

Presentation #4

- 24th Annual South Dakota Department of Environmental and Natural Resources Environmental and Ground Water Quality Conference, Fort Pierre, South Dakota, March 21, 2012, by Sharon Diehl

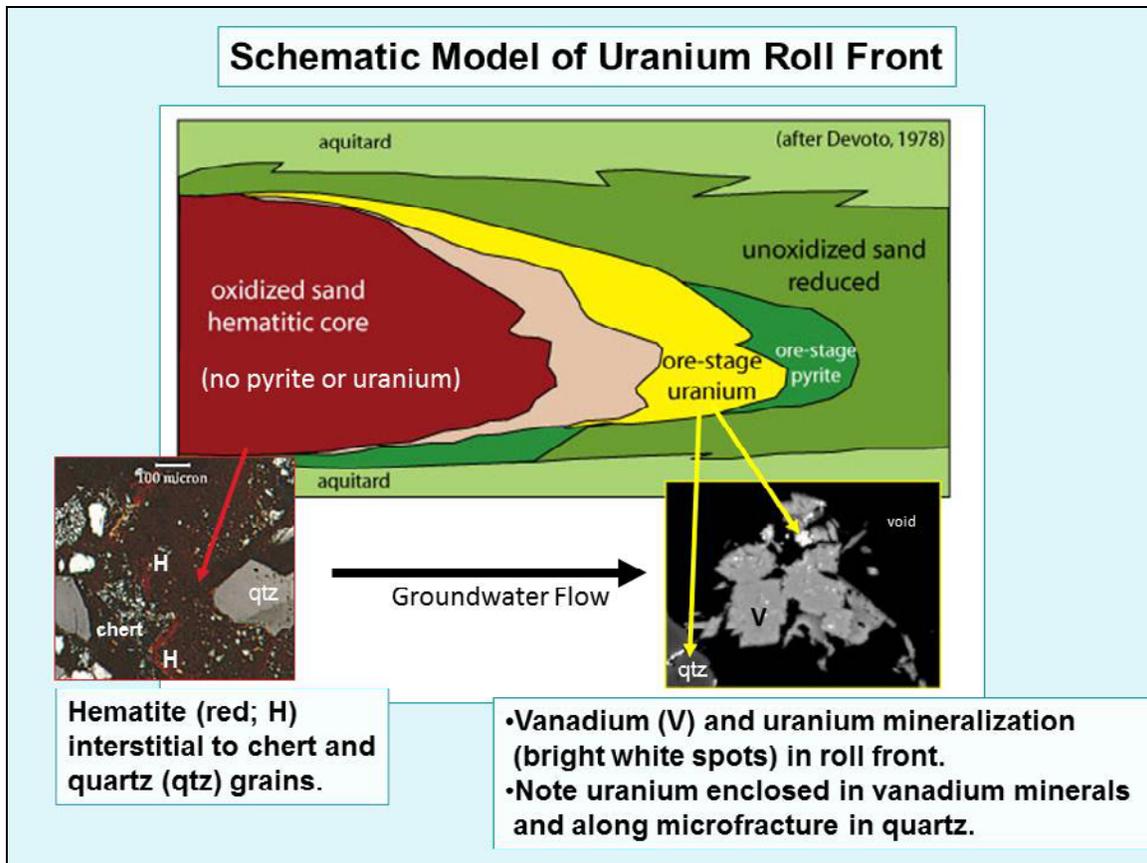


Mineralogic and Microstructural Observations of Uranium and Vanadium Mineralization in Porous Channel Sandstone, Inyan Kara Group, near Edgemont, South Dakota

Sharon Diehl, Raymond Johnson, William Benzel



This talk shows constituent minerals, mineral cements, and alteration textures from cores drilled into the oxidized and reduced parts of the Dewey Burdock uranium roll-front deposit, along with mineralogy and textural features at the microscopic scale using transmitted, reflected, and scanning electron microscopy (SEM) micrographs.

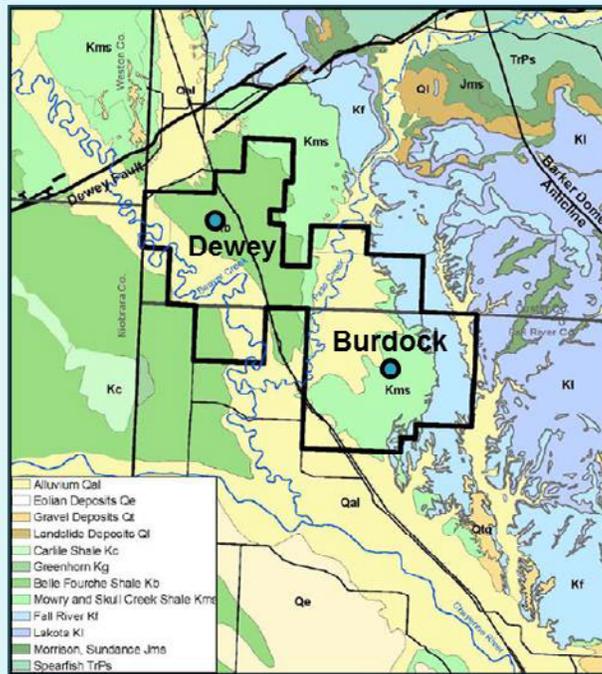


This is a classic depiction of a uranium roll-front deposit from the oxidized core (left side) to the ore-bearing nose (middle/right). Micrographs in this talk, such as transmitted light and scanning electron micrograph (SEM) images, show material that makes up the oxidized areas to the ore-mineralized areas. To the left is a preview of a transmitted light micrograph showing common constituent sandstone grains of chert and quartz.

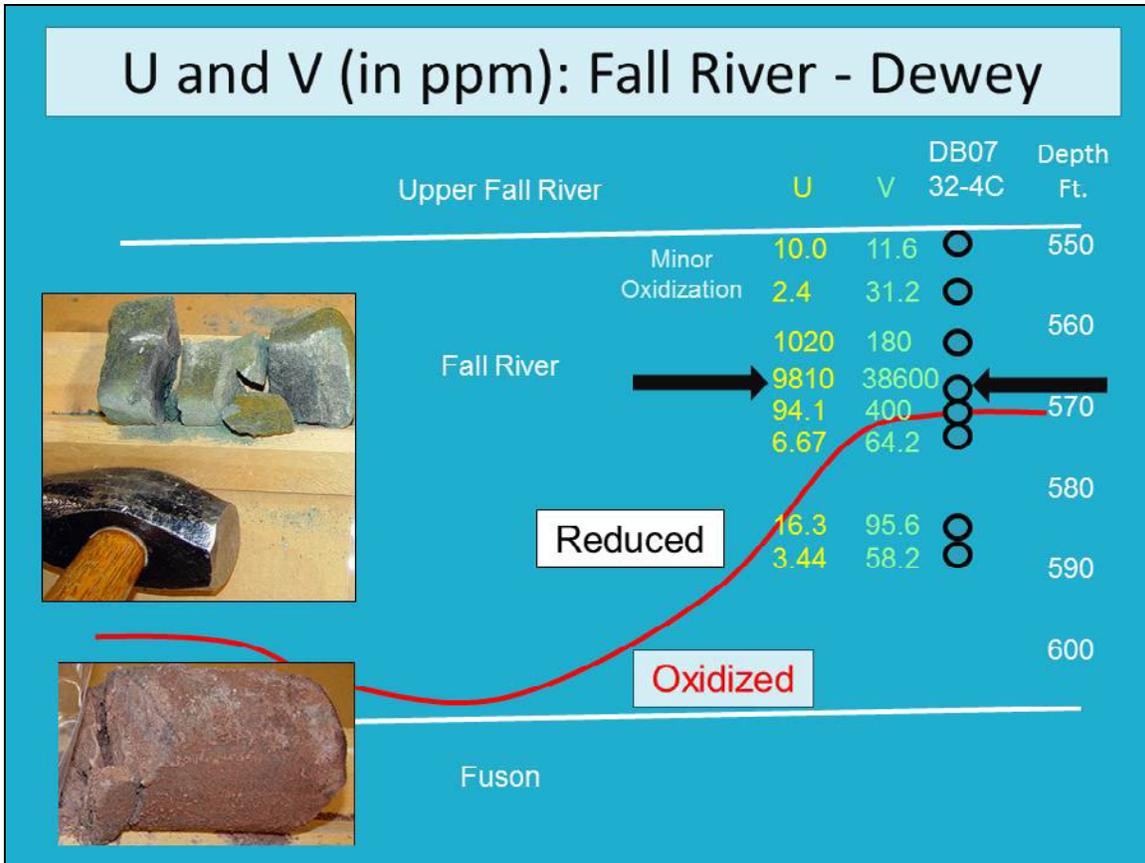
Hematite is the opaque to red material, probably after oxidized pyrite. To the right is a preview/example of a scanning electron micrograph, showing uranium as micron-sized bright white minerals encased in this medium-gray vanadium mineral. The black area is void space, porosity between grains, and this dark gray mineral down below is quartz, note the bright white uranium mineralization along a microfracture. Images in this talk use backscatter SEM—heavy elements such as uranium strongly backscatter electrons, so areas with uranium will appear brighter.

Reference: DeVoto, R.H., 1978, Uranium geology and exploration: Lecture notes and references: Golden, CO, Colorado School of Mines, 396 p.

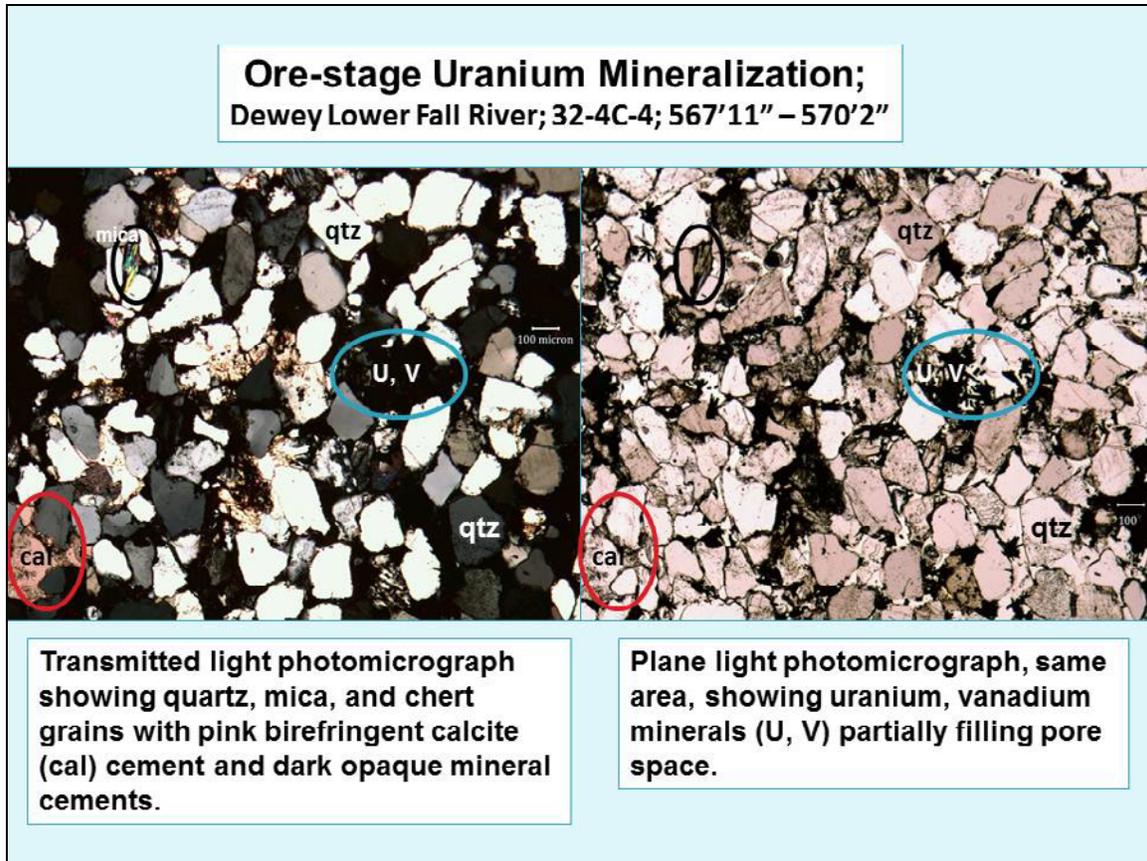
Dewey and Burdock Mineralogic Differences



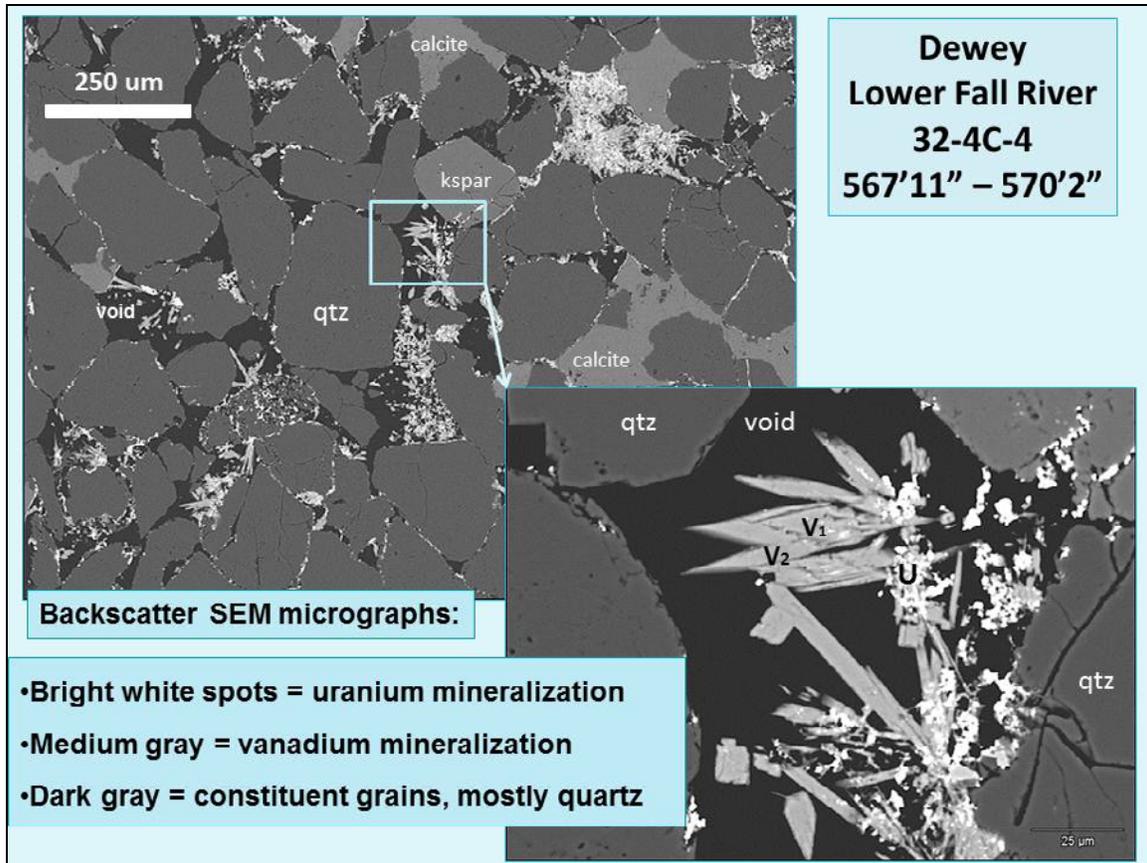
Dewey Burdock area where the circles are the approximate positions of the cores from which thin sections were made.



This slide and several following slides are from drill hole 32-4C, specifically 32-4C-4, marked by the dark arrows, where the highest U and V concentrations were recorded.

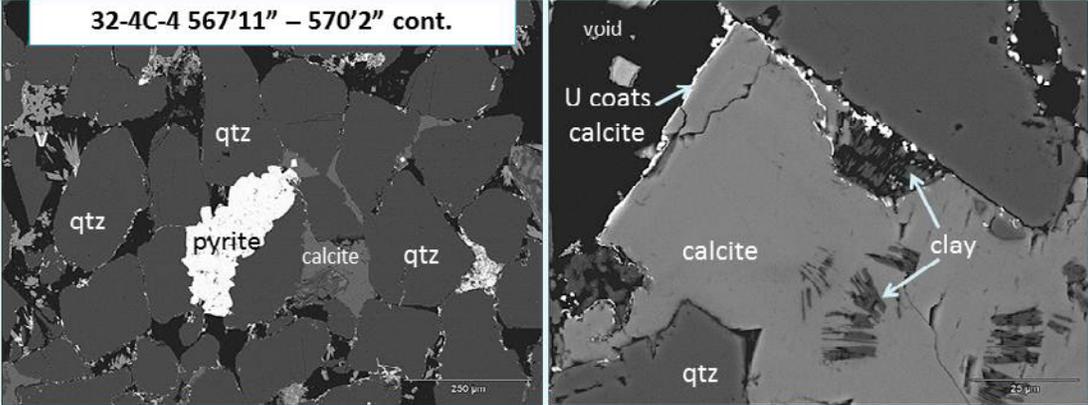


Common constituent grains seen here in transmitted light are quartz, chert, some feldspar and mica. Calcite cement, the pink mineral in the red oval, is patchy. Pyrite and uranium minerals are opaque, as seen in the crossed nicols and plane light images. Therefore, SEM techniques were used to determine mineral paragenesis (the sequence of precipitation of authigenic minerals) and identify chemical processes that may have occurred, such as local dissolution.



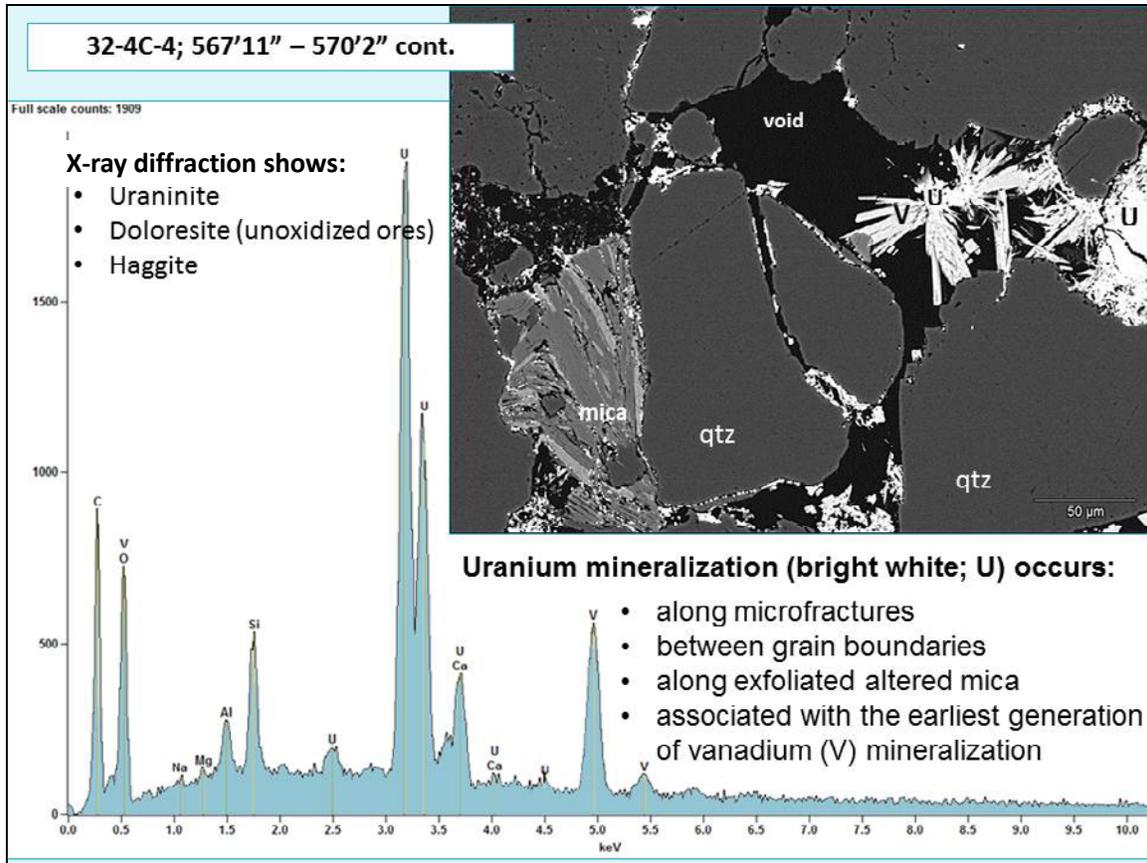
Backscatter SEM brings out the heavy elements = bright white areas. Black areas are void space, filled by epoxy. Dark gray grains are quartz; medium gray rounded grains are feldspar. Medium light gray areas between quartz grains is calcite cement. Uranium minerals are bright white. Note that the uraninite occurs between grain boundaries and is enclosed by vanadium minerals. There are two generations of vanadium minerals; the late-stage V2 generation is U free. Note that uranium occurs along microfractures in the quartz grains and also between grain boundaries. The edges of the quartz grains are embayed, suggesting dissolution etching.

32-4C-4 567'11" – 570'2" cont.



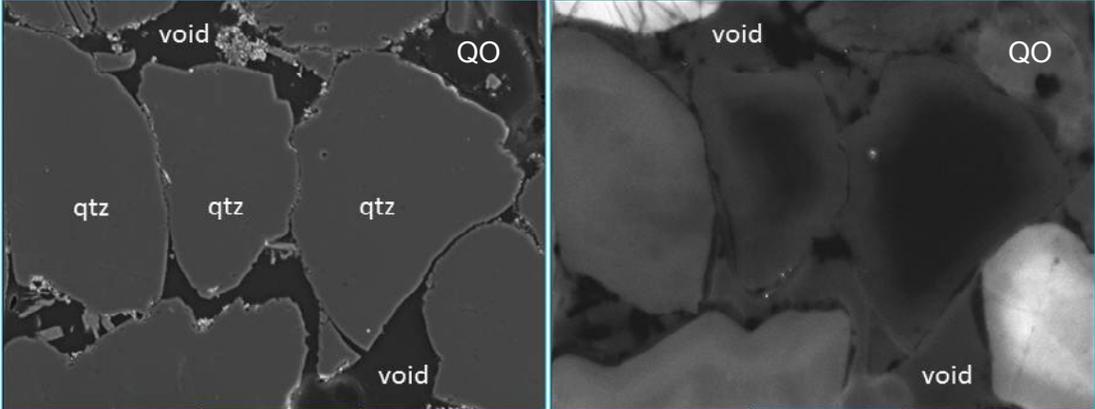
- Euhedral pyrite is a patchy cement, partially replacing quartz grains.
- Calcite is a patchy cement, partially replacing quartz grains and enclosing earlier kaolinitic clay.
- Uranium minerals coat euhedral calcite and fill microfractures.
- Vanadium minerals partially occlude pore space and enclose uranium minerals.
- Paragenesis (sequence of mineral pptn): kaolinite-calcite-uranium-vanadium
- Multiple pyrite generations

Where pyrite fits into the paragenetic sequence has not yet been determined, as there are several generations of pyrite, from micron-size grains associated with chert and stylolite residue, to intergranular grain-size cement that partially replaces quartz grains. Morphological forms of pyrite in other photomicrographs are in upcoming slides.



This is an energy-dispersive X-ray spectroscopy (EDS) spectral pattern of the uranium and vanadium mineralization. Note the strong high peaks of U and V. X-ray diffraction shows uraninite, doloresite, and haggite, which is typical of unoxidized uranium/vanadium ores. Coffinite has been reported in earlier publications, but our lab did not detect its presence. Note that the mica grain has been compacted and deformed; pale gray areas along cleavage are areas of chlorite or clay; quartz grains are microfractured. Uranium mineralization is discontinuous along microfractures and occurs along the altered exfoliated cleavage planes of the altered mica grain. As noted earlier, the edges of quartz grains look like they have been dissolution etched, and dissolution has occurred between detrital grain boundaries and overgrowths. Uranium occurs along some microfractures but not others. This discontinuous nature of U mineralization and the dissolution embayments in quartz, point to mineral dissolution and U undergoing local dissolution and reprecipitation. To investigate this, cathodoluminescence (CL) was used (shown in next slide).

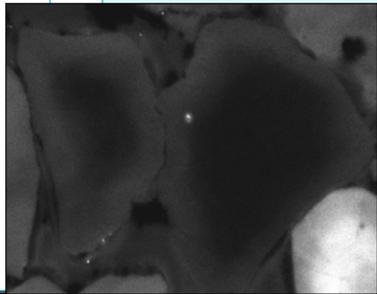
32-4C-4 567'11" – 570'2" cont.



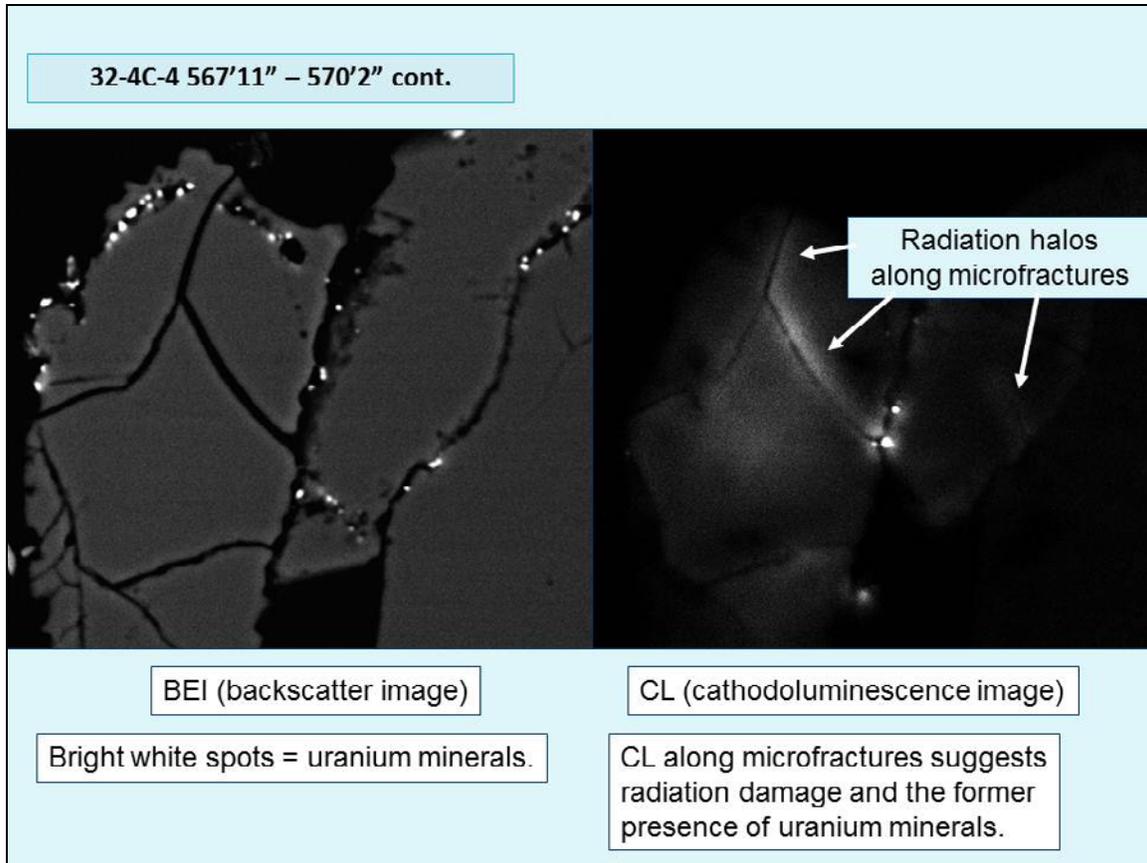
SEI Image

CL Image

- **Constituent quartz grains show varying cathodoluminescence (CL) = different source areas and different internal chemistry**
- **Quartz overgrowths (QO) are dark = no CL; therefore different generation of quartz cement**
- **Pale-gray halos within quartz grains suggest radiation damage rims**

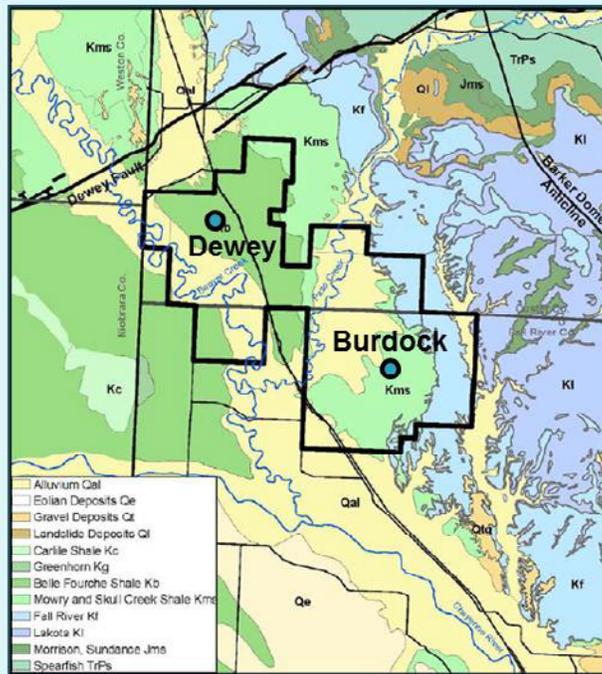


Other researchers have demonstrated that detrital quartz grains surrounded by uranium minerals commonly display radiation damage rims. Even if uranium is subsequently leached from the sandstone and locally or more regionally redistributed, radiation damage rims persist.

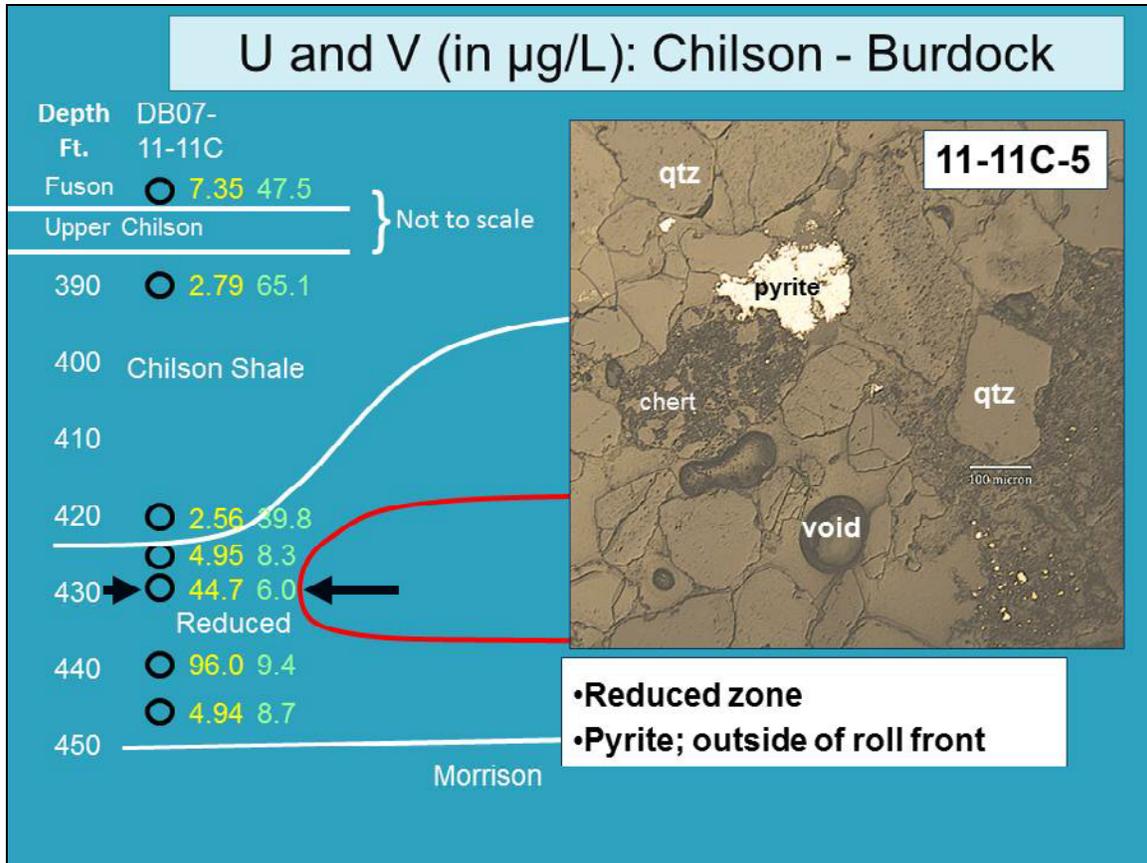


These Backscatter (left) and CL (right) micrographs are of the same image area, showing a fractured quartz grain with uranium minerals partially lining some microfractures. When looking at these fractures under CL, we see luminescence along microfractures that do not currently host U minerals. This suggests that uranium that has been locally remobilized. Very faintly in the micrograph to the right, CL occurs along a healed fracture in the quartz.

Dewey and Burdock Mineralogic Differences

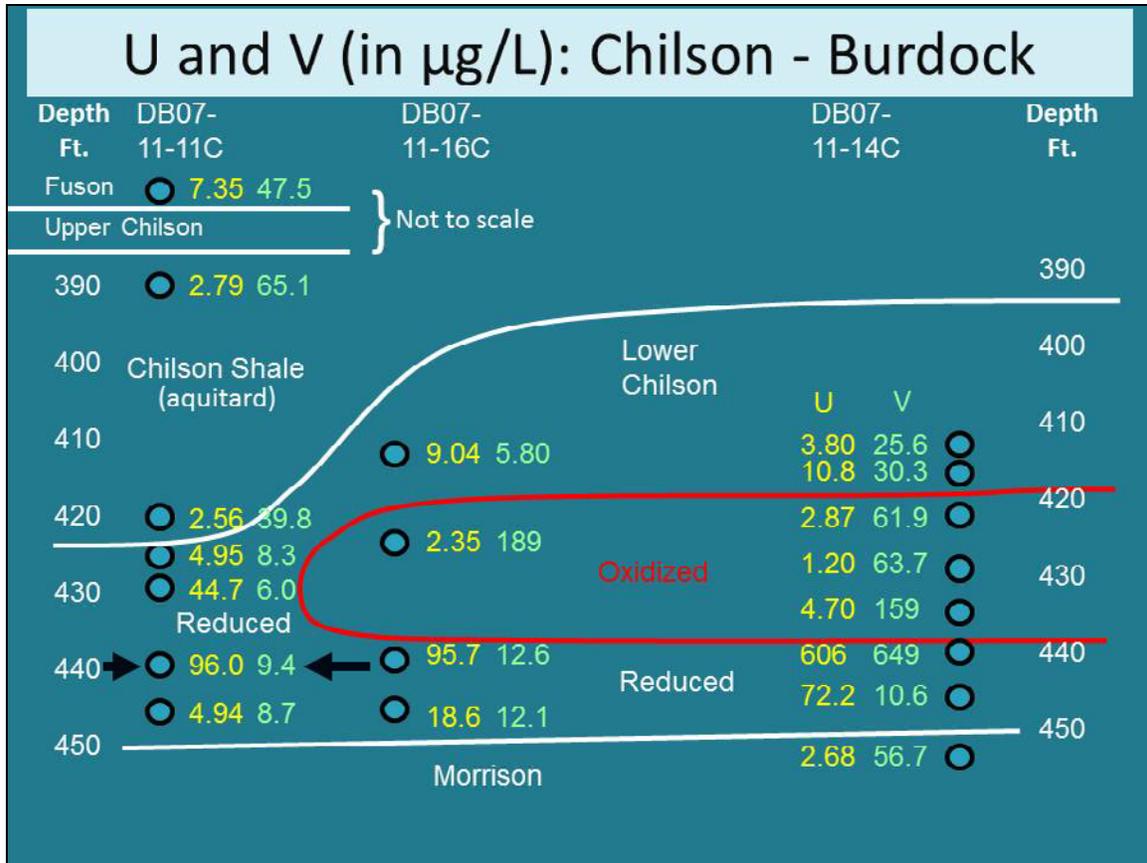


Next section discusses the mineralogic features of core from the Burdock area.

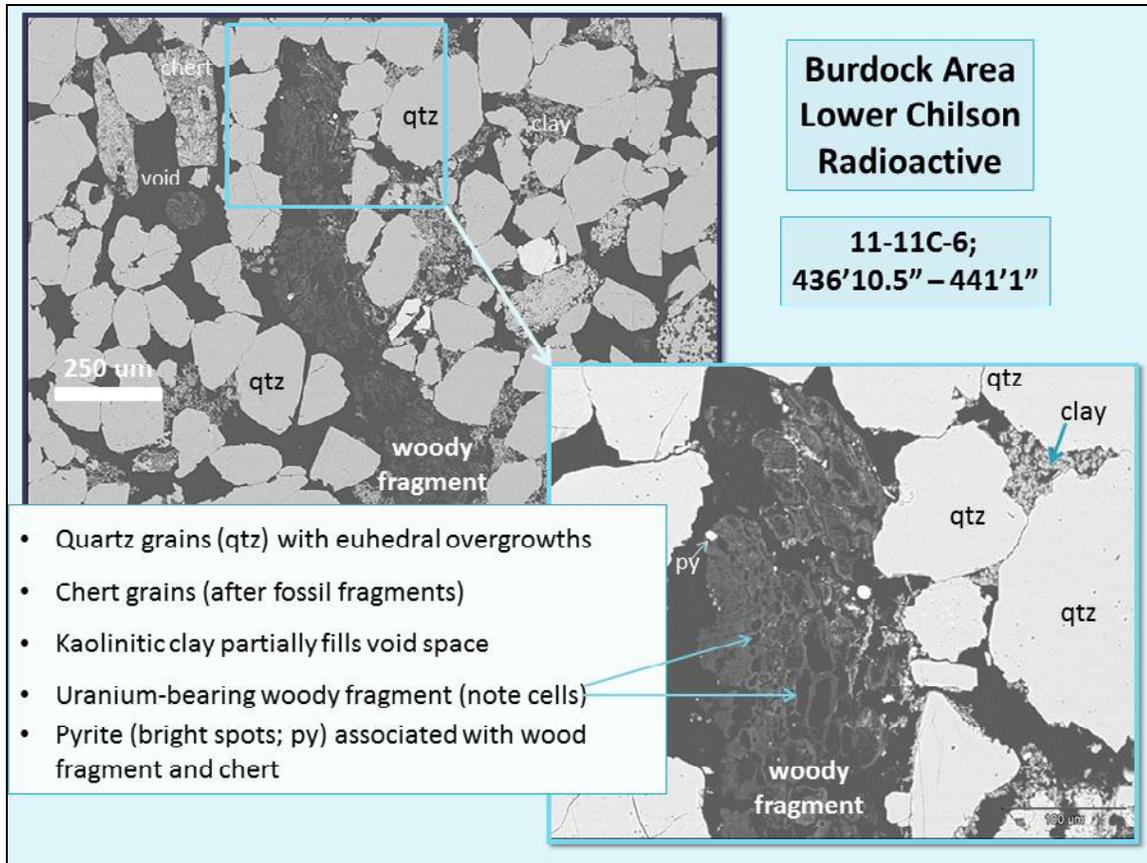


This is a reflected light photomicrograph of pyrite, demonstrating the presence of pyrite in the reduced zone at the nose of the roll front.

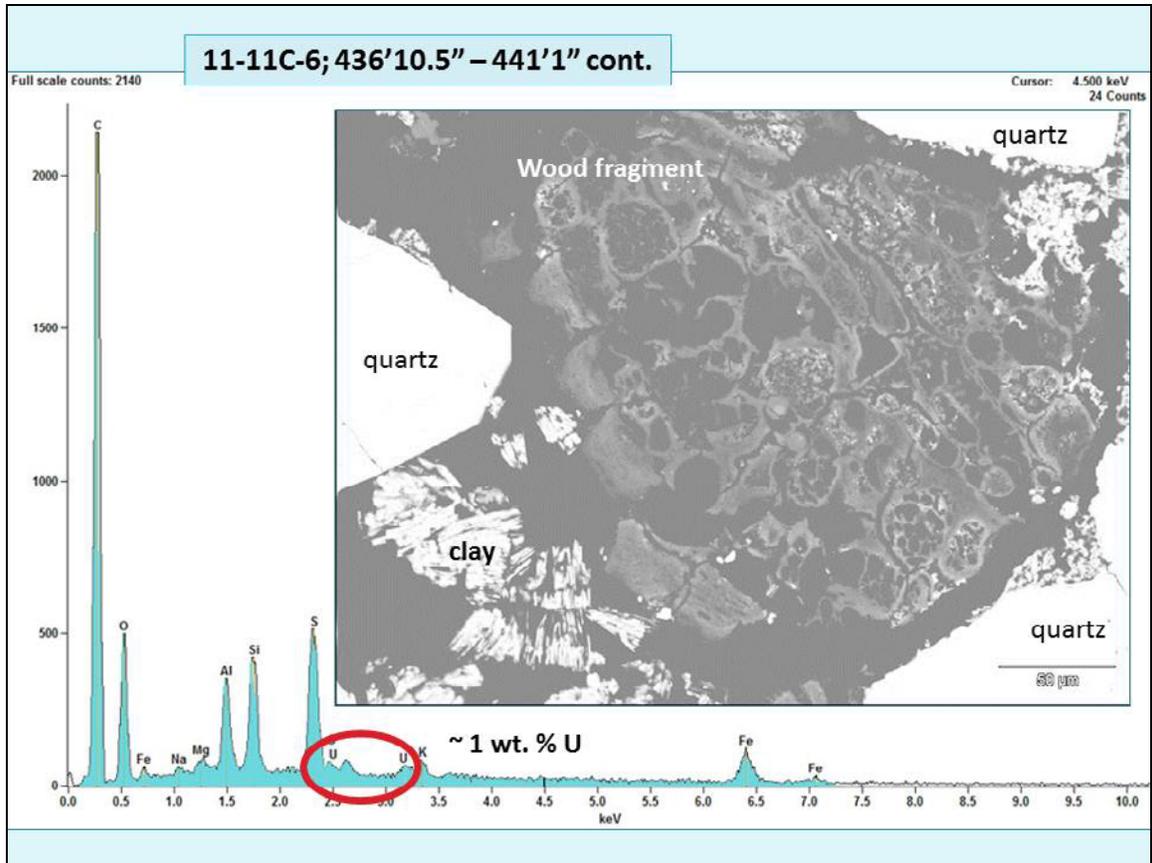
Pyrite is pale yellow. Pyrite occurs as micron-sized grains (lower right) to grain-size cement (upper left). Pyrite partially replaces constituent quartz grains.



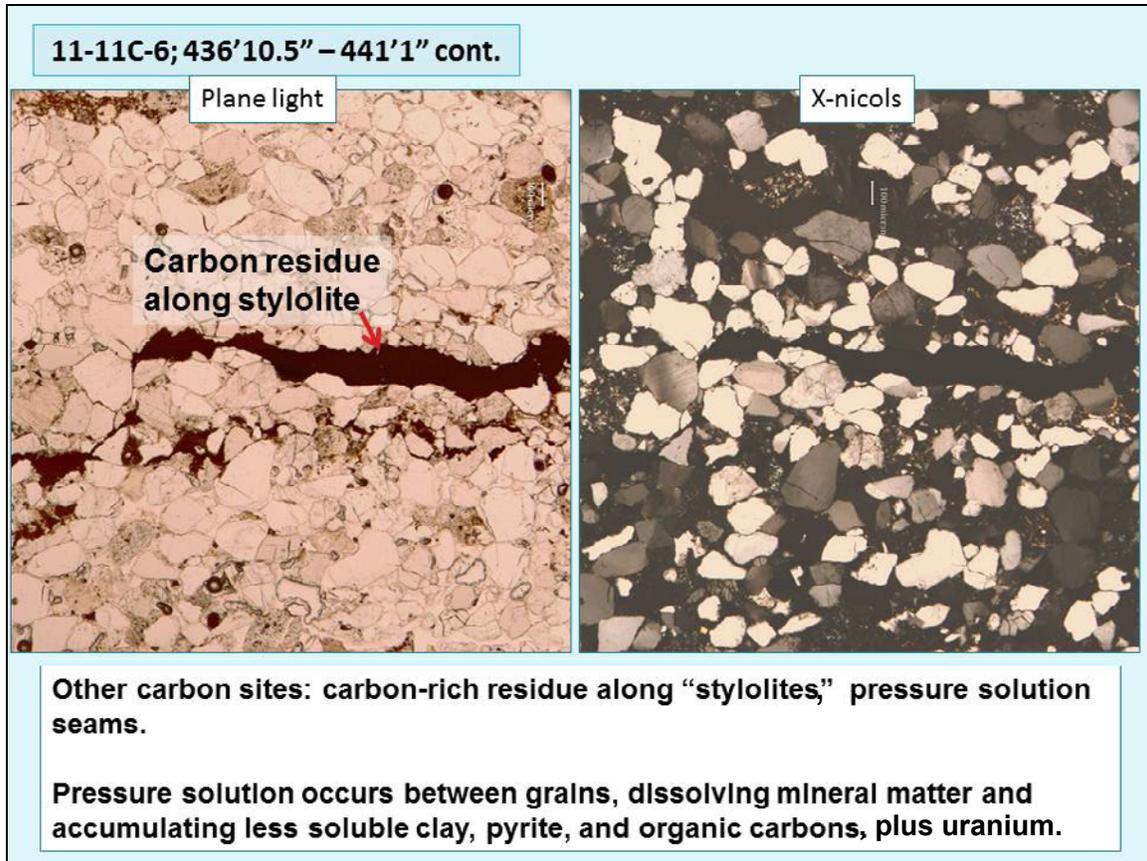
The following thin section micrographs are from the sample with the highest uranium reading, but note how much lower the U and V values are compared to Dewey (see slide #5).



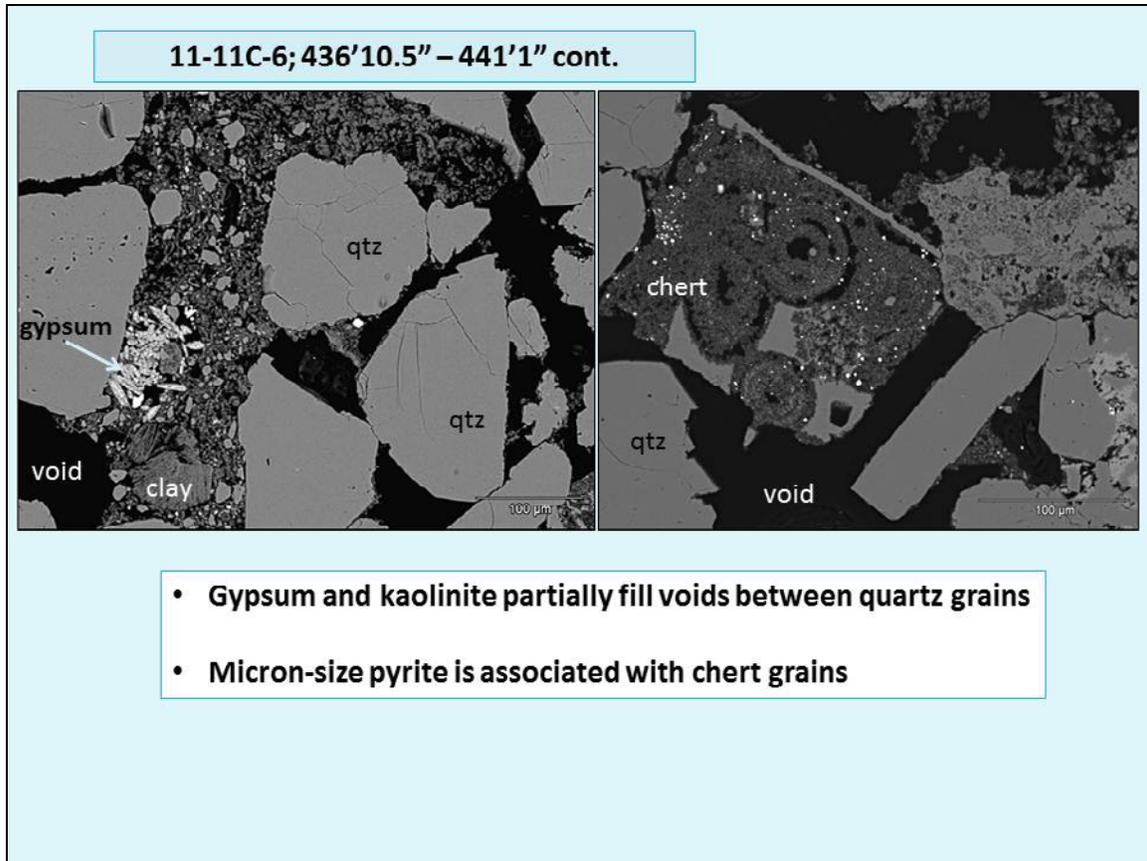
SEM micrograph showing a woody fragment between constituent quartz and chert grains. At the detection limits of the SEM, U associated with the woody fragment averaged about 1 wt. %. Discrete uranium and vanadium minerals were not seen as in the Dewey core.



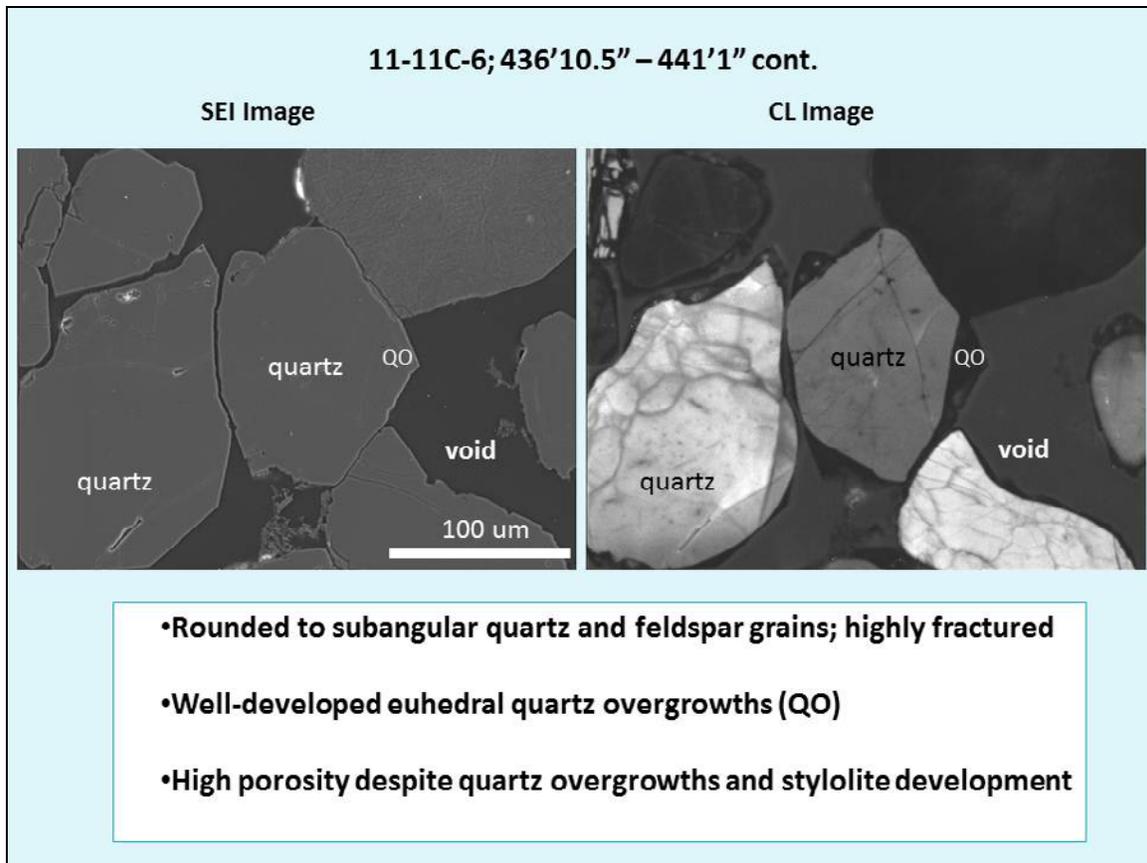
Close up of the remnant cell structure. Note the very high carbon peak from the wood fragment in the spectral image. U is adsorbed onto the carbon and no discrete uranium minerals were detected. Uranium content is usually around 1 wt. %, right at the detection limit of the SEM (low peaks of U in the spectrum).



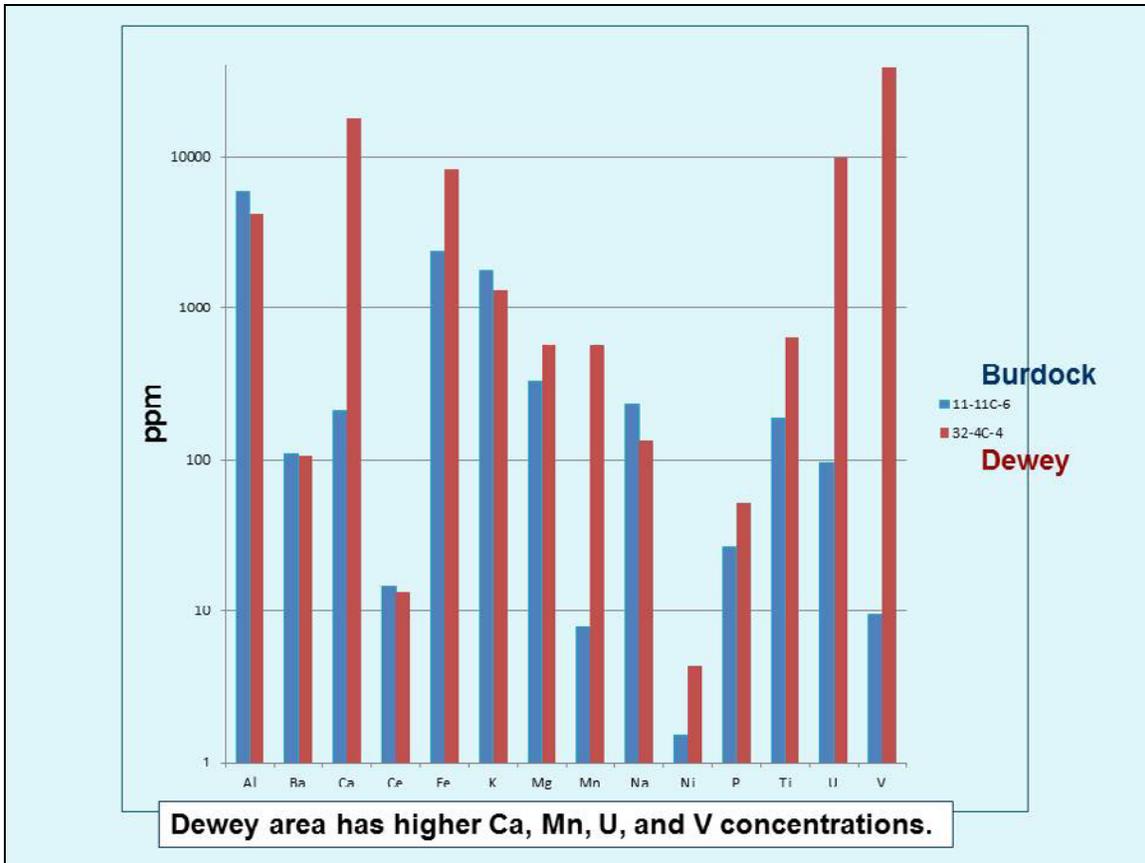
Stylolites, which are pressure solution seams, can locally concentrate organic matter, clays, and uranium. At the time of this presentation, uranium element maps of the carbon-rich residue on the electron microprobe were being obtained for subsequent presentations. U content is right at the detection limits of the SEM, so the addition of elemental maps from electron microprobe data can confirm the presence of U and V. Using a variety of microanalytical techniques helps to verify the presence of trace elements.



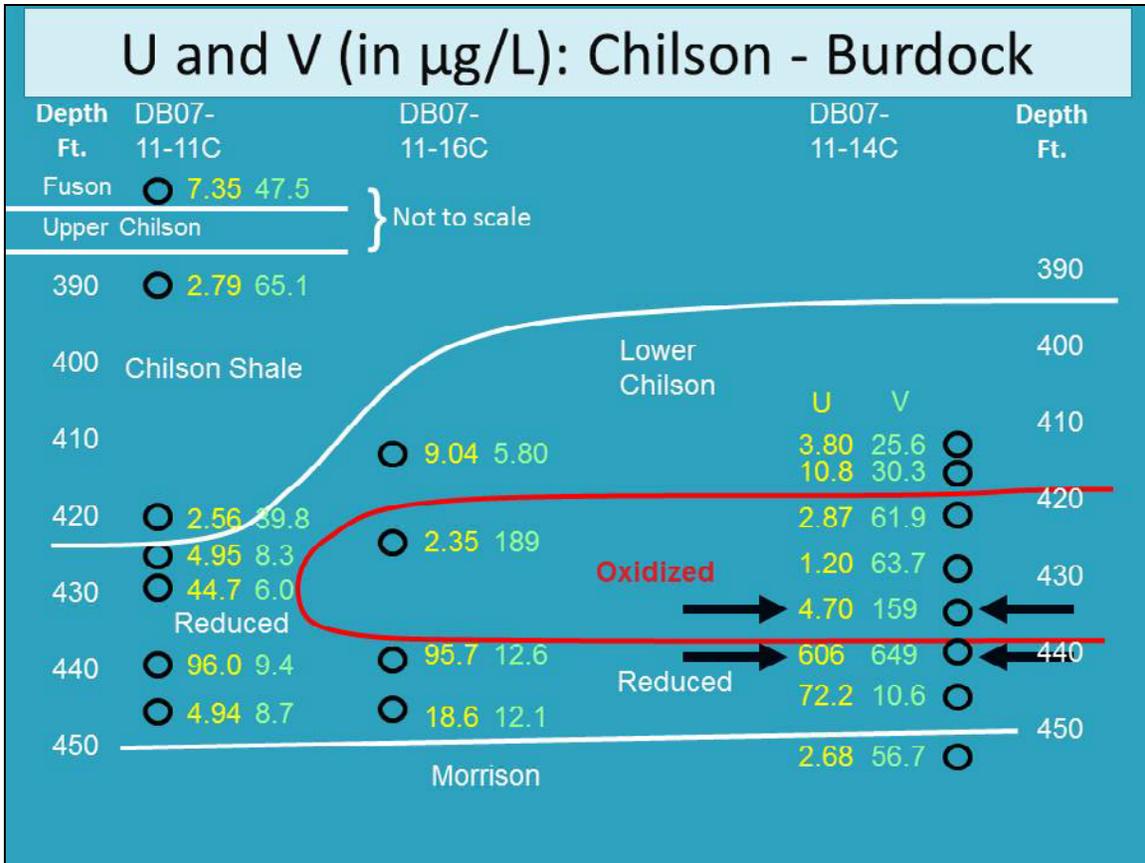
The medium gray elongated minerals in the matrix in the SEM micrograph to the left is gypsum. To the right, the bright spots are pyrite within chert. Note the organic forms in the chert, as silicified fossiliferous former carbonate grains are common, with the carbonate having been replaced by chert.



CL shows that quartz overgrowths (QO, nonluminescent) have grown into one another. Some of the internal microfracturing of grains may be inherited from source and transport, rather than compaction. Note the dark nonluminescent overgrowths in comparison to the core of the quartz grains = different chemistry. Note, especially, the pale radiation damage halos in the quartz grains are not observed, leading to the conclusion that different processes occurred in the Burdock cores than in the Dewey cores.

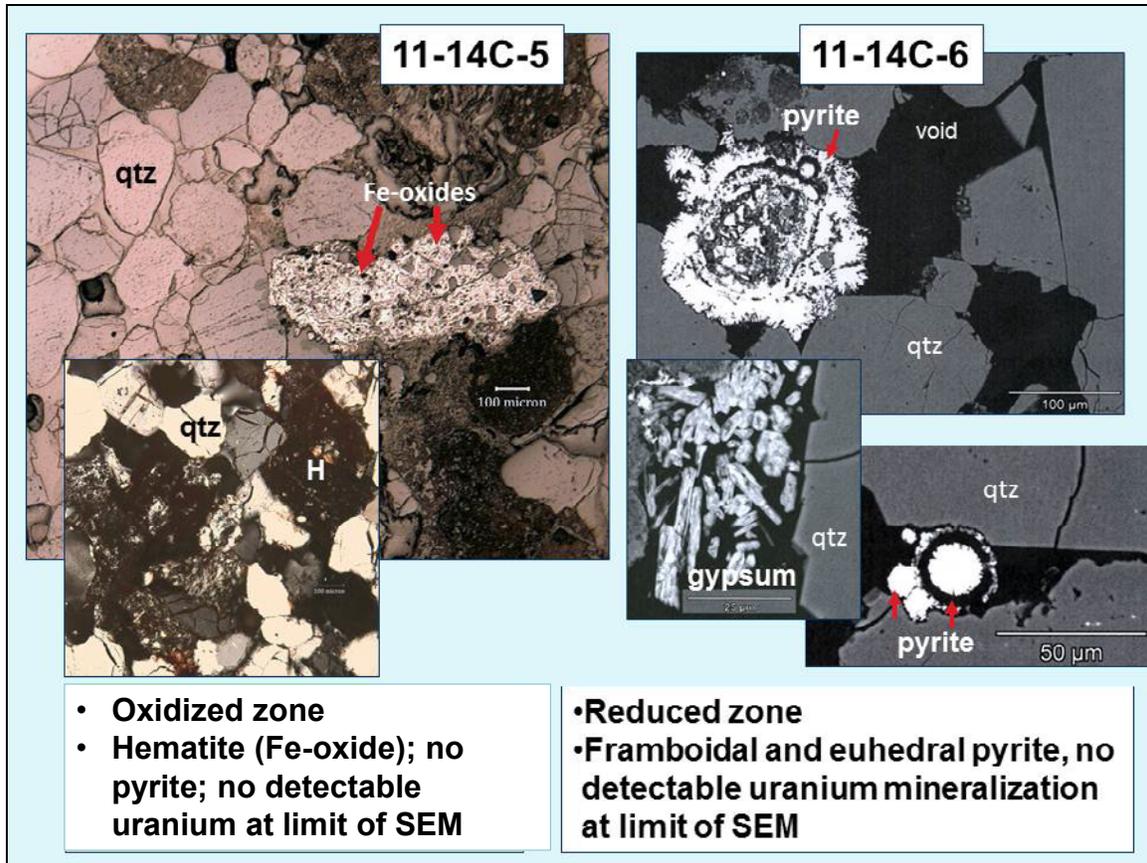


This plot shows inductively coupled plasma – mass spectrometry (ICP-MS) data. The Dewey samples were higher in Ca, Mn, U, and V than the Burdock samples. Ni sulfides were observed in coaly partings, which may account for the higher Ni content.



Lastly are a few slides from the limb of a roll front, from the oxidized zone into the reduced zone, to emphasize the change in mineralogy within several feet (see black arrows pointing to core sample depths).

Oxidized sample is 11-14C-5 and reduced sample is 11-14C-6.



To the left (top) is a reflected light photomicrograph of hematite; note the red Fe oxide staining in the clays in the transmitted light micrograph (left bottom). To the right, SEM images of pyrite and gypsum intergranular cements. These show the mineral difference between the reduced zone sample with pyrite (11-14C-6) and no detectable uranium at the limits of the SEM, compared to an oxidized zone sample (11-14C-5), where there is no pyrite, but there is hematite (an Fe-oxide) and no detectable uranium mineralization.

Summary

- **Mineralogy reflects typical controls on uranium roll front formation:**
 - oxidized zone: feldspars have altered to clays; secondary Fe-oxides precipitated; organic carbon has biodegraded.
 - redox front: pyrite, calcite cements, U, V mineralization.
- **Modeling uses mineralogy and XRD for quantitative values for sulfide content.**
- **Dewey vs. Burdock:**
 - Different mineralogy; e.g., Burdock area is chert-rich; has carbon- and clay-filled stylolites.
 - At Dewey, uranium is associated w/vanadium mineralization; pyrite and calcite cements.
 - At Burdock, uranium is associated w/organic carbon.
- **Thus far, based on mineral observations, modeled reactions are reasonable.**
- **Because of differences in mineralogy and uranium host sites, lab studies of possible reactions (beyond modeling) that use actual core material are important.**

In the Dewey cores (Fall River Formation), the extensive formation of stylolites was not observed as it was in the Burdock cores (Chilson Member of the Lakota Formation).