# PSDiagenesis of the Upper Three Forks Formation – The North Dakota Perspective*

**Ketki Kolte[1] and Sven Egenhoff[1]**

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[1]Department of Geosciences, Colorado State University, Fort Collins, CO, USA (ketki.kolte@gmail.com)

## Abstract

The upper part of the Three Forks Formation in the Williston basin of North Dakota and Montana is one of the prime targets for oil exploration in the onshore part of the US today. The unit is mainly composed of dolomite, yet the details of dolomite formation and its relative timing are unknown. This study is the first that combines cement generations and porosity into a diagenetic scheme based on detailed microscopical observations. The upper Three Forks Formation shows seven dolomite generations along with some anhydrite and pyrite. Most of the rock consists of an inclusion-rich dolomite, likely dolomite II, that forms mm- to sub-mm- size rhombic crystals showing overgrowth of five more alternating clear and inclusion-rich dolomite generations, and in places a core of iron-rich dolomite I. Porosity types in the Three Forks Formation are intercrystalline, intracrystaline, and "moldic" which here stands for the dissolution of entire dolomite crystals. Detrital components are quartz, feldspars, mica, and clay particles.

The Three Forks Formation was most likely deposited on a mixed carbonate-siliciclastic ramp as a limestone unit with varying amounts of detrital input. Initial replacement of limestone into dolomite probably occurred early entirely changing the texture of this unit. Several dolomite phases occurred during burial post-dating early dolomitization. The effective porosity, characterized by intercrystalline and "moldic" pores, is linked to the dolomitization, most likely originally to an early event as no late dolomite is seen filing these pores. Up to centimeter-size voids, though, representing mostly non-effective porosity, are generally partly filled with several generations of dolomite and leaving some part of the vugs open. This indicates that most likely, the voids were formed before the last few generations of dolomite cement, and also that not all open space was easily occluded by these dolomitizations but left some of the porosity untouched.

Based on a limited data set, porosity distribution in the upper Three Forks Formation does not show a clear link to the distribution of dolomite. However, it does show a trend to overall increased values from the east (less than 1%) to the west (around 5%) with a north-south extending zone of maximum porosities (about 10-12%) around 103.50. It is therefore likely that potential hot spots in this basin are rather located in western North Dakota while towards the east porosities are less promising.

# Diagenesis Of The Upper Three Forks Formation – The North Dakota Perspective

Ketki Kolte and Sven Egenhoff

Department of Geosciences, Colorado State University, Fort Collins, CO

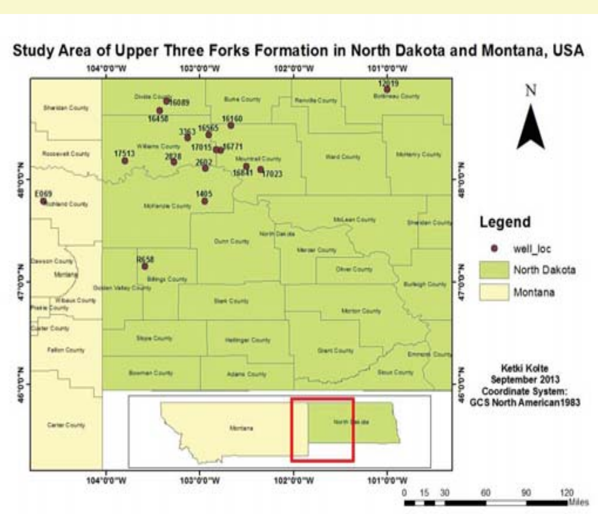
## INTRODUCTION

The Williston basin is an elliptical intracratonic depression that contains numerous oil-rich formations. (Gerhard et al., 1990). Underlying the widely recognized Bakken Formation is the Three Forks Formation (Pitman et al., 2001). The Devonian Three Forks Formation, deposited approximately 390 million years ago is one of the productive reservoirs in the Williston basin of North Dakota and Montana (Nicolas, 2007). With increasing oil prices, it has become one of the substantially targeted formations in this region. The upper Three Forks Formation comprises mainly dolomitic rocks, making up the potential reservoir in this formation (Heck et al., 2002). The sequence stratigraphy and the depositional history of the Three Forks Formation have been previously explored by Egenhoff et al. (2011), but detailed compositional variations, diagenetic history and types of porosities of this formation have remained unclear to date. This study will therefore focus on unraveling the cement chronology, undefined and poorly understood mineralogical composition and establishing a porosity makeup for the dolomitic portion of the upper Three Forks Formation.

## OBJECTIVES

- Examine and understand the diagenetic phases occurring in the upper Three Forks Formation
- Establish a relative timing of these diagenetic phases in the diagenetic history
- Recognize potential sweet spot locations in the study area

## STUDY AREA & METHODS

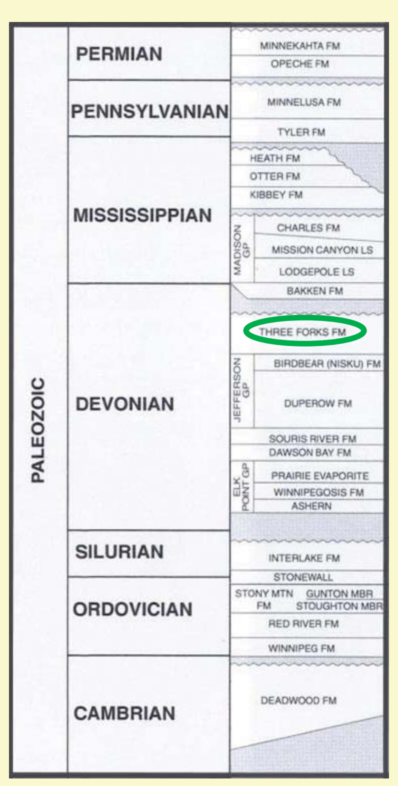



- Core logging in NDGS and USGS
- Quantitative analysis by point-counting
- Porosity estimation and description
- Generation of maps using GIS - ArcMap
- Scanning electron microscope analysis
- Electron microprobe analysis
- Sedimentology

## GEOLOGICAL SETTING & STRATIGRAPHY


Late Devonian - 360 MA (Blakey)

- Intracratonic basin
- ~500 km N-S and ~750 km E-W
- Diameter of basin ~560 km
- Area of basin ~250,000 km$^2$
- Sediment thickness ~4900 m
- Highest subsidence during Devonian
- Depocenter located in Mountrail, Dunn and McKenzie counties of North Dakota
- Generally warm and arid climate



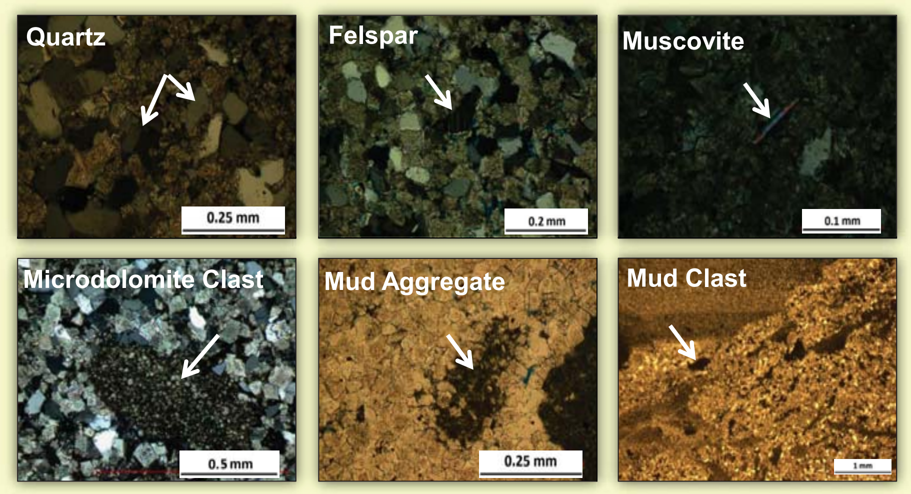

Three Forks Formation:

- Average thickness: 150 ft
- Sediments: Shallow-marine carbonates, evaporites, with minor amounts of silt and sand
- Depositional environment: Sabkha-like with shallow subtidal environment, on an epeiric ramp

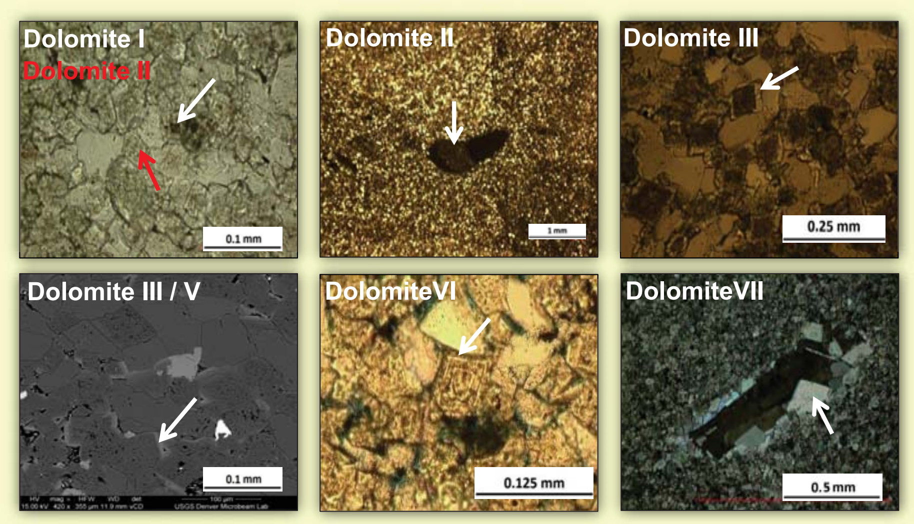
Contact Info:
E-mail: ketki.kolte@gmail.com
Mobile: 512-423-1972

## RESULTS

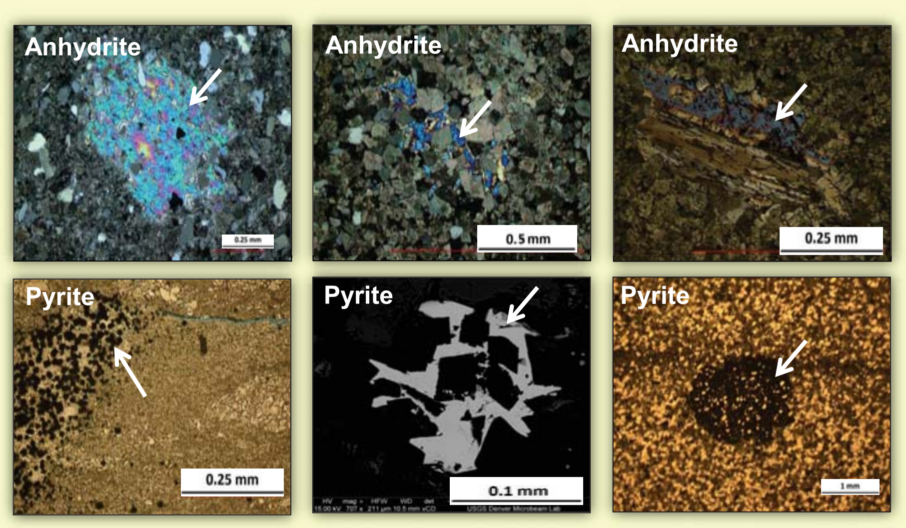
### Detrital Components



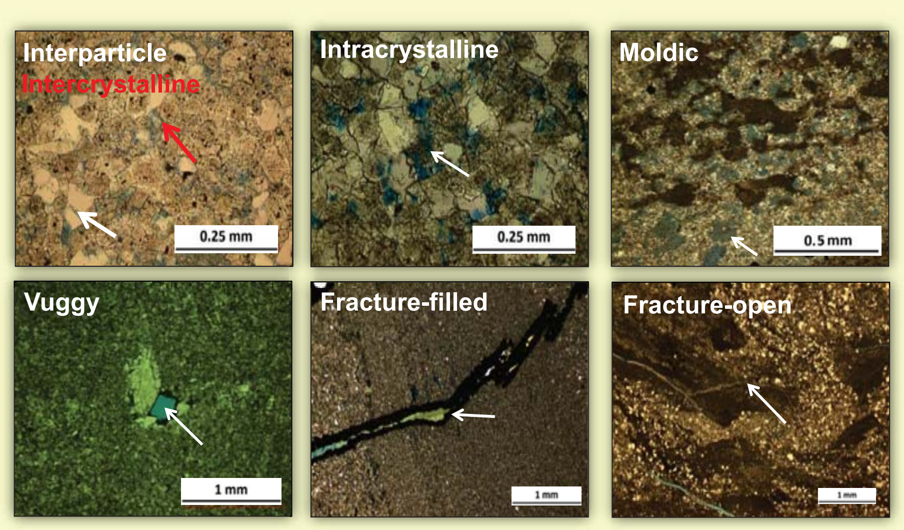

### Dolomite Diagenetic Phases



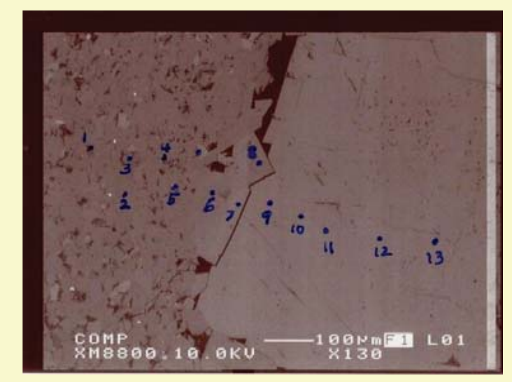

### Anhydrite & Pyrite Diagenetic Phases




### Types of Porosities

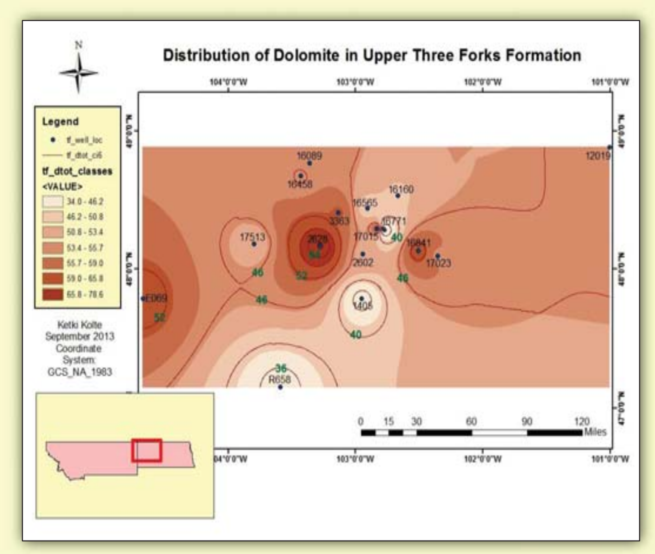



### Electron Microprobe Analysis

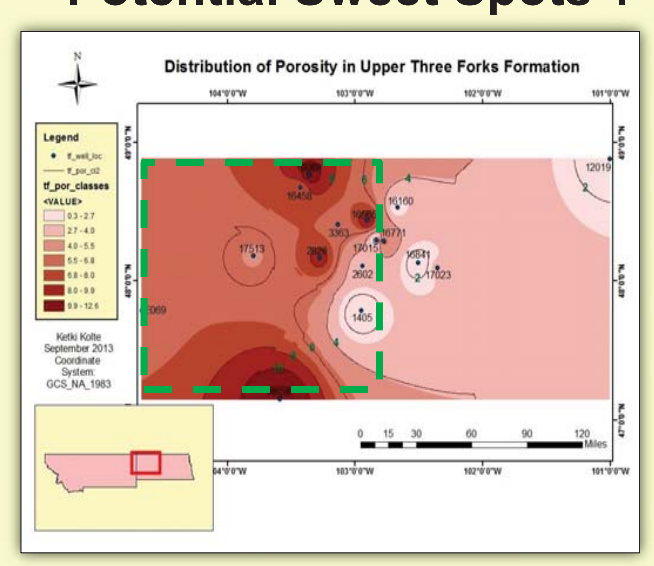


SEM image showing various points targeted for electron microprobe measurements

| Dolomites | FeOWt% |
|---|---|
| Inclusion-rich | 0.2 to 0.5 |
| Inclusion-poor | 0.9 to 1.3 |
| Dolomite VII | 9.9 to 12.6 |

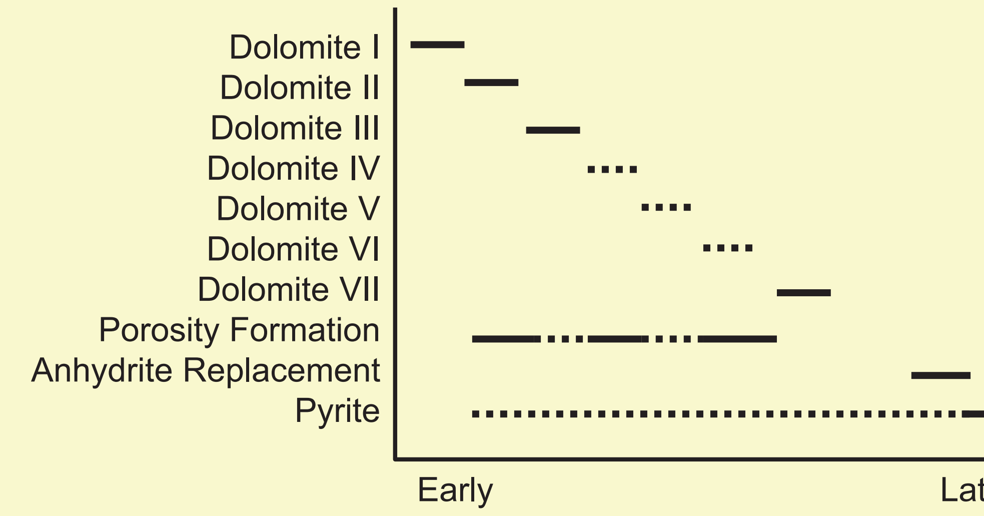



### Potential Sweet Spots ?




## INTERPRETATIONS

### Relative Timing




- Dolomite I is the oldest phase and pyrite is the youngest phase
- Dolomite II represents the bulk of the preserved dolomite
- Inclusion-rich and inclusion-poor dolomite phases represents alternatingly changing chemistry of diagenetic fluids
- Dolomite cements get more Fe-rich through time
- Anhydrite replaces dolomite cements
- Pyrite formation occurred in one to three phases
- All porosity is secondary or post-depositional except interparticle porosity
- Secondary porosity formation:
  - intercrystalline porosity - linked to an early event forming dolomite II
  - intracrystalline porosity - associated with inclusions of inclusion-rich dolomite phases
  - Vuggy and moldic porosity - caused by dissolution of dolomite crystals
  - fracture porosity - result of brittle rock behavior

## CONCLUSIONS

- The diagenetic succession shows:
  - seven dolomite phases along with anhydrite and pyrite phases
- Six types of porosities:
  - intercrystalline, intracrystalline and moldic porosity types - relatively common
  - interparticle, vuggy and fracture porosity types - relatively rare
- Average porosity: 5%
- Geospatial maps may not be an ideal representation of the distribution of cements and porosity:
  - does not take into account the sparse data density and local geological features

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