# BARABOO INTERVAL QUARTZITE IN WASHINGTON COUNTY, IOWA

by

Raymond R. Anderson[1] and Gregory A. Ludvigson[1]

## ABSTRACT

A previously unreported red Proterozoic quartzite was encountered in two drill holes in Washington County in southeastern Iowa. At least 46.7 m of the unit, the Washington County quartzite, was penetrated with the uppermost 5.5 m cored and cuttings recovered from the remainder of the well. Petrographic examination and modal analyses of thin sections prepared from the cored interval disclose a sequence of poorly-sorted, fineto coarse-grained quartzite interbedded with thin phyllitic units. The quartzite exhibits extreme compositional maturity. Larger constituent quartz grains are well-rounded. Phyllites and phyllitic quartzite units include a matrix dominated by muscovite with minor iron oxides, and are characterized by a steeply dipping foliation which is cut by a later cleavage, indicating polyphase deformation. These observations indicate strong compositional, sedimentologic, and structural similarities between the Washington County and Baraboo-type quartzite, and may indicate that the Washington County Quartzite is genetically related to the Baraboo, Sioux, and other generally correlative quartzite units of the midcontinent. As such it represents the southernmost reported occurrence of a probable Baraboo interval quartzite.

## INTRODUCTION

The name Washington County Quartzite is here assigned to a sequence of Precambrian, probably Baraboo interval (Dott, 1983a), quartzite and phyllite encountered in two drill holes in west-central Washington County, Iowa. The formation was described from a diamond-drill core and rock-bit cuttings from two wells drilled in 1972 by the Natural Gas Pipeline Company of America at the SE¼SW¼SW¼ sec. 19, T. 76 N., R. 9 W., M. Flynn M-1 (IGS W-23141), and at the NW¼SE¼NW¼ sec. 20, T. 76 N., R. 9 W., W. F. Flynn M-1 (IGS W-23148) (fig. 1). Based on the structural relief on Paleozoic sedimentary units which drape over the Washington County Quartzite forming the Keota Dome, we infer that the unit is limited to the northwest and central Washington County and adjacent areas of northeast Keokuk County.

The Washington County Quartzite is similar in composition and general appearance to the Baraboo Quartzite, located 300 km to the northeast, and the Sioux Quartzite, 350 km to the northwest (fig. 1). It has only previously been reported by Yaghubpur (1979) and Anderson and Ludvigson (1983). Rock of the formation probably is the product of braided fluvial deposition, and is described in detail later in this paper.

The discovery well, completed early in 1972, was drilled by the Natural Gas Pipeline Company of America as a part of exploration of the Keota Dome for underground natural gas storage. This well, M. Flynn M-1 (IGS W-23141), was drilled on the flank of a domal structure that was mapped on an Ordovician datum (Hase and Koch, 1968). It reached quartzite at the Precambrian surface at a depth of 870 m (640 m below sea level) and penetrated 13.5 m into the unit. Rock bit cuttings were collected at 1.5 m intervals, but are of generally poor quality.

Upon completion of the discovery well a second test hole was drilled on the crest of the Ordovician structure. Named the W. F. Flynn M-1 (IGS W-23148), this well is located about 2 km northeast of the discovery well. It encountered the Washington County Quartzite at a depth of 706 m (461 m below sea level), 179 m higher than the discovery well (fig. 2). In this well the basal 107.6 m of the Cambrian System and the upper 5.5 m of the underlying Washington County Quartzite were cored. Recovery of the 113.1 m of 7.6 cm diameter core was virtually complete. The well was then deepened an additional 40.5 m to a final depth of 752.2 m using a rock bit. The cuttings collected at 1.5 m intervals during this deepening are of excellent quality. The core and cuttings from both wells are reposited at the Iowa Geological Survey Rock Library.

## UPPER CONTACT

The contact between the Washington County Quartzite and the overlying Mt. Simon Formation displays a marked unconformity. The basal Mt. Simon is dominated by clasts of quartzite, apparently eroded from the underlying Washington County Quartzite.

---

1. Iowa Geological Survey, 123 North Capitol Street, Iowa City, Iowa 52242

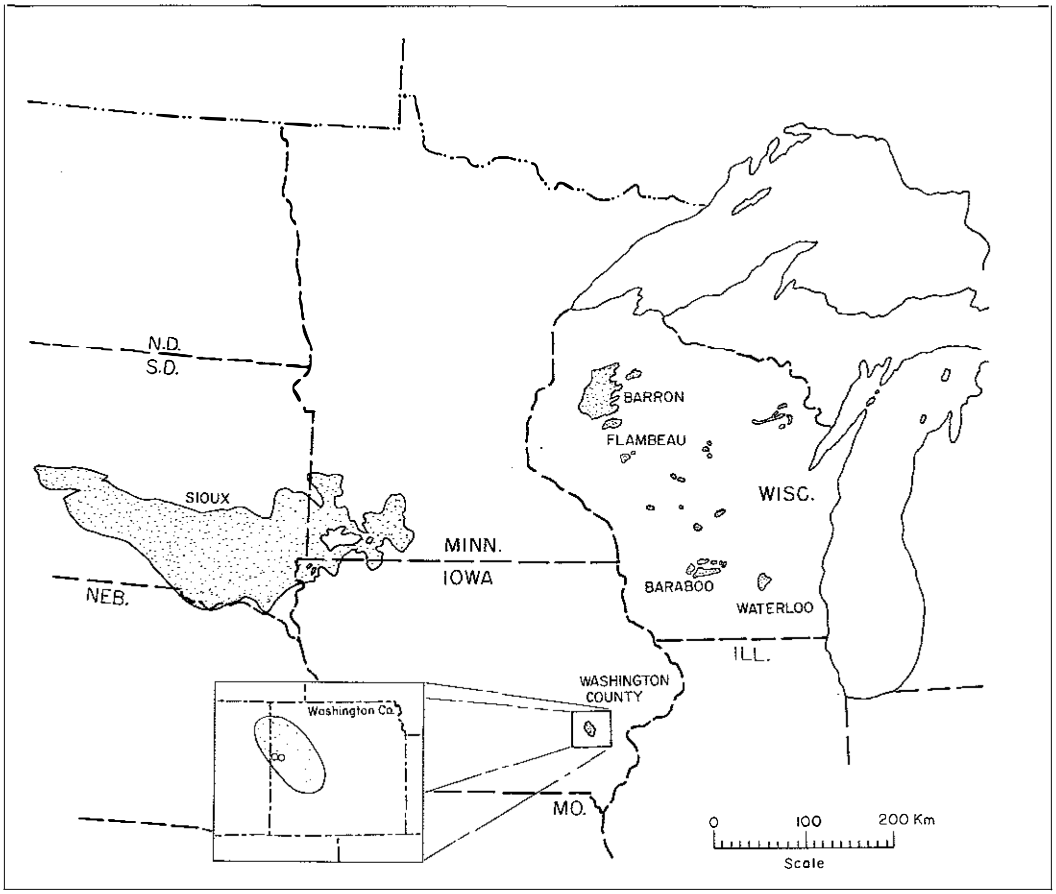


Figure 1.--Location of the Washington County Quartzite and known Baraboo interval quartzite.

The upper one metre of the Washington County quartzite encountered in the W. F. Flynn well is a gray-green to maroon phyllite with a pervasive foliation dipping at 52°. All dip angles were measured from the horizontal plane, assuming that the core axis is vertical. Modal analysis of this unit identified a 72 percent matrix content dominated by sericite with minor iron oxide (fig. 4, table 1). The possibility of other phyllosilicate minerals being present in this rock should be investigated. Muscovite has been noted from the Waterloo Quartzite, but pyrophyllite is the dominant phyllosilicate mineral from most of the other Baraboo interval quartzites (Dott, 1983b). The presence of muscovite is generally consistent with greenschist facies metamorphism of mudstone within the Washington County Quartzite. Silt-size grains identified were all quartz with 25 percent of the counts polycrystalline quartz and 3 percent monocrystalline.

## PHYLLITIC QUARTZITE

The upper phyllite unit grades downward into a 2.5-m thick unit of maroon and gray mottled phyllitic quartzite with a pronounced foliation dipping 42°. The foliation is manifested as an alignment of mica grains which are evenly dispersed throughout the rock (fig. 5), similar to the quartzite cleavage illustrated from the Baraboo quartzite by Dalziel and Dott (1970, p. 25). Two modal analyses in this unit averaged 25 percent matrix, again dominated by phyllosilicates with minor iron oxides. The iron oxide is dominantly hematite with both rhombohedral and hexagonal crystal habits petrographically observed, as was a spinel group mineral, possibly magnetite. The presence of minor sulfide minerals in these rocks was reported by Yaghubpur (1979), but none were observed in this investigation.

The coarse component of the phyllitic quartzite was entirely quartz, with 65 percent of the counts polycrystalline and 10 percent monocrystalline grains (fig. 7). Phyllitic quartzite intervals were also encountered in rock bit drilling beneath the cored interval at depths from 718.8 m to 719.4 m and 723.7 m to 728.6 m.

Table 1. Modal analyses (in percent) of lithologic samples from the Washington County Quartzite and Baraboo interval rocks from other midwestern localities, from thin sections reposited at the Iowa Geological Survey. These reconnaissance analyses were performed by making 100 point counts for each thin section for the purpose establishing the mineralogical composition of the major framework grains.

| Rock Suite | Sample | Lithology | Mono. Qtz. | Poly. Qtz. | Phyllo-silicate | Fe-oxide | K-feldspar | Muscovite schist lithoclast | Zircon | Plucked grain |
|---|---|---|---|---|---|---|---|---|---|---|
| Washington County Quartzite W.F. Flynn M-1 core | WQ-1 (2318.5') | Phyllite | 3 | 25 | 71 | 1 | -- | -- | -- | -- |
| | WQ-2 (2320') | Phyllitic Quartzite | 1 | 71 | 27 | 1 | -- | -- | -- | -- |
| | WQ-4 (2324.5') | Phyllitic Quartzite | 16 | 61 | 14 | 9 | -- | -- | -- | -- |
| | WQ-5 (2328') | Phyllitic Quartzite | 7 | 25 | 55 | 13 | -- | -- | -- | -- |
| | WQ-6A (2330.5') | Quartzite | 19 | 61 | 13 | 15 | -- | -- | -- | -- |
| | WQ-6B (2330.5') | Quartzite | 36 | 54 | -- | 3 | -- | -- | -- | 7 |
| | WQ-7 (2331.4') | Quartzite | 12 | 71 | 2 | 7 | -- | -- | 1 | 7 |
| | WQ-8 (2332') | Quartzite | 13 | 84 | 1 | 1 | -- | -- | -- | 1 |
| Flambeau Quartzite | #1 | Quartzite | 42 | 48 | 9 | 1 | -- | -- | -- | -- |
| | #2 | Quartzite | 24 | 51 | 14 | 9 | 2 | 1 | -- | -- |
| Baraboo Quartzite | Wis-1 | Quartzite | 17 | 78 | 5 | -- | -- | -- | -- | -- |
| Sioux Quartzite | SD-1 | Quartzite | 54 | 44 | -- | 2 | -- | -- | -- | -- |

## QUARTZITE

Below the phyllitic quartzite the lithology of the Washington County Quartzite changes to a poorly-sorted, fine-grained to pebbly quartzite with an overall appearance similar to the Sioux, Baraboo, and some other Baraboo interval quartzites. Quartz grain sizes observed in this section ranged from a minimum of 0.004 mm to a maximum of 5 mm. The color of this section of the core is dark maroon. This interval displays bedding dipping 70° and numerous healed fractures dipping about 35°. Some of the fractures display local color bleaching. Bedding can be recognized as alternating bands of finer and coarser grains. One 5 cm thick band of pebbly quartzite at 711.3 m exhibits apparent tabular cross bedding, disclosed by a possible clay drape over foreset laminae.

Modal analyses of thin sections from three quartzite intervals showed a matrix content ranging from 2 percent to 9 percent and averaging 2.7 percent, dominated by iron oxide with subordinate amounts of sericite (fig. 6). Quartz grains comprise an average of 90 percent of this unit, with 70 percent polycrystalline quartz and 20 percent monocrystalline.

## STRUCTURES

The most obvious structure evident in the W. F. Flynn M-1 core is the extensive foliation ($S_1$), especially pronounced in the finer-grained rock of the Washington County Quartzite. This folia- tion is expressed as a planar alignment of phyllosilicate minerals. In the phyllitic quartzite a penetrative muscovite foliation ($S_1$) was observed dipping at about 60°.

A phyllitic cleavage ($S_2$) which cross-cuts the penetrative muscovite foliation (fig. 7) was observed in the phyllitic quartzite, indicating a complex deformational history. A series of en echelon, muscovite-filled cleavage surfaces ($S_2$ in fig. 7) were identified dipping at about 30°. These features closely resemble deformational fabrics illustrated from the Baraboo Syncline (Dalziel and Dott, 1970, p. 25).

DISCUSSION

The compositional maturity, stratigraphic succession, and sedimentologic characteristics of the rock of the Washington County Quartzite closely resemble those noted in the better-studied Baraboo interval quartzites in the midcontinent. Terrigenous sandstone in the quartz arenite compositional field (fig. 4) are believed to be derived from stable cratonic source terranes of low relief, although deposition may have ultimately taken place in other tectonic settings (Dickinson and others, 1983, p. 223; Dickinson and Suczek, 1979, p. 2175).

The interbedded silty mudstone and poorly-sorted sandstone, which comprised the terrigenous sediments of the Washington County Quartzite prior to metamorphism, are generally consistent with braided fluvial deposition, as hypothesized by Dott (1983a,b) for much of the exposed Baraboo interval sequence in Wisconsin. The limited sample available for study precludes detailed interpretation of the depositional environments of the Washington County Quartzite. Nevertheless, the dominance of coarse-grained over fine-grained clastic sedimentary units and the poorly-sorted nature of the known stratigraphic succession are most easily reconciled with deposition by low-sinuosity braided stream systems (Brown, 1973, p. 13; Ore, 1964, p. 12). The possible presence of tabular cross bedding with clay drapes over foreset laminae, previously noted from the core at 711.3 m, would be consistent with this depositional setting.

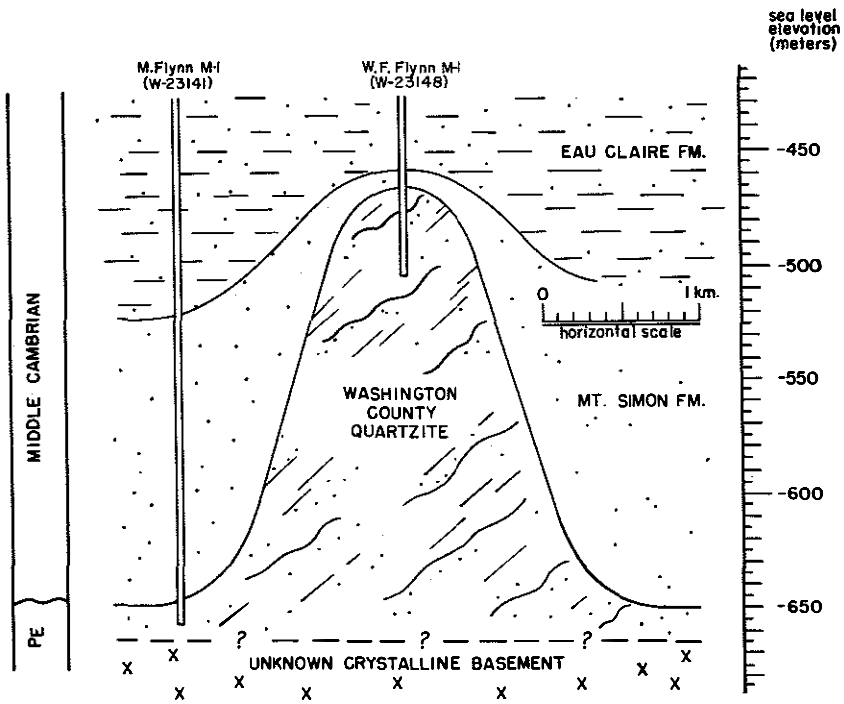


Figure 2.--Schematic geologic cross section of the Washington County Quartzite.

Estimates of the extent and geometry of this deposit are presently controlled only by the two drill holes, neither of which fully penetrate the unit. Therefore, all that can be stated with assurance is that the Washington County Quartzite has a linear extent of at least 2 km, that these rocks form a buried Precambrian hill with a paleotopographic relief of no less than 180 m, and that the thickness of the unit exceeds 46.7 m. Yaghubpur (1979) proposed that the difference in elevation of the quartzite surface between the two drillholes could be explained by vertical faulting of the basement surface. Overlying Phanerozoic deposits, however, do not display similar vertical displacement, and comparison with well-known Baraboo interval quartzite from other localities suggests that the relief of the Washington County Quartzite may be most easily explained as paleotopographic relief on the pre-Phanerozoic surface. The resistant hills of the Baraboo Range in Wisconsin have a documented pre-Phanerozoic topographic relief of greater than 300 m (Dalziel and Dott, 1970, Plate II). Shurr (1981, p. 28) has documented similar paleotopographic relief on the pre-Phanerozoic surface of the Sioux Quartzite, which forms a large buried resistant range called the Sioux Ridge.

The style of deformation and general metamorphic grade of the Washington County Quartzite is very similar to that observed in the Baraboo Syncline. While no radiometric age data are presently

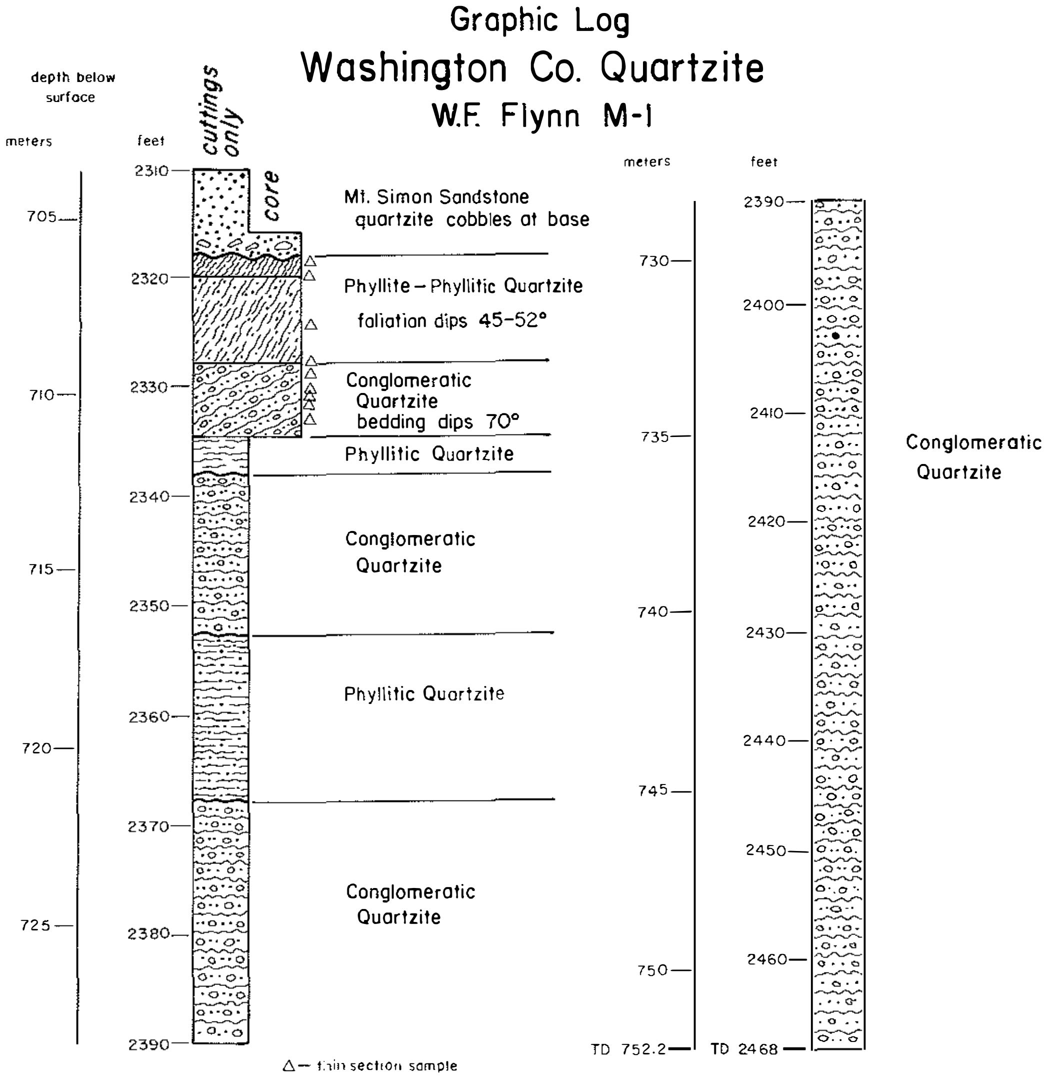


Figure 3.--Graphic lithologic log of the Washington County Quartzite from W.F. Flynn M-1.

available for this rock, their macroscopic appearance, petrology, and location far to the south of known Archean and Penokean terranes (Anderson and Black, 1983) argue that they were probably deposited and deformed contemporaneously with other Baraboo interval quartzites between 1,760 and 1,500 Ma (Van Schmus and others, 1975; Smith, 1978; Van Schmus, 1979; Van Schmus and Bickford, 1981; Dott, 1983a,b; Greenberg and Brown, 1984). This argument is strengthened by a recent review (Ojakangas and Morey, 1982) of the known Proterozoic sedimentary sequences of Lake Superior region that postdate the Penokean orogeny (1,860 to 1,800 Ma, Anderson and Black, 1983) but preceded Keweenawan volcanism about 1,100 Ma. Ojakangas and Morey (1982, p. 85) grouped these rocks into two major suites: (1) the Baraboo interval quartzites to the south of Lake Superior; and (2) a northern group of subarkosic, sublitharenitic, and arkosic quartzite whose outcrop belts fringe the Lake Superior Basin, including the Sibley Group (1,339 ± 33 Ma) and younger units. The Washington County Quartzite resembles their Suite 1 (Baraboo interval quartzites) much more closely than their Suite 2 quartzites.

## REGIONAL TECTONIC IMPLICATIONS

Two differing tectonic interpretations have recently been proposed for the Baraboo interval. Dott (1983a,b) proposed that the Baraboo interval metasedimentary rock is a remnant of a miogeoclinal sequence that was deformed and regionally metamorphosed by plate collisional orogeny about 1,600 Ma. An alternative anorogenic setting for the deposition and deformation of the Baraboo interval rock has been proposed by Greenberg and Brown (1983a,b,c, 1984). According to their hypothesis, epicratonic Baraboo interval sedimentation was preceded by and partly contemporaneous with anorogenic felsic magmatism, and was followed by gravity-induced folding related to epiorogenic uplift in central Wisconsin. Greenberg and Brown (1983b, p. 11; 1984, p. 168) further argue that all instances of high-grade metamorphism in Baraboo interval rocks are related to contact metamorphic effects of the 1,500 Ma Wolf River batholith and related intrusive rock. We are using (and presently favor) the miogeoclinal hypothesis of Dott (1983) because: (1) it specifically makes testable predictions about the crustal evolution of buried Proterozoic terrane to the south of Wisconsin, whereas Greenberg and Brown's hypothesis does not; (2) it can be broadly integrated into the North American chronology of Proterozoic crustal accretion proposed by Van Schmus and Bickford (1981); and (3) many of the claims which Greenberg and Brown (1984) cite as evidence against Dott's (1983b) hypothesis have not been documented well enough for us to evaluate their validity.

Dott (1983b, p. 138) described the Baraboo interval quartzites as the "remnants of a vast sedimentary wedge that blanketed at least the southern margin of the post-Penokean craton of Proto-North America." He suggested that a "combination of braided rivers...and shallow marine processes dispersed clastic sediments across that continental margin." These sediments were subsequently "subjected to strong compressive tectonics, which folded and metamorphosed the... sequences" (Dott, 1983b). The "most plausible hypothesis to explain the seemingly anomalous deformation and metamorphism of the mature red quartzites...is either an arc-continent or continent-continent collision about 1600 m.y. ago" (Dott, 1983b p. 139). The suture proposed by Dott (1983b, p. 130, fig. 1) extends generally east to west across southern Wisconsin and northern Iowa, passing to the south of the outcrop belts of the Waterloo, Baraboo, and Sioux Quartzites (fig. 8).

Data obtained in studies of samples of the Washington County Quartzite are compatible with a braided fluvial mode of deposition. Metamorphism and deformation observed in the W. F. Flynn M-1 core might be the product of convergent tectonics. The Washington County quartzite, however, is located about 200 km south of the Proterozoic continental margin and suture zone proposed by Dott (1983b) If they are Baraboo interval rock, the quartz-rich sediment of the Washington County Quartzite could not have been located on the plate to the south of the suture, as their deposition would have been influenced by a nearby volcanic arc highland required by the southward subduction of oceanic crust in Dott's (1983b, p. 139) model. Terrigenous sediments derived from such a provenance would not compositionally resemble the Washington County Quartzite (Dickinson and Suczek, 1979). A modification of Dott's (1983b) plate tectonic model, including Washington County rock as authentic Baraboo interval quartzites, follows.

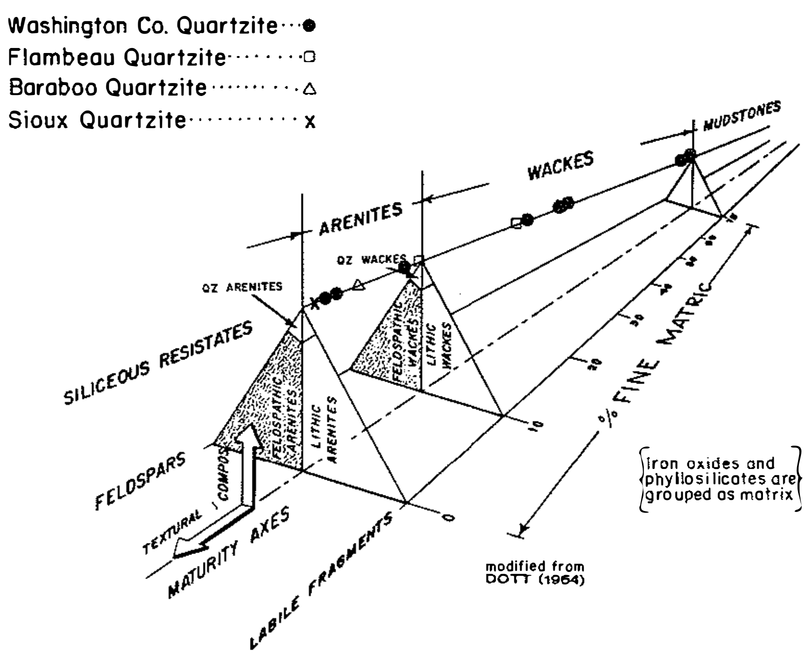


Figure 4.--Modal analyses of samples from the Washington County Quartzite and known Baraboo interval rocks from table 1. Triangular composition diagram in the prism corresponds to the QFL diagram of Dickinson, and others (1983).

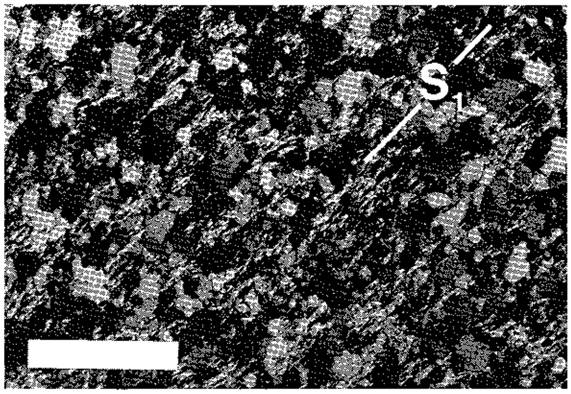


Figure 5.--Photomicrograph of phyllitic quartzite from W.F. Flynn M-1 (IGS W-23148), 707.8 m, showing foliation ($S_1$) developed by alignment of phyllosilicate grains. Scale bar is 0.5 mm. (polarized light).

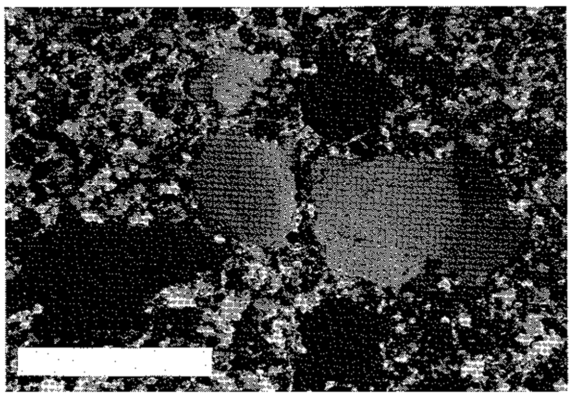

Figure 6.--Photomicrograph of pebbly quartzite from W.F. Flynn M-1 (IGS W-23148), 711.5 m. Note difference in original detrital quartz grains. Scale bar is 2 mm. (polarized light).

We propose that the Washington County Quartzite was deposited as part of the same sedimentary wedge and on the same passive trailing continental margin as the other Baraboo interval quartzites. To accommodate this interpretation, the continental margin and subsequent suture zone would have to be located to the south of Washington County, Iowa. A possible location for this suture is along a northeast trending zone of apparent crustal thickening first interpreted by Black (1981) and trending from panhandle Texas, across southeastern-most Iowa, and into Lake Michigan in the area of the Wisconsin-Illinois border (fig. 8). We feel this location for the suture has some merit, for the reasons outlined below.

The 1,630-Ma suture proposed by Dott (1983b, fig. 8) was discussed earlier by Van Schmus and Bickford (1981, p. 272, p. 280), who located it further south and referred to the feature as the Mazatzal Belt, a probable 1,680 to 1,610 Ma convergent plate boundary which they tentatively extended from southern Arizona to northern Illinois (fig. 8). Black (1981) identified a trend of high values on a map of the earth's magnetic field as recorded by NASA's MAGSAT satellite (fig. 9). The zone of high magnetic values corresponds directly to a pronounced gravity low, a combination of which is "indicative of crustal thickening" (Black, 1981, p. 78). Black (1981, p. 82) further noted the geographic coincidence of these paired geophysical anomalies with the Mazatzal

Belt of Van Schmus and Bickford (1981), and discussed possible relationships between them. This relationship suggests that the geophysical anomalies of Black (1981) may be a deep crustal signature of the Mazatzal Belt, the collisional orogen which is believed to have caused the foreland deformation of the Baraboo interval rocks north of the Baraboo suture (Van Schmus and Bickford, 1981, p. 272). Determination of the exact location of the Baraboo suture along Black's zone of crustal thickening is complicated by the subsequent emplacement of rocks of the "granite-rhyolite terrane" (Van Schmus and Bickford, 1981), the Wolf River batholith, and other felsic volcanic and plutonic rocks between about 1,500 and 1,380 Ma. This later terrane partially overlaps our proposed location for the Baraboo suture.

Our proposal is to use three admittedly speculative criteria to constrain our interpretation of the location and trend of the Baraboo suture. These are: (1) the MAGSAT contours of Black (1981) may be used as form lines to show the general trend of the Baraboo suture (fig. 9), which is the boundary between the Mazatzal Belt orogen and the passive continental margin upon which the Baraboo interval miogeoclinal rocks were deposited; (2) the Washington County Quartzite, which we propose to be part of this miogeoclinal sequence, would thus have been deposited on a basement of continental crust, and should be north of the Baraboo suture; and (3) the intensity of foreland deformation and regional metamorphism in Baraboo interval rock should decrease to the north away from the Mazatzal Belt orogen, and thus the metamorphic grade of pelitic rocks interstratified with the Baraboo interval quartzite can be used to further constrain the interpreted position of the Baraboo suture.

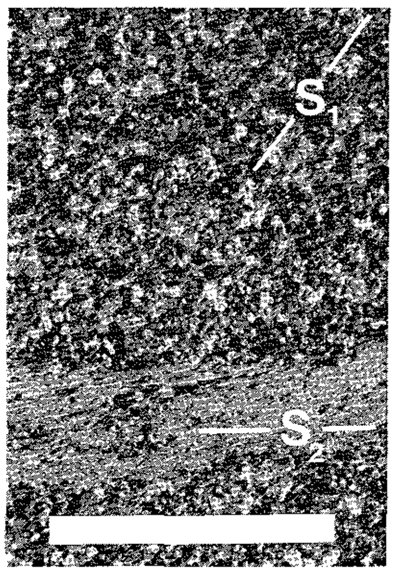


Figure 7.--Photomicrograph of phyllitic quartzite from W.F. Flynn M-1 (IGS W-32148), 707.1 m, showing a muscovite-filled cleavage surface. $S_1$ is the penetrative muscovite foliation, and $S_2$ is the crosscutting phyllitic cleavage. Scale bar is 3 mm (polarized light).

Metapelites from the Waterloo Quartzite apparently record a complex deformational and metamorphic history that was culminated by low-grade amphibolite-facies metamorphism, all of which Geiger and others (1981, p. 33) interpreted to be caused by a regional thermo-tectonic event related to the deformation of the Baraboo interval quartzite. Phyllite from the Baraboo and Washington County Quartzite, however, has apparently been metamorphosed to the greenschist facies. Finally, mudrock from the Barron (Campbell, 1981, p. 138) and Sioux (Austin, 1972, p. 455) Quartzites display only minor metamorphism, indicated by their alteration to argillite or pipestone. These observations can be used to construct a crude regional metamorphic zonation in the quartzites, as is shown in figure 8. High-grade metamorphism observed in the Rib Mountain and McCaslin Quartzites (putative Baraboo interval rock from northern Wisconsin) do not relate to this proposed regional metamorphic pattern, since they apparently are roof pendants to the 1,500 Ma Wolf River batholith, and have been contact-metamorphosed (Greenberg and Brown, 1983b, p. 11). The origin of the high-grade metamorphism in the Waterloo Quartzite (regional versus contact) however, is pivotal to the zonation shown in figure 8 and further attention should be focused on this problem.

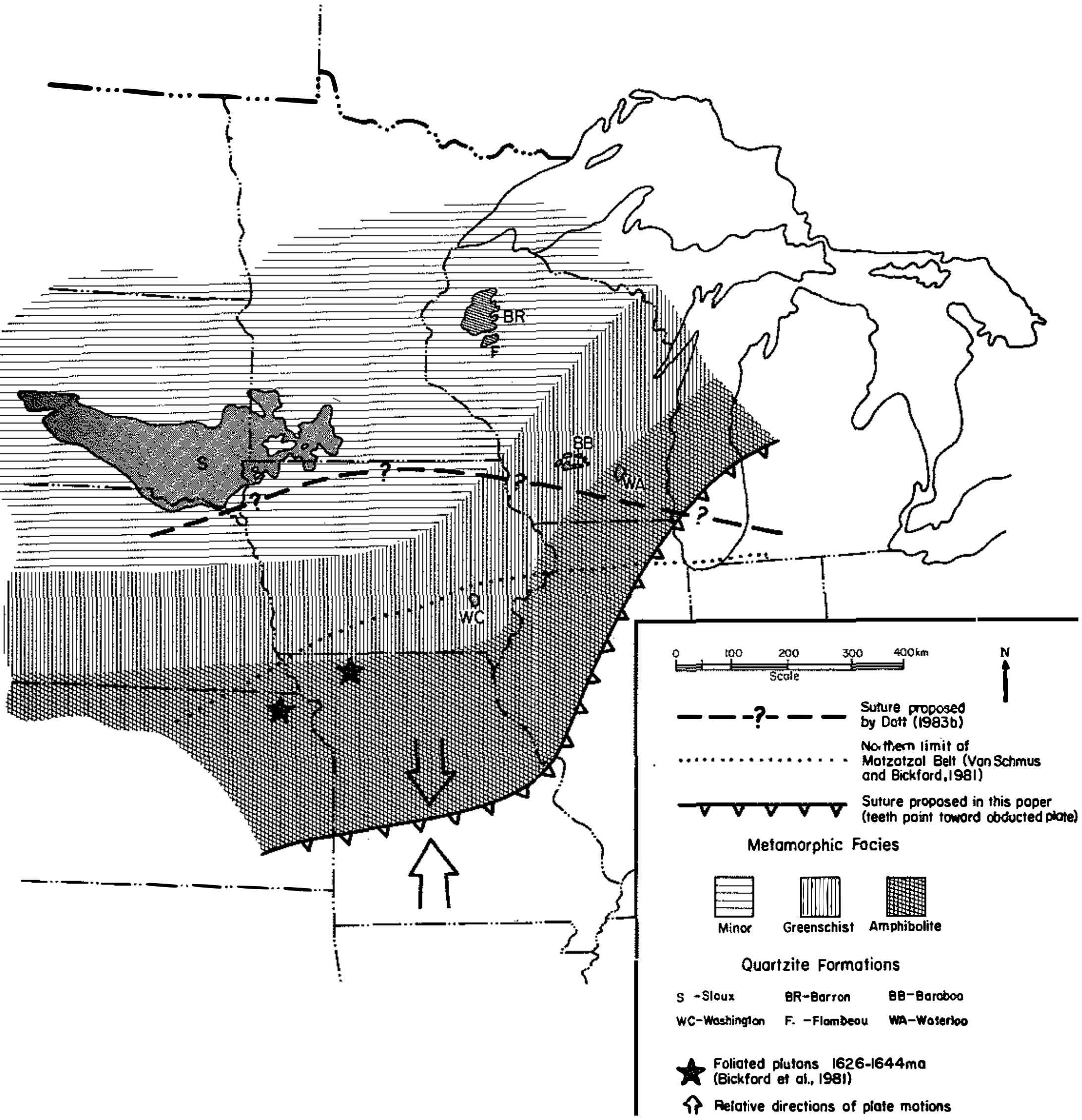


Figure 8.--Proposed locations for the Baraboo suture (1630 Ma) by Dott (1983b)and this paper with possible associated metamorphic zonation.

A possible location and trend for the Baraboo suture, using the constraints outlined above, is shown in figure 8. Note the positions of the 1,626- to 1,644-Ma, foliated plutons in northeast Kansas and northwest Missouri with respect to our proposed suture (fig. 8). These units were cited by Van Schmus and Bickford (1981, p. 275) and Bickford and others (1981, p. 339) as critical evidence for extending the Mazatzal Belt into the midcontinent region. The petrology of these foliated granitic plutonic rock indicates that they have been deformed by cataclasis, and that the granite from Gentry County, Missouri appears to be "a sheared and recrystallized igneous rock of granitic to quartz monzonitic composition" (Bickford and others, 1981, p. 330). The chemical affinities of this rock to continental crust is consistent with its location to the north of the proposed Baraboo suture, as shown in figure 8. Since the collisional orogeny leading to the development of the Baraboo suture is postulated to have been preceded by southward subduction of oceanic crust (Dott, 1983b, p. 139), volcanic-arc or Andean-type volcanism would be expected to have occurred on the plate to the south of the suture. We tentatively suggest that the foliated granitic plutons in northeast Kansas and northwest Missouri may have originated as the continental basement rock upon which the Baraboo interval miogeoclinal sediment was deposited (the 1,690 to

1,780 Ma Belt of Van Schmus and Bickford, 1981, p. 282), and that the rock possibly may be anatexite, deformed because of their proximity to the collisional Mazatzal Belt orogen (as in Schermer and others, 1984, p. 116).

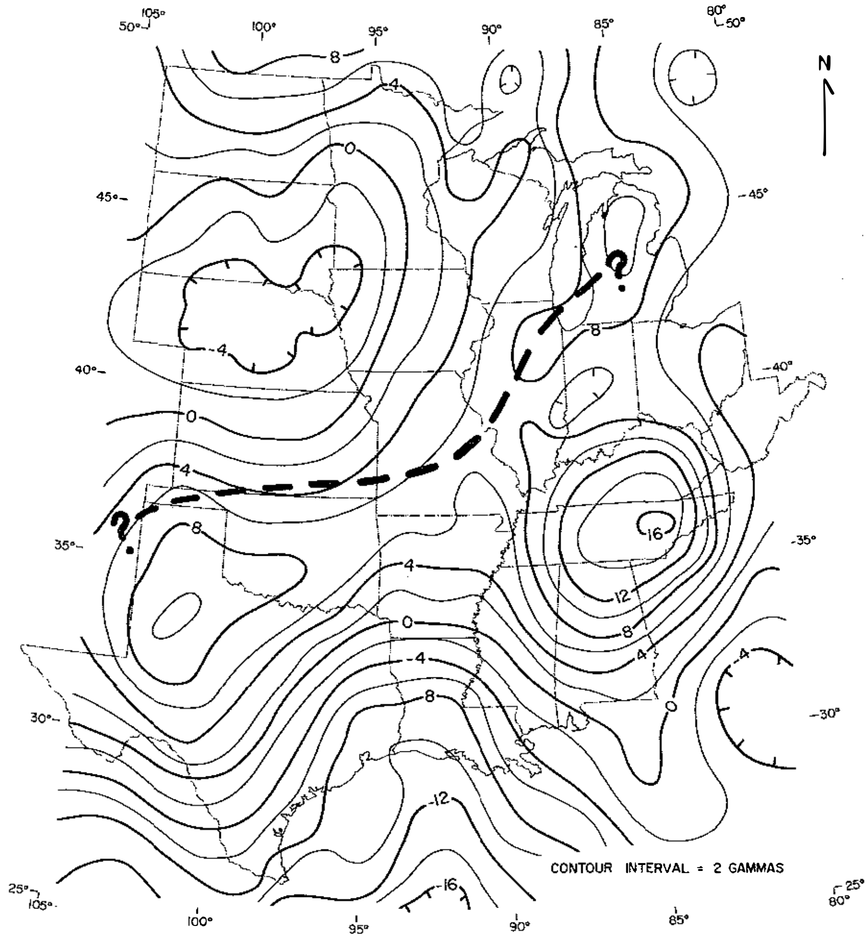


Figure 9.--MAGSAT vector magnitude map, reduced to the magnetic pole, filtered, one degree weighted-average (from Black, 1981, p. 74). Heavy dashed line shows the location for the Baraboo suture proposed in this paper.

One apparent weakness of our hypothesis is the troubling lack of parallelism between the east-west trending fold axes known from the exposed Baraboo interval quartzite (Dalziel and Dott, 1970; Brandon, 1983) and the generally northeast-trending collisional suture proposed here. This disparity might be explained by oblique continental convergence. It is hypothesized that the east-west trending folds record compressive foreland deformation along a northeast-southwest trending continental margin by a north-south directed plate collision (fig. 8).

Two alternative plate tectonic interpretations might be applied to the Washington County Quartzite: (1) the Washington County Quartzite was carried to its present position as part of an exotic terrane that was accreted onto the proto-North American continent during the 1,630 Ma collision or later. Thus, the Washington County Quartzite records the tectonic history of a different continental shield; or (2) the Washington County Quartzite was deposited and deformed on a passive trailing continental margin that developed to the south of Dott's (1983b) proposed suture during a post-Baraboo interval Wilson Cycle, and is younger than the Sioux, Baraboo, or related quartzite.

It seems unlikely that Washington County Quartzite was accreted onto the proto-North American continent as suggested in the first alternative interpretation. Integration of available drill data, outcrop studies, and geophysical signatures by Anderson and Black (1983) has led to the interpretation of the position of the Penokean (1,860 to 1,800 Ma old) suture, extending west and south from Green Bay (south of Escanaba, Michigan), across northern Wisconsin along the trend of the Niagara tectonic zone (Brown, 1983), then across southeastern Minnesota, northwestern Iowa, and into Nebraska following the Storm Lake geo physical trend (Anderson and Black, 1983). The nature of the gravity and magnetic signatures between the Washington County Quartzite and Penokean suture to the north (broken only by the Midcontinent Geophysical Anomaly, about 1,000 Ma) argues against a post-Penokean suture zone and any post-Penokean microcontinental accretion in this area.

The second proposed interpretation, that the Washington County Quartzite records post-Baraboo interval deposition and deformation, is also considered unlikely. The only presently known post-Baraboo interval, pre-Keweenawan Proterozoic clastic rock sequences in the region are located far to the north (Ojakangas and Morey, 1982), and are petrologically distinctive from Baraboo interval quartzite. If the rock of the Washington County Quartzite do indeed record a post-Baraboo interval Wilson Cycle, it would be the first known sedimentary rock from that interval.

In our opinion the relationships between the exposed Baraboo interval rock and the Washington County Quartzite will ultimately be resolved by investigation of the Proterozoic geology in areas presently covered by Phanerozoic sedimentary rock. It is apparent from Van Schmus and Bickford (1981) that a roughly east-northeast trending convergent plate boundary (the Mazatzal Belt) existed in the region during the 1,680 to 1,610 Ma interval. Since all interested workers seem to agree that the Baraboo interval rock was folded approximately during this time (Van Schmus and Bickford, 1981, p. 272; Greenberg and Brown, 1983b, p. 11; Dott, 1983b, p. 138), the precise location, trend, and tectonic history of the Mazatzal Belt in the midcontinent is obviously of great interest in resolving the regional tectonic setting for the Baraboo interval. This paper is intended to help further that end.

## CONCLUSIONS

Petrologic studies of the Precambrian quartzite from Washington County in southeastern Iowa indicate that the sedimentology and style of deformation of this unit are closely similar to those known from the Baraboo Quartzite of Wisconsin. We suggest that the Washington County Quartzite may be reasonably correlated with the general depositional and tectonic episodes of the mid-Proterozoic Baraboo interval (Dott, 1981), during which the Baraboo, Barron, Flambeau, Sioux, Waterloo, and other unnamed quartzites were deposited and deformed. The compositional maturity of the Washington County Quartzite (table 1, fig. 4) is identical with that observed in samples from the Baraboo interval quartzite. The interbedding of terrigenous silty mudstones and poorly-sorted sandstones in the Washington County Quartzite is compatible with the braided fluvial origins interpreted by Dott (1983b) for most of the Baraboo interval sequence in Wisconsin. Alignment of phyllosilicate minerals in the finer-grained units imparts a steeply-dipping foliation ($S_1$) in the rock of the Washington County Quartzite. This feature, and later phyllitic cleavage surfaces ($S_2$ fig. 6), closely resemble structures illustrated from the Baraboo Quartzite (Dalziel and Dott, 1970, p. 25). Finally, the texture, color, and overall megascopic appearance of the unit strongly resembles other quartzite of the Baraboo interval.

The Washington County Quartzite represents the southernmost reported occurrence of probable Baraboo interval quartzite in the midcontinent. Its identification may provide an important constraint on interpretation of the former areal extent of the quartzite, and the location and orientation of a Proterozoic passive trailing continental margin and later collisional suture zone, which may have controlled the deposition and deformation of the quartzite (Dott, 1981, 1983a,b).

Both core and cutting samples of the Washington County Quartzite are reposited at the Iowa Geological Survey and are available for additional study. Future work may provide information important to the development of an understanding of these areally extensive but extremely enigmatic deposits.

## ACKNOWLEDGMENTS

The authors thank Jeff Greenberg and Bruce Brown of the Wisconsin Geological and Natural History Survey for their early encouragement to begin this investigation, and for their editorial guidance during the preparation of this manuscript. Thin sections utilized during this study were prepared by Mike Farmer, IGS Support Services. Various drafts of the manuscript were typed by Laurie Comstock and Mary Pat Heitman. Finally, review comments by Jeff Greenberg, Bruce Brown, Dick Ojakangas, Dick Hoppin, Bob Dott, Bob Brenner, and Brian Witzke materially improved this manuscript, although any errors are the responsibility of the authors.

## REFERENCES CITED


Anderson, R.R. and Black, R.A., 1983, Early Proterozoic development of the southern Archean boundary of the Superior Province in the Lake Superior Region (abs.): Geological Society of America Abstracts with Programs, v. 15, p. 515.

Anderson, R.R. and Ludvigson, G.A., 1983, A new Proterozoic quartzite, Washington County, S.E. Iowa (abs.): Geological Society of America Abstracts with Programs, v. 15, p. 209.

Bickford, M.E., Harrower, C.L., Hoppe, W.J., Nelson, B.K., Nasbaum, R.L., and Thomas, J.L., 1981, Rb-Sr and U-Pb geochronology and distribution of rock types in the Precambrian basement of Missouri and Kansas: Geological Society of America Bulletin, Part 1, v. 92, p. 323-341.

Black, R.A., 1981, Geophysical processing and interpretation of MAGSAT satellite magnetic data over the U.S. midcontinent: Iowa City, University of Iowa, unpublished M.S. thesis, 116 p.

Brandon, C.N., III, 1983, Geology of the Precambrian Waterloo Quartzite, Waterloo, Wisconsin (abs.): Geological Society of America Abstracts with Programs, v. 15, p. 209.

Brown, B.A., 1983, History of Precambrian and Proterozoic rocks; in Brown, B.A., ed., Three billion years of geology, Archean, Proterozoic, and Pleistocene geology Black River Valley: Wisconsin Geological and Natural History Survey, Field Trip Guidebook 9, p. 1-9.

Brown, L.F., Jr., 1973, Cratonic basins: Terrigenous clastic models: University of Texas Bureau of Economic Geology, Guidebook 14, p. 10-30.

Campbell, F.K., 1981, Geology of the upper Precambrian Flambeau Quartzite, Chippewa County, north-central Wisconsin: Duluth, University of Minnesota Duluth, unpublished M.S. thesis, 176 p.

Dalziel, I.W.D. and Dott, R.H., Jr., 1970, Geology of the Baraboo District, Wisconsin: Wisconsin Geological and Natural History Survey Information Circular 14, 164 p.

Dickinson, W.R., and Suczek, C.A., 1979, Plate tectonics and sandstone compositions: American Association of Petroleum Geologists Bulletin, v. 63, p. 2164-2182.

Dickinson, W.R., Beard, L.S., Brakenridge, G.R., Erjavec, J.L., Ferguson, R.C., Inman, K.F., Knepp, R.A., Lindberg, F.H., and Rhyberg, P.T., 1983, Provenance of North American Phanerozoic sandstones in relation to tectonic setting: Geological Society of America Bulletin, v. 94, p. 222-235.

Dott, R.H., Jr., 1964, Wacke, graywacke and matrix--what approach to immature sandstone classification?: Journal of Sedimentary Petrology, v. 34, p. 625-632.

Dott, R.H., Jr., 1981, The Proterozoic red quartzite enigma in the north-central United States--resolved by plate collision? (abs.): International Proterozoic Symposium, University of Wisconsin-Madison Abstracts.

Dott, R.H., Jr., 1983a, The Baraboo Interval--A tale of red quartzites (abs.): Geological Society of America Abstracts with Programs, v. 15, p. 209.

Dott, R.H., Jr., 1983b, The Proterozoic red quartzite enigma in the north-central United States--resolved by plate collision?: in Medaris, L.G., ed., Early Proterozoic Geology of the Great Lakes region: Geological Society of America Memoir 160, p. 129-141.

Geiger, C.A., Guidotti, C.V., and Petro, W.L., 1981, Some aspects of the petrologic and tectonic history of the Precambrian rocks of Waterloo, Wisconsin: Geoscience Wisconsin, v. 6, p. 21-40.

Greenberg, J.K., and Brown, B.A., 1983a, Anorogenic setting of the Baraboo interval (abs.): Geological Society of America Abstracts with Programs, v. 15, p. 209.

Greenberg, J.K., and Brown, B.A., 1983b, Middle Proterozoic to Cambrian rocks in central Wisconsin: anorogenic sedimentary and igneous activity: Wisconsin Geological and Natural History Survey Field Trip Guidebook 8, 50 p.

Greenberg, J.K., and Brown, B.A., 1983c, Proterozoic cratonization south of the Superior Provinence in Wisconsin (abs.): Geological Society of America Abstract with Programs, v. 15, p. 586.

Greenberg, J.K., and Brown, B.A., 1984, Cratonic sedimentation during the Proterozoic: an anorogenic connection in Wisconsin and the upper midwest: Journal of Geology, v. 92, p. 159-171.

Hase, D.H., and Koch, D.L., 1968, Geophysical study of the Keota Dome--Keokuk and Washington Counties, Iowa: Notes and Discussions, Geological Society of America Bulletin, v. 79, p. 935-940.

Ojakangas, R.W., and Morey, G.B., 1982, Proterozoic se dimentary rocks; in Wold, R.J., and Hinze, W.J., ed., Geology and tectonics of the Lake Superior Basin: Geological Society of America Memoir 156, p. 83-96.

Ore, H.T., 1964, Some criteria for recognition of braided stream deposits: University of Wyoming Contributions to Geology, v. 3, p. 1-14.

Schermer, E.R., Howell, D.G., and Jones, E.L., 1984, The origin of allochtonous terranes: Perspectives on the Growth and Shaping of Continents: Annual Reviews Earth and Planetary Sciences, v. 12, p. 107-131.

Shurr, G.W., 1981, Cretaceous sea cliffs and structural blocks on the flanks of the Sioux Ridge, South Dakota and Minnesota: in R.L. Brenner, R.F. Bretz, B.J. Bunker, D.L. Iles, G.A. Ludvigson, R.M. McKay, D.L. Whitley, and B.J. Witzke, Cretaceous stratigraphy and sedimentation in northwest Iowa, northeast Nebraska, and southeast South Dakota, Iowa Geological Survey, Guidebook Series 4, p. 25-42.

Smith, E.I., 1978, Precambrian rhyolites and granites in south-central Wisconsin: Field relations and geochemistry; Geological Society of America Bulletin, v. 89, p. 875-890.

Van Schmus, W.R., 1979, Geochronology of the southern Wisconsin rhyolites and granites: Geoscience Wisconsin, v. 2, p. 9-24.

Van Schmus, W.R. and Bickford, M.E., 1981, Proterozoic chronology and evolution of the Midcontinent Region, North America, in A. Kröner, ed., Precambrian plate tectonics, Elsevier Scientific Publishing Company, p. 261-269.

Van Schmus, W.R., Thurman, M.E., and Petermann, Z.E., 1975, Geology and Rb-Sr chronology of middle Precambrian rocks in eastern and central Wisconsin: Geological Society of America Bulletin, v. 86, p. 1255-1265.

Weber, R.E., 1981, Petrology and sedimentation of the upper Precambrian Sioux Quartzite--Minnesota, South Dakota, and Iowa: Minneapolis, University of Minnesota, unpublished M.S. thesis, 151 p.

Yaghubpur, A., 1979, Preliminary geologic appraisal and economic aspects of the Precambrian basement of Iowa: Iowa City, University of Iowa, unpublished Ph.D. dissertation, 294 p.