Measuring carbon isotopic variations and their relationship to dolomitization in the Devonian Jefferson Formation

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Abstract

The Jefferson Formation (Late Devonian) of western Montana is a ~170 m thick package of dolomite that represents cyclic deposition along a shallow carbonate platform during the Frasnian (382.7 – 372.2 Ma). Variations and patterns in dolomitization have long been recognized in the Jefferson Formation but no recent studies have attempted to explore the relationship between dolomitization, cyclicity, depositional environment, and recorded stable carbon isotopic values. For this study, we test two hypotheses: 1) that dolomitization and carbon isotopic alteration increase to the west in more basin-ward sections and 2) that dolomitization and carbon isotopic alteration increase toward cycle tops. We test these hypotheses by focusing on four sections in western Montana: Baker Mountain, Sacagawea Peak, Cottonwood Canyon Road, and Gibson Reservoir. We present 475 new carbon isotopic values paired with detailed sedimentological and petrographic observations. Carbon isotopic values range from -4.44‰ to 3.68‰ with an average of 0.36‰ and fall within the range of typical values for the Late Devonian. We found that carbon isotopic values from western sections are statistically distinct from our easternmost section. These initial results are consistent with hypothesis one, which merits further exploration. The relationship between dolomitization carbon isotopes and cyclicity is not as straightforward as indicated in hypothesis two.

Project Motivation

This project was designed to text two hypothesis from the scientific literature about the nature of dolomitization and geochemical alteration in the Jefferson Formation (e.g. Smith and Dorobek 1989).

- **Hypothesis 1:** Dolomitization and carbon isotopic alteration increases westward in the Jefferson Formation. This geographical trend was proposed to reflect increased brine influence from the overlying Three Forks Formation (Smith and Dorobek, 1989).
- **Hypothesis 2:** Dolomitization and carbon isotopic alteration increases upward within shallowing-upwards parasequences.

To test these hypotheses, we deploy a series of statistical tests which have been performed in SPSS (IBM Corp, 2021).

Depositional Environments of the Jefferson Formation

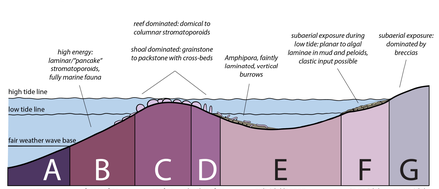


Figure 1: *Range of environments represented in the Jefferson Formation. Facies associations used in this study are indicated with letters and are modified from Da Silva and Boulvain (2004).*

Hypothesis 1, Test 1: Compare carbonate carbon and oxygen isotopic values in study sections along an east-to-west transect. If Hypothesis 1 is supported, we expect to observe western-most section (Gibson Reservoir) to be distinct from the eastern-most section (Baker Mountain).

Figure 2: *Frequency distribution curves for carbon isotopic values as a function of study section. Moving from west to east our sections are Gibson Reservoir, Cottonwood Canyon Road, Sacagawea Peak, and Baker Mountain. ANOVA tests indicate that there is a statistically significant difference in the carbon isotopic values of Cottonwood Canyon Road when compared to the other sections. (p-value: <0.001) but not for Gibson Reservoir and Baker Mountain (p-value: 0.333)*

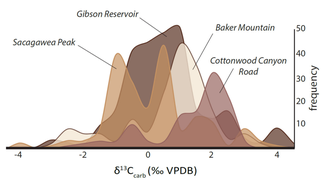
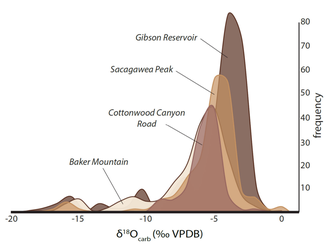


Figure 3: *Frequency distribution curves for oxygen isotopic values as a function of study section. Moving from west to east our sections are Gibson Reservoir, Cottonwood Canyon Road, Sacagawea Peak, and Baker Mountain.) ANOVA tests indicate that there is a statistically significant difference in the oxygen isotopic values of the study sections p-value: <0.001).*



Hypothesis 2, Test 1: Qualitative comparison of trends within shallowing-upwards parasequences. If Hypothesis 2 is supported, we expect to observe systematic changes in carbon isotopes upwards within shallowing-upward parasequences.

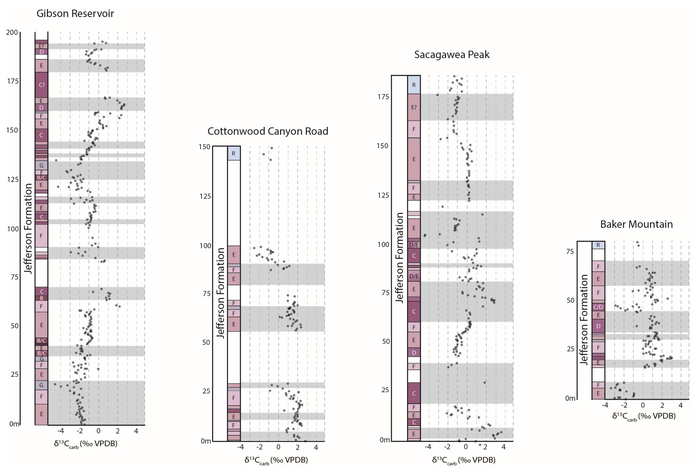


Figure 5: *Carbon isotopic results for study sections along a west to east transect. Facies associations are indicated with a letter and color. Parasequences are marked with alternating grey and white boxes.*

Conclusions

Hypothesis 1: There is increased dolomitization and carbon isotopic alteration in western sections.

- We do observe statistically significant differences in the carbon isotopic values of our study sections, but not in the manner predicted. Instead, we find that Cottonwood Canyon Road (a section in the middle of the east-to-west transect) is distinct
- We do observe statistically significant differences in the oxygen isotopic values of our study sections that matches our prediction. Our westernmost section (Gibson Reservoir) is distinct from the eastern-most section (Baker Mountain).
- We find no systematic statistically significant differences in the carbon isotopic values of dolomite vs. calcite.
- We did find systematic statistically significant differences in the oxygen isotopic values of dolomite vs. calcite.

Interpretation: Oxygen isotopic values do follow a pattern consistent with hypothesis 1 but there is no compelling evidence that carbon isotopic values are altered in a systematic manner.

Hypothesis 2: Carbon isotopic alteration increases upward within shallowing-upwards parasequences

- We do no observe systematic patterns in carbon isotopic values related to shallowing cycles.
- We do observe statistically significant differences in the carbon isotopic values of facies associations but not in the manner predicted. Instead, shallow and deeper water facies are consistent, but the lagoonal facies is distinct.
- We do observe statistically significant differences in the oxygen isotopic values of facies associations but not in the manner predicted.

Interpretation: Carbon and oxygen isotopic values do not follow a pattern consistent with Hypothesis 2.

References

- Da Silva, A.C. and Boulvain, F., 2004. From palaeosols to carbonate mounds: facies and environments of the middle Frasnian platform in Belgium. Geological Quarterly, v. 48(3), p. 253-266.
- IBM Corp, 2021. IBM SPSS Statistics for Windows, Version 28.0. IBM Corp, Armonk, NY.
- Smith, T.M. and Dorobek, S.L., 1989. Dolomitization of the Devonian Jefferson Formation, south central Montana. The Mountain Geologist, v. 26, p. 81-96

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Hypothesis 1, Test 2: Compare carbonate carbon and oxygen isotopic values of dolomite vs. calcite samples. If Hypothesis 1 is supported, we expect to observe a systematic difference between these datasets.

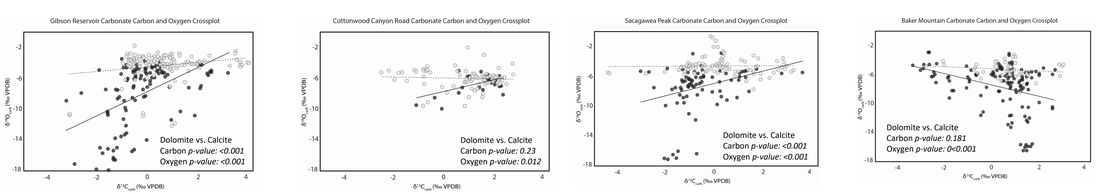

Figure 4: *Cross-plot of carbonate oxygen and carbon isotopic values for each study section. The grey dots indicate dolomitic samples, and the black dots indicate calcitic samples. If there is a relationship between dolomitization and geochemical values, we would expect the dolomite samples to be systematically different from calcite. We find no systematic statistically significant differences in the carbon isotopic values of dolomite vs. calcite in Cottonwood Canyon Road, Sacagawea Peak, and Baker Mountain. We do observe statistically significant differences in the carbon isotopic values of dolomite vs. calcite at Gibson Reservoir. We did find systematic statistically significant differences in the oxygen isotopic values of dolomite vs. calcite.*

Hypothesis 2, Test 2: Use ANOVA tests to determine if there are statistically significant differences in carbonate carbon and oxygen isotopic values as a function of facies association. If Hypothesis 2 is supported, we expect to observe that shallow water facies (E, F, and G) are distinct from deeper water facies (D, C, B, and A).

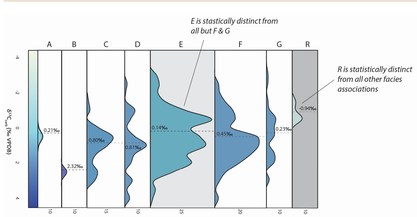

Figure 6: *Frequency distribution curves of carbon isotopic values as a function of facies association. ANOVA analysis indicates that are statistically significant differences among the facies associations (p-value: <0.001).*

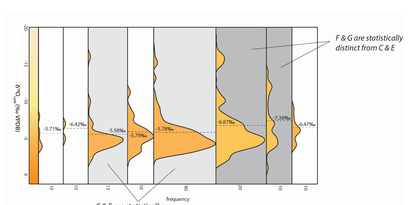

Figure 7: *Frequency distribution curves of oxygen isotopic values as a function of facies association. ANOVA analysis indicates that are statistically significant differences among the facies associations (p-value: <0.001).*