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

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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


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)

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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
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, Particularly 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

Mississippian Leadville LS

Coffee Pot Dolomite
Limited Fossils (ostracods, calcispheres) or None

Broken Rib Limestone
(Very fossiliferous)

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

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

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

Field of View ~10 cm wide
Photomicrographs of Chalcedony (Chert) in Basal Coffee Pot Detrital Dolomite Siltstone

Nodule of length-fast zebrafish 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 images 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).
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 detrital 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

**Location:**
- Sec. 5, T148N, R91W, Heart Butte Field
- Dunn County, North Dakota

**Lodgepole Fm. Core Interval Diagram:**
- Lower Bakken Silt
- Lower Bakken Shale
- Middle Bakken
- Upper Bakken Shale

*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
Upper Three Forks Fm.
Cross-Beded 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

Upper Three Forks Fm. First Bench

Detrital Dolomite in Injectite Dike through a Shaly Bed

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

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

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

MHA 2-5-4, 9918.5 Dry

XRD
93% dol.
5% Qtz
2% Pyr.
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

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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.