Sequence Stratigraphic Control on Distribution and Porosity Evolution in Cherts in the Mississippian of the Mid-Continent*

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Abstract

Intervals of chert in the Mississippian carbonates of the Mid-Continent are primary reservoir targets, yet little is known about the origin of the chert or the controls on porosity development within them. The primary source of silica is generally thought to be from the dissolution of siliceous sponges, interpreted due to the presence of abundant spicules and spiculitic molds in many of the cherts. Further influx of silica into the system (volcanic ash or detrital quartz) may accelerate sponge productivity and thus help account for the abundance of chert found in these units. Chertification of carbonate was initiated by dissolution of biogenic amorphous silica and the subsequent precipitation of opal-CT and quartz. Carbonate replacement was achieved by a force of crystallization-controlled replacement, where dissolution of carbonate material was driven by the precipitation of various silica phases. Dissolution of carbonate and silica, as well as the volumetric change from amorphous silica to quartz, created pore space in many of the cherts. Porosity abundance in the cherts is controlled by the relative rate of burial during deposition, as it controls the initial ratio of carbonate to spicules. Extremely slow burial resulted in minimal carbonate input, resulting in the dissolution and re-precipitation of spicules as nearly pure, non-porous cherts. Slow burial rates resulted in a higher percentage of spicules in the carbonate, allowing for nearly complete replacement of limestone by silica and forming abundant porosity in the rock. Faster burial increased the overall ratio of carbonate to spicules, effectively decreasing the volume of carbonate that could be replaced, resulting in a decrease in the total porosity. In outcrop, the variety of chert exhibits a strong correlation to the sequence stratigraphic framework. Overall, gradational changes from pure, to highly porous, to less porous cherts are observed vertically at multiple frequencies due to varying orders of sea level cyclicity. The link between chert variety, relative sea level fluctuation, and the observed sequence stratigraphic framework aids in explaining the controls on porosity distribution at both the 3rd and 4th order scales.

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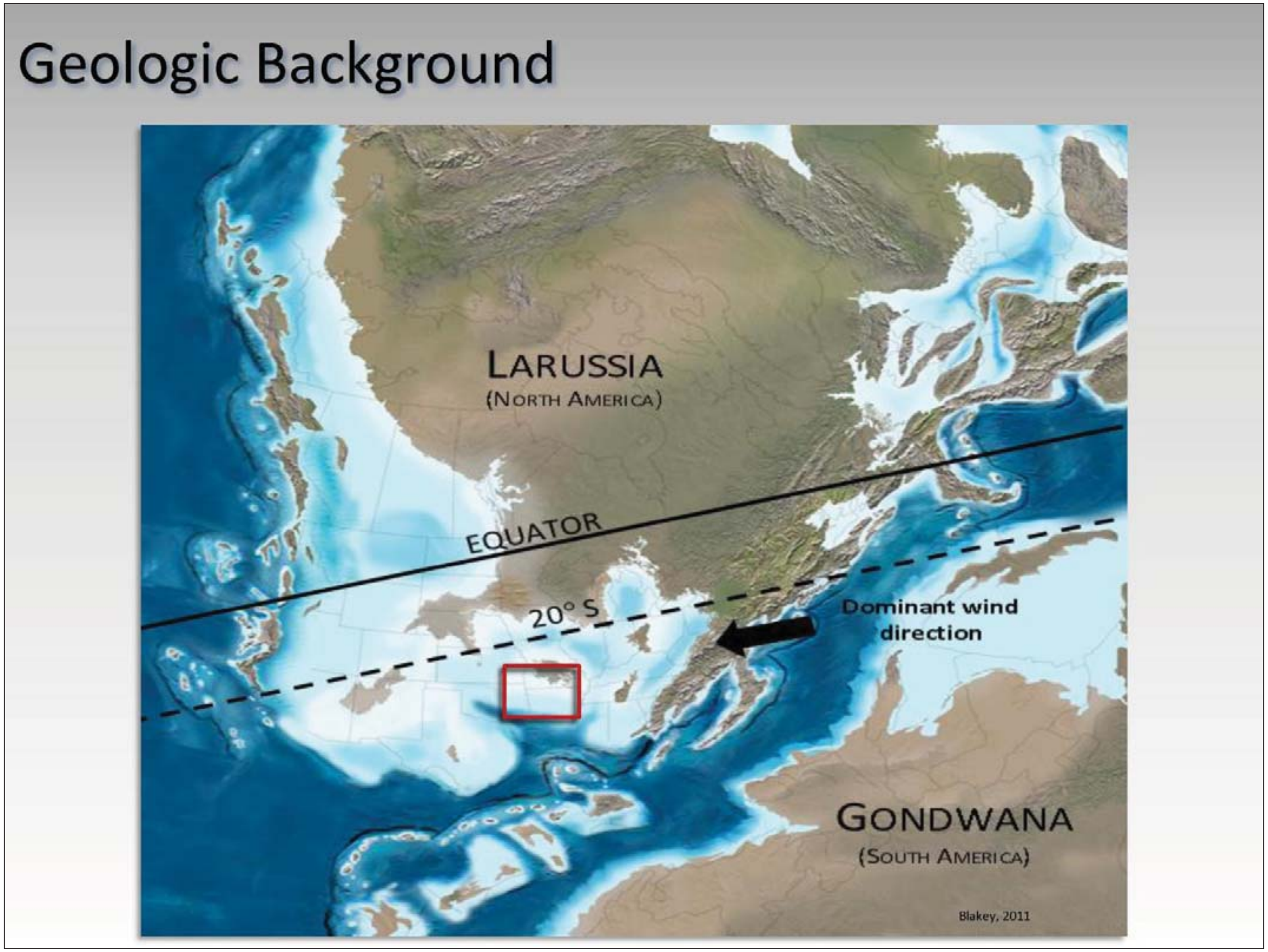
Outline

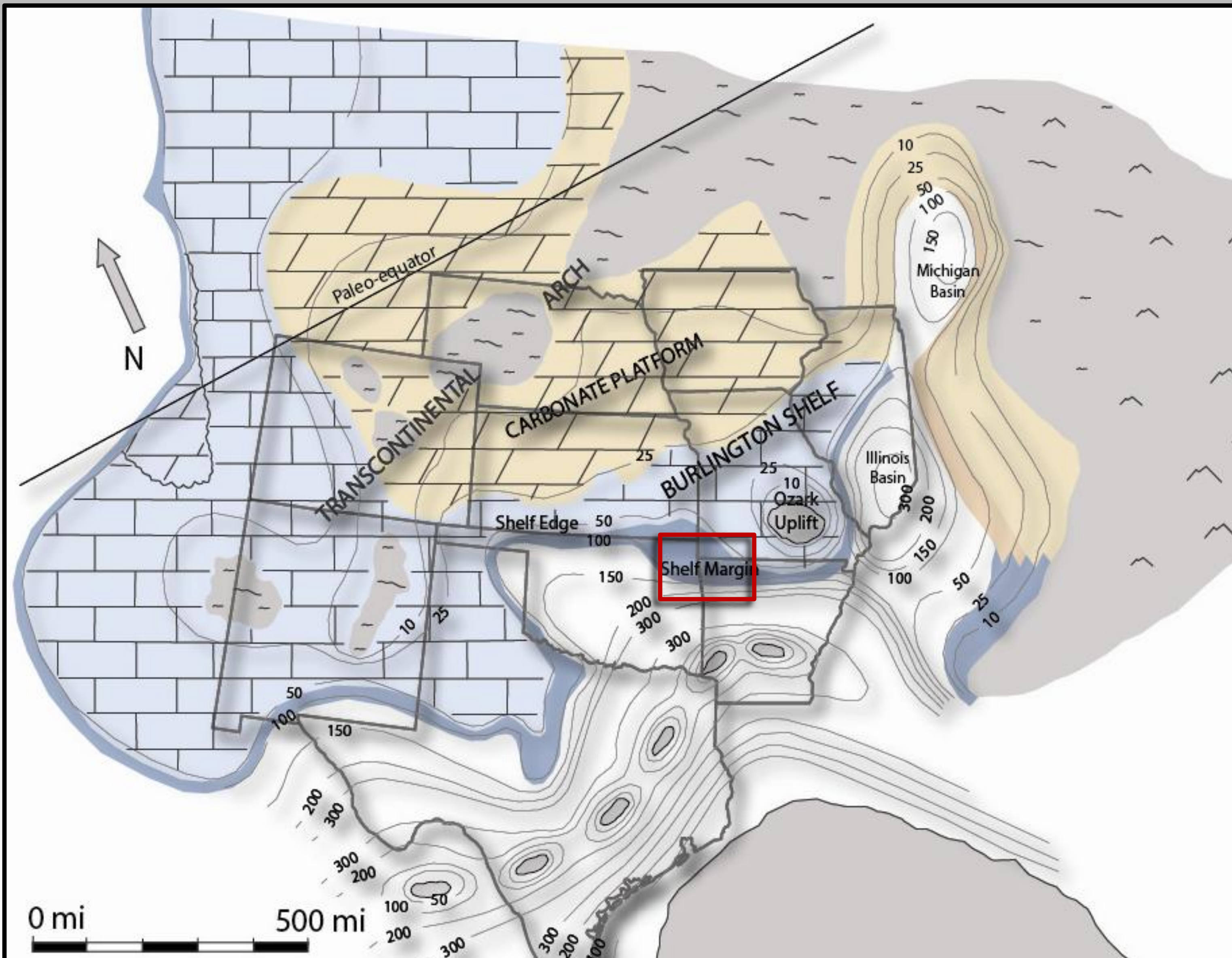
- Geologic Background
- Stratigraphy
- Types of Chert
- Source of Silica
- Porosity Evolution
- Sequence Stratigraphic Control

Presenter's notes: Chert is abundant throughout much of the Mississippian section in the Mid-Continent. In many instances the chert is highly porous and makes excellent oil and gas reservoirs. The evolution of the chert and its porosity has been debated for many decades. There is still no consensus for how the chert was formed and how the porosity in the chert formed. The purpose of this research is to explain the formation of porosity in the chert. We used some key work that had been done on cherts, mainly Maliva and Siever, to explain how the porosity formed. With that understanding, we were then able to explain how the porosity evolution in the cherts is controlled to a large degree by the overall sequence stratigraphic framework and depositional environments that changed and migrated at various frequencies due to sea level change.



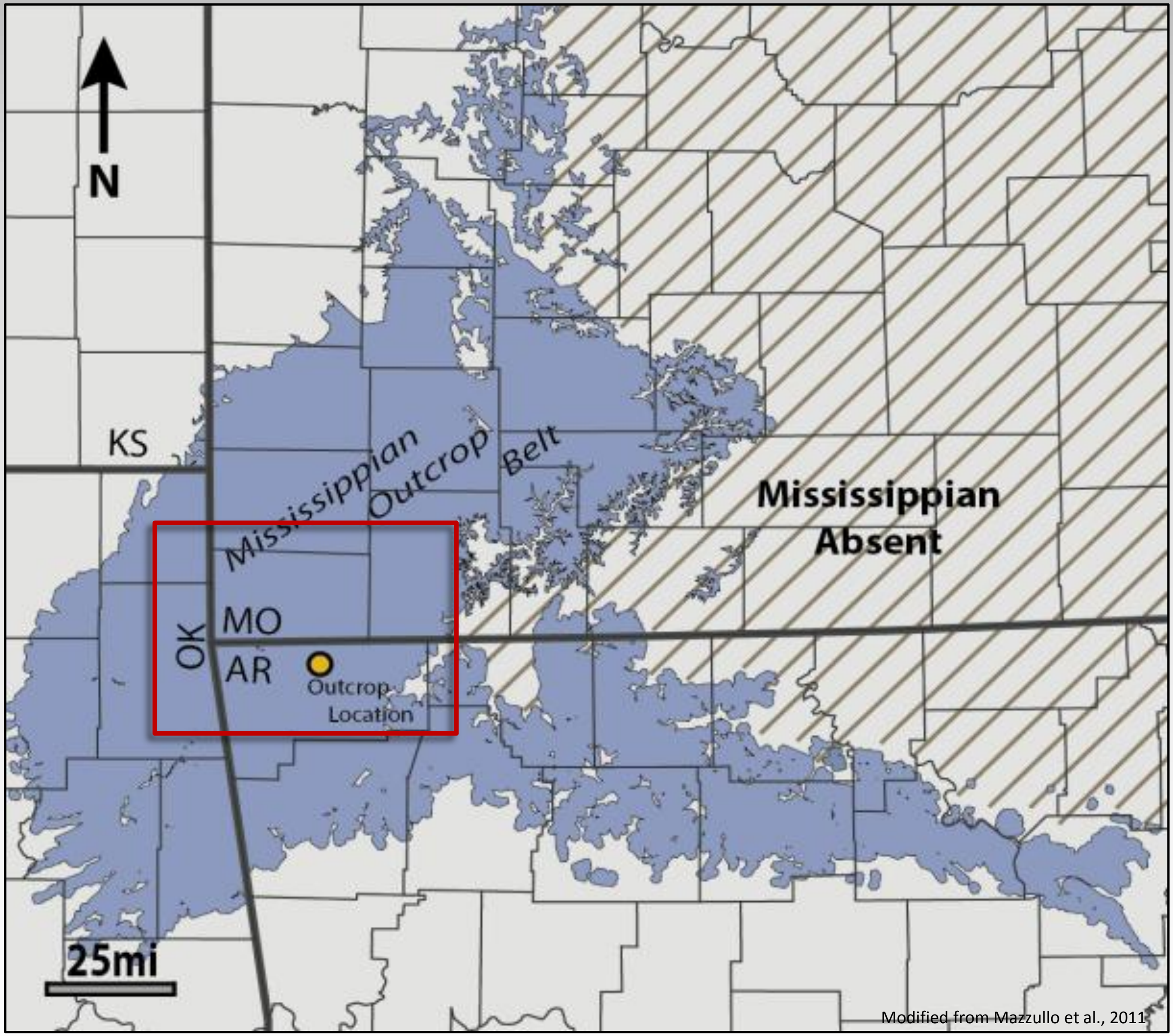
Presenter's notes: Deposition occurred 25-30 degrees south of paleo-equator, shallow tropical to sub-tropical conditions adequate for carbonate deposition. Deposited on a distally steepened ramp, bounded by Ozark Uplift to the east, Transcontinental Arch to the north and west, and to the south by deeper water conditions provided by the ancestral Anadarko and Arkoma Basins Important to note that the dep models are a snapshot of geologic time and large amounts of variability and deviations from the models should be expected Also note that the depositional model places the study area in approximately 50-100m water depth. There are already fundamental flaws with the depths provided, but keep that in mind.

Geologic Background

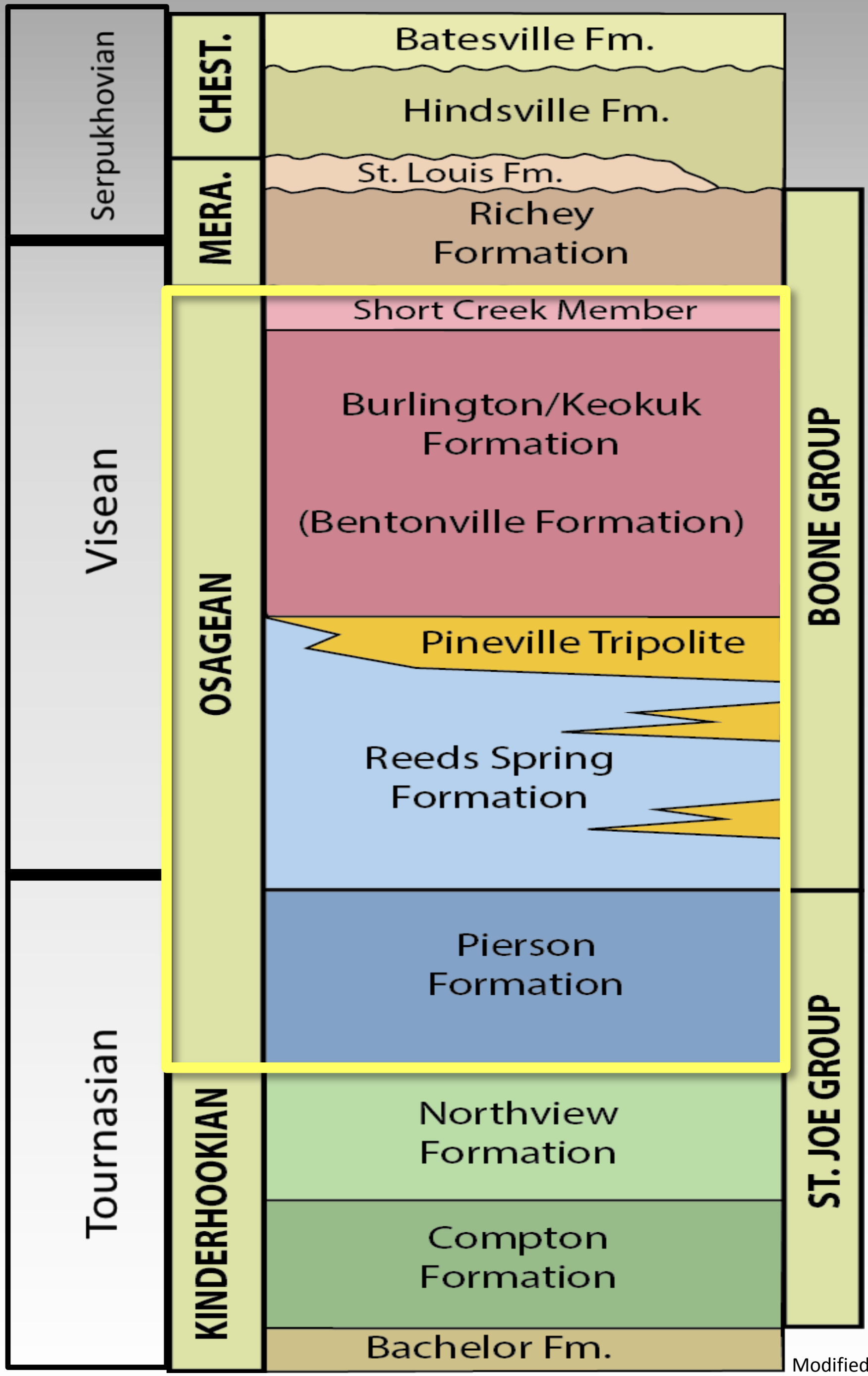


Modified from Gutschick and Sandberg, 1983

Geologic Background- Study Area



Study Area

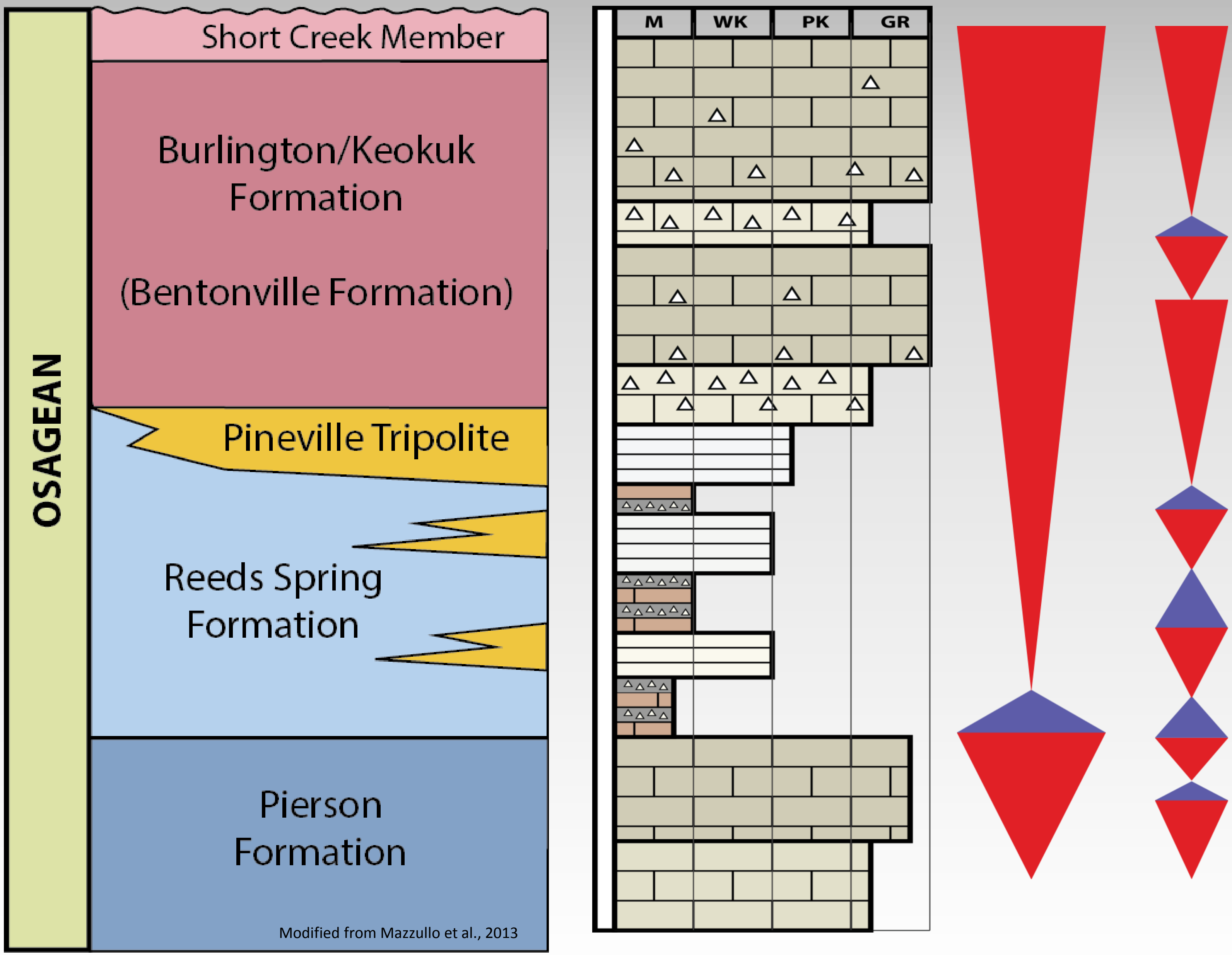


Modified from Mazzullo et al., 2013

Outcrop Stratigraphy

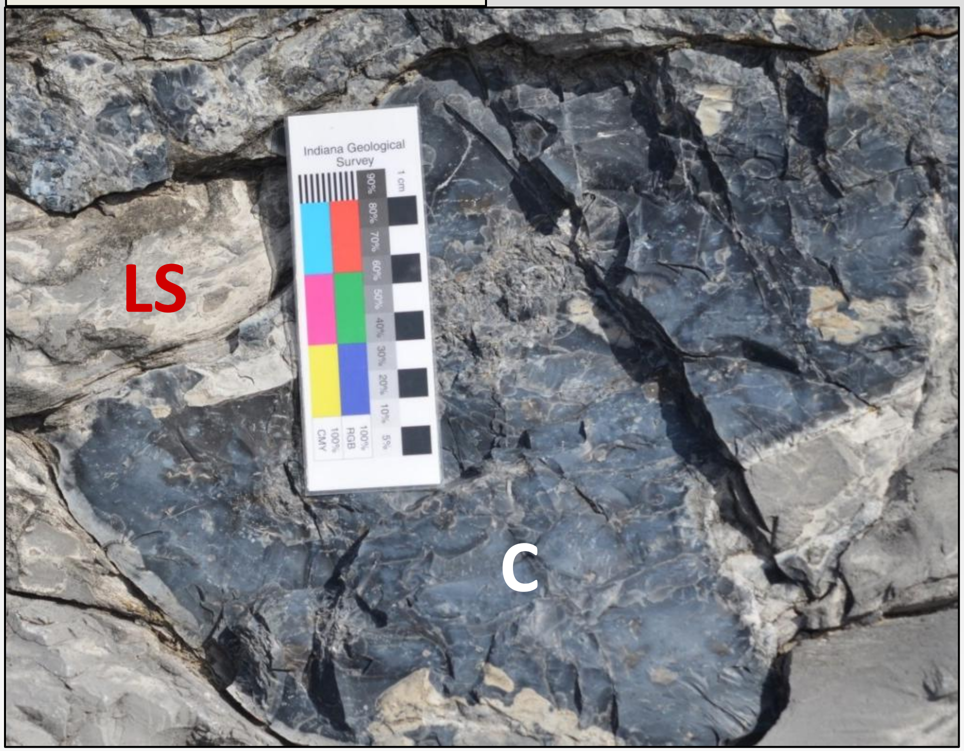
Only Osagean exposed in study area

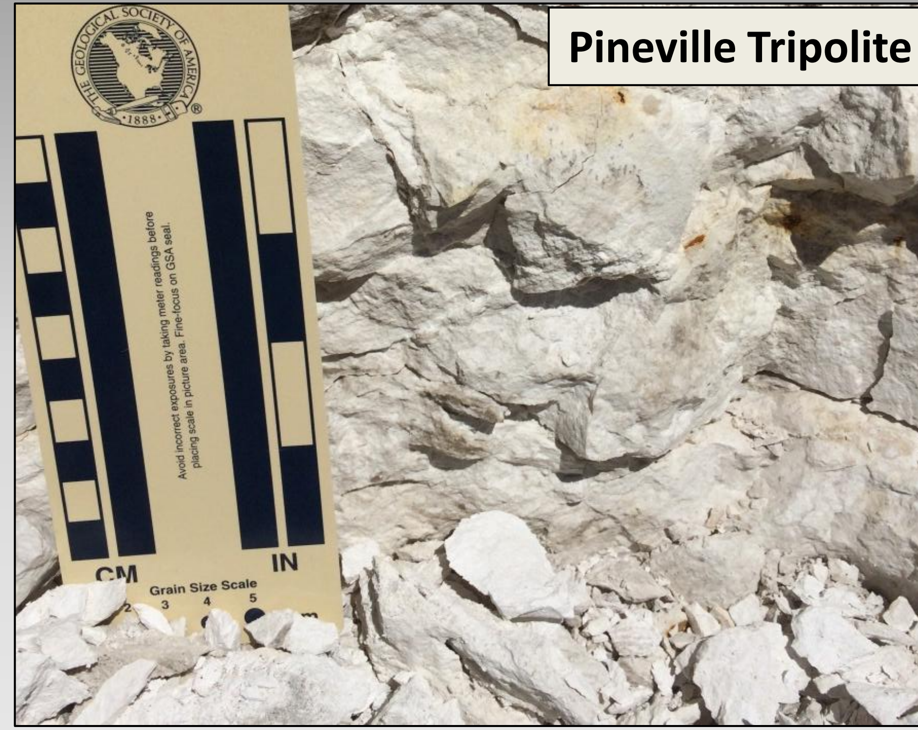
Sequence Stratigraphy



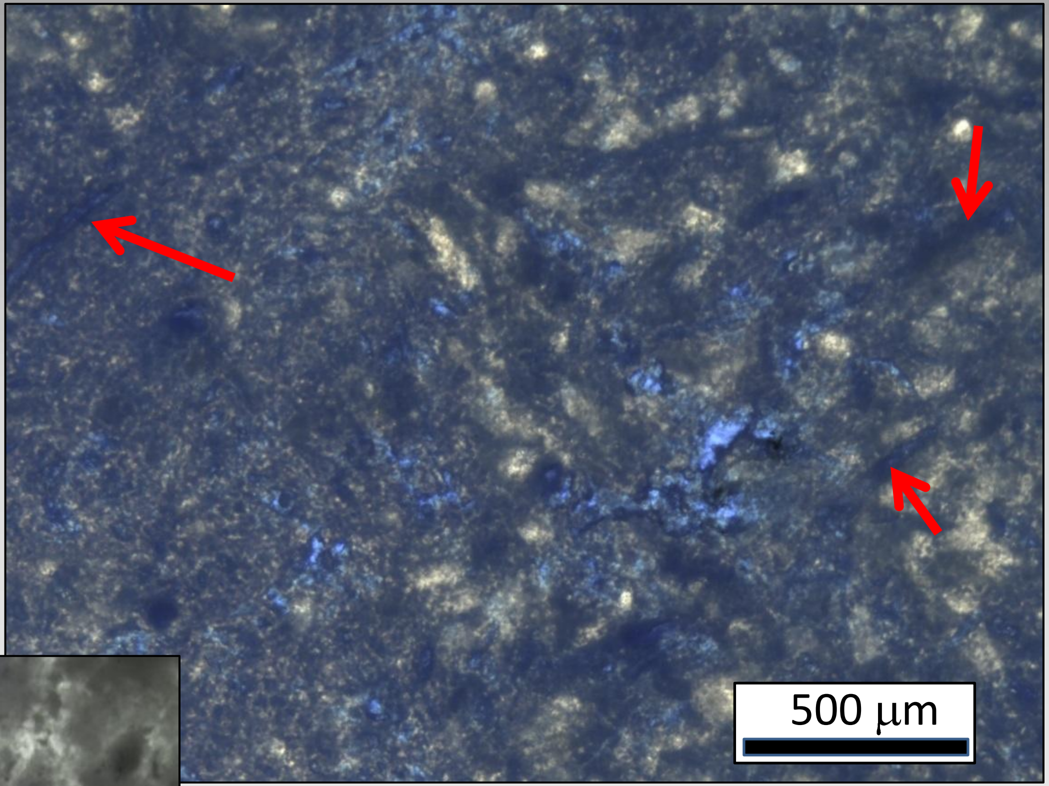
Types of Chert

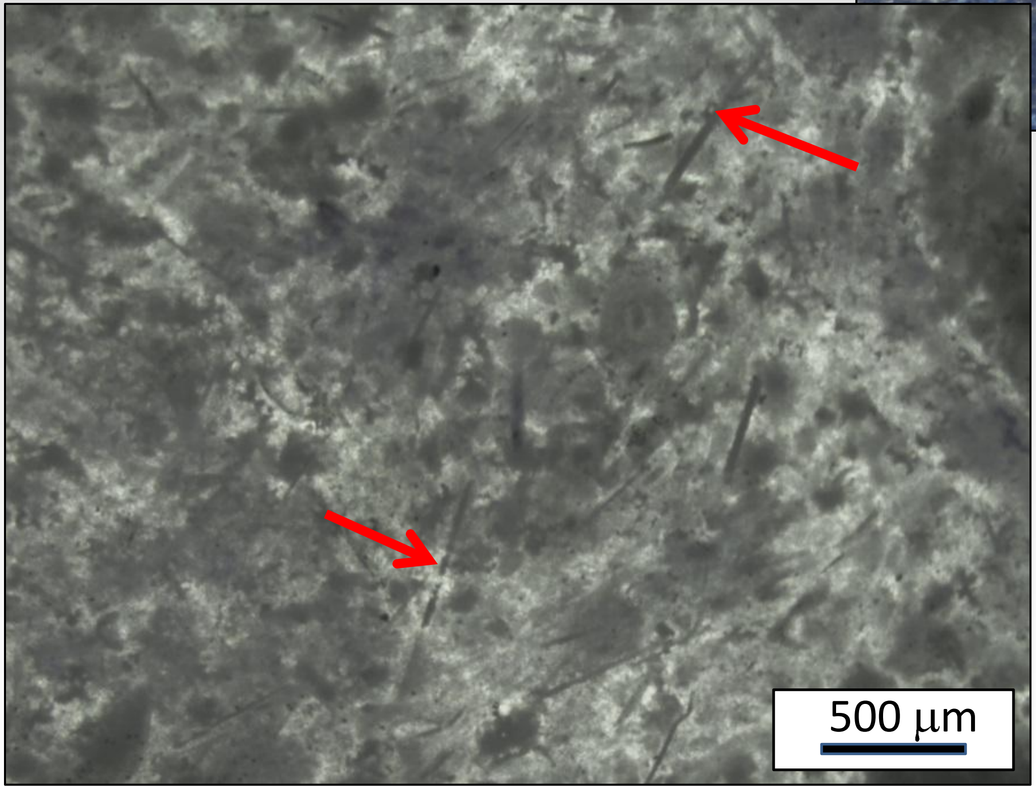
Non-Porous Chert- RS



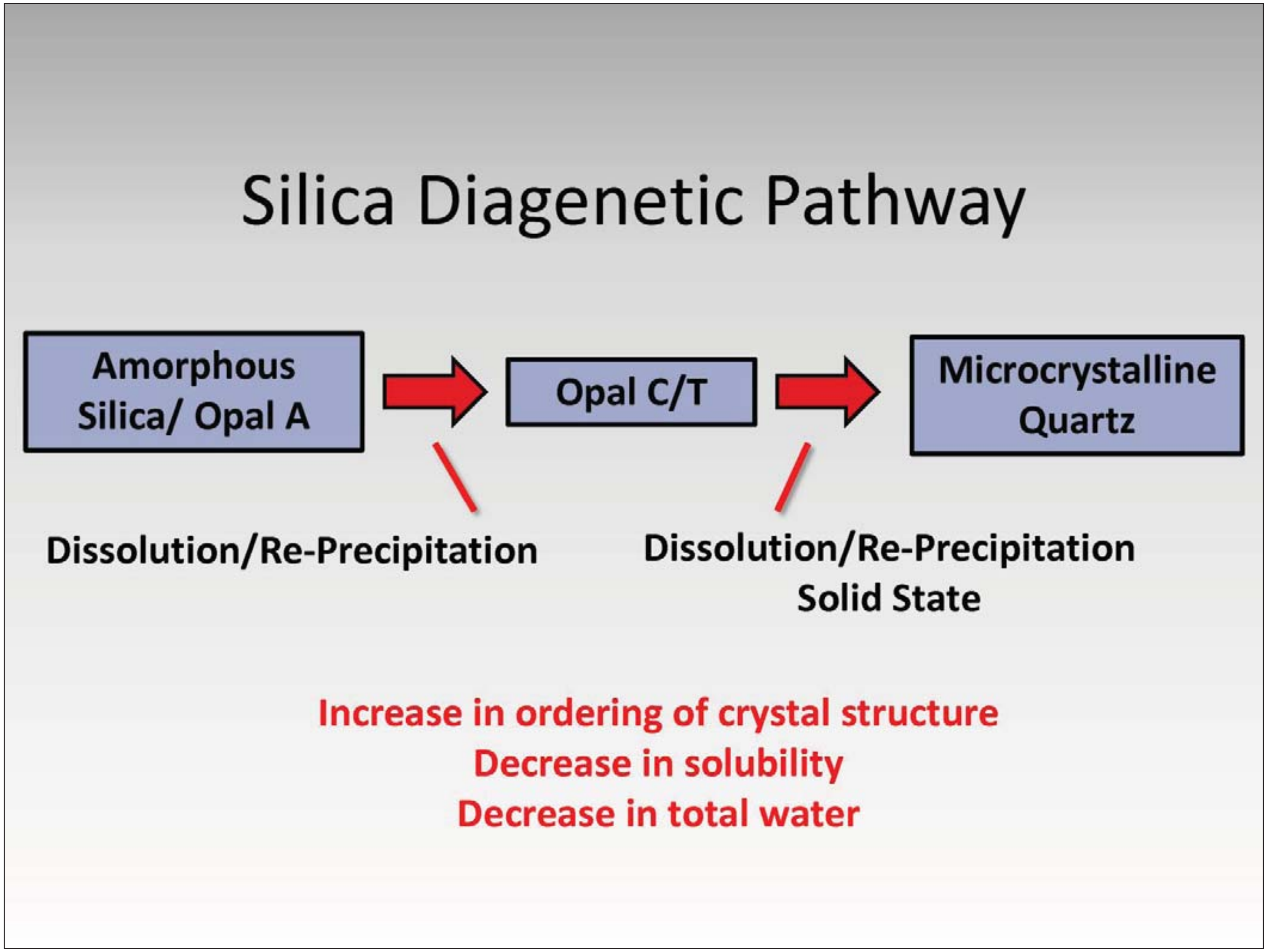


Source of Silica





Siliceous Sponge Spicules



Presenter's notes: Amorphous silica is disordered opal. It has a poor to non-existent crystal structure, contains 10-12% water and its saturation equilibrium is 120-140ppm at 25° C. Opal CT is a mix of stacked cristobalite and tridymite layers in an amorphous silica matrix. It has better order than opal-a. It contains 3-10% water. Solubility equilibrium varies based on the degree of ordering but is in the range of 20-100 ppm at 25° C. Microcrystalline quartz has the best degree of order in the crystal structure. It may contain between 0.5-2.5% water. Its saturation equilibrium is 6-10ppm at 25° C.

Porosity Evolution

Controlled by the relative ratio of siliceous sponge spicules to carbonate in the sediment

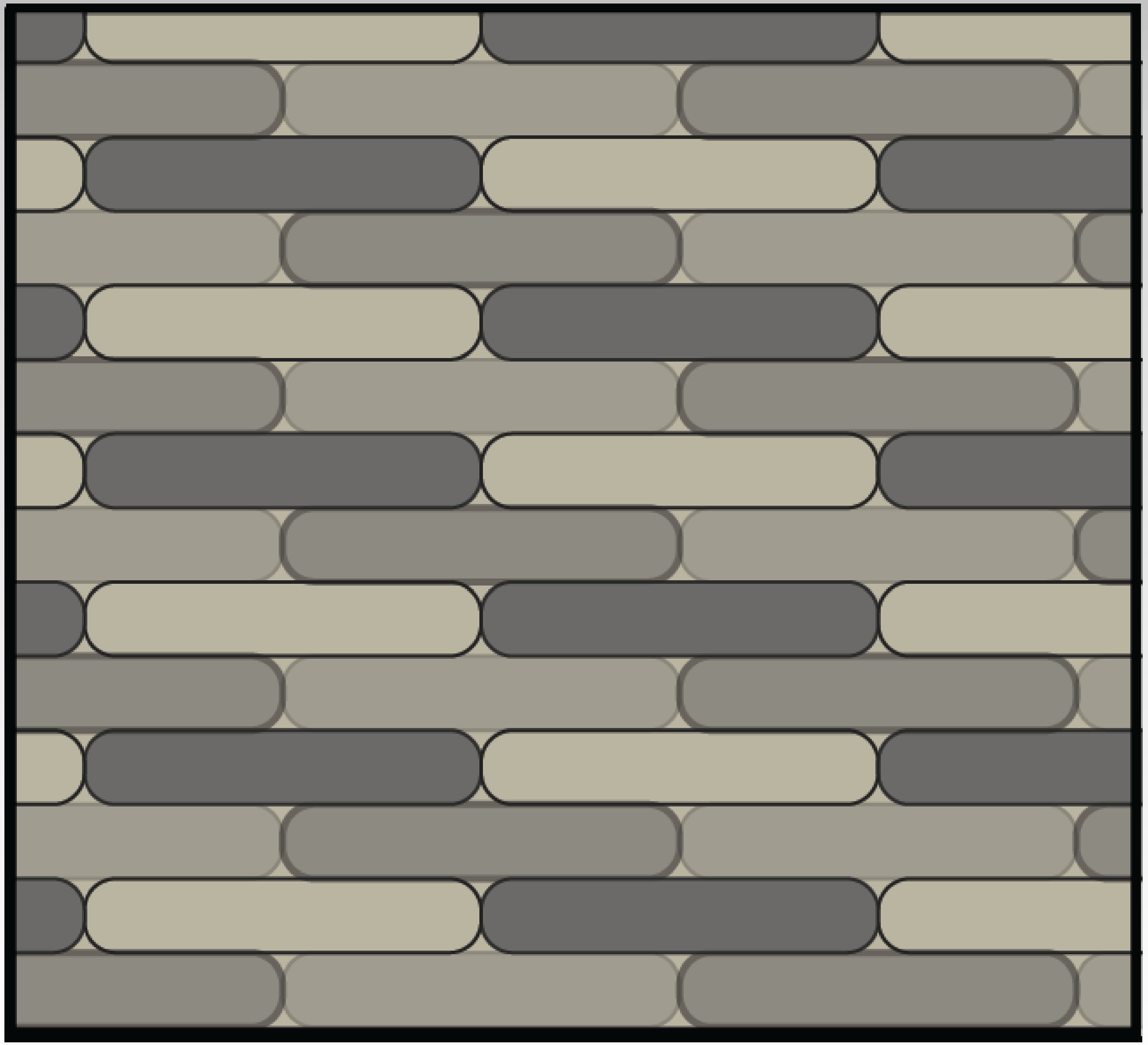
Spicules **>>** Carbonate = Non-porous chert

Spicules **>/=** Carbonate = Tripolite

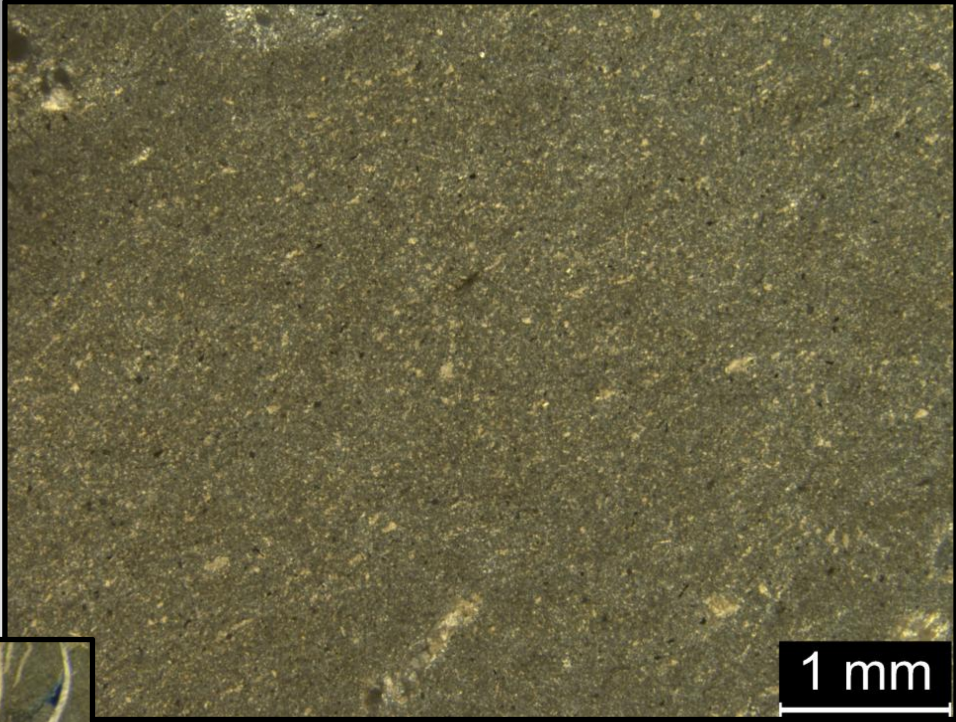
Spicules < Carbonate **=** Silicified Limestone

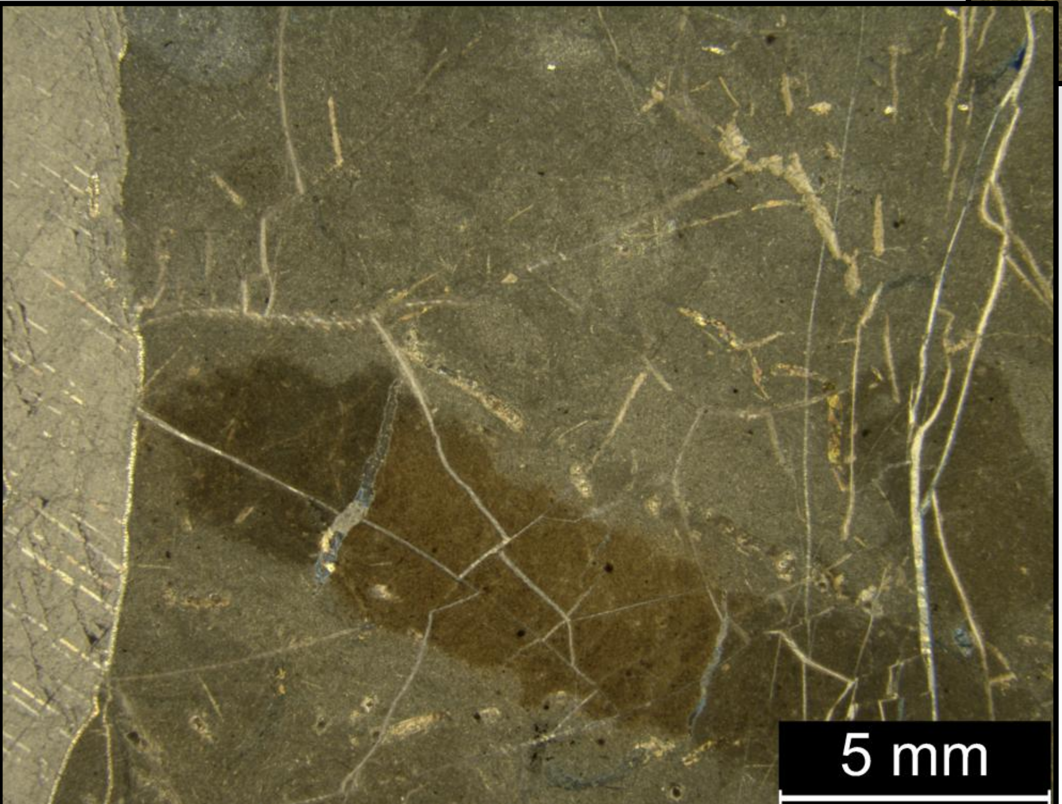
Sequence Stratigraphically Controlled

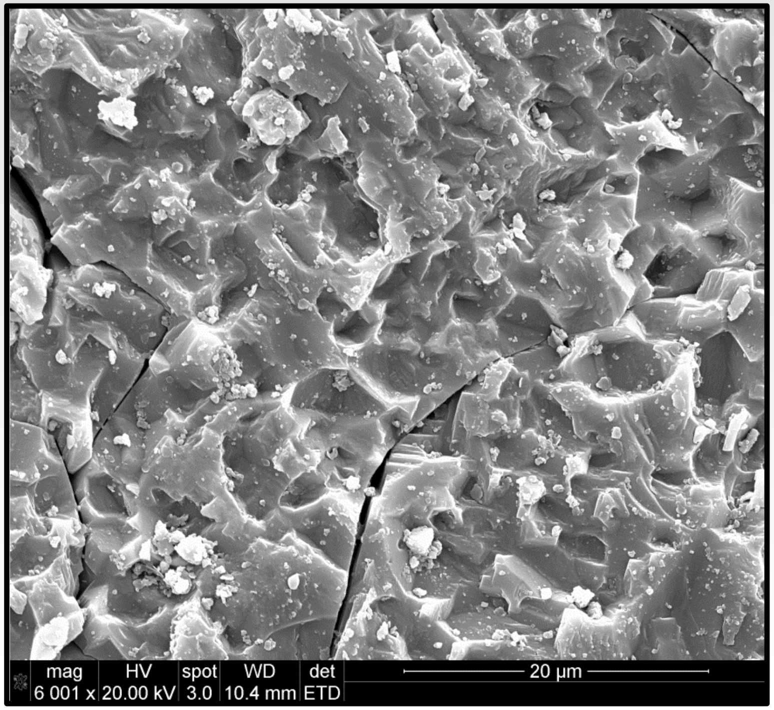
Non-Porous Chert



Non-Porous Chert

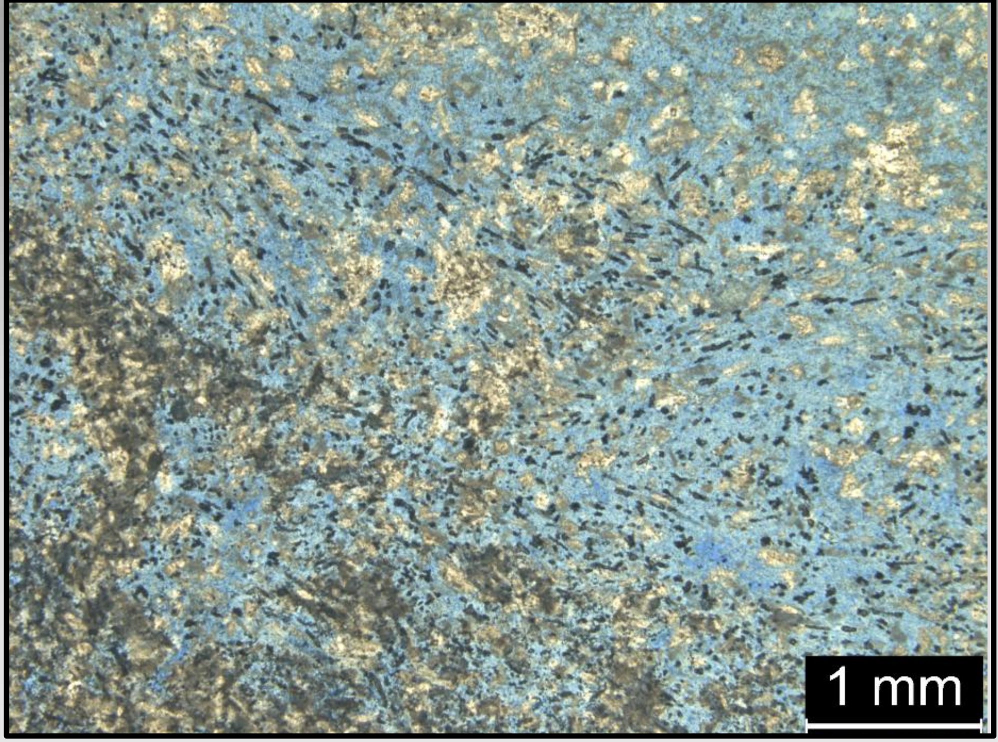






Tripolite

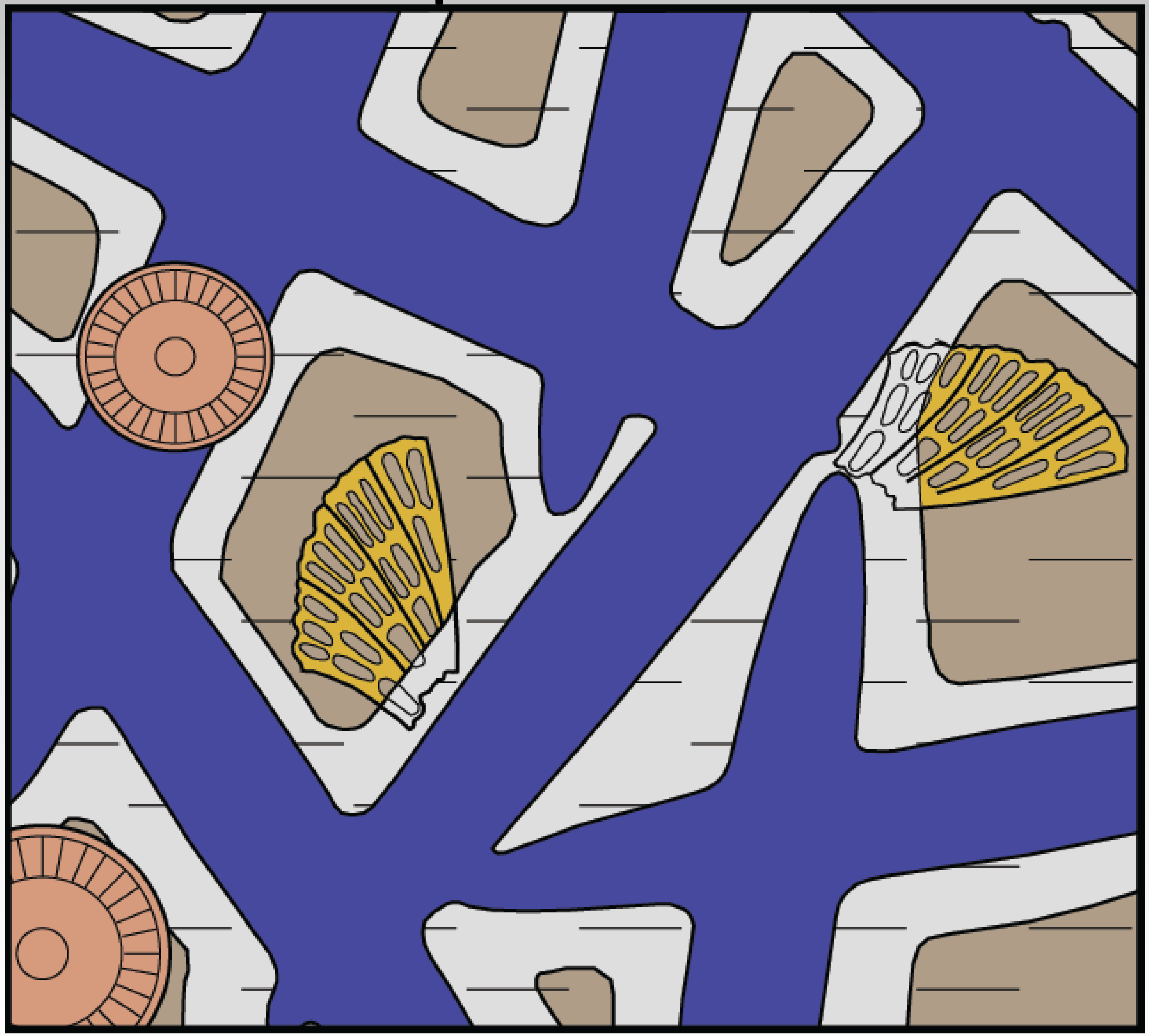
Primary Depositional Fabric- wackestone to packstone with minor to abundant amounts of silt to very fine sand-sized crinoidal debris



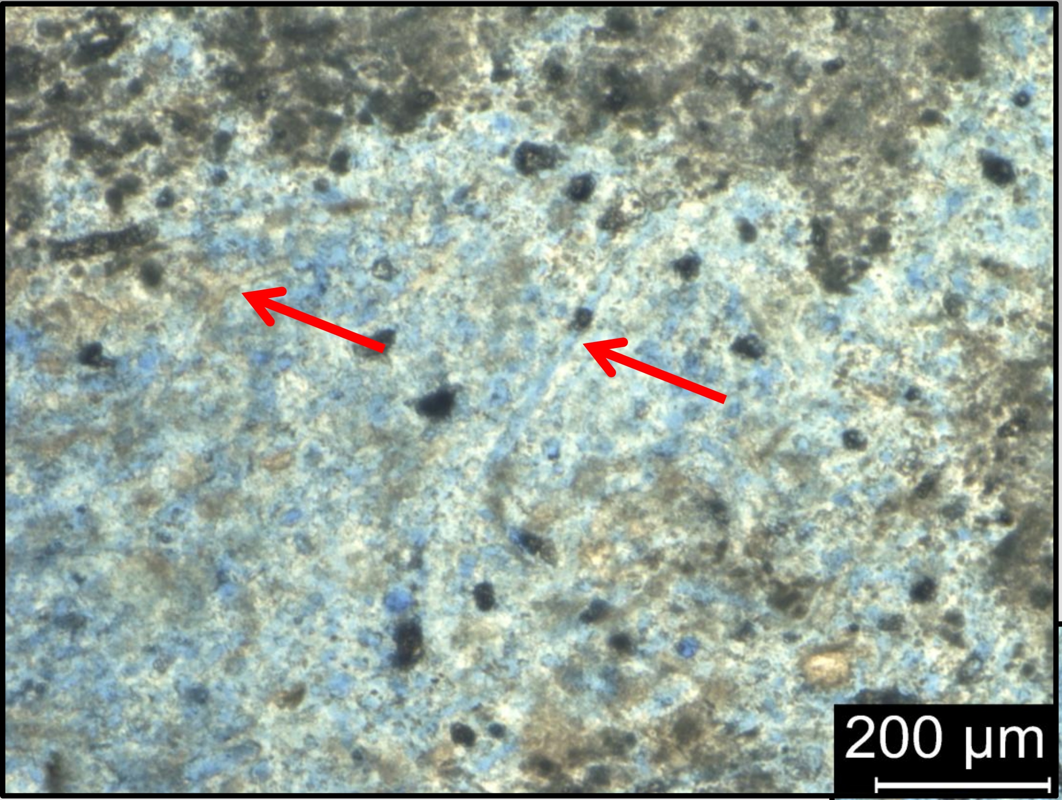
Mechanisms for Porosity Development and Preservation

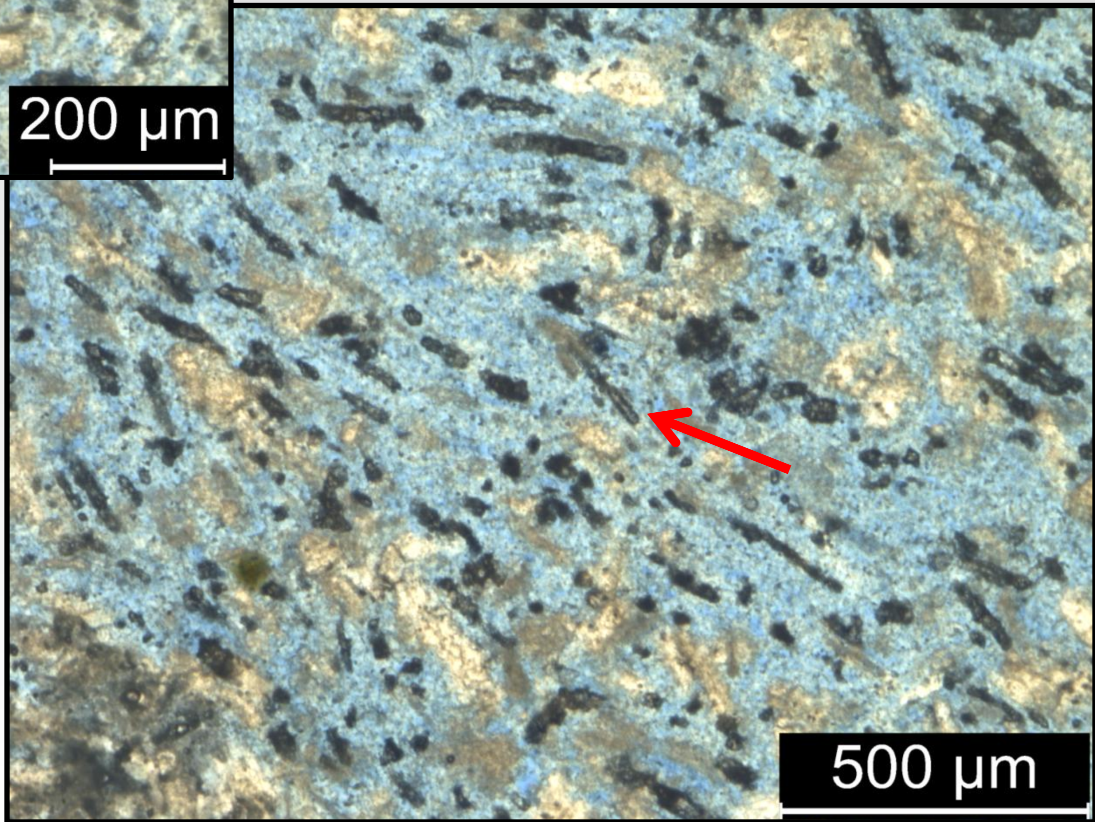
- 1) Force of crystallization controlled replacement (Maliva and Siever, 1988)
- 2) Re-precipitation of microcrystalline quartz around crinoidal grains, inhibiting calcite cementation

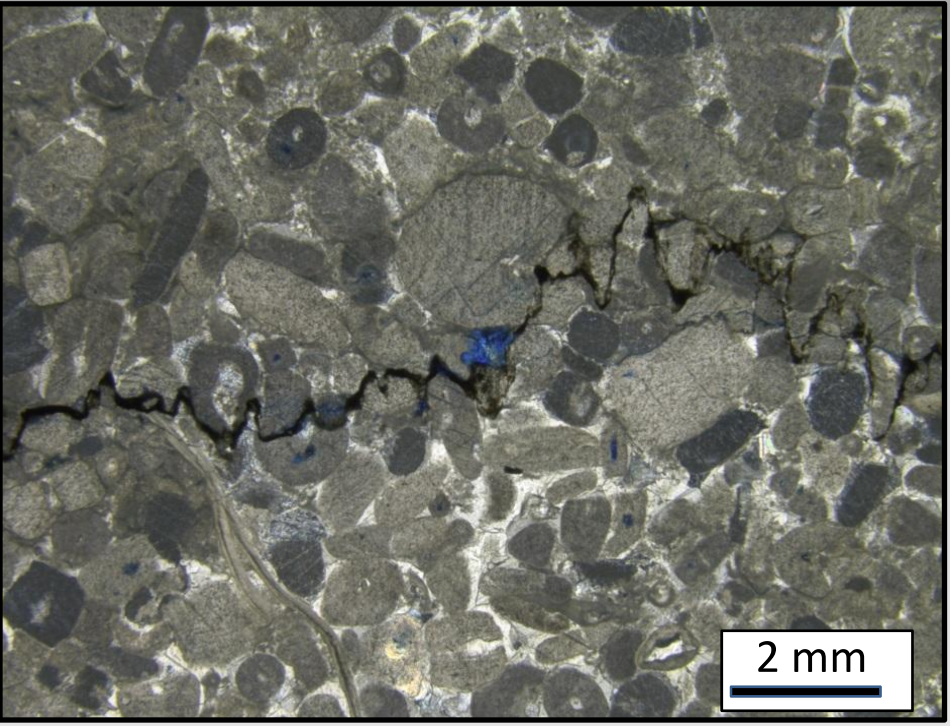
Force of Crystallization Controlled Replacement

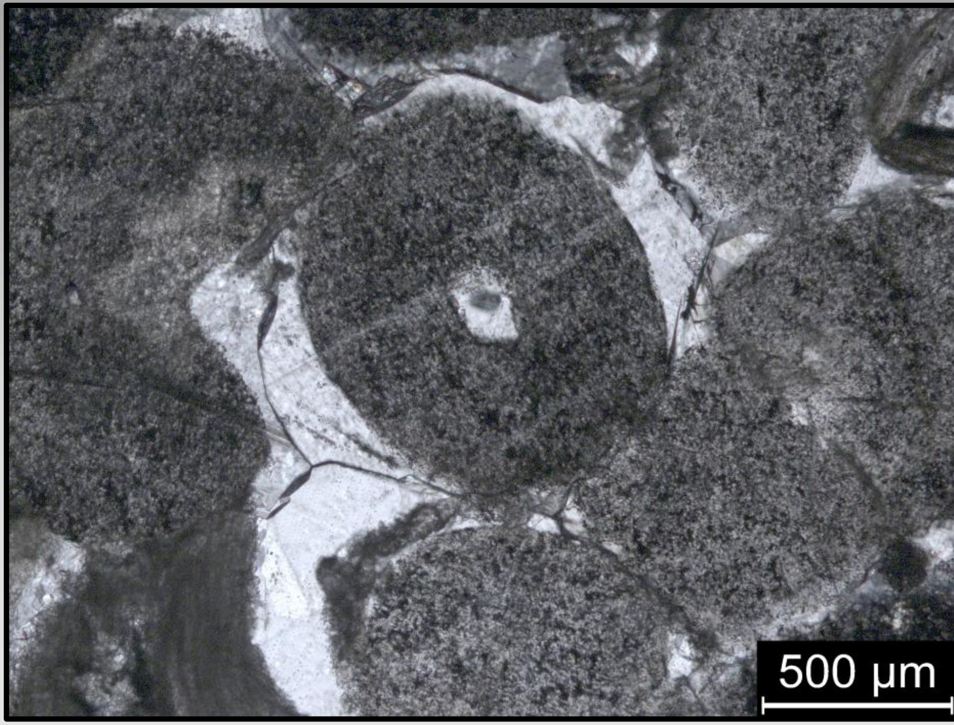


Force of Crystallization Controlled Replacement

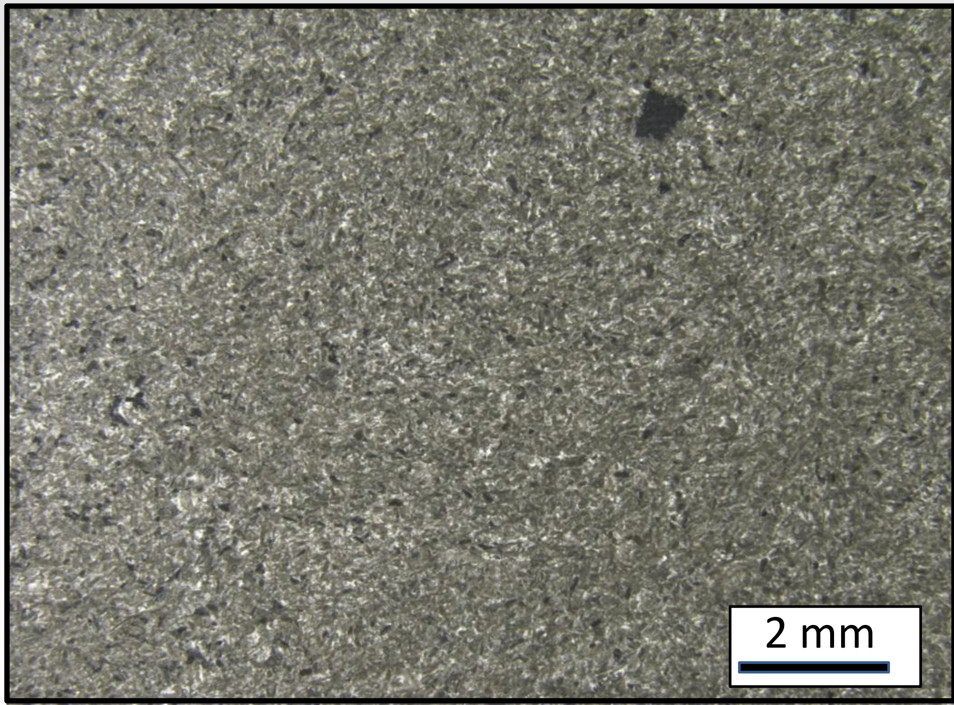




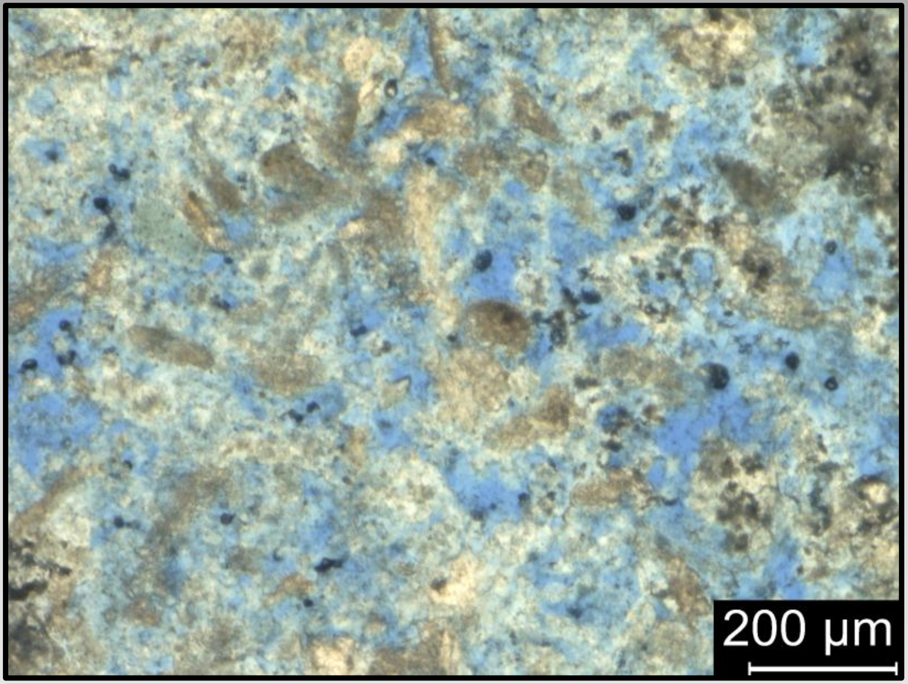


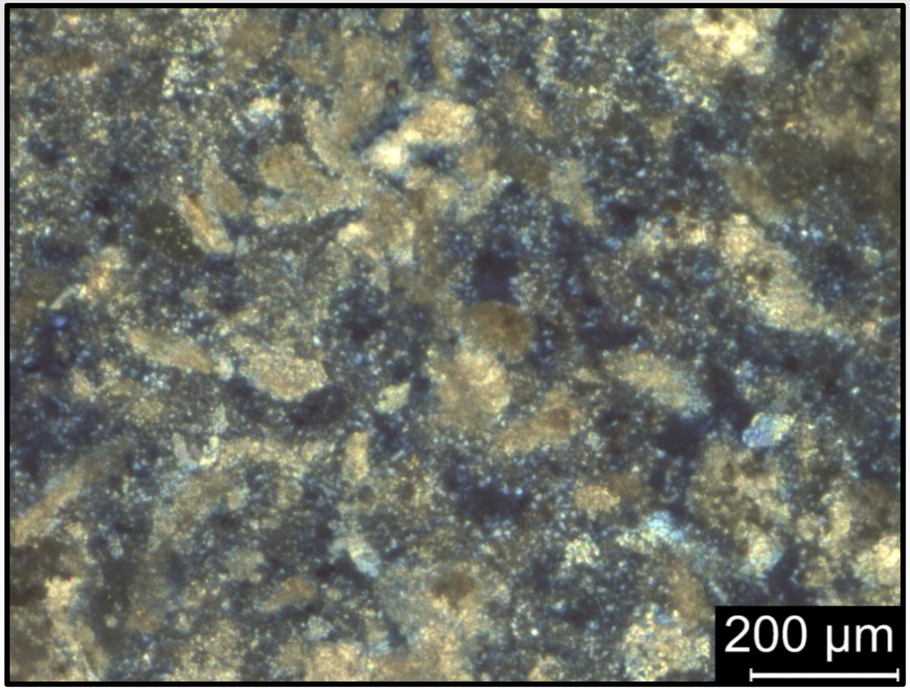


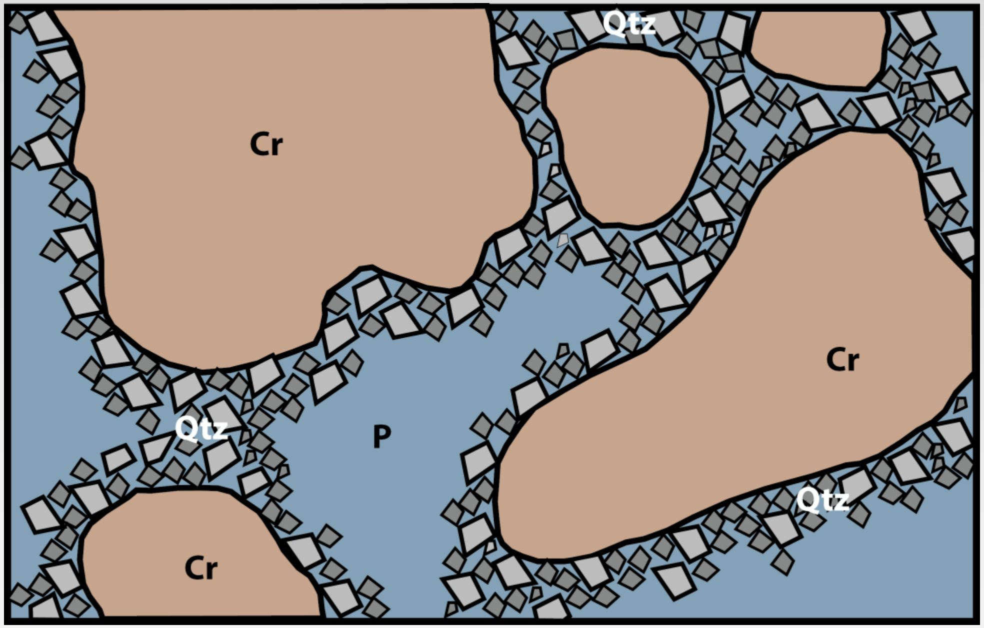
Inhibition of Calcite Cementation



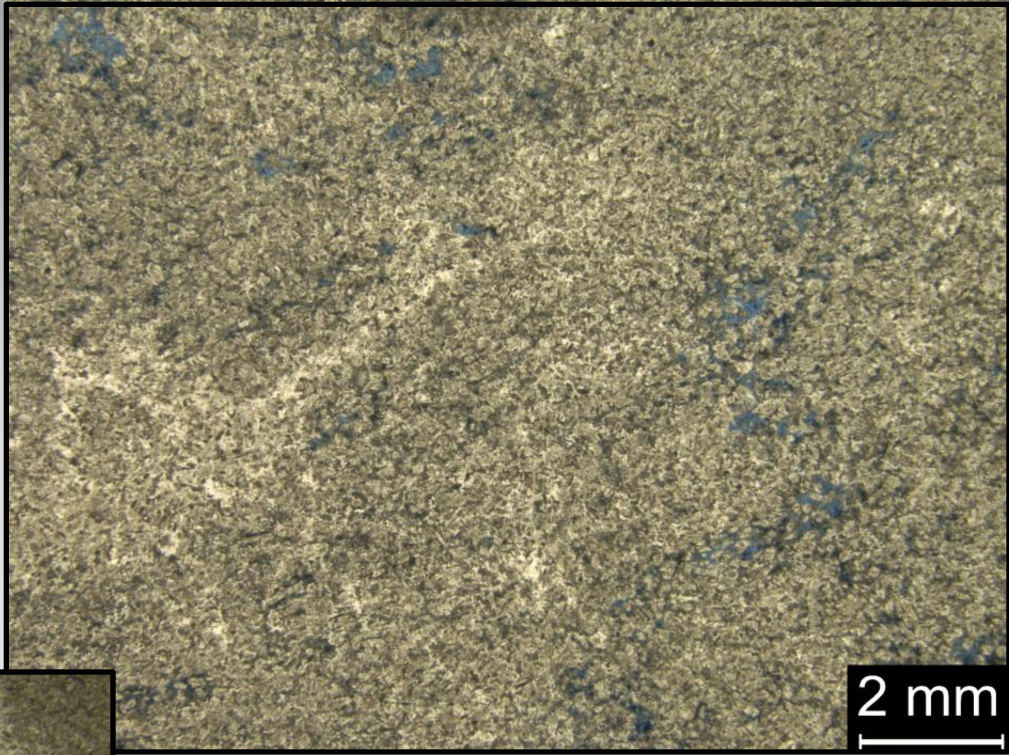
Inhibition of Calcite Cementation

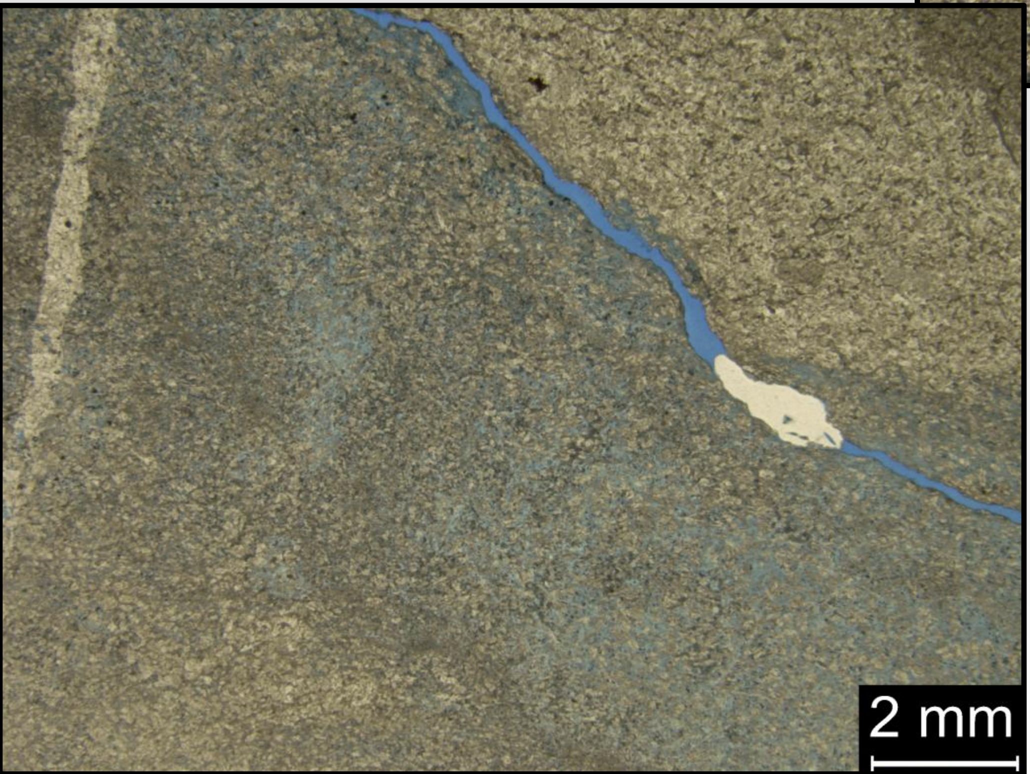






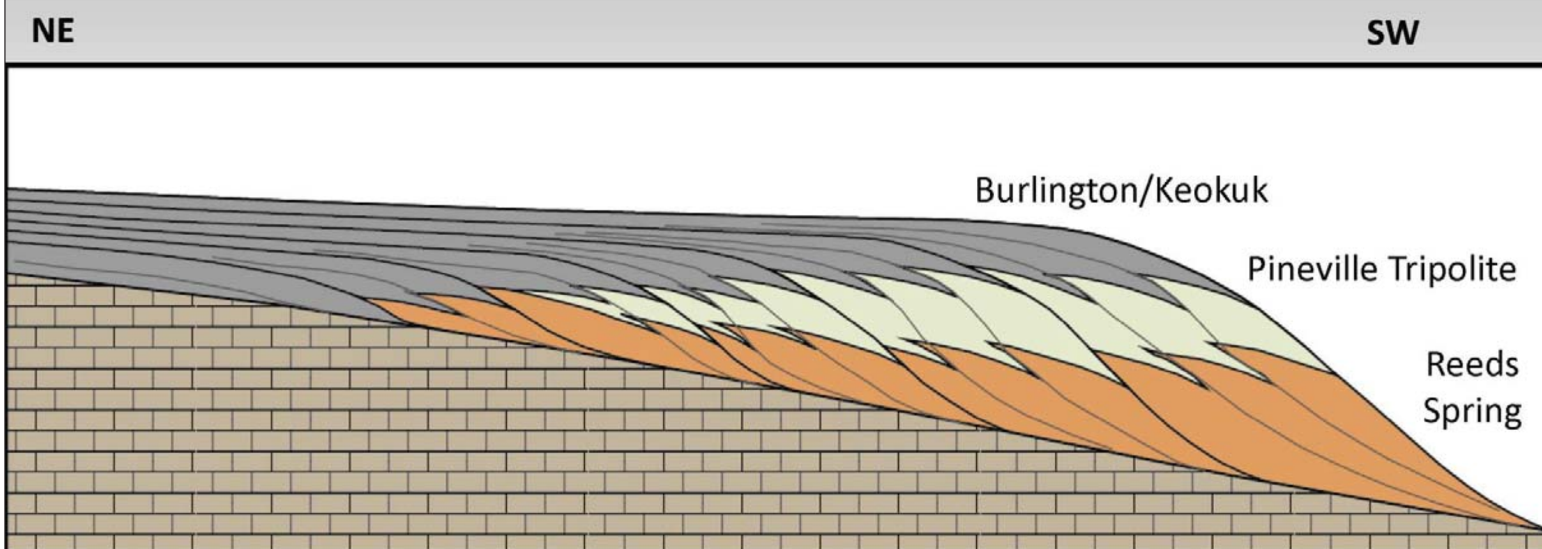
Silicified Limestone





- Higher energy than tripolite
- More crinoidal debris and fewer spicules

Depositional Model



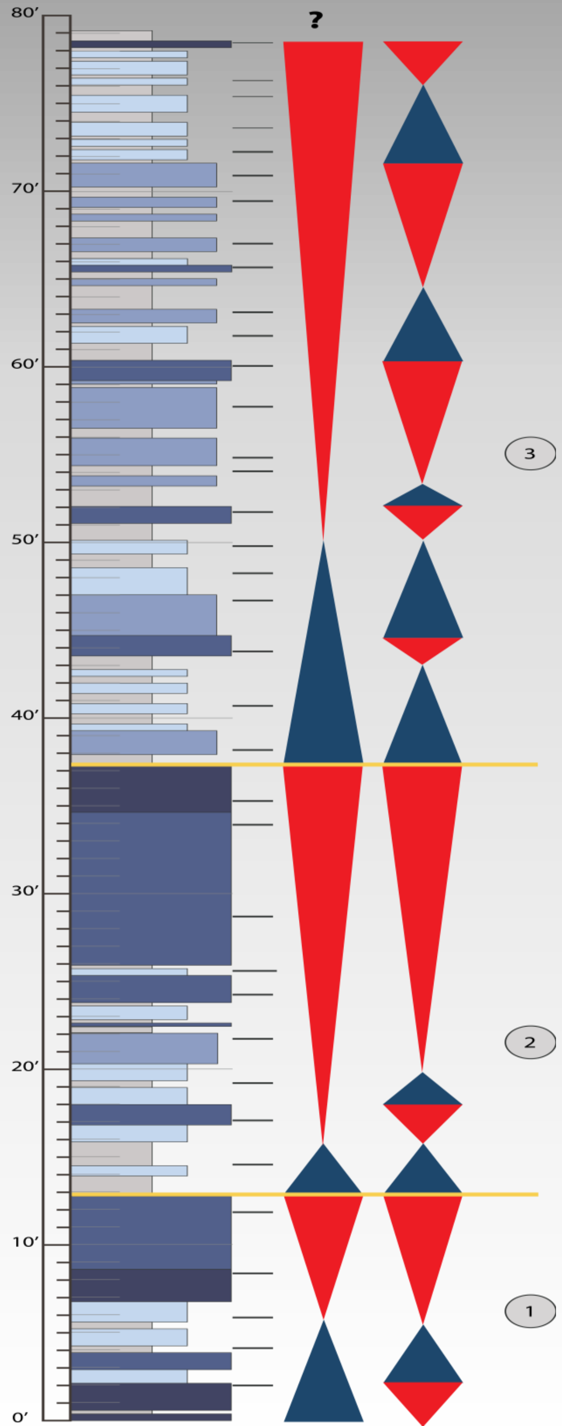
Depositional Environment controls the type of chert

Lower order sea level fluctuation controls overall distribution of chert

Higher frequency sea level fluctuation controls fine-scale chert variability

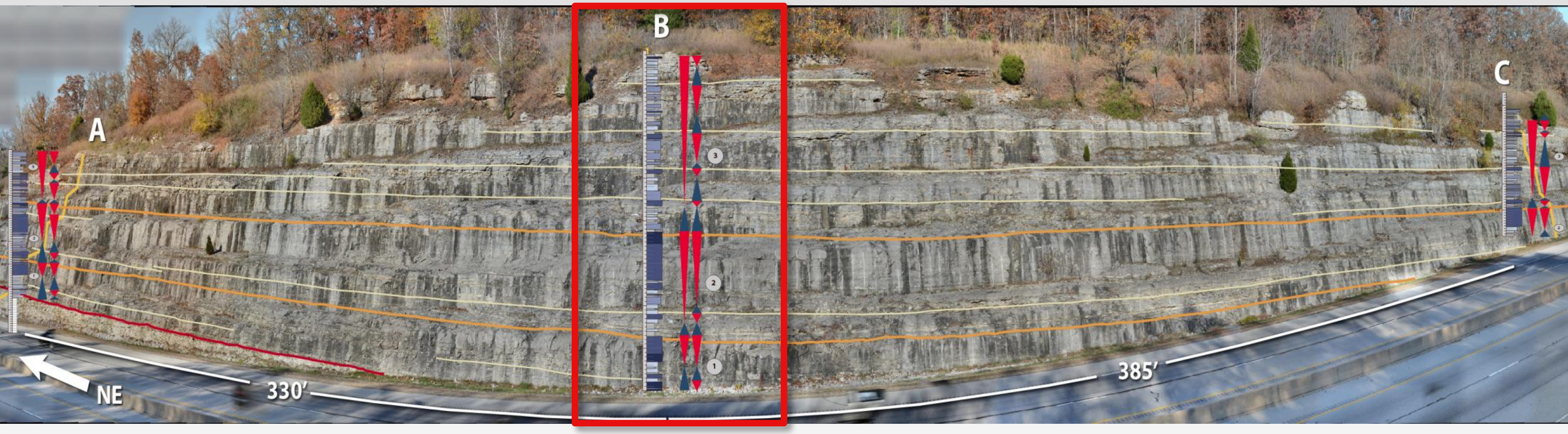
Presenter's notes: Position within the depositional environment controls the type of chert, lower order sea level fluctuation controls chert distribution.

Burlington/Keokuk Formation

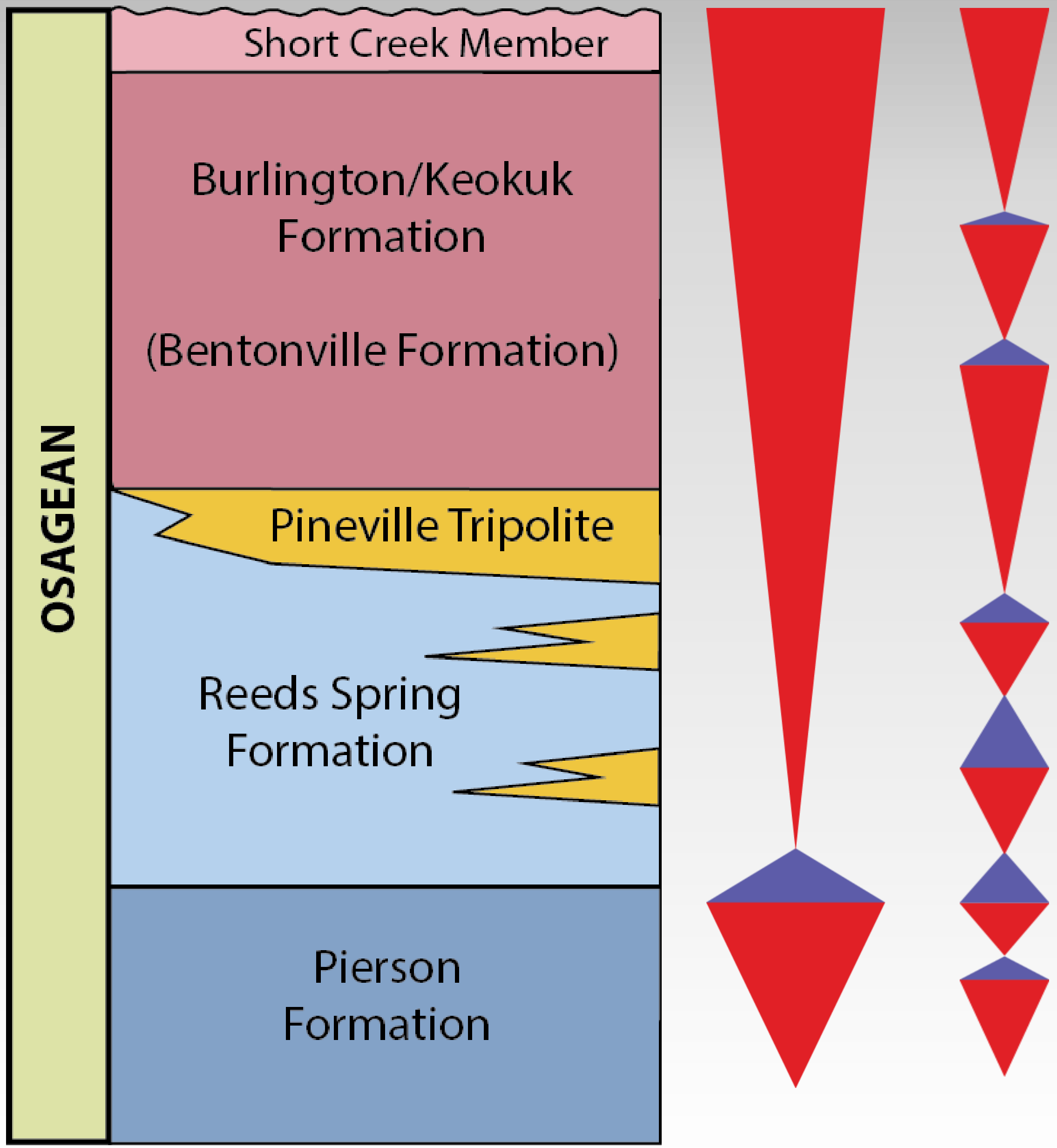


- 5 **Crinoidal Grainstone C**
- 4 **Crinoidal Grainstone B**
- 3 **Crinoidal Grainstone A**
- 2 **Skeletal Packstone/ Grainstone**
- 1 **Silicified Limestone/ Chert**

Burlington/Keokuk Formation



Sequence Stratigraphic Control

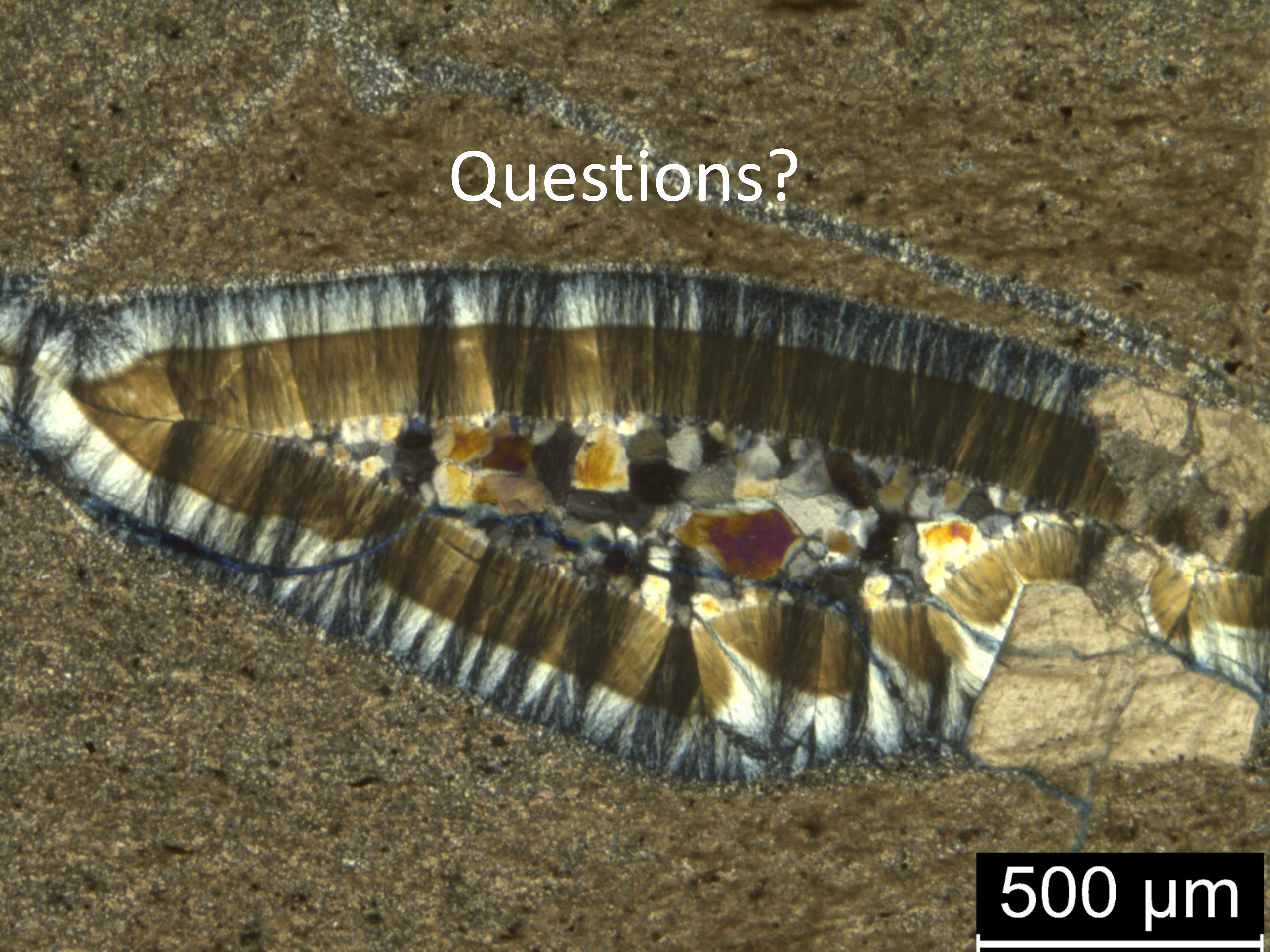


Variation in chert is controlled by lower order sea level fluctuation and position within the depositional environment

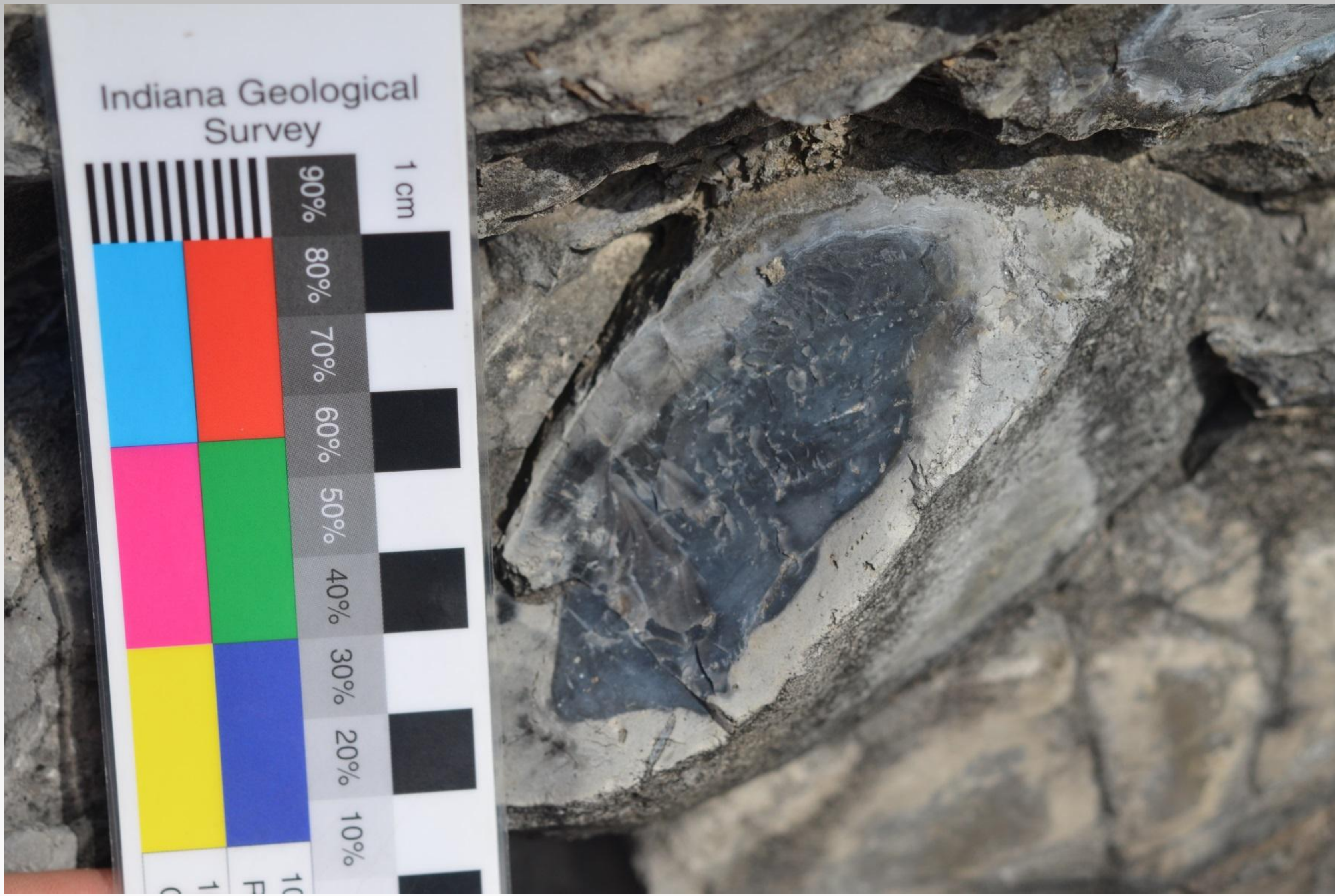
Higher frequency sea level change controls fine-scale chert variability

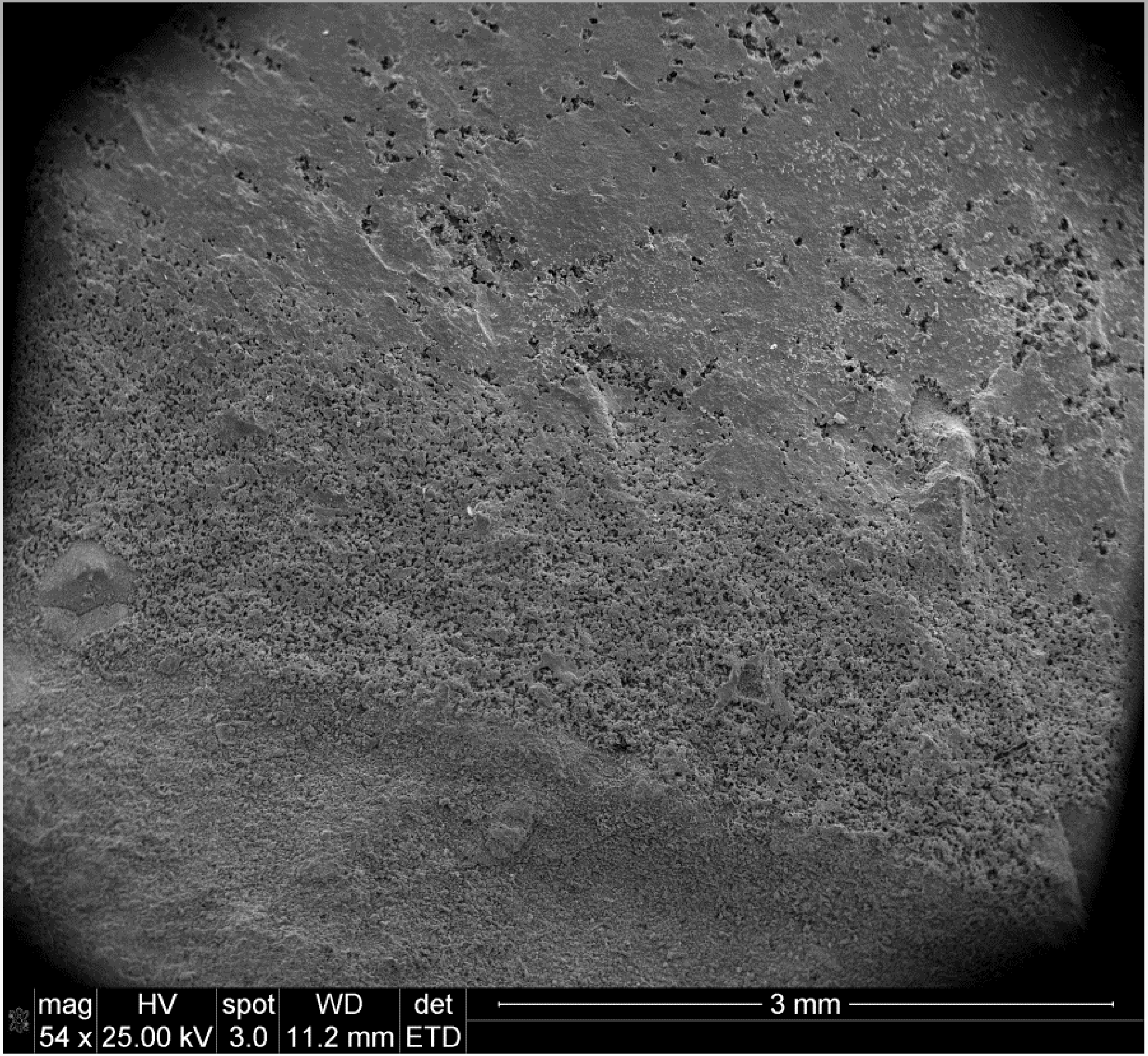
Conclusions

- The source of silica in the study area is interpreted to have been derived from siliceous sponges.
- Porosity development and preservation in chert is driven by force of crystallization-controlled replacement as well as inhibition of calcite cementation.
- Variations in the types of chert are largely controlled by lower-order sea level fluctuation and position within the depositional environment (facies).
- Fine-scale lateral distribution and variability of porosity in chert is driven by higher-order sea level fluctuation.


Questions?
500 µm

Transition from Chert to Tripolite




mag
54 x
HV
25.00 kV
spot
3.0
WD
11.2 mm
det
ETD
3 mm

Appendix and Thoughts

- The bedding and nodular nature of the chert and limestone could be due to differing pulses of sedimentation based on differing energy regimes- sponge spicules are bigger and may require more energy to be moves. But they are also hollow and may require less energy to be moves
- Another way to explain the difference is variation in the dominant fauna living at a given time, sponges may flourish for awhile, remove all the silica from the water and then die back, allowing muds to form again

Old Interpretations

- Porosity in Chert derived from a subaerial unconformity during the Osagean. Alteration from ground water.
- Throughout portions of northern Ok and southern Kansas, chert reservoirs are a primary target in the Mississippian.
- Research not dealing with “Chat”, but more so with bedded tripolite
- Interval Consists of limestone and chert. Limestones typically have poor porosity (compaction in mud-rich facies that destroys porosity, and syntaxial cementation on crinoidal fragments that occludes porosity in coarser facies