Comparing Joint Orientation in the Sioux Quartzite and Oneota Dolomite

By

Keenan Day Diggins

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Under the supervision of Rory McFadden

ABSTRACT

The Sioux Quartzite and Oneota Dolomite are two major lithologic units exposed in southern Minnesota. Despite both formations being heavily fractured, jointing has not been extensively studied in either formation. Joint orientations were compared in the Sioux Quartzite and Oneota Dolomite. Sioux Quartzite joints (n=190) were measured at the Jeffers Petroglyphs site, while Oneota Dolomite joints (n=127) were measured at a quarry near Kasota, Minnesota. The vast majority of joints studied were vertical or near vertical, so dip was generally not measured. Measurements were taken systematically to avoid duplicate measurements. Fractures attributed to freeze-thaw were not measured. Data were then examined using rose diagrams. This revealed three potential joint sets common to both formations, with average azimuth orientations of approximately 55°, 120°, and 165°. If these are indeed related joint sets, this would suggest that the development of these joints postdates the 485-478 Ma deposition of the Oneota Dolomite (Mossler, 2008). Comparisons made in the 55° and 165° sets are inconclusive, however, given the insufficient number of Oneota Dolomite measurements representing these sets (N=9 in the 55° set, and N=13 in the 165° set). While there is strong evidence that the 120° joint set exists in both formations, it is necessary to collect more data in the Oneota Dolomite to test the validity of the other two joint sets.

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INTRODUCTION

Joint orientation measurements have several applications. Firstly, they can be correlated to the regional strike, as they are in Holst and Foote (1981), to help develop a more complete picture of a region's geologic history. Any discrepancies between joint orientation and regional strike can be used to rule out causal events. Moreover, understanding local patterns of jointing has application in hydrogeology, as jointing is the dominant means of groundwater storage in many aquifers.

The geology of the upper Midwest has been altered by several major orogenic events since the Paleozoic. These include the Ouachita, Taconic, Acadian, and Alleghanian orogenies. Orogenic events occurring as far from Minnesota as the Appalachians have been shown by Craddock and van der Pluijm (1989) to affect Minnesotan geology, so they should be considered as possible causes of jointing in Minnesotan rock.

The Sioux Quartzite is a 1,729-1,615 Ma (Southwick, 2014) unit outcropping in Minnesota, South Dakota, and Iowa. The Oneota Dolomite is much younger, at 485-478 Ma (Mossler, 2008). Jointing has not been extensively studied in either of these formations. This study focuses on two particular outcrops; a Sioux Quartzite outcrop at the Jeffers Petroglyphs site in southwestern Minnesota, and an Oneota Dolomite outcrop at a quarry near Kasota, Minnesota. The two outcrops are approximately 90 km apart, comparable to the distance between outcrops studied by Holst and Foote (1981). Figure 1 situates the region of study on a map of the United States, while figure 2 shows the relative locations of the two outcrops studied.

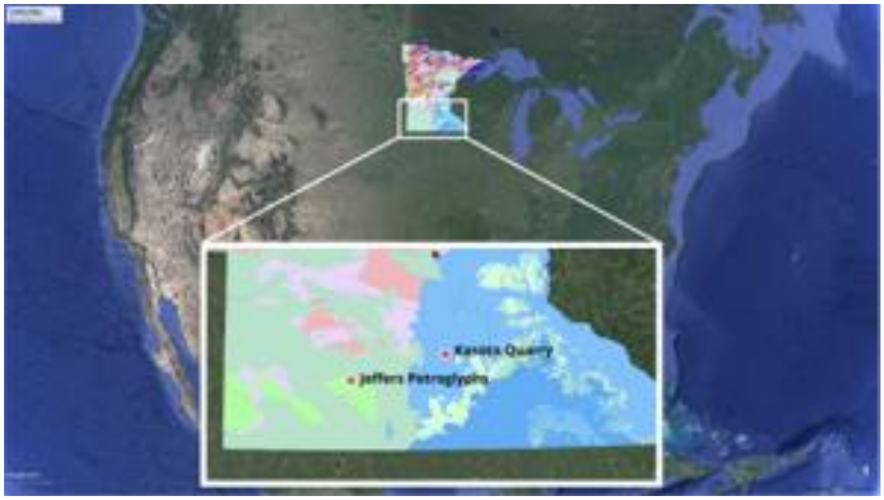

Figure 1: Area of study on map of U.S. (Nicholson et al.)

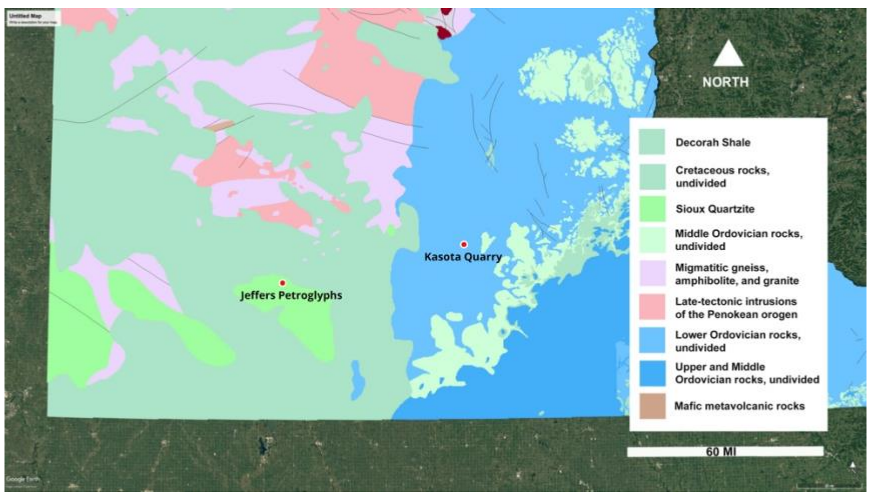

Figure 2: Locations of Jeffers Petroglyphs and Kasota quarry sites (Nicholson et al.)

The trends (orientations of lines) of Oneota Dolomite and Sioux Quartzite joints were recorded as azimuth measurements (numbers between 0 and 360 communicating strike direction). The comparison of many trend measurements may reveal the presence of systematic joints, occurring as sets of joints of similar orientations spaced at relatively even intervals. By comparing jointing in the Sioux Quartzite and Oneota Dolomite formations, this study seeks to evaluate whether the two formations share any common joint sets.

GEOLOGIC SETTING

The Sioux Quartzite is a Proterozoic formation outcropping in Southwestern Minnesota, Eastern South Dakota, and Northwestern Iowa. The unit is light pink in color due to the presence of iron oxide (Ojakangas and Weber, 1984). The unit is made up of mature to supermature quartz arenite grains, suggesting fluvial deposition prior to metamorphism (Ojakangas and Weber, 1984). The Sioux Quartzite was metamorphosed between 1,729 and 1,615 million years ago, placing the age of metamorphism within the Baraboo interval (Southwick, 2014). Koch suggested that the formation was later uplifted in the late Cretaceous (1986). The southwestern boundary of the formation in eastern South Dakota and northeastern Nebraska is a fault, trending N50W, which separates the Sioux Quartzite from a 3-3.6Ga gneiss to the south (Houser, 1987). Houser (1987) suggested that there may have been movement along this fault as recently as the late Cretaceous. This study focuses on the Sioux Quartzite outcrop at the Jeffers Petroglyphs site in southern Minnesota, (figure 3).

The Oneota Dolomite is an Ordovician (485-478 Ma) unit outcropping in southeastern Minnesota and northeastern Iowa (Mossler, 2008). The unit falls within the Prairie Du Chien Group of aquifers, making it an important reservoir of groundwater in Southern Minnesota. The Oneota Dolomite is subdivided into two members, the Hagar City Member and the underlying Coon Valley Member (Mossler, 2008). The Hagar City Member is generally characterized as a silty dolostone, while the Coon Valley Member is characterized by interbedded sandstone and sandy dolostone (Mossler, 2008). The unit's thickness varies greatly, from around 15m near the Twin Cities to 55m near the Iowa border (Mossler, 2008). The upper portion of the Hagar City Member is the most heavily fractured portion of the unit (Runkel et al., 2003). Runkel et al.

(2003) describe two types of fracturing in the Oneota: high angle, stress-relief related fractures; and planar, vertical fractures (2003). This study focuses on an Oneota Dolomite outcrop located at a quarry near Kasota, Minnesota (figure 4).

The geology of the upper Midwest has been influenced by several major tectonic events since the 485 Ma formation of the Oneota Dolomite, including the Ouachita, Taconic, Acadian, Alleghanian, and Laramide orogenies. These orogenies make up some of the possible causes of jointing in the Sioux Quartzite and Oneota Dolomite.

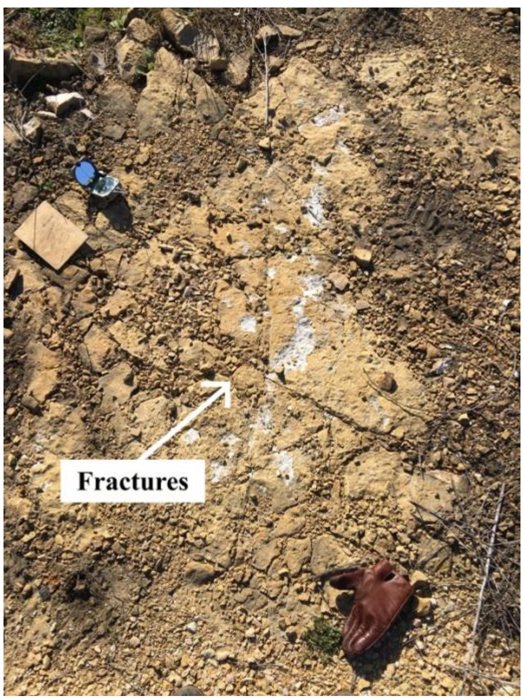

Figure 4: Oneota Dolomite Outcrop at a Quarry Near Kasota, MN.

Figure 3: Sioux Quartzite Outcrop at the Jeffers Petroglyphs Site.

METHODS

The trend orientations of fractures in the Oneota Dolomite and Sioux Quartzite were measured. As all fractures were near vertical, dip angles were difficult to determine and generally not measured. Measurements were taken using a Brunton compass and recorded in azimuth notation. Oneota Dolomite measurements were taken at a dolomite quarry located in Kasota, MN (44° 14’ 27”N, 93° 59’ 21”W). Measurements were taken on a flat surface above the quarry walls. The research was conducted over the course of two days, with different exposures studied on the second day. Individual exposures were generally small (roughly 2x2m), and each exposure was analyzed in its entirety before moving on to the next to avoid duplicate measurements. Fractures clearly representing freeze-thaw fracturing were not measured. Figure 5 represents a fractured Oneota Dolomite exposure. The trend orientations of the fractures were then plotted on a rose diagram (figure 7).

Sioux Quartzite measurements were taken at the Jeffers Petroglyphs site (44° 5’ 32”N, 95° 3’ 9”W). All measurements were taken on a flat exposure of rock. Measurements were taken over the course of two days, with a different exposure studied on the second day to prevent duplicate measurements. First, the outcrop was sectioned off into roughly 4x4m squares. All identifiable fractures within the section were then measured. Fractures which clearly represented freeze-thaw were not measured. Figure 6 represents a fractured Sioux Quartzite exposure. The trend orientations of fractures were plotted on a rose diagram (figure 8).

Figure 5: Fractured Oneota Dolomite exposure (glove for scale)

Figure 6: Fractured Sioux Quartzite Exposure (gloves for scale).

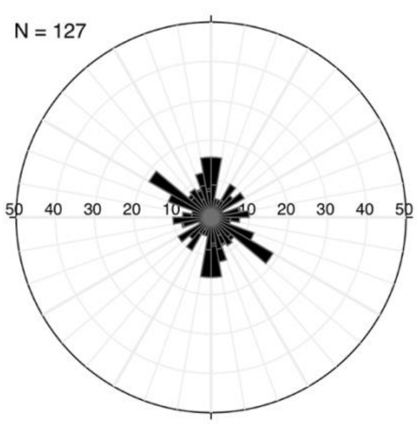

Figure 7: Oneota Dolomite Rose Diagram. Radial numbers represent the number of measurements making up each bin.

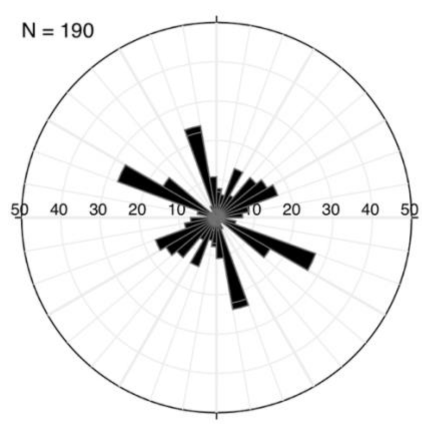

Figure 8: Sioux Quartzite Rose Diagram. Radial numbers represent the number of measurements making up each bin.

RESULTS

The joint orientation data were analyzed using rose diagrams. Figure 7 represents the trends of Oneota Dolomite joints and figure 8 represents the trends of Sioux Quartzite joints. The circular diagram reads like a compass, with the length of each ‘petal’ corresponding to the relative number of joints of that orientation. Relatively long petals, therefore, are indicative of joint sets. It is important to keep in mind that the radial numbers of the rose diagrams refer to the number of measurements, rather than the percentage of measurements. Because the Sioux Quartzite has n=190 measurements while the Oneota Dolomite only has n=127, the Sioux Quartzite diagram’s petals are generally longer. The Sioux Quartzite displays three distinct joint sets, with mean orientations of 165° (n=40), 117° (n=37), and 50° (n=81). Similarly, the Oneota Dolomite displays three distinct joint sets, with mean orientations of 170° (n=13), 125° (n=27), and 63° (n=9). It should be noted that the Sioux Quartzite outcrop at the Jeffers Petroglyphs site displays regional preferences for specific joint sets, with the eastern third of the site almost exclusively containing joints of the 50˚ joint set. The n value in the upper left corner of each diagram depicts the number of measurements making up the data.

Figures 9 and 10 are histograms representing joint spacing data for the 165˚ and 50˚ Sioux Quartzite joint sets. The x-axis represents the distance between joints of the same set, while the y-axis displays the number of measurements making up each bin. The n number in the bottom right-hand corner displays the number of measurements making up the data set. It is worth noting the much greater variety of spacings, as well as the generally further spacings in the 50.6° set. The 50.6° set has an average joint spacing of 99.2 cm, while the 165.2° set has an average spacing of 41.8 cm. Similar measurements were not possible at the Oneota Dolomite site, as exposures were small and isolated from one another.

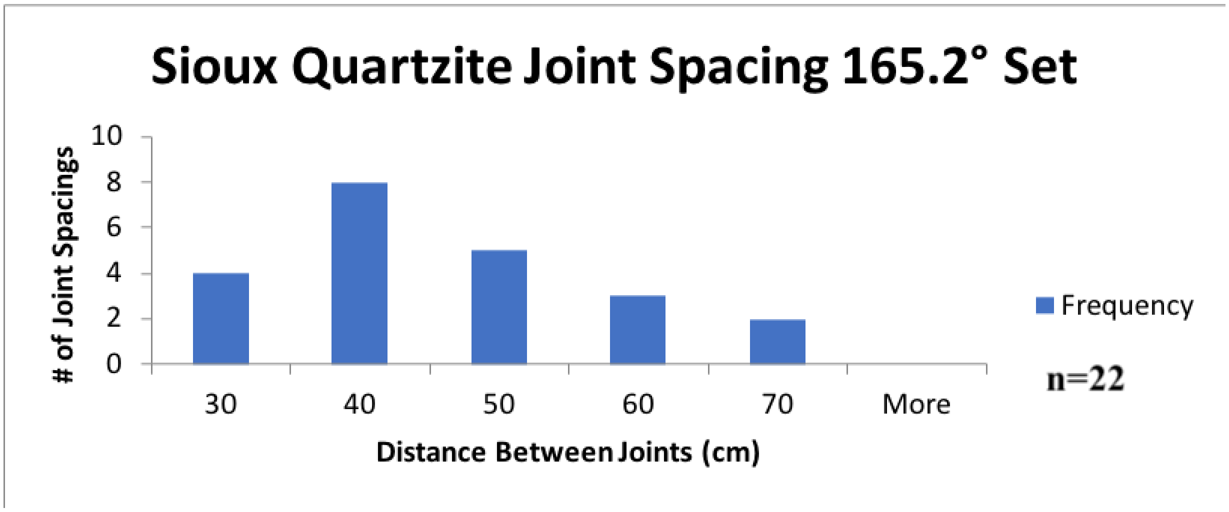

Figure 9: Histogram representing joint spacing in the Sioux Quartzite 165˚ set.

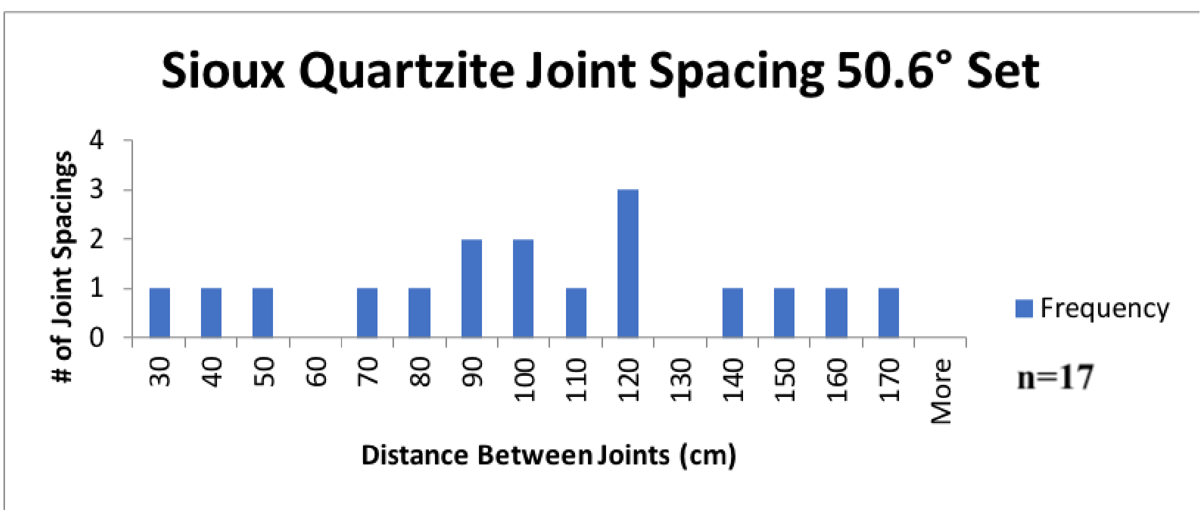

Figure 10: Histogram representing joint spacing in the Sioux Quartzite 55˚ set.

DISCUSSION

The comparison of joint orientations can provide insight into the complex geologic history of a region. Additionally, joints are the primary means by which groundwater is stored and transported in many aquifers, providing a practical motivation for developing a general understanding of jointing patterns.

Three correlating joint sets exist in both the Sioux Quartzite and Oneota Dolomite formations, which will be denoted as the 55°, 120°, and 165° joint sets. Figures 11, 12, and 13 compare corresponding joint sets spatially. The black lines represent the mean azimuth orientation of each joint set. The N values portray the number of measurements representing that specific joint set at that location. The two locations are approximately 90km apart. Similarly distant joint sets were compared by Holst and Foote (1981).

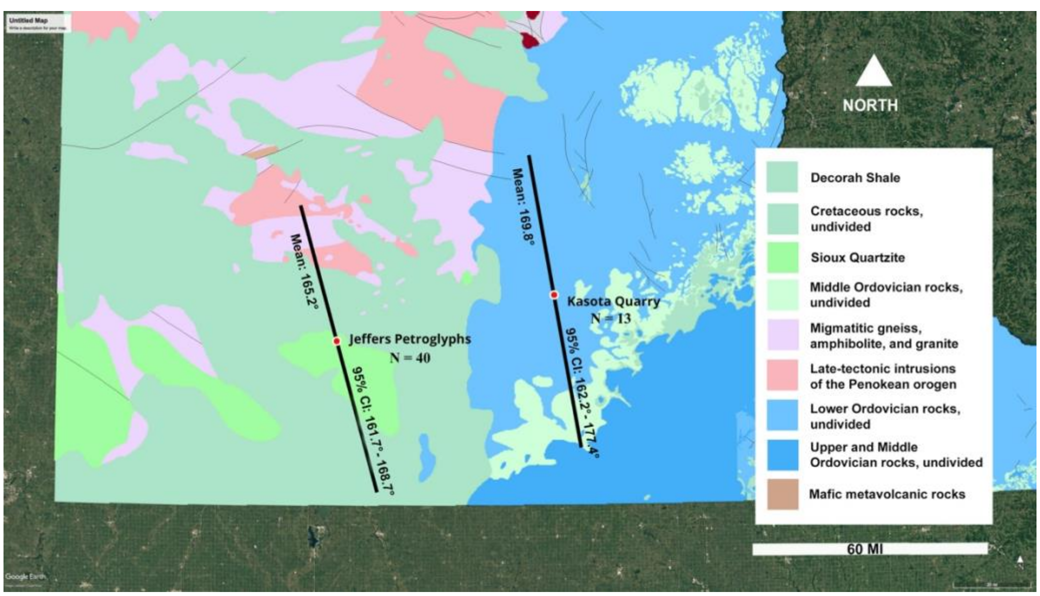

Figure 11: Spatial comparison of the 165° joint set. N values display the number of measurements representing the 165° joint set at each location.

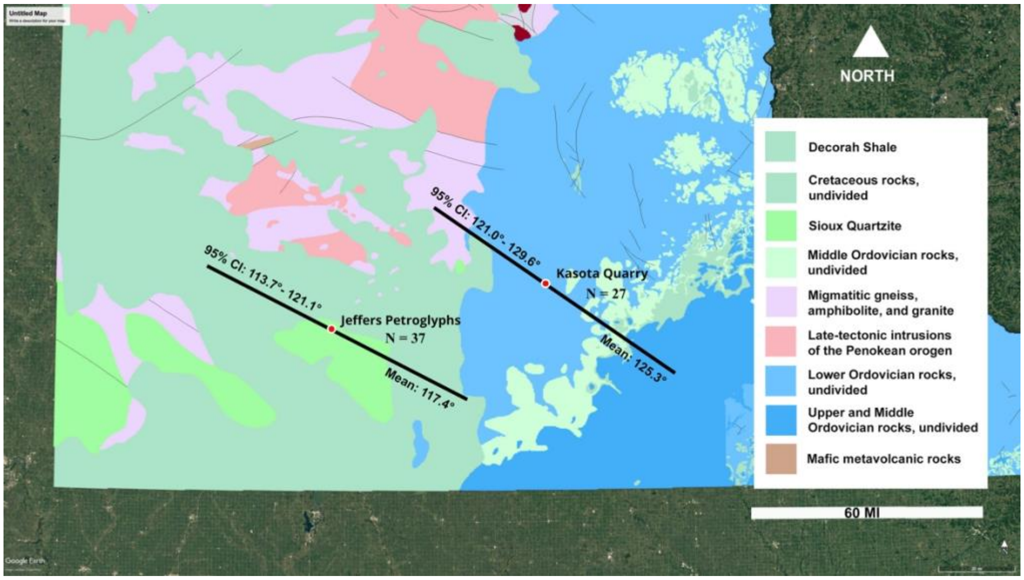

Figure 12: Spatial comparison of the 120° joint set. N values display the number of measurements representing the 120° joint set at each location.

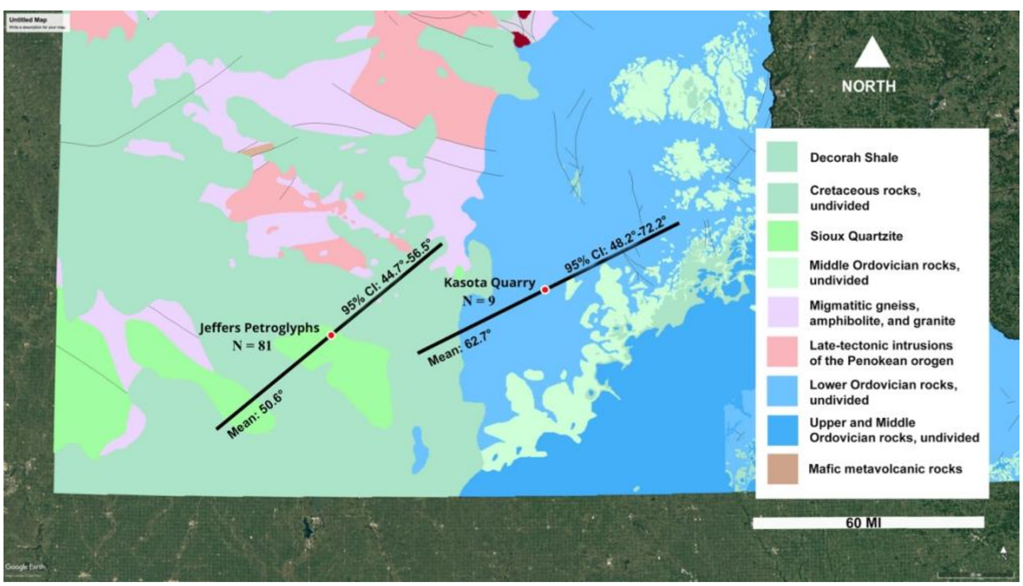

Figure 13: Spatial comparison of the 55° joint set. N values display the number of measurements representing the 55° joint set at each location.

The 165° joint set has the greatest degree of correspondence between the mean joint orientation at both locations (169.8°-165.2° = a difference of 4.6°). The 120° joint set had the next greatest degree of correspondence (125.3°-117.4° = 7.9), while the 55° joint set had the least correspondence (62.7°-50.6° = 12.1°). It is worth noting that the 165° and 55° joint sets had insufficient representative measurements in the Oneota Dolomite (N=13 in the 165° set, and N=9 in the 55° set), weakening any conclusions drawn by this comparison. Although the 165° joint set has the greatest degree of correspondence of the three, its lack of representative measurements in the Oneota Dolomite means one should remain skeptical that this is truly a shared joint set.

The 165° joint set has a standard deviation of 1.8° in the Sioux Quartzite, and 3.9° in the Oneota Dolomite, calculated using the Von Mises Distribution in Stereonet 10. This difference is likely due to the smaller number of representative measurements in the Oneota (N=13, versus N=40 in the Sioux). The 120° joint set has a standard deviation of 1.9° in the Sioux Quartzite, and 2.2° in the Oneota Dolomite. The 55° set generally had the highest standard deviation, with a standard deviation of 3.0° in the Sioux Quartzite and 6.1° in the Oneota Dolomite. This highlights the necessity of taking more measurements representing the 55° set in the Oneota, as the 95% confidence interval of the mean orientation of this set is 48.2°-72.2° (calculated using Stereonet 10). 95% confidence intervals for the means of each joint set are found along the black lines in figures 11, 12, and 13.

It is worth noting that the easternmost portion of the Sioux Quartzite outcrop at the Jeffers Petroglyphs site almost exclusively contains joints of the 55° joint set, perhaps hinting at the presence of folding or faulting. An examination of figures 9 and 10 supports the notion that the Sioux Quartzite may be thicker in the eastern portion of the Jeffers Petroglyphs site, as joint spacing tends to increase with bed thickness. This data is inconclusive, however, and one would need to return to Jeffers and collect additional data to test this hypothesis.

The presence of correlating joint sets at both locations suggests that these sets may be related and may have a common cause. If this is the case, these joint sets must have developed since the deposition of the younger formation, the Oneota Dolomite, which was formed between 485 and 478 Ma (Mossler, 2008).

Some tectonic events that may have led to the development of these joint sets include the Ouachita, Taconic, Acadian, Alleghanian and Laramide orogenies. Even Appalachian orogenies cannot be ruled out, as strain fabrics have revealed that such events have influenced Minnesotan geology (Craddock and van der Pluijm, 1989). The Ouachita orogeny occurred during the late Paleozoic, around 318-271 Ma (Tennyson et al., 2017). The Taconic orogeny is middle-late Ordovician in age (Faill, 1997), or approximately 470-445 Ma. The Acadian orogeny is middle-late Devonian in age (Swezey et al., 2008), or approximately 393-359 Ma. The Alleghanian orogeny occurred during the late Carboniferous or early Permian, around 325-260 Ma (Hatcher, 2008). Finally, the Laramide orogeny is late Cretaceous-early Tertiary age (Koch, 1986). This orogeny caused uplift in the Black Hills, and is discussed in relation to the Sioux Quartzite by Koch (1986). Since all of these orogenies occurred since the deposition of the Oneota Dolomite, they may have influenced jointing in both the Sioux Quartzite and Oneota Dolomite.

CONCLUSION

The comparison of joint orientations may provide useful insights into a region's geologic history. Two units outcropping in southern Minnesota, the Sioux Quartzite and Oneota Dolomite, were studied and compared. Three potential shared joint sets, with approximate azimuth orientations of 55°, 120°, and 165°, were discovered. A shortage of measurements representing the 55° and 165° sets in the Oneota Dolomite weaken this comparison, however, and more data must be collected before any definitive conclusions can be drawn about these sets. Though these data cannot determine what caused the joint sets with any certainty, it is worthwhile to suggest some potential causal events; including the Ouachita, Taconic, Acadian, Alleghanian, and Laramide orogenies.

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