UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Southwestern Bounding Fault of the Sioux Quartzite, South Dakota and Nebraska

By

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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ABSTRACT

On the basis of stratigraphic data from drill holes and temperature data from water wells compiled as of 1980, a fault about 375 km long is inferred to be the southwestern boundary of the subcrop of the Sioux Quartzite in south-central South Dakota and northeastern Nebraska. A compilation of the Precambrian basement of the mid-continent region (Sims, 1985; Sims and Peterman, 1986) showed that the fault separates 3.0-3.6 Ga gneiss on the southwest from the early Proterozoic Sioux Quartzite on the northeast, and that the fault is one of a group of faults trending about N. 50° W. across north-central United States. Stratigraphic data suggest that there may have been movement along the fault as recently as late Cretaceous time. Deep circulation of ground water along the fault is suggested as the heat source for the geothermal area noted first by Darton (1920) in south-central South Dakota and northeastern Nebraska.

INTRODUCTION

The Sioux uplift or Sioux Quartzite ridge in southeastern South Dakota and southwestern Minnesota is one of a few exposures of Precambrian basement rock south of the Canadian Shield in the Central Stable region of North America (fig. 1). The Sioux Quartzite ridge is part of the Transcontinental arch (fig. 1), a broad southwest-trending structural high that was at least partly emergent as an island archipelago during much of Paleozoic time (Webers, 1972; Ross, 1976). Data chiefly from drill holes suggest that the southwestern boundary of the Sioux Quartzite in the subsurface is a fault (figs. 2, 3) (Sims, 1985; Sims and Peterman, 1986), and that the site of the Sioux Quartzite ridge may have been a topographically positive feature during much of Phanerozoic time, due in part to recurrent movement along the inferred fault. In this report, data are presented that suggest that the heat source of the southeastern South Dakota geothermal area (Schoon and McGregor, 1974) may be heated ground water rising from a deep zone of increased permeability along the fault plane.

GEOLOGIC SETTING

The tectonic map of the Precambrian basement (Sims, 1985; Sims and Peterman, 1986) of the mid-continent region (fig. 2) showed the inferred southwestern bounding fault (hereafter simply called "the inferred fault") of the Sioux Quartzite subcrop to be one of a group of faults that trend about N. 50° W. across the north-central United States. The inferred fault was shown to be a right-lateral strike-slip fault about 450 km long extending from south-central South Dakota into northeastern Nebraska. It is parallel to, but about 50 km northeast of the northeastern edge of the Central Plains orogen (fig. 2) (Sims and Peterman, 1986, figs. 1, 2). The southwest side of the inferred fault consists of an Archean terrane composed chiefly of 3.0-3.6 Ga gneiss. Northeast of the inferred fault is the early Proterozoic Sioux Quartzite which unconformably overlies the Archean gneiss in apparent depositional contact (Baldwin, 1951 and Miller, 1961; cited by Austin, 1972).

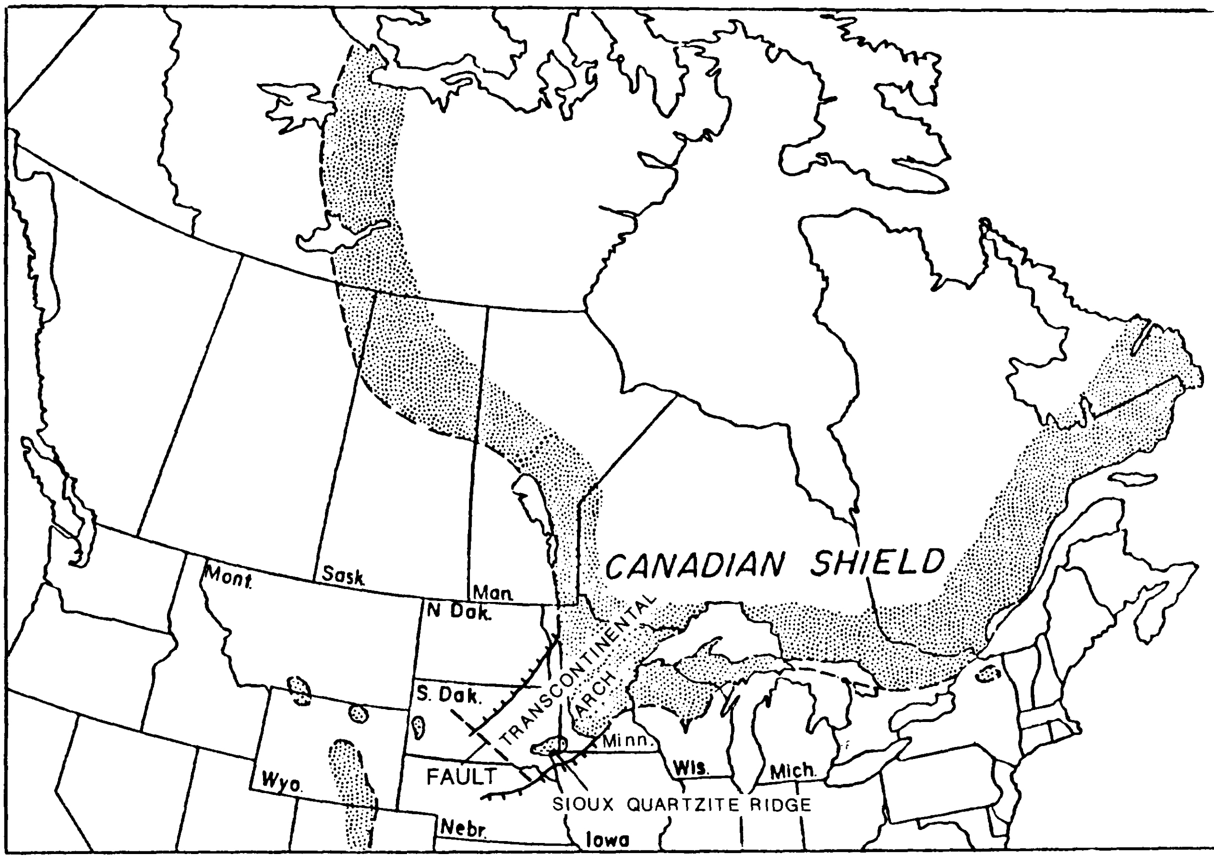

Figure 1.--Map showing the inferred southwestern bounding fault of the Sioux Quartzite subcrop in South Dakota and Nebraska, the Transcontinental arch, and the location of exposures of Precambrian rock (stippled pattern) in the Canadian Shield and north-central United States. Modified from Lidiak (1971).

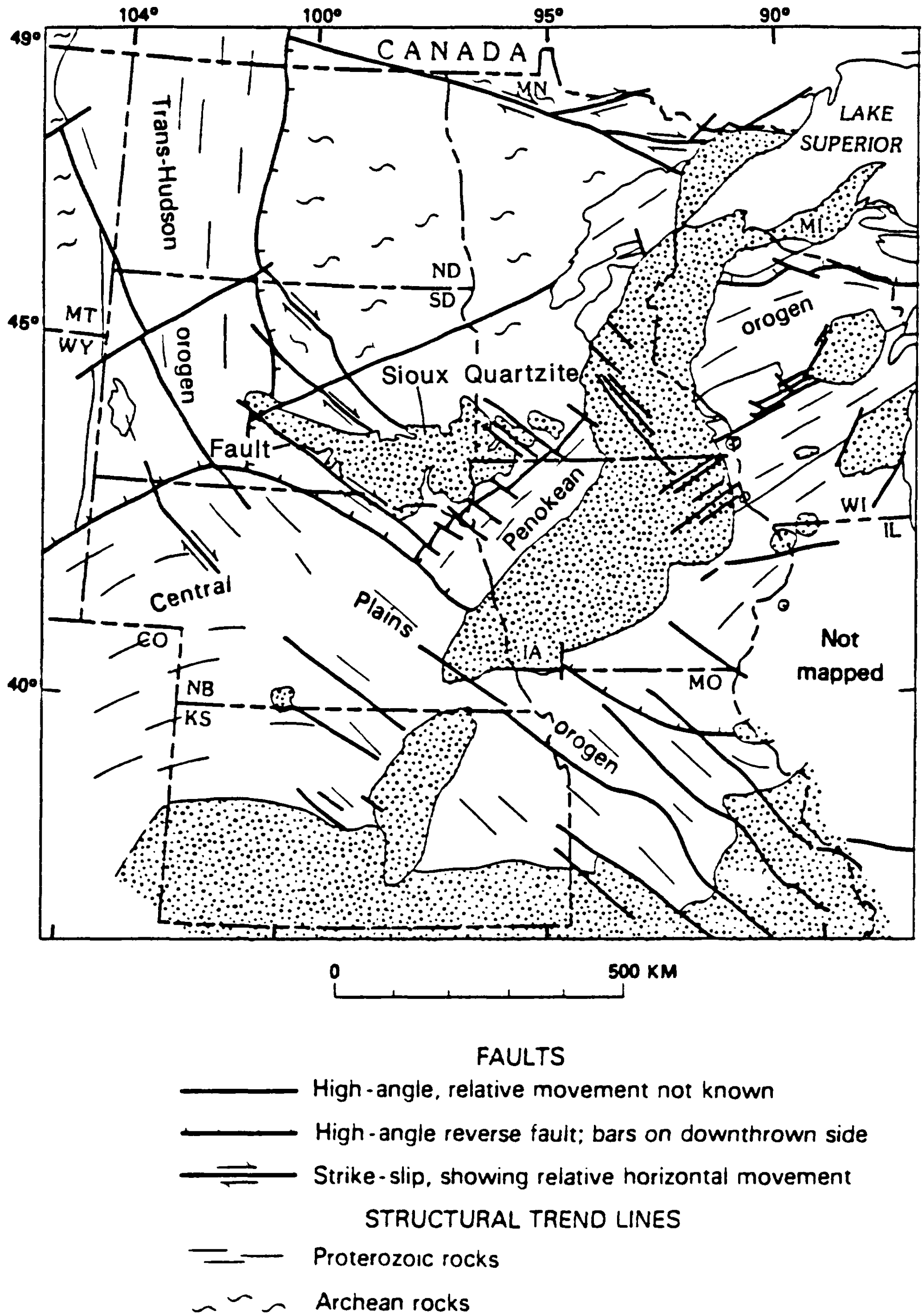

Figure 2.--Tectonic map of Precambrian basement rocks in north-central United States showing Sioux Quartzite subcrop and location of southwestern bounding fault. Stipple pattern denotes rock units of 1,600 Ma age and younger and Early Proterozoic quartzite of the "Baraboo interval." Modified from Sims and Peterman (1986).

STRATIGRAPHY

The basement rocks on the southwest side of the inferred fault consist of a variety of Precambrian crystalline rocks but are chiefly felsic gneisses (Lidiak, 1971, 1972). The northeast side of the inferred fault is composed dominantly of Sioux Quartzite for most of its length. Surface exposures of the Sioux Quartzite in South Dakota and Minnesota are chiefly pink, medium grained, tightly cemented quartzite with some poorly cemented zones (Austin, 1972). Minor lithologies include conglomerate and mudstone. The Sioux Quartzite has been calculated to be as much as 1,600 m thick in basinal structures in Minnesota (Baldwin, 1951, in Austin, 1972; Weber, 1977). A well near Wagner, South Dakota (fig. 3), penetrated 1,154 m of orthoquartzite without reaching the base of the formation (Barkley, 1952, p. 23). The age of the Sioux Quartzite is 1,470±50 m.y. or older on the basis of a Rb-Sr age on rhyolite flows or sills interbedded with Sioux Quartzite from a well near Hull, Iowa (Lidiak, 1971; Austin, 1972).

The Phanerozoic sedimentary strata of the region consist of a southwestward thickening wedge of Cambrian through Pennsylvanian rocks on the southwest side of the inferred fault; nearly 500 m of Cretaceous rocks that rest directly on the Sioux Quartzite on the northeast side of the inferred fault; and as much as 50 m of Cenozoic rocks (figs. 3, 4). An erosional unconformity marks the contact between the Precambrian basement and the overlying sedimentary rocks. Southwest of the inferred fault, Cambrian, Ordovician, and Carboniferous marine strata were deposited on a relatively smooth, south-southwest sloping surface of the gneissic rocks in a transgressive relationship (fig. 3). There are no Paleozoic rocks northeast of the fault; there, Cretaceous sedimentary rocks directly overlie the Sioux Quartzite.

The contact of the Cretaceous sedimentary rocks with the Sioux Quartzite northeast of the inferred fault is an erosional unconformity. Barkley (1953) suggested that the Sioux Quartzite ridge was a highland until early Cretaceous time as indicated by the absence of any older units overlying the Sioux Quartzite. Stream valleys were eroded into the surface of the Sioux Quartzite prior to deposition of the lower Cretaceous rocks, as shown in figure 3. An extensive layer of grit which has been penetrated in many drill holes above the irregular surface of the quartzite (Bolin and Petsch, 1954) may be a lag deposit representing part of this long period of subaerial erosion. The Cretaceous units present in this area are the lower Cretaceous Dakota Sandstone and the upper Cretaceous Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Formation, and Pierre Shale (fig. 4).

STRUCTURE

The inferred southwest bounding fault of the Sioux Quartzite may be one of a group of features (defined by lineaments) thought to bound Precambrian basement blocks in the north-central United States (Shurr, 1979). A compilation of lineaments from Landsat imagery and vertical intensity magnetic data by Shurr (1979) showed a lineament 100 km in length that may be the extension of the inferred fault to the northwest (fig. 5). Shurr visualized the lineaments and the faults that some of them are related to as major zones of weakness in the Precambrian basement, although their exact structural nature is not known. The lack of sediments older than early Cretaceous over the Sioux Quartzite ridge suggests that the inferred bounding fault may have acted as a hinge zone throughout the Paleozoic and early Mesozoic and controlled the location of shorelines during that time.

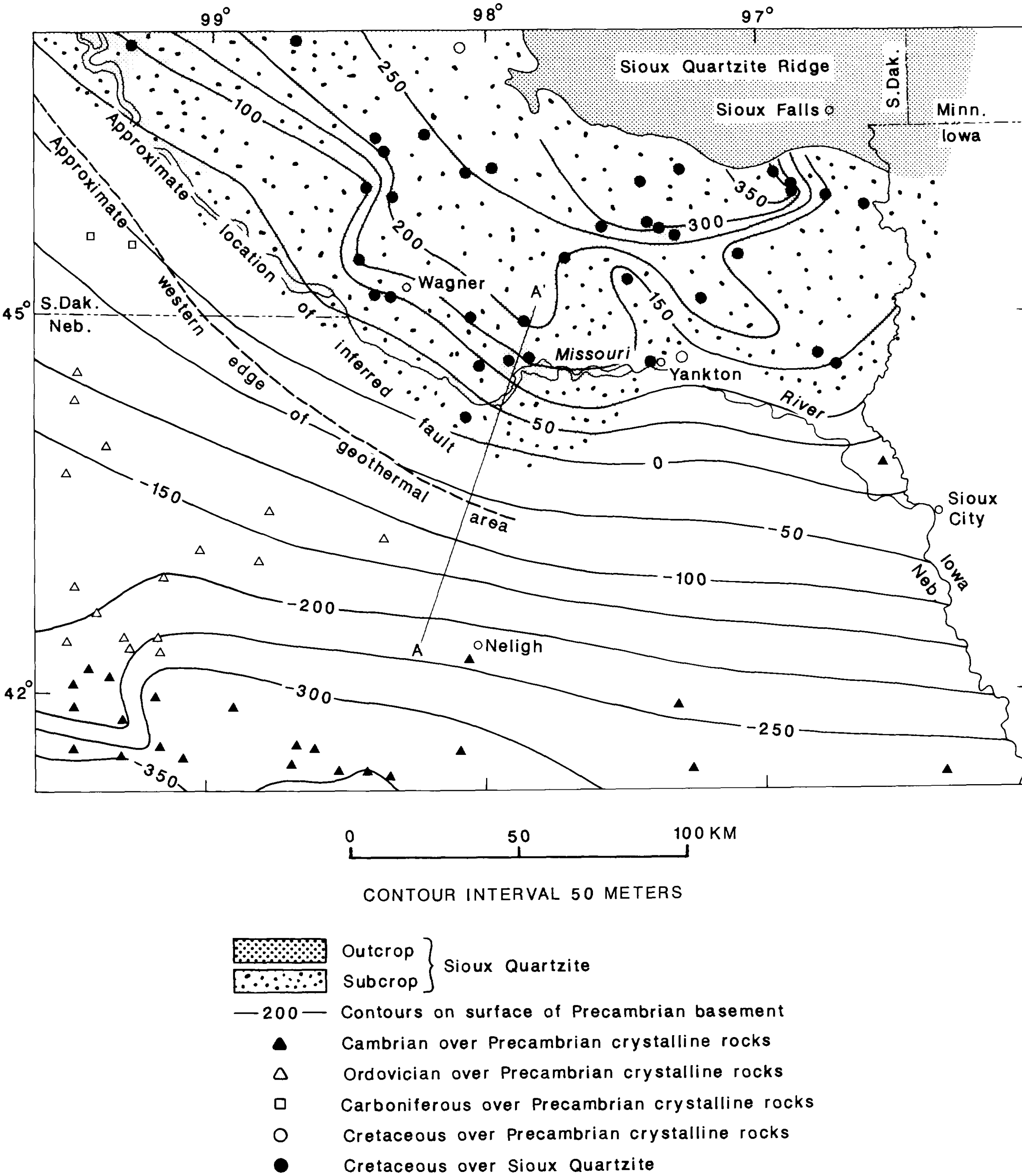

Figure 3.--Map of the Precambrian basement in northeastern Nebraska and southeastern South Dakota showing topography, generalized geology, ages of sedimentary rocks deposited on the basement, and approximate locations of the inferred fault and western edge of the geothermal area. Section A-A′ is shown on figure 4.

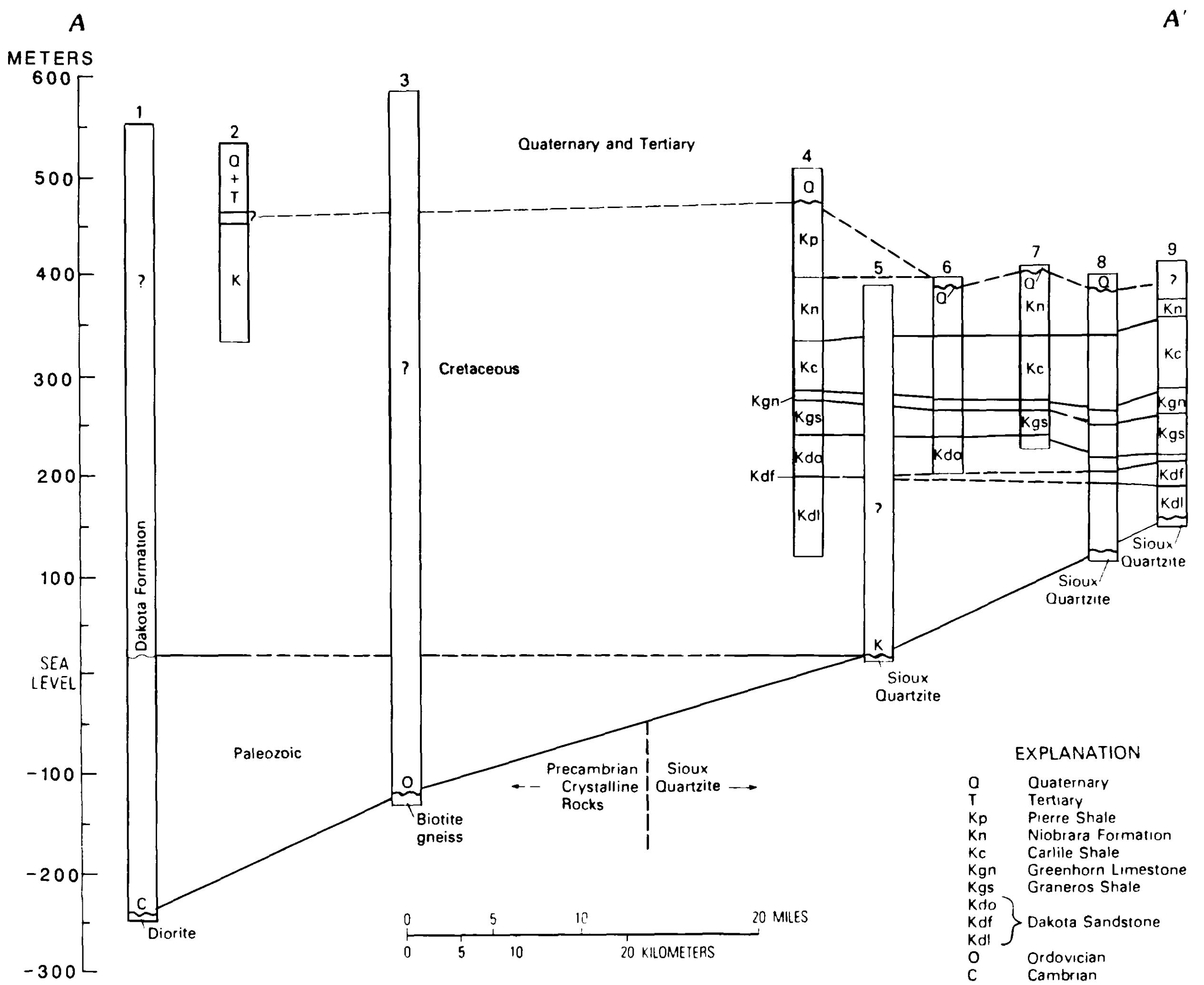

Figure 4.--Geologic cross section of strata overlying the inferred southwestern bounding fault of the Sioux Quartzite, southeastern South Dakota and northeastern Nebraska. Location of line of section shown on figure 3. Locations of wells used in constructing the cross section are given in table 1.

Table 1. Locations of wells used in constructing the geologic cross section shown on figure 4

1. No. 2 Taylor, Cave and Baxter: 1943: Antelope Co., Nebraska: NW 1/4 NE 1/4 SW 1/4, sec. 31, T. 25 N., R. 6 W.: (Schulte, 1952; Carlson, 1967).

2. Neligh Well; Central and Northwestern R.R.: Antelope Co., Nebraska: sec. 18, T. 25 N., R. 6 W.: (Condra and others, 1931, p. 48).

3. No. 1 Asher, Lloyd J. Twibell: 1952: Holt Co., Nebraska: Center SW 1/4 SE 1/4 NE 1/4, sec. 9, T. 28 N., R. 9 W.: (Carlson, 1967).

4. No. 1 Stahl, Bloomfield Oil and Gas Co.: 1914: Knox Co., Nebraska: Center NE 1/4 NE 1/4, sec. 9, T. 30 N., R. 3 W.: (Condra and others, 1931; Reed and Svoboda, 1957).

5. No. 1 Nielson, Palinsky and Sons: 1958: Knox Co., Nebraska: NW 1/4 NE 1/4 NE 1/4, sec. 24, T. 32 N., R. 7 W.: (Carlson, 1967).

6. Niobrara Flour Mill Well: ~1890: Knox Co., Nebraska: sec. 16, T. 32 N., R. 6 W.: (Condra and others, 1931, p. 45).

7. Santee Indian School Well: ~1901: Know Co., Nebraska: sec. 13, T. 33 N., R. 5 W.: (Condra and others, 1931, p. 45).

8. Jelsma No. 1, Bon Oil: 1952: Bon Homme Co., South Dakota: SE 1/4 SE 1/4, sec. 10, T. 93 N., R. 60 W.: (Bolin and Petsch, 1954; Simpson, 1960).

9. Isaacs and Byrne No. 1, Bon Oil: 1952: Bon Homme Co., South Dakota: SW 1/4 SW 1/4, sec. 8, T. 93 N., R. 59 W.: (Bolin and Petsch, 1954).

There is indirect evidence of post-Cretaceous faulting (up on the northeast) in Charles Mix County near Wagner, South Dakota, about 25 km northeast of the inferred fault. A comparison of the topography on the surface of the Sioux Quartzite (fig. 3) and the structure contour map of the top of the Dakota Formation (Barkley, 1952) shows that on both maps there is a northwest-trending, southwest-facing scarp about 50 m high that extends for about 35 km northwest of Wagner. The spatial coincidence of the two scarps suggests a fault origin. However, a cross section (fig. 4) drawn perpendicular to the southeastern end of the inferred fault does not show any significant vertical displacement of the surface of the Sioux Quartzite or of the overlying Cretaceous units for a distance of 35 km northeast of the inferred fault. Unfortunately, the drill hole data used in constructing the cross section are not complete enough to determine if there has been any vertical displacement at the fault itself.

Koch (1986) suggested that there has been post-Cretaceous uplift of the Sioux Quartzite ridge along faults parallel to the axis of the Transcontinental arch (fig. 5). He presented a map showing that structure contours drawn on the top of the Greenhorn Limestone were warped upward about 120 m around the Sioux Quartzite ridge in southeastern South Dakota. Koch also cited evidence (Iles, in press) that units from the Dakota Sandstone through the Niobrara Formation were upwarped 120 m just south of the Sioux Quartzite ridge near Sioux Falls, South Dakota. Additional study is necessary to evaluate the possibility and nature of post-Cretaceous uplift of the Sioux Quartzite ridge.

Chleborad (1986) conducted a study of variations in the thickness of bentonite and shale beds in the upper Cretaceous Pierre Shale across the lineament that extends northwestward from the inferred fault (Shurr, 1979) (fig. 5). He found an abrupt thickening from northeast to southwest across the lineament in all of the seven beds that were studied. From this study it was concluded that the lineament may be an important northwest-trending block boundary, and that during the period from 72-68 Ma (depositional interval of the beds studied) there was a paleotopographic low southwest of the lineament. If the lineament mapped by Shurr is a surface expression of the inferred fault, Chleborad´s study may indicate that the fault was active during late Cretaceous time and had a vertical component of movement, down on the southwest.

Nichols and Collins (1987) studied faults in the Pierre Shale in the same area as Chleborad´s study, and found evidence indicating that faulting may be active. Colluvium dated at less than 1,300 years (C 14 dates) was deformed by faults in the Pierre Shale at two locations, and Pleistocene deposits were faulted at another location.

SOUTH DAKOTA AND NEBRASKA GEOTHERMAL AREA

Anomalously high ground-water temperatures occur in a linear region above the inferred fault. In this area (fig. 5) water temperatures in wells range from about 38^{o}-71^{o}C (Darton, 1905; Schoon and McGregor, 1974). The warm water in the wells comes from the Dakota Sandstone, a principal aquifer of the area. Schoon and McGregor (1974) called upon an anomalously high geothermal gradient in this part of South Dakota, perhaps involving mantle convection currents, to explain the high water temperatures. Adolphson and LeRoux (1968) described a "hot water belt" in South Dakota about 30 km west of the geothermal area shown in figure 5, but with similar trend and width. (The westward displacement of the "hot water belt" may be due to Adolphson and

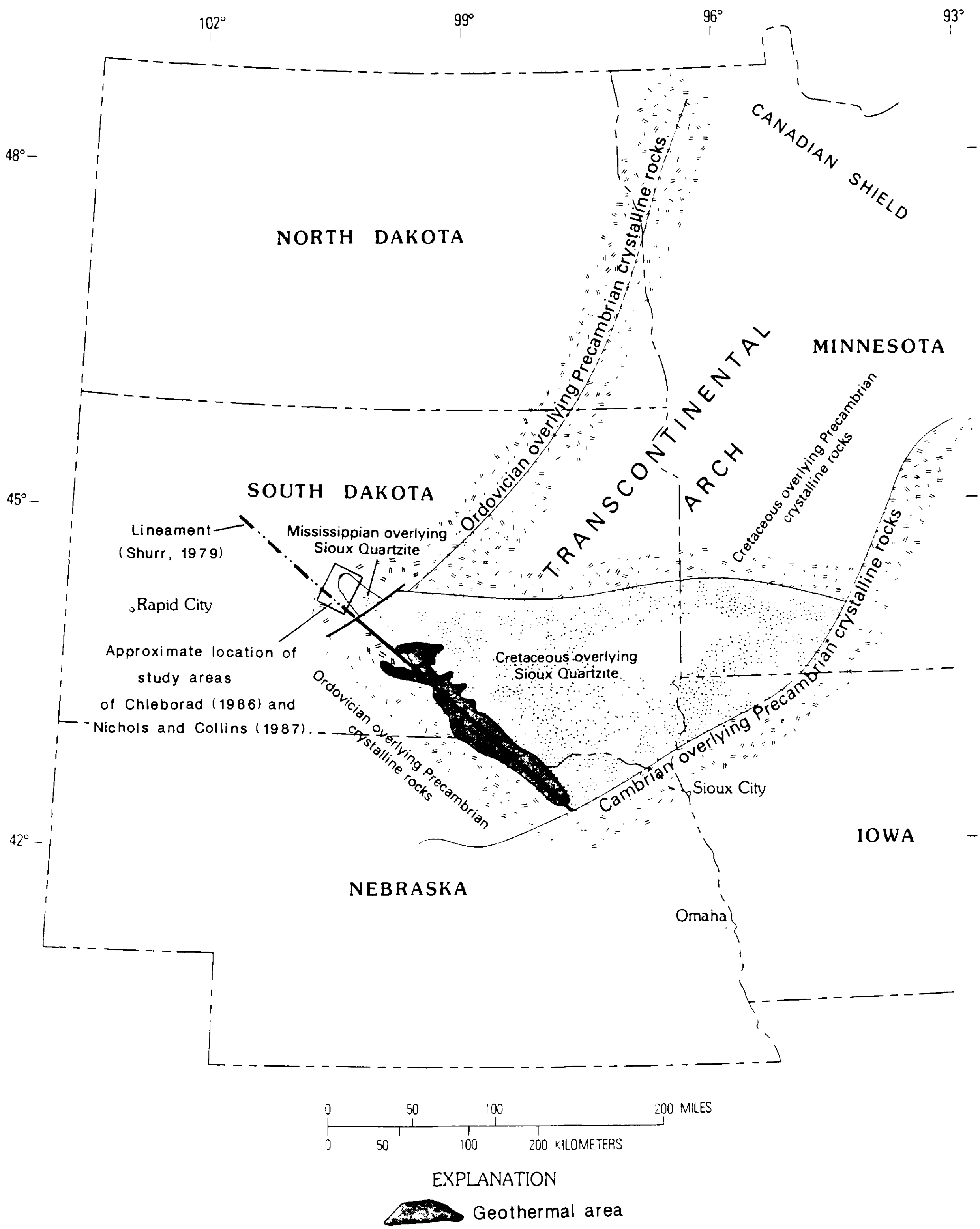

Figure 5.--Map showing the location of the inferred southwestern bounding fault in relation to the South Dakota and Nebraska geothermal area, the lithology of the basement, age of strata directly overlying the basement, and the location of the Transcontinental arch.

LeRoux's emphasis on the northwestern end of the belt, or to the use of a different data base). In this belt, water from the Dakota Sandstone ranges in temperature from 34^{o}-54^{o}C. Adolphson and LeRoux ascribed the "hot water belt" to recharge of the Dakota by warm water from deeper pre-Cretaceous aquifers which wedge out in this area.

The coincidence of the geothermal area with the subsurface trace of the inferred fault suggests an alternative to the models of Schoon and McGregor (1974) and Adolphson and LeRoux (1968). The source of the heat may be ground water that has descended to considerable depths in permeable zones in the Sioux Quartzite, and then ascended along the fault under artesian pressure to mix with water in the Dakota Sandstone. The close correspondence of the northwestern and southeastern ends of the geothermal area with the width of the subcrop area of the Sioux Quartzite to the northeast (fig. 5) lends support to this model.

An approximate minimum depth of ground-water circulation required to attain a temperature of 71^{o}C in south-central South Dakota can be calculated by assuming a heat flow of 1.5 HFU (Lachenbruch and others, 1985, fig. 4) which gives a geothermal gradient of about 4.5^{o}C/100 m, and by using a mean annual surface temperature of 10^{o}C. With these parameters, a depth of about 1,350 m was calculated. This is a minimum depth of circulation because the possibility of mixing with cooler ground water was not taken into account. Assuming an average depth of 450 m to basement in the vicinity of the inferred fault, then the minimum required circulation depth within the basement is 900 m which is well within the 1,600 m estimated maximum thickness of the Sioux Quartzite (Austin, 1972).

DISCUSSION

Recognition of the possibility of recurrent movement during Phanerozoic time along the inferred fault and particularly the possibility of Recent faulting, has important implications for other basement faults in the region. Additional studies of the inferred southwestern bounding fault including geologic mapping, stratigraphic studies of the Tertiary rocks, study of drill hole records, and study of ground-water chemistry may aid in better defining the history of the fault.

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