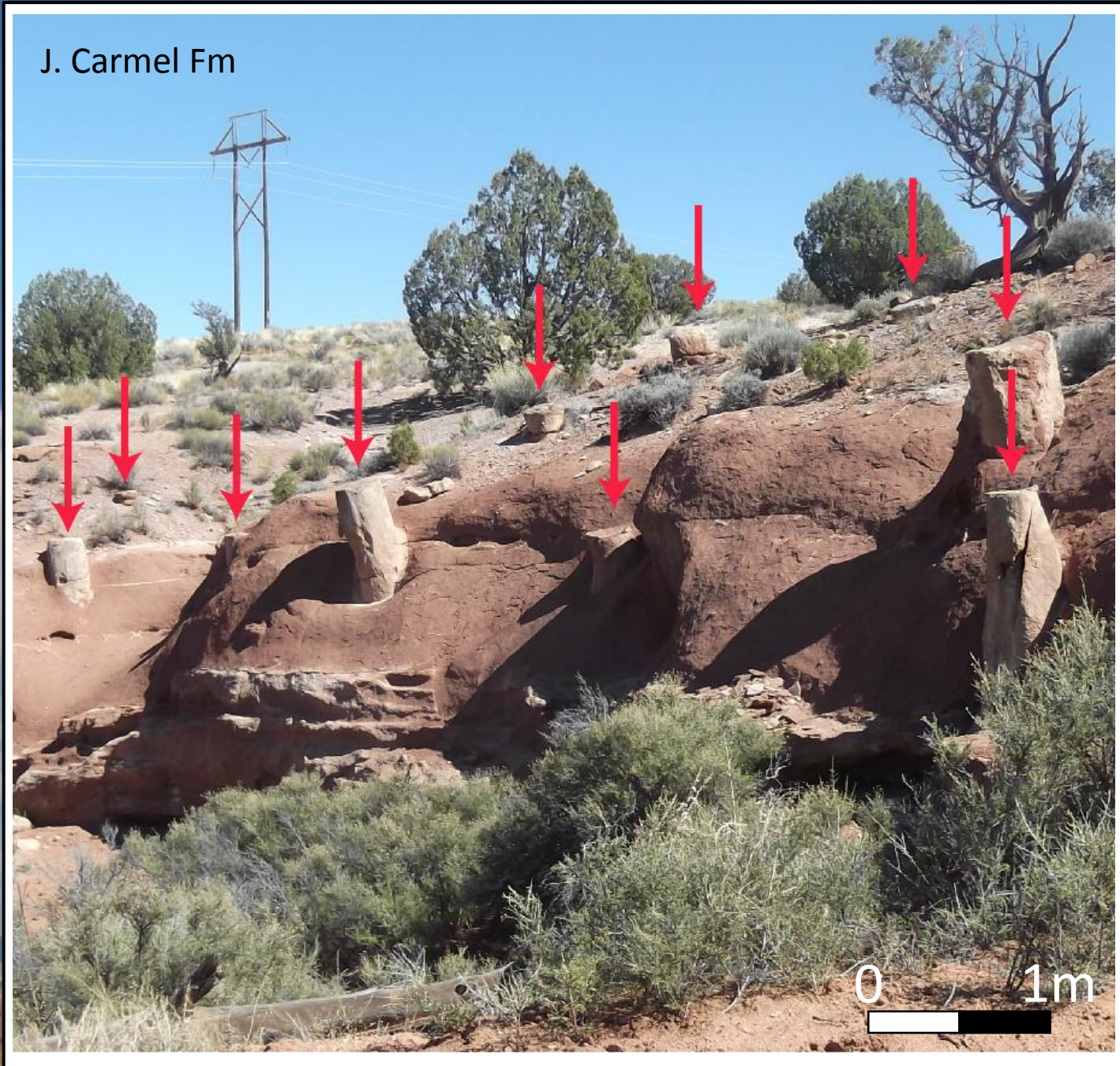
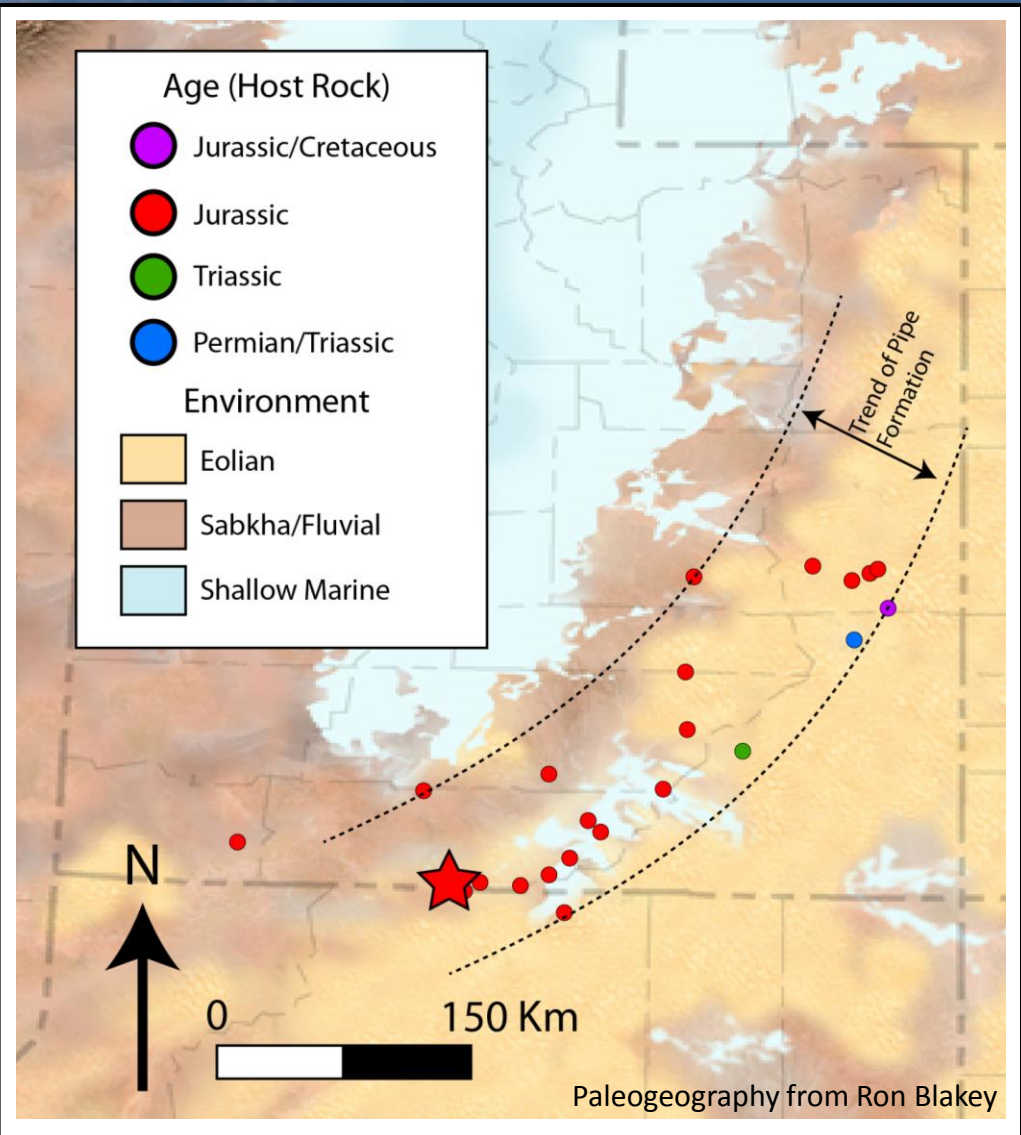
- Do all pipes act as fluid conduits?
 - “Diagenesis problem”
- When do pipe cements form?
- Over-predicting/under-predicting reservoir size, connectivity

Research Questions:

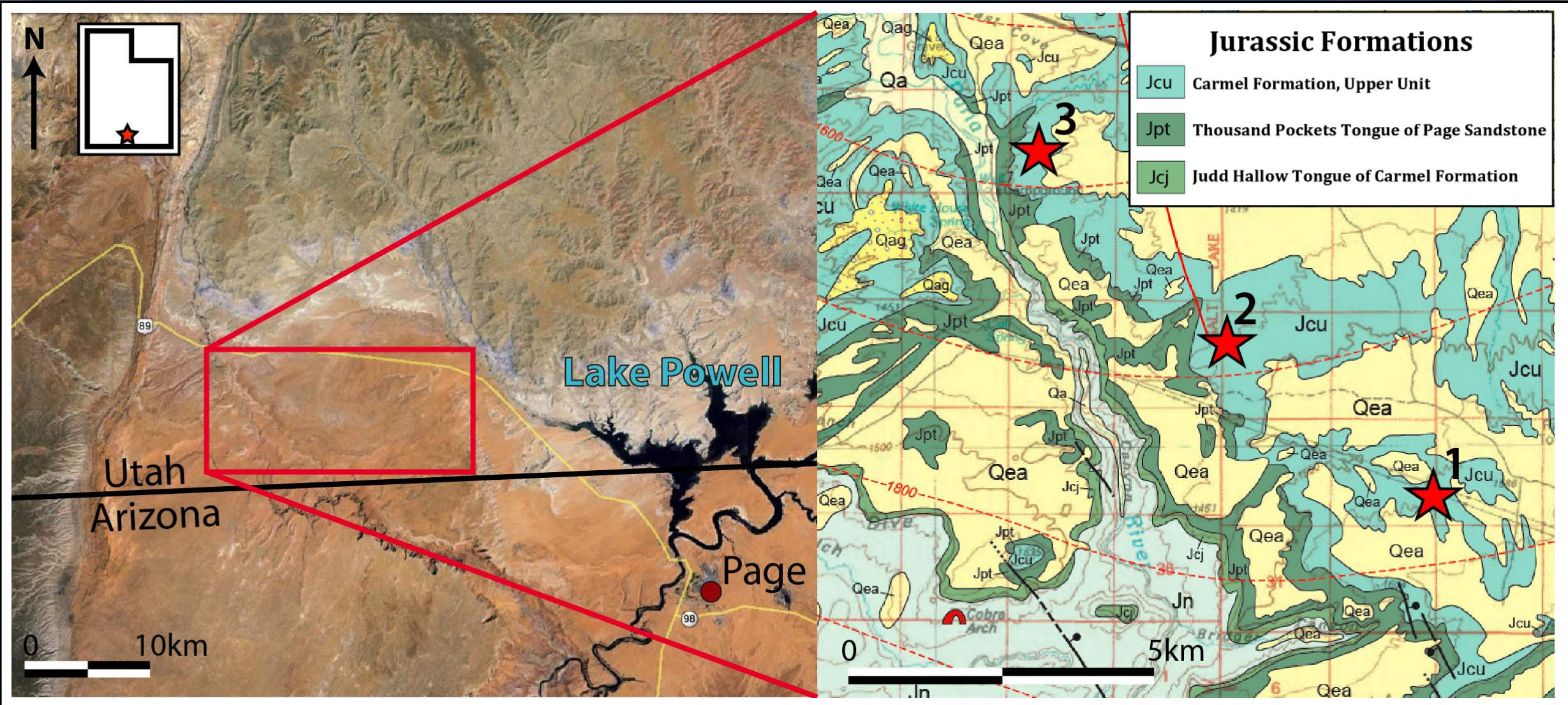
- Timing and degree of diagenesis?
- Composition of the fluids?
- Hydrocarbons flowed through pipes?



Clastic Pipes, S. Utah

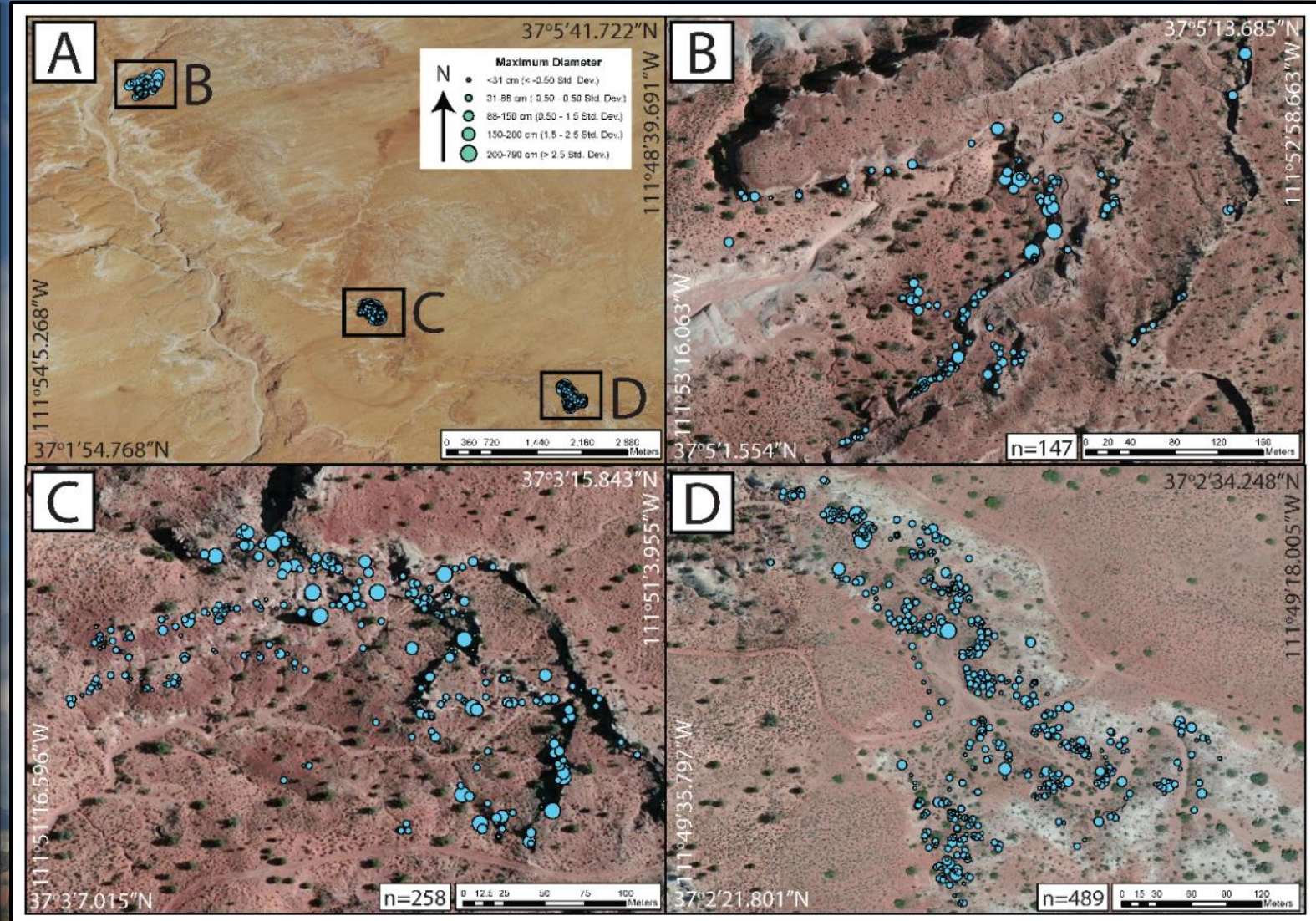


Study Area



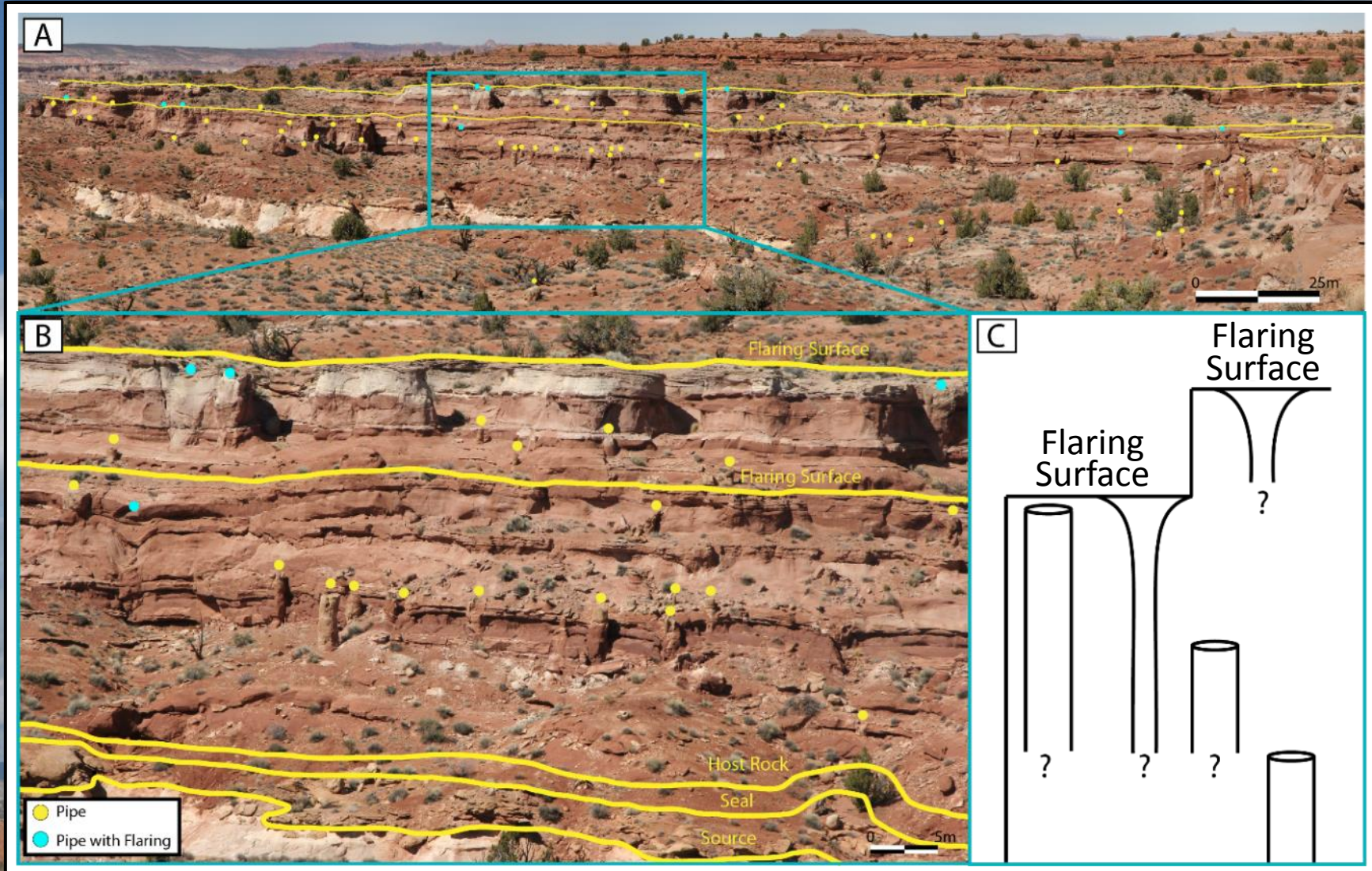
Spatial Distribution/Stratigraphic Relationships

- 3 major field sites
- ~900 cataloged injectites
 - Location
 - Geometry
 - Material properties
 - Diagenetic features
 - Stratigraphic relationships
- ~1100+ observed on field transects
- High pipe density
 - Exposures constrained to cliff faces, dry riverbeds



Spatial Distribution/Stratigraphic Relationships

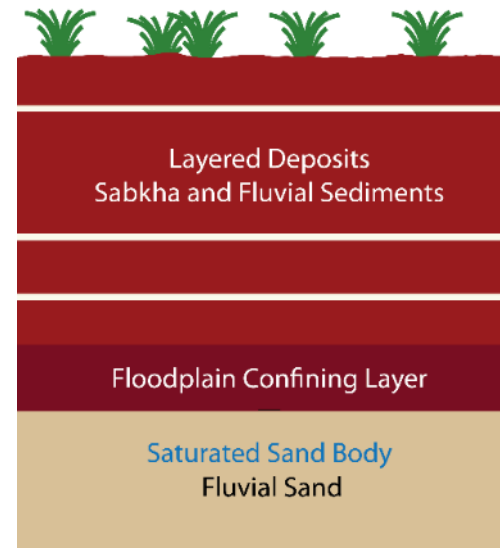
- Stratigraphically bound
 - Paria River Member
- Multiple flaring surfaces
 - Eruption surfaces
- Few exposed bases



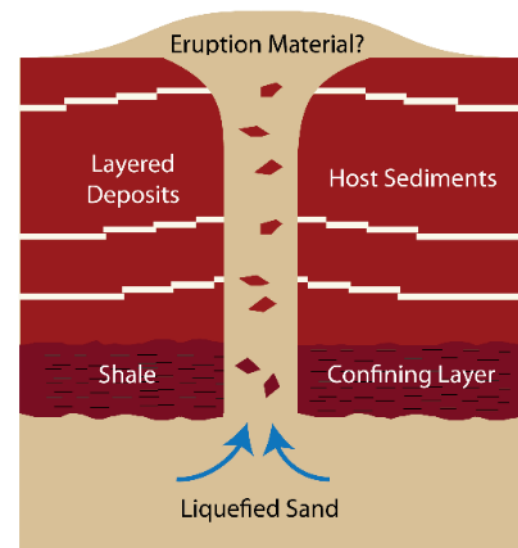
Formation Mechanism

- Liquefaction + fluidization
- Multiple, violent, discrete events
 - Crosscutting pipes
 - Multiple eruption surfaces
 - Breccia blocks
 - Syn-sedimentary faults

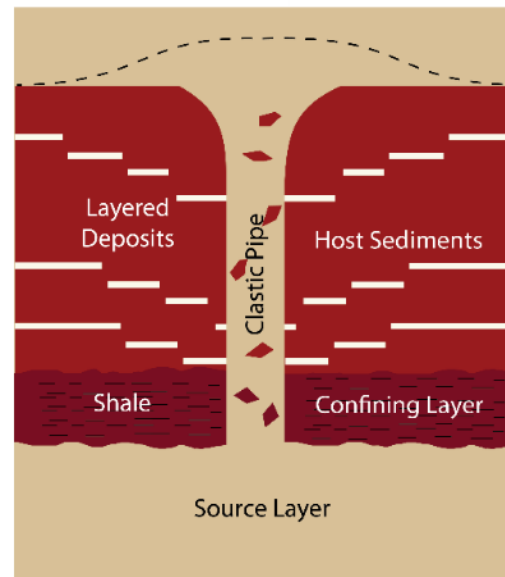
1) Initial Conditions



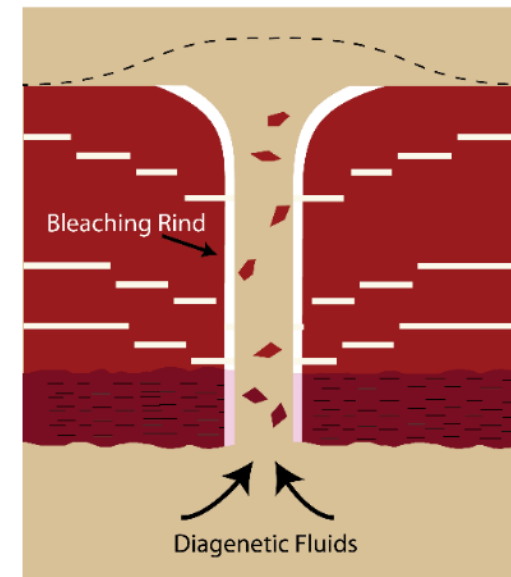
2) Pipe Emplacement



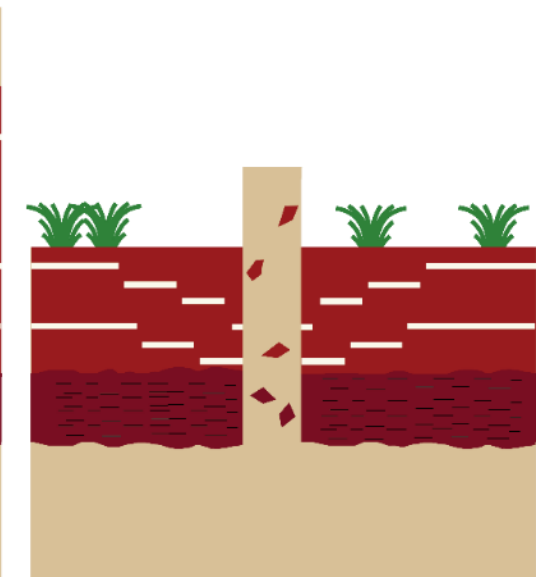
3) Dewatering and Deposition



4) Diagenesis



5) Eroded Modern Landscape



Field (Host Rock)

- Early host rock diagenesis
 - Brecciation
 - Bleaching rinds
 - Syn-sedimentary faults
 - Stratigraphically bound
- Bleaching
 - Pre + post formation
- Iron oxide cements
- Carbonate cements



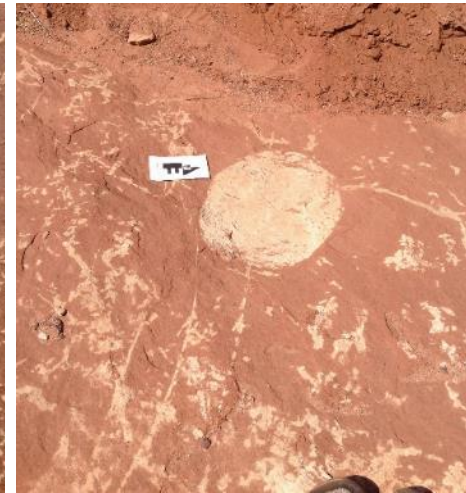
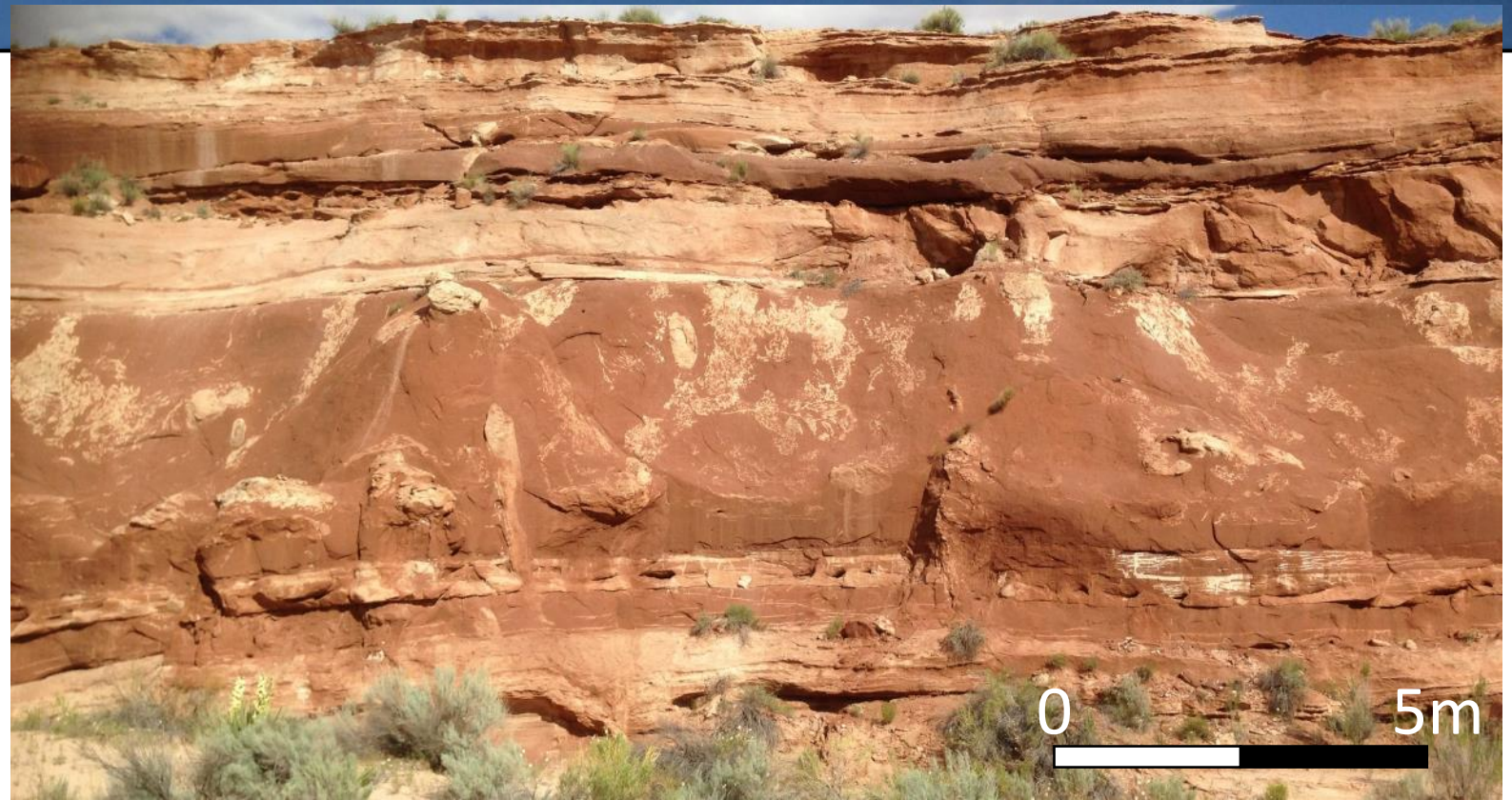
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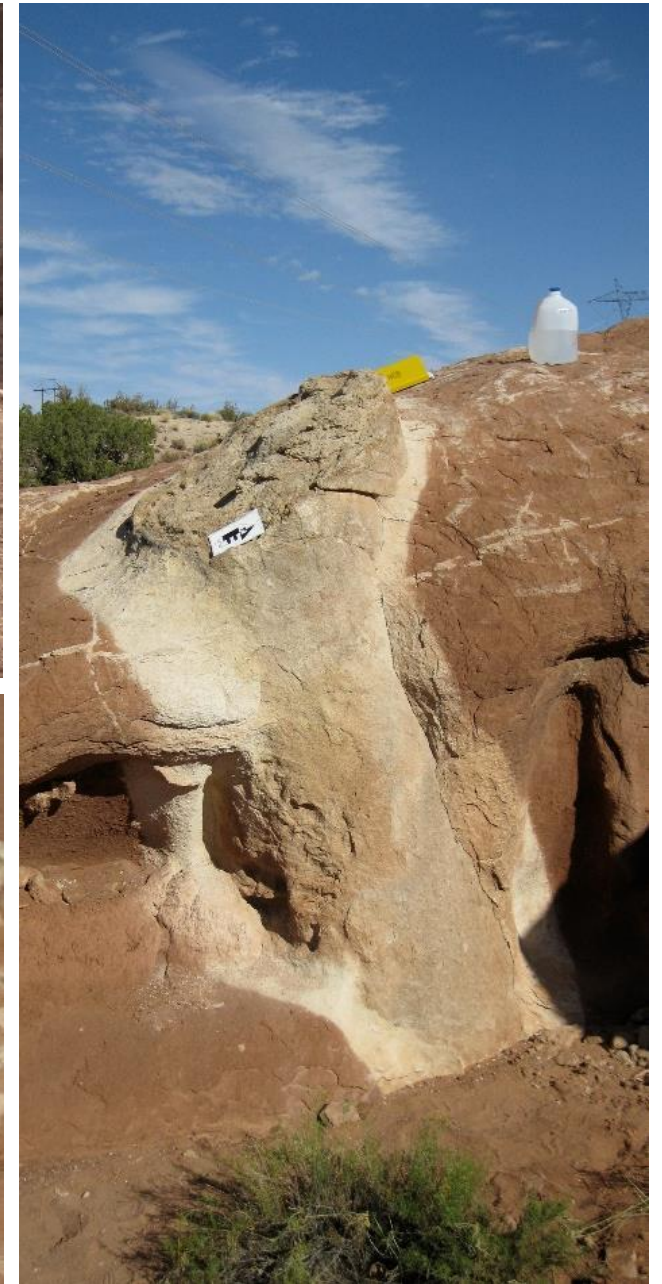
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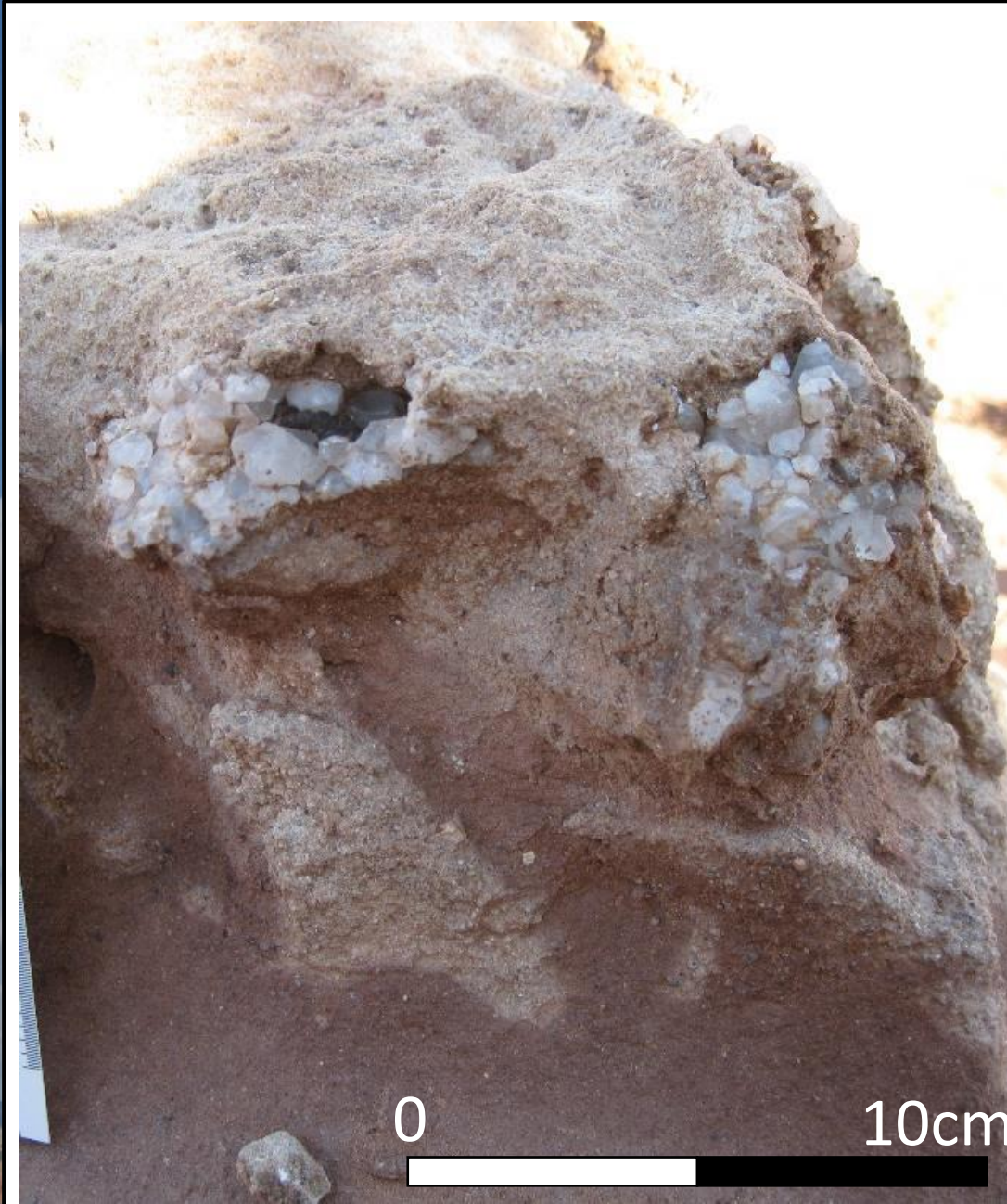
Field (Clastic Pipes)

- Bleaching rims
 - <1 cm - ~30 cm
 - Reducing fluids
- Carbonate nodules
 - Outside of pipes
- “Armchair weathering”
 - Greater cementation of outer rind
 - More mineralizing fluids



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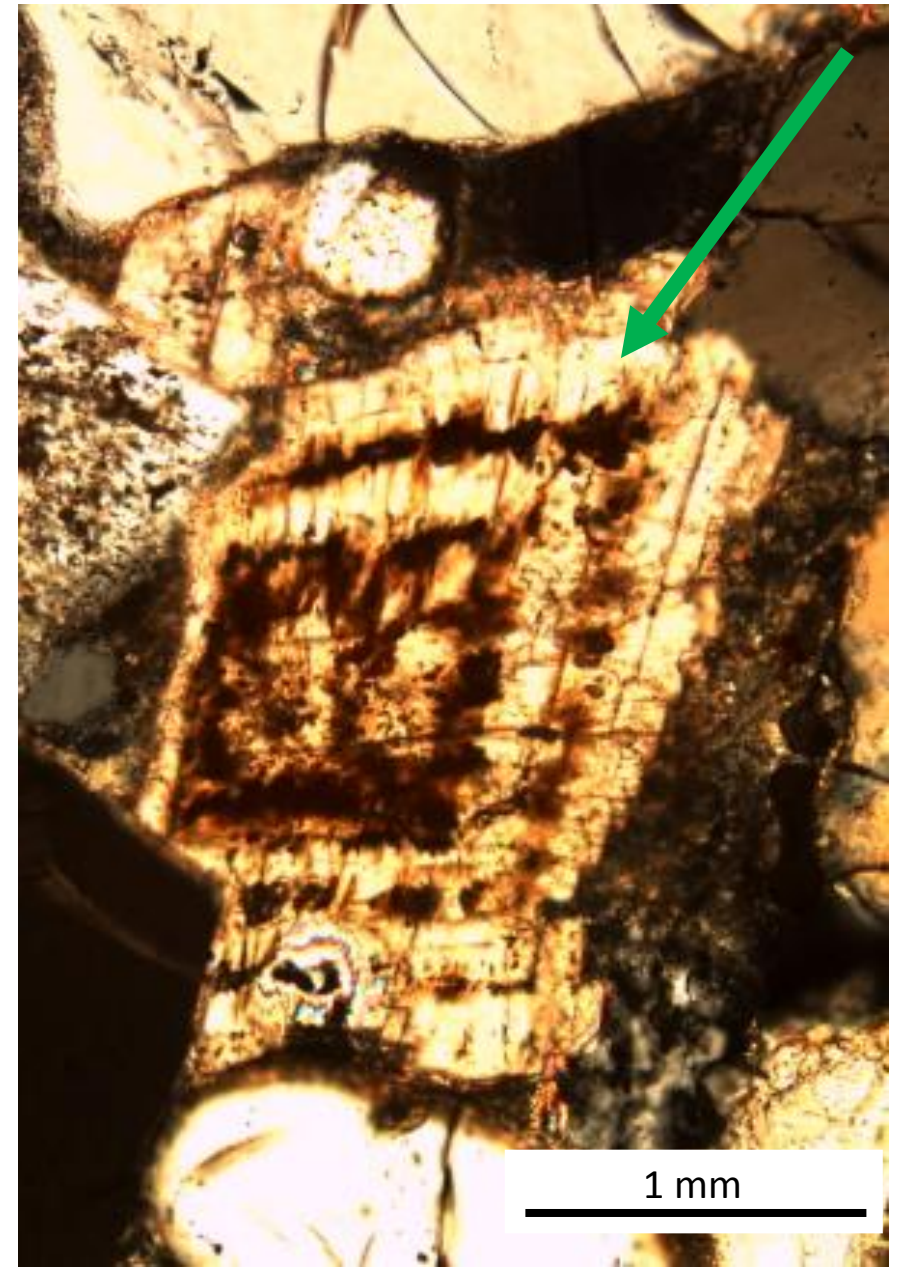
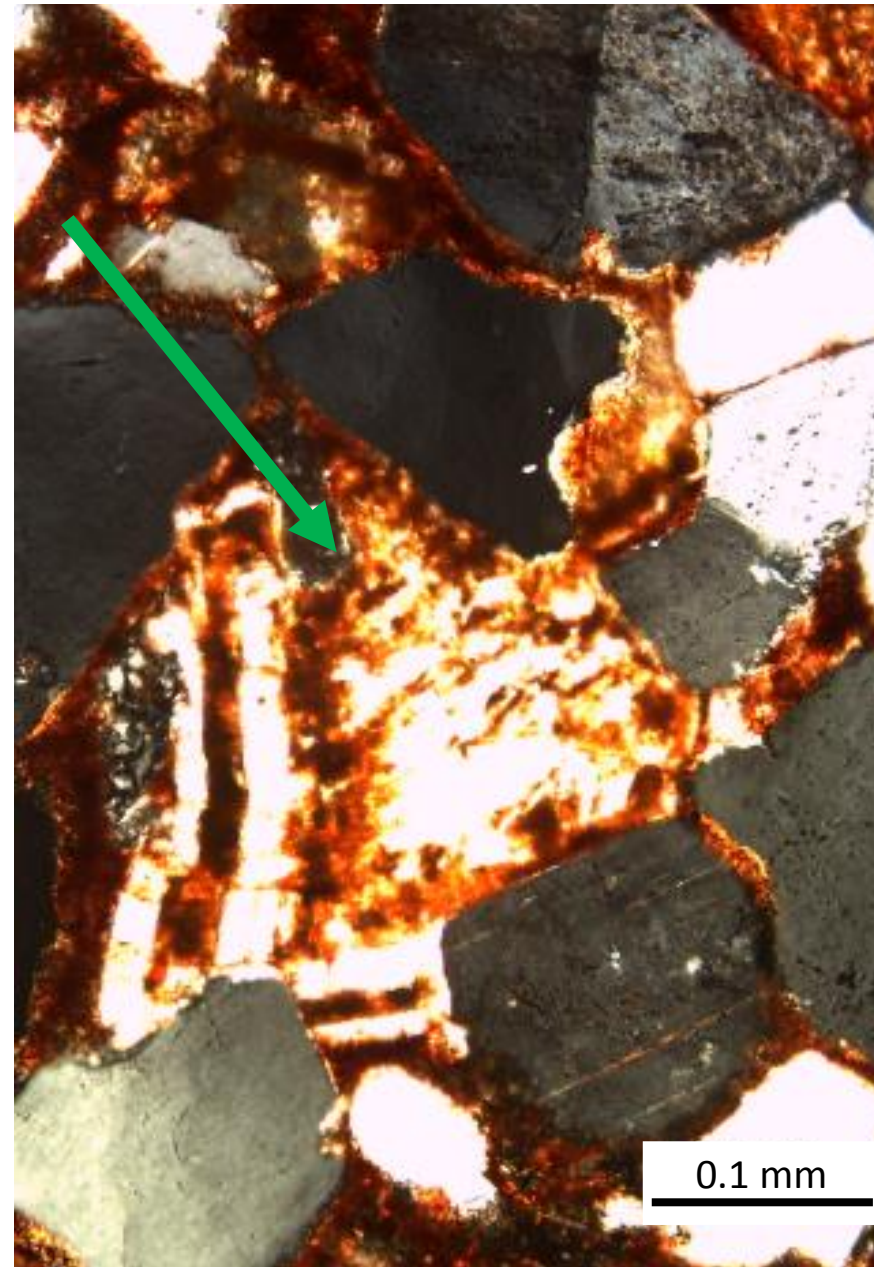
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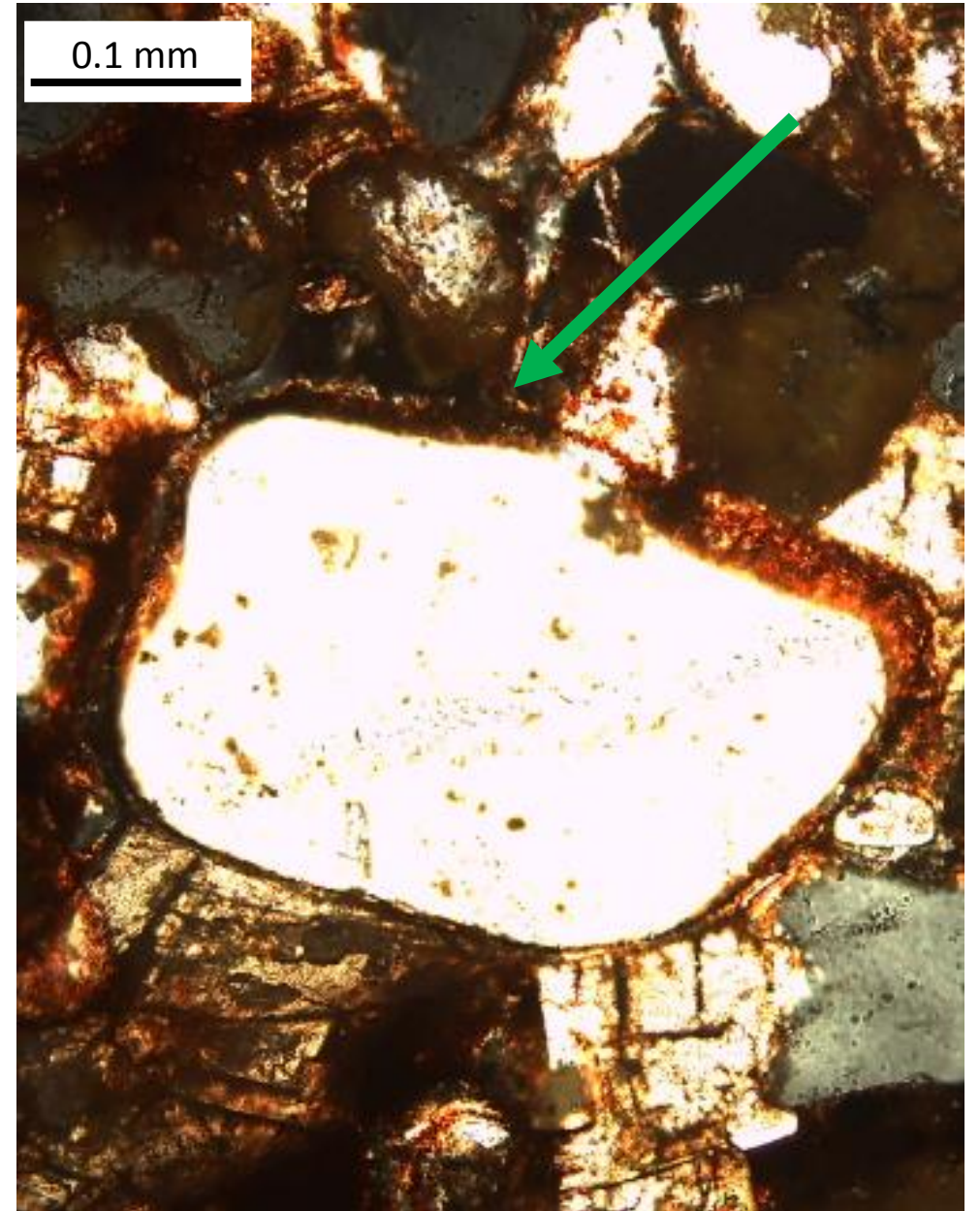
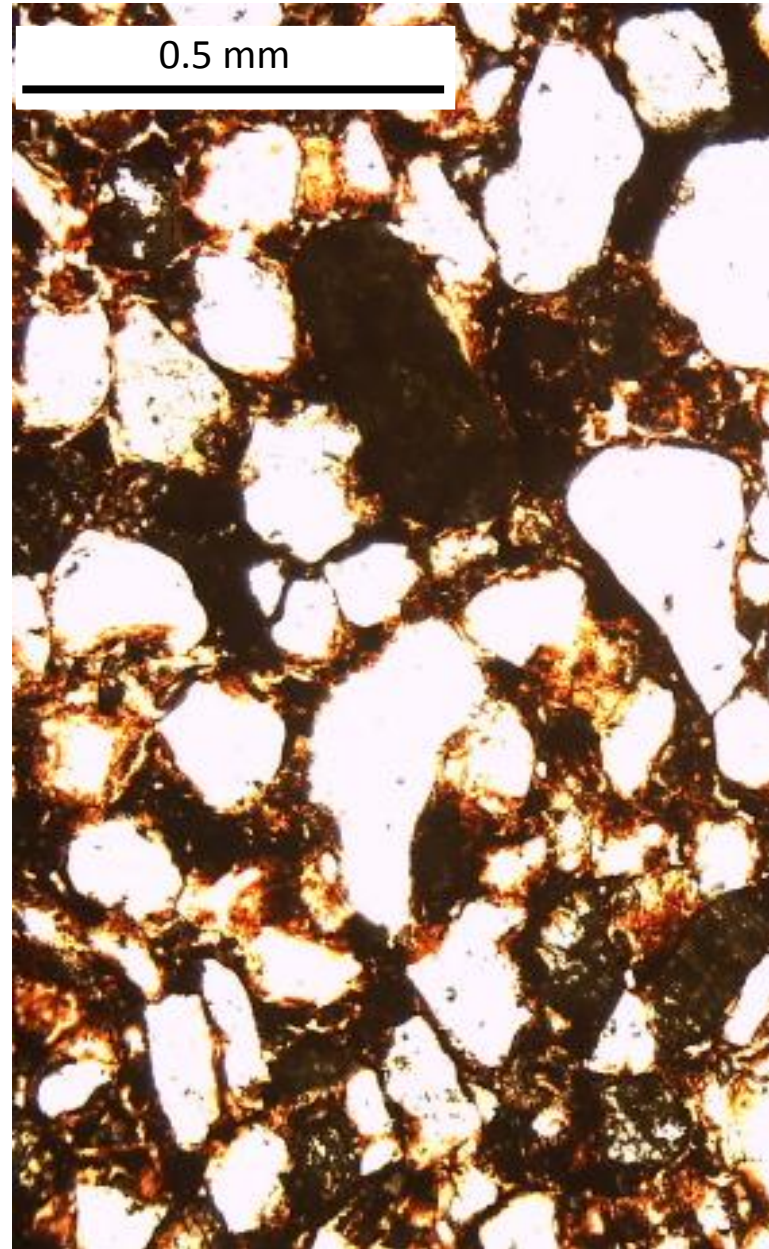
Petrography

- Banded iron oxide and carbonate cements
- Iron oxide cements
 - Rims
 - Pore filling
- Carbonate cements
 - Pore filling
- Clay cements (?)



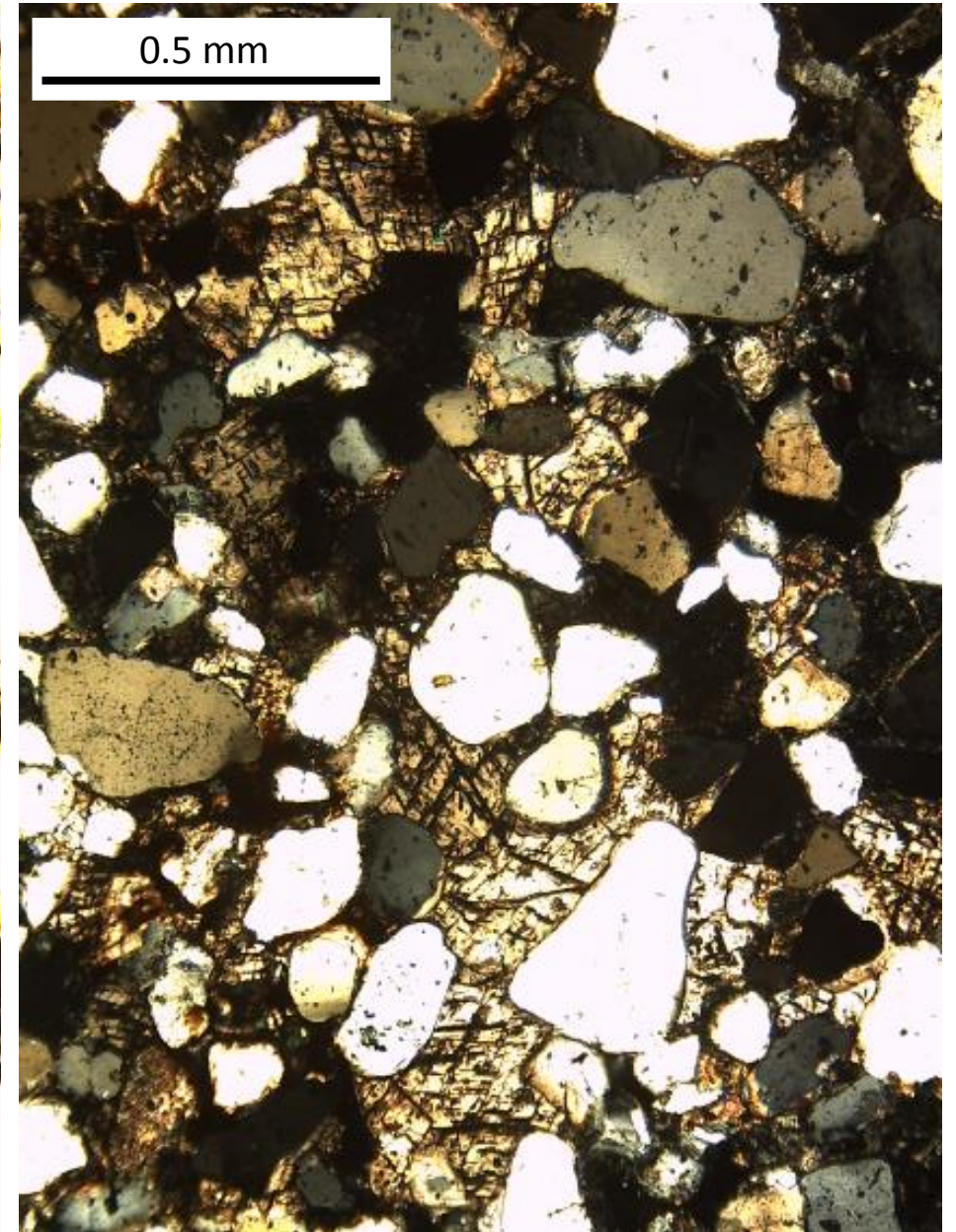
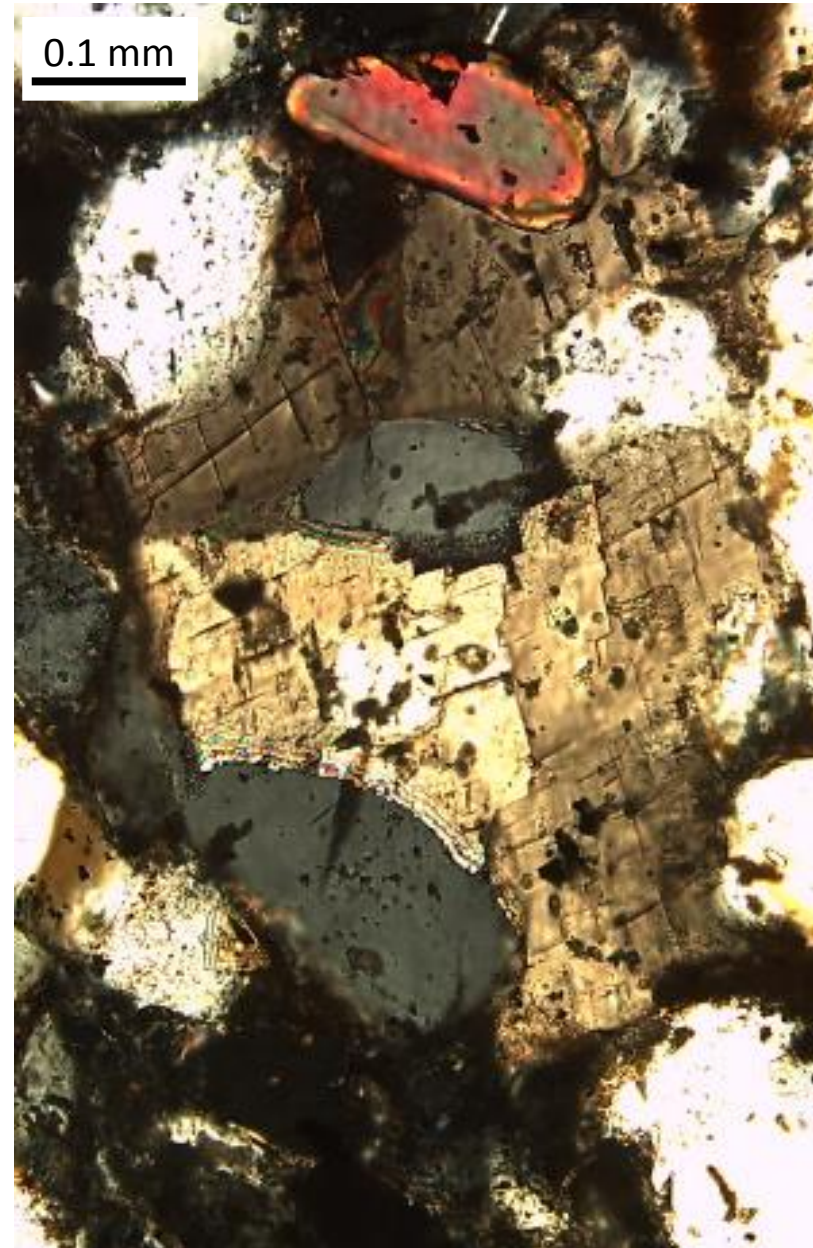
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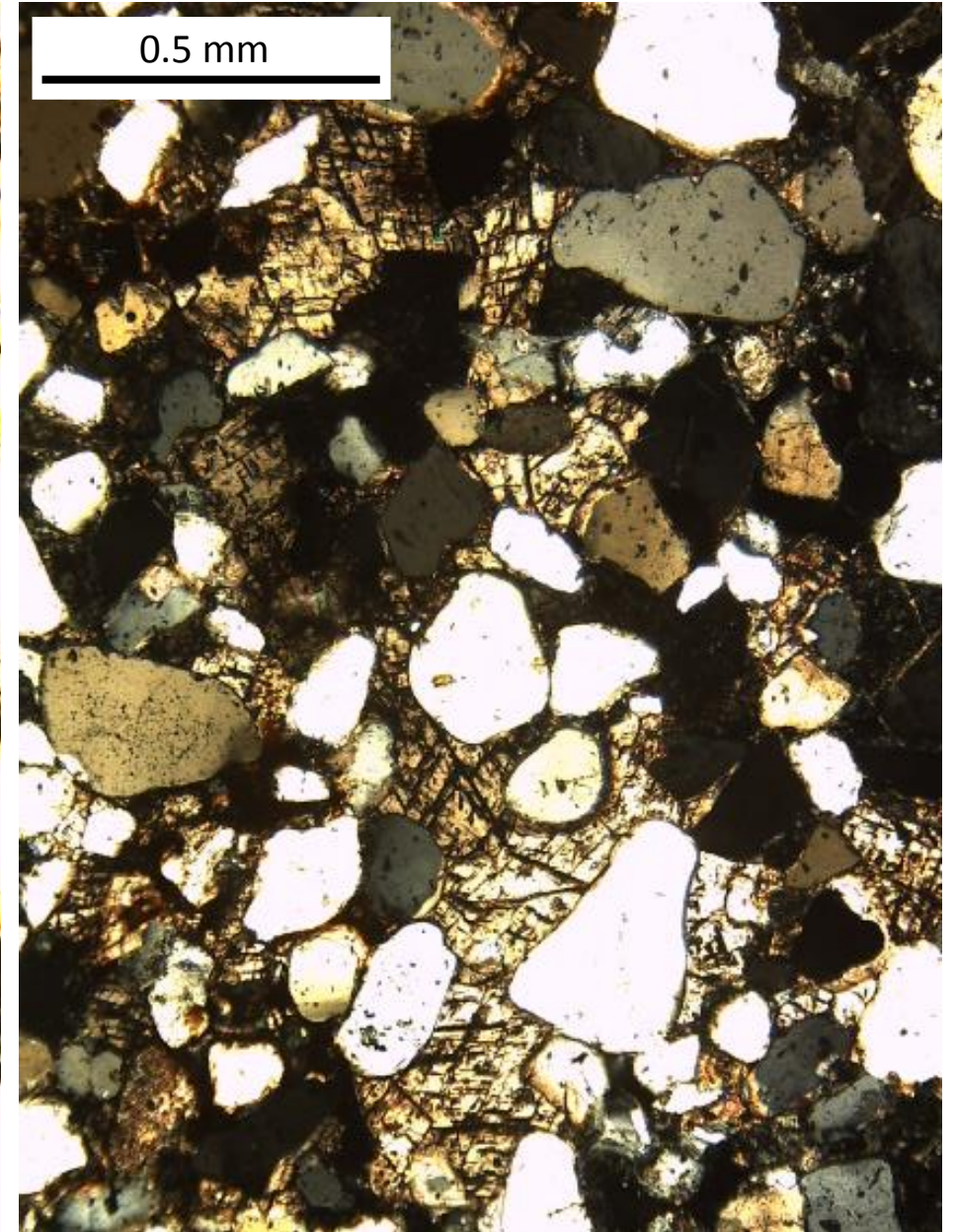
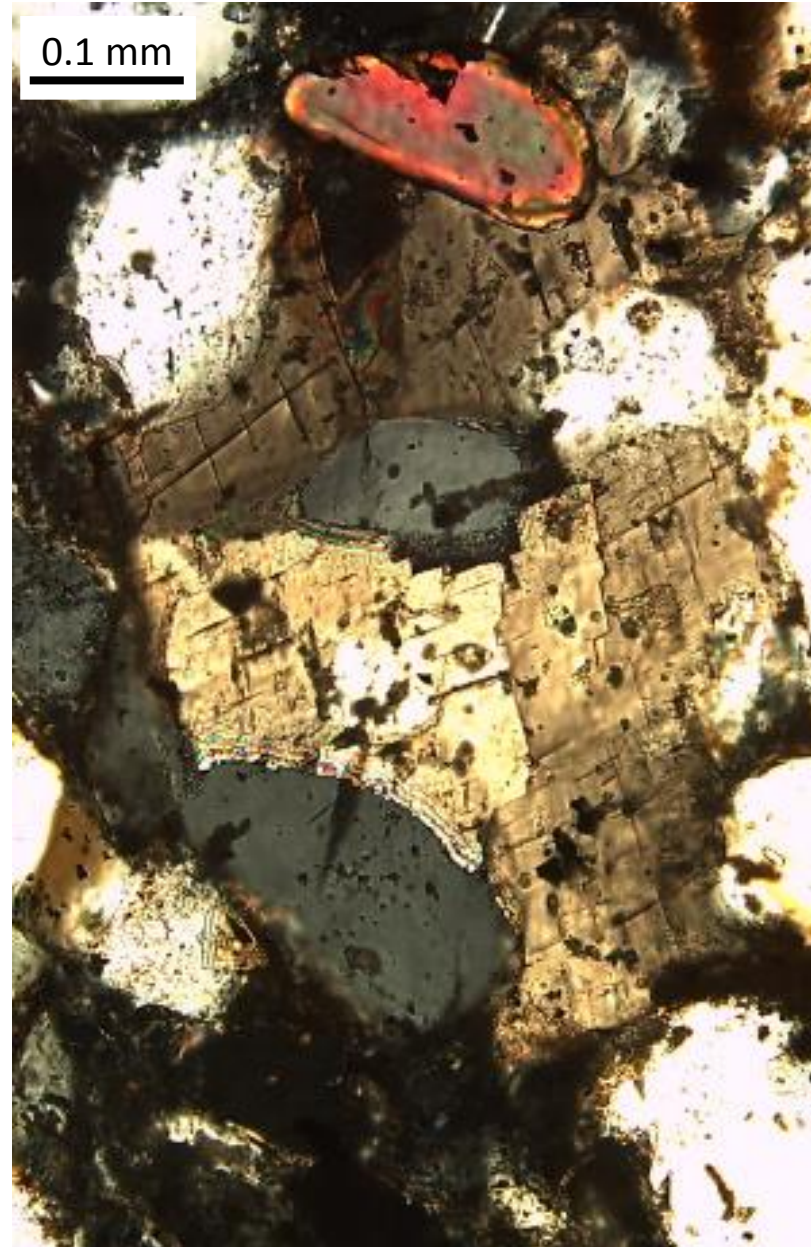
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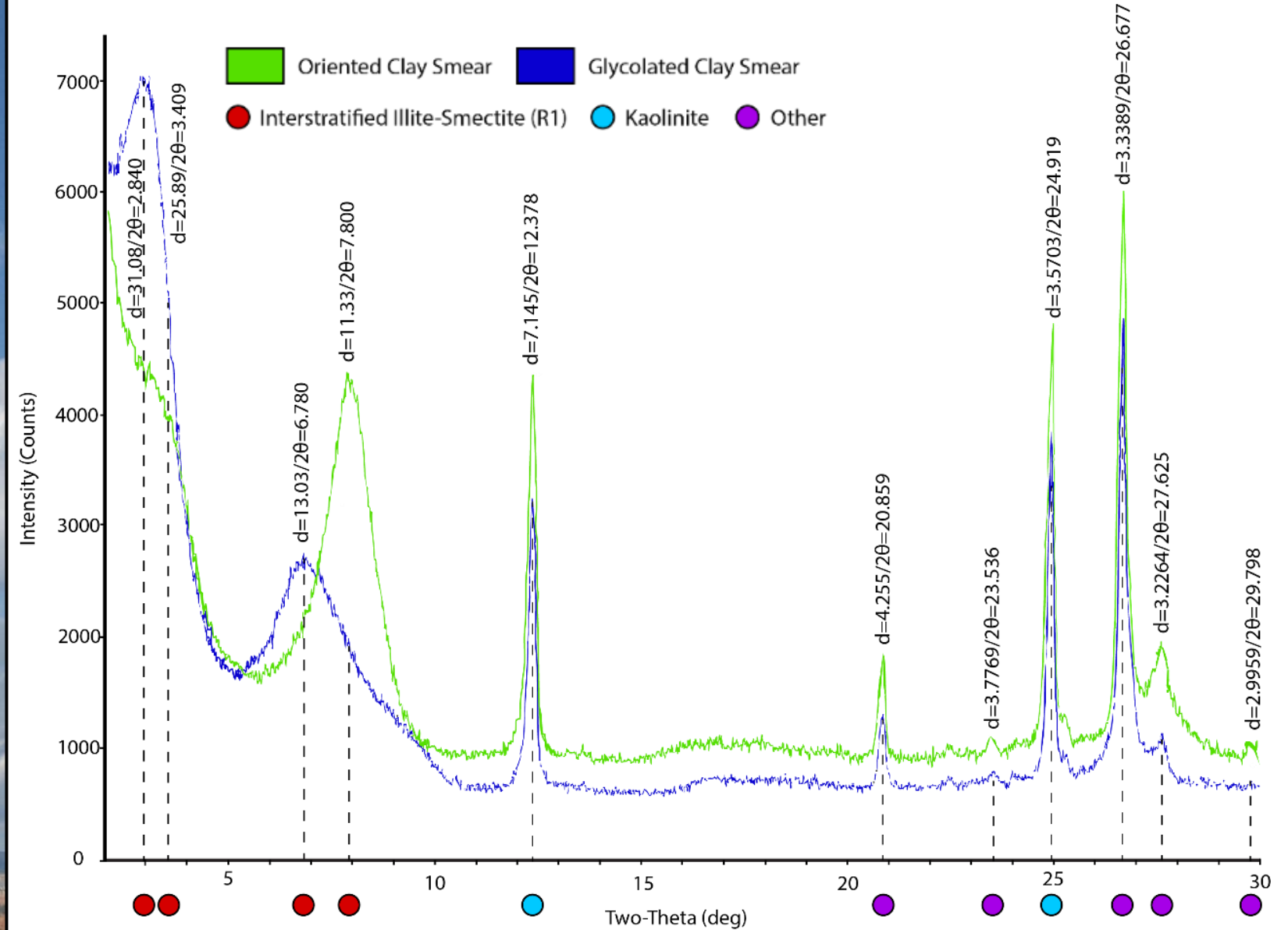
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XRD

- Multiple Clay Minerals
 - Interstratified Illite-Smectite
 - Kaolinite
- Interstratified Illite-Smectite (R1)
 - Indicates burial diagenesis
 - 110-170°C (~2.5-4.5 km burial)



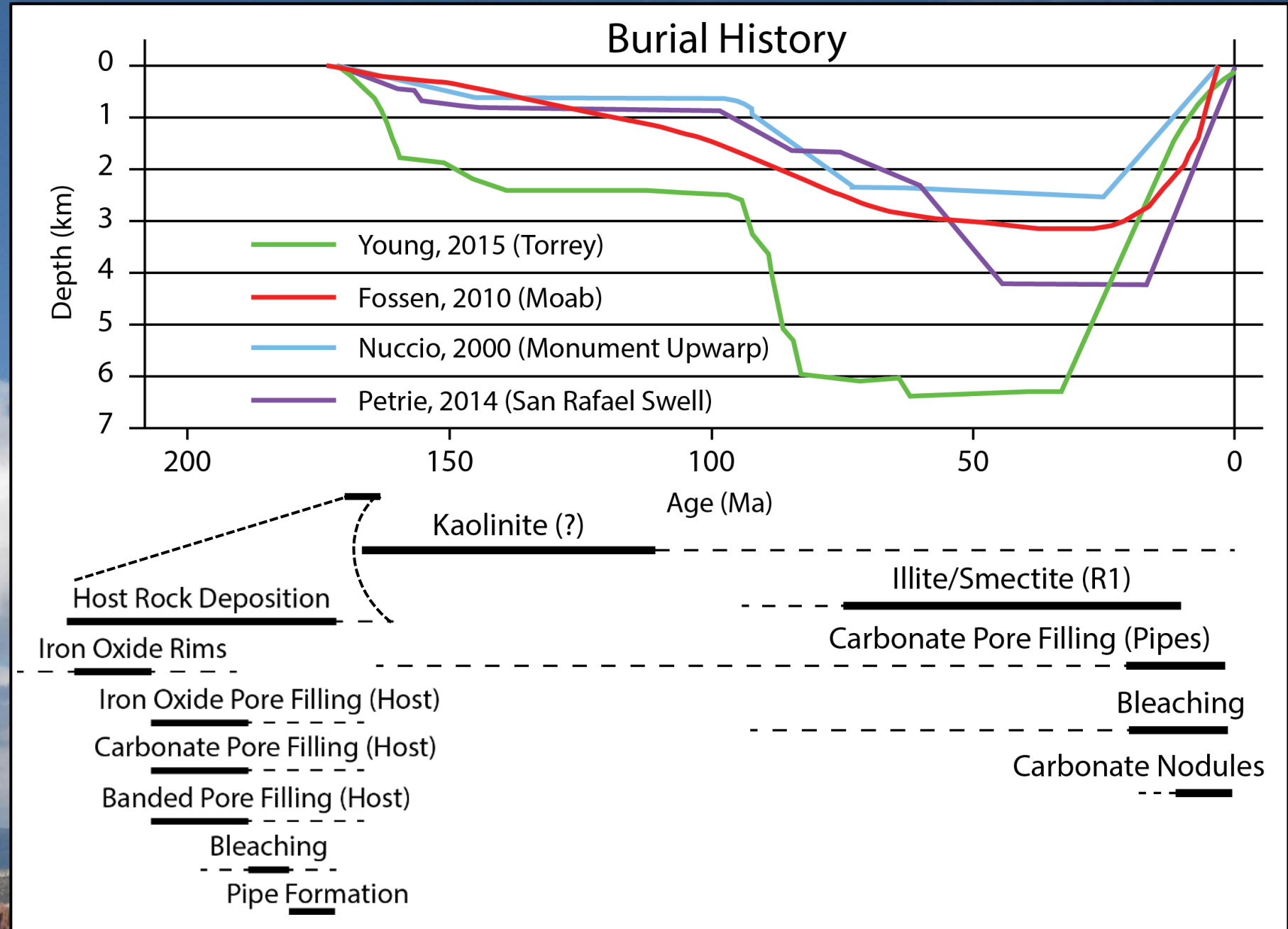
Fluid Inclusions

- Monophase inclusions
 - Within carbonate nodules
- Brackish salinity
 - 7000-14000 ppm
 - Groundwater with an evaporative component
- Low formation temperature
 - <70-80°C (~<1 km burial)
- Hydrocarbons, CO₂
 - Both oil and gas
 - Thermogenic and biogenic gas



Paragenesis

- Early host rock diagenesis
 - Multiple (coeval?) iron oxide + carbonate cements
- Clay burial diagenesis
- Late stage bleaching, carbonate nodule formation



Conclusions

Composition:

- Iron oxide + carbonate rich fluids
- Hydrocarbons + CO₂
 - Bleaching (i.e. reducing) fluids

Timing:

- Early, middle/burial, and late stage diagenesis
- Pipe cements form late
 - Relative to early host rock diagenesis



Questions?

