UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Precambrian basement map of the northern midcontinent, U.S.A.

Compiled by

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[1]Denver, Colorado

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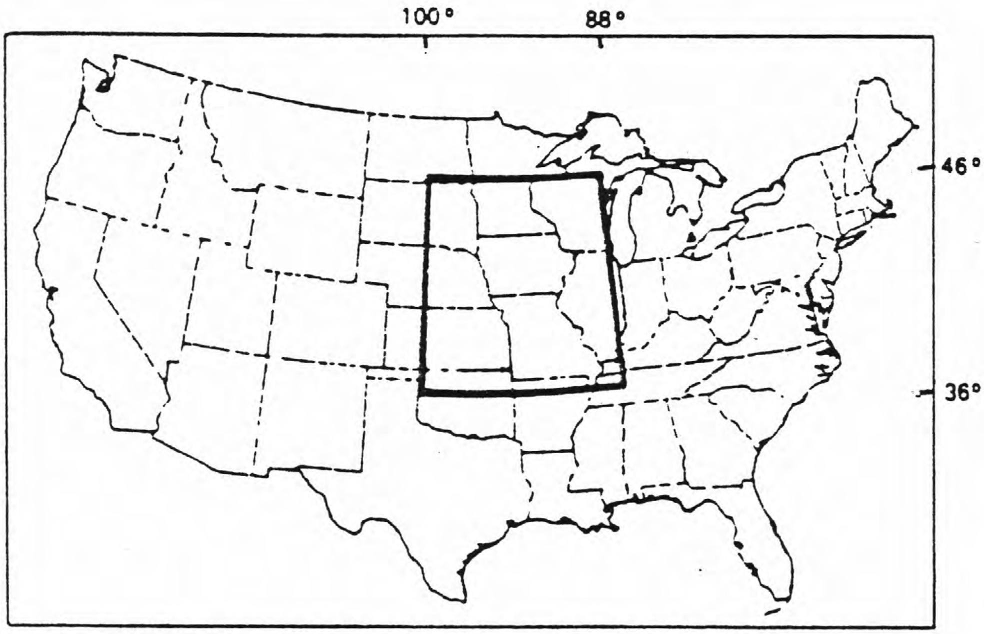
INTRODUCTION

The northern midcontinent region includes the buried basement of the interior platform and the southernmost exposed Precambrian rocks of the Canadian Shield (see index map). Structurally, it is part of a continent-wide "tectonic collage" consisting of (1) Archean cratonic elements (>2500 Ma) and remnants of Early Proterozoic (~1,900-2,100 Ma) cratonic cover, (2) anastomosing Early Proterozoic orogenic belts culminating at ~1,850 Ma and ~1,650 Ma, which partly enclose and marginally affect the Archean cratons, and (3) intracratonic igneous and sedimentary rocks, mainly of Middle Proterozoic age but including an older rhyolite-granite terrane (~1,760 Ma) and somewhat younger, scattered quartzite, assigned by Dott (1983) to the "Baraboo interval".



The map was compiled as part of a cooperative federal-state project from 1:500,000-scale maps submitted by respective state geological surveys showing basement drill holes, lithotypes or sketchy geologic map units, and basement topography, contoured at 200-foot intervals. In compiling the map, available aeromagnetic (Zietz, 1982; Burchett, 1985) and gravity anomaly maps (Hildenbrand and others, 1982) were utilized to define insofar as possible the trend, extent, and boundaries of individual rock bodies, and all available isotopic age data were used.

The principal geologic contribution resulting from the compilation is the delineation of a major buried, northwest-trending Early Proterozoic orogen, named the Central Plains orogen (Sims and Peterman, in press). It extends from Nebraska through Kansas into Missouri, where it is overlapped by Middle Proterozoic rhyolite-granite terranes; and it sharply truncates Archean rocks and an older Proterozoic orogenic (Penokean) belt in the inner part of the craton.

PREVIOUS WORK

A major, integrated, pioneering effort to compile and assess the geology and geochronology of the basement rocks in the continental interior of the United States (Muehlberger and others, 1967) culminated in 1968 with publication of the Basement rock map of the United States (Bayley and Muehlberger, 1968). This map shows the gross distribution and known structural features of the basement rocks, but does not attempt to delineate specific lithotypes or related rock types. The geochronology, based on Rb/Sr and K-Ar methods, was discussed in companion publications (Goldich and others, 1966a; Goldich and others, 1966b; Muehlberger and others, 1966; Lidiak and others, 1966). Later, more detailed studies of basement drill samples in Nebraska (Lidiak, 1972), Missouri (Kisvarsanyi, 1974), and Kansas (Bickford and others, 1979) further refined knowledge of the nature and distribution of specific basement rock units. In the early 1980's, Denison and others (1984) compiled the available lithologic data, isotopic age data, and a generalized correlation chart for the midcontinent region; and Van Schmus and Bickford (1981) summarized the chronology and proposed an accretionary model for crustal evolution in the region. Subsequent studies have concentrated on isotopic dating of rocks from available drill cores, emphasizing the U-Pb zircon method, because the Rb-Sr whole-rock systems are disturbed. The age dating succeeded in identifying (1) two widespread rhyolite-granite terranes of Middle Proterozoic age in the southern part of the area (Van Schmus and Bickford, 1981; Bickford and others, 1981; Thomas and others, 1984)--the St. Francois and Spavinaw rhyolite terranes; (2) an ill-defined northern metamorphic terrane ~1,700 Ma; Bickford and others, 1981)--the Central Plains orogen; and (3) numerous anorogenic plutons (~1,350-1,480 Ma) that cut the older metamorphic rocks. Most of the age dating has been done at the University of Kansas.

The isotopic dating and related petrologic and chemical studies of the rhyolite and granite led Van Schmus and Bickford (1981) and Thomas and others (1984) to propose an origin for them by partial crustal melting following accretion of calc-alkaline arcs at ~1,800 Ma. This mechanism is compatible with Nd-Sm model ages on samples of the 1,350-1,480 Ma rhyolite and granite by Nelson and DePaolo (1985), which indicate that these rocks were derived from older crustal rocks that separated from the mantle at ~1,800-1,900 Ma.

GEOLOGIC TERRANES

Eight major terranes have been identified in the northern midcontinent, from oldest to youngest:

(1) Archean gneiss terrane (age, 2,600-3,600 Ma)
(2) Archean greenstone-granite terrane (age, 2,600-2,750 Ma)
(3) Wisconsin magmatic terrane and associated epicratonic rocks of the Penokean orogen (age, 1,830-2,100 Ma)
(4) Southern Wisconsin rhyolite-granite terrane (age, ~1,760 Ma)
(5) Northwest-trending metamorphic belt (Central Plains orogen) (age, ~1,600-1,800 Ma)
(6) St. Francois rhyolite terrane (age, ~1,480 Ma)
(7) Spavinaw rhyolite terrane (age, 1,350-1,400 Ma)
(8) Midcontinent rift system (age, 1,000-1,200 Ma)

In addition, other coherent rock units include quartzite of the "Baraboo interval" (Dott, 1983) and plutons of anorthosite and rapakivi granite of the Transcontinental anorogenic province (Anderson, 1983).

Geologic and geophysical characteristics of each major terrane are described below.

Archean gneiss terrane (age, 2,600-3,600 Ma)

The Archean gneiss terrane is exposed sporadically in the Minnesota River Valley (Grant, 1972) and has been penetrated by numerous drill holes in southern Minnesota. It is a complex migmatitic terrane consisting of granite gneiss, more local schistose to gneissic amphibolite, and lesser amounts of metasedimentary gneisses and metagabbro. Most of the rocks are older than 3,000 Ma and have undergone a long and complex history of multiple deformation and metamorphism, which culminated at approximately 2,600 Ma, the age of emplacement of large granite plutons. The protolith of the gneisses is in part ~3,600 Ma (Goldich and Wooden, 1980). The exposed rocks are folded into large-scale, moderately open, and gently plunging antiforms and synforms (Bauer, 1980). The gneisses are inferred to extend in the subsurface southward into northern Nebraska and westward into central South Dakota (beyond map area), where they apparently are truncated by the Early Proterozoic Central Plains and Trans-Hudson orogens, respectively.

Archean greenstone-granite terrane (age, 2,600-2,700 Ma)

The greenstone-granite terrane is the southern extension of the Superior province of the Canadian Shield into the United States (Sims, 1976; Sims and Peterman, 1981). It consists mainly of greenschist-facies volcanic and volcanogenic rocks and intrusive plutonic rocks that are 2,600-2,700 Ma (Peterman, 1979). The unit is not exposed in the map area, but can be mapped grossly by diagnostic northeast-trending magnetic (Zietz, 1982) and gravity (Craddock and others, 1970) anomalies that extend from exposed areas in northern Minnesota into central South and North Dakota. It is truncated in the central Dakotas by the Trans-Hudson orogen.

The boundary between the greenstone-granite and the gneiss terrane is an east-northeast-trending shear zone (suture) named the Great Lakes tectonic zone (Sims and others, 1980).

Wisconsin magmatic terrane and associated epicratonic rocks of the Penokean orogen (age, 1,830-2,100 Ma)

The Penokean orogen, as defined in the Lake Superior region (Cannon, 1973; Sims and Peterman, 1983), has a well-defined tectonic-stratigraphic zonation. Early Proterozoic (~2,100-1,900 Ma) epicratonic sedimentary rocks that overlie an Archean basement, on the north, are separated from a volcanic-plutonic (Wisconsin magmatic terrane) province (~1,830-1,890 Ma; Van Schmus, 1980), on the south, by a major shear zone (Niagara fault; Sims and others, 1985). The shear zone is interpreted as a collision zone formed at ~1,850 Ma when the magmatic arc collided with the continental margin and triggered the Penokean orogeny.

The epicratonic rocks are dominantly clastic sedimentary rocks but include the vast iron-formations for which the Lake Superior region is famed (Sims, 1985; Bayley and James, 1973; Morey, 1983). The rocks are assigned to the Mille Lacs and Animikie Groups in Minnesota (Morey, 1983) and the Marquette Range Supergroup in Michigan (Cannon and Gair, 1970).

The Wisconsin magmatic terrane is composed mainly of basalt, rhyolite, and minor andesite, which are intruded by abundant plutonic rocks ranging in composition from quartz diorite to granite (Schulz, 1984). The volcanic rocks are steeply-dipping and, generally, isoclinally folded.

The Wisconsin magmatic terrane is truncated on the west by the Midcontinent rift system, and it does not extend into eastern Minnesota. However, it is interpreted from sparse lithologic and isotopic age data, as well as magnetic and gravity anomaly data, as forming a northeast-trending belt extending from south-central Minnesota through northwest Iowa into northeastern Nebraska. This belt is characterized by moderately high gravity values (commonly 0 to -10 mGal), which distinguishes it from adjacent rocks. It is interpreted as being truncated in northeastern Nebraska by the younger Central Plains orogen.

Southern Wisconsin rhyolite-granite terrane (age, ~1,760 Ma)

An extensive terrane of ~1,760 Ma rhyolite and coeval epizonal granite is exposed locally in river valleys in south-central Wisconsin and has been penetrated in several drill holes. The outline of the terrane on the map is based on conspicuous northeast-trending positive magnetic anomalies, which are parallel to open folds observed in the rhyolite (Smith, 1978), and prominent magnetic lineaments along part of the northwest margin. The magnetic lineaments are subparallel to the folds and are interpreted as rift-related faults.

The terrane consists generally of two mineralogically and chemically distinct rock suites (Smith, 1983): (1) a peraluminous suite of texturally variable ash-flow tuffs and two-mica granites, and (2) a metaluminous suite containing quartz- and orthoclase-bearing rhyolites and biotite granites. Granite intrusions and mafic dikes are spatially associated with, but are younger than, the rocks of the two main suites.

The rhyolites record a critical change from the calc-alkaline magmatism in the Wisconsin magmatic terrane to post-Penokean anorogenic magmatism. The rhyolite and granite are the oldest anorogenic volcanic and plutonic rocks in the central United States. They are approximately the same age as the older volcanic-plutonic rocks (1,650-1,790 Ma) in the Early Proterozoic foldbelt in Colorado and Wyoming (Hedge and others, 1967; Bickford and Boardman, 1984; Premo, 1984) and the Central Plains orogen.

The map unit (X^3gr, pl. 1) to the southeast of the rhyolite-granite unit has not been dated, but in Dane County, Wisconsin it consists largely of a fine-grained epizonal granite that is similar petrographically to a major granite type in the rhyolite unit (Smith, 1978). This granite is cut by gabbro and diorite dikes. Also, the rocks of the X^3gr unit are overlain at places by quartzite, as is the rhyolite, suggesting that the unit is comparable in age to the 1,760 Ma rhyolite-granite.

Northwest-trending metamorphic belt (Central Plains orogen) (age, 1,600-1,800 Ma)

The northwest-trending metamorphic belt that traverses Nebraska, Kansas, and Missouri, defined for the first time in this study, is reflected by conspicuous linear magnetic (Zietz, 1982) and gravity anomalies (Hildenbrand and others, 1982; Arvidson and others, 1984). The most prominent gravity feature is the "Missouri gravity low", which is 700 km long and 120 km wide; it has a maximum amplitude of ~40 mGal. Kisvarsanyi (1984) has delineated five major northwest-trending tectonic zones in Missouri, (shown on map), which are marked by faults, igneous intrusions, and cataclastic textures in basement rocks. Their long-lived tectonic influence is indicated by the alinement of Paleozoic structures with them. Similar northwest-trending basement faults, which were also reactivated in Paleozoic time, occur in Kansas and Nebraska.

The northern boundary of the orogen is only approximately located. It is based on: (1) the position of the Cheyenne belt (Houston and others, 1979) (see fig. 1), the northern margin of the presumed correlative Colorado-Wyoming foldbelt; (2) lithologic units delineated in Nebraska by Lidiak (1972); and (3) an abrupt southwest-decreasing gravity gradient (from 0 mGal on the north to -40 mGal on the south) in northeastern Nebraska, which is interpreted as marking the truncation of the northeast-trending Penokean volcanic belt by the younger Central Plains orogen. The boundary in intervening areas is extrapolated from magnetic and gravity data.

Judged from the detailed studies of subsurface samples in Nebraska (Lidiak, 1972), Kansas (Bickford and others, 1979), and Missouri (Kisvarsanyi, 1974) and data compiled by the state geological surveys specifically for this map, the principal lithotypes are quartz-feldspar gneiss, biotite, hornblende, and quartz-muscovite schist, amphibolite, granofels, metarhyolite, marble, micaceous quartzite, and phyllite (see also Denison and others, 1984). The quartzite in western Nebraska contains sillimanite and muscovite (Treves and Low, 1985). The metamorphic rocks are mainly amphibolite facies (Lidiak, 1972) but include greenschist and, possibly, granulite-facies assemblages, as well as retrogressive assemblages, and range in texture from granoblastic to mylonitic. Mesozonal syntectonic granitoid rocks ranging in composition from quartz diorite to granite and epizonal granitic rocks (Lidiak, 1972) intrude the metamorphic rocks. The latter are particularly abundant in Kansas and Missouri.

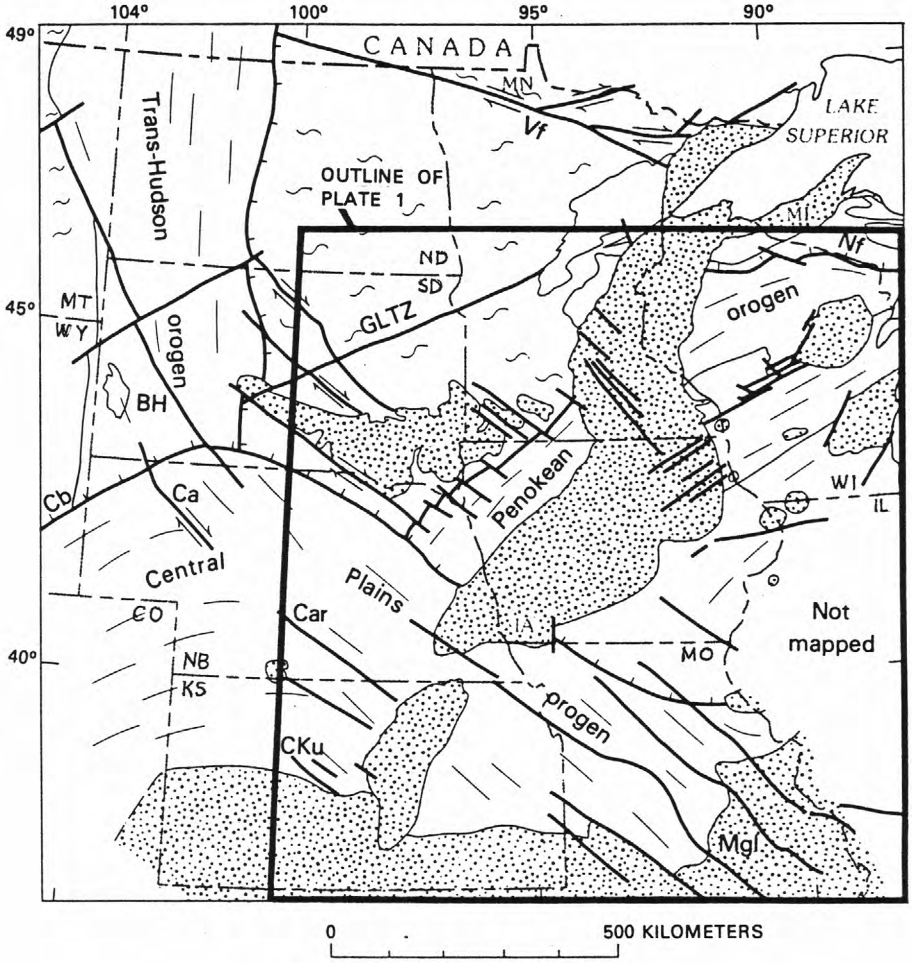
Ages of the metamorphic and syntectonic granitoid rocks are rather poorly constrained, partly because the Rb-Sr whole rock and mineral systems are disturbed (Van Schmus and Bickford, 1981), and until recently this was the principal isotopic method used for age dating (Goldich and others, 1966b). Available U-Pb zircon ages are in the range 1,600-1,800 Ma (M. E. Bickford, written commun., 1984; W. R. Van Schmus, written commun., 1985).

This terrane is largely equivalent to the "northern terrane" of Bickford and others (1981).

St. Francois rhyolite terrane (age, ~1,480 Ma)

The St. Francois rhyolite terrane is exposed in the St. Francois Mountains (Bickford and Mose, 1975; Pratt and others, 1979; Bickford and others, 1981) and extends outward for some distance, particularly to the northeast, as shown on the map. It could compose the uppermost basement rock over a much larger part of Illinois (see Van Schmus and Bickford, 1981). It is part of the "southern terrane" of Bickford and others (1981).

The terrane is composed mainly of epizonal, anorogenic granite plutons that have intruded and engulfed their extrusive sequence of rhyolitic ash-flow tuffs and related flows (Kisvarsanyi and Kisvarsanyi, 1977). These rocks have been emplaced on the surface and at shallow crustal depths, and have not been regionally metamorphosed. Several calderas and related structures have been delineated recently (Kisvarsanyi, 1980, 1981; Brown and Hagni, 1981; Sides and others, 1981). The rocks have a firm ~1,480 Ma age (Bickford and Mose, 1975; Bickford and others, 1981).



EXPLANATION

FAULTS

High-angle, relative movement not known

High-angle reverse fault; bars on downthrown side

Strike-slip, showing relative horizontal movement

STRUCTUAL TREND LINES

Proterozoic rocks

Archean rocks

GLTZ	Great Lakes tectonic zone
BH	Black Hills uplift
Ca	Chadron arch
Car	Cambridge arch
Cb	Cheyenne belt
CKu	Central Kansas uplift
Mgl	Missouri gravity low
Nf	Niagara fault
Vf	Vermilion fault

Figure 1.--Simplified tectonic map of Precambrian basement rocks, north-central United States. Stipple pattern denotes rock units of 1,600 Ma age and younger and Early Proterozoic quartzite of the "Baraboo interval".

Spavinaw rhyolite terrane (age, 1,350-1,400 Ma)

The Spavinaw rhyolite terrane, as used herein, encompasses the 1,350-1,400 Ma rhyolite and epizonal granite in southern Kansas, southwest Missouri, and adjacent areas in Oklahoma (see map). Recently published data (Thomas, and others, 1984) show that this terrane extends into the Texas Panhandle.

Denison (1981) has shown in the subsurface of Oklahoma that the terrane consists mainly of a volcanic suite composed of rhyolite, dacite, and lesser andesite flows and tuffs and coeval micrographic granite porphyry and granite. Related mesozonal granite has been identified in southwestern Missouri (E. B. Kisvarsanyi, oral commun., 1985). In north-central Oklahoma, the rhyolite (Y^2mv unit) is metamorphosed (Denison, 1981), and in areas to the west, the volcanic-granitic rocks of the terrane are intruded by granitic rocks (Central Oklahoma Granite Group of Denison, 1981). Denison (1984) has traced the rhyolite and granite into northwestern Arkansas.

Midcontinent rift system (age, 1,000-1,200 Ma)

The youngest Precambrian terrane in the midcontinent region is the volcanic, gabbroic, and clastic sedimentary rocks associated with the Keweenawan Midcontinent rift system, an aborted intracontinental rift that extends from southern Kansas to Lake Superior, a distance of ~1,300 km. The geology and tectonics of the rift system, especially the northern exposed segment, has been described in detail recently (Wold and Hinze, 1982; Van Schmus and Hinze, 1985).

In general, the rift consists of a medial horst of basalt-rhyolite flows and local overlying sedimentary basins that is flanked by red beds, which compose clastic wedges along the margins of the rift. A layered gabbro body, possibly similar to the Duluth Complex in northeastern Minnesota (Weiblen, 1982), is inferred from geophysical anomalies and two drill hole penetrations to be present in northeastern Iowa.

The central horst of dominantly volcanic rocks in the Midcontinent rift system forms the largest positive gravity feature in North America, and because of its distinctive gravity and magnetic anomalies it can be mapped quite accurately. The flanking sedimentary rocks overlie pronounced gravity lows, but inasmuch as they are magnetically neutral, drilling is required to outline them.

Three structural aspects of the rift system in the map area are of special interest. First, the southern segment of the rift, in Kansas, recently discussed by Serpa and others (1984) as a result of COCORP reflection data, clearly is separated from the main, northern part. Probably, the separation resulted from a preexisting northwest-trending fault, which affected the geometry of the opening of the rift during Keweenawan extension. The fault does not appear to have acted as a transform during the rifting because of the apparent north-south separation of the two segments of the rift system.

Another interesting aspect is the sinistral offset of about 100 km in the central volcanic horst in southeastern Minnesota. The offset is interpreted as resulting from northwest-trending transform-like faults. The faults differ from true transforms in that basaltic rocks occur between fault strands as well as in the rift itself. The faults are interpreted as reactivated older structures of Early Proterozoic or Archean age, or both.

Further, the general coincidence in orientation of the rift system in Iowa and the northeast-trending faults in buried older bedrock in northeastern

Iowa and southern Wisconsin probably also reflects the influence of preexisting regional structures on the local orientation of the rift. The faults in Wisconsin are interpreted as rift structures that probably were initiated at ~1,760 Ma, when the rhyolite of this age was extruded; presumably they were reactivated during Keweenawan rifting.

Quartzite

"Baraboo interval quartzite" (Dott, 1983) that is younger than the 1,760 Ma southern Wisconsin rhyolite-granite is exposed sporadically in Wisconsin and Minnesota and locally in the subsurface of eastern Iowa. It is inferred to have been mildly metamorphosed and folded at ~1,630 Ma (Van Schmus and Bickford, 1981). The quartzite bodies include the Sioux Quartzite in Minnesota, South Dakota, and Iowa, and the Baraboo, Barron, Flambeau, McCaslin, and Waterloo Quartzites in Wisconsin. In addition, a large unnamed body of quartzite occurs in the subsurface in southeastern Wisconsin (Smith, 1978).

The quartzite bodies consist primarily of vitreous pink to red to purple orthoquartzite; cross beds and ripple marks are abundant. Thin red argillite ("pipestone") is present locally in the Sioux, Barron, and Baraboo units. Mature basal conglomerates are present in the Sioux (Ojakangas and Weber, 1984; Southwick and Mossler, 1984) and McCaslin Quartzites (Olson, 1984). The Baraboo Quartzite is overlain conformably in the subsurface (Dalziel and Dott, 1970) by units of slate, dolomite, and iron-formation.

The quartzites are interpreted mainly as braided fluvial deposits, although the upper parts of some bodies probably are of shallow marine origin. The considerable thickness of some units suggests that the basins of deposition were moderately tectonically unstable--probably rift-related basins. Deposition apparently occurred between 1,760 Ma and ~1,630 Ma.

Intrusive rocks of transcontinental anorogenic province

The Wolf River batholith of north-central Wisconsin and other smaller, generally circular plutons in the subsurface of Wisconsin, Iowa, and Illinois are part of the 1,400-1,500 Ma transcontinental anorogenic province of North America (Silver and others, 1977). They generally formed from initial crystallization of anorthosite and charnockitic monzonite (mangerite) followed by voluminous epizonal rapakivi granite. Except for the ilmenite-series Wolf River batholith, the rocks generally have magnetite-series affinities (Anderson, 1983) and are expressed by positive magnetic anomalies.

The rocks occur sporadically within a diffuse, northeast-trending belt extending from southwestern United States to Labrador (Silver and others, 1977). They are interpreted as crustal-derived magmas formed under anorogenic conditions probably related to incipient rifting (Anderson, 1983).

ORIGIN AND AGE OF DEXTRAL FAULTS

Many of the faults in the area are northwest-trending dextral faults (fig. 1). They cut rocks of the Central Plains orogen and are part of a family of faults of this trend and sense of movement of both Archean and Early Proterozoic ages. Several of the known faults of this type in the United States are shown on figure 1. The major known dextral faults in the Superior craton of Canada have recently been compiled by K. D. Card (written commun., 1985).

A possible mechanism for the origin of the dextral faults, at least for those of Archean age, has been proposed by Hudleston and Southwick (1984) from studies in the Archean greenstone-granite terrane in northern Minnesota. They proposed that the Vermilion fault (Vf, fig. 1), which displaces Archean units a distance of about 17 km (Sims and Southwick, 1985) and related faults were formed during Late Archean time as part of a continuum of dextral shear of regional extent. Regional folding was followed by later faulting, which was simply a more brittle expression of the shear regime. They attributed the deformation to transpression: oblique compression between two more rigid (?) crustal blocks to the north and south. A similar structural regime occurs along the U.S.-Canadian border (Day and Sims, 1984) and, apparently, in areas northward to Hudson Bay. Probably this mechanism of dextral shear is applicable to the entire Archean Superior craton.

The northwest-trending dextral faults cut rocks of the Wisconsin magmatic terrane (1,830-1,890 Ma) and the Central Plains orogen (1,600-1,800 Ma), as well as Archean rocks. Further, reactivated faults of this orientation appear to border northwest-trending basins of Sioux Quartzite (Southwick and Mossler, 1984), suggesting that reactivation of possible Archean faults persisted at least to ~1,600 Ma. Tentatively, I suggest that dextral shear of subcontinental extent persisted intermittently(?) in the Superior craton and its marginal Early Proterozoic mobile belts from ~2,600 Ma to ~1,600 Ma. At any rate, the mild folding and cataclasis in the 1,760 Ma rhyolite and granite and in the younger "Baraboo interval" quartzite could be related to regional dextral shear, in a manner similar to that proposed by Hudleston and Southwick (1984) for Archean structures in northern Minnesota.

Houser (in Houser and Gray, 1980) has shown that one northwest-trending fault, the Reservation fault, named from the Santee Indian Reservation in northeast Nebraska, has had a long, intermittent history of movement subsequent to its formation. It forms the southwest boundary of the Sioux Formation at places; the Sioux is locally more than 1150 m thick immediately north of it. Southwest of the fault, the basement consists of Precambrian crystalline rocks overlain by Ordovician sedimentary rocks, indicating that the northeast side was downdropped during or shortly after deposition of the Sioux. Stratigraphic evidence within Paleozoic strata indicates that the fault acted as a hinge line (southwest side down) controlling the position of Paleozoic shorelines. Paleozoic rocks are absent immediately northeast of the fault, whereas they thicken southwestward from it. By Cretaceous time movement on the fault had ceased, for there is no apparent vertical displacement of the base of the Cretaceous succession on opposite sides of the fault. At present, the fault is the locus of abnormally high-temperature ground water in the Dakota Sandstone, the principal aquifer in the area.

TECTONIC EVOLUTION OF NORTH-CENTRAL UNITED STATES

The geographic and temporal evolution of the major Archean and Early Proterozoic terranes in the north-central part of the United States can be discussed with respect to the tectonic map shown on figure 1.

During the Late Archean, the two Archean terranes in the Lake Superior region (Morey and Sims, 1976) were juxtaposed to form a composite Archean (Superior) craton. The presumed suture (Great Lakes tectonic zone; Sims and others, 1980) is oriented N.65°-70°E. and apparently has resulted from thrusting of the northern greenstone-granite terrane over the gneiss terrane (Gibbs and others, 1984).

In the Early Proterozoic, rifting of the southeast segment of the Superior craton at ~1,900 Ma led to the development outboard of oceanic crust, and culminated in continent-island arc collision at ~1,850 Ma (Schulz and others, 1984). At about the same time, rifting of the western part of the Superior craton on a more northerly axis resulted in the development of additional oceanic crust and eventual collision of oceanic arc systems with the continent (Lewry, 1981), to yield the Trans-Hudson orogen (Hoffman, 1981), or the southerly part of the Churchill province. Whether the Wyoming Archean craton was rifted from the Superior craton and subsequently returned or whether it represents an exotic continental mass (Dutch, 1983) is not known. Continent-arc collision occurred at ~1,850 Ma.

Later in the Early Proterozoic, rifting of the southern margin of the composite Archean-Early Proterozoic craton culminated again in continent-arc(?) collision (Central Plains orogen). Possibly, rifting began before or at ~1,760 Ma--the time of extrusion of rhyolite of that age in southern Wisconsin--and terminal collision occurred at or slightly after 1,650-1,700 Ma. An argument could be made that collision occurred at ~1,630 Ma--a time of widespread resetting of Rb-Sr whole rock ages in the Lake Superior region, especially in eastern Wisconsin and upper Michigan (Van Schmus and others, 1975; Van Schmus and Bickford, 1981; Peterman and others, in press). However, the 1,630 Ma reset ages more likely resulted from northwest-oriented dextral faulting and related folding on northeast axes caused by dextral shear (transpression) of subcontinental scope, analogous to the dextral shear of Archean age demonstrated in northern Minnesota (Hudleston and Southwick, 1984).

The Central Plains orogen has been correlated with the Colorado-Wyoming Early Proterozoic foldbelt (Sims and Peterman, in press) because of similarities in lithology and isotopic ages and permissible gravity and magnetic patterns. Karlstrom and Houston (1984) and earlier workers have proposed an arc-continent collisional plate tectonic model for the Cheyenne belt along the northern margin of the Colorado-Wyoming foldbelt.

Following development of the Central Plains orogen, diachronous rhyolite and granite of 1,480 Ma and 1,350-1,400 Ma, respectively, were deposited on the southern part of the orogen, mainly as subaerial deposits and associated shallow intrusive bodies (Van Schmus and Bickford, 1981). Van Schmus and Bickford (1981) and Thomas and others (1984) interpreted these rocks as having been derived by crustal melting following accretion of calc-alkaline arcs at ~1,800 Ma. Such an origin is supported by Nd-Sm model ages on the rhyolites and granites of ~1,800-1,900 Ma (Nelson and DePaolo, 1985).

The tectonic pattern inferred in figure 1, resulting from successively younger Early Proterozoic events in north-central United States, suggests that the addition of accreted oceanic-arc terranes in Precambrian time terminated by 1,600 Ma. Subsequently, supracrustal rhyolite-granite terranes were deposited on the southern margin of the stabilized craton.

DISCUSSION

The anastomosing pattern of Early Proterozoic orogenic belts in the north-central part of the United States demonstrates the remarkable mobility of the craton in Early Proterozoic time, extending from ~2,100 Ma to ~1,650 Ma. Repeated rifting, crustal breakup, and the development of oceanic crust and island arcs were followed by continent-arc collisions and the development of orogens of sub-continental dimensions. Apparently, growth of the continent during this geologic interval was mainly by the addition of new materials to the crust from sub-crustal depths; reworking of older crustal material seems to have been minimal, except perhaps for the Trans-Hudson orogen where Archean rocks were reworked locally (Lewry and Sibbald, 1980). Following cratonization at ~1,600 Ma, additions to the crust were dominantly vertical, and the supracrustal rocks were derived by partial melting at depth of older crustal material. An exception is the rocks that were formed during the Middle Proterozoic (Keweenawan) rifting (~1,100 Ma), an aborted rift that did not develop into an ocean. The volcanics and gabbro in the rift system were derived from mantle depths (Naldrett, 1981).

The tectonic collage of intersecting Proterozoic mobile belts surrounding stable Archean cratons is comparable to that known in other large and better exposed Precambrian cratons, such as Western Australia (Plumb, 1979) and southern Africa (Brock, 1959). In these areas, as well as the central United States, cratonization ceased by ~1,600 Ma (Plumb and James, in press), and in Western Australia, at least, was followed by diachronous felsic volcanism (Goode, 1981).

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