The Importance of Detrital Dolomite in Upper Devonian Carbonates: Examples from the Bakken/Three Forks Petroleum System (Williston Basin) and Dyer Formation (Northwest Colorado)*

Mark W. Longman[1] and Donna S. Anderson[1]

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[1]Denver, Colorado (mwlongman1@aol.com)

Abstract

Detrital dolomite in the rock record generally consists of tiny fragments of dolomite less than 100 microns in size that have been transported by wind and/or water. Grains of detrital dolomite have been widely recognized as small crystal fragments in marine sandstones across the Rocky Mountain region, but similar grains can form relatively pure carbonate beds such as some of those in the Upper Devonian Dyer, Three Forks, and Bakken formations. Recognition of these detrital dolomites is based on sedimentary structures such as scours, ripple and small-scale hummocky crossbeds, injectites, and soft-sediment deformation features (microfaults, fluidized beds, flame structures, etc.) formed in the dolomite fragments. Other clues include grain size relationships with non-dolomite detrital grains (e.g., quartz silt), and petrographic textures that commonly include inclusion-rich (cloudy) abraded dolomite crystal fragments encased in clearer authigenic rhombic overgrowths. Recognizing detrital dolomite is important not only in creating an accurate depositional and diagenetic history, but also in understanding carbon and oxygen isotope data, which may be misleading if the reworked nature of the detrital dolomite grains is unrecognized.

The Late Devonian in the Rocky Mountains was a particularly good time for forming widespread detrital dolomites because many of the subtle paleohighs surrounding the depositional basins were capped by older Paleozoic dolomites. Around the Williston Basin, these older dolomites occur in the Red River, Interlake, Winnipegosis, and Duperow formations. An arid climate led to common dust storms rich in silt-sized dolomite crystal fragments with the silt subsequently reworked in water. Similar detrital dolomite crystal fragments are also found in the black shales of the Bakken Formation. Once deposited and buried, these detrital dolomite crystal fragments were nuclei for syntaxial overgrowths, many of which are ferroan, and formed under reducing conditions during burial.

References Cited

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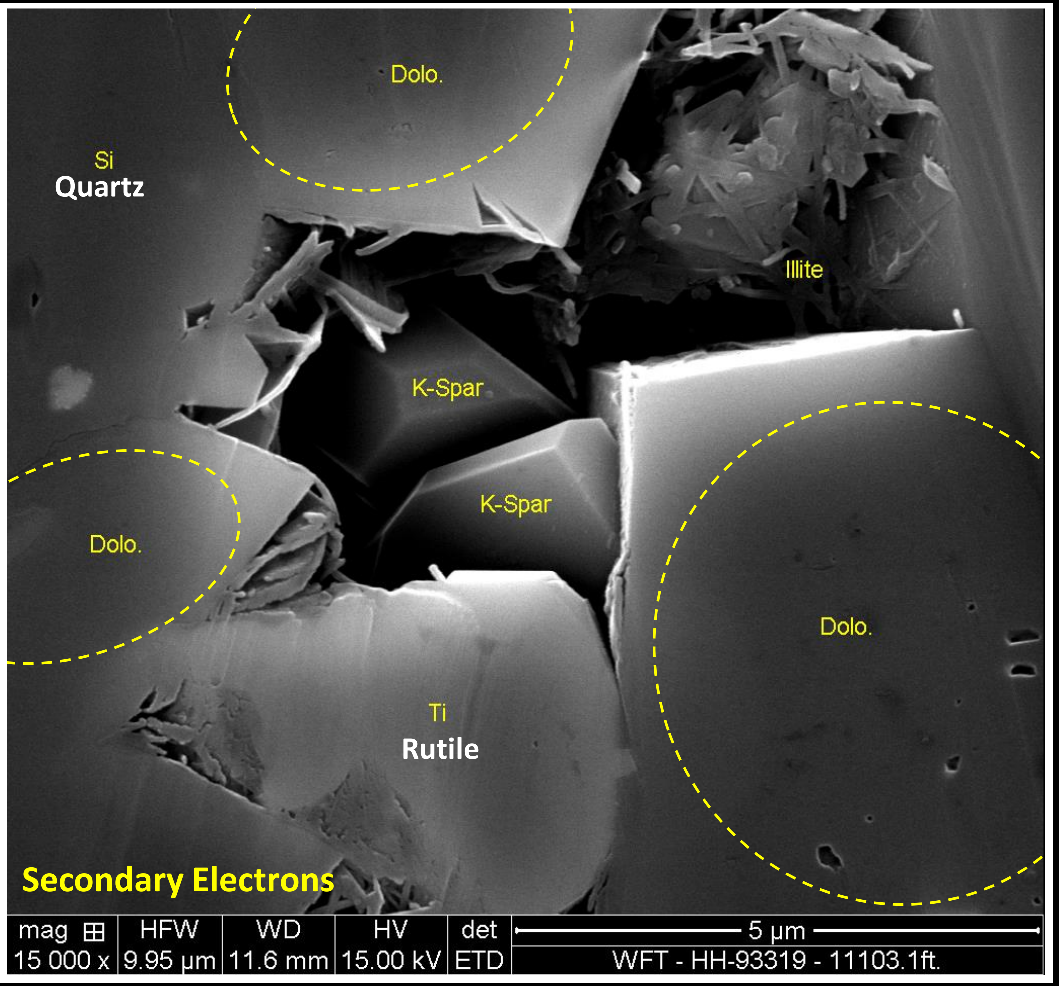
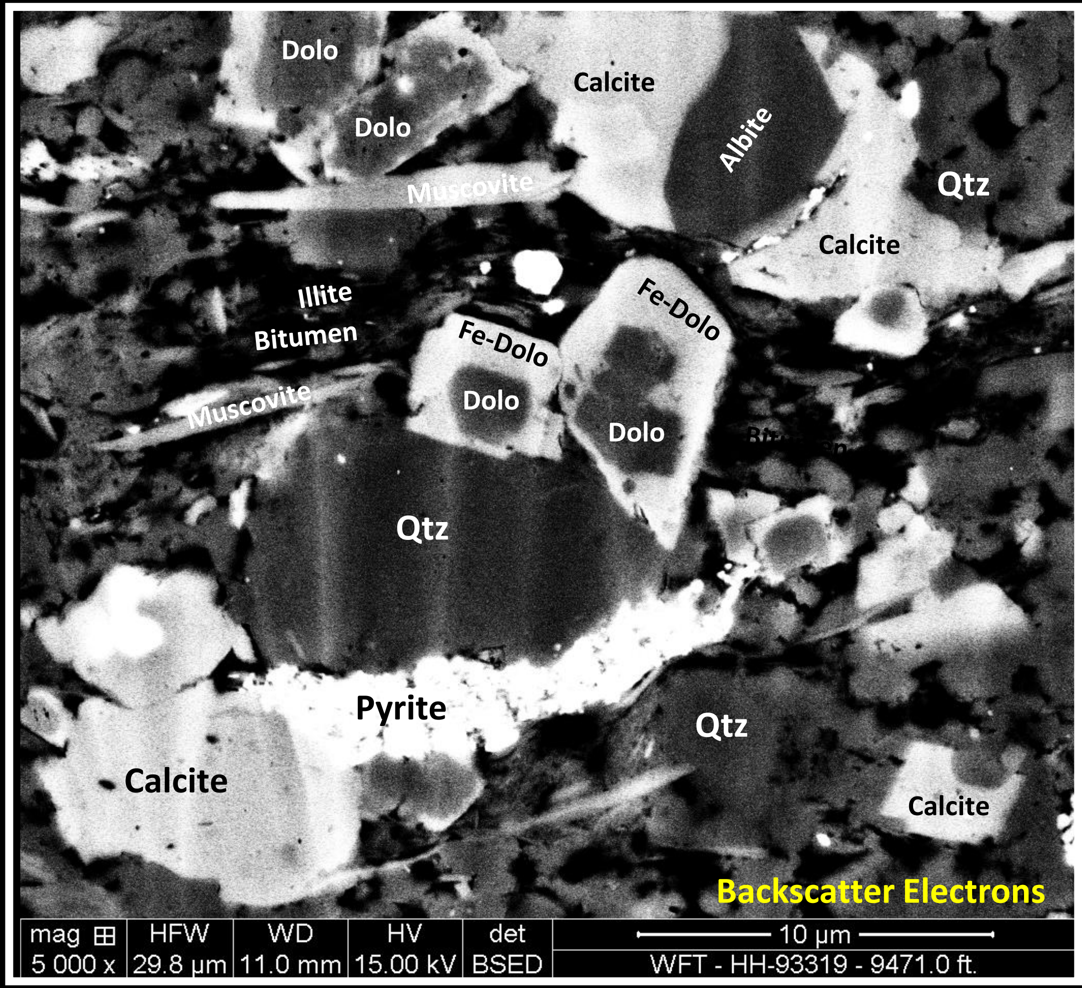
Skinner, O., L. Canter, M. Sonnenfield, and M. Williams, 2012, Discovery of "Pronghorn" and "Lewis and Clark" Fields: Sweet-Spots within the Bakken Petroleum System Producing from the Sanish/Pronghorn Member NOT the Middle Bakken or Three Forks!: Discovery Thinking talk given by Orion Skinner at AAPG Annual Convention and Exhibition in Long Beach, California, April 22-25, 2012.

The Importance of Detrital Dolomite in Upper Devonian Carbonates: Examples from the Bakken/Three Forks Petroleum System (Williston Basin) and Dyer Formation (Northwest Colorado)



Upper Devonian Three Forks Fm., First Bench, Ernie 7-2-11, 11,103.1 ft



Lower Permian Spraberry Shale, University 7-27 #9, 9471 ft

Mark Longman and Donna Anderson, Denver, Colorado

RMS-AAPG Meeting, Cheyenne, Wyoming, September 16-17, 2019

Definition of Detrital Dolomite: Dolomite fragments derived and transported from pre-existing dolomite-containing sediments or rocks

Transport Mechanisms: Generally Wind and Water, but also glaciers and debris flows

Grain Size: Mostly Medium Silt to Very Fine Sand (30 to 100 microns)

Chemically Stable in Normal to Hypersaline Sea Water; Somewhat Unstable in Fresh Water

Ages: Precambrian to Recent Peaking in Siluro-Devonian before most Land Plants

Particularly Common in Arid Settings with Eolian Abrasion and Grain Transport

Synonyms: Clastic Dolomite, Terrigenous Dolomite, Allochthonous Dolomite

Tools and Techniques for Recognizing Detrital Dolomite Grains

In Cores and Outcrops: Understanding of the Sedimentary Structures that indicate Current Transport of Sedimentary Dolomite Grains

In Thin Sections: Look for Dolomite Grains with Cloudy or Inclusion-Rich Centers and “Cleaner” Euhedral Overgrowths (but this is not always definitive)

Know that Detrital Dolomite Grains are Commonly Silt-Sized (25-60 Microns)

Detrital Dolomite Commonly Occurs with Detrital Quartz Silt Grains of Similar Size

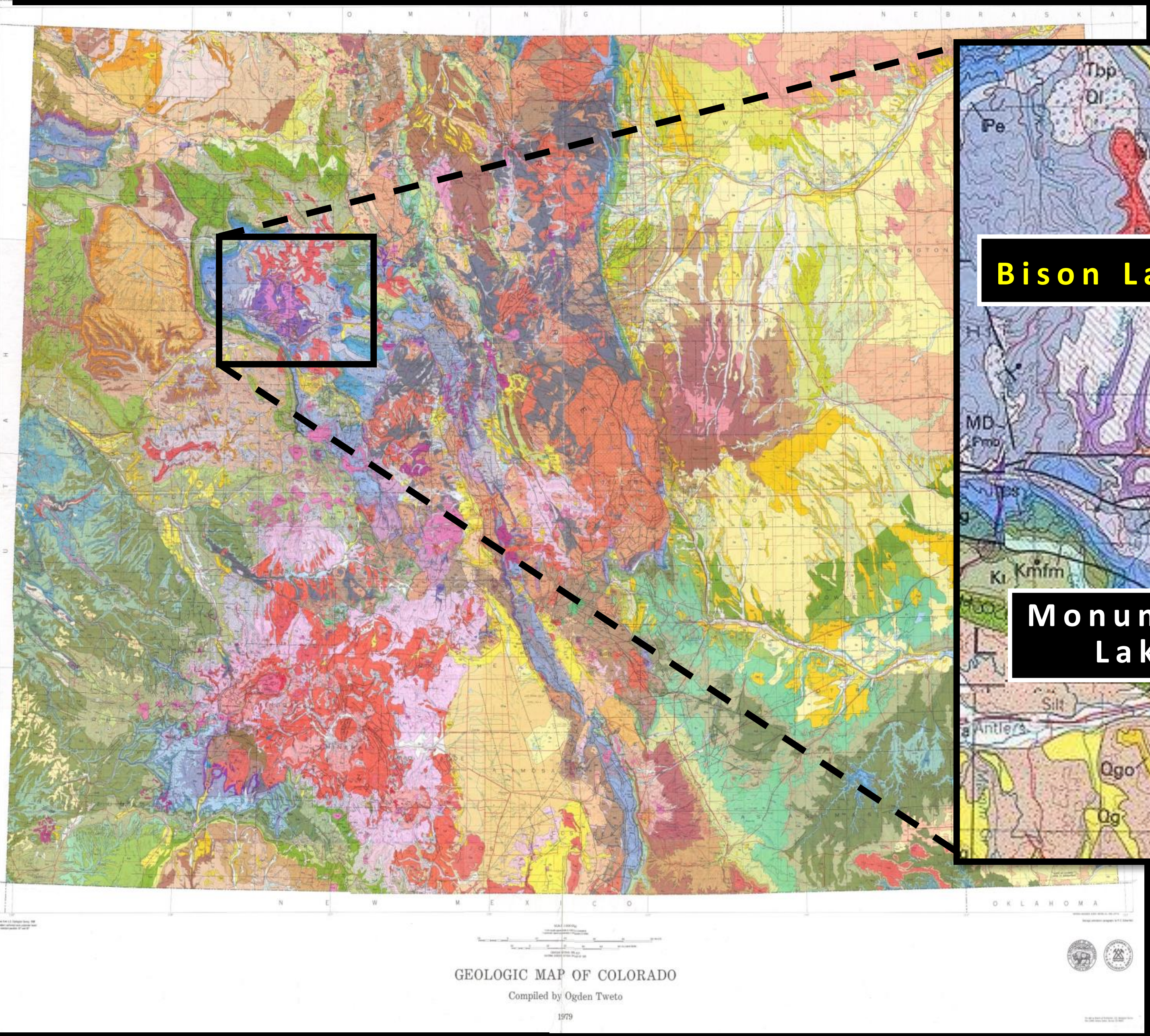
With the SEM, particularly with Ar-Ion-Milled Samples, Detrital Dolomite Grains are generally Non-Ferroan, but the Dolomite Overgrowths are Ferroan

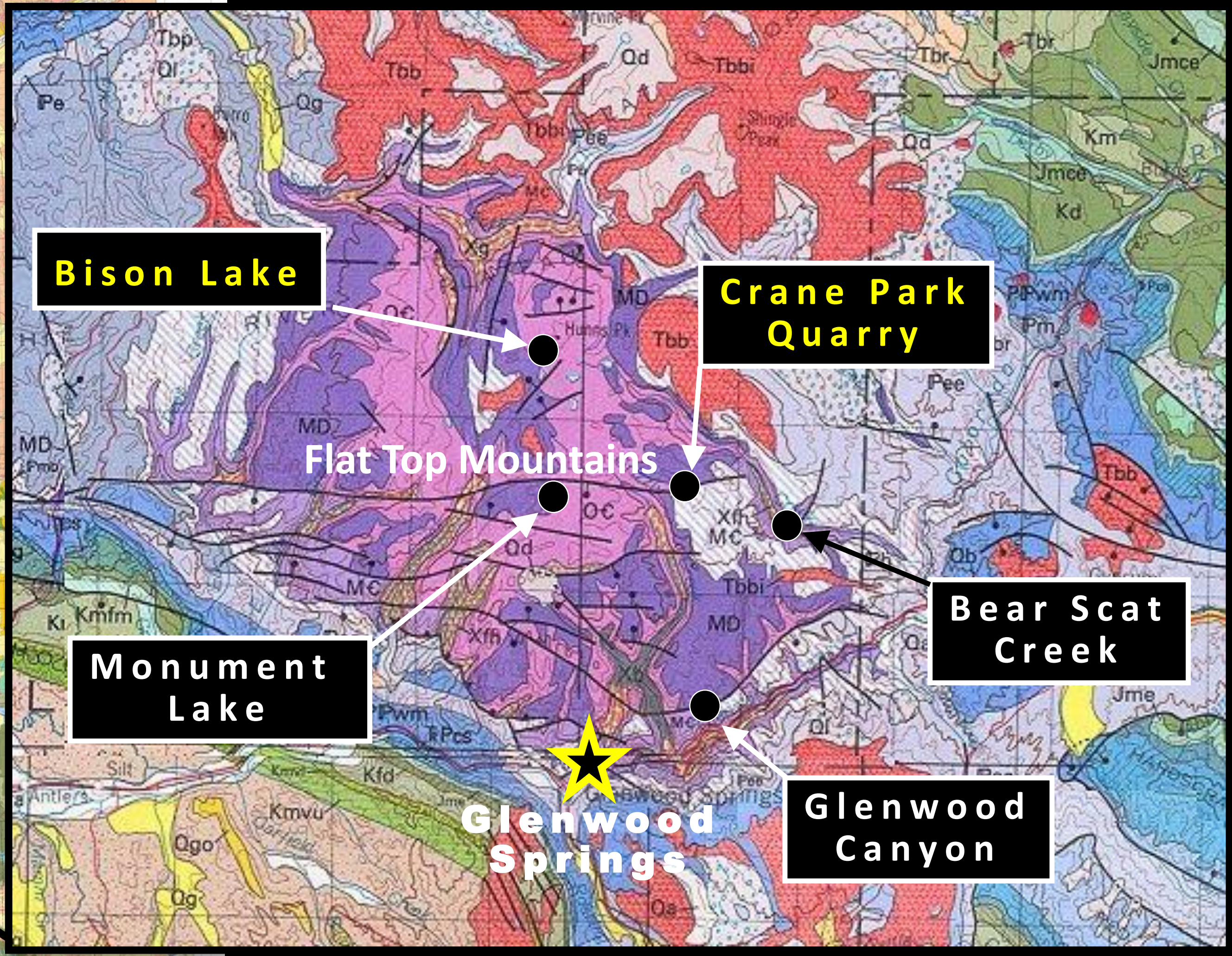
Know that Detrital Dolomite Grains are Common, Particulary in mid-Paleozoic Rocks. We tend to see what we look for!

So let's look at the Upper Devonian Dyer Formation in the Flat Top Mountains of Northwestern Colorado

Our First Example of Detrital Dolomites

Location of Measured Sections of the Upper Devonian Dyer Formation's Coffee Pot Member

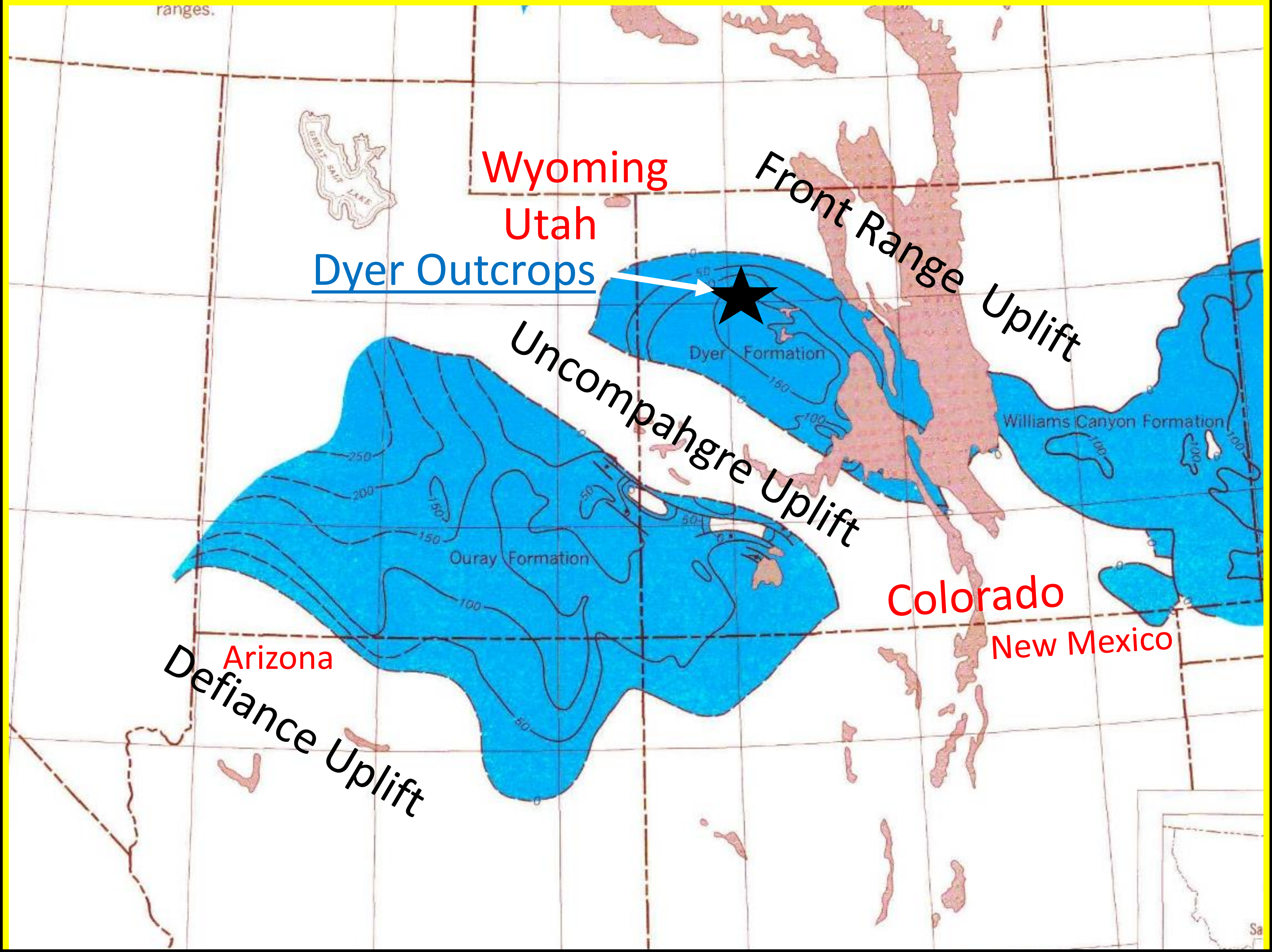




Outcrops are above 10,000 ft so the field season is short

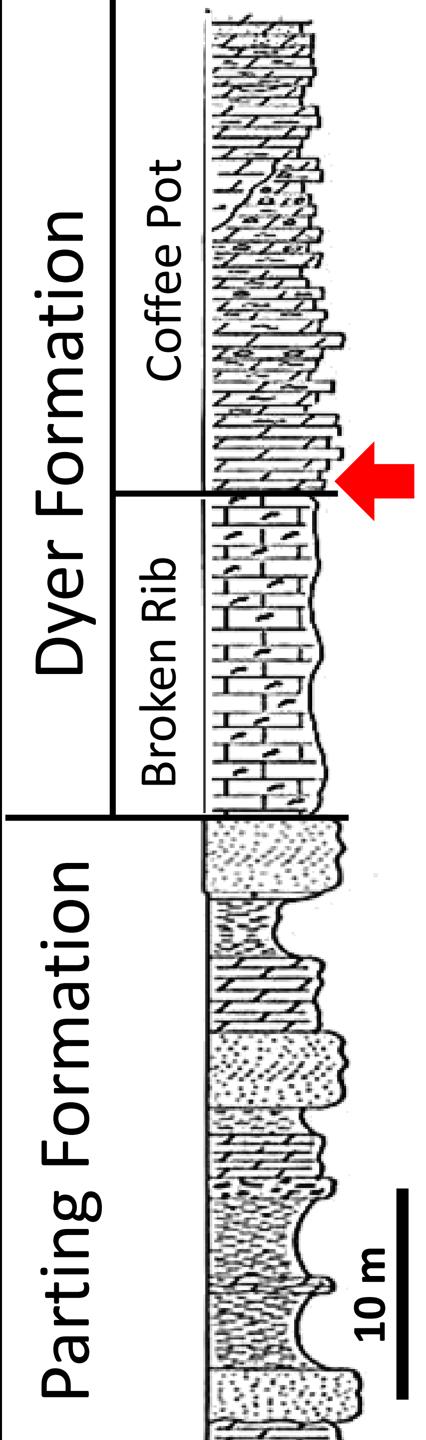
Bear Scat Creek Section

Isochore Map of the Upper Devonian (Fammenian) Dyer and Ouray Formations



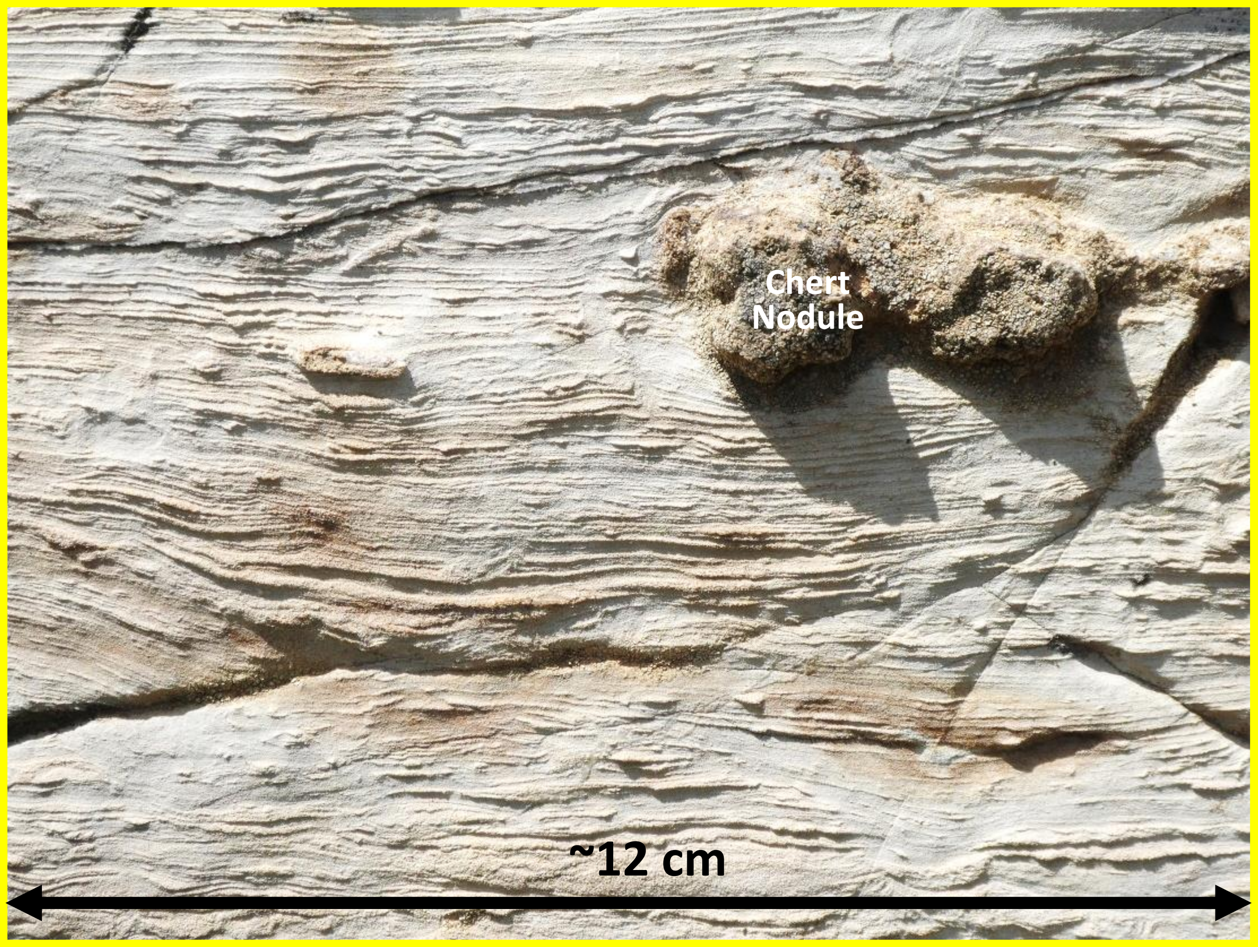
Adapted from Baars (1972), RMAG "Big Red Book," p. 97

Bison Lake Outcrop: Detrital Dolomite Siltstone, Basal Coffee Pot Member

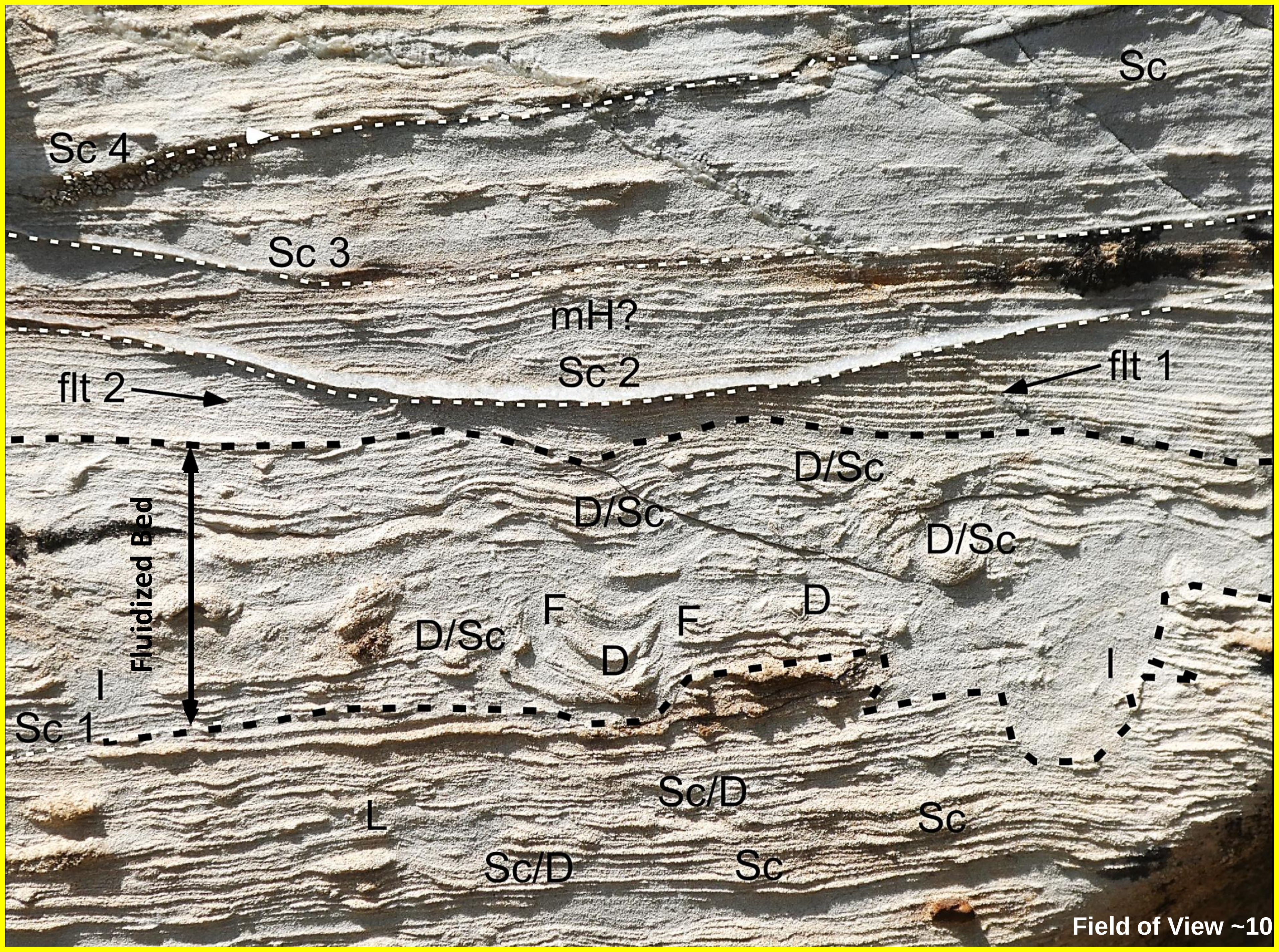


Bison Lake Outcrop: Dyer Fm.: Base of Coffee Pot Member

Detrital Dolomite Siltstones with about 98% Dolomite & 2% Quartz Silt



The abundance and size hierarchy of scours suggests high-velocity flows. The abundance and distribution of soft-sediment deformation features suggests high pore pressures during and shortly after deposition. The co-occurrence of scours and soft-sediment deformation suggests a genetic link between the two types of sedimentary features.



Basal Coffee Pot:
~98% detrital dolomite silt grains; 2% quartz silt grains

LEGEND

Sc 1, 2, 3 = "Large" Scours

Sc = Small Scours

Sc/D = Scour and Deformation features

D = "Droplets," Disturbed bedding, possibly small scours

Flt 1, 2 = Synsedimentary faults

mH = Microhummocks?

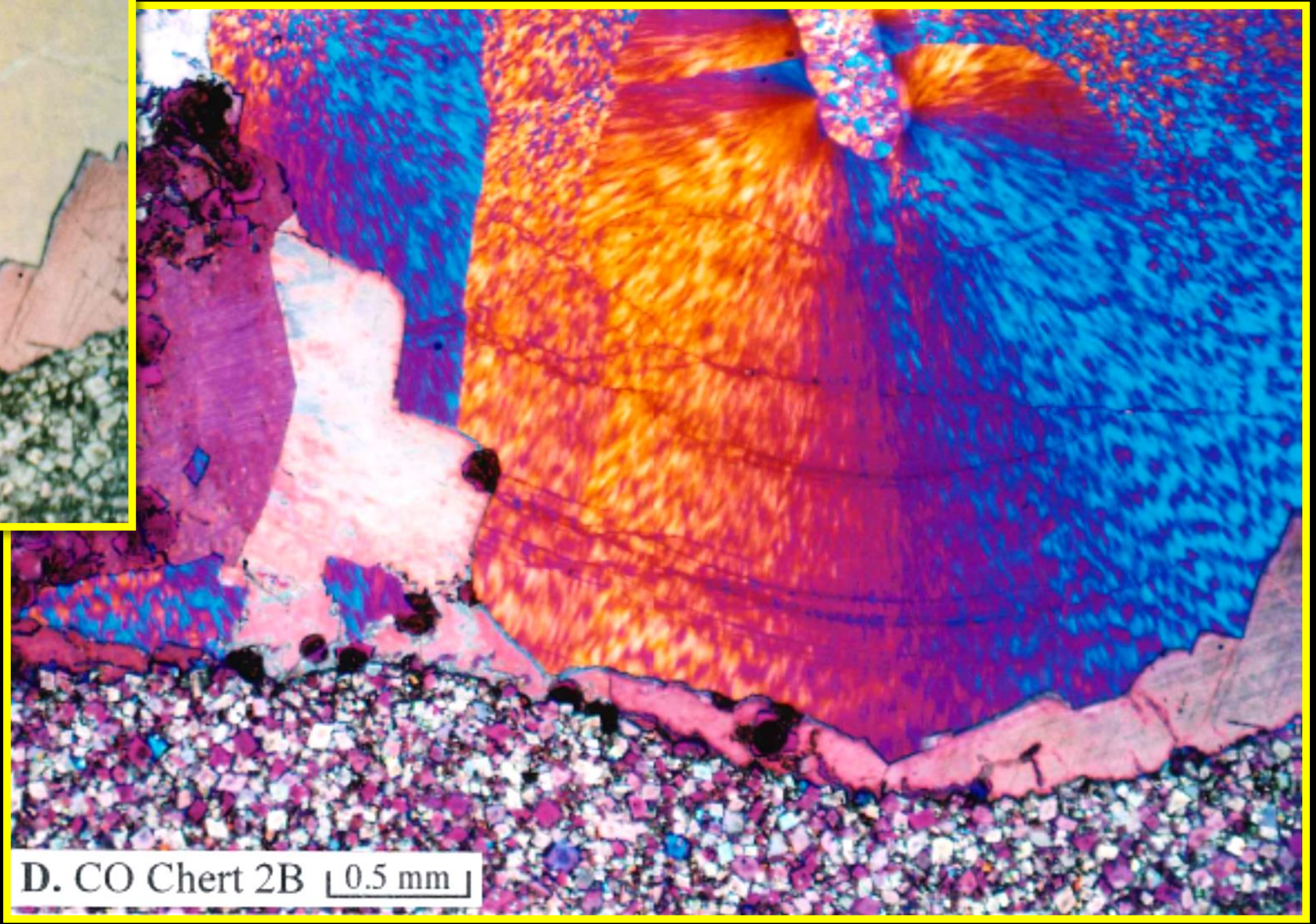
I = Injection features

F = Flame structures

Conclusion: Storm-dominated tidal flat to shallow lagoon with sporadic supercritical flow regime

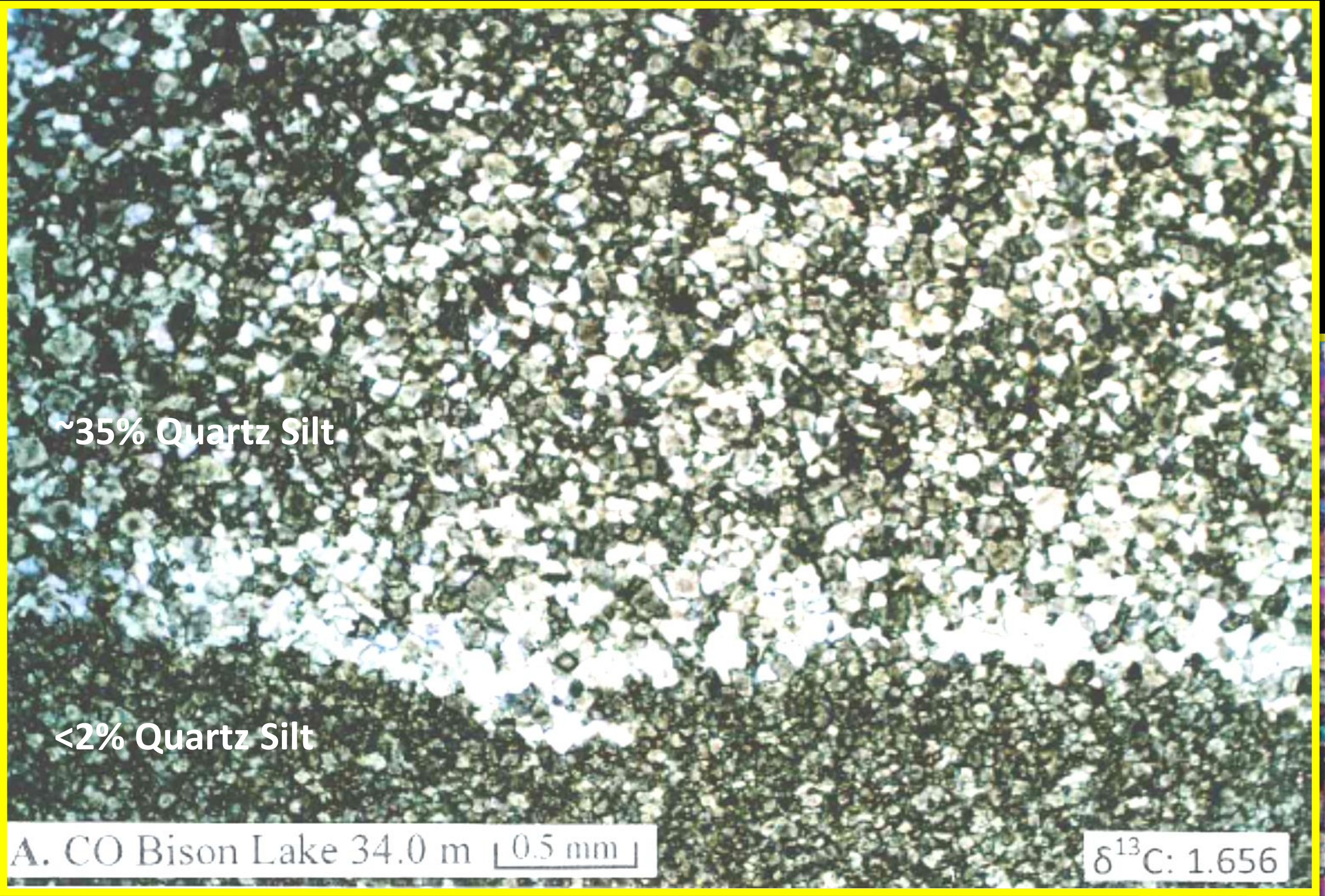
Photomicrographs of Chalcedony (Chert) in Basal Coffee Pot Detrital Dolomite Siltstone

Nodule of length-fast zebraic chalcedony and equant calcite with hematite patches (black) in a matrix of finely crystalline detrital dolomite

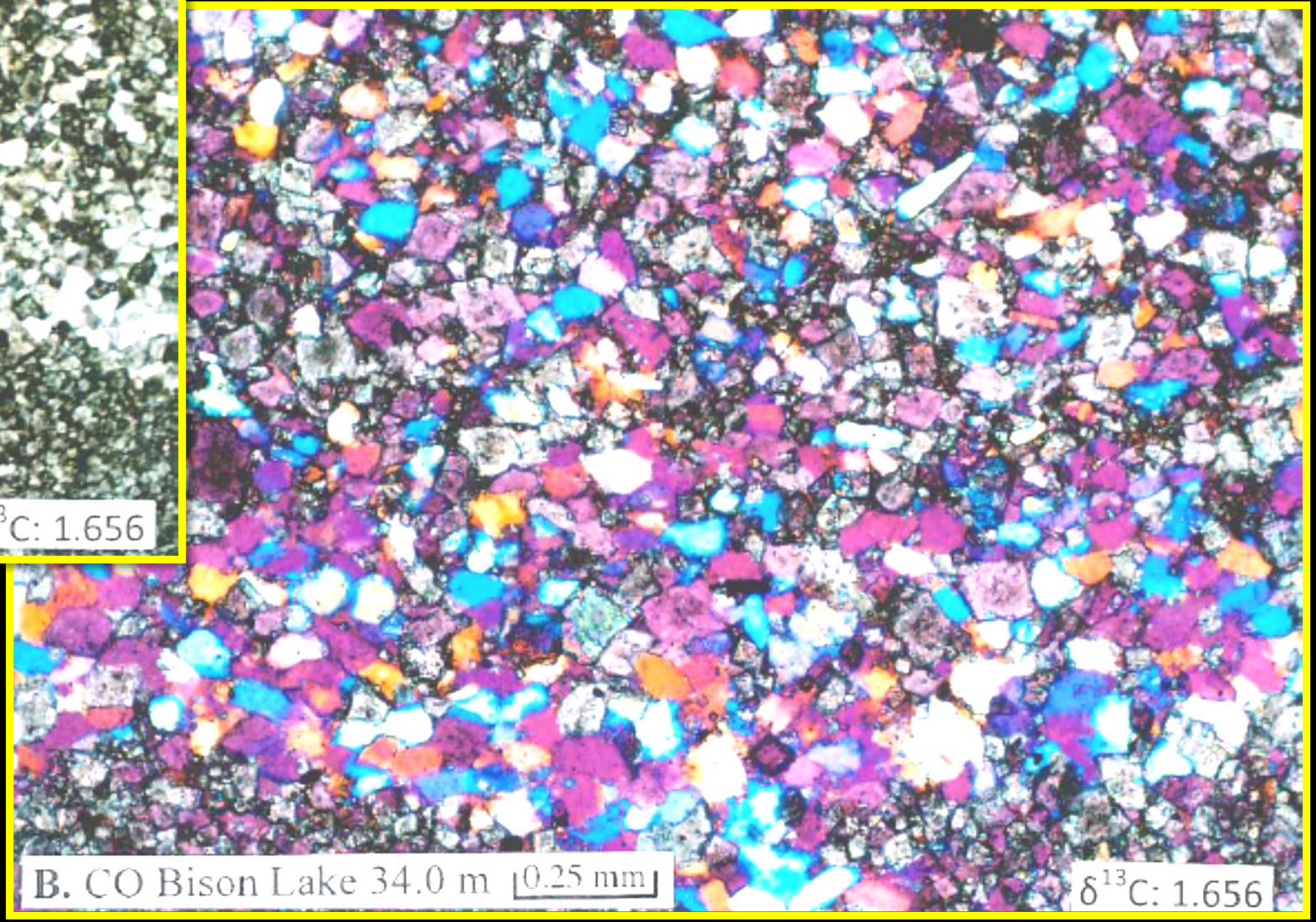


Same photo taken with crossed polarized light and a gypsum plate to show radiating fans of length-fast chalcedony in fine dolomite

Photomicrographs of Basal Coffee Pot Detrital Dolomite Siltstones

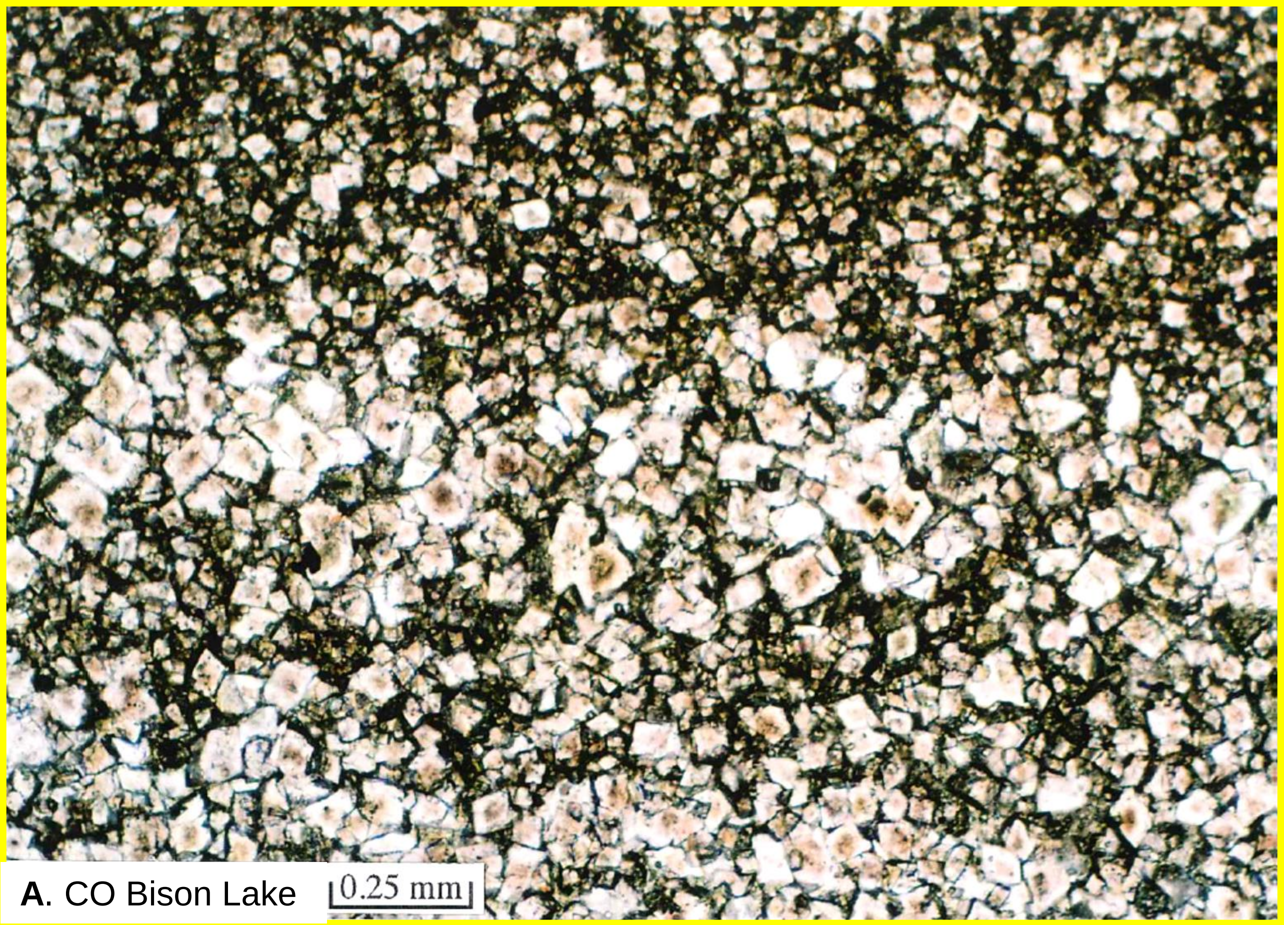


Current-sorted grains of quartz silt and detrital dolomite with cloudy centers and rhombic overgrowths of "cleaner" dolomite (top) above scour into bed of 30-40 micron detrital dolomite

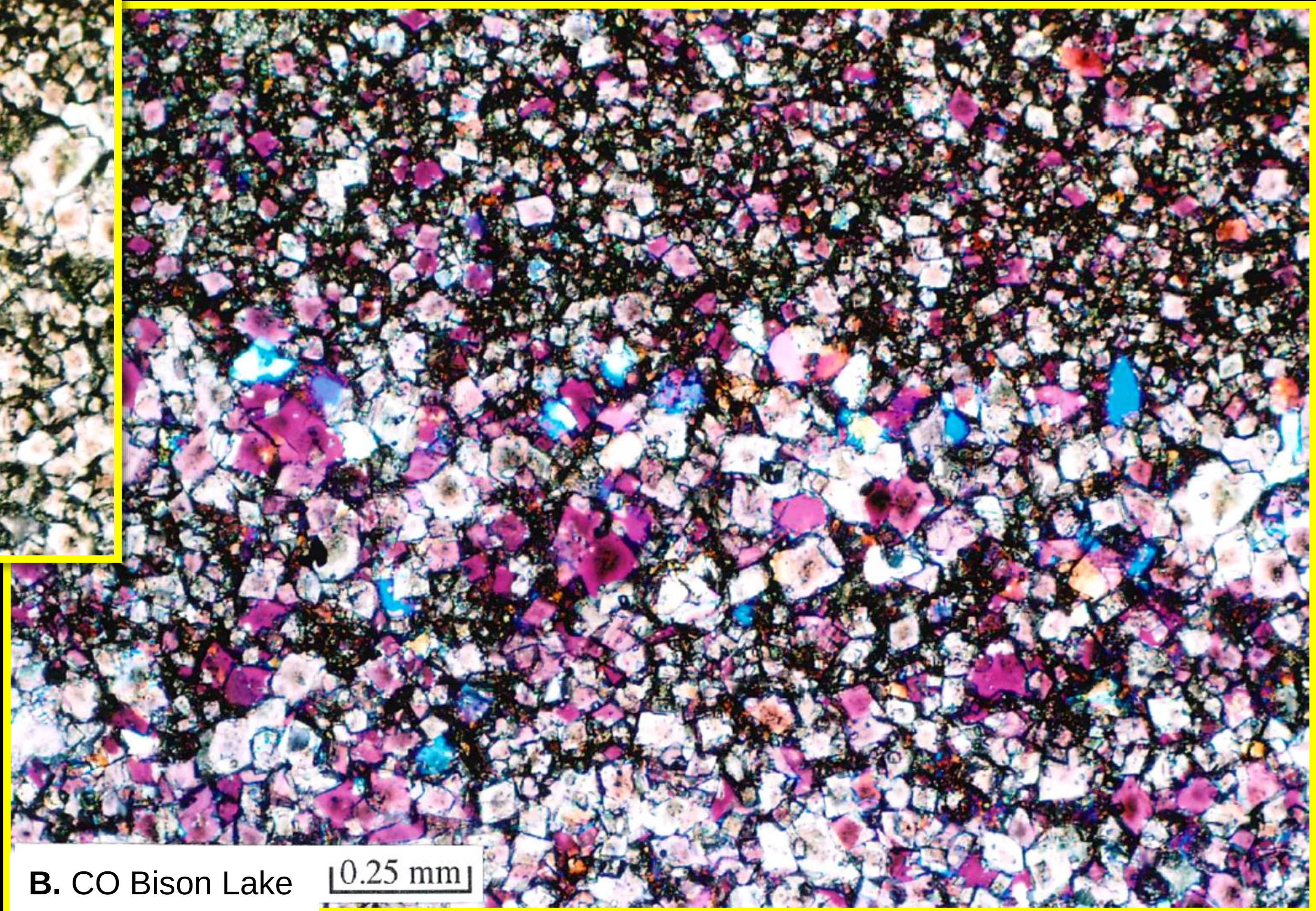


Same field of view taken with crossed polarized light and a gypsum plate to show the common grains of quartz silt (blue, yellow, orange) about the same size is the detrital dolomite nuclei

Photomicrographs of Basal Coffee Pot Detrital Dolomite Siltstones

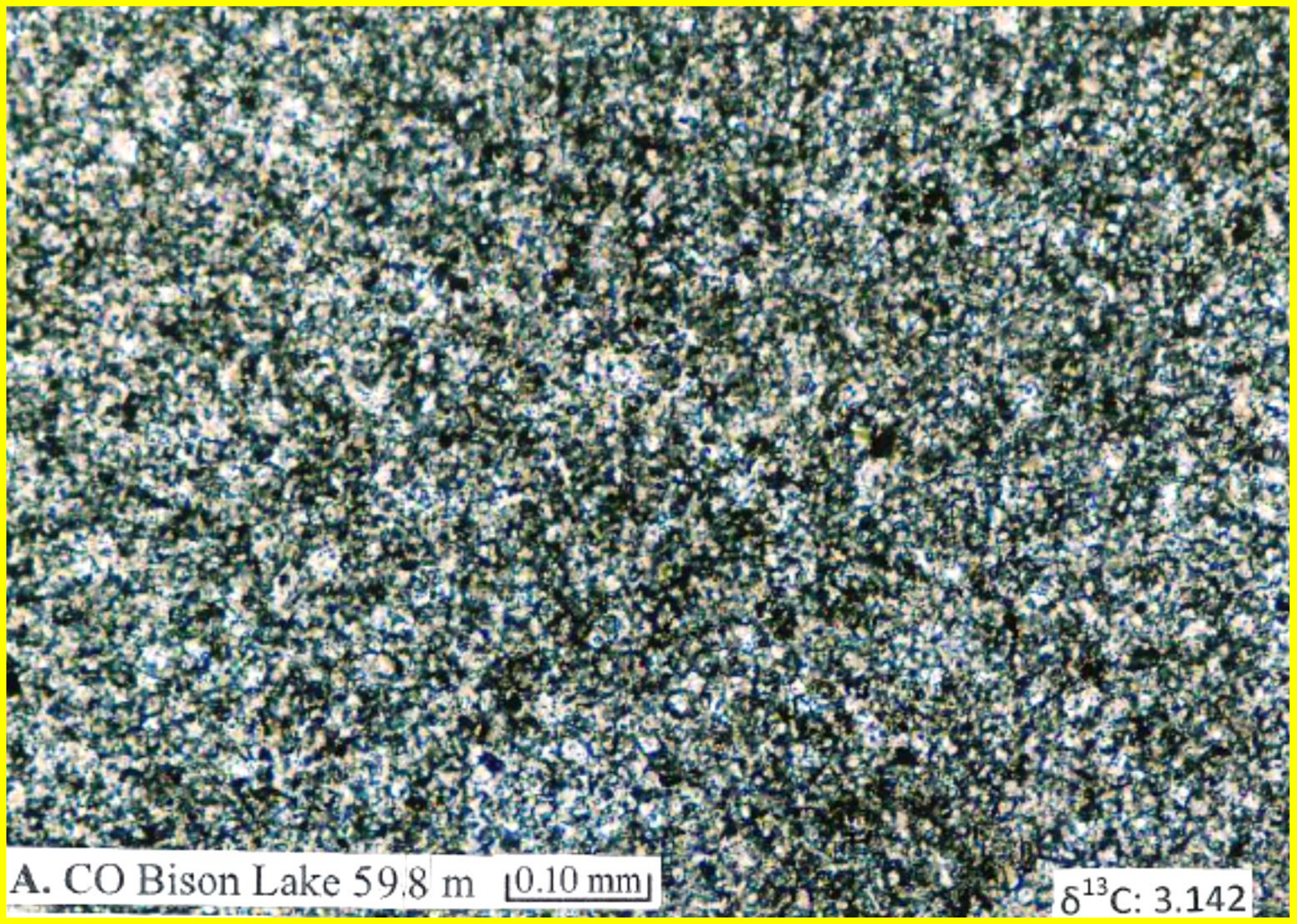


Current-sorted detrital dolomite grains of various sizes (note cloudy centers) with ~3% detrital quartz silt. Note euhedral rhombic overgrowths of "cleaner" dolomite



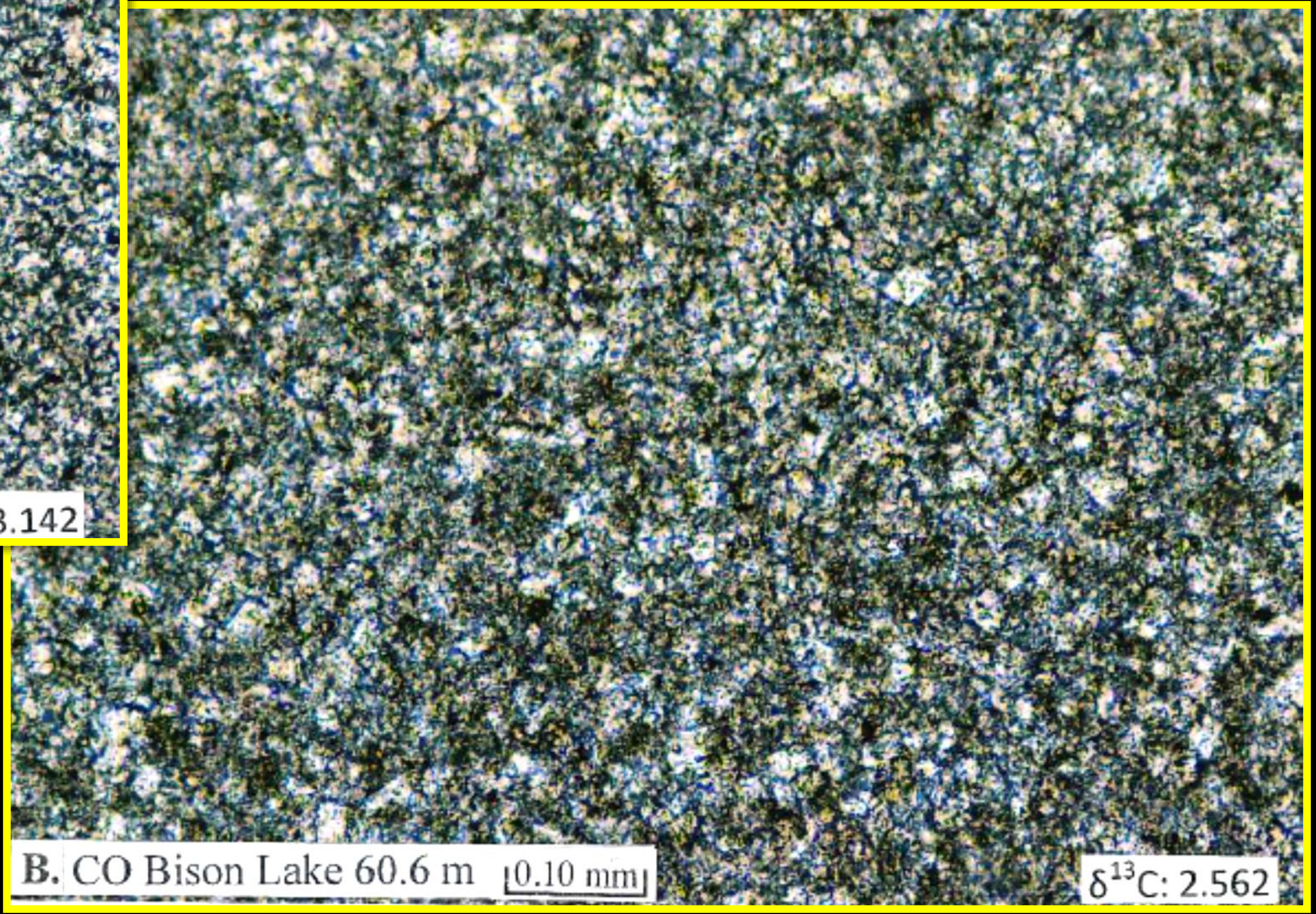
Same field of view taken with crossed polarized light and a gypsum plate to show the sparse quartz silt grains (blue, yellow) roughly the same size is the detrital dolomite nuclei

Photomicrographs of Upper Coffee Pot Detrital Dolomite Siltstones

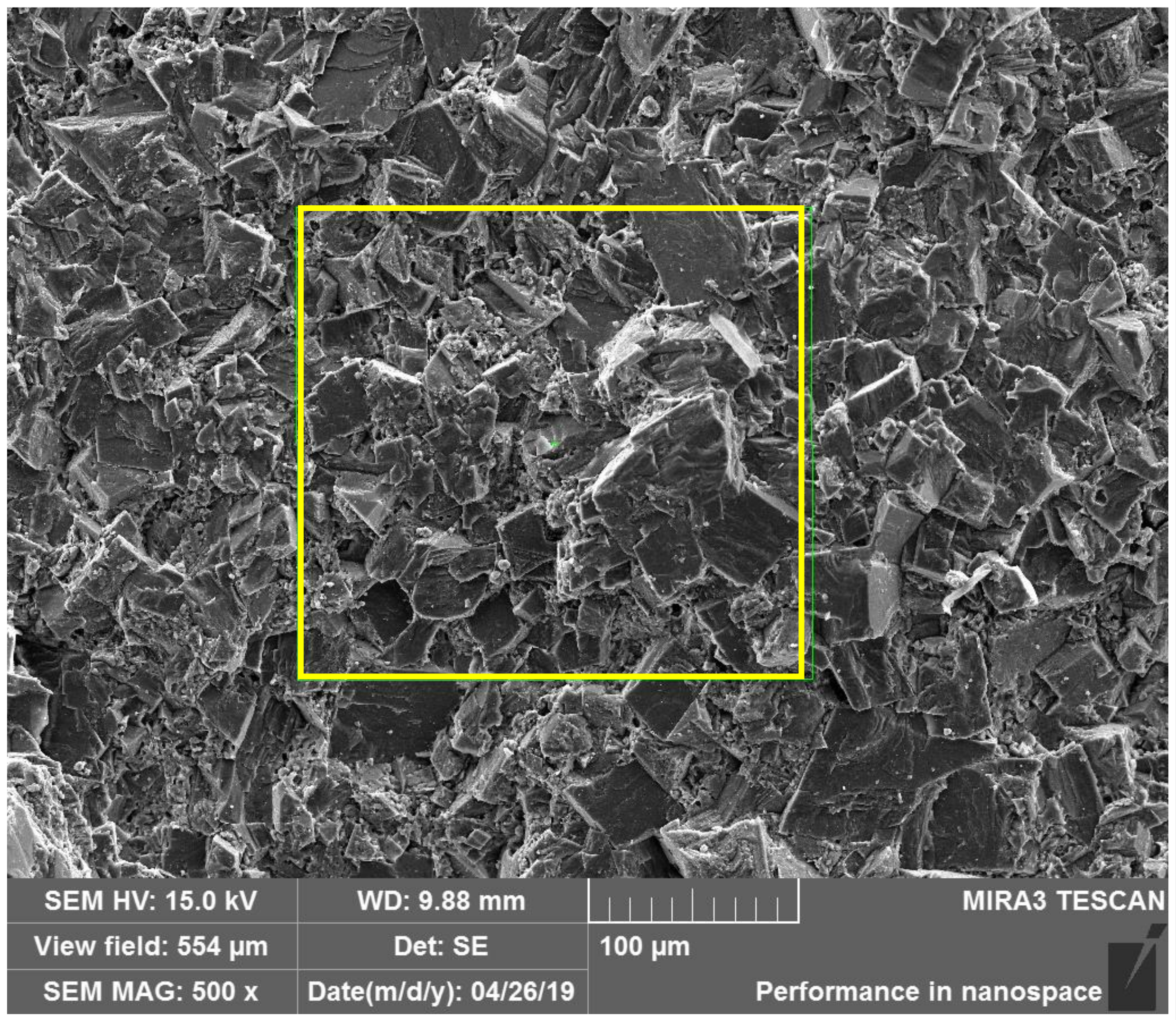


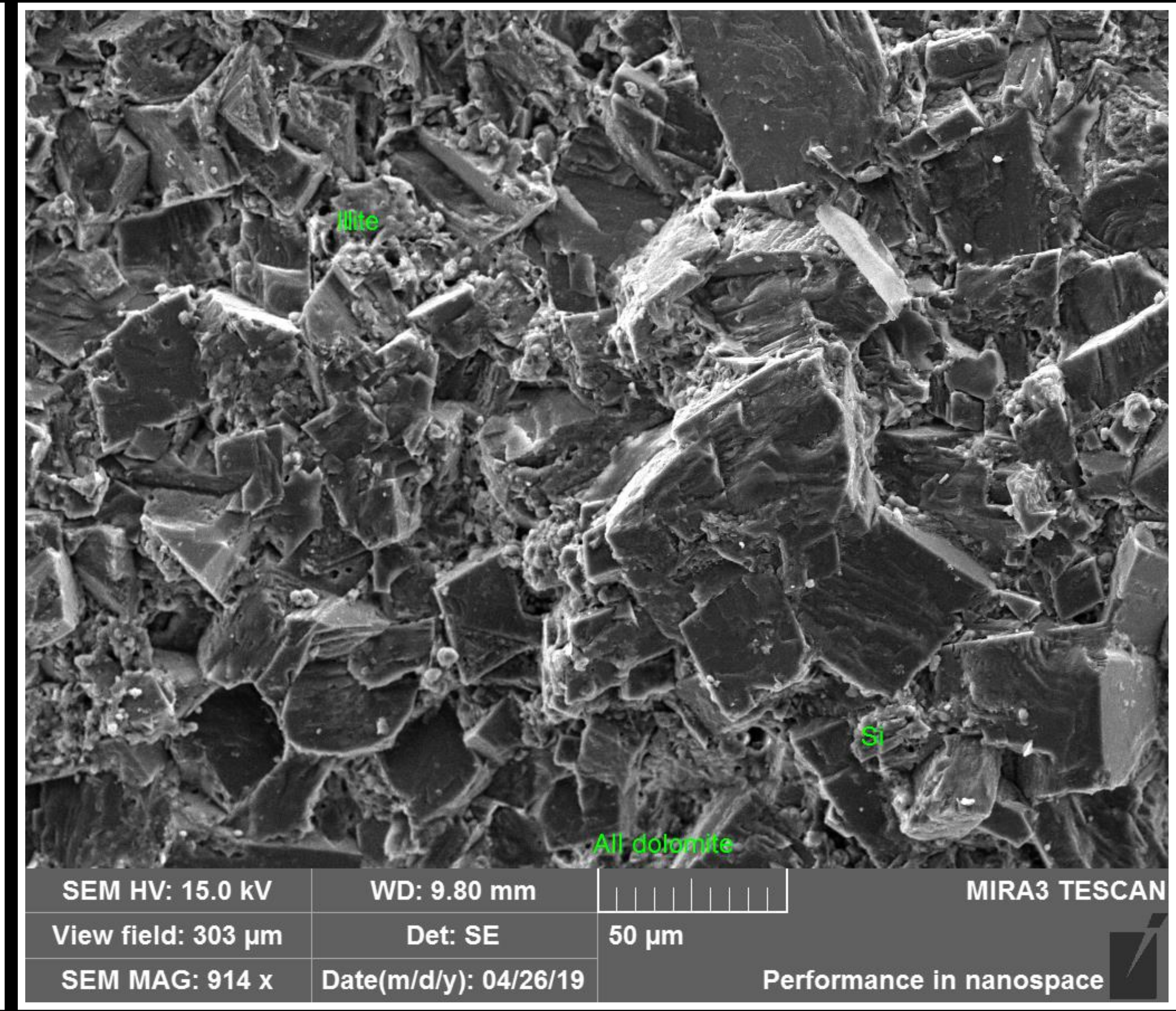
Current-transported grains of detrital dolomite with cloudy centers 15 to 30 microns in size & some overgrowths of "cleaner" dolomite

Another sample 0.8 m higher in the section showing similar detrital dolomite silt grains 15 to 30 microns in size.



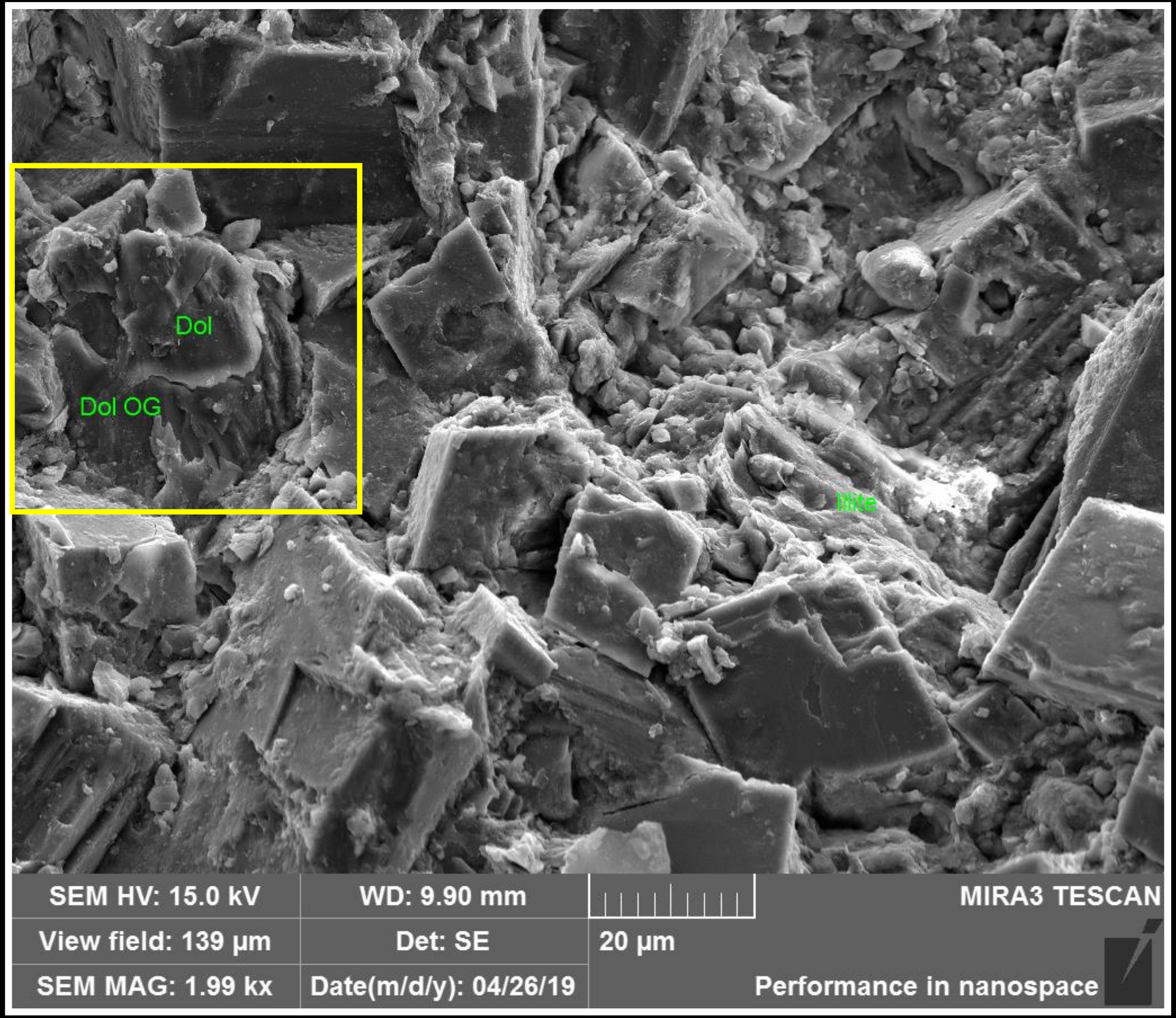
CO-Bison Lake-34.0 m: Basal Coffee Pot Dolomite Mudstone with Small Patches of Illite and Rare Quartz Silt





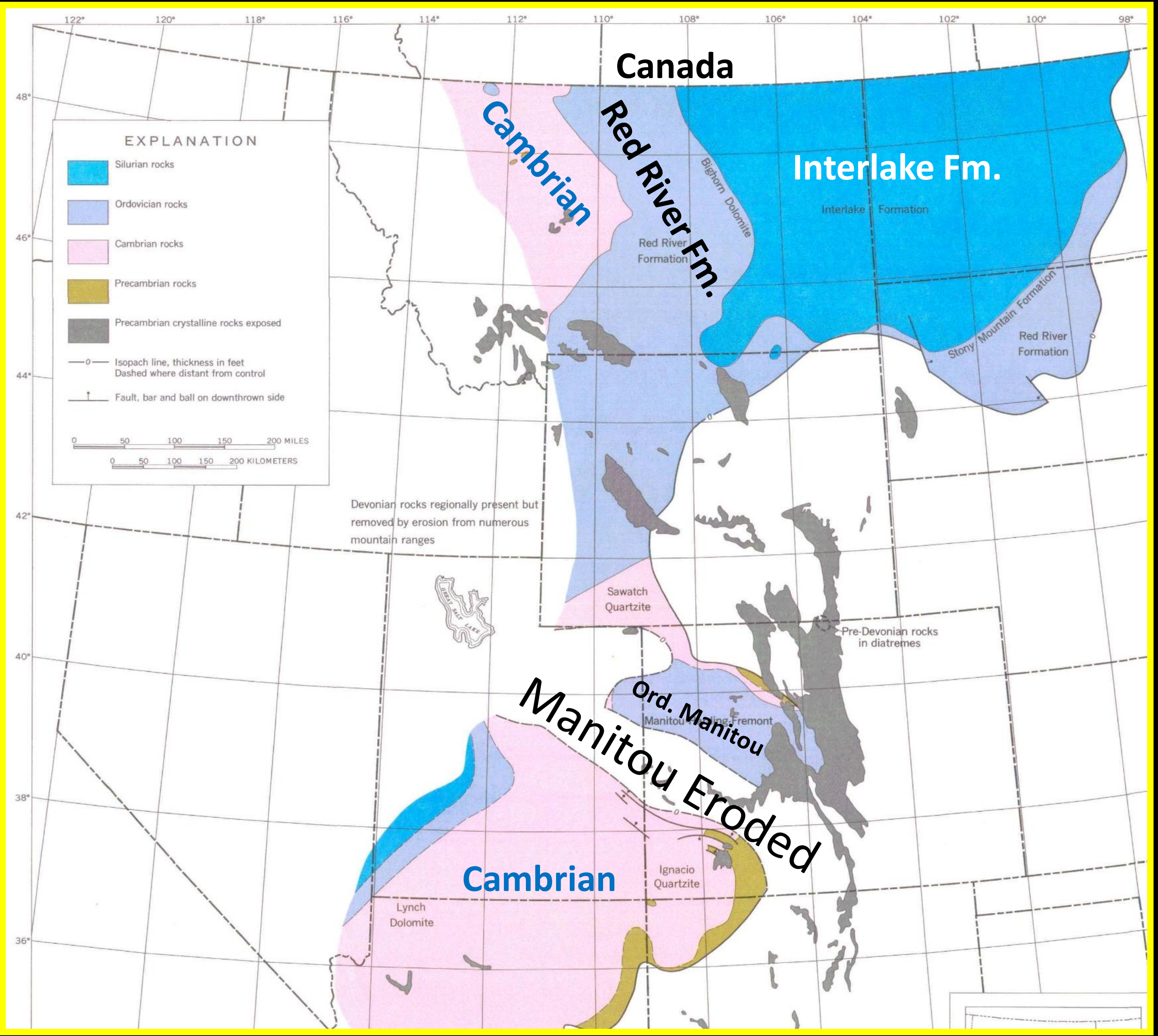
These image taken at 500X and 914X show abundant rhombic crystals of dolomite that range in size from about 20 to 50 microns and average about 30 microns. Sedimentary structures visible in the outcrop and in thin section show that this sample was originally composed of subrounded detrital dolomite but the grains now have euhedral dolomite overgrowths that obscure the original grains. This sample is essentially 100% dolomite, but does contain small patches of detrital illite and sparse grains of quartz silt (labeled in image at right).

CO-Bison Lake-34.0 m: Lower Coffee Pot Dolomite with Detrital Dolomite Grain in Dolomite Overgrowth



This image taken at almost 2000X shows a subrounded grain of detrital dolomite (inside yellow box) with a large overgrowth of dolomite (Dol OG). Other rhombic crystals of dolomite shown probably have similar cores of detrital dolomite beneath the visit euhedral crystal faces.

Subcrop Map of Rocks below the Devonian. Shades of Blue indicate Common Dolomites
Sources of detrital dolomite include the Ordovician Red River and Silurian Interlake Fms.



Adapted from Baars (1972), RMAG "Big Red Book," p. 93

Conclusions about Dyer Fm

1. The Coffee Pot Member of the Upper Devonian Dyer Formation in the Bison Lake outcrop contains abundant current-transported silt-sized grains of detrital dolomite mixed with variable amounts of similar-sized detrital quartz silt.

2. Some beds of detrital dolomite have little or no quartz silt

3. Sedimentary structures indicate grain transport in high-energy storm deposits in a peritidal to shallow lagoonal environment

4. The silt-sized detrital dolomite fragments were derived from eolian abrasion of adjacent older Paleozoic (pre-Fammenian) dolomites

5. Coffee Pot fossils are rare suggesting arid, hypersaline conditions

Now on to the Three Forks/Bakken Petroleum System

1. These rocks are much more extensively studied than the Coffee Pot Member of the Dyer Formation, but equivalent in age (Upper Devonian)

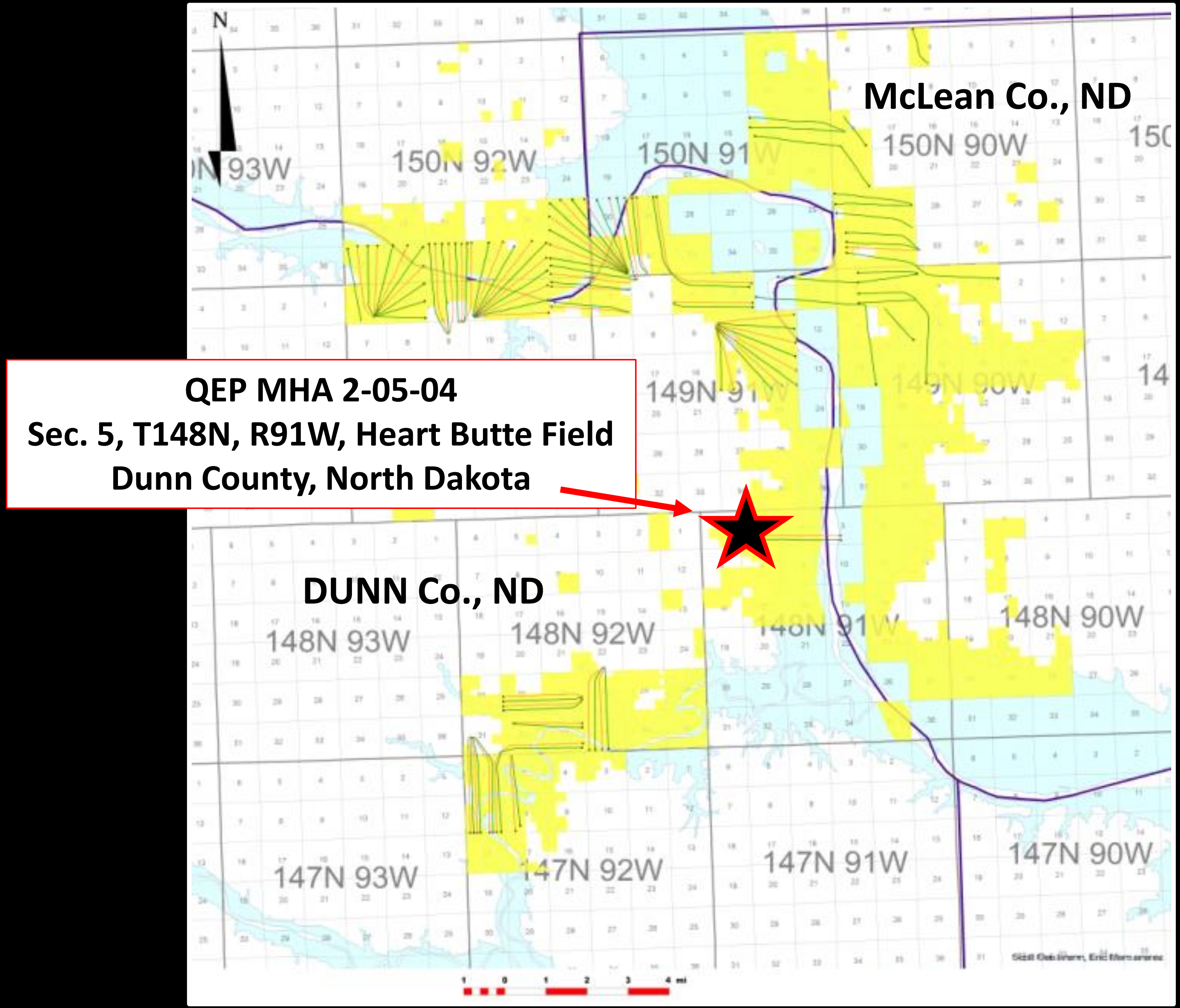
2. Bottjer et al. (2011) and Fresca et al. (2018) report some detrital dolomite in the Three Forks Formation (based mainly on sedimentary structures)

3. Skinner et al. (2012) report detrital dolomite in the Pronghorn Member (aka Sanish Sand) on the northeast flank of the Cedar Creek Anticline

4. Although Middle Bakken sedimentary structures suggest common detri-tal dolomite, no confirmed/published cases of detrital dolomite to date

5. We Interpret Detrital Dolomite to be Common in the Middle Bakken. It also occurs as wind-blown silt in the Bakken Black Shales

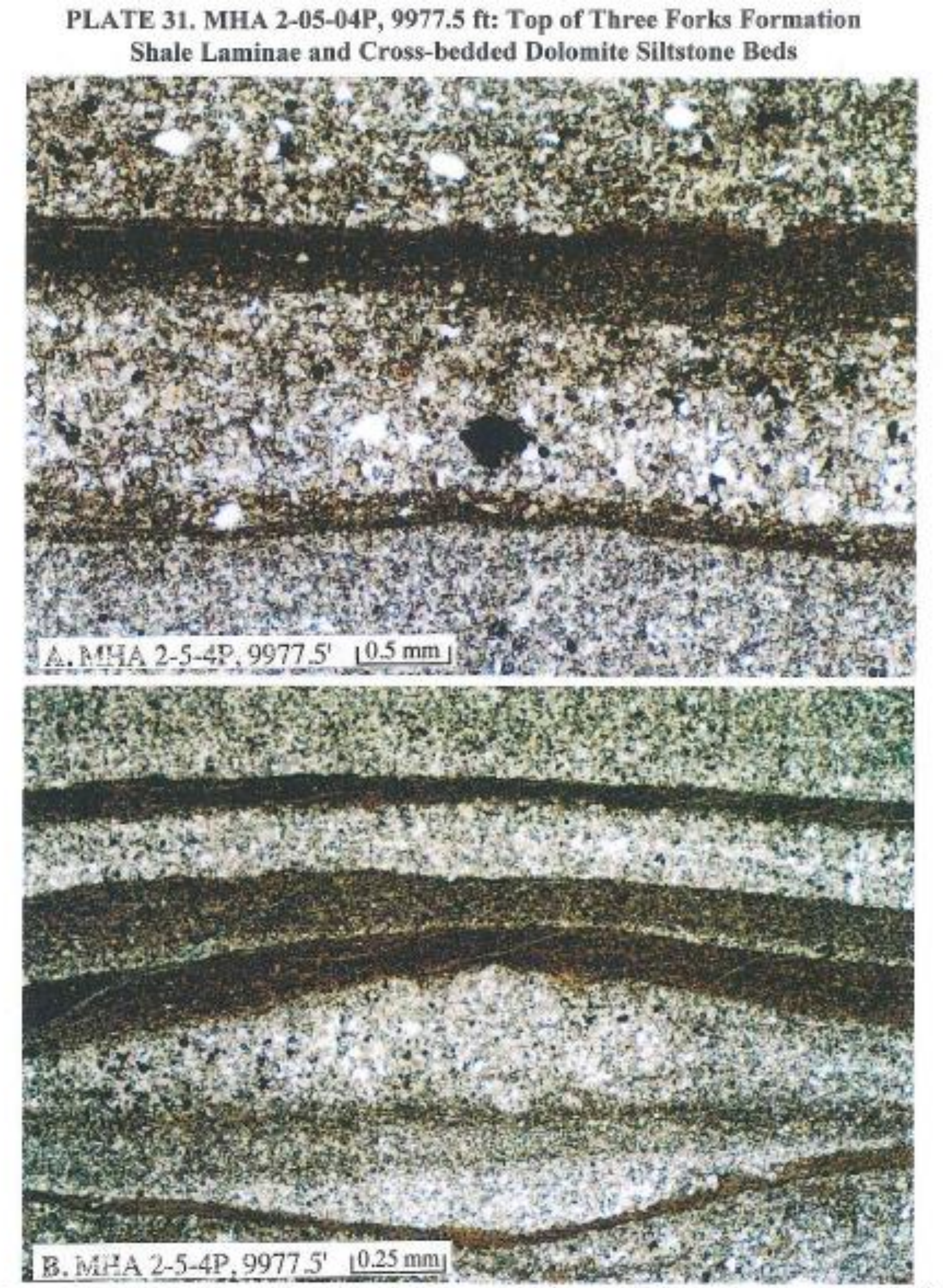
Key Core: QEP's MHA 2-05-04H (Black Star) of the Bakken and Three Forks



*Log depth is 12' below core depth

Upper Three Forks Formation First Bench
Bedded Dolomite with Current Ripples, Dewatering (Fluid Escape) Structures, and Intraclasts

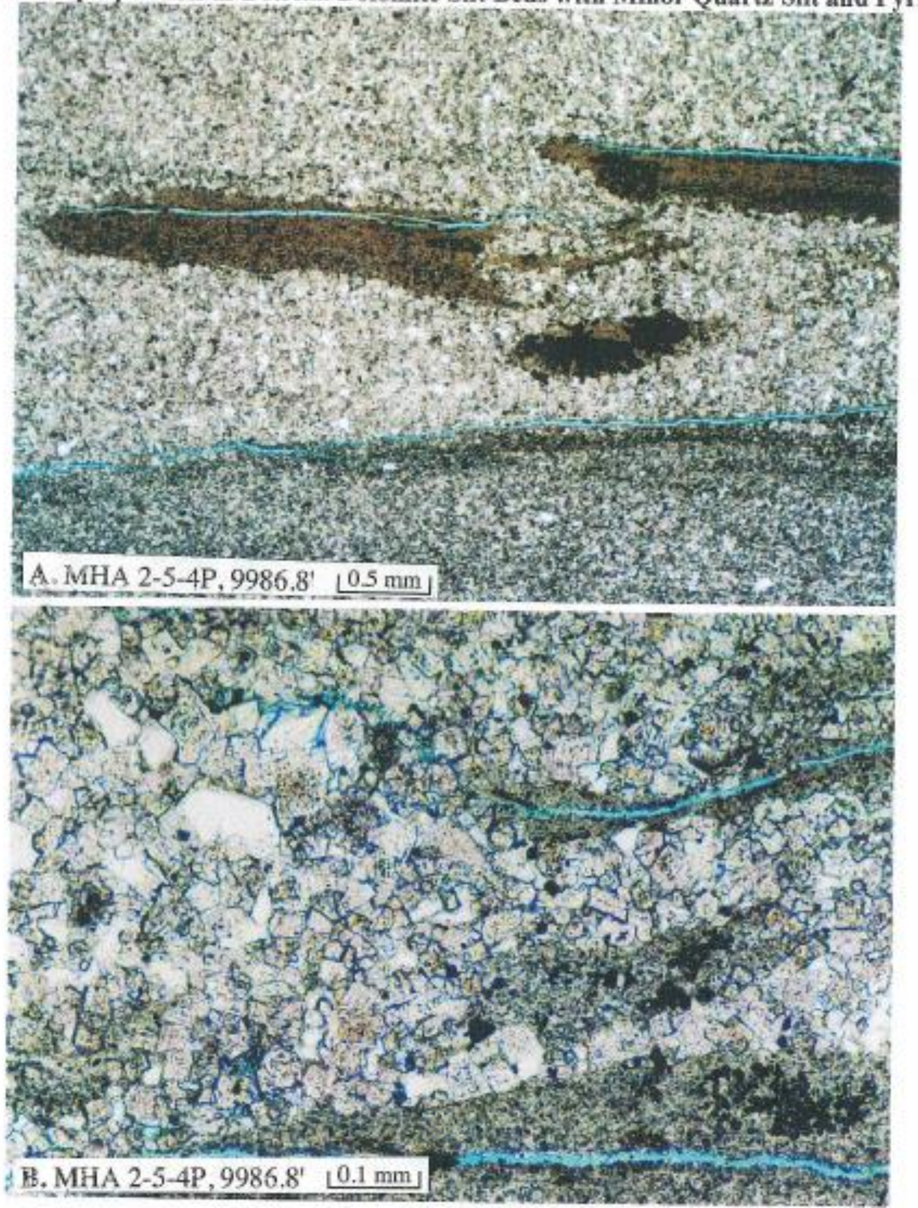
MHA 2-5-4, 9977.0 ft: Wet with Crossbedding and Climbing Ripples



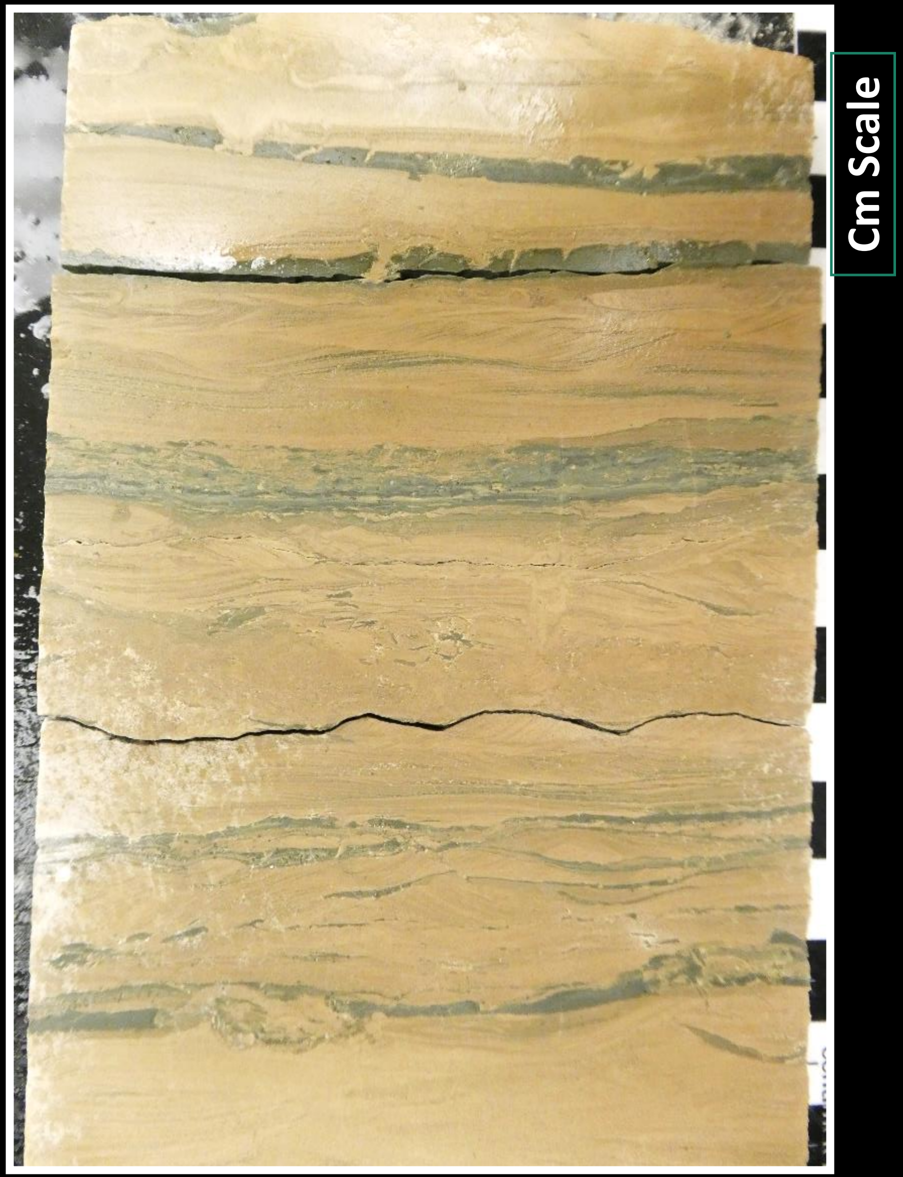
Upper Three Forks Fm. "A" Bench: Current Ripples Formed Mainly of Detrital Dolomite with Quartz Silt Grains and Shale Drapes with Minor Shale Rip-up Clasts

MHA 2-5-4, 9987.5 ft: Wet Close-up with Ripples and Shale Laminae and Rip-up Clasts

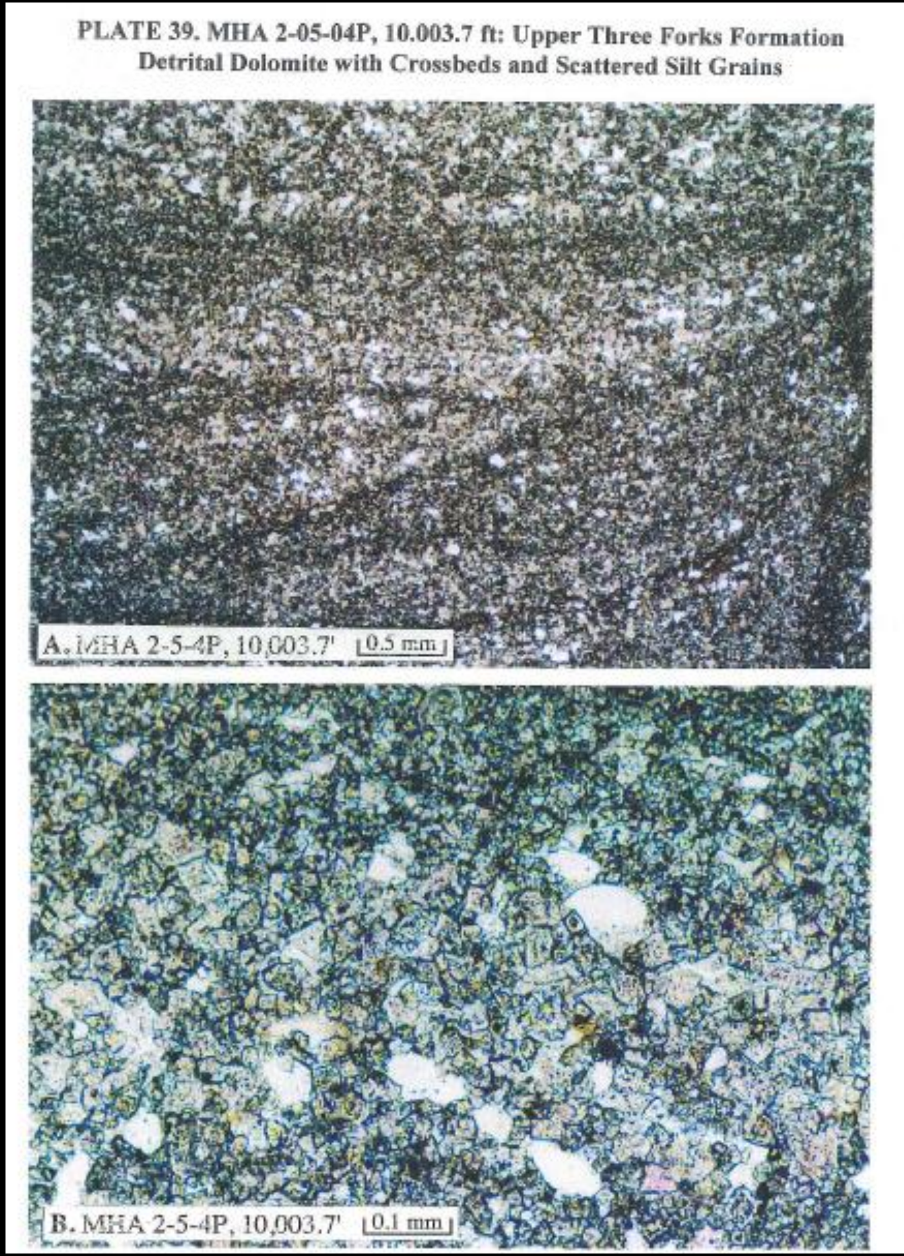
PLATE 35. MHA 2-05-04P, 9986.8 ft: Upper Three Forks Formation
Shale Rip-up Clasts in Detrital Dolomite Silt Beds with Minor Quartz Silt and Pyrite



Upper Three Forks Fm.
Cross-Bedded Detrital Dolomites with Dewatering (Fluid Escape) Structures, and Ripples



MHA 2-5-4, 10,004.5 ft



Ripple Crossbed of Detrital Dolomite in Siltstone between Shaly Beds

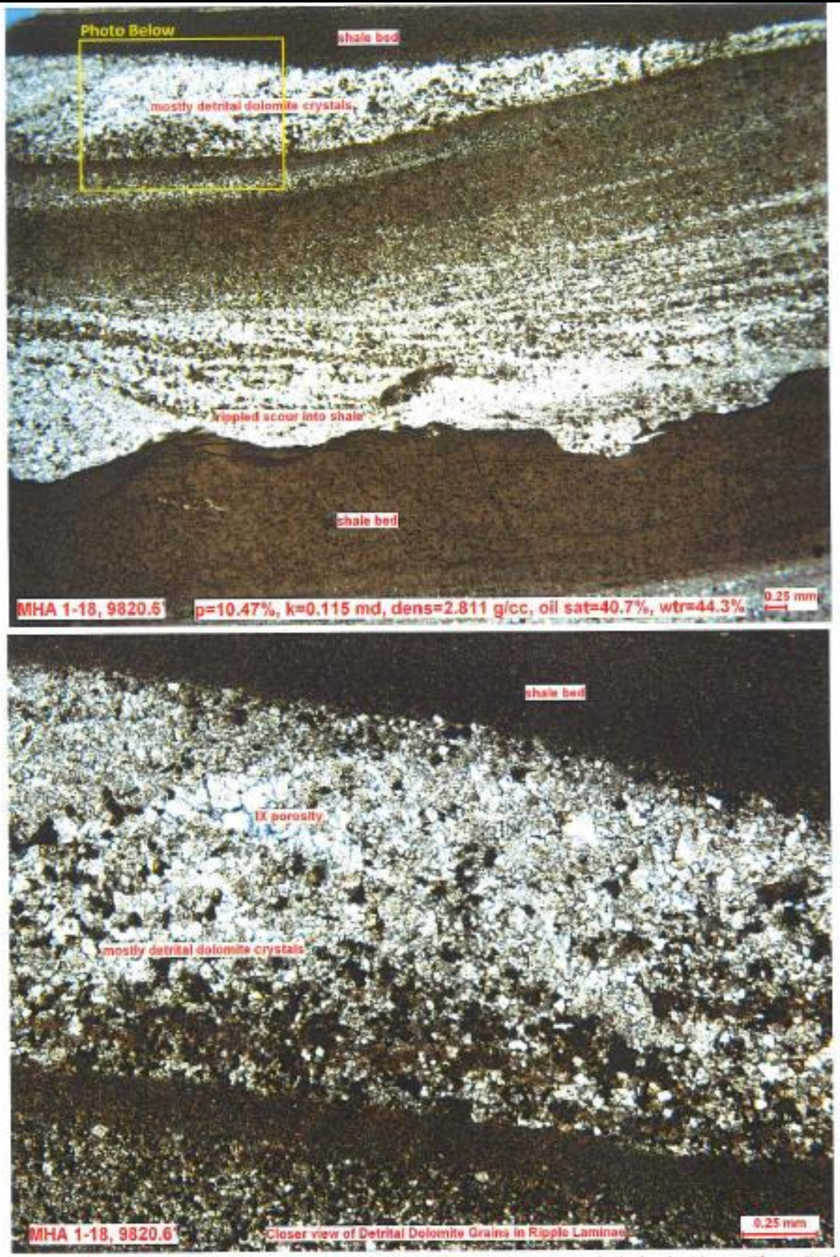


Plate 25. Ripple crossbedded Laminae of detrital dolomite between shale beds. Upper Three Forks.

Upper Three Forks Fm. First Bench

Detrital Dolomite in Injectite Dike through a Shaly Bed

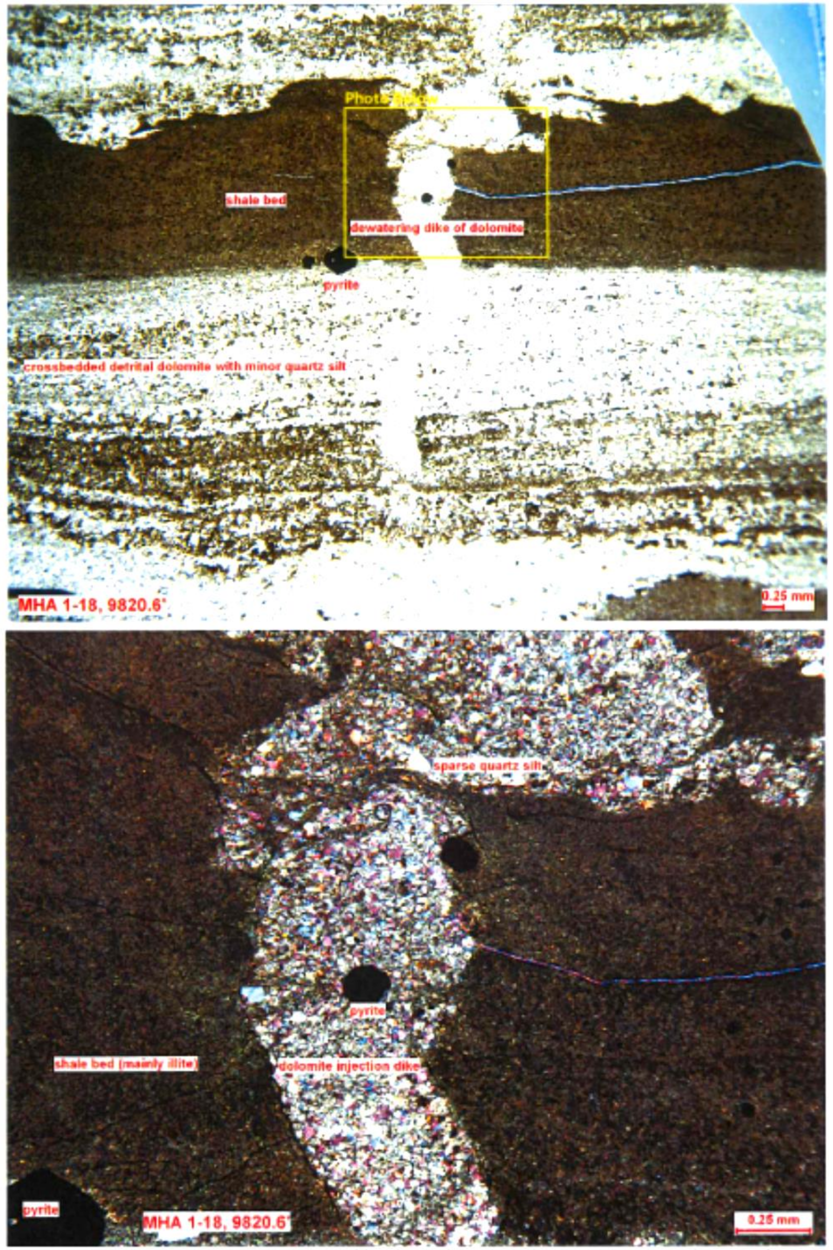
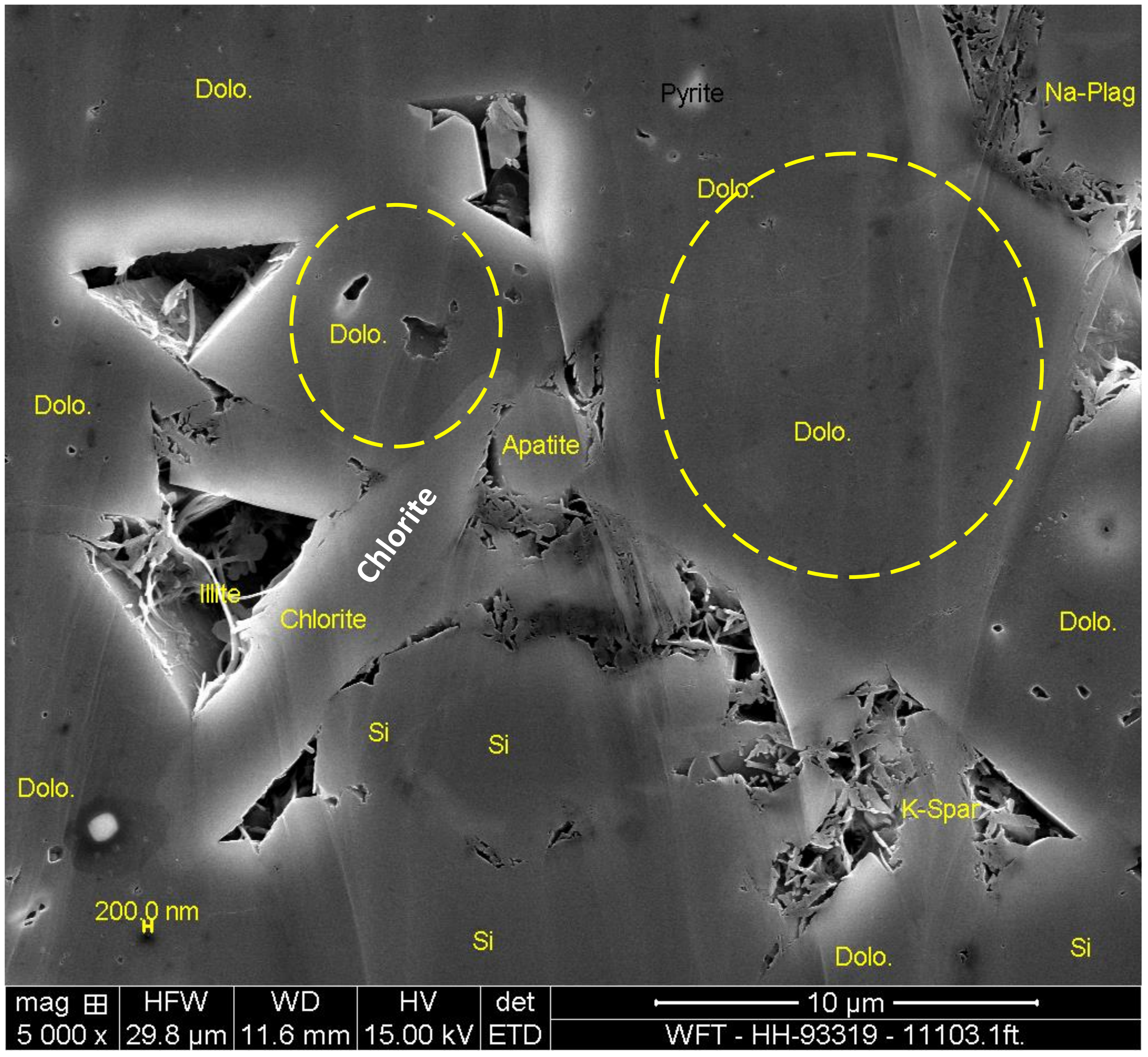


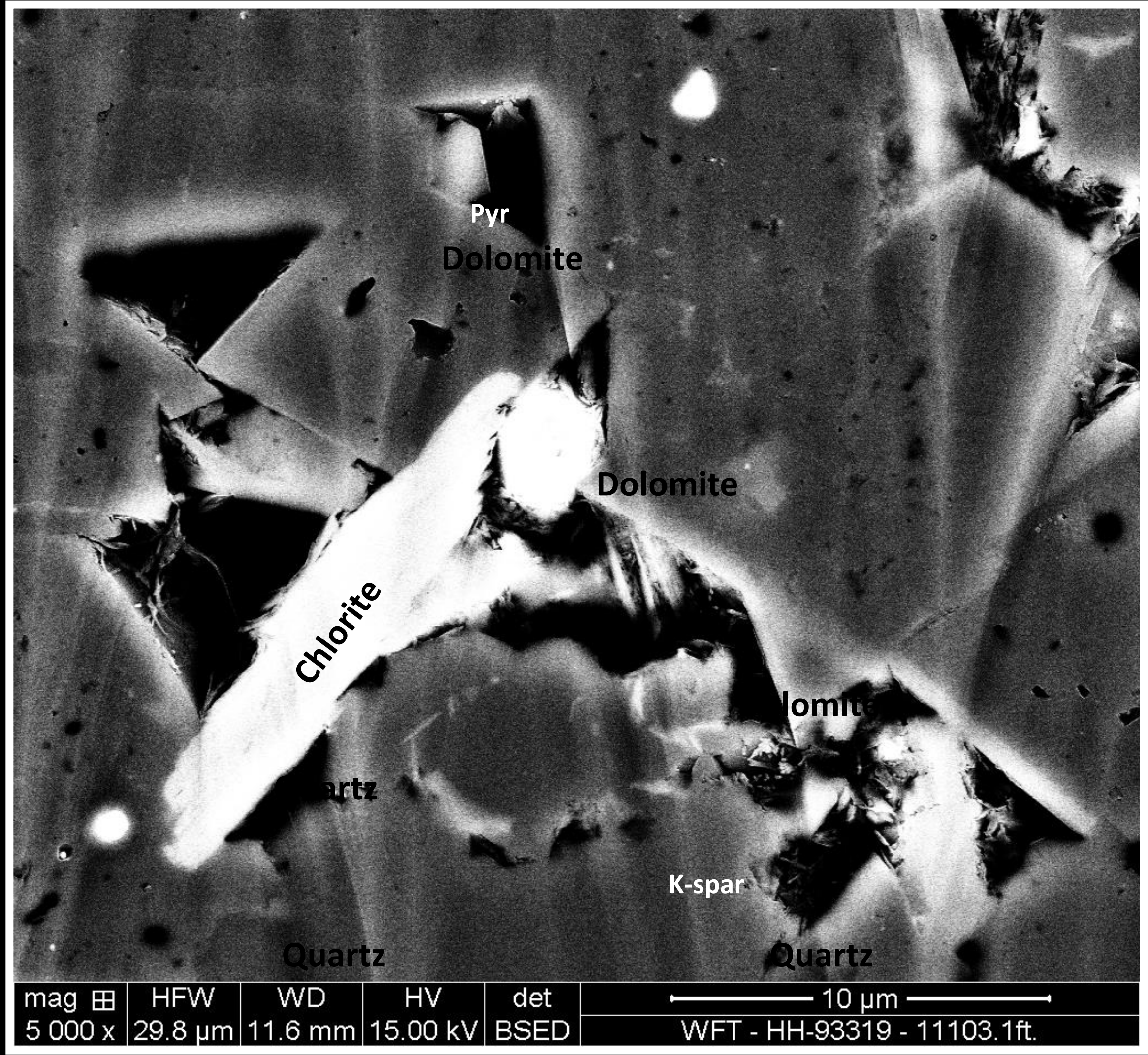
Plate 26. Detrital dolomite in injection dike through a shale bed in the Upper Three Forks Fm.

View of Detrital Dolomite Cores Overgrown by Ferroan Dolomite Rims & Authigenic Clays: Three Forks First Bench at 11,103.1 ft

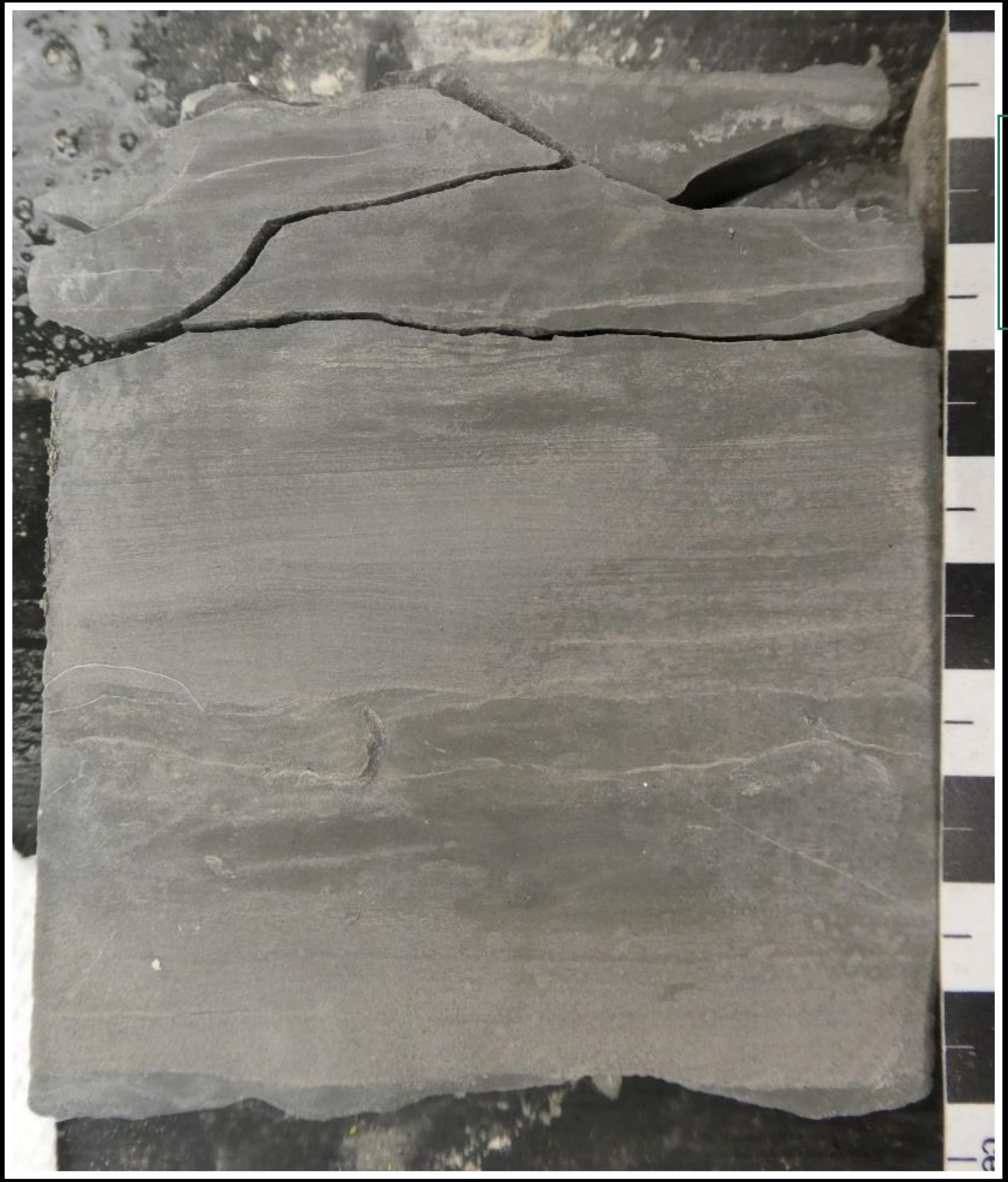


The secondary electron image at left shows intercrystalline porosity between the ferroan dolomite overgrowths on the detrital dolomite grains. A flake of detrital chlorite is present at left center. The detrital dolomite cores have common pores.

The backscatter image (BSED) at right reveals the heavy elements such as the Fe in the chlorite and ferroan dolomite overgrowths. Grains of quartz silt (bottom center) and iron-poor dolomite appear gray.

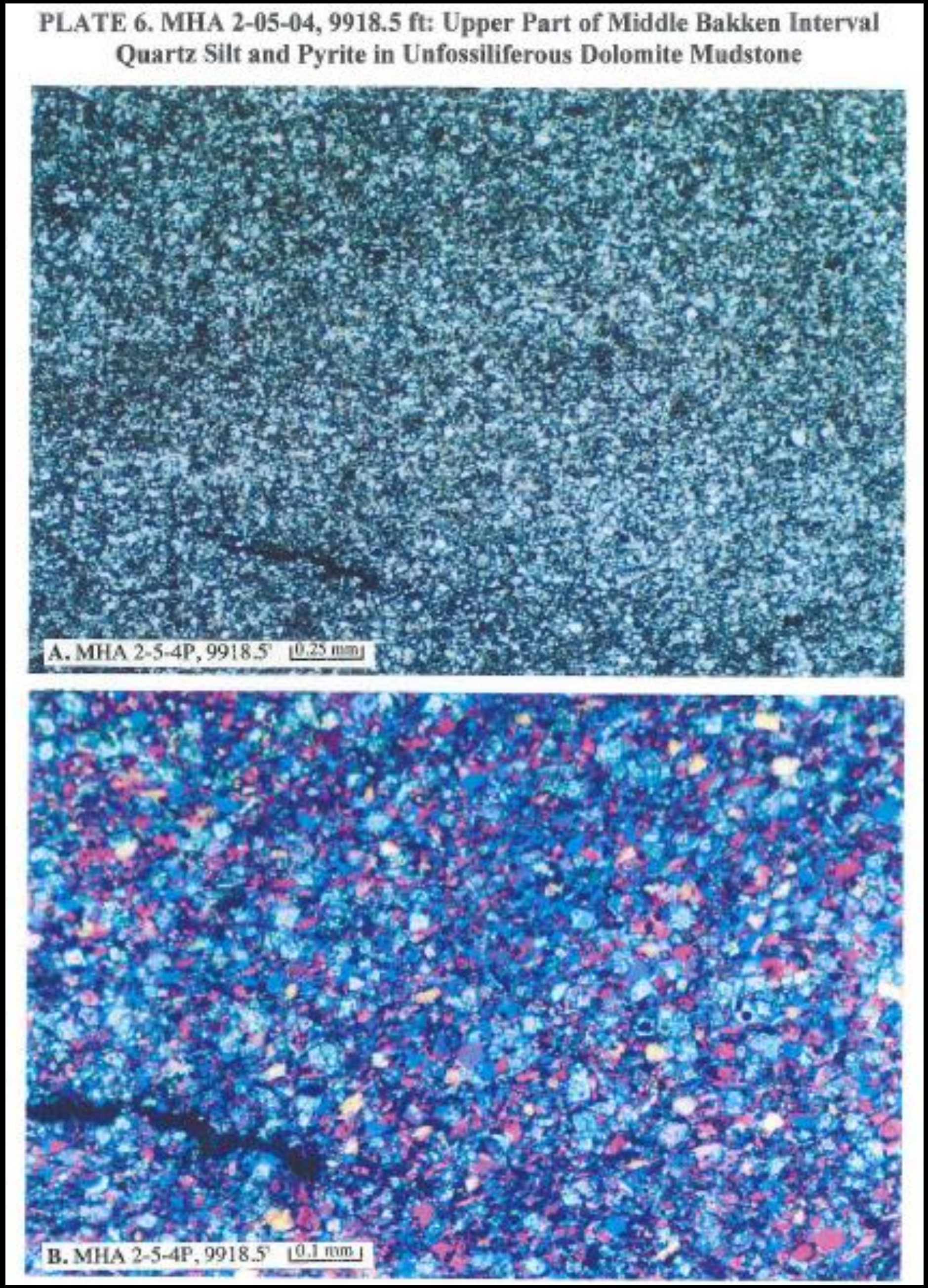


Bedded Dolomite “Mudstone” (actually Siltstone) from Upper Part of Middle Bakken (“CSM “E” Facies)



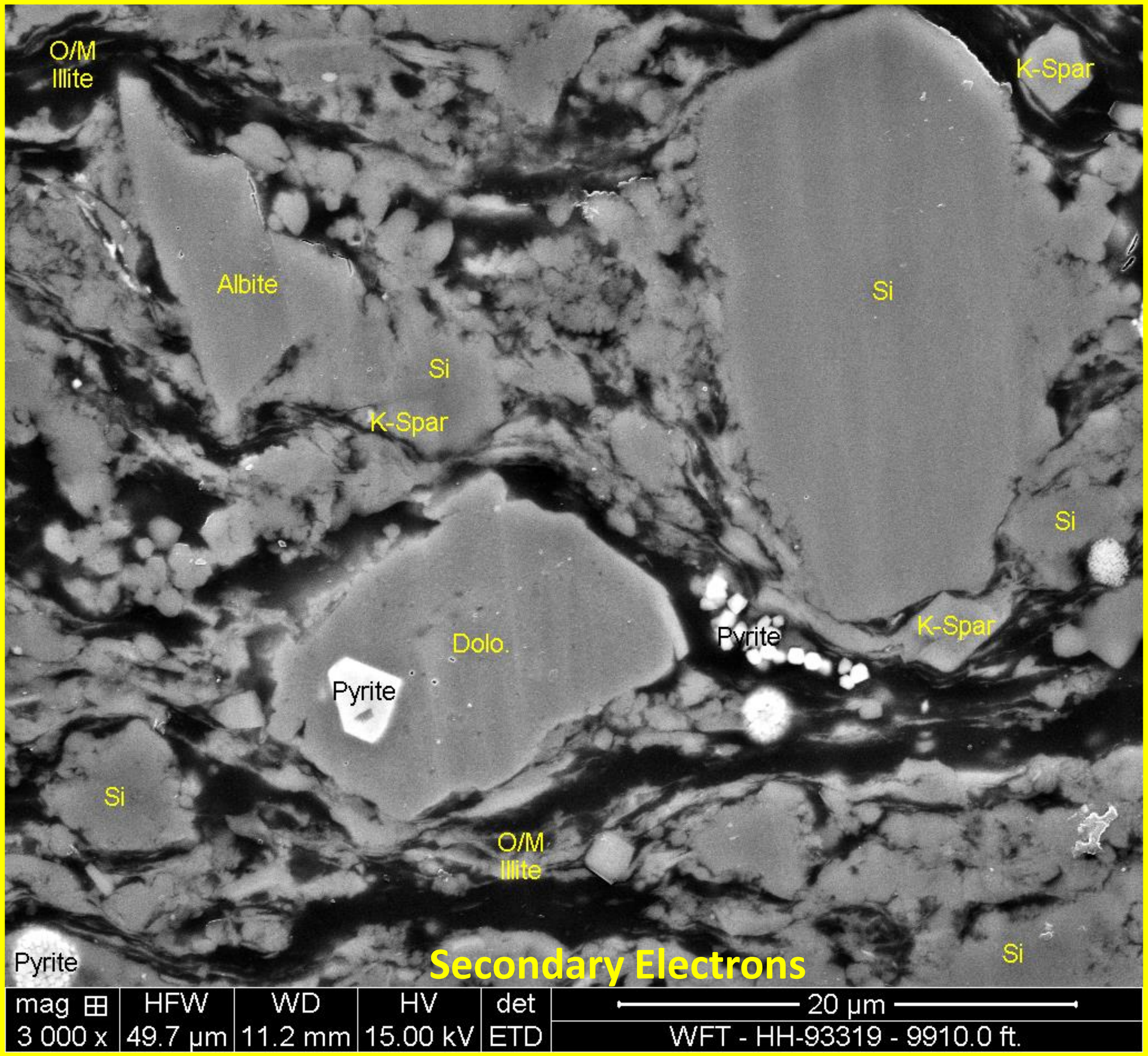
Cm Scale

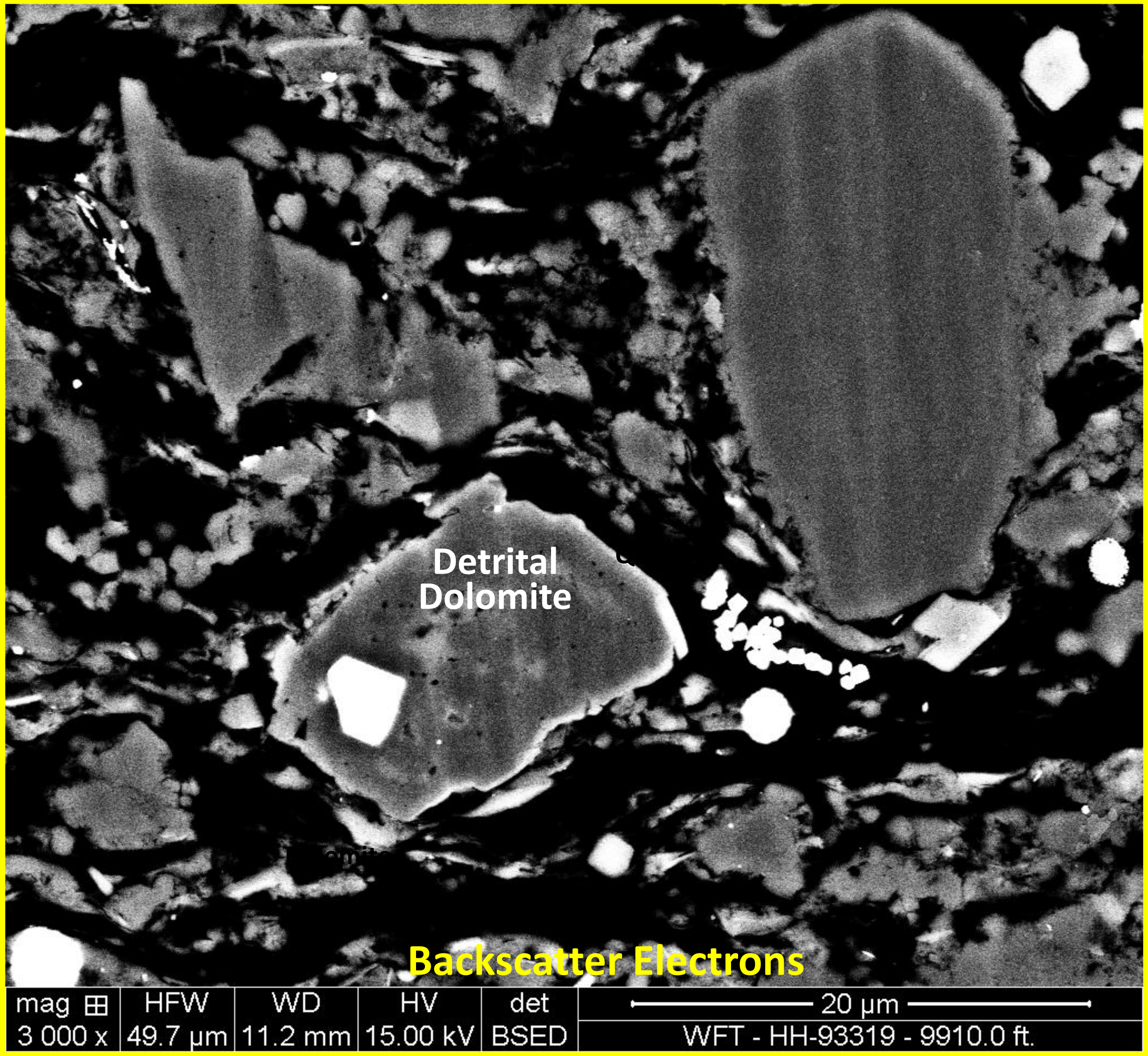
MHA 2-5-4, 9918.5 Dry



<u>XRD</u>
93% dol.
5% Qtz
2% Pyr.

Silt Grains including Detrital Dolomite with Organic Matter, Bitumen, Pyrite, and Detrital Illite in the Upper Bakken Black Shale in Secondary Electron and Backscatter Images: MHA 2-5-4, 9910 ft





The dolomite silt grain near the center of each photo is almost 20 microns long. It contains a crystal of authigenic pyrite (white) and common small holes (black, best seen in the backscatter view at right) that indicate partial dissolution. It also has a very thin overgrowth of ferroan dolomite (white rim).

Conclusions

1. Silt-Sized Detrital Dolomite Grains are Abundant (but greatly under-recognized) in the Three Forks and Middle Bakken Formations

2. Sand-Blasted (eroded) Ordovician, Silurian, and Lower Devonian Dolomites on the Flanks of the Williston Basin are the probable source of these silt-sized Detrital Dolomite Grains

3. Most, but not all, of the detrital dolomite beds have some quartz silt

4. Sedimentary structures indicate grain transport in high-energy storm deposits in a peritidal to shallow lagoonal environment

5. Skeletal Fossils are rare in the beds with common Detrital Dolomite, which suggests arid, hypersaline conditions

Acknowledgments

The Dyer Formation outcrops were studied as part of an ongoing sedimentologic and paleontologic study being conducted by the Denver Museum of Nature and Science.
Thanks to Linda Soar and James Hagadorn for guiding us to the outcrops.

QEP Resources provided access to the MHA and Ernie Cores from the Bakken and Three Forks Formations in the Williston Basin

Triple O Slabbing provided layout space for the QEP Cores