Diagenesis and Reservoir Quality of the Oligocene Vedder Sandstone of the Rio Bravo Oil Field, California*

Stephanie Caffee[1] and Robert A. Horton[1]

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[1]Geological Sciences, California State University, Bakersfield, California (rhorton@csub.edu)

Abstract

The Rio Bravo oil field is located about 15 miles northwest of Bakersfield, CA. The zone of importance is the Vedder Sandstone, which is about 1250 feet (380m) in thickness. The thin (<100ft, 30m) Miocene Rio Bravo Sandstone, which unconformably overlies the Vedder, is included in the main Vedder reservoir. Burial depths range from approximately 10,750 feet (3415m) to 12,450 feet (3800m), with reservoir temperature at 120°C. The mineralogy and lithology of Oligocene sandstones of the Rio Bravo oil field were examined using a petrographic microscope and a scanning electron microscope equipped with an energy dispersive X-ray spectrometer (SEM-EDS) and a cathode luminescence imaging system (SEM-CL). The Vedder sandstones are medium to fine-grained, subangular to subround, very poorly to well sorted, arkosic arenites and wackes. Accessory minerals of the Vedder Formation include biotite, muscovite, chlorite, glauconite, pyrite, zircon, zeolite, hornblende, rutile, phosphate, and apatite. The diagenetic features affecting reservoir quality of the Vedder sandstones are similar among wells. Albitization occurs extensively along fractures in plagioclase and K-feldspar grains. Plagioclase shows varying degrees of alteration to clay or sericite. Biotite has been altered to chlorite and pyrite. Precipitation of cements include clays (kaolinite, chlorite, and illite and/ or mixed-layer illite/smectite or illite/chlorite), and carbonates. Kaolinite occurs as pore-filling cement, commonly associated with feldspar dissolution. Carbonates include calcite and dolomite. Calcite cement occurs within some through-going fractures. Both calcite and dolomite have partially to completely replaced framework grains. Porosity within the Vedder sands is controlled mainly by compaction and dissolution of framework grains. Compaction decreased porosity through ductile grain deformation of shale clasts and micas, which commonly were squeezed into adjacent pores to form pseudomatrix. Rotation and slippage of grains and fracturing of brittle grains are also widespread. Dissolution of framework grains created oversized and elongate pores, with the result that secondary intergranular porosity contributes significantly to overall reservoir quality.

Selected References

Dickinson, W.R., 1985, Interpreting detrital modes of greywacke and arkose: Journal Sedimentary Petrology, v. 40, p. 695-707.

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Pettijohn, R.J., 1983, Sedimentary Rocks (3rd edition): Harpercollins, 628 p.

Pettijohn,F.J. , P.E. Potter, and R. Siever. 1987, Sand and Sandstones: Springer-Verlag; New York, 553 p.


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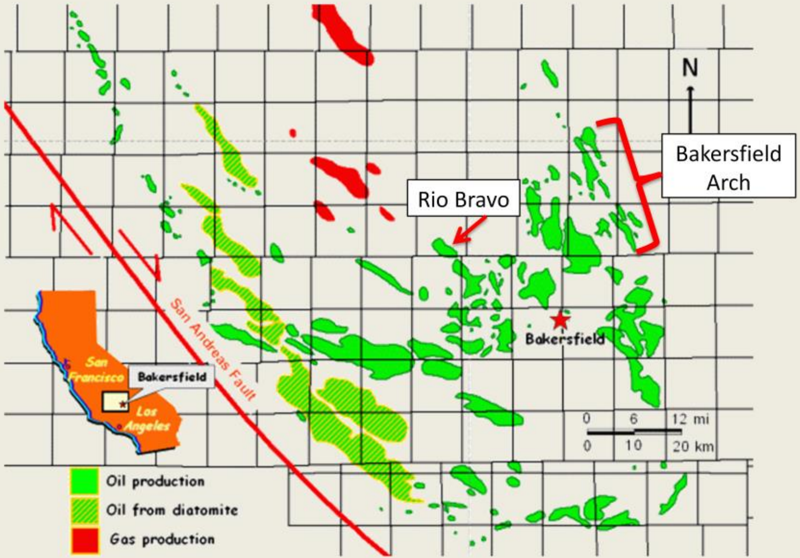
Introduction

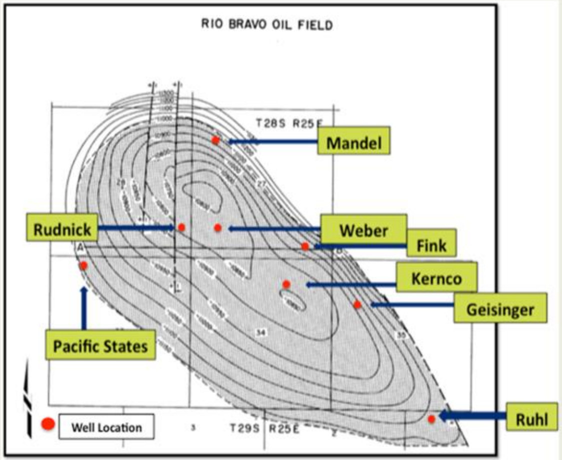
- The Vedder Sandstone at Rio Bravo oil field has been identified as a candidate for Carbon Capture and Sequestration.
- This is part of a large ongoing project at CSUB
- Purpose- Determine the mineralogy and lithology and interpret the diagenetic processes that affect the reservoir quality of the Vedder Sandstone.
- Determining the diagenetic history of a reservoir is of great importance to the petroleum industry because it can aid in understanding the post-depositional changes that modify the storage capacity of a reservoir and its potential for CO_2 sequestration.

Location



Presenter's notes: The Rio Bravo oil field is located about 15 miles northwest of the city of Bakersfield; it is located on the north flank, just off the crest of the Bakersfield arch.

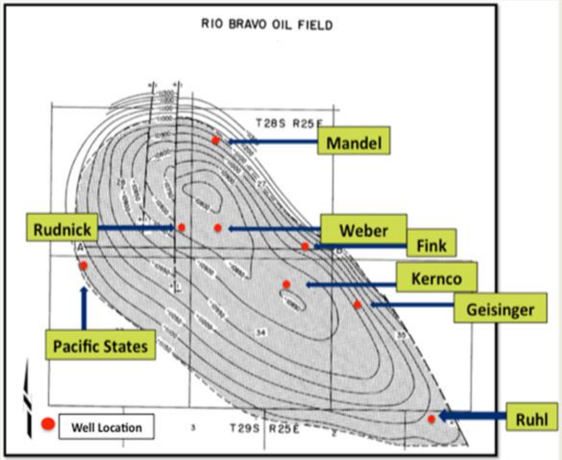
Geologic Background



- The Rio Bravo-Vedder pool consists of an elongated, asymmetrical dome

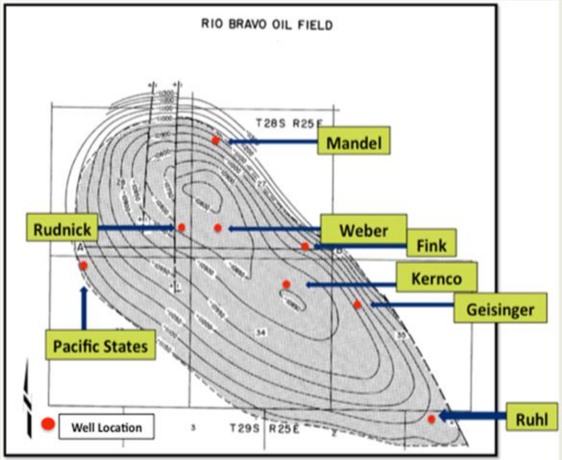
Presenter's notes: This is a structure map of the the Rio Bravo field showing the location of the eight wells from which samples were obtained for the study.

Geologic Background



- The Rio Bravo-Vedder pool consists of an elongated, asymmetrical dome
- Trends northwest-southeast

Geologic Background



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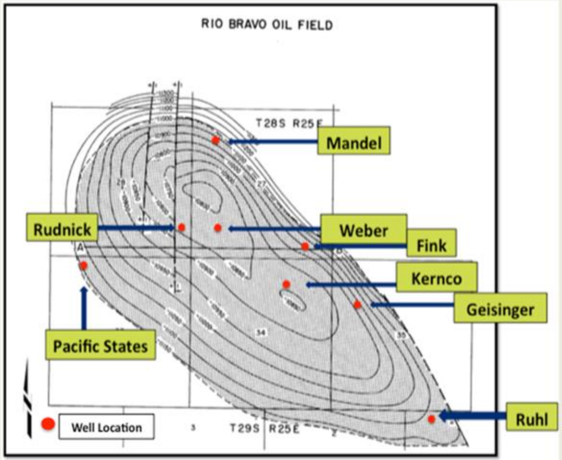
Geologic Background



- The Rio Bravo-Vedder pool consists of an elongated, asymmetrical dome
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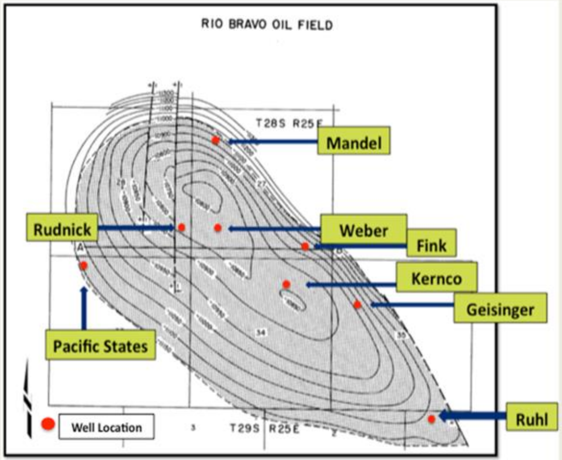
- Bound by a major fault that determines the southeastern limits of production

Geologic Background



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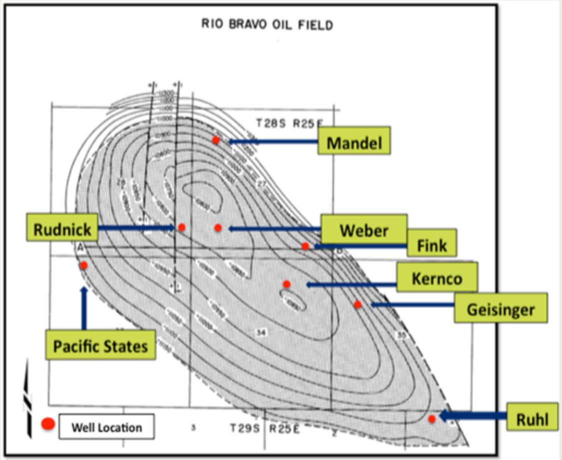
- Vertical displacement is about 76 m (250 feet)

Geologic Background



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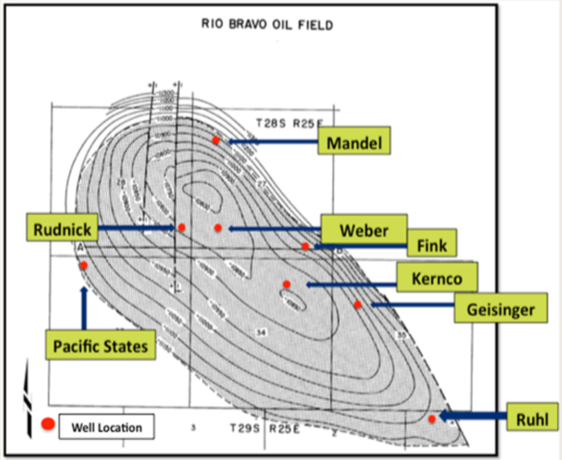

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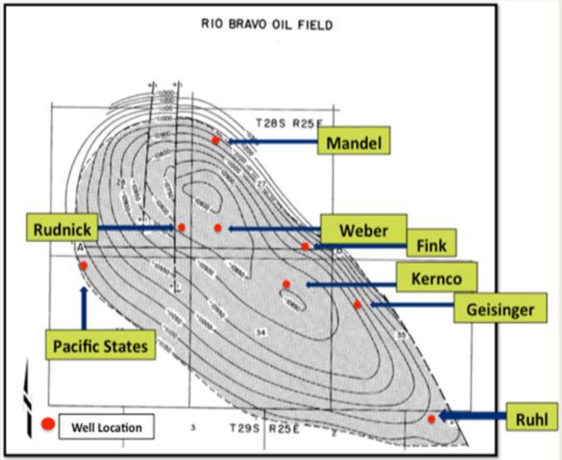

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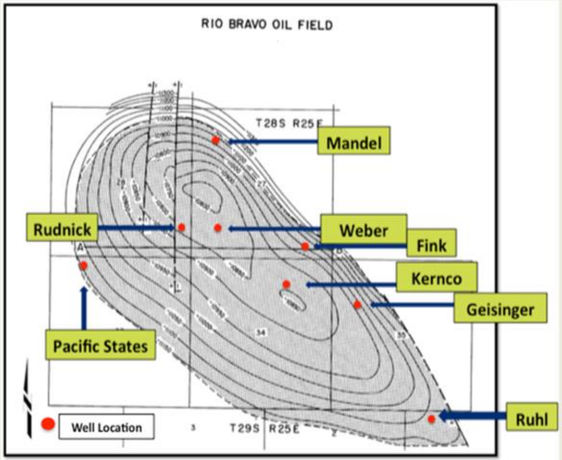
Geologic Background



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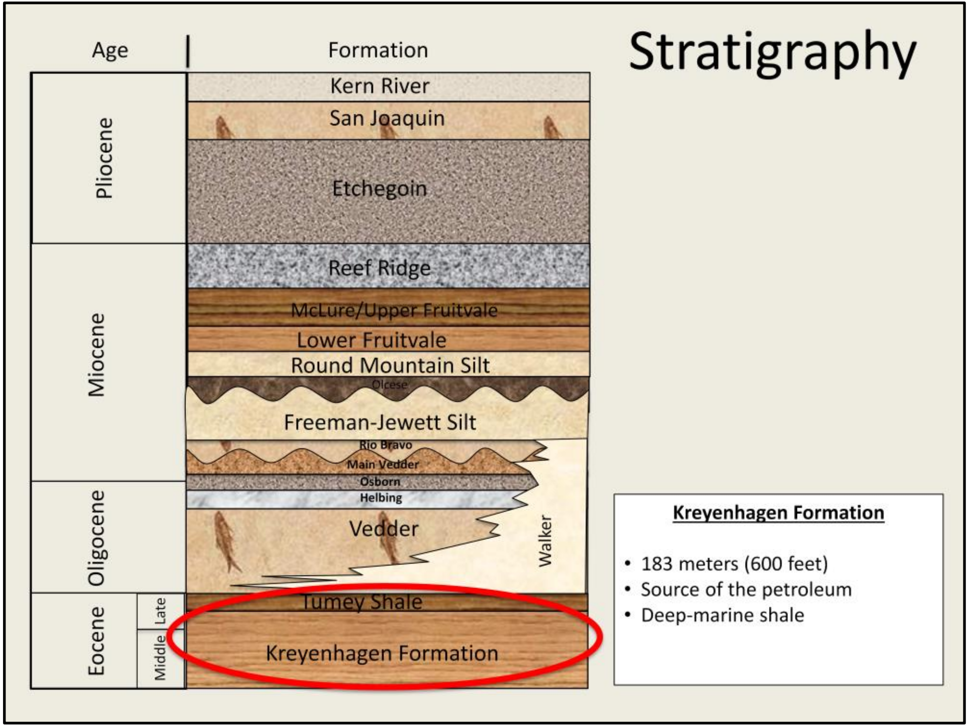
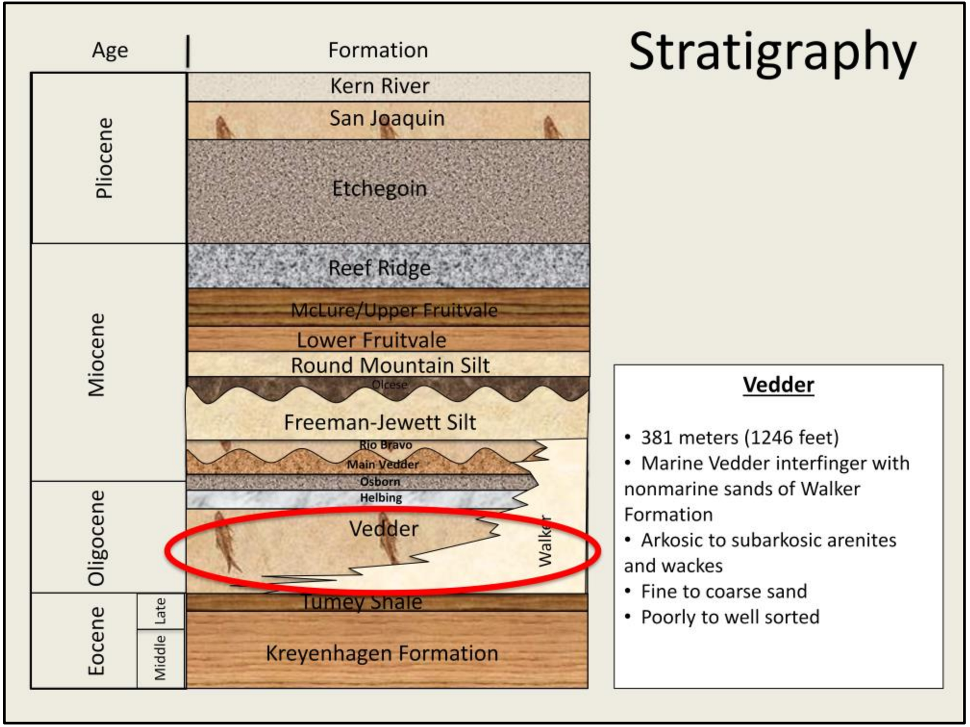
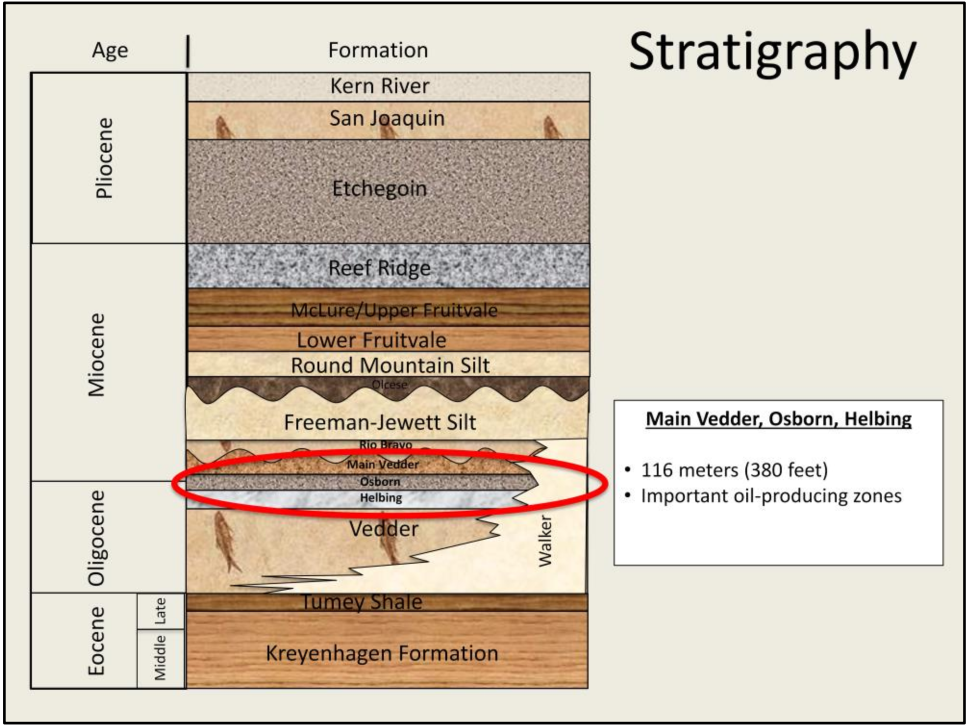
- Permeability varies
- 35-40 degree gravity
- Water drive



Presenter's notes: This is a general stratigraphic column of the Rio Bravo oil field. The Kreyenhagen is the source of the petroleum and is a deep-marine shale.

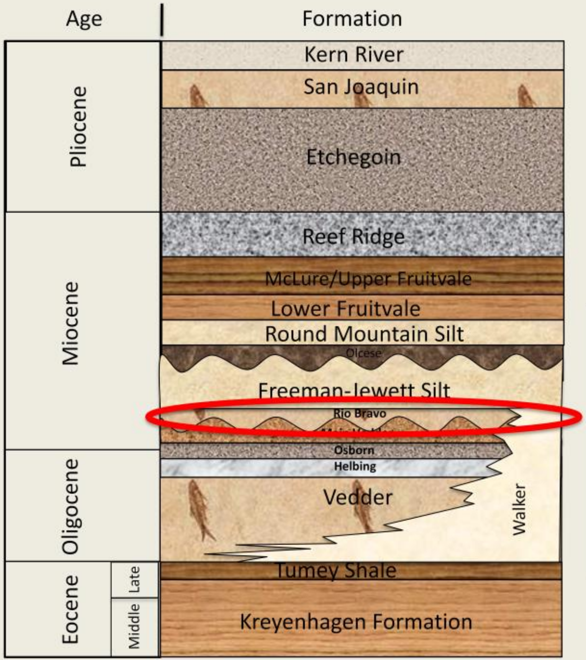


Presenter's notes: The focus of this study again is concentrating on the Vedder sands. Subsurface--The Marine Vedder sands disconformably overlie and interfinger with the nonmarine sands of the Walker Formation; this most likely resulted from eustatic oscillation.



Presenter's notes: Included within the upper portion of the Vedder sands are three important oil-producing zones: Main Vedder, Osborn, and Helbing.

Stratigraphy

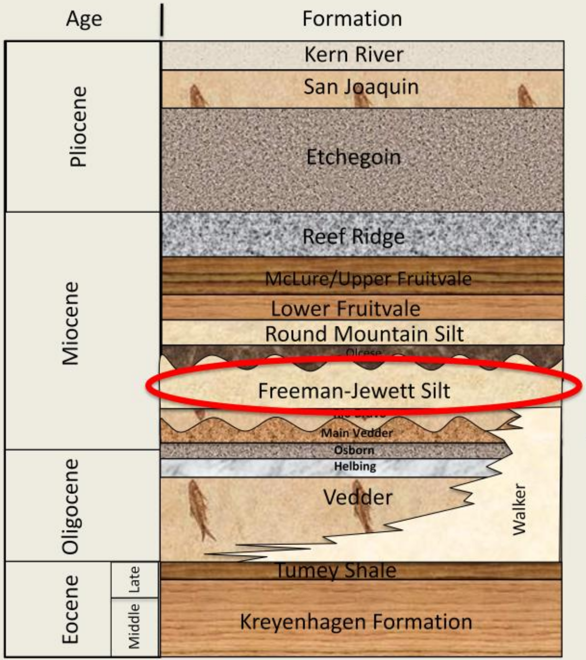


Rio Bravo

- 24 meters (78 feet)
- fine- to medium-grained, well sorted, marine sand
- Base contains well cemented pebble conglomerate, aka "grit"

Presenter's notes: The marine Rio Bravo sands, unconformably overlie the three upper Vedder sands.

Stratigraphy



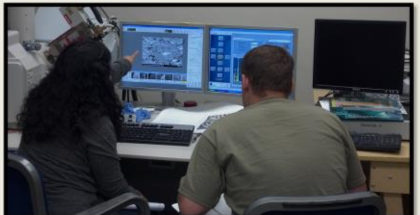
Freeman-Jewett Silt

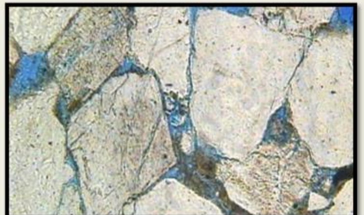
- 259 meters (850 feet)
- Deep-marine shales

Presenter’s notes: The Rio Bravo sands are bound above by deep marine shales of the Freeman-Jewett Formation.

Methods

- Samples for this study were obtained from the California Well Sample Repository located on the campus of CSU Bakersfield
- Wells range in depths of 11387’-11574’
- Sixty-five (65) thin sections of core samples from eight (8) wells were examined and point counted at a minimum of 300 points per slide using a petrographic microscope
- All thin sections were impregnated with blue epoxy in order to show porosity, and some were stained for potassium
- Scanning Electron Microscope-Energy Dispersive Spectroscopy (SEM-EDS).





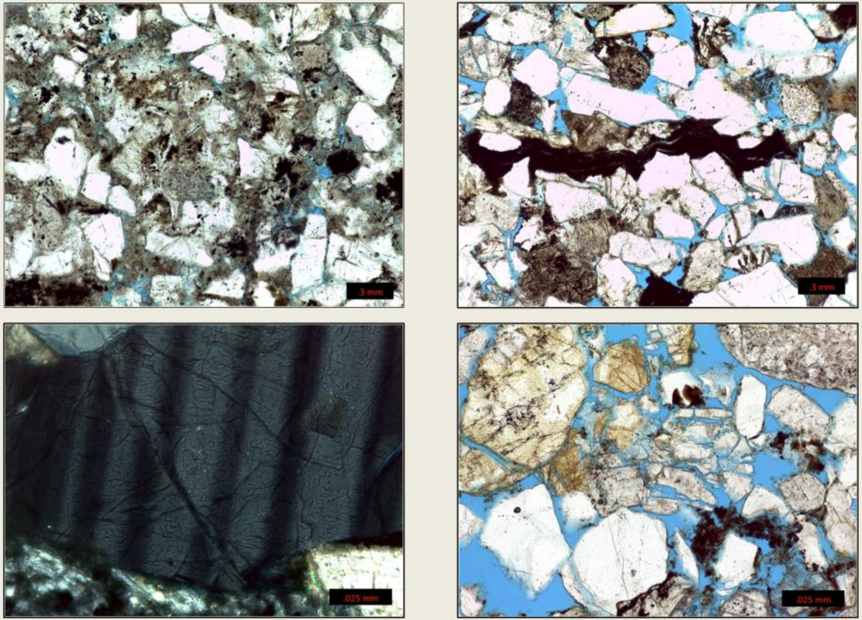
Burial and Diagenetic Processes

Four Important Processes

1. Compaction
   - Ductile, Brittle and Pressure-Induced Dissolution
2. Cementation
   - Grain Coatings, Overgrowths, Pore-Filling Cements and Clays
3. Alteration
   - Replacement, Albitization
4. Dissolution
   - Feldspars, Quartz, Calcite

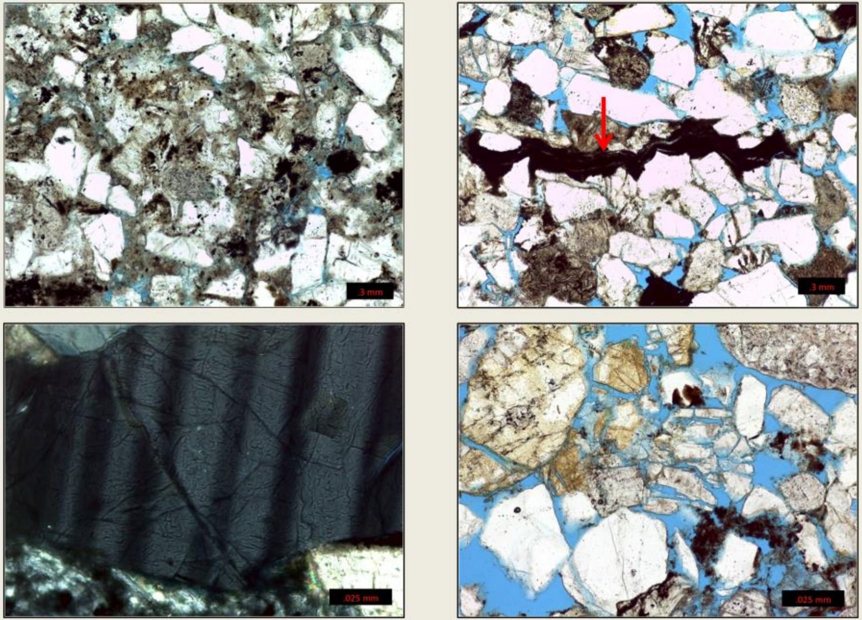
Presenter’s notes: From the standpoint of an oil reservoir, all 4 of these processes are important in terms of getting the reservoir prepared. Most important is whether there is oil in it, but if you don’t have the right combination of the 3 processes, the oil will not be there or you will not get it out.

Compaction- Labile and Brittle Deformation



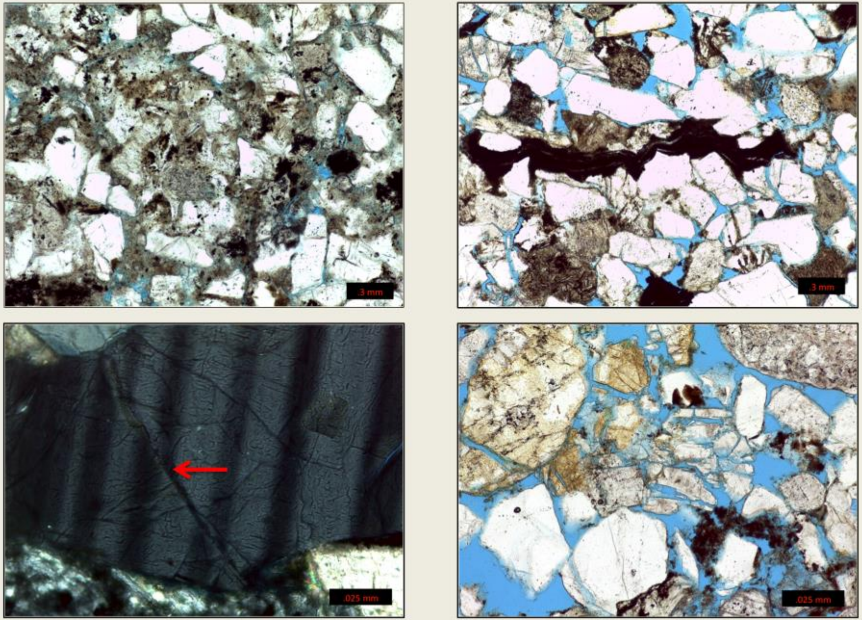
Presenter's notes: The top left figure is a photo of volcanic grains that are altered and squeezed into surrounding pore spaces that we formerly called pseudomatrix. Most pores are clogged up; so there's not a lot of effective porosity and connectivity to provide permeability. This does not make for a good reservoir rock.

Compaction- Labile and Brittle Deformation

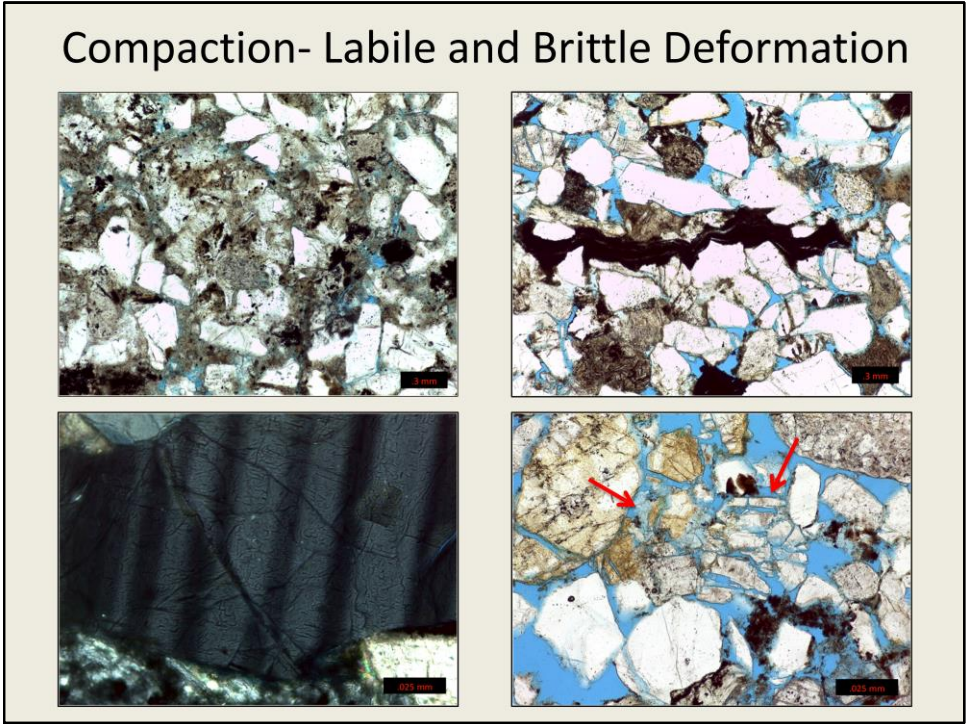


Presenter's notes: In the upper right is a biotite grain that has been deformed by compaction and squeezed into surrounding pore space. Again sands containing significant volumes of ductile grains can undergo a total destruction of intergranular porosity, thus reducing the permeability.

Compaction- Labile and Brittle Deformation

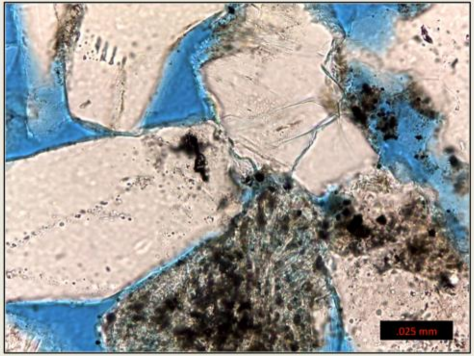


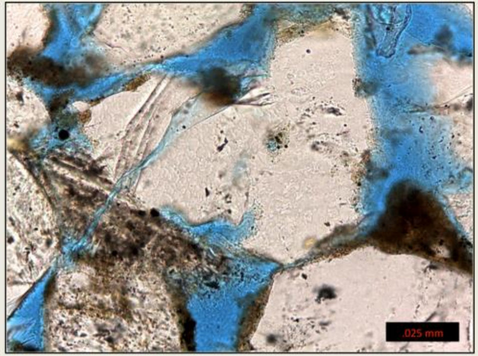
Presenter's notes: The lower left demonstrates brittle deformation of a fractured plagioclase grain, showing offset of the twins, characteristic of plagioclase grains.



Presenter's notes: In the center of the lower right photo is intense fracturing of feldspar grains. With depth there is change from individual-grain fracturing to through-going fractures, shown in this slide.

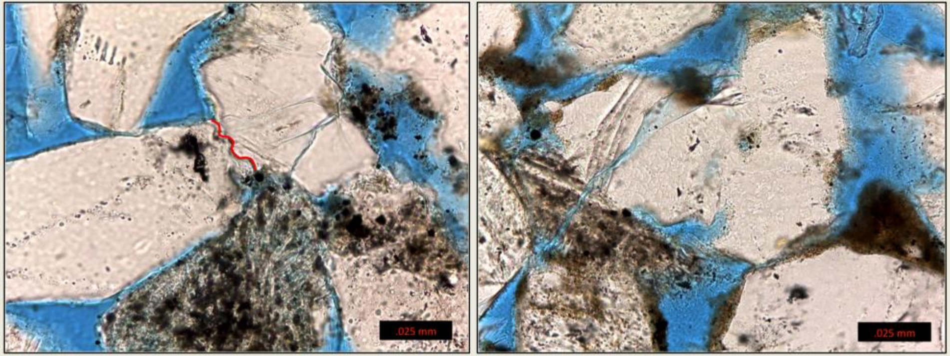
Compaction- Pressure-Induced Dissolution





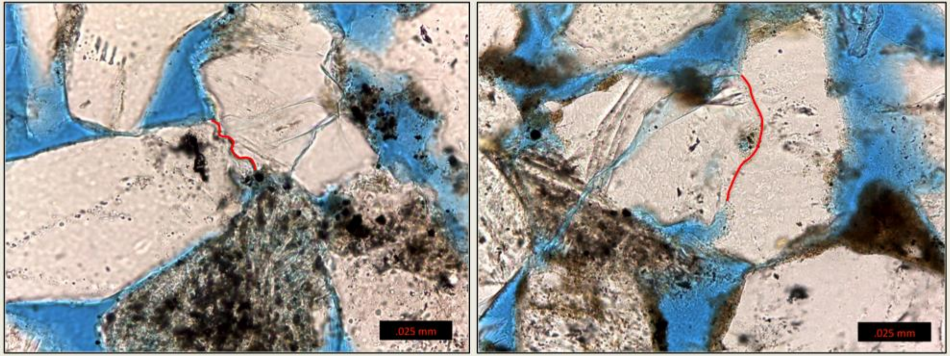
Presenter's notes: Pressure-induced dissolution involves grains that are truncated against each other. Because solubility varies, grains tend to dissolve into one another.

Compaction- Pressure-Induced Dissolution



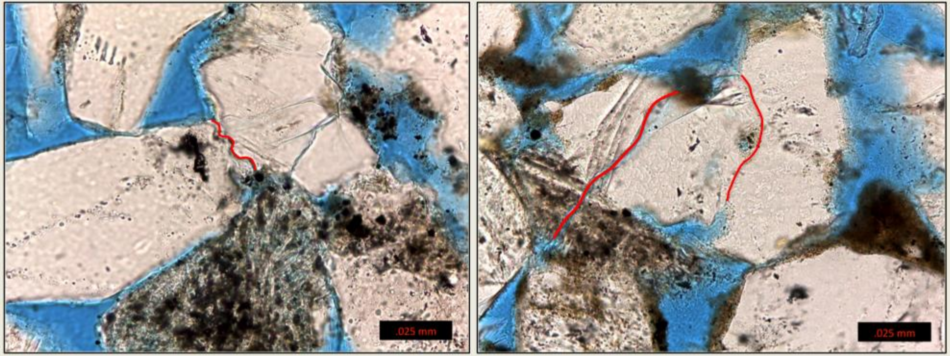
Presenter’s notes: The image to the left shows two grains that have been sutured together.

Compaction- Pressure-Induced Dissolution



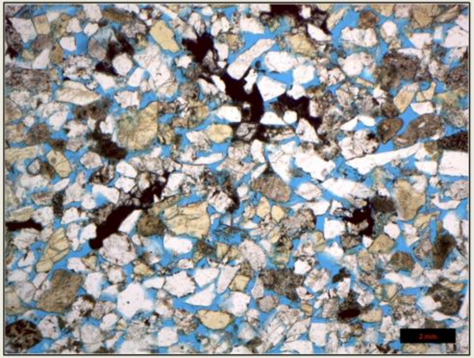
Presenter's notes: Other less obvious grains that are sutured and have dissolved into one another.

Compaction- Pressure-Induced Dissolution

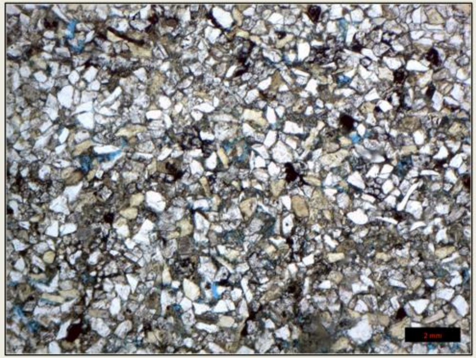


Presenter's notes: The right photo also demonstrates through-going fractures that were mentioned in an earlier slide.

Compaction- Porosity



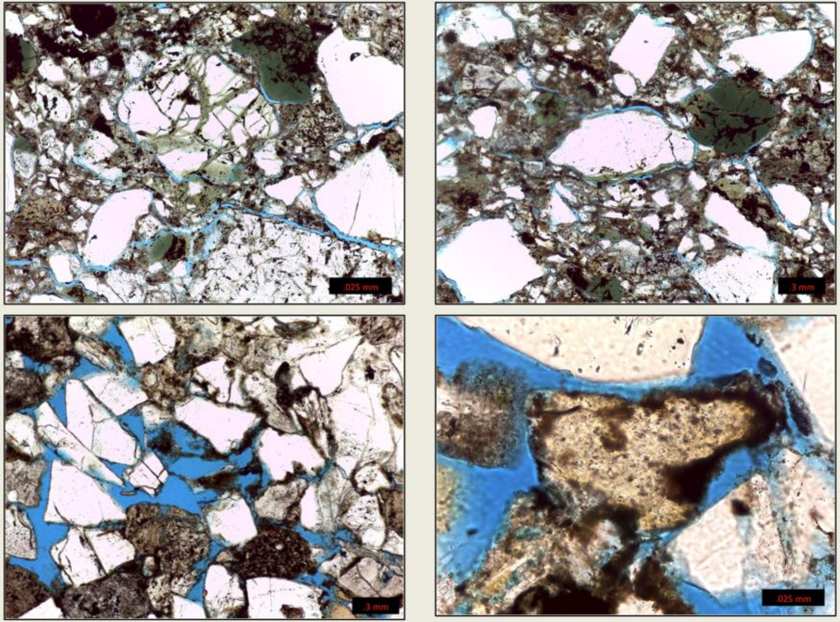
Ruhl 11,437



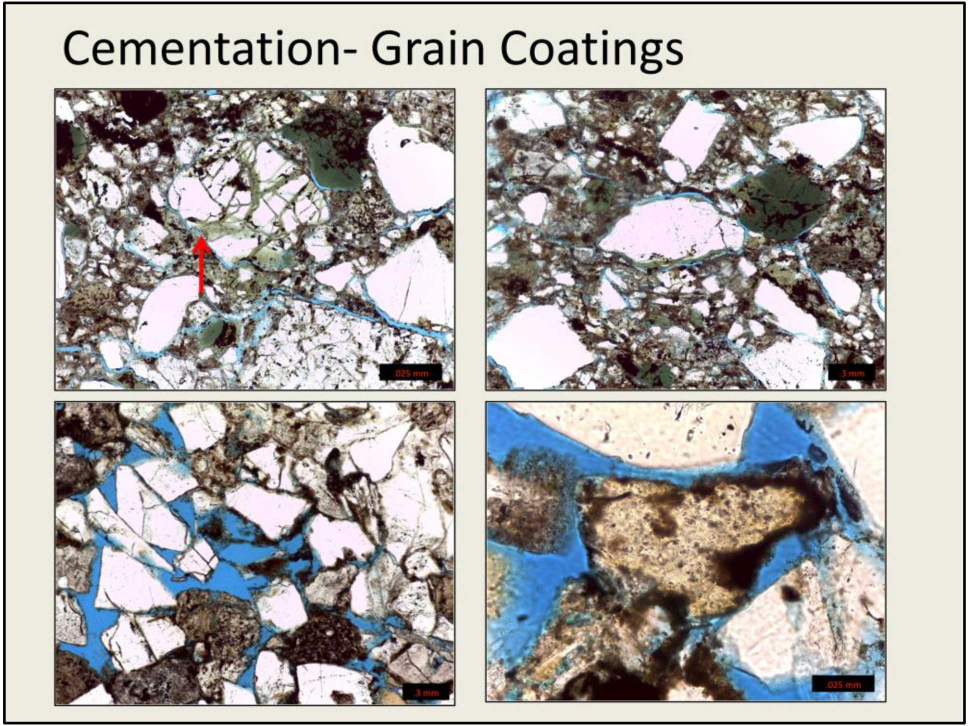
Ruhl 11,574

Presenter's notes: Compaction also affects porosity. On the left is a well sorted sand with secondary porosity, with elongate and oversized pores. On the right is a sand with pseudomatrix that is occluding the pore space, making for a poor reservoir rock.

Cementation- Grain Coatings

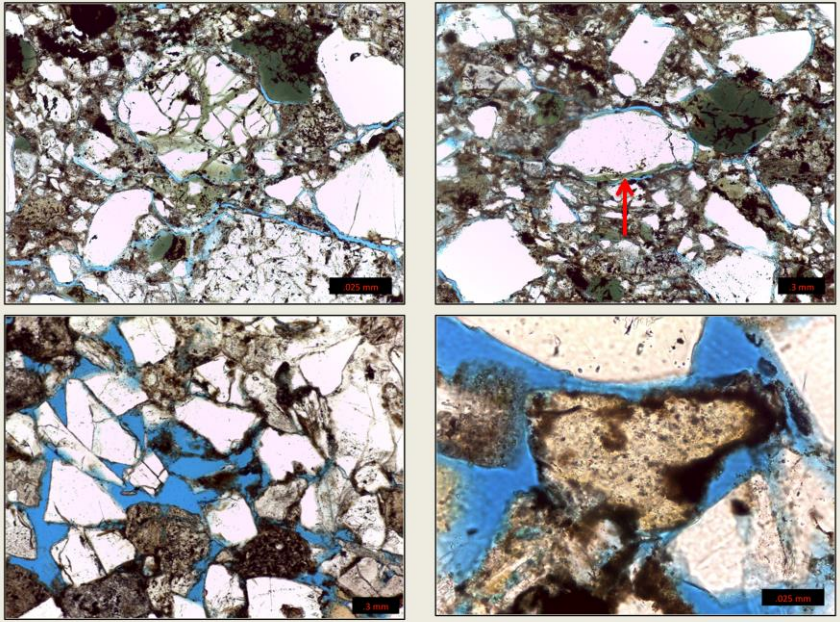


Presenter's notes: Cementation occurs as grain coatings, overgrowth, and pore-filling cements. Cementation is not good for porosity.



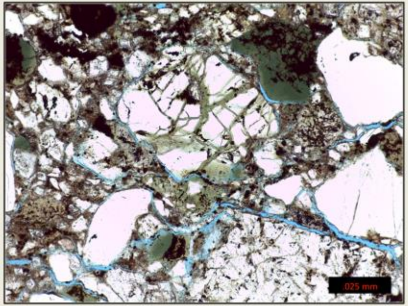
Presenter's notes: The top two pictures show chlorite. In the upper left chlorite occurs along the fracture within the grain.

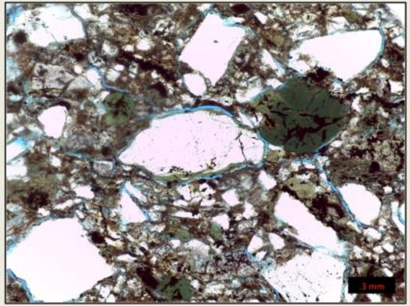
Cementation- Grain Coatings

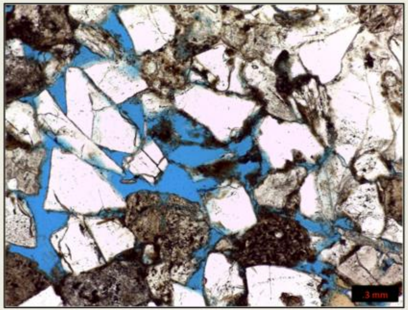


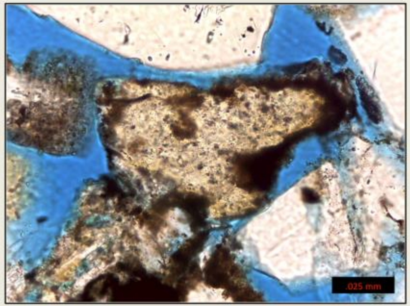
Presenter's notes: In the upper right chlorite occurs as a thin coating on a detrital grain. Chlorite formed early in the diagenetic history but only after the initiation of grain fracturing. The chlorite in some cases separates the grains from overgrowths.

Cementation- Grain Coatings









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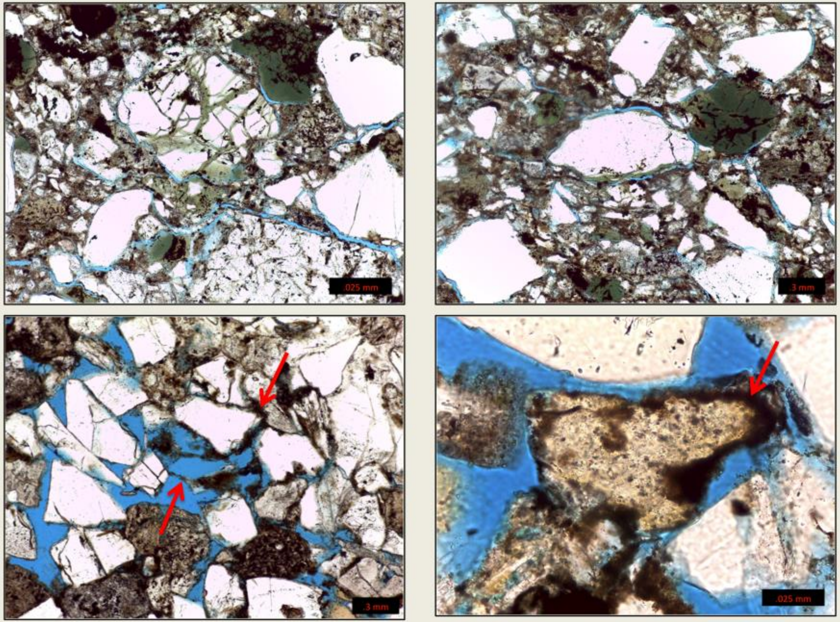
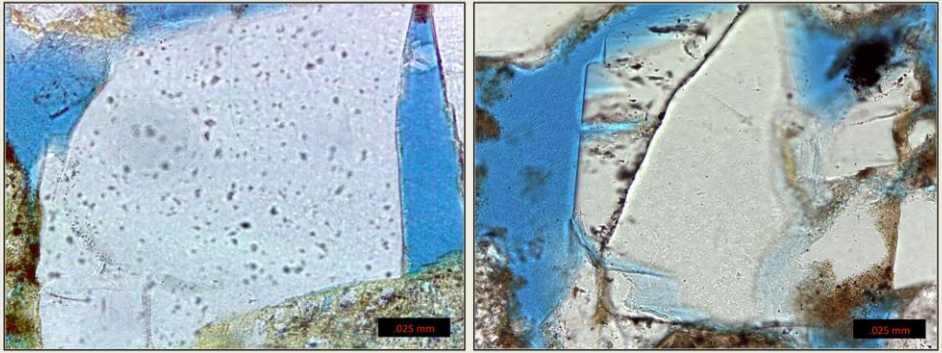


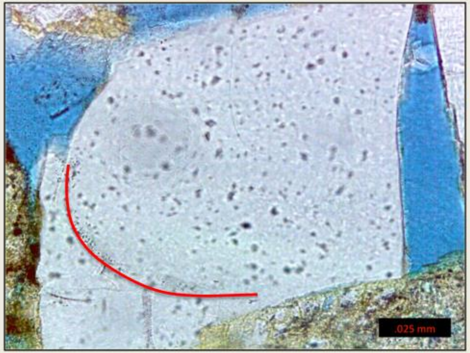
Presenter's notes: Authigenic clays occur as grain coatings, and even in small amounts can severely restrict pore throats and thus significantly reduce permeability.

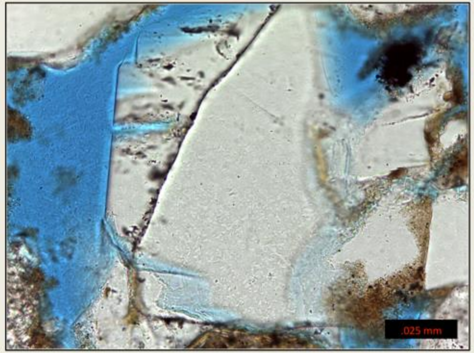
Cementation- Overgrowths



Presenter's notes: Overgrowths are similar to grain coatings, but they grow on minerals essentially as comparable composition.

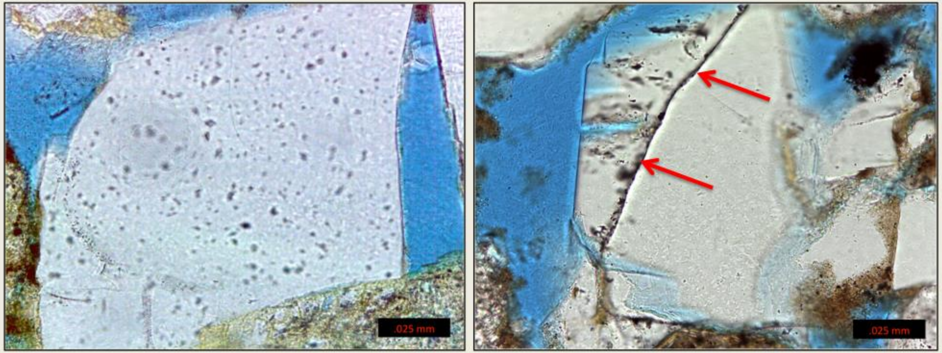
Cementation- Overgrowths





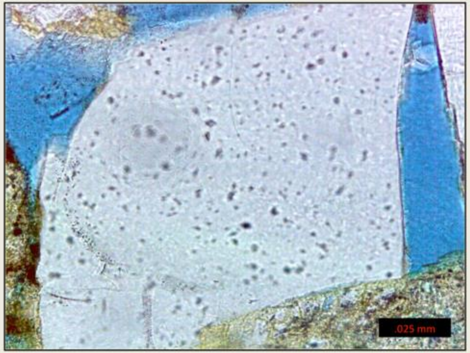
Presenter's notes: The picture to the left shows an authigenic overgrowth on a detrital quartz grain. The authigenic overgrowth shows euhedral crystal shape where fully developed.

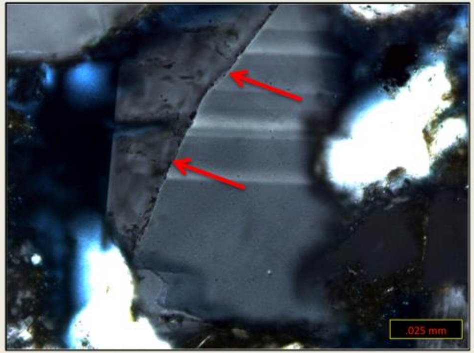
Cementation- Overgrowths



Presenter's notes: Importantly, overgrowths were not observed in sands cemented by poikilotopic calcite, suggesting that the overgrowths formed after early calcite precipitation. The picture to the right shows an overgrowth of a feldspar grain.

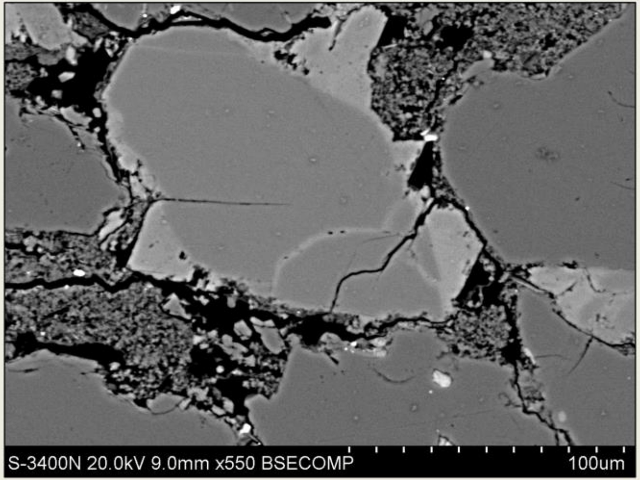
Cementation- Overgrowths





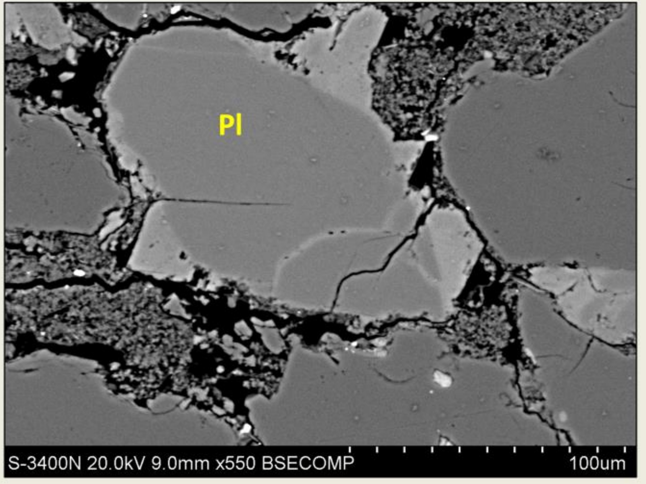
Presenter's notes: Shown in crossed polars both the overgrowth and the original grain are in optical continuity of each other, an indication of similar chemistry.

Cementation- Overgrowths

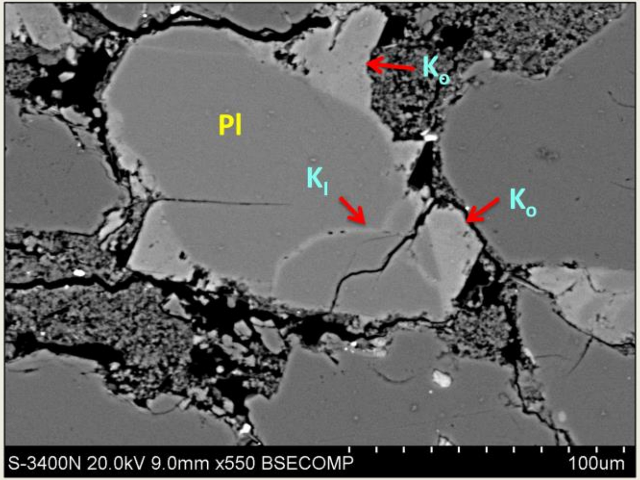


Presenter's notes: This is a BSE of a plagioclase grain. In the SEM you can see a little more clearly overgrowths and healed fractures.

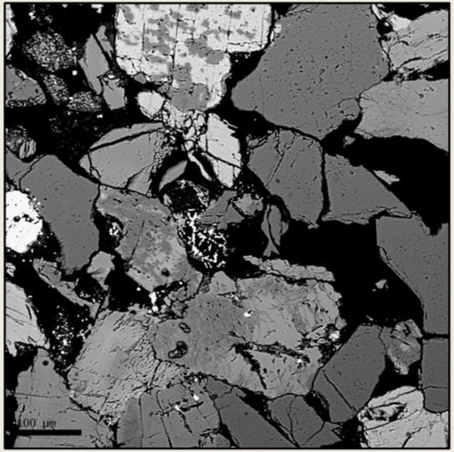
Cementation- Overgrowths



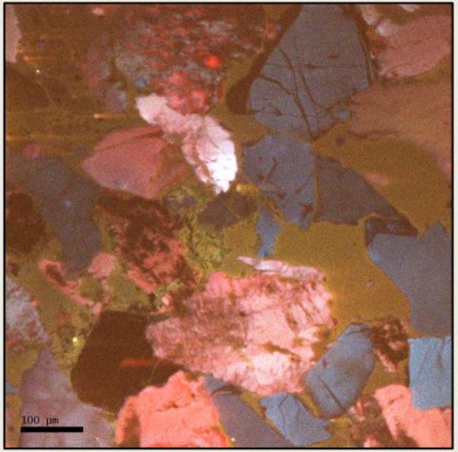
Cementation- Overgrowths



Cementation- Overgrowths



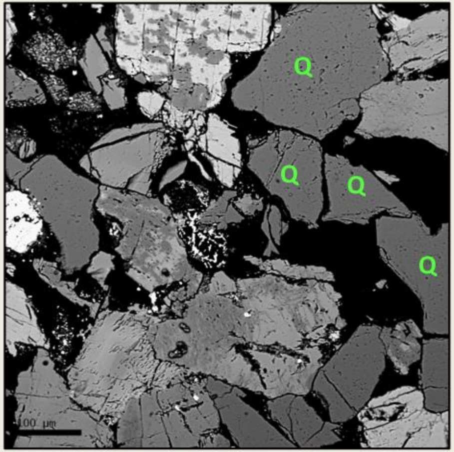
SEM-BSE



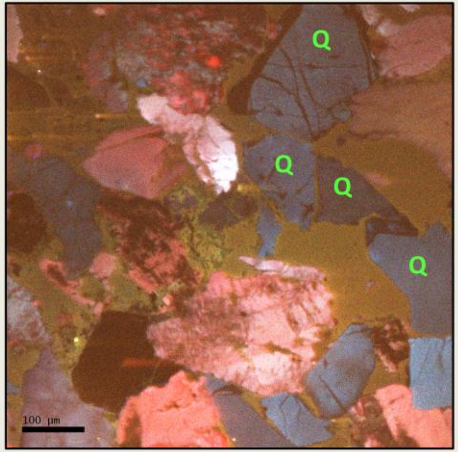
SEM-CL

Presenter's notes: The picture on the left is of a back-scattered image; to the right is a cathode luminescence detector on the SEM. Quartz grains are blue and quartz cement is black Putting the two images together, we get a composite image where you can clearly see the authigenic quartz overgrowth along with fractures that were healed by quartz.

Cementation- Overgrowths



SEM-BSE



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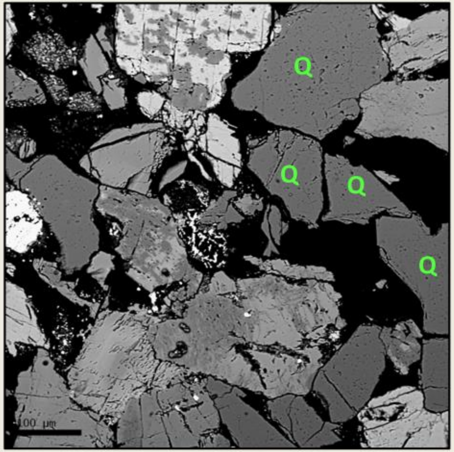
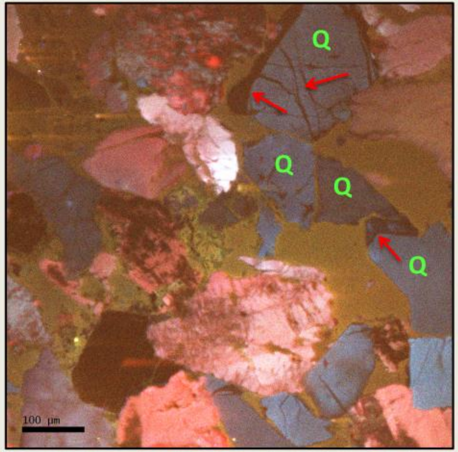


SEM-BSE



SEM-CL

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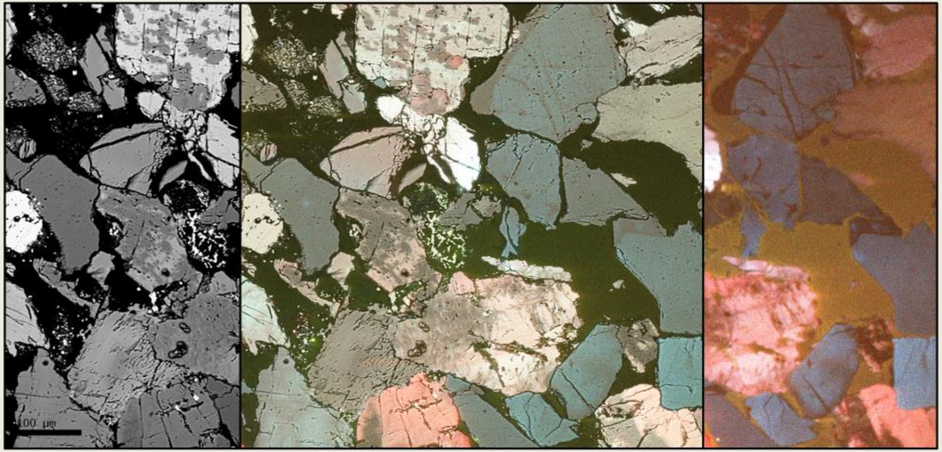
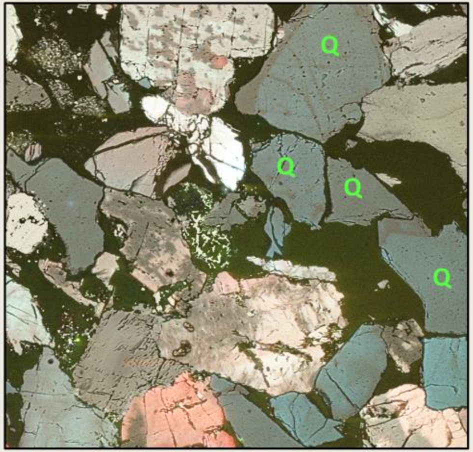
Cementation- Overgrowths



SEM-BSE BSE-CL Composite SEM-CL

Presenter's notes: The photo on the left is of a back-scattered image; to the right is a cathode luminescence detector on the SEM. Quartz grains are blue and quartz cement is black. Putting the two images together, we get a composite image where you can clearly see the authigenic quartz overgrowth along with fractures that were healed by quartz.

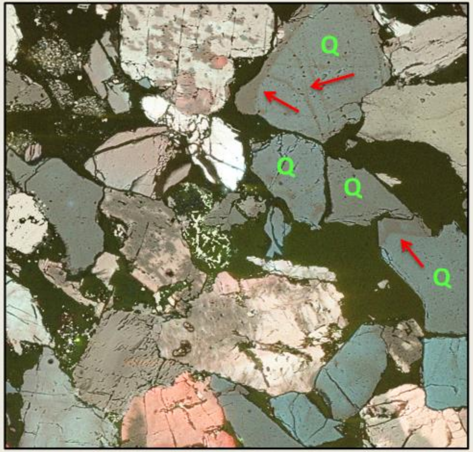
Cementation- Overgrowths



BSE-CL Composite

Presenter's notes: The photo on the left is of a back-scattered image; to the right is a cathode luminescence detector on the SEM. Quartz grains are blue and quartz cement is black. Putting the two images together, we get a composite image where you can clearly see the authigenic quartz overgrowth along with fractures that were healed by quartz.

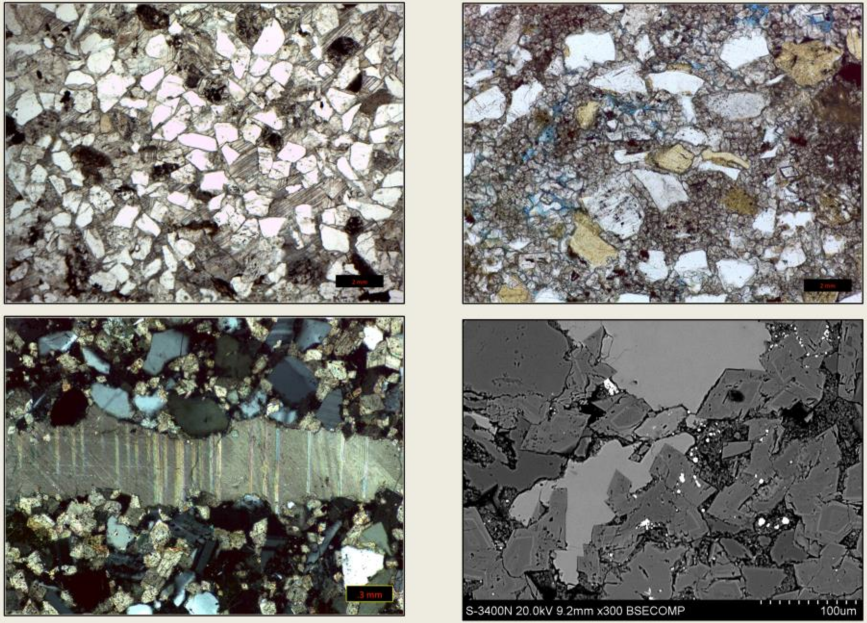
Cementation- Overgrowths



BSE-CL Composite

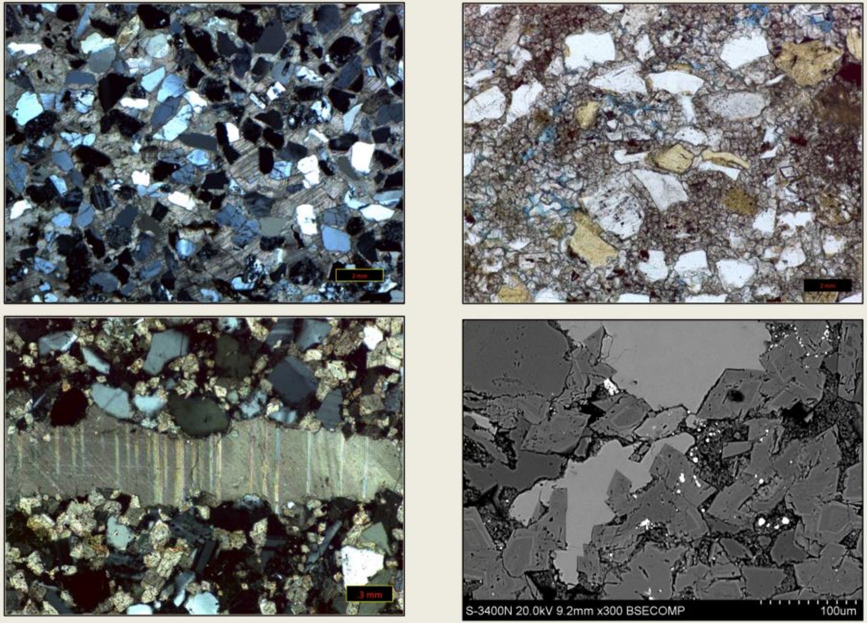
Presenter’s notes: The photo on the left is of a back-scattered image; to the right is a cathode luminescence detector on the SEM. Quartz grains are blue and quartz cement is black. Putting the two images together, we get a composite image where you can clearly see the authigenic quartz overgrowth along with fractures that were healed by quartz.

Cementation- Pore-Filling Cements



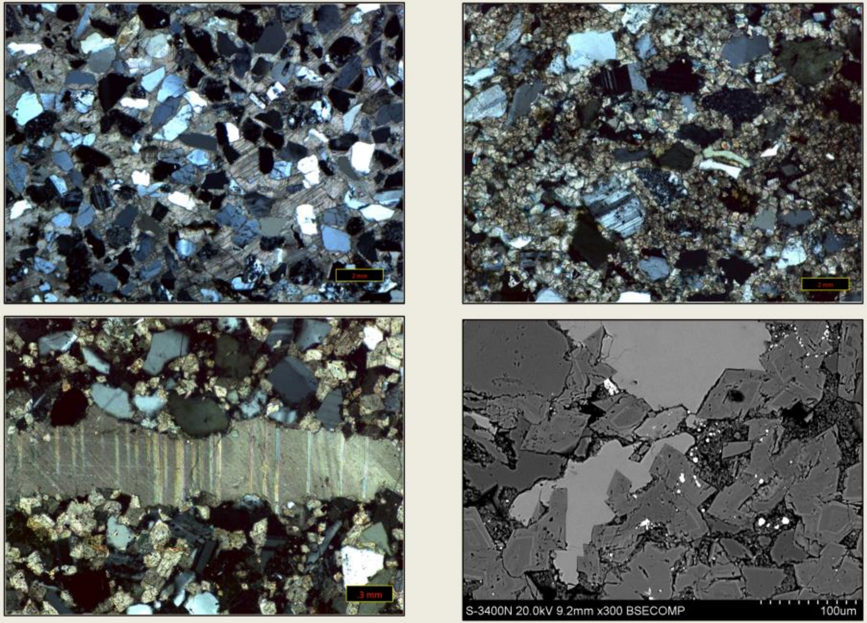
Presenter's notes: There are two pore-filling cements observed: Calcite and dolomite.

Cementation- Pore-Filling Cements



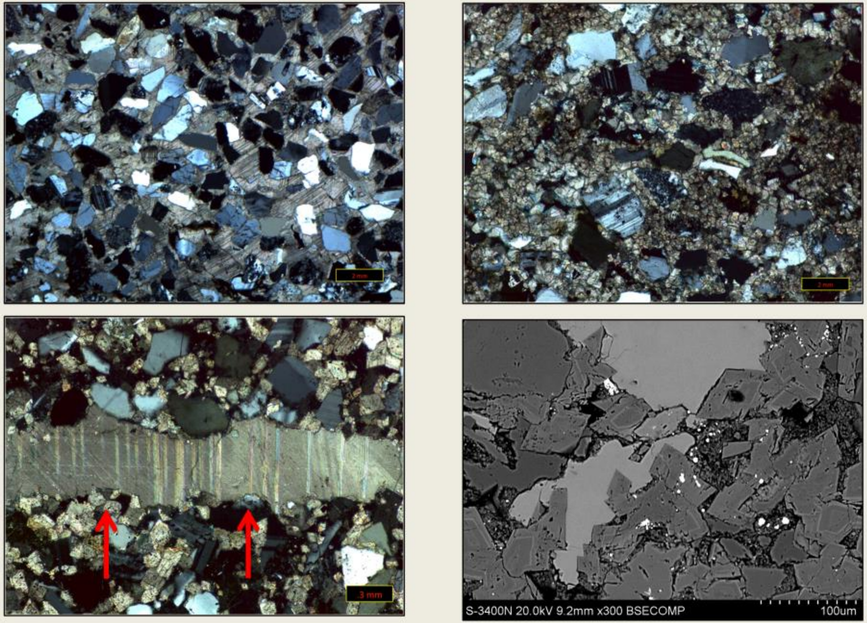
Presenter's notes: The upper left shows calcite. Early-stage calcite forms as a poikilotopic pore-filling cement in large pore spaces between floating grains, leaving very little to no pore space visible in the thin section. You can see some clay rims on the detrital grains, indicating that the clay rims formed early before the cement. Again overgrowths were not observed in sands cemented by poikilotopic calcite.

Cementation- Pore-Filling Cements



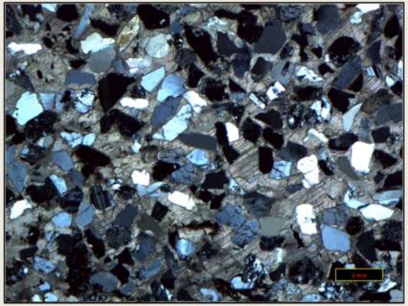
Presenter's notes: Upper right dolomite is present as pore-filling cement and is euhedral rhombic crystals. More rarely it occurs as a replacement of detrital feldspars (shown subsequently).

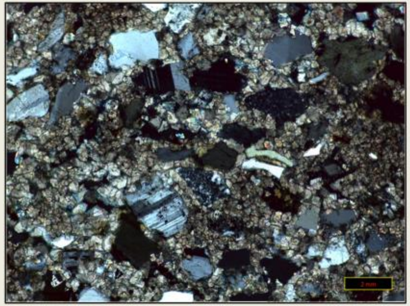
Cementation- Pore-Filling Cements

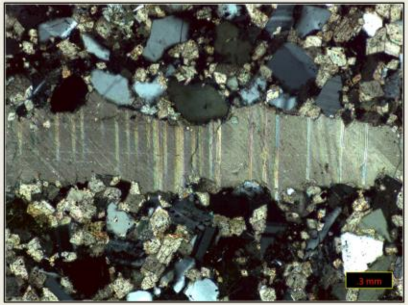


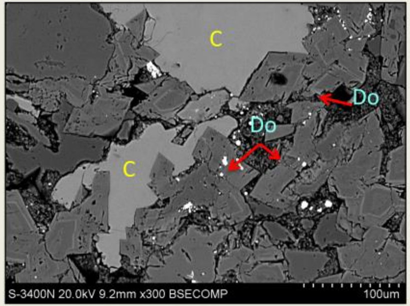
Presenter's notes: Lower left shows a fracture filled by calcite cement, indicating that the fracture served as a pathway for migrating pore fluids.

Cementation- Pore-Filling Cements



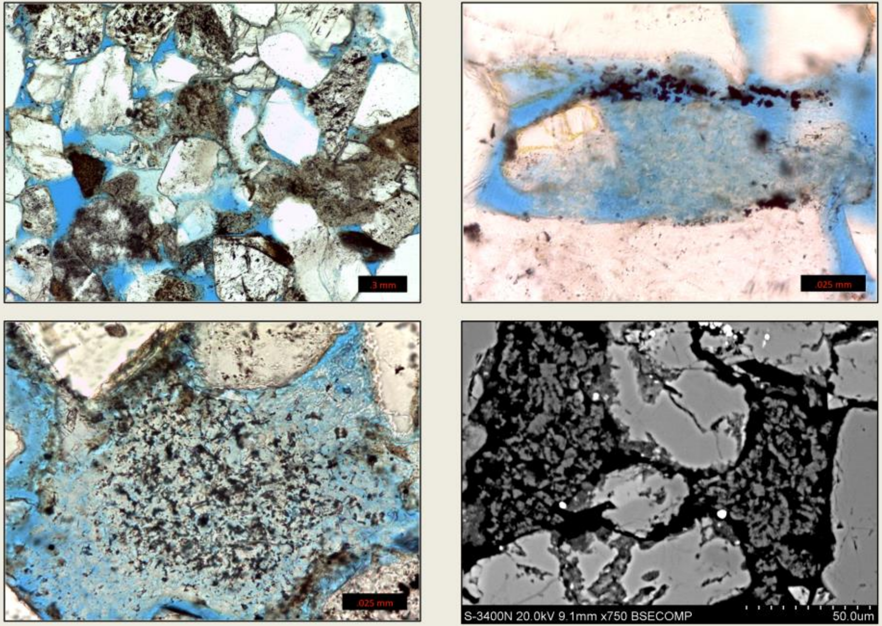






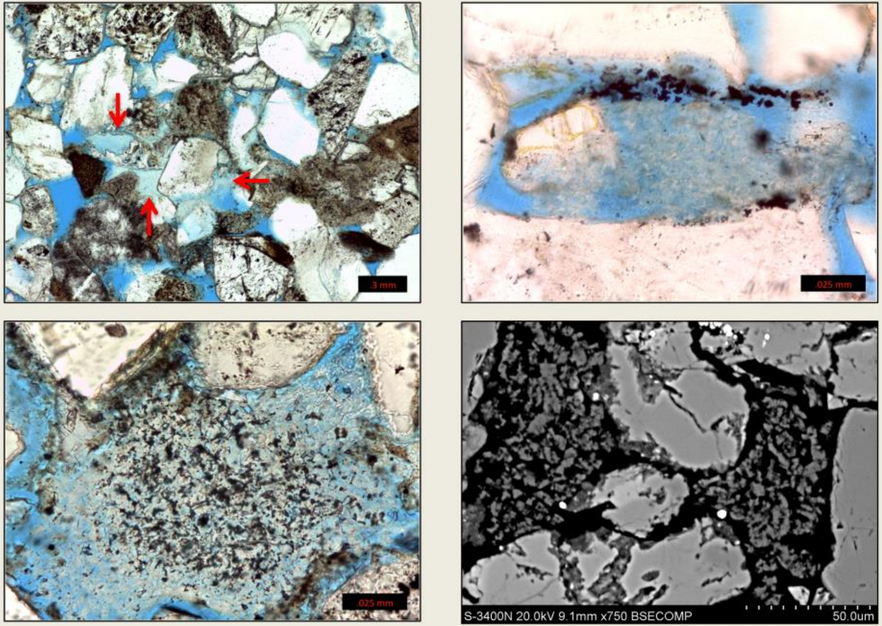
Presenter's notes: The lower right is a SEM-BSE image of dolomite and calcite cement. Here you can easily see that dolomite occurred before calcite.

Cementation- Clay Cement

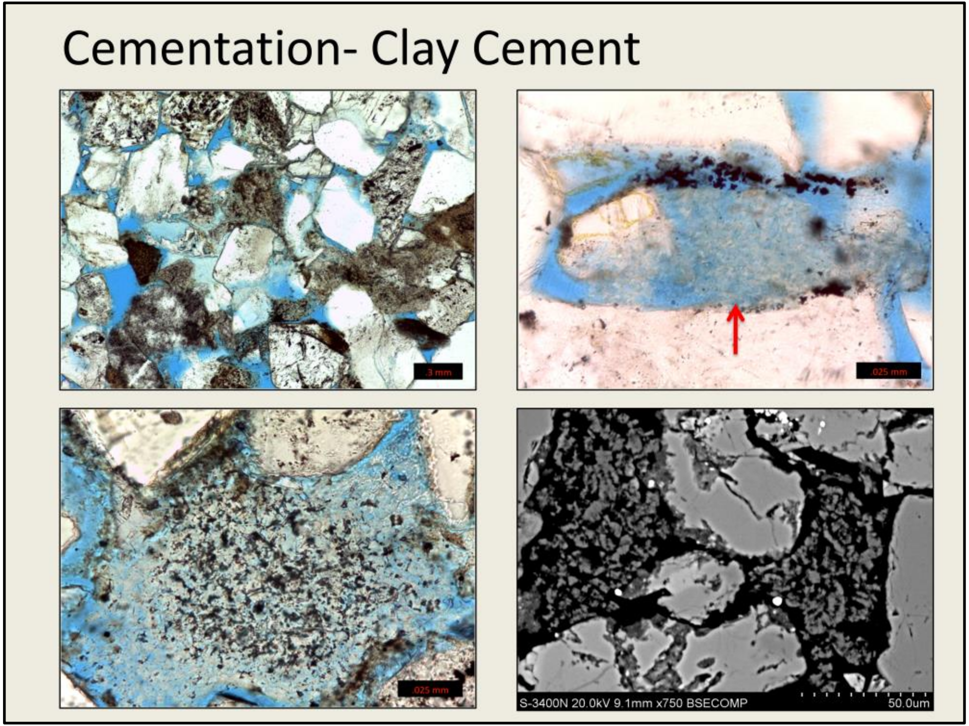


Presenter's notes: Certain authigenic clays may create problems during drilling, stimulation, and production of hydrocarbons due to their ability to block pores by expansion or migration. Most kaolinite formed during a later-stage of diagenesis after significant compaction.

Cementation- Clay Cement

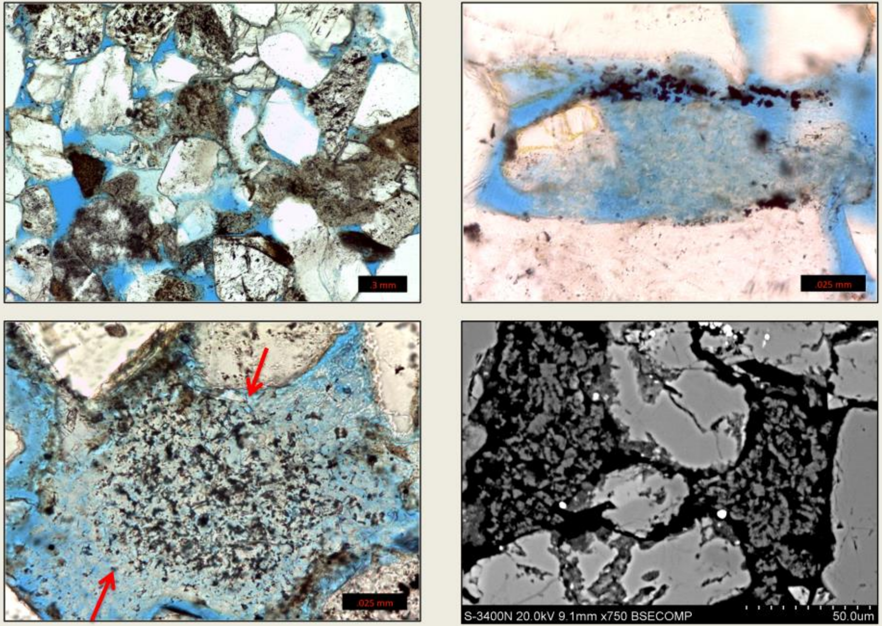


Presenter's notes: The top right shows kaolinite occurring as a pore-lining and pore-filling cement and as a product of feldspar grain alteration. Most commonly associated with feldspar dissolution.

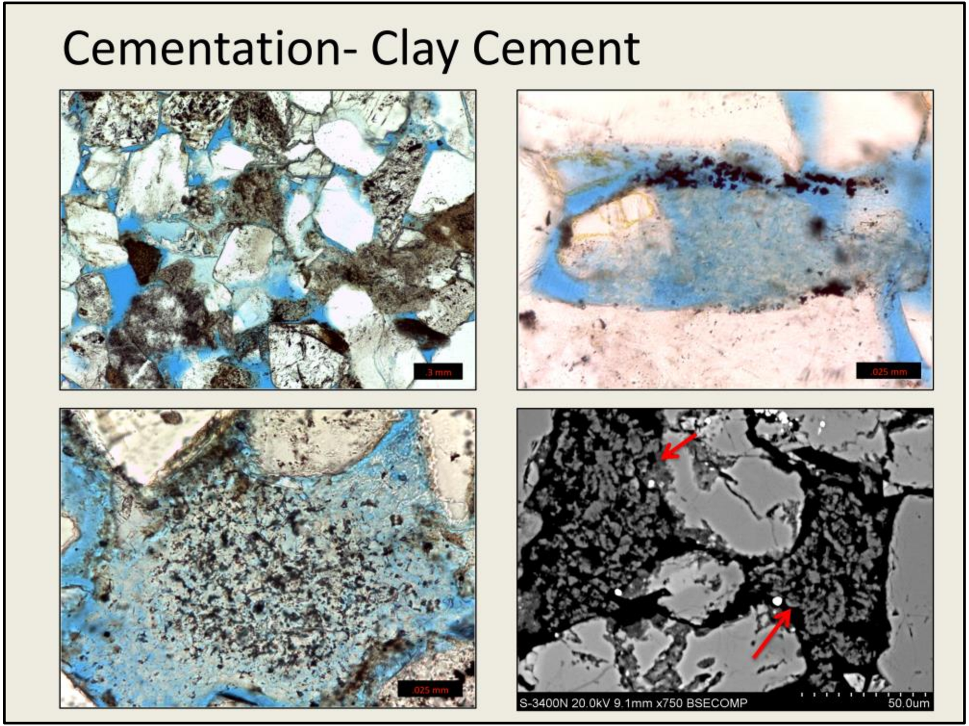


Presenter's notes: The top right shows kaolinite that precipitated adjacent to a partially dissolved grain.

Cementation- Clay Cement

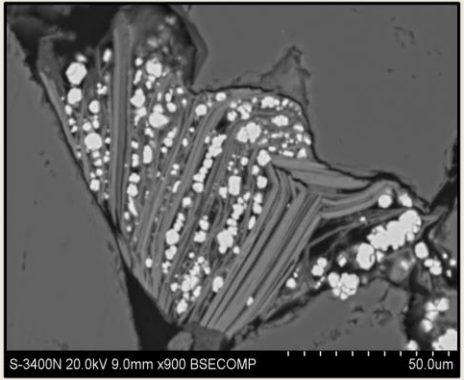


Presenter's notes: Lower left shows kaolinite occluding pore spaces, ultimately affecting reservoir quality. –Although kaolinite has some porosity within it, it is not effective porosity.

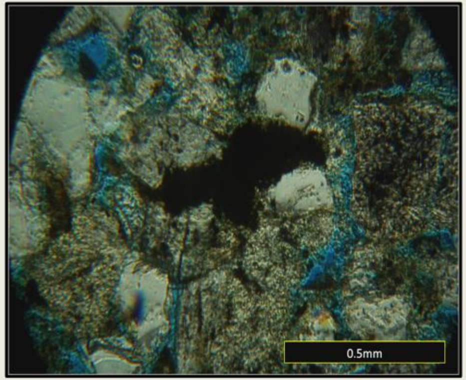


Presenter’s notes: Lower left shows kaolinite occluding pore spaces, ultimately affecting reservoir quality. –Although kaolinite has some porosity within it, it is not effective porosity.

Cementation- Pyrite



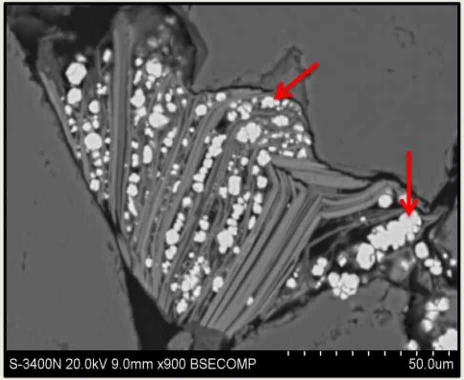
SEM-BSE



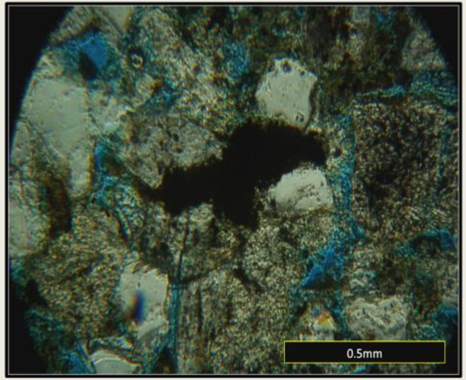
Transmitted Light

Presenter's notes: Authigenic pyrite occurs throughout the sandstones, forming along biotite cleavage planes and within hydrocarbon-filled pores.

Cementation- Pyrite



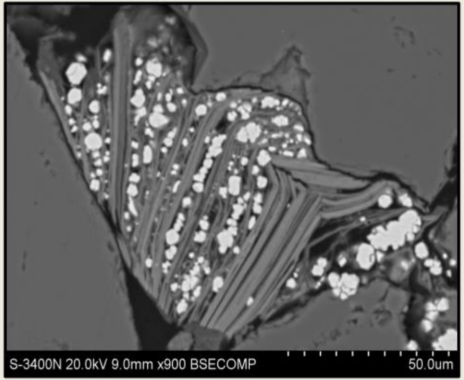
SEM-BSE



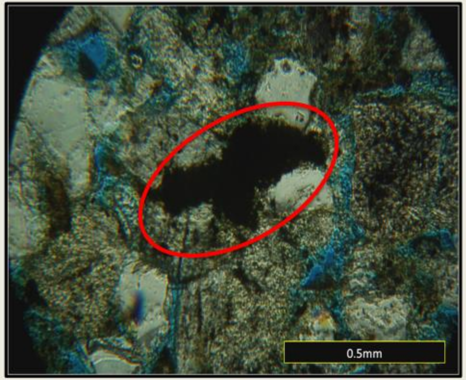
Transmitted Light

Presenter's notes: Left photo: Formation of pyrite crystals expanded the biotite fabric such that pore space was created along the cleavage planes. These open pores are present even though the rocks have been tightly compacted. Such expansion to create open pore spaces would be unlikely once the rocks were tightly compacted; thus early formation of this pyrite is indicated. Early precipitation of pyrite would have occurred as the sediments transitioned from the post-oxic to the sulfidic diagenetic environment. Occurrence of these crystals within biotite suggests that alteration of biotite may have been the source of iron.

Cementation- Pyrite



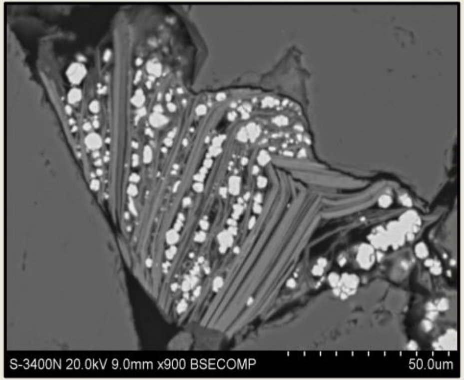
SEM-BSE



Transmitted Light

Presenter's notes: Pyrite cement (right photo) occurs with hydrocarbons in oversized or secondary pores filled with oil. Distribution of pyrite suggests it is a late feature that formed as the oil changed in composition and liberated sulfur.

Cementation- Pyrite

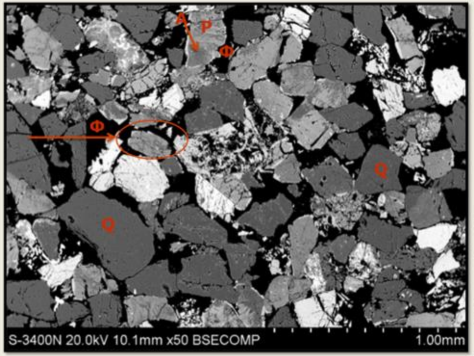


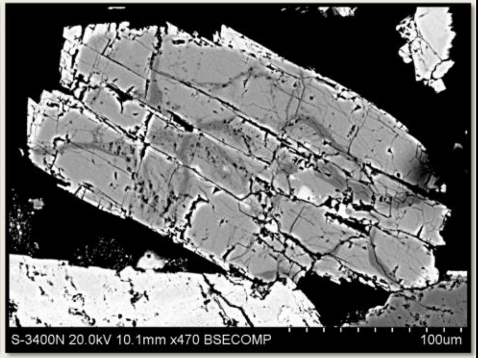
SEM-BSE

Reflected Light

Presenter's notes: With reflected light, pyrite is readily seen within the hydrocarbons.

Alteration- Albitization of Feldspars

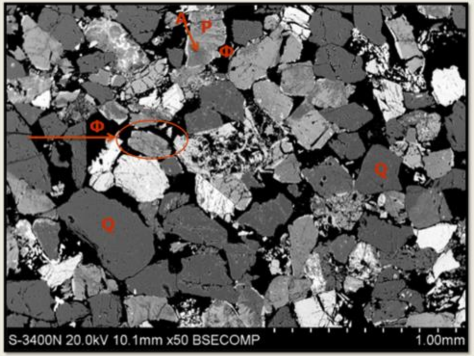


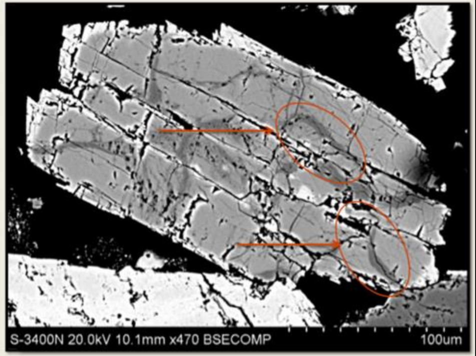


SEM photo showing albitization along with dissolution of K-feldspar and quartz grains. Well Weber, depth: 11,445 ft.

Presenter's notes: Blocky albite in upper highlighted (P) grain.

Alteration- Albitization of Feldspars

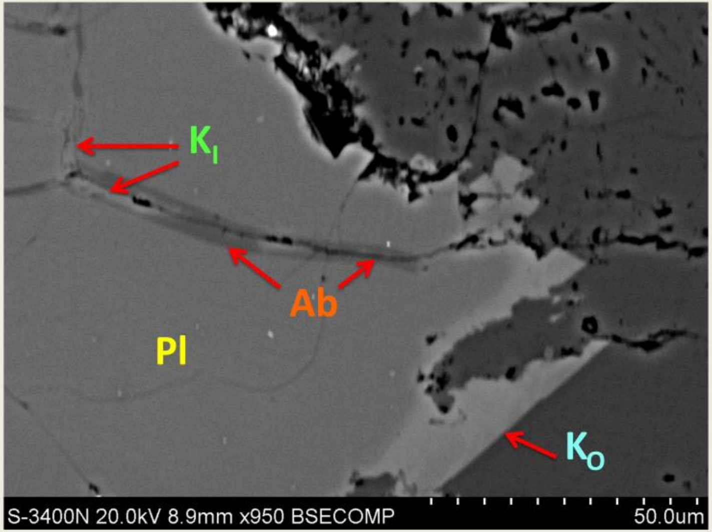




SEM photo showing albitization along with dissolution of K-feldspar and quartz grains. Well Weber, depth: 11,445 ft.

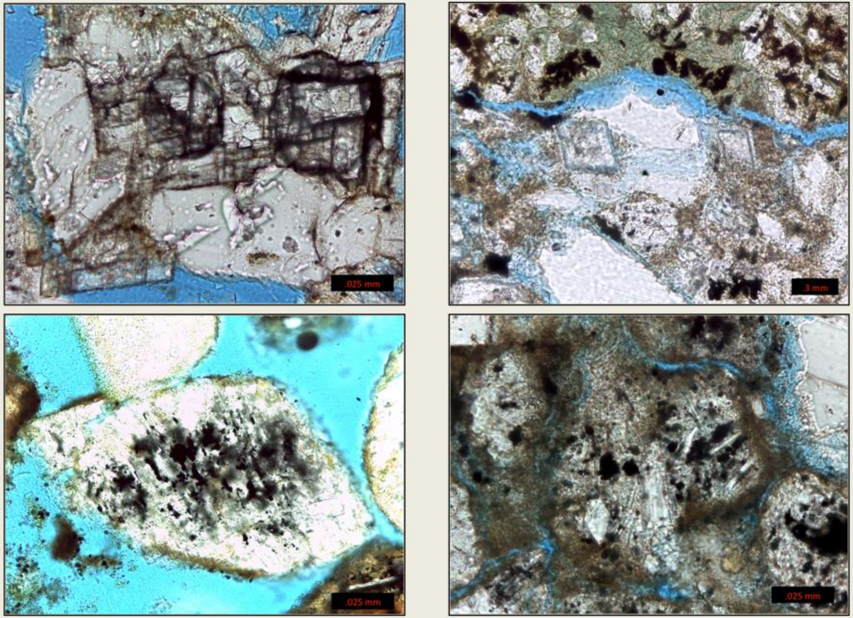
Presenter's notes: Right photo is a closer view of the circled plagioclase grain (in left photo); albitization is associated with fractures that allow the diagenetic fluids rich in Na to migrate into the interior of the grain and albitize the exposed parts of the grain.

Alteration- Albitization of Feldspars



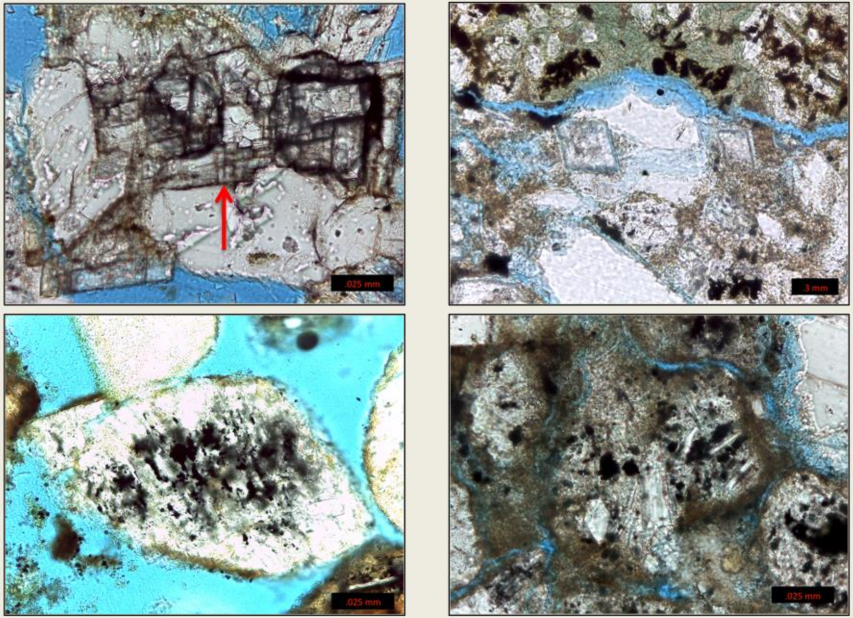
Presenter's notes. This is a plagioclase grain exhibiting K-spar infilling fractures. The x-cutting relationship between albite and K-spar-fill fractures indicates albitization occurred before authigenic K-spar. Kernco 11,410-6 site 9.

Alteration

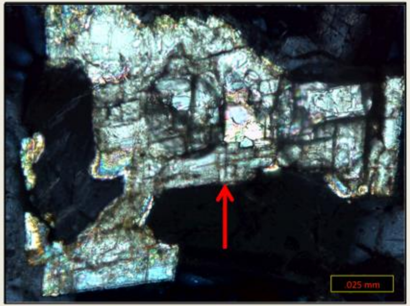


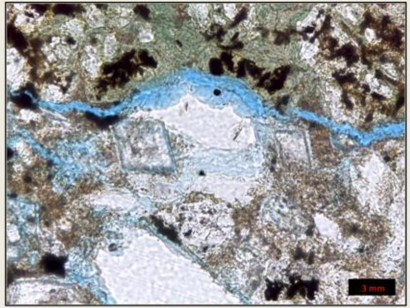
Presenter's notes: Top left shows plagioclase partially altered to calcite. Oil entered the pore space associated with calcite, suggesting this is a later phase in the diagenetic history.

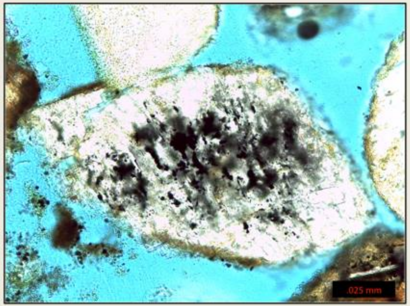
Alteration

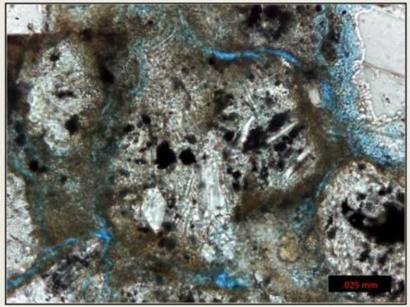


Alteration

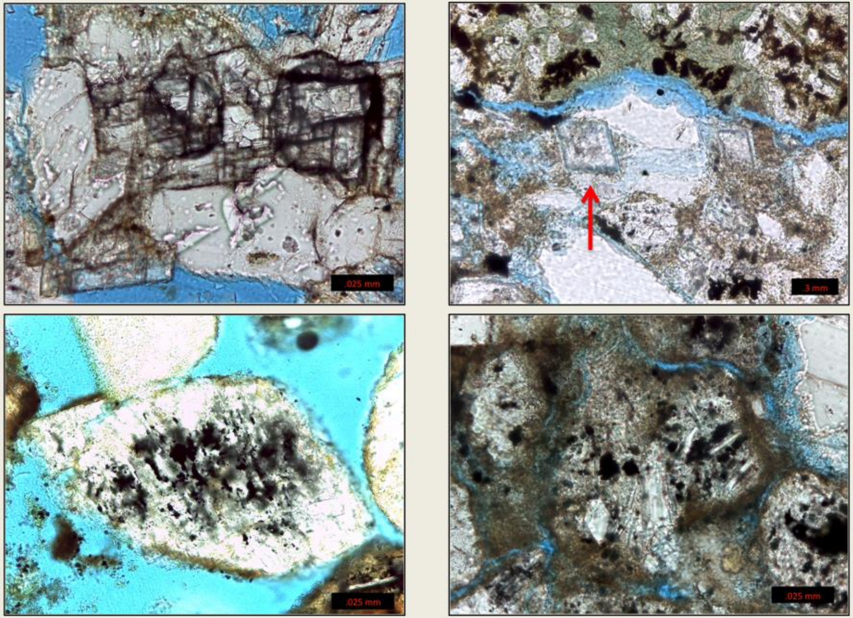






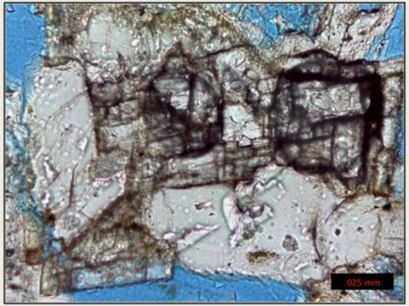


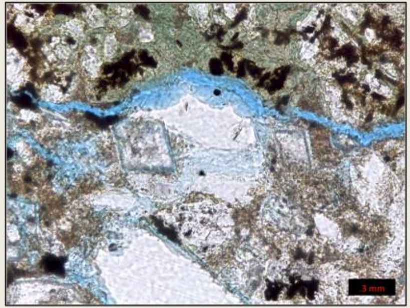
Alteration

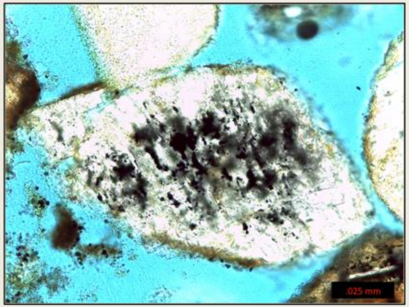


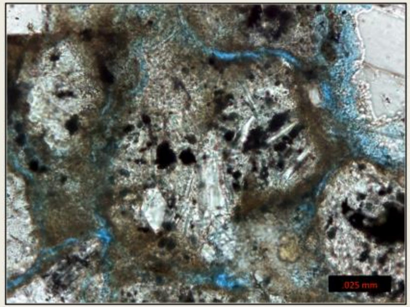
Presenter’s notes: Upper right- dolomite growing in a detrital feldspar grain.

Alteration

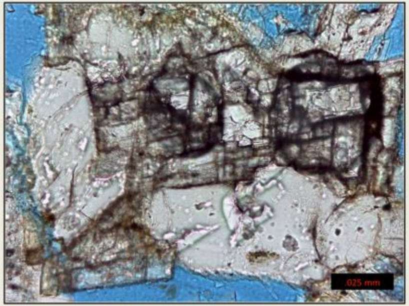


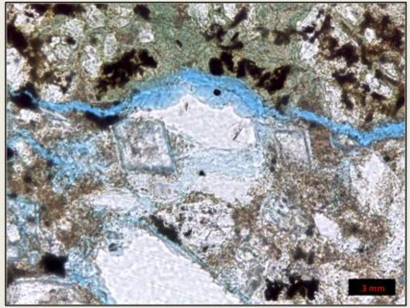


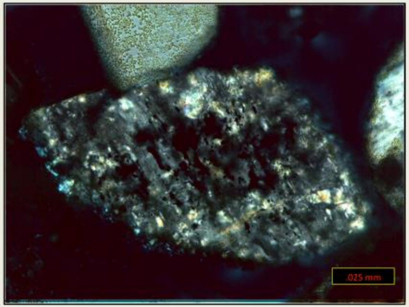


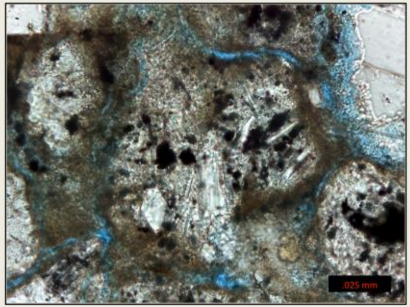


Alteration

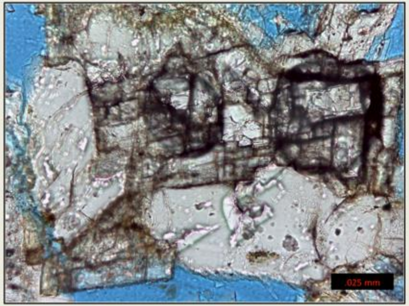


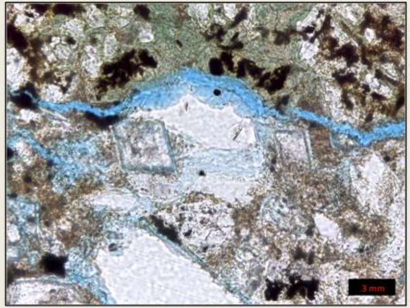


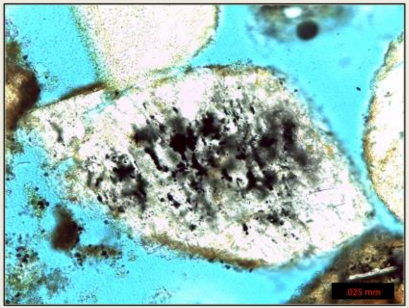


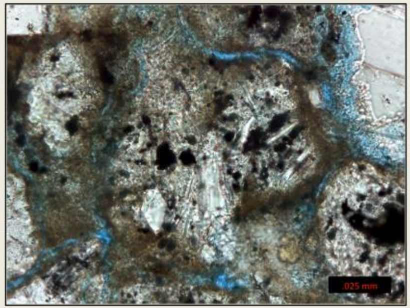


Alteration

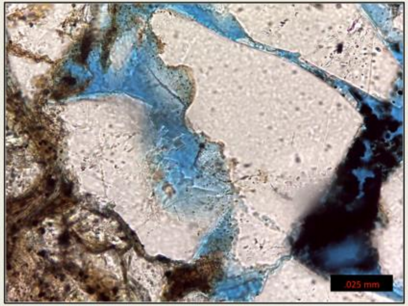


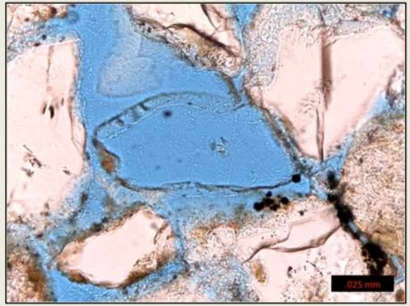


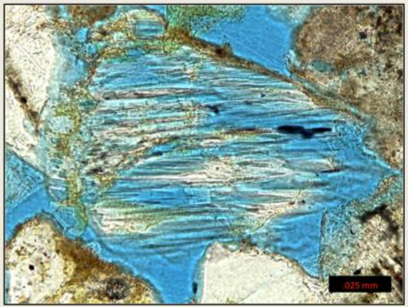


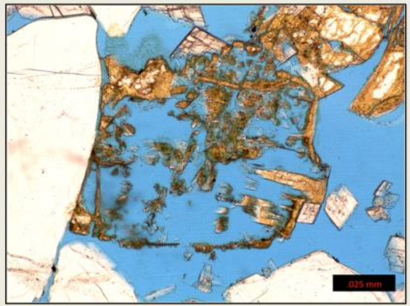


Dissolution

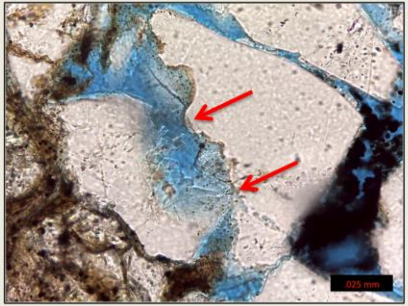


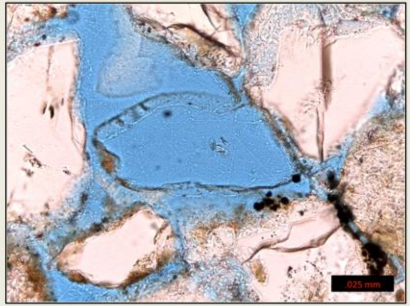


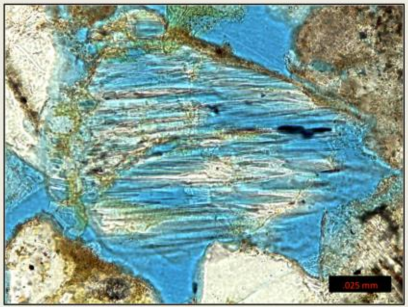


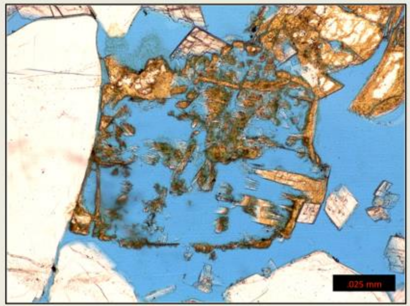


Dissolution

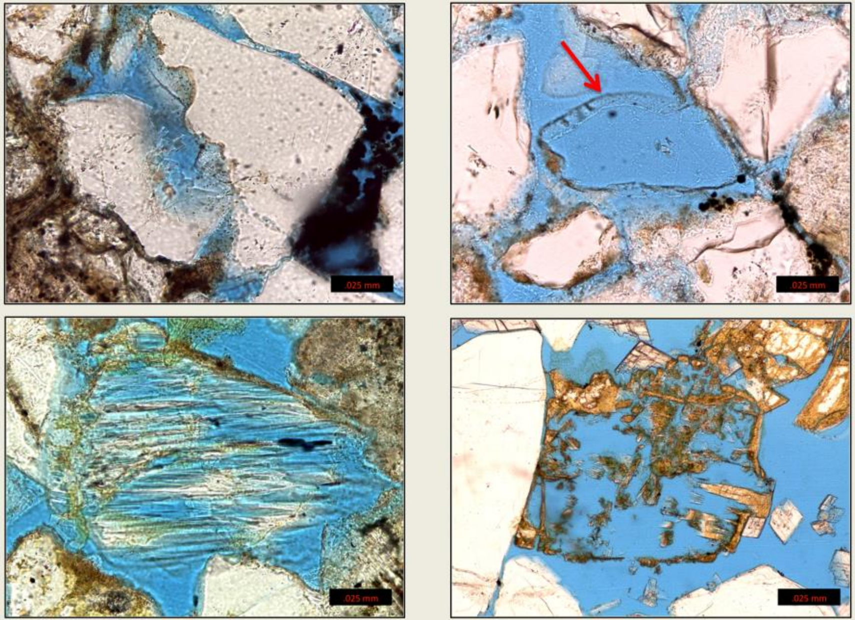




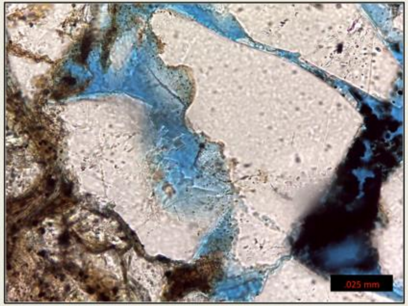


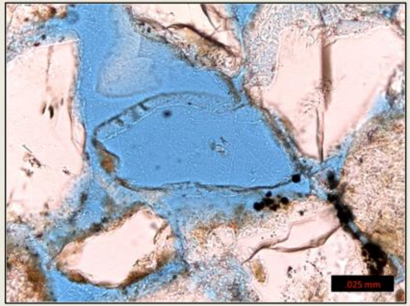


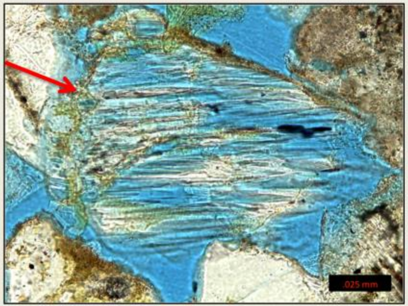
Dissolution

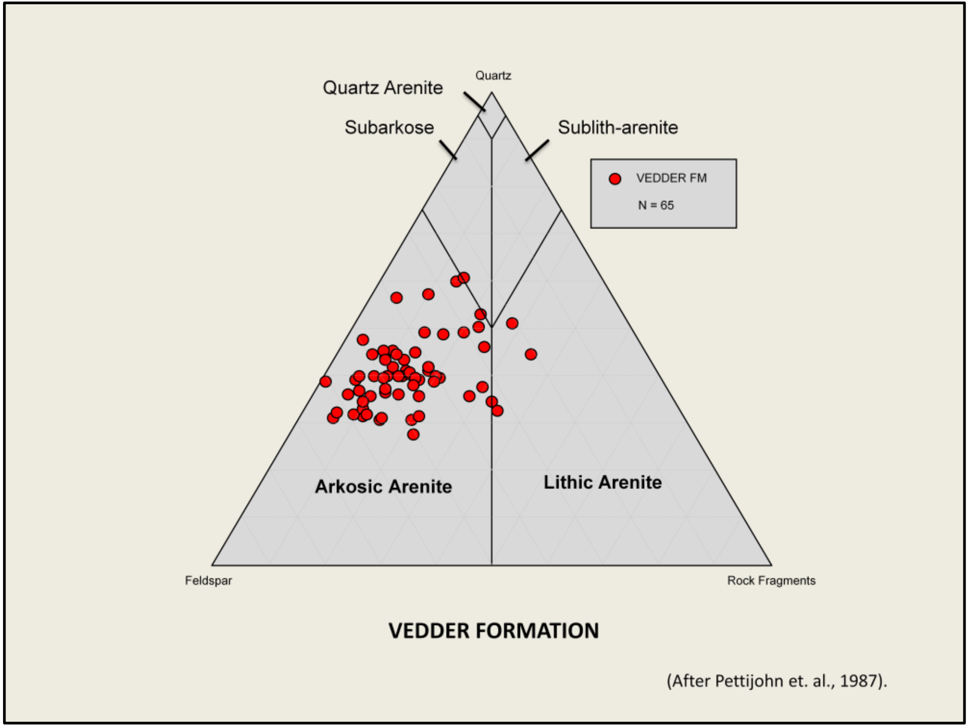


Dissolution

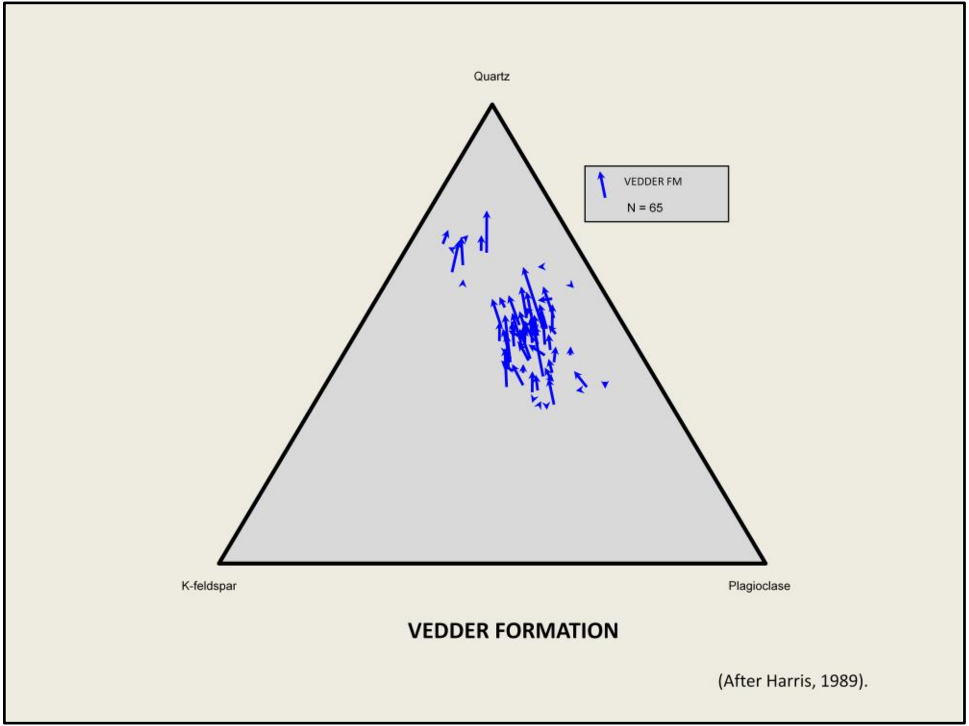




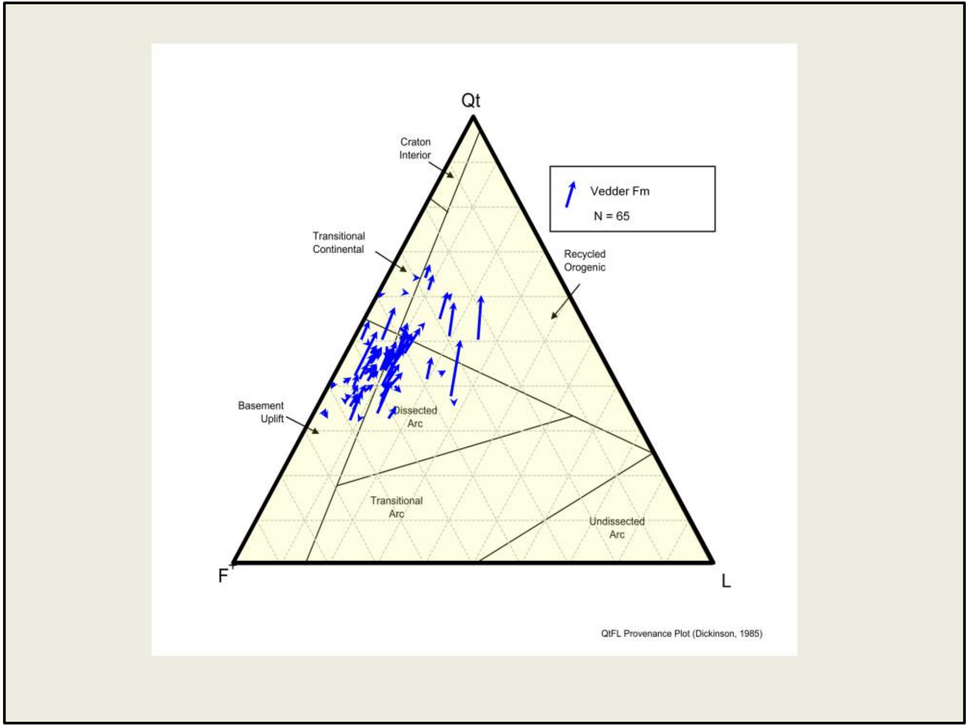




Presenter's notes: QFRf ternary diagram (Pettijohn et. al., 1987). For the Vedder sands. It is anticipated that deeper samples are more quartz-rich than shallower samples.



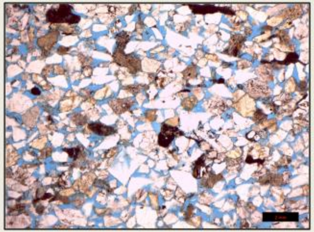
Presenter's notes: -QKP ternary diagram plotted for the Vedder sands, following the methodology of Harris (1989). The compositions are adjusted for dissolution. The arrows point to the present composition; they originate at the reconstructed compositions. This suggests significant plagioclase dissolution has occurred, as evidenced by the arrows pointing toward the quartz corner.

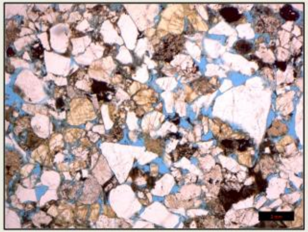


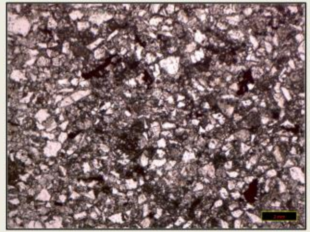
Presenter's notes: QFL ternary diagram (Dickinson, 1985) for Vedder sands. The results indicate most of the samples are derived from basement uplift and dissected arc.

Summary

- Rock Type
  - Moderate to well sorted, subangular to sub-rounded, fine to coarse sand, arkosic to lithic arenites and wackes

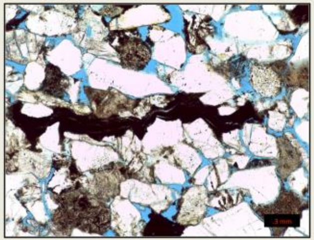


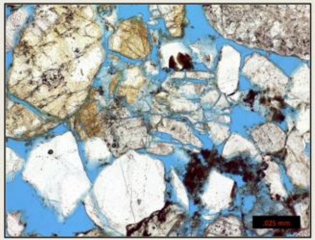


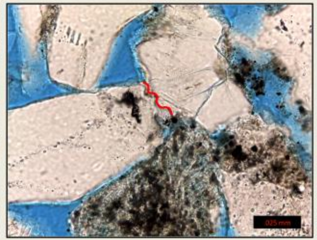


Summary

- Porosity
  - Controlled by compaction, cementation, and dissolution of framework grains



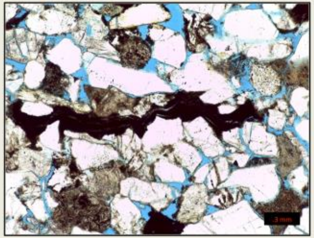


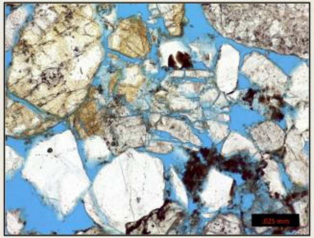


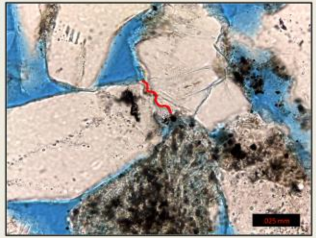
Summary

- Porosity
    - Controlled by compaction, cementation, and dissolution of framework grains

- **Compaction**
    - **Mechanical compaction is evidenced by deformed labile grains, fractured and broken framework grains, and sutured grains to sutured-grain contacts**



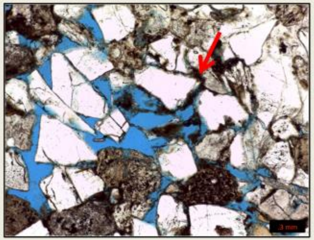


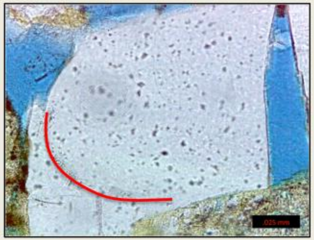


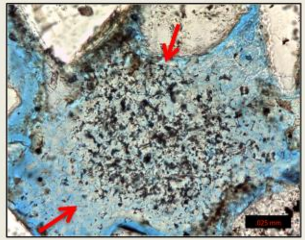
Summary

- Porosity
  - Controlled by compaction, cementation, and dissolution of framework grains

- **Cementation**
  - **Occurs as grain coatings- Clays, Chlorite**
  - **Overgrowths- Quartz and feldspar overgrowths**
  - **Pore-filling cement- Carbonates and Kaolinite**



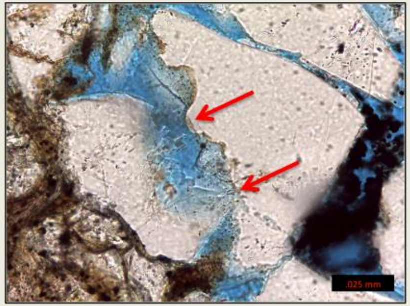




Summary

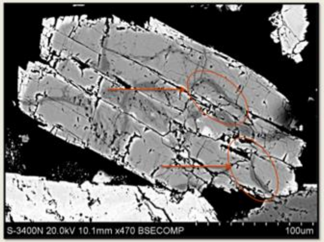
- Porosity
  - Controlled by compaction, cementation, and dissolution of framework grains

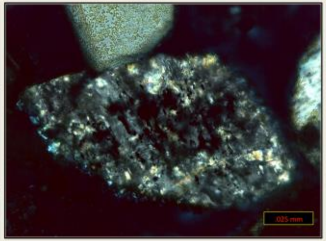
- **Dissolution**
  - **Feldspar and volcanic grains were most susceptible to dissolution**
  - **Quartz grains dissolved along edges**

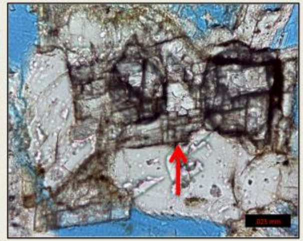


Summary

- Alteration
  - Feldspars most commonly altered to albite, clays/sericite, and carbonates
  - Volcanic grains were also very susceptible to alteration







Summary

- It is important to determine the diagenetic history of sandstones in order to understand the effect on porosity and permeability.

- The results of this project will not solve the question as to whether sequestration of CO_2 is feasible, however when finished the results will be combined with other projects in order to determine feasibility.

Acknowledgments

- Dr. Horton
- Elizabeth Powers
- CSUB NSF CREST Grant

Questions?