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FOREWORD

The volume of mineral production from any area ultimately declines as known reserves are depleted. However, a more detailed analysis of the geologic factors that controlled mineralization often has led to the discovery of new reserves. Such an analysis is presented in this report. The information should stimulate renewed interest in exploration for lead and zinc deposits in the Upper Mississippi Valley base metal district.

Stanley C. Grant
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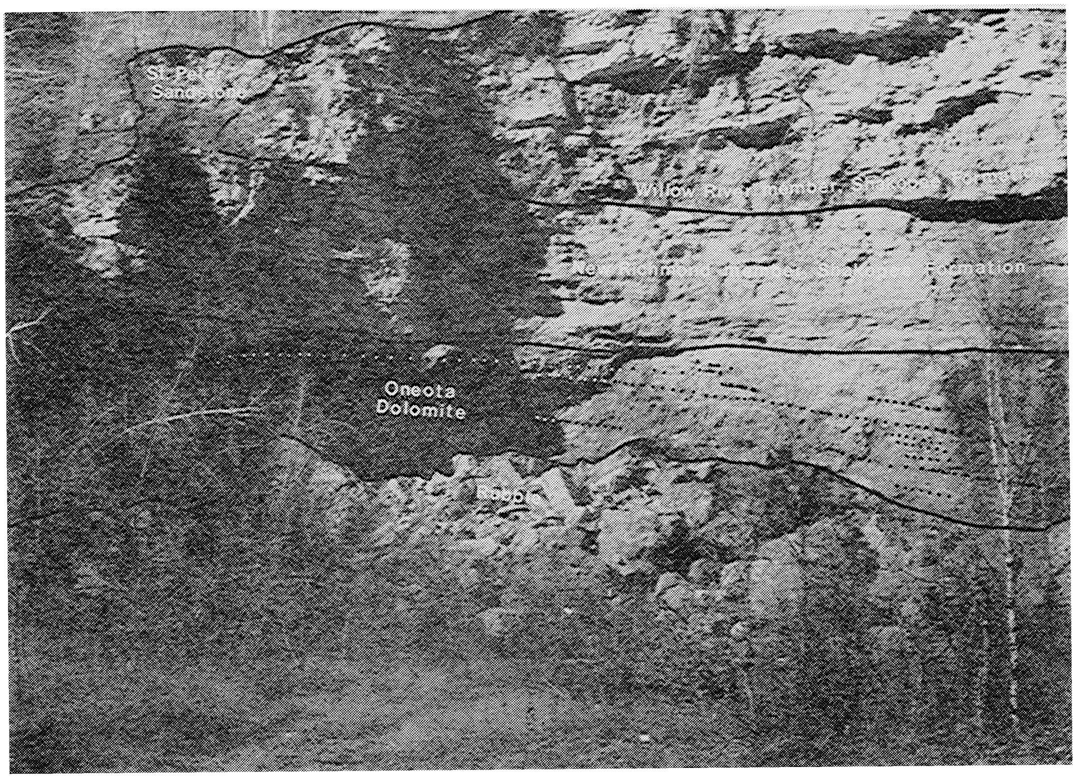

An angular unconformity between the Oneota Dolomite and the overlying Shakopee Formation is exposed in the Eastman Quarry in Crawford County, Wisconsin. Bedding traces in the Oneota Dolomite, dotted in this annotated photograph, show an apparent dip of 12° to the east on the south-facing quarry wall. The description of this quarry by Andrews (1955) revived an old controversy over the tectonic history of the area. A visit to this location by the senior author in 1973 began a program of research which is summarized in this report.

NEW EVIDENCE OF EARLY ORDOVICIAN TECTONISM IN THE UPPER MISSISSIPPI VALLEY

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ABSTRACT

Recent stratigraphic investigations in the Upper Mississippi Valley have reinstated Ulrich's controversial "Canadian-Ozarkian" unconformity at the base of the Shakopee Formation in the Prairie du Chien Group (Early Ordovician). The cause of the locally angular truncation of strata beneath the unconformity, however, has never been satisfactorily explained. The hypothesis of tectonic origin was tested by making strike and dip measurements from folds truncated by the Shakopee Formation, and by measuring a large number of fracture orientations from strata above and below the unconformity. The strike azimuths measured from folds beneath the unconformity align along an east-west trend ($\bar{x}=89^{\circ}$), and have a standard deviation (33°) that compares favorably with that from data reported from the Precambrian rocks of the Baraboo synclinorium in Wisconsin. The fracture populations from rocks above and below the unconformity were compared by the Chi-Square test and are significantly different at the 95% confidence interval. A standardized residual technique was used to identify those fracture orientations in the pre-Shakopee units which may have been present before Shakopee sedimentation. The fracture sets obtained are arrayed in extension, conjugate shear, and tension fracture orientations that would result from a stress field with with σ_1= north-south, σ_2= vertical, and σ_3= east-west. This stress field is consistent with the postulated east-west fold trend, strongly suggesting that the structures below the unconformity are tectonic in origin. The study area is characterized by east-west trending linear magnetic gradients, indicating the possibility of reactivation of basement structures during Early Ordovician tectonism. These long-ignored structures may be economically significant. They apparently have controlled the distribution of ore deposits in the Lower Ordovician rocks, and this suggests that a new vertical exploration model is appropriate for the Upper Mississippi Valley base metal district.

INTRODUCTION

Paleozoic epeirogenic tectonism in the midcontinent region of North America is recorded by several major unconformities (Ham and Wilson, 1967). These regional unconformities are the result of tectonic events which bracket discrete cratonic sedimentary sequences of generally continuous deposition (Sloss, 1963). The thicknesses and lithologic characteristics of the resultant sequences of sedimentary rocks were controlled by broad intracratonic structures which were active contemporaneously with deposition. Ostrom (1970, p. 14) showed that in western Wisconsin, marginal to the Wisconsin Dome, there are several unconformities within Sloss' (1963) earliest (Sauk) cratonic sequence. These unconformities have less regional extent than those recognized by Sloss (1963), or by Ham and Wilson (1967), but they are important in interpreting the Phanerozoic tectonic history of the Wisconsin Dome and the midcontinent region.

One of the unconformities recognized by Ostrom (1970) occurs in the Lower Ordovician Prairie du Chien Group (fig. 1) at the base of the New Richmond Sandstone, the lower member of the Shakopee Formation. This locally angular unconformity was first recognized by Ulrich (1924), who proposed that the Ordovician system be divided into two new separate systems at this break. The new (Canadian and Ozarkian) systems never achieved widespread use or acceptance, and subsequent workers (Trowbridge and Atwater, 1934;

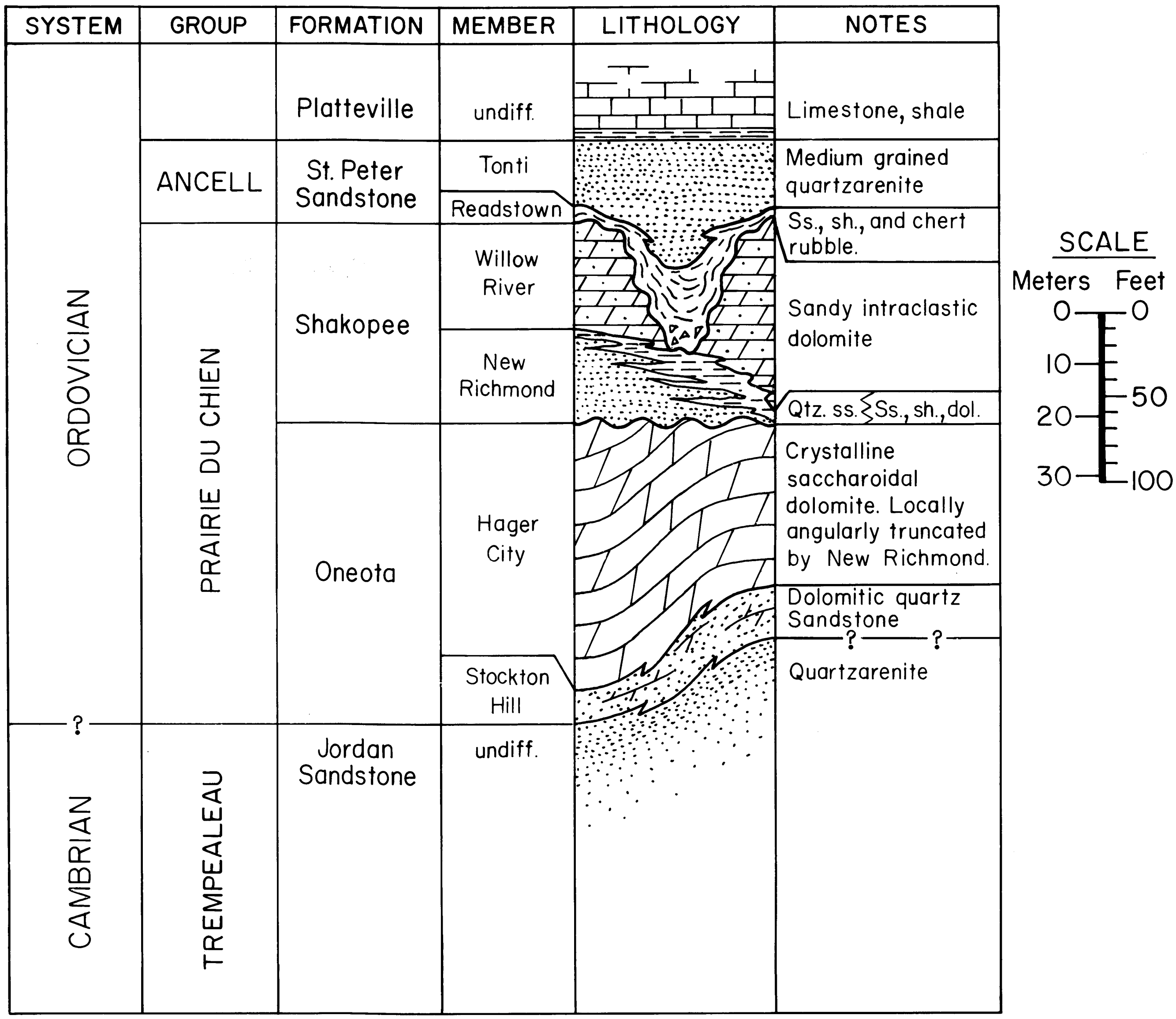


Figure 1.
Lithostratigraphy of the Prairie du Chien Group and adjacent stratigraphic units.

Powers, 1935; Twenhofel, 1954; and Thwaites, 1961) discredited the evidence for an unconformity within the Prairie du Chien Group.

Furnish (1938) found evidence for a faunal break between the Shakopee and Oneota Formations. More recent investigators (Andrews, 1955; Davis 1968, 1979; and Ostrom, 1970) have validated the concept of the unconformity, and emphasized the importance of the locally angular relationship between units above and below the unconformity. Andrews (1955) described truncated folds beneath the unconformity near Eastman, Wisconsin, but was unable to discriminate between tectonic or syn-sedimentary origin. The purpose of this paper is to present evidence that the folds truncated by the pre-Shakopee unconformity are of tectonic origin, and to evaluate the regional significance of the Early Ordovician tectonism discussed herein.

METHODS OF INVESTIGATION

Structures truncated by an angular unconformity are difficult to study at the land surface, unless local dissection is sufficient to provide abundant exposure. In the study area these structures are exposed in quarries, roadcuts, and natural exposures. Small areas such as these have been mapped in detail (Ludvigson, 1976, p. 103), but they are too widely scattered for systematic regional mapping of sub-Shakopee structure. Since mapping cannot be used to resolve the regional fabric of the structures below the unconformity, a large body of outcrop structural data (figure 2) was obtained

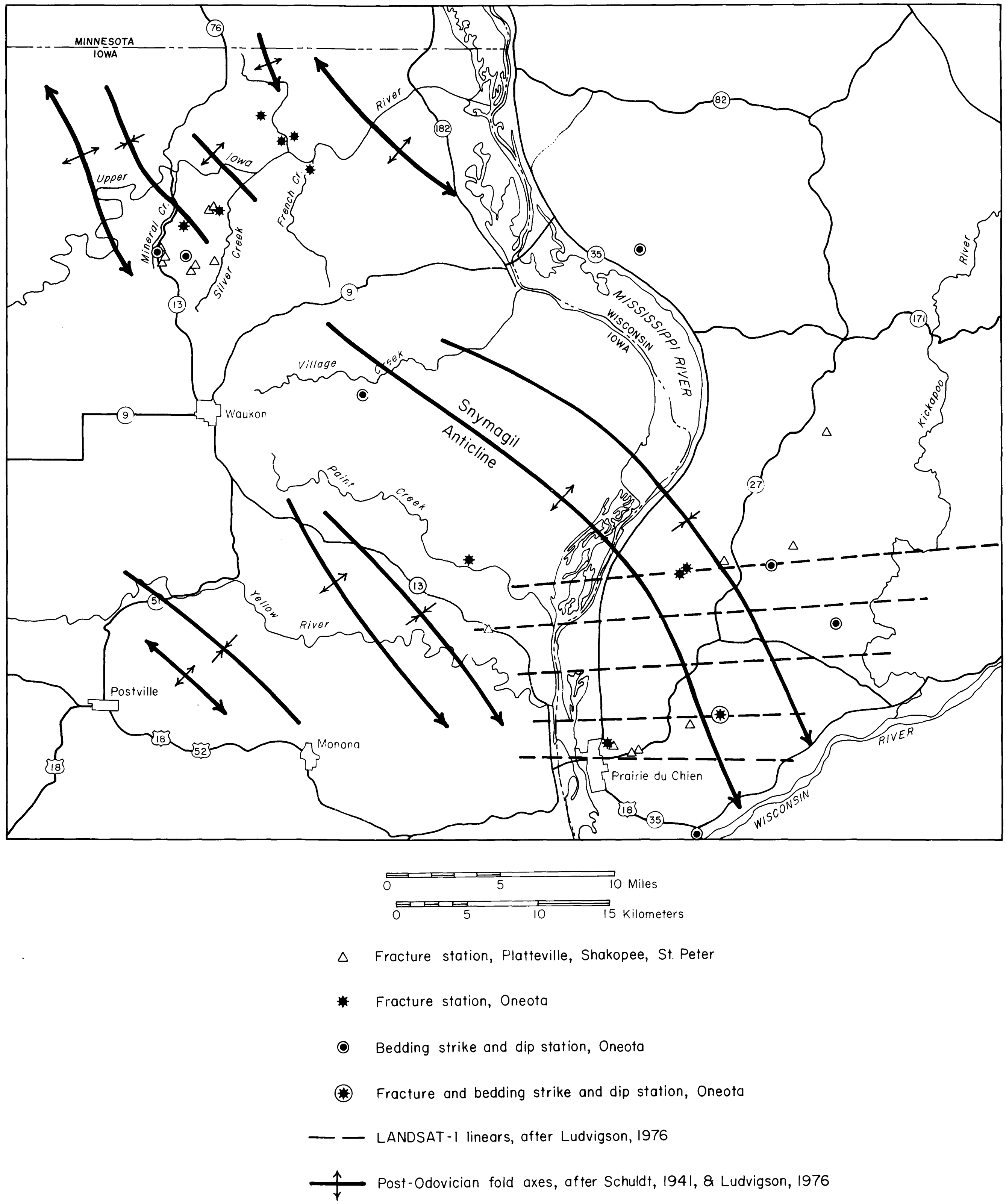


Figure 2.
Location map of study area and sites of data collection.

to test the hypothesis of tectonic origin for the folds in the Oneota Formation. If the structures below the Shakopee Formation were derived from tectonic activity, they would be expected to exhibit a directional fabric, and the local structural data should be consistent with that fabric. The structural data consist of two major types: 1) strike and dip data from folds truncated by the pre-Shakopee unconformity, and 2) fracture data from rocks above and below the unconformity.

Strike and dip measurements (fig. 3) were obtained from 8 locations where dipping beds of the Oneota Formation are exposed beneath the angular unconformity (fig. 1). These measurements were made at quarries, roadcuts, and natural exposures where a brunton compass could be placed in contact with the bedding plane. The locations are described in detail by Ludvigson (1976).

A total of 1,345 fracture orientations was measured at 22 stations. The location and stratigraphic unit were recorded for each station. The original intent was to measure 100 fractures at each station; however, restricted exposures and low fracture densities at some locations prevented measurement of a full complement. The data for each station were compiled in five-degree increments for use in rose diagrams and for ease in statistical manipulation. Finally, the fracture data from all stations were grouped in two populations: all those measured in rocks older than the pre-Shakopee unconformity, and all those measured in rocks younger than the unconformity. Several statistical methods were applied to the data set to test for a statistically significant variation between the two domains.

RESULTS

Strike and Dip Data

If the folds truncated by the pre-Shakopee unconformity are of tectonic origin, they would be expected to have a generally consistent trend, and the strike azimuths from dipping beds on the fold limbs should exhibit a high degree of parallelism. In order to make this determination, a comparative standard was needed for strike-azimuth alignment controlled by tectonic folds. The abundant structural data available from the Baraboo area was chosen for comparison.

The mean strike of the 13 strike and dip measurements from the Oneota Formation (fig. 3) is N89°E, with a standard deviation of 33°. This is identical to the standard deviation calculated from 321 measurements from the Baraboo synclinorium (Dalziel and Dott, 1970, Plate IV). The existing strike and dip data suggest that the folds beneath the pre-Shakopee unconformity are tectonically derived, and have a generally parallel, east-west trend.

Fracture Data

All of the rocks in the study area have been folded by post-Ordovician tectonic activity (figure 2). The principal

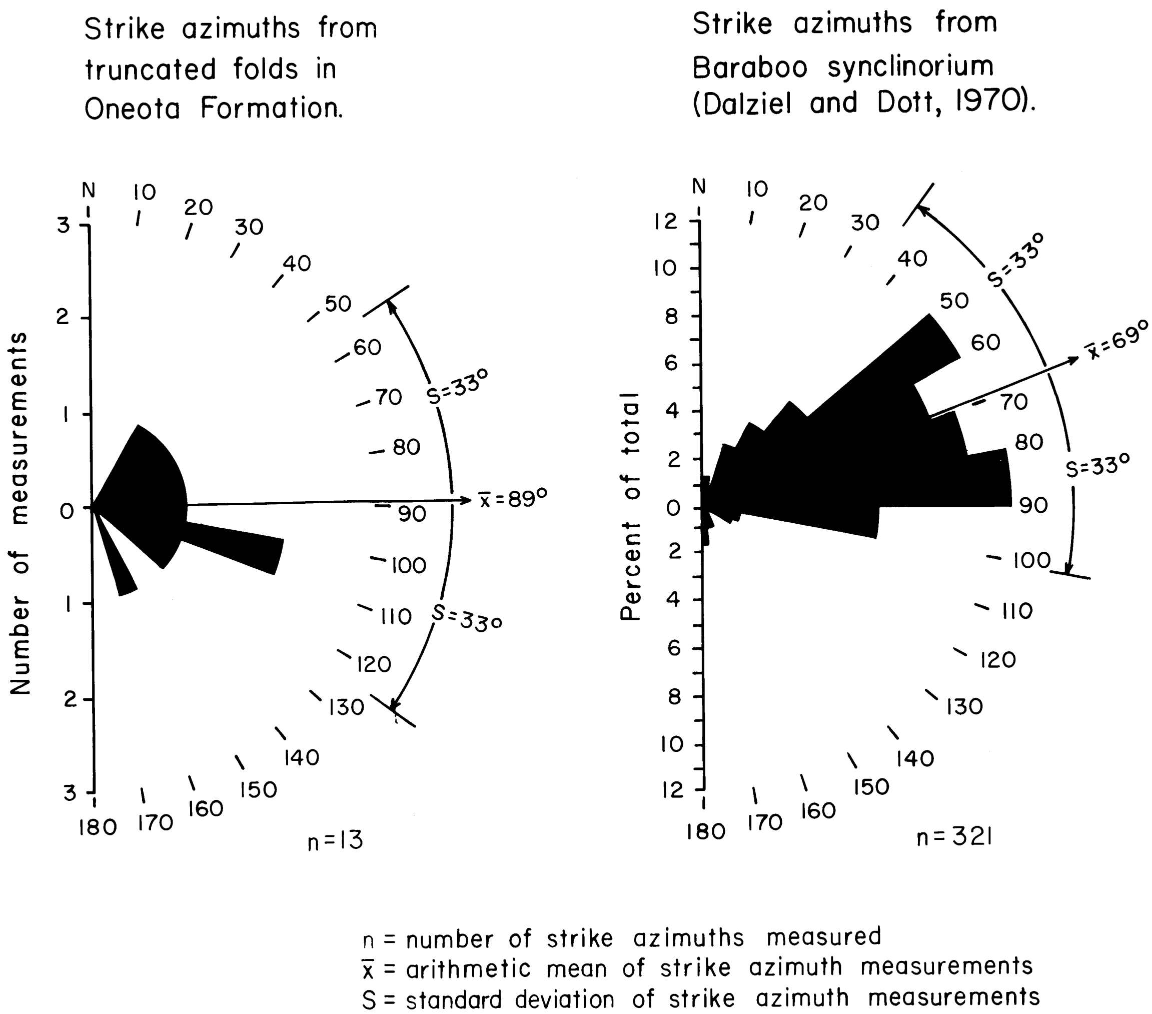
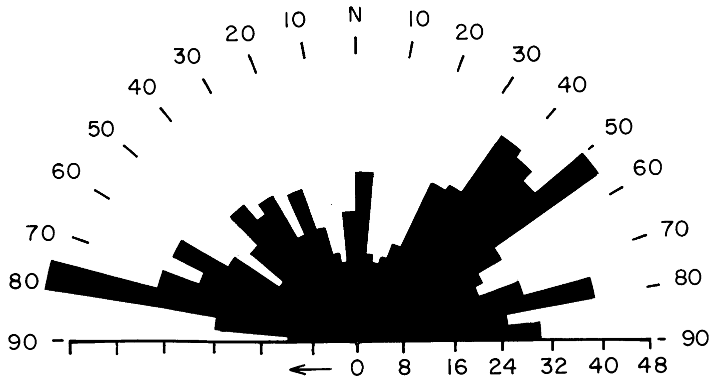


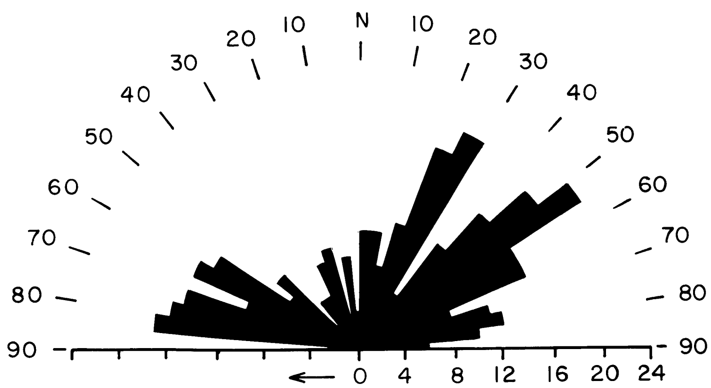
Figure 3.
A comparison between strike azimuth alignments of pre-Shakopee folds and the Baraboo synclinorium.

element in this group of low amplitude, northwest trending folds is the Snymagil anticline (Calvin, 1894), with a structural relief of just over 100 feet, or 30.5 meters (Ludvigson, 1976). The flanks of these folds dip at 1° or less, compared to dips of up to 28° on the flanks of folds truncated by the pre-Shakopee unconformity. If it is assumed that the Ordovician sedimentary rocks of the study area have fairly uniform mechanical properties, and that only post-Ordovician tectonism has stressed them, they should be uniformly characterized by a fracture pattern formed in response to that stress. If, however, the pre-unconformity rocks were fractured by a tectonic event prior to Shakopee sedimentation, the fracture distribution in the pre-unconformity units will record at least two tectonic events (pre-Shakopee and post-Ordovician). Thus, the fracture distribution below the unconformity resulting from these two events would differ from the fracture distribution above the unconformity--which was the result of only one discernable tectonic event.

The fracture diagrams for the pre- and post-unconformity rocks are shown in figure 4. Fracture maxima in both sets occur at approximately N50°E and N80°W. Ludvigson (1974, 1976) noted that the N50°E set is normal to the fold axes of the northwest-trending post-Ordovician folds (figure 2), and suggested that the folds and fracture set (extension fracture orientation) were formed in response to a post-Ordovician stress field with σ_1 = N50°E, σ_2 = vertical, and σ_3 = N40°W. A qualitative assessment of the differences



Fracture Data for Pre-Unconformity Rocks
960 fractures



Fracture Data for Post-Unconformity Rocks
385 fractures

Figure 4
Rose diagram comparison of fractures measured in pre- and post-unconformity rocks.

and similarities between the two fracture distributions can be done by visual inspection of the rose diagrams. However, in order to quantify the relationships between the two, it is necessary to statistically analyze the data.

Statistical Analysis of Fracture Data

The rock fracture data consists of two samples; one from the pre-unconformity population of fractures, and one from the post-unconformity population. Each observation from each population was classed within a discrete 5° strike interval. The data are arranged (Table 1) so that each of the two fracture populations is in a row (i). Each row has j columns, with j equal to the number of 5° strike intervals (36). This forms a 2 row (i=2) by 36 column (j=36) contingency table. The Chi-Square Method is used to test the hypothesis that the distribution of fractures in one row is significantly different from the distribution in the other row (Conover, 1971). It is assumed that the two samples are random and mutually independent.

The Chi-Square test statistic is calculated as:

$$\chi^2 = \sum_{i=1}^{2} \sum_{j=1}^{36} \frac{(\eta ij - \xi ij)^2}{\xi ij}, \text{ with } \xi ij = \frac{(\eta i°) \cdot (\eta° j)}{N}$$

where:

ηij = the number of fractures observed in the i^{th} row and the j^{th} column.

$\eta i°$ = the row total for the i^{th} row.

$\eta° j$ = the column total for the j^{th} column

N = the grand total of all fractures.

Table 1. Contingency Table for fracture data

EAST

		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
Pre-unconformity	Oij	28	15	13	14	21	29	30	41	40	38	48	27	23	21	28	39	26	30
	Eij	27.12	17.84	14.28	17.84	27.84	34.97	24.98	44.25	39.26	40.68	49.96	29.98	27.12	20.7	27.84	36.4	25.7	25.7
	dij	.32	-1.27	-.64	-1.72	-2.46	-1.92	1.9	-.94	.23	-.80	-.53	-1.03	-1.5	.13	.06	.82	.11	1.61
Post-unconformity	Oij	10	10	7	11	18	20	5	21	15	19	22	15	15	8	11	12	10	6
	Eij	10.88	7.16	5.72	7.16	11.16	14.03	10.02	17.75	15.74	16.32	20.04	12.02	10.88	8.3	11.16	14.6	10.3	10.3
	dij	-.32	1.27	.64	1.72	2.46	1.92	-1.9	.94	-.23	.80	.53	1.03	1.5	-.13	-.06	-.82	-.11	-1.61

WEST

		90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5
Pre-unconformity	Oij	12	24	48	34	28	34	25	16	23	29	26	29	20	27	20	15	13	26
	Eij	9.28	29.26	45.68	34.97	27.12	34.97	27.84	16.42	22.84	21.41	22.13	24.27	17.84	24.98	20.7	12.13	14.99	20.7
	dij	1.68	-1.85	.66	-.31	.32	-.31	-1.02	-.19	.06	3.10	1.56	1.82	.96	.76	-.29	1.55	-.97	2.2
Post-unconformity	Oij	1	17	16	15	10	15	14	7	9	1	5	5	5	8	9	2	8	3
	Eij	3.72	11.74	18.32	14.03	10.88	14.03	11.16	6.58	9.16	8.59	8.87	9.73	7.16	10.02	8.3	4.87	6.01	8.3
	dij	-1.68	1.85	-.66	.31	-.32	.31	1.02	.19	-.06	-3.10	-1.56	-1.82	-.96	-.76	.29	-1.55	.97	-2.20

$n1j = 960$ $n2j = 385$

$N = 1345$

$\chi^2 = 58.54$

The χ^2 test statistic for the 2 x 36, rock fracture table equals 58.54, which is significant at the 95% confidence level (Conover, 1971, p. 367). This means that there is only a 5% chance that the difference between the two fracture samples is due to random sampling errors. Therefore, it is concluded that the pre- and post-unconformity rock fracture distributions are significantly different. This in turn strongly suggests that the pre-unconformity rocks were fractured by tectonic activity prior to the deposition of the post-unconformity sedimentary sequence.

The Chi-Square test does not provide evidence concerning the orientation of the pre-unconformity stress field. Strike and dip measurements from the pre-Shakopee folds indicate that the predominant fold trend is east-west. This suggests that σ_1 was north-south, σ_2 was vertical, and σ_3 was east-west (figure 5). Given this hypothetical stress field, sets of vertical fractures with consistent angular orientations relative to the stress field would be expected. These would be extension fractures, striking north-south; conjugate shears, each striking approximately 30° from north-south; and tension and/or release fractures striking east-west (figure 5). If the hypothesized pre-unconformity tectonic event fits this model, then at or near these 5 azimuths, the pre-unconformity units should exhibit a greater frequency of fracturing than do the post-unconformity units. The technique of analysis of residuals was applied to the contingency table to test the model.

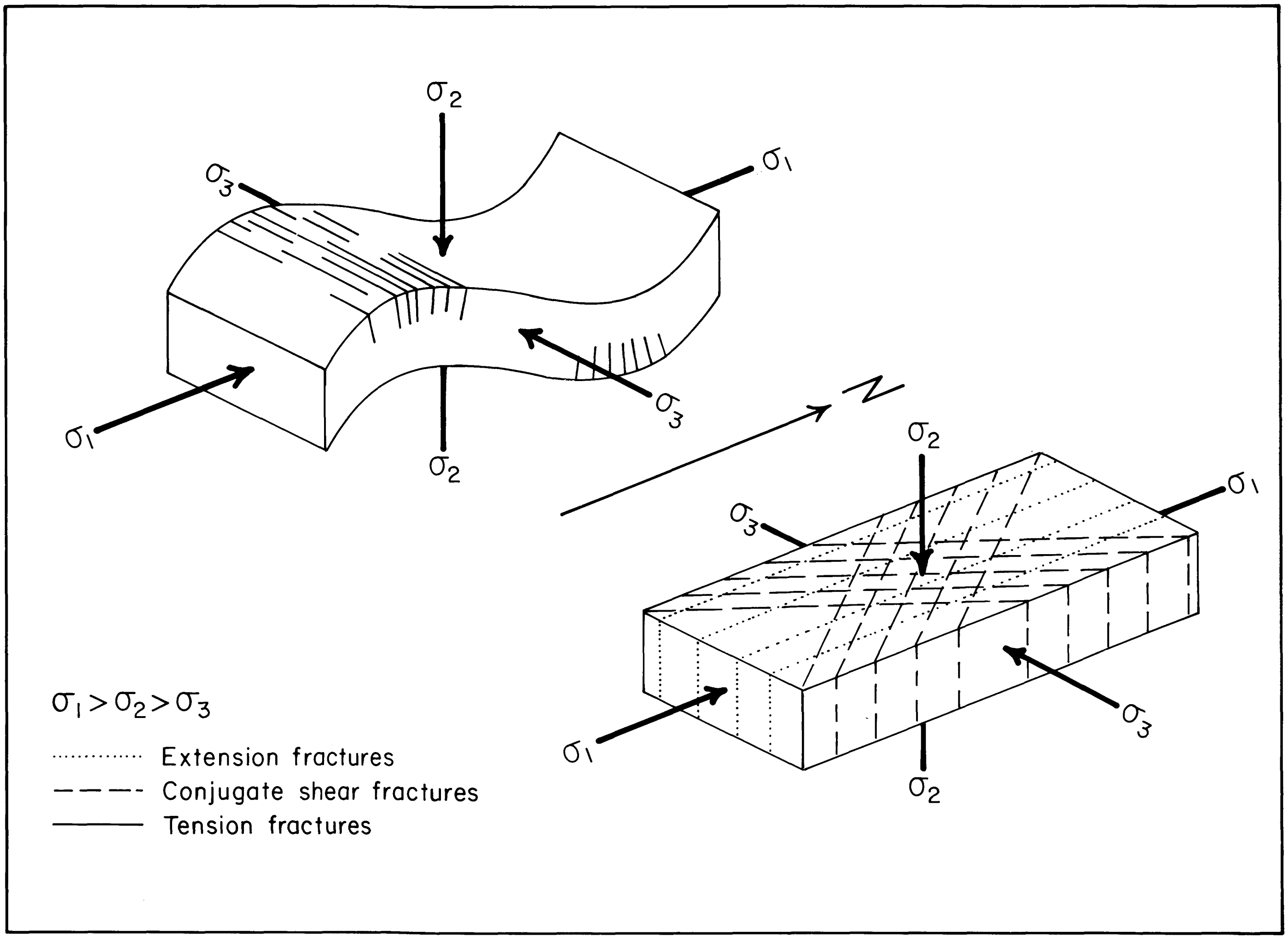


Figure 5.
Block diagrams showing fold and fracture geometry from hypothesized stress field.

Haberman (1973) outlines a procedure for examining the standardized residual, eij, given by:

$$eij = \eta ij - \xi ij/\sqrt{\xi ij}$$

An estimate of the variance (Vij) of eij is given by:

$$Vij = (1-\eta i^\circ/N) \times (1-\eta^\circ j/N).$$

Thus for each cell in Table 1 an adjusted residual (dij) can be calculated:

$$dij = eij/\sqrt{Vij}$$

The dij values are calculated such that intervals with more than the expected frequency of fracturing in the pre-unconformity sequence will have positive values. Furthermore, when the variables forming the contingency table are independent, the terms dij are approximately normally distributed with a mean of 0 and a standard deviation of 1. Therefore, the importance of the adjusted residuals can be determined by comparing them to a standard normal deviate of chosen confidence levels (Everitt, 1977).

Figure 6 is a rose diagram showing the orientation and magnitude of the positive values of dij from the first row of the contingency table. The maxima of the residuals correspond closely to the 5 strike intervals of maximum fracturing which would result from the postulated pre-unconformity stress field. This subjective analysis suggests that the model is valid.

There is, however, always the possibility that these residuals are the result of sampling error and are not, in fact, the result of differences in the two fracture populations. Table 2 lists for the five strike intervals the values

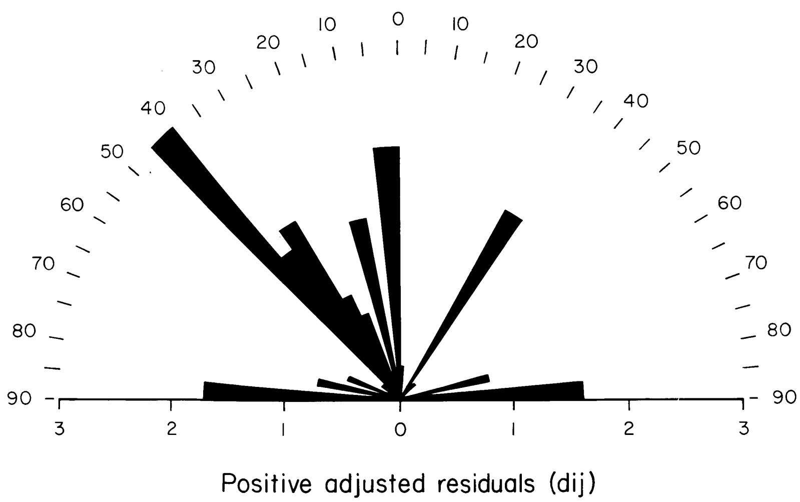


Figure 6.
Rose diagram showing five-degree strike increments for which residuals (dij) have positive values.

of dij, the confidence level and the probability of occurrence due to random sampling error.

Table 2

Azimuth Interval	dij	Confidence level in percent	Probability of occurrence due to sampling error
86°-90°W	1.68	95.35	4.65%
41°-45°W	3.10	99.90	0.10%
0°- 5°W	2.20	98.61	1.39%
31°-35°W	1.90	97.13	2.87%
86°-90°E	1.61	94.63	5.37%

The table must be interpreted with some caution. It is correct to state that the probability of an adjusted residual of 3.10 occurring due to random sampling error is only one-tenth of one percent. Consequently, we can conclude with great certainty that the interval N41°-45°W contains an anomalously high number of fractures in the pre-unconformity rocks, relative to the post-unconformity rocks. Similar statements can be made for each azimuth interval. The probability that all five residuals as a group are statistically significant, however, is not the probability of the lowest interval (94.63%). Rather it is the product of the five probabilities, which is 86.33%. Therefore, the probability that all five residuals are the result of population differences is 86.33%, which is considerably lower than the value for any one interval.

Based on this analysis it is concluded that there is an 86% chance that the group of 5 strike intervals contains a higher frequency of fracturing in the pre-unconformity units relative to the post-unconformity sedimentary sequence. This supports the hypothesis of pre-Shakopee tectonism with a stress field oriented such that σ_1 was north-south, σ_2 was vertical, and σ_3 was east-west (see figure 7).

The occurrence of residuals with negative values, especially those with significant departures from the mean, indicates that these are fracture orientations which were measured with greater relative frequency in the post-unconformity units than in the pre-unconformity units. Assuming that these observations reflect a real occurrence, some fracture-producing mechanical process was operant on the post-unconformity units and had no effect on the older, pre-unconformity units. Tectonic processes cannot be invoked to explain this, because any crustal deformation which has affected the Shakopee Formation and younger units must have affected the subjacent units.

One geologically plausible hypothesis is that the younger rocks were fractured shortly after deposition by a near-surface phenomenon which was not operant on the underlying rocks. Topographically controlled fracturing is a possibility. The Shakopee Formation is disconformably overlain by the St. Peter Sandstone (figure 1). The local relief on this erosional surface (Thwaites, 1961) exceeds 240 feet (73.1 m) in the study area (Ludvigson, 1976, p. 113). Fractured zones in the St. Peter Sandstone, apparently compaction structures related to high relief on the underlying erosion surface,

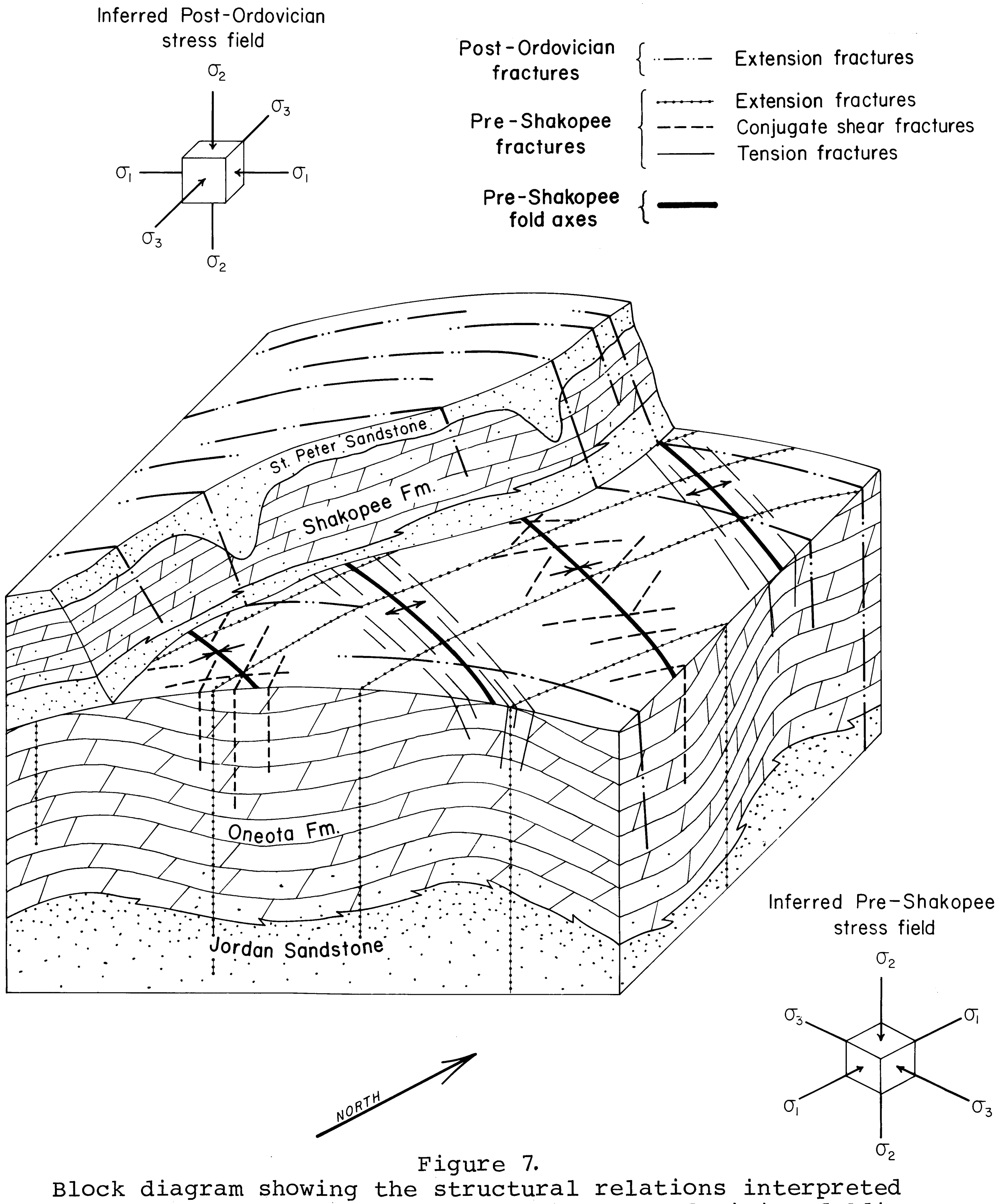


Figure 7.

Block diagram showing the structural relations interpreted from the study area, including: 1) post-Ordovician folding, extension fractures, and inferred stress field; and 2) pre-Shakopee folding, extension, conjugate shear, and tension fractures, and inferred stress field.

have been described by Palmquist (1965) and Ludvigson (1976, pp. 123-131). Fracture orientations exhibiting large negative residuals (Table I) may reflect topographically controlled fracturing by downslope movement along sub-St. Peter Sandstone drainageways.

DISCUSSION

While the trend of the pre-Shakopee structures has been relatively easy to detail, their origin and significance are problematic. The structures were "rediscovered" during an investigation of LANDSAT-1 linears (Ludvigson, 1976). The study indicated that the linears (see fig. 2) are controlled by the pre-Shakopee structures, although subsequent accentuation by later Ordovician karst development played an important role. The linears appear to exhibit basement control, as they coincide with similarly trending positive magnetic anomalies and linear magnetic gradients (IGS Aeromagnetic Survey No. 5). The magnetic anomalies, linears, and pre-Shakopee structures are all along the extrapolated trend of the Baraboo synclinorium, located further to the east. All of these features strike just slightly north of due east.

The Baraboo synclinorium is a structurally preserved remnant of Late Precambrian metasediments and volcanics that was deformed in an east-west trending orogenic belt approximately 1,300-1,500 m.y. ago (Dott and Dalziel, 1972). Correlative Late Precambrian metasediments (deposited 1,500-1,600 m.y. ago) are preserved in synclinal structures from eastern Wisconsin to central South Dakota, apparently remnants of a once continuous sedimentary sequence covering the region (Dott and Dalziel, 1972). While the trend and structural patterns of the Late Precambrian orogeny are known only from these isolated structurally depressed supracrustal rocks, this tectonic event undoubtedly imprinted itself upon the pre-existing basement rocks (Animikie Series and older).

The structural configuration of the basement rocks producing the magnetic anomalies in the study area is not known, but it is possible that they reflect post-Baraboo Quartzite deformation of the basement rocks. Whatever the origin of the anomalies, their coincidence with the LANDSAT-1 linears and pre-Shakopee structures is suggestive of reactivation of movement along basement structures during the Early Ordovician.

ECONOMIC IMPLICATIONS

The pre-Shakopee structures may have economic significance. Studies on the northern fringe of the Upper Mississippi Valley base metal district, where local dissection has exhumed units below the Middle Ordovician host beds (Platteville Fm. and younger units, figure 1) have shown that a structurally controlled vertical sequence of metallic mineralization exists (Ludvigson, 1976, 1978). Base metal sulfide mineralization in the rocks below the main host beds occurs as scattered, small, structurally controlled deposits in virtually all of the exposed underlying Cambrian-Ordovician units (Heyl, 1959, pp. 135-137). Some of these deposits were developed in the early history of the mining district. The larger of these deposits were confined principally to the Hager City member of the Oneota Formation, directly beneath the pre-Shakopee unconformity (Ludvigson, 1976, p. 174).

The structural geometries of some of these deposits bear a striking resemblance to the pre-Shakopee structures identified in this report. Gash vein deposits in the Hager City member of the Oneota Formation occur in the pre-Shakopee extension fracture orientation (north-south; e.g. the Lansing lead mine; Heyl, 1959, p. 136, pp. 295-296) and one of the pre-Shakopee conjugate shear orientations (N30°W; e.g. the Demby-Weist mines; Heyl, 1959, pp. 280-282). Ludvigson (1976, pp. 79-80, pp. 91-92, pp. 101-107) described intense brecciation of the brittle Hager City member of the Oneota Formation along the hinges of pre-Shakopee folds. East-west trending disseminated galena deposits in the brecciated Hager City (e.g. the Little Kickapoo lead diggings and the Wauzeka Ridge lead diggings; Heyl, 1959, p. 294) parallel the axes of pre-Shakopee folds.

In addition to direct structural control, the pre-Shakopee folds appear to have localized Middle Ordovician karst development in the Prairie du Chien Group (Ludvigson, 1976, pp. 101-107, pp. 131-135, p. 170). These karst features are filled with St. Peter Sandstone, and in some instances have localized base metal sulfide mineralization (e.g. the Plum Creek copper mine; Heyl, 1959, pp. 294-295; Ludvigson, 1976, pp. 131-135).

Heyl, et. al. (1959, 1970) have shown that post-Ordovician folds localize zinc-lead ore deposits in the Middle Ordovician carbonates, the principal producing host beds in the Upper Mississippi Valley base metal district. There is abundant exploration experience to show that while the ore deposits occur along the post-Ordovician folds, the folds themselves are not uniformly mineralized.

What other geologic factors may be involved which localize ore deposition? The structural anisotropy in the Lower Ordovician rocks is discordant with previously identified structures in the synthesis of prior exploration models in the district. A more inclusive model might suggest that ore deposits in the Middle Ordovician carbonates would be underlain by mineralized pre-Shakopee structures. Thick sections of St. Peter Sandstone, filling structurally controlled paleokarst depressions in the Prairie du Chien Group would also be expected to control mineralization.

No systematic effort has been made to test this model, although some test drilling in the Prairie du Chien Group was done by the U.S.G.S. (Heyl, et. al., 1951). In that investigation, drilling was extended beneath ore bodies in the Middle Ordovician carbonates to see if base metal sulfide mineralization occurs in underlying strata. The test drilling found:

1) Disseminated sphalerite deposits in brecciated dolomite from the "middle" of the Prairie du Chien Group (mineralized hinges of pre-Shakopee folds?)

2) Anomalously thick sections of St. Peter Sandstone (structurally controlled paleokarst in the Prairie du Chien Group?)

3) Secondary pyrite and quartz (common gangue minerals in the district) cementing the St. Peter Sandstone beneath ore deposits in the Middle Ordovician carbonates (evidence that ore fluids were exchanged between the Prairie du Chien Group and the Middle Ordovician carbonates through the intervening St. Peter Sandstone?).

It is suggested here that ore deposits of the Upper Mississippi Valley District are located where:

1) Proper ground preparation (Park and MacDiarmid, 1970, p. 60) occurred in the Middle Ordovician host carbonate rocks (i.e. post-Ordovician folding, fracturing, and solutional modification)

2) Proper ground preparation occurred in the underlying rock sequences (pre-Shakopee folding and fracturing, and/or pre-St. Peter karst development).

Thus, the location of the ore bodies may be controlled by the chance intersection of two independent discordant fabrics. The implication is that known ore bodies are multi-levelled, and are <u>not</u> stratigraphically bound, but merely attenuated by the chemical unsuitability of certain stratigraphic units as host rocks. If the ore minerals themselves become economically attractive in the future, deeper (<u>vertical</u>) exploration beneath known ore bodies <u>may</u> be more cost-effective than the resumption of prior (<u>lateral</u>) exploration techniques. This is suggested because in many cases, the initial cost of underground development has already been expended, and the size and tenor of some of the gash-vein deposits in the Prairie du Chien (when unoxidized) may be attractive.

CONCLUSIONS

The data presented herein suggest that Ulrich's (1924) old "Canadian-Ozarkian" unconformity, later reinstated by Andrews (1955), Davis (1970), and Ostrom (1970), is a tectonically derived angular unconformity within the study area (fig. 2). Strike and dip measurements from strata below the unconformity align along an east-west trend, indicating a fold geometry which is consistent with the stress field inferred from fractures in the pre-unconformity rocks.

The pre-Shakopee structures parallel some linear magnetic gradients within the study area, and may reflect Early Ordovician reactivation of basement structures. Where exhumed, the pre-Shakopee structures have been shown to localize base metal sulfide deposits in the Prairie du Chien Group. These long ignored Early Ordovician structures are probably buried beneath the Upper Mississippi Valley base metal district to the south of the study area, and suggest the possibility of a new vertical exploration model for metallic sulfide deposits in the mining district.

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