Integrated Diagenetic and Paleomagnetic Study of the Mississippian Limestone, North Central Oklahoma*

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Abstract

The Mississippian Limestone in Oklahoma is a petroleum exploration target in northern Oklahoma and southern Kansas, and diagenetic events are a significant factor in controlling reservoir quality. In this study, petrographic, geochemical, and paleomagnetic data were used to determine the origin and timing of diagenetic events in five unoriented cores from northern Oklahoma. Petrographic analysis indicates a complex paragenetic sequence. Early diagenetic events include silica precipitation and dolomitization. Middle diagenetic events include brecciation, silica dissolution, fracturing, dolomitization, and silica precipitation, and they are interpreted as resulting from subaerial exposure. Late diagenetic features, attributed to burial and hydrothermal fluid flow, include stylolitization, dissolution, and precipitation of megaquartz, calcite, sphalerite, pyrite, and baroque dolomite. The $^{87}Sr/^{86}Sr$ isotopic data for the limestone range from coeval to radiogenic. Samples from the two cores which are located to the north and closer to the Tri-State MVT district contain the most elevated values. Thermal demagnetization removes a low temperature viscous remanent magnetization (VRM) and a chemical remanent magnetization (CRM) from 240 - 500°C that is interpreted to reside in magnetite. Rock magnetic studies confirm the magnetite interpretation. An attempt was made to orient the cores using the VRM but it resulted in a 300° streaked distribution of declinations with shallow inclinations, and as a result, was not successful. The inclinations of the CRM in the five cores are similar (mean = -2.5°, $\alpha 95$ = 1.4°, n = 270). The age of the CRM was determined by comparing the measured inclinations with the expected

inclinations for the study area. This analysis indicates that the CRM was acquired in the Permian. This is consistent with the dates for mineralization in the nearby Tri-State MVT deposit and interpretations in other studies which hypothesize a Permian hydrothermal system. Burial remagnetization mechanisms, such as maturation of organic matter or clay diagenesis, are not likely because of low organic matter and clay content. The age of the CRM and the evidence for hydrothermal alteration suggest that CRM acquisition was caused by external hydrothermal fluids.

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Website

Major geologic provinces of Oklahoma, http://www.ogs.ou.edu/MapsBasic/Provinces.jpg.

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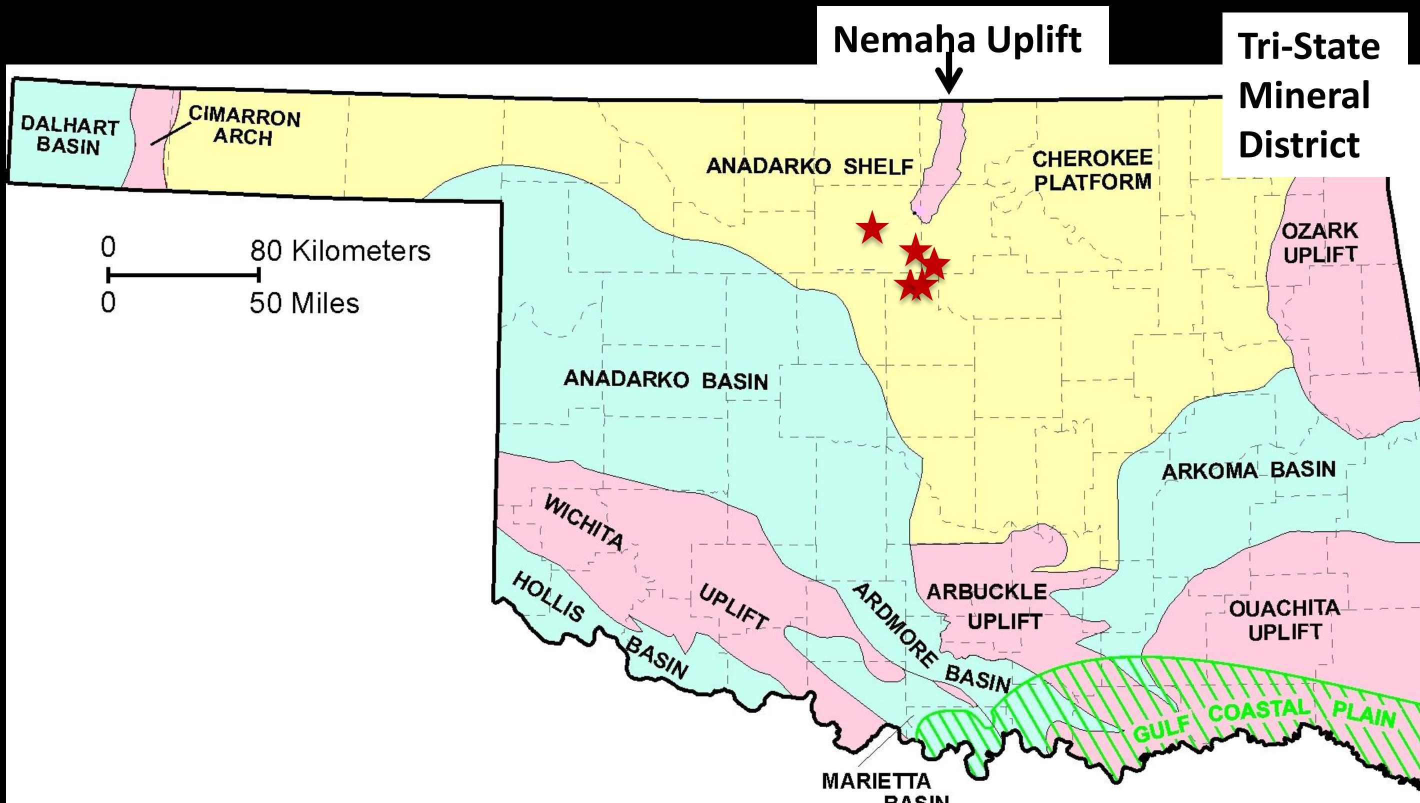
devon

Objectives

- **Characterize and determine timing of diagenesis in the Mississippian Formation**
  - Previous studies documented that diagenesis influences reservoir properties
    - Subaerial exposure and/or enhancement by hydrothermal fluids
- **Test if paleomagnetic data can be used to date alteration**
  - Cores are unoriented - test if Viscous Remanent Magnetization (VRM) method can be used to orient chemical remagnetizatons in cores
  - Test if timing of chemical remagnetization is consistent with hypothesized Permian hydrothermal systems (Goldstein & King, 2014)

Mississippian Limestone - 5 Cores

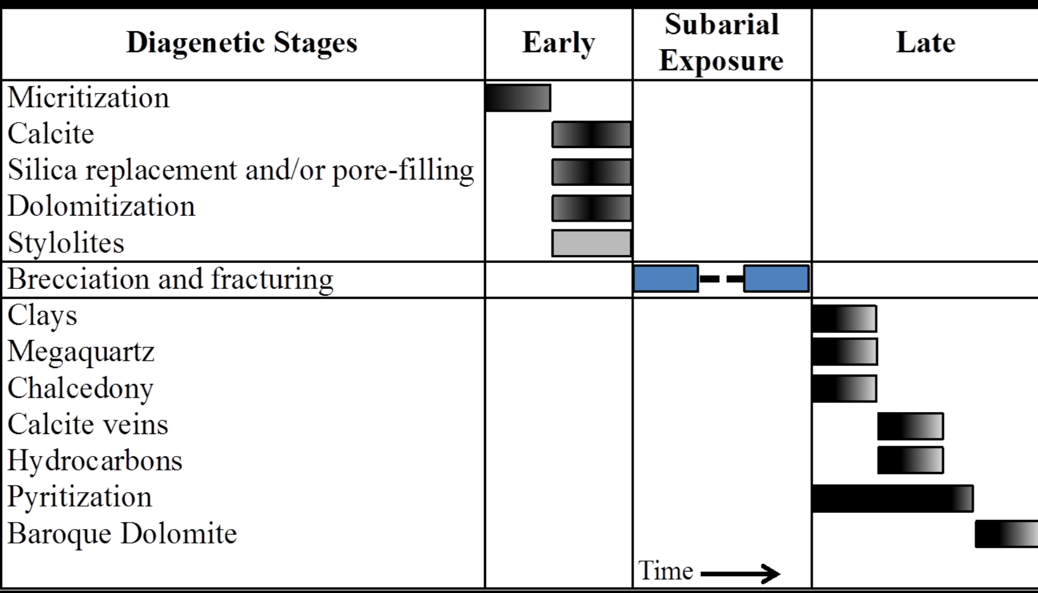


(Modified from http://www.ogs.ou.edu/MapsBasic/Provinces.jpg)

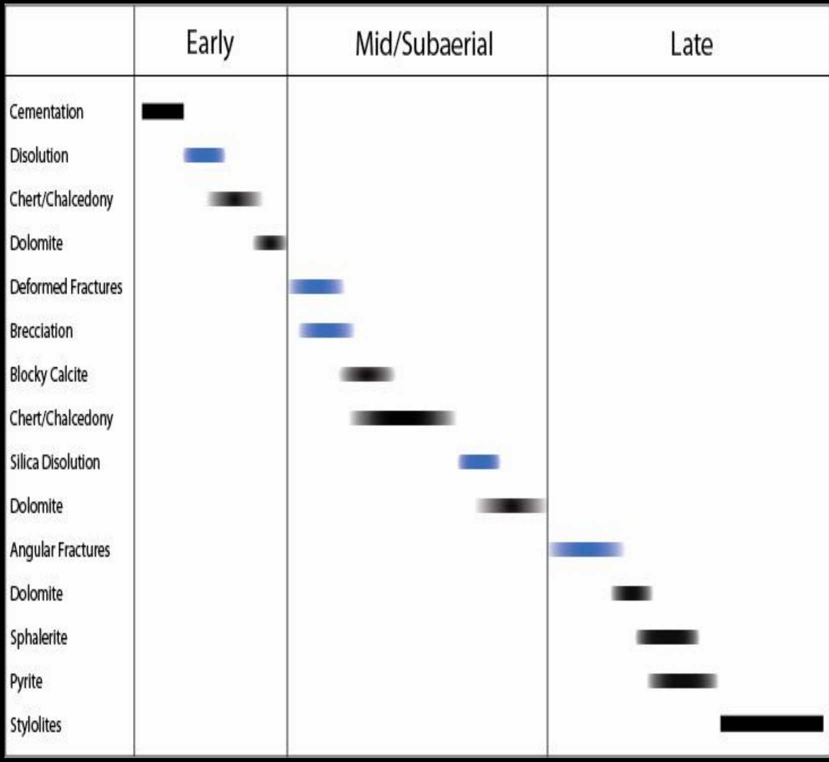
Presenter's notes: Major Geologic Provinces in OK. The study area is west of the Nemaha Uplift and just north of the Anadarko Basin. The Tri-State Mineral District is in northeasternmost OK.

Paragenetic sequences

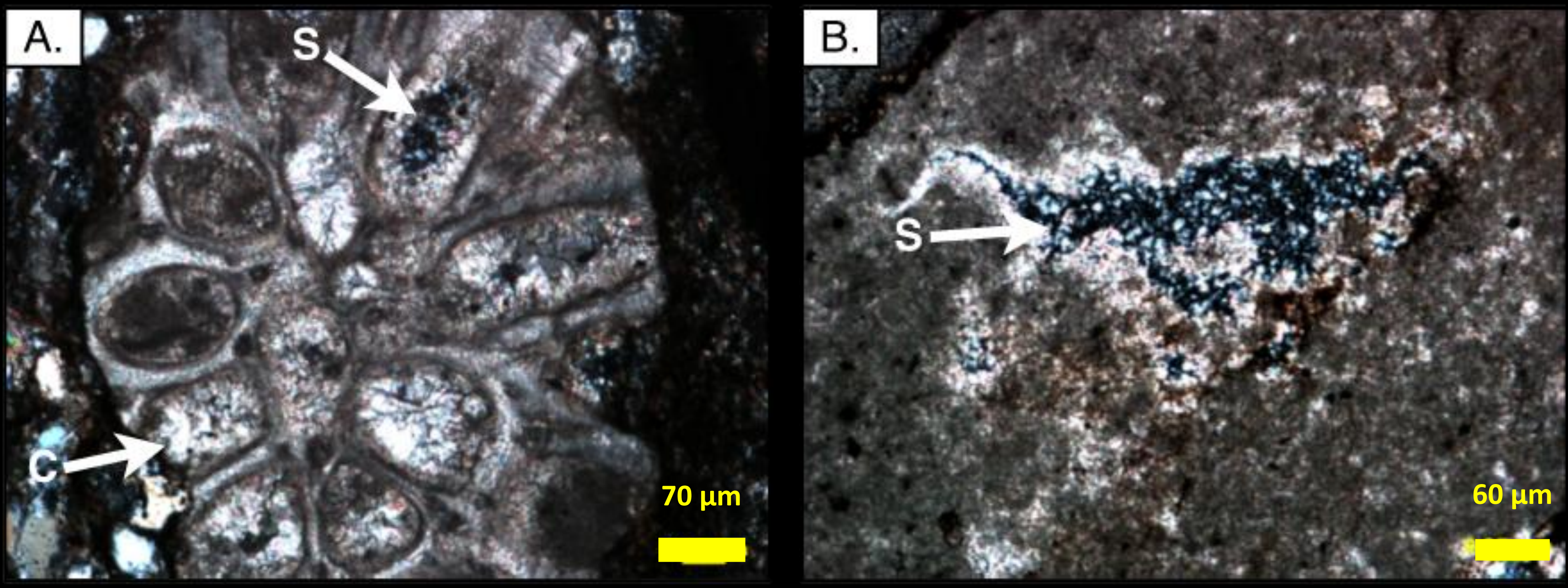
Richard Chelf #1 (Garfield County) & Tubbs #3 Noble County



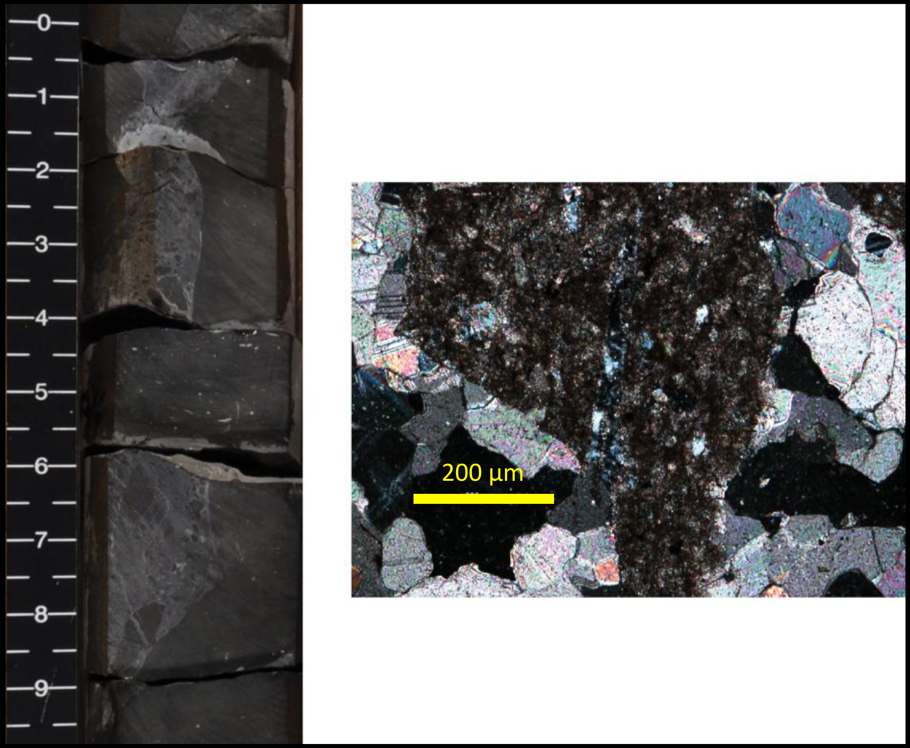
A. F. Severin core, Garfield County



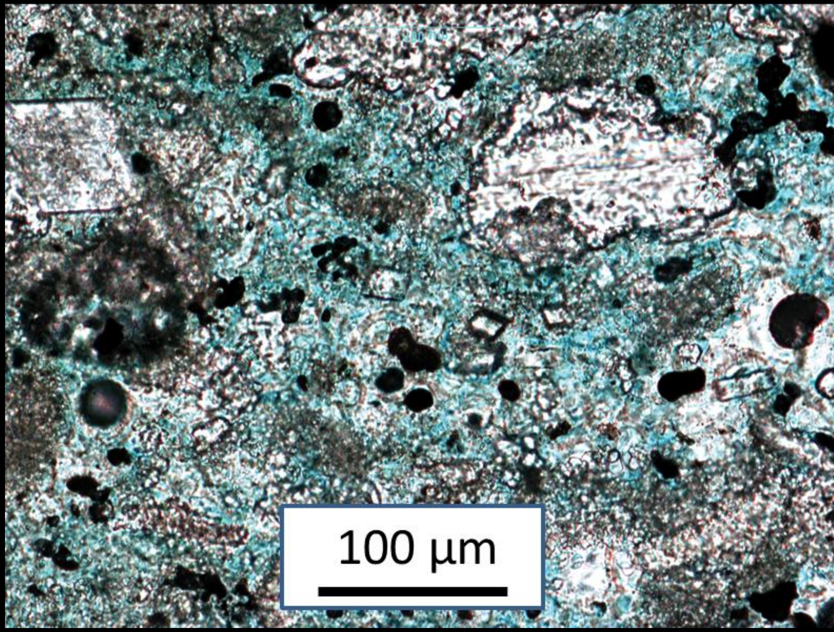
Early Silica and calcite



Chert breccia

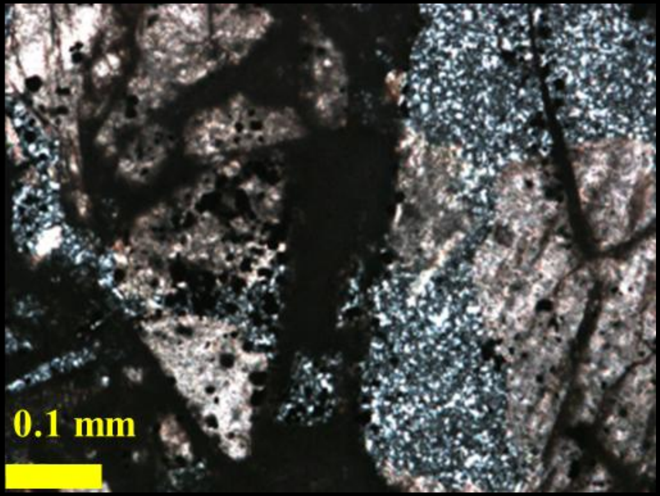


Porosity in
Chert breccia



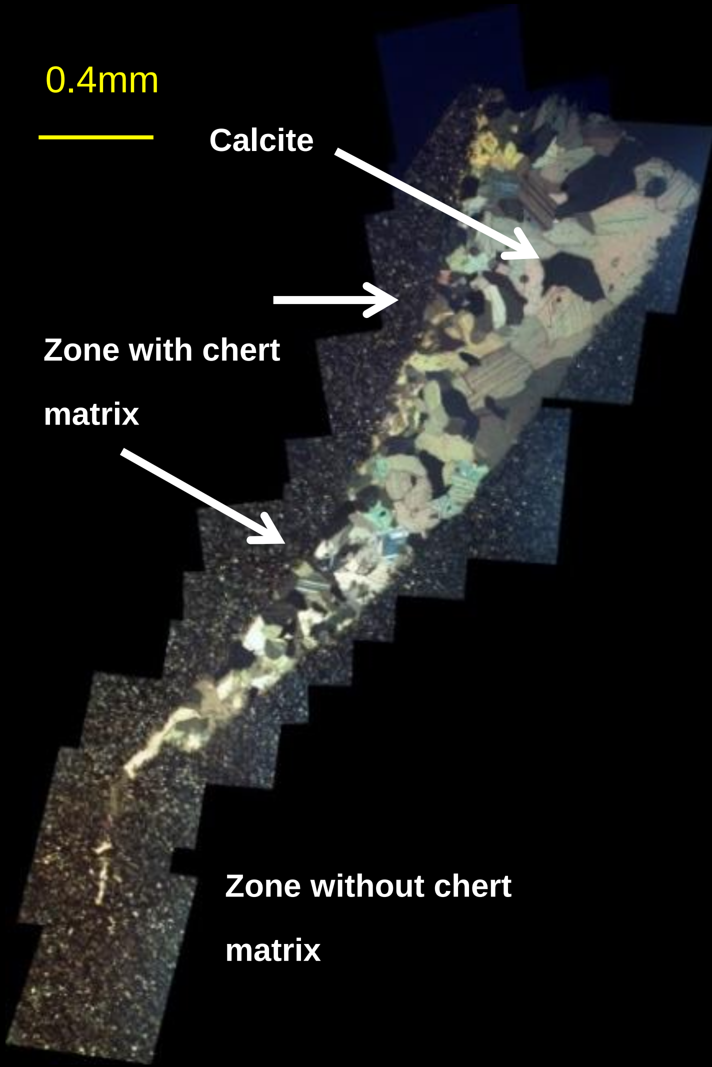
Chert Breccia (RC) – Fracture fill?

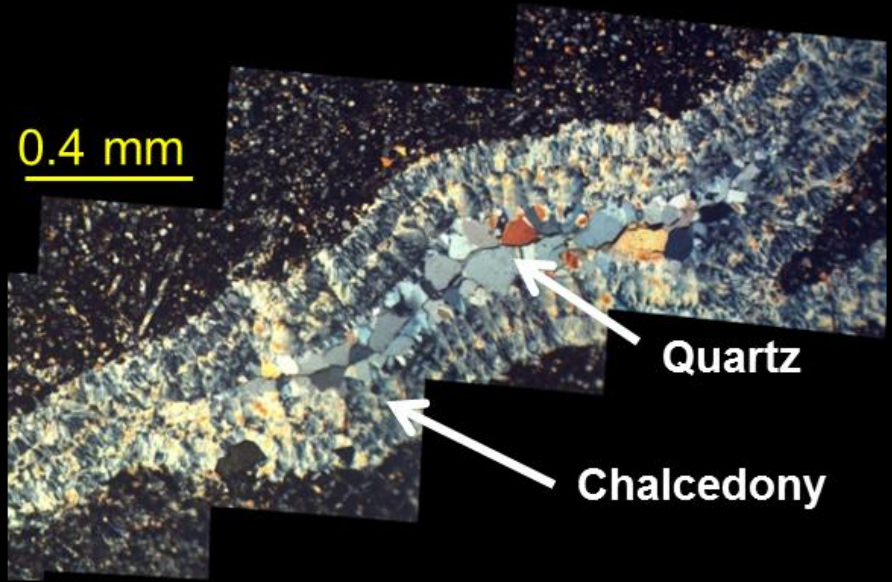
60 cm thick, middle of core

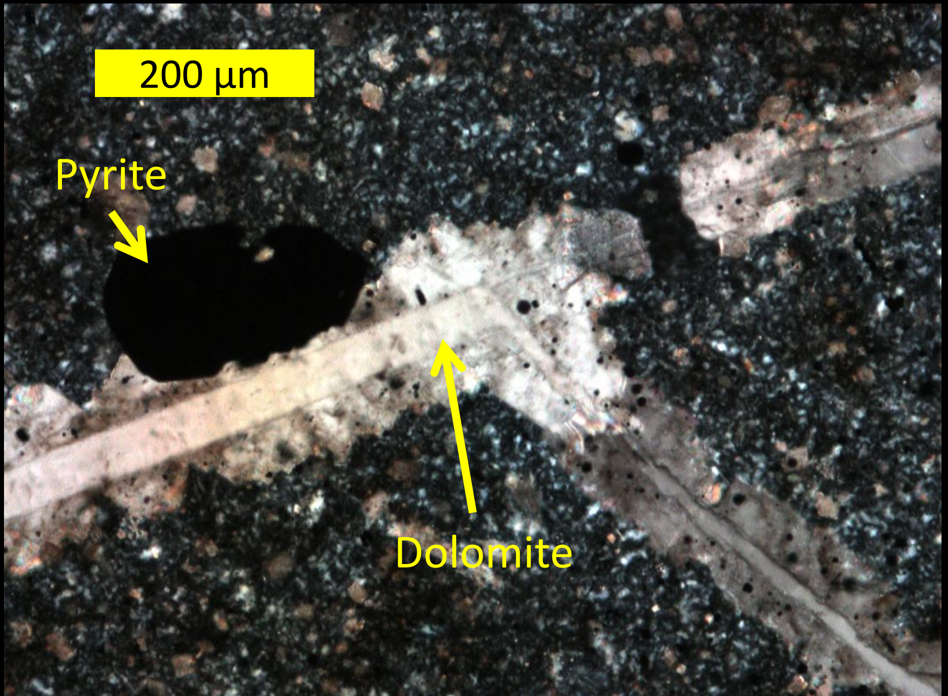


Yenugu et al. (2010) & Elebiju et al. (2011), based on seismic attributes, suggested some fractures are filled with chert and they may have been conduits for fluids

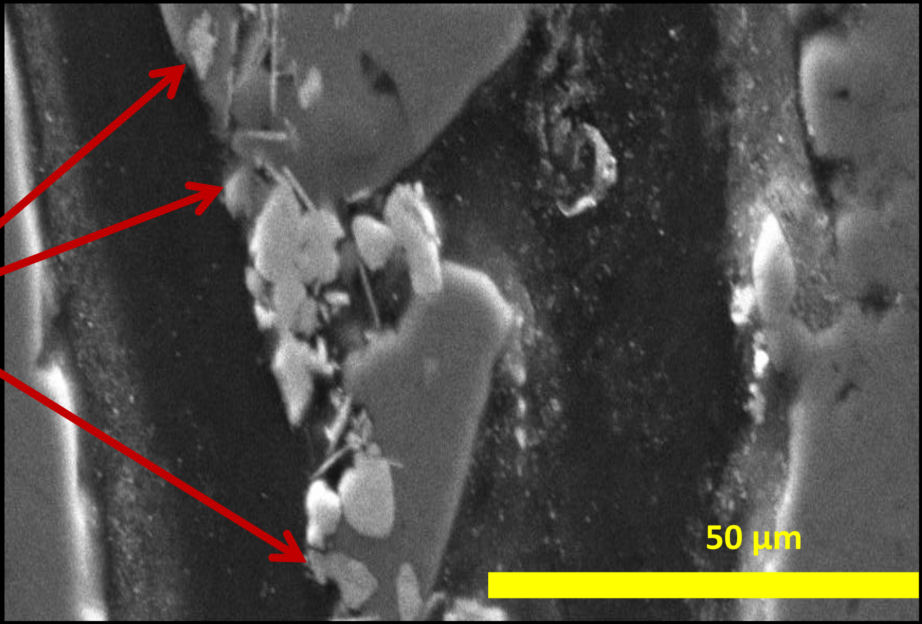
Fractures

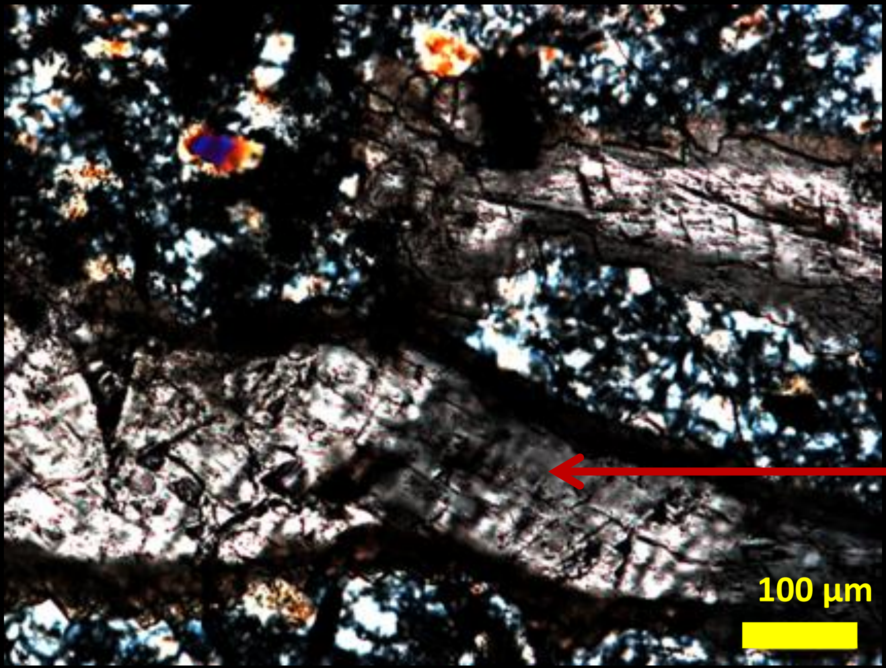

0.4mm
Calcite
Zone with chert
matrix
Zone without chert
matrix


0.4 mm
Quartz
Chalcedony


200 µm
Pyrite
Dolomite

Sphalerite



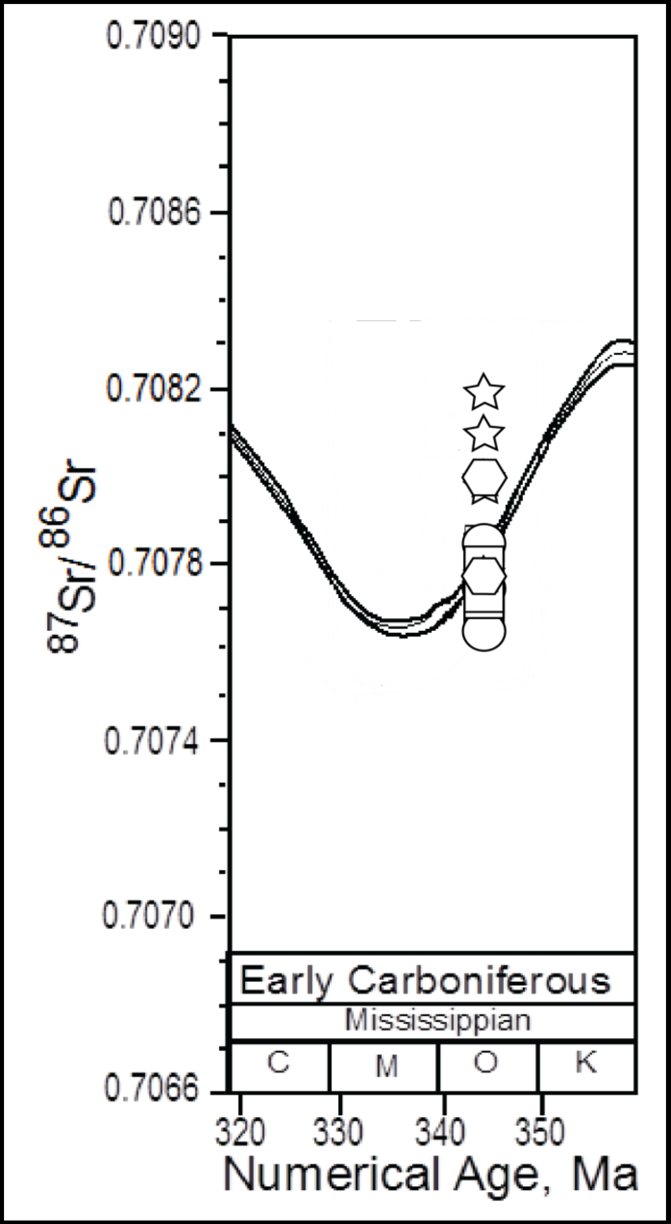


Baroque Dolomite

$^{87}Sr/^{86}Sr$ data

Some samples have elevated ratios but for some Mississippian

- ◯ Oldenberg #1-16 – 5 samples
- □ Sutton #1-16 – 5 samples
- ☆ Richard Chelf #1 – 6 samples
- ⬡ Tubbs #3 – 2 samples



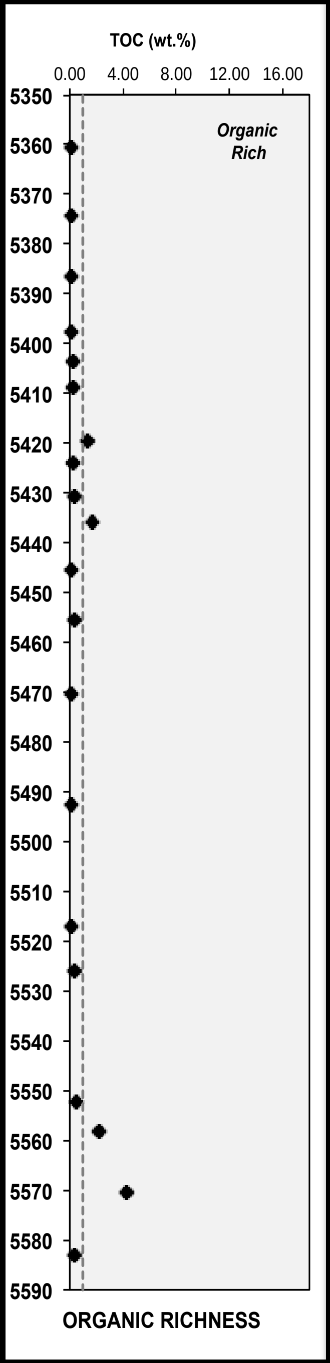
(Modified from McArthur et al., 2001)

TOC measurements

- Overall not organic rich
  - Most Samples: 0-1 wt. % TOC
  - Few 1-4 wt. % TOC

- Other cores have similar results

(plot modified from Humble Geochemical Services)



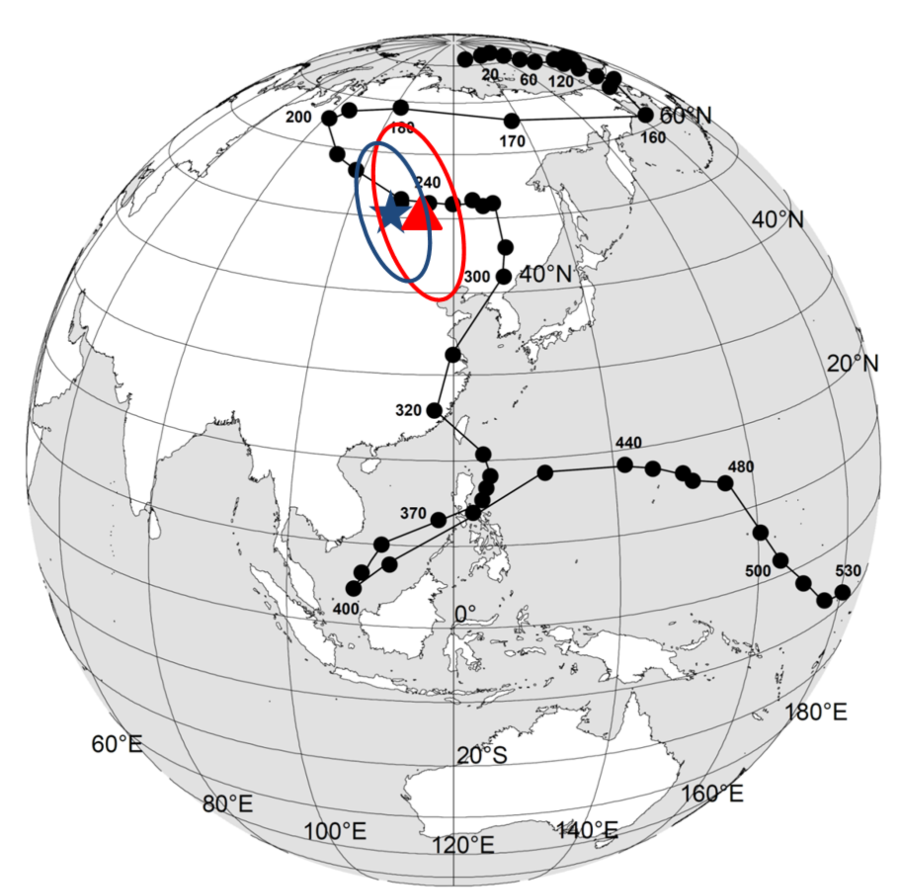
Paleomagnetism – Dating of diagenetic events

- Diagenetic processes cause authigenesis of magnetic minerals that acquire a chemical remanent magnetization (CRM) which traps the Earth’s magnetic field

- The timing of CRM determined by comparing the corresponding pole position to Apparent Polar Wander Path

- Geochemical, petrographic, and field tests are used to determine if the CRMs are related to specific diagenetic processes

Barnett CRM poles from oriented cores



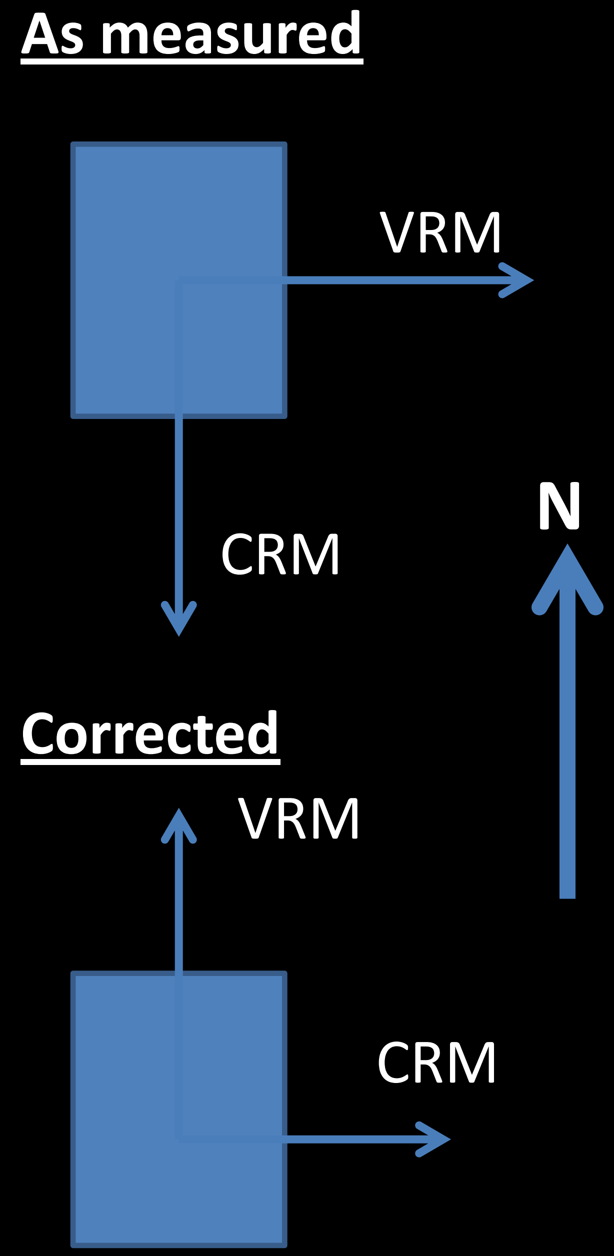
(Torsvik et al., 2012)

But if cores are not oriented?

Use VRM orienting method

VRM removed at low temperatures during demagnetization and the direction is aligned with the Modern magnetic field

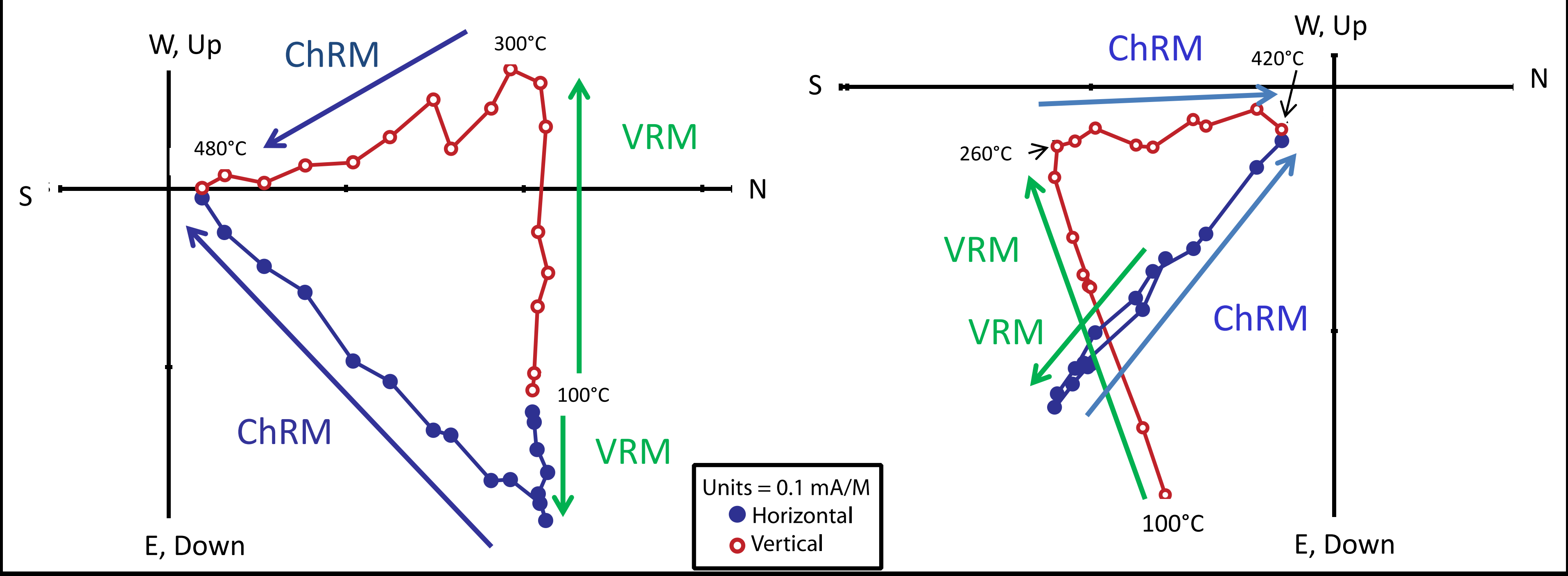
Isolate VRM, rotate the direction to the Modern direction, and rotate the CRM to the "correct" direction



Paleomagnetic Results

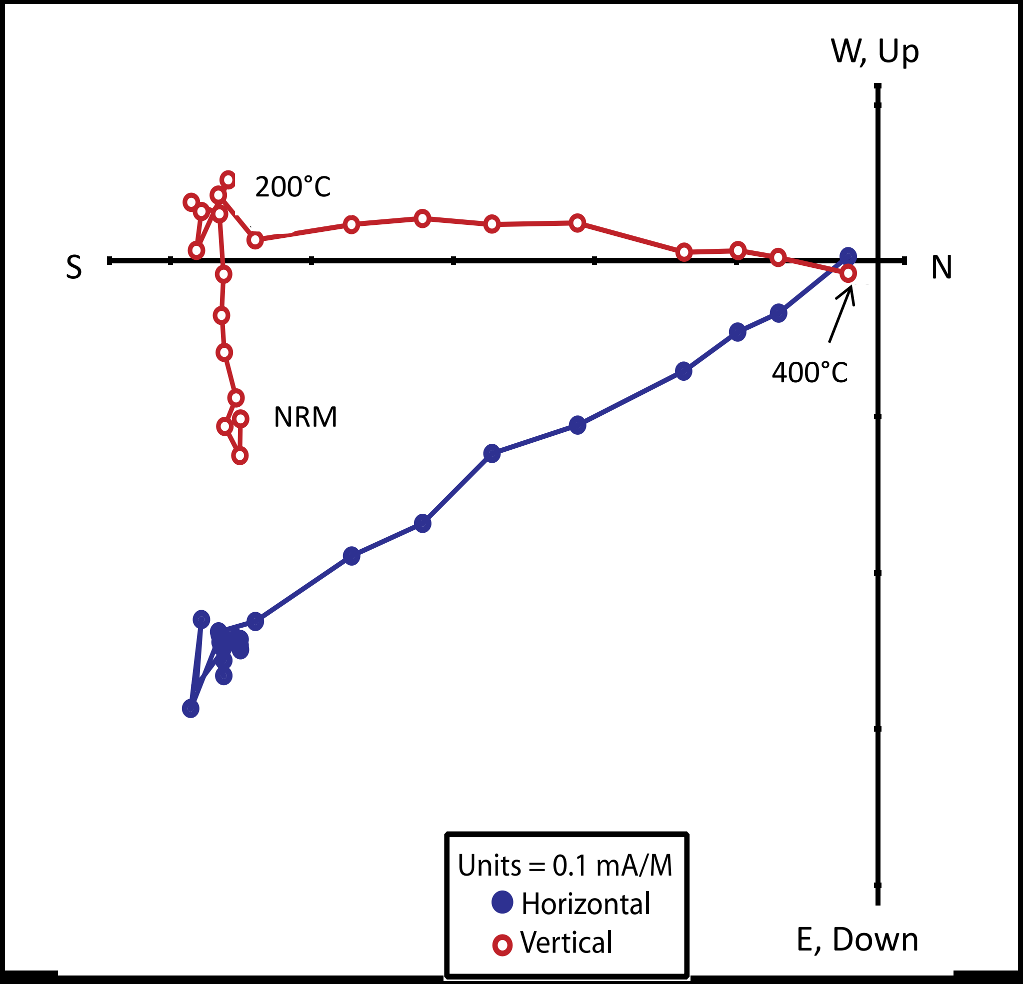
- Low temperature demagnetization removed < 5% of the natural remanent magnetization with no change in direction for pilot specimens
- VRM in some specimens
- No evidence of drilling-induced component
- Characteristic remanent magnetization (ChRM)

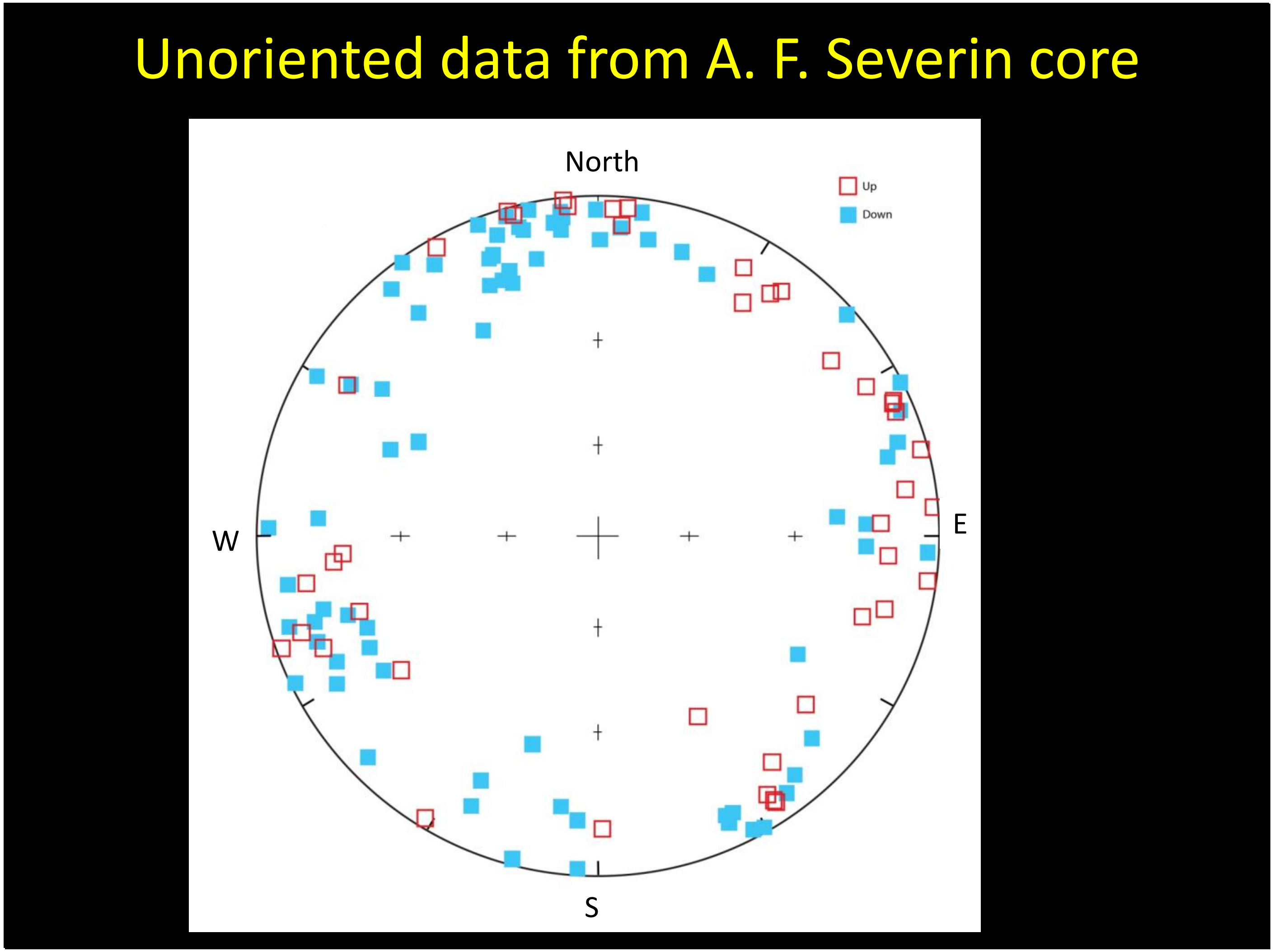
  480 C : resides in magnetite



- Poorly defined VRMs: data unable to be oriented
- ChRM

380°C - 440°C: magnetite

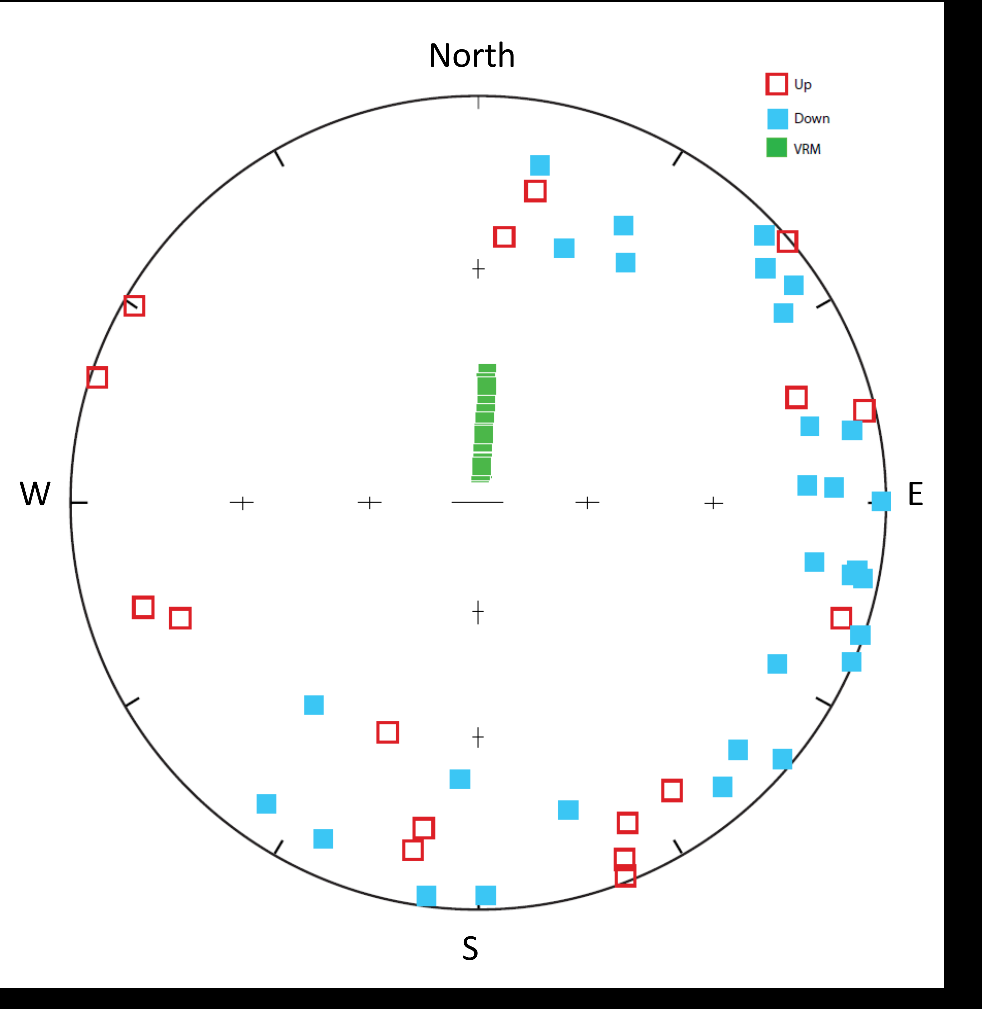




Presenter's notes: This plot of all of the ChRMs ignores the viscous components. Included are the additional data points from specimens without VRMs. 113 specimens had a ChRM, coming from 65 out of 126 of the individual sample sites. The average inclination for these components is -2.53 deg with a standard deviation of 9.58 deg.

Oriented

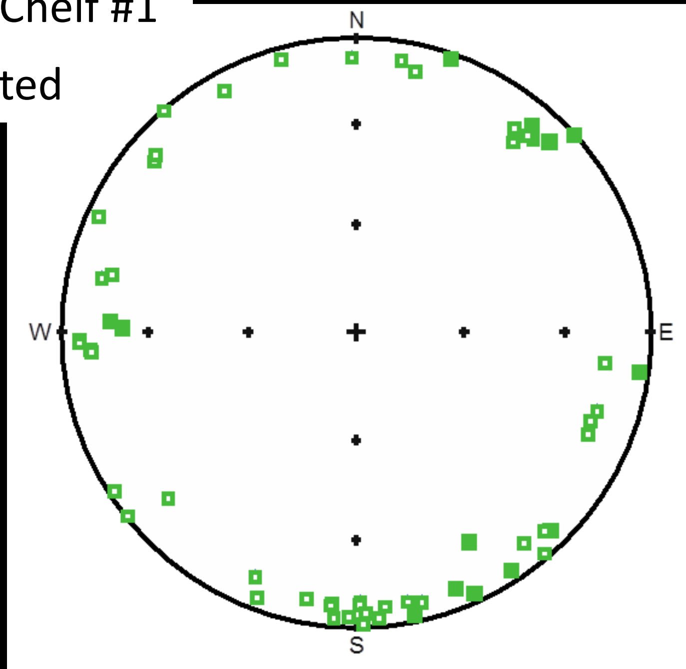
- Orienting with the VRM yielded no grouping of ChRMs



Presenter's notes: This equal area plot shows the data from specimens with a VRM and a ChRM. The VRMs are rotated. This did not produce any useful grouping of the ChRMs resulting in the streak. If they had grouped into a cluster anywhere, we would consider orientation with the VRMs successful.

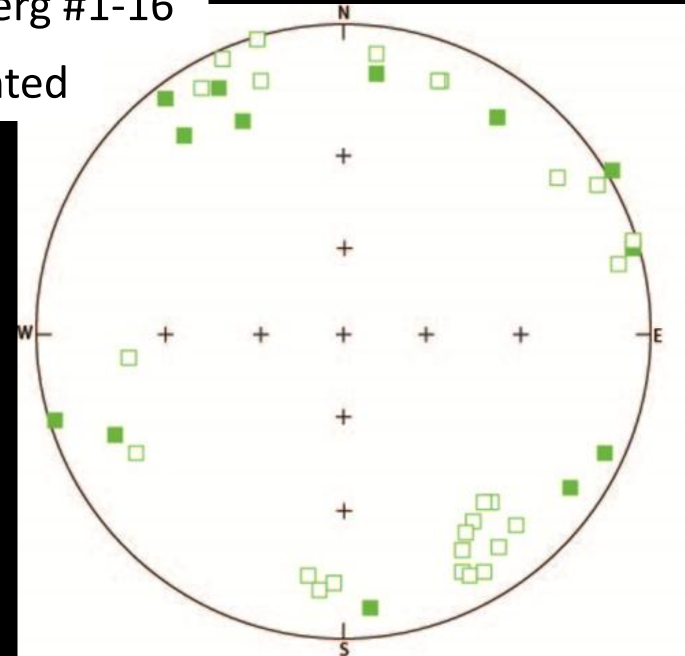
Richard Chelf #1

Unoriented

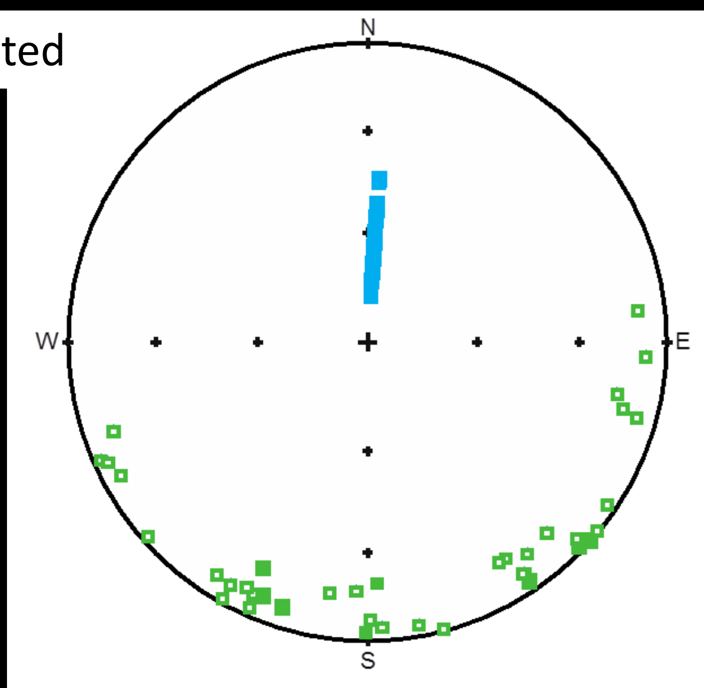


Oldenberg #1-16

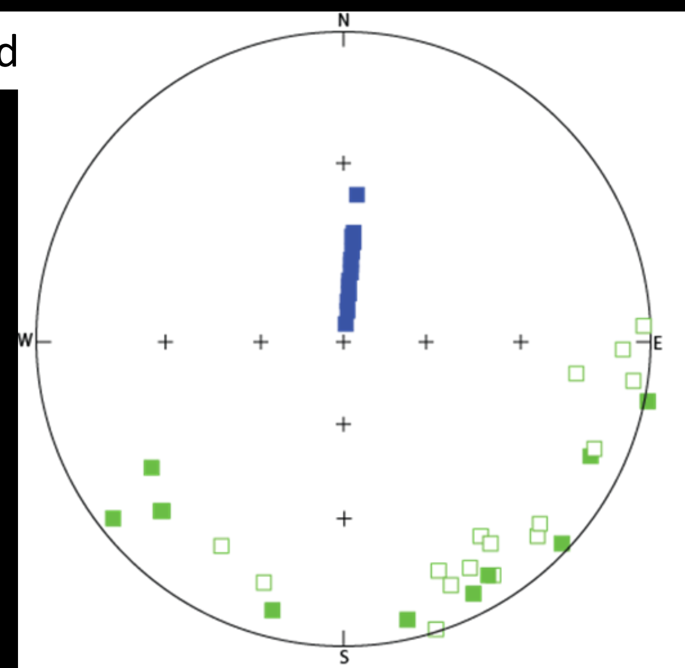
Unoriented



Oriented



Oriented

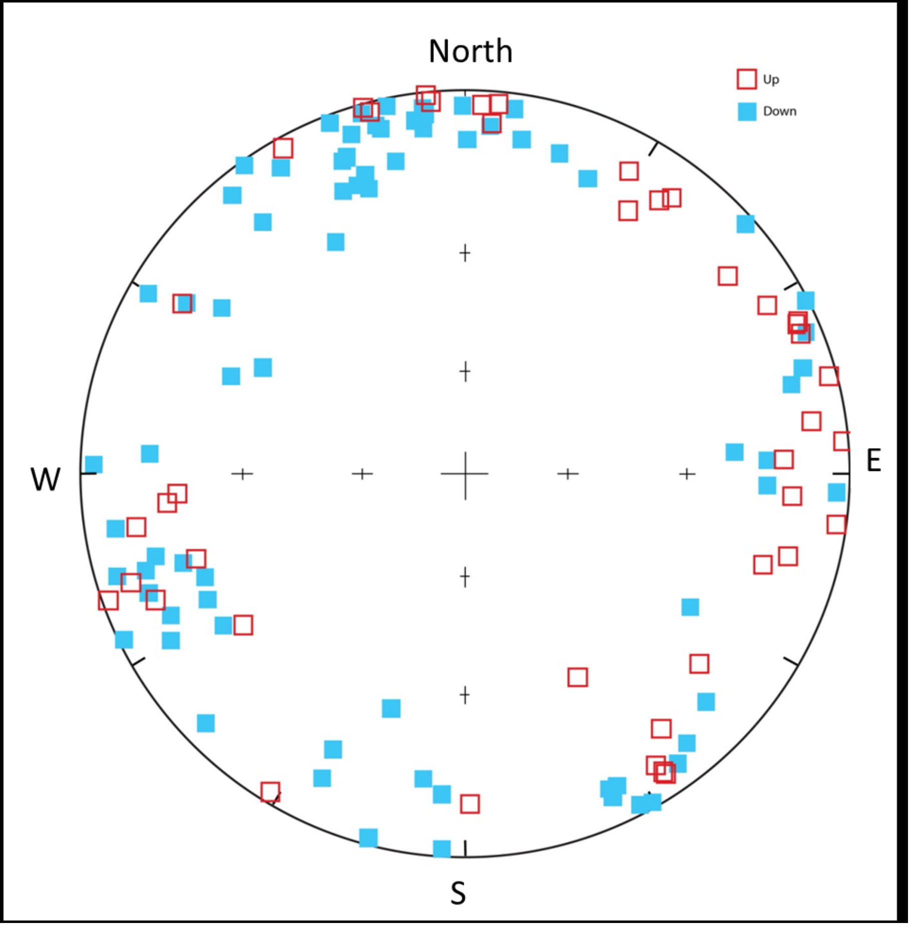


Unoriented

- A. F. Severin core: mean ChRM inclination = -1.7 , α_{95} = 1.7 , n = 104

 (McFadden and Reid, 1982)

- Other cores have a similar data distribution



Presenter's notes: This plot of all of the ChRMs ignores the viscous components. Included are the additional data points from specimens without VRMs. 113 specimens had a ChRM, coming from 65 out of 126 of the individual sample sites. The average inclination for these components is -2.53 deg with a standard deviation of 9.58 deg.

Expected Inclination

All specimens

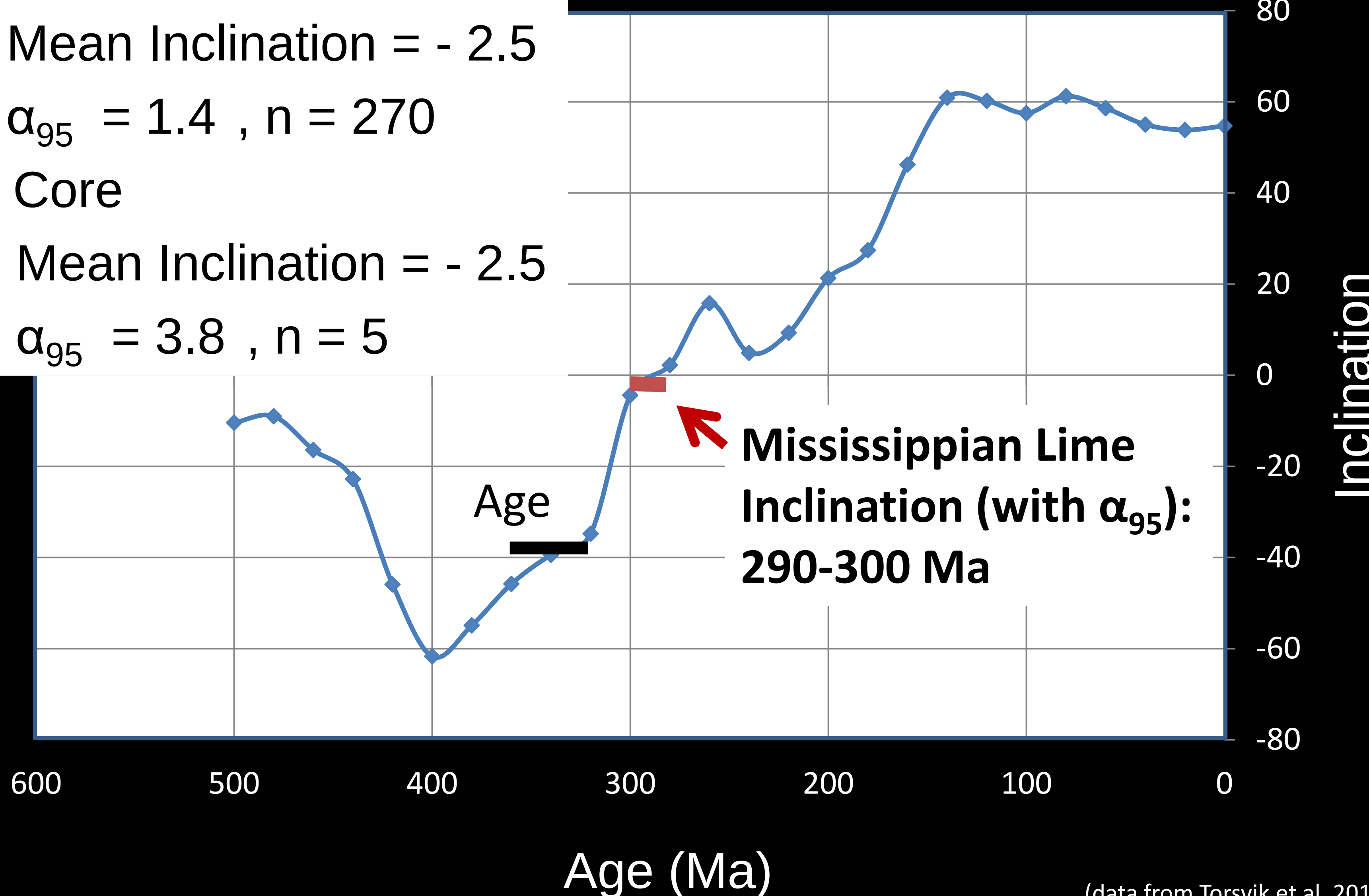
Mean Inclination = - 2.5

α_{95} = 1.4 , n = 270

By Core

Mean Inclination = - 2.5

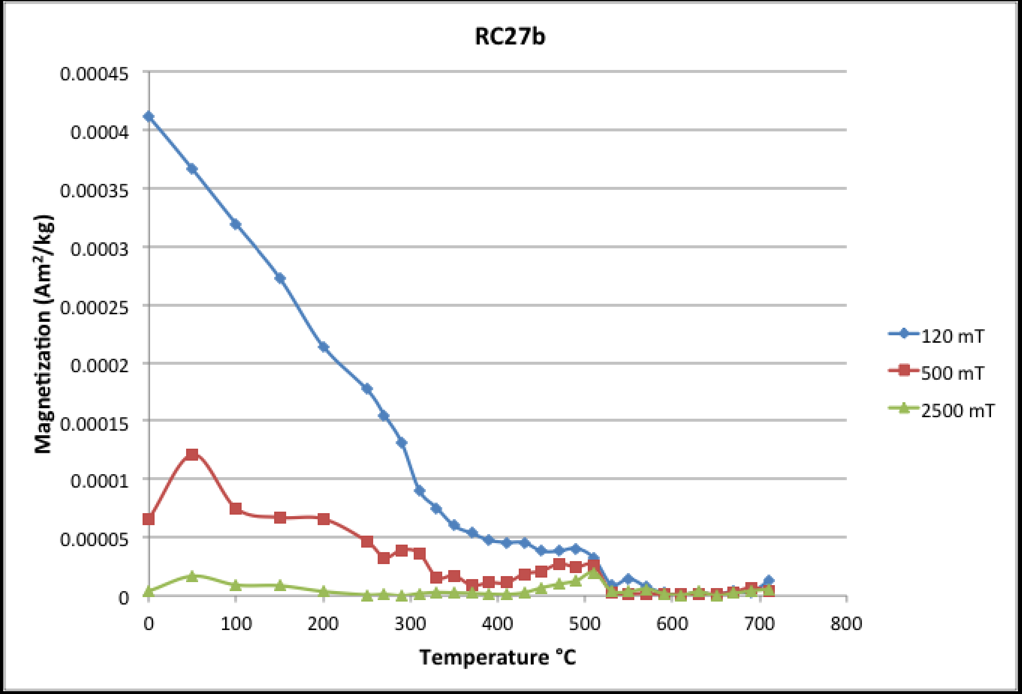
α_{95} = 3.8 , n = 5

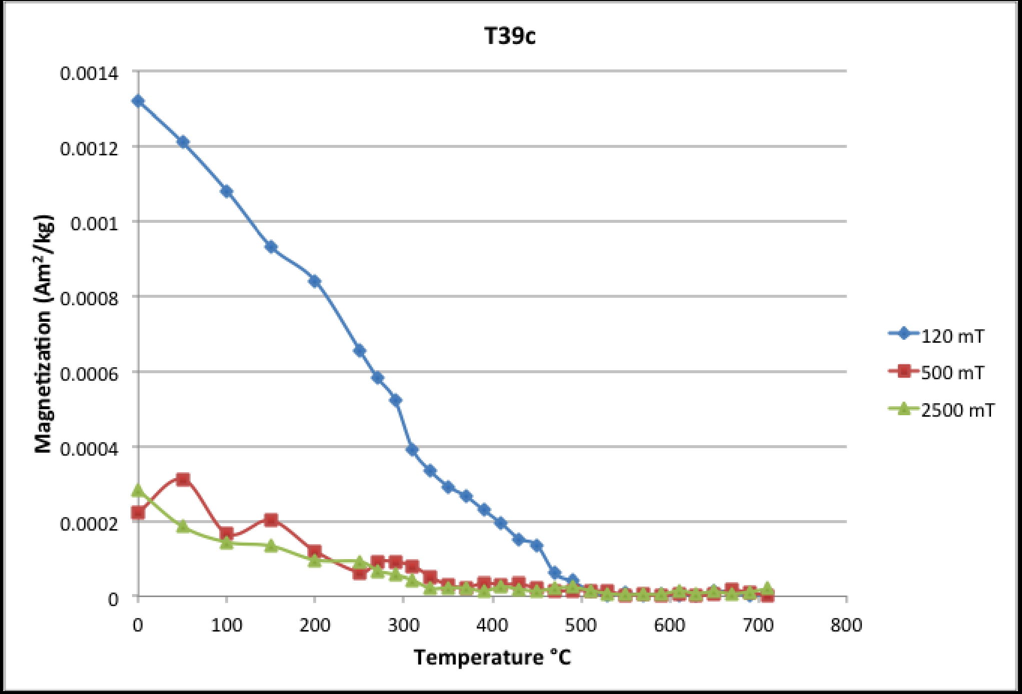


(data from Torsvik et al. 2012)

Rock Magnetism

- Triaxial decay curves
  - Magnetite
    - Low coercivity curve (120mT)
      - Decays by 580°C





Origin of ChRM

Low burial temperatures – Chemical remanent magnetization (CRM)

Timing of CRM is 290-300 Ma (Permian)

CRM mechanism

- External fluids
  - Some samples have elevated $^{87}Sr/^{86}Sr$ ratios but for some Mississippian
  - Baroque Dolomite and Sphalerite suggest external fluids

- Burial Processes - Maturation of organic matter

  But low (~1%) TOC

Sphalerite

Discussion

- Permian timing of CRM acquisition
- Permian age consistent with hypothesized hydrothermal system (Phase 2 – Permian to post-Permian; Goldstein & King, 2014) based on fluid inclusions, $\delta^{18}O$, Sr isotopes, MVT minerals
  - Radiometric and paleomagnetic dating of MVT deposits in tri-state area resulted in a Late Permian – Early Triassic age (Symons et al., 2005; Brannon et al., 2006)
  - Sphalerite, Baroque Dolomite, Sr isotopes
  - Fractures with breccias (fault tectonism?) could have been conduits for fluids

Conclusions

- When oriented with VRM - Streaked data
  - VRM orienting method does not work
    - Alternative - Use FMI logs

- Timing of Permian CRM consistent with hypothesized migration of hydrothermal fluids into the Mississippian Limestone
  - These fluids probably enhanced porosity