STATUS OF MINERAL RESOURCE INFORMATION FOR THE LOWER BRULE INDIAN RESERVATION, SOUTH DAKOTA

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SUMMARY AND CONCLUSIONS

Identified (known) mineral resources in order of importance on the Lower Brule Indian Reservation include sand and gravel, manganese, clay, and shale. Only sand and gravel has been produced.

An estimated 200 million cubic yards of sand and gravel remains in four terrace deposits along the Missouri River on the reservation. Development of this resource is directly related to its demand for local construction projects. Recovery of part of the resource may be hampered by the competing use of terraces as irrigation land.

About 3 million tons of metallic manganese are in low-grade deposits in the DeGrey Member of the Pierre Shale on the reservation. The geology and methods of mining and processing this subeconomic mineral resource have been studied extensively; technologically, extraction of manganese is possible. However, development of this resource is unlikely barring a national emergency or prices that are many times higher than at present. Moreover, an efficient, economical method to separate manganese-bearing nodules from the shale host rocks has yet to be found.

Substantial amounts of clay and shale occur in the Pierre Shale on the reservation; some of these materials are probably suitable for making brick or other structural clay products and lightweight aggregate. Detailed geologic and economic feasibility studies would be needed to determine if these resources can be developed profitably.

Undiscovered mineral resources that may occur on the reservation include natural gas, petroleum, and geothermal energy. A moderate potential exists for discovery of limited flows of natural gas for local use, but little potential has indicated for development of petroleum or low-temperature (warm water) geothermal resources.

Occurrences of zeolites, low-grade oil shale, and uranium in the Sharon Springs Member of the Pierre Shale nearby but off the reservation suggest the possibility of their presence in the same strata on the reservation and may point to future mineral resources.

INTRODUCTION

This report was prepared for the U. S. Bureau of Indian Affairs (BIA) by the U. S. Geological Survey (USGS) and the U. S. Bureau of Mines (USBM) under an agreement to compile and summarize available information about the geology, mineral resources, and potential for economic development of certain Indian lands. Source materials were published and unpublished reports and personal communications. There was no fieldwork.

The Lower Brule Indian Reservation, which includes parts of Lyman and Stanley Counties, lies along the right bank of the Missouri River in south-central South Dakota. It is bounded generally on the northeast by Lake Francis Case and by Lake Sharpe, main stem reservoirs on the Missouri, and on the west and south by north-south and east-west lines of survey (Figure 1). The reservation comprises 126,475.44 acres: 99,629.60 acres are tribally owned, and 26,845.84 acres are individual allotted lands (U. S. Bureau of Indian Affairs, 1979). According to BIA, the population of the reservation in 1979 was estimated at 877; Lower Brule, the tribal headquarters, and Iron Nation are the only communities on the reservation. Larger cities or towns in the region include Pierre (population 9,699) and Chamberlain (population 2,626), (1970 Census).

Commercial air transportation and train service are available at Pierre, the state capital, about 30 miles northwest of the reservation. Bus and truck service are available at communities along Interstate 90, about 10 miles south of the reservation. Tracks of the Chicago, Milwaukee, St. Paul, and Pacific Railroad run parallel to Interstate 90 and serve these communities as well. On the reservation, surface transportation is via hard-surfaced, all-weather County Route 10, which runs from northwest to southeast, and State Highway 47W, which crosses the southeastern part; graveled and graded secondary roads also serve the area.

The topography of the Lower Brule Reservation consists of a high rolling upland on the south and west that gives way to deeply eroded badlands and terraces along the Missouri River (Howells, 1974). Elevations range from 1,350 feet above sea level on the shore of Lake Francis Case to slightly over 2,000 feet at the southwestern corner of the reservation. In this region, the climate is rigorous, and precipitation averages 17 inches per year. Owing to rugged topography or poor soils, most of the reservation is rangeland used for grazing, but some of the terraces and lowlands along the Missouri have been developed for irrigation.

Map Coverage

The entire Lower Brule Reservation has been mapped at several scales of detail, both topographically and geologically.

Recent topographic maps that include the whole reservation are the Huron, Mitchell, and Pierre sheets of the United States 1:250,000-scale series, published by the USGS. At a larger scale, recently published maps in the Survey's 7½-minute quadrangle series provide detailed coverage of the entire reservation at a scale of 1:24,000 (Figure 2).

Geologic maps at a scale of 1:62,500 (Figure 2), five published by the South Dakota Geological Survey and one by the USGS, portray the geology of most of the reservation (Petsch and others, 1950; 1950a; Curtiss and Waddel, 1951;1951a; Petsch and Fairbanks, 1952; Crandell, 1954). More recently, Howells(1974) has mapped the surficial geology of the entire reservation (scale1:125,000).

Previous Work

Although many reports, dating from before the turn of the century, allude to the geology or mineral resources in the vicinity of the Lower Brule Reservation, interest in the region was first focused on manganese resources in the years shortly before, during, and just after World War II. The result was a series of publications, mostly by USBM and the South Dakota Geological Survey, about the manganese resource and how it might be mined and processed; the work is described in detail in a subsequent section of this report.

The first comprehensive report specifically about mineral resources of the reservation (and the Crow Creek Indian Reservation adjacent to it) was prepared by Henkes and Gries (1963, 42 p.). The present study, designed to bring that report up-to-date, necessarily borrows much from it. Publications of three groups stand out among numerous sources of information about the geology and mineral resources of the Lower Brule Reservation: the South Dakota Geological Survey, USGS, and USBM. These agencies are the prime sources of data on mineral resources of the reservation.

GEOLOGY

The reservation is in the Missouri Plateau section of the Great Plains physiographic province (Fenneman, 1931; Flint, 1955). It lies in a transitional area in which the thick lenses of sedimentary rocks of the Williston basin to the northwest meet the resistant Precambrian Sioux Quartzite ridge in the east (Figure 3). Paleozoic and older Mesozoic formations thin eastward from the basin and pinch out against the Sioux uplift. Thus approximately 1,500-2,000 feet of sedimentary rocks, mostly Cretaceous in age, overlie the folded Precambrian basement.

The flat-lying Pierre Shale forms the bedrock under virtually all of the reservation. Unconformably covering the Pierre Shale are Cenozoic sediments largely resulting from the Pleistocene continental glaciation which is also responsible for shaping the high rolling upland topography of the area. Erosion has cut deeply into the upland near the deep meandering trench of the Missouri River and forms a badlands area known as the "breaks" (Howells, 1974).

Structure

The reservation lies between two of the large structural features of South Dakota: the Precambrian Sioux Quartzite ridge to the east and the Lemmon syncline to the west (Figure 3), The resistant quartzite ridge extends westward toward Chamberlain from the vicinity of Sioux Falls. It plunges gently to the west and probably extends beneath the reservation. The general regional picture of the Precambrian surface is a broad, flat terrace about 60 miles wide that slopes westward into the Lemmon syncline at a rate of 1 or 2 feet per mile.

Locally, the principal structure of the exposed bedrock is a northwest trending "high" extending from west of Chamberlain to slightly west of the Big Bend of the Missouri river. The structure has not been delineated precisely because of limited outcrop; however, a 1940 magnetometer study shows a "high" trending along the same northwest path (Wing and Gries, 1941, p. 67).

Structure is a major consideration in prospecting for oil and gas, but in this area the structure of potentially oil-bearing formations at depth is not necessarily reflected at the surface. Many of the formations extending from the Lemmon syncline thin and pinch out toward the east and eventually extend onto and overlap the folded surface of the Sioux Quartzite ridge (Wing and Gries,1941). The fold in the Cretaceous overlap at Chamberlain is the Medicine Butte anticline (Petsch, 1946).

Stratigraphy

Descriptions of the rock units underlying the reservation are summarized in a generalized stratigraphic column (Table 1). Information on bedrock older than Upper Cretaceous is limited to the few wells in the area that have been drilled deeper than the Newcastle (Dakota) Sandstone and to correlation with the well-known succession of pre-Cretaceous rocks in western South Dakota.

At one time Tertiary formations covered much of South Dakota but have since been removed by erosion (Tertiary remnants are found capping buttes, for example Medicine Butte in northern Lyman County (Petsch, 1946).)

TABLE 1

Stratigraphic Section, Lower Brule Indian Reservation

System and Series	Unit Group, Formation, Member	Maximum Thickness (feet)	Character and Distribution
Quaternary	Alluvium	185	Water-laid deposits consisting of clay, silt, sand and some gravel; occupies flood plains, bars, islands, and other channel features of the Missouri River and its tributaries. The youngest alluvium has been deposited by present streams, but alluvial deposits have been accumulating in the Missouri Valley since the Pleistocene Epoch. The underlying valley fill and higher terraces have in part been deposited by melt water from Pleistocene glacial ice. Deposits may reach 185 feet (Howells, 1974; Petsch, 1946).
	Dune Sand		Wind-blown and -sorted deposit, mostly rounded quartz sand; often grass- stabilized.
Pleistocene			During the Pleistocene Epoch, ice sheets advancing from the east greatly modified the topography and drainage of South Dakota and established the course for the present Missouri River. the earliest ice apparently extended west of the river but later ice advanced only to its eastern bank. A mantle of glacial drift, the material eroded from the surface over which the glaciers moved, was left on the surface as the ice retreated.
	Loess	100	Air-sorted and -deposited drift consisting of unconsolidated, well-packed, buff- colored silt to fine sand with some clay and medium sand. A thin coat of loess overlies most of the area. Deposits reach 100 feet in thickness. Those less than 5 feet thick are not shown on Figure 4 (Howells, 1974; Petsch, 1946).
	Glacio-fluvial (Outwash)	30	(Outwash) - Water-sorted drift consisting of mixed sand and gravel. Located in dissected terraces of the Missouri River and its tributaries.

	(Terrace)	100	(Terraces) - Fairly level areas of alluvium located above the present flood plain. Terraces are remnants of the former Missouri River valley, left behind as the river channel deepened during torrential flooding due to the melting glaciers. The 3 types of terrace materials include: glacial gravels consisting of hard materials such as granite, quartzite, vein quartz, flint, chert, and gneiss; light gray and bluish gray chalcedony and limestone pebbles carried by streams from the west; local shale and iron carbonate fragments (Rothrock, 1944). Younger terraces and alluvium contain material reworked from older terraces. Deposits are sometimes over 100 feet thick (Petsch, 1946; Rothrock, 1944).
	(Colluvium)	30	(Colluvium-alluvium) - Heterogeneous mixtures of water- laid and slumpage detritus of terrace material and Pierre shale fragments. Commonly found at the bases of steep slopes. As much as 30 feet thick (Howells, 1974).
	Gravel		Fluvial and glacio-fluvial heterogeneous materials. Gravel deposits are a part of the terraces and are distinguished in Figure 4 because the sand and gravel size of the material make them of economic interest. Deposits are generally silt- or loess--covered (Curtiss and Waddel, 1951a; Rothrock, 1944).
Upper Cretaceous	Pierre Shale	360	Dark gray, fissile, carbonaceous, marine shale; contains several zones of bentonitic beds and concretions; weathers to a yellowish gumbo.
	Mobridge Member	20	Bluish-gray foraminiferal chalk and calcareous clay. A few flat limestone concretions and bentonite layers. Limited outcrop (Petsch and Fairbanks, 1952; Petsch and others, 1950).
	Virgin Creek Member	120	Upper Virgin Creek: Medium gray bentonitic clay and noncalcareous shale. Contains small bluish-gray limestone concretions bearing the fossil remains of small crabs. Breaks down to slope-forming gumbo. Poorly exposed. Lower Virgin Creek: Resistant, dark bluish gray bentonitic shale. Many closely spaced bentonite beds. Weathers to thin gray flakes with a submetallic, silvery appearance. Small barite rosettes occur near the base. The lower zone is approximately 75 feet thick (Petsch and others, 1950a; Petsch and Fairbanks, 1952; Curtiss and Waddel, 1951a; Searight, 1937; Petsch, 1946).
	Verendrye Member	60	Upper Verendrye: Gray shale containing numerous large, flat, iron-manganese carbonate concretions. The concretions have weathered black surfaces and greenish-gray interiors. Lower Verendrye: Banded gray and yellowish gray shale containing a few small buff concretions; intervals with continuous ledges

		of flat, white to rusty brown limestone concretions and a few thin black concretions. Successions of 1- to 6-foot -thick shale beds alternate with 1/2- to 4-inch -thick layers of bentonite (Wing and Gries, 1941).
DeGrey Member	65	Upper DeGrey: Succession of highly bentonitic gray shale and clay alternating with grayish yellow bentonite beds and persistent to intermittent layers of concretions. Beds range from less than an inch to less than 2 feet in thickness, The zone is characterized by the presence of abundant black iron-manganese carbonate concretions which form a conspicuous black band of outcrop running parallel to the river. The shale weathers to gumbo but the concretions weather out in relief and accumulate on the surface. The concretions are 1-4 inches thick and 3-8 inches in diameter. In many places they occur in lenticular beds as much as 8 inches thick and 10 feet long. The color of fresh nodules ranges from pale gray to olive- green. Weathered surfaces are black (Wing and Gries, 1941; Searight, 1937). Traceable bentonite beds include: 1) The Lower Micaceous Bentonite (LMB)- a 1- to 6-inch yellow bentonite with abundant biotite flakes that occurs consistently at the base of the concentration of iron- manganese concretions; 2) The Big Bentonite Bed (BBB)- an 8-inch bentonite separated from an underlying l-inch bentonite by 2 inches of shale; 3) The Upper Micaceous Bentonite (UMB)- 5 to 10 feet above BBB (Wing and Gries, 1941). Altogether the maximum thickness of the upper member is 35 feet. Lower DeGrey: Light gray bentonitic clays and siliceous shales containing noticeably fewer concretions and bentonites than the upper DeGrey. Every exposure shows three prominent 4- to 6-inch beds of bentonite, with or without additional thin beds. This lower subdivision is approximately 30 feet thick. The entire member ranges from 40 to 64 feet (Wing and Gries, 1941, Cox and others, 1962; Crandell, 1950; Searight, 1937).
Crow Creek Member	10	Light gray foraminiferal marl and buff chalk. 6-12 inches of uniform, persistent, brown sandy marl to sandstone at the base; 10 feet thick. Weathers to a yellow soil (Wing and Gries, 1941; Curtiss and Waddel, 1951; Petsch and others, 1950a).
Gregory Member	60	Banded brown to dark gray bentonitic shale containing numerous brown limonitic concretions and bentonite layers. Limestone ledges 1 foot thick occur near the base and an intermittent chalky bed a few feet below the top of the member crops out opposite the mouth of Crow Creek. The limonitic concretions range from 2 to 6 inches in thickness and form either small and intermittent lay-

			ers or nearly continuous ledges. Within the concretions are numerous large specimens of Inoceramus and Baculites. Abundant septarian nodules are found near the base. The Gregory is approximately 60 feet thick (Wing and Gries, 1941).
	Sharon Springs Member	25	Hard, fissile, dark gray to black bituminous shale speckled with fish scales, various twig-like particles and bone splinters. Toward the base are thick layers of bentonite and a thin, 5-inch layer of volcanic ash. A bed of impure, rusty selenite occurs at the contact with the underlying Niobrara Formation. Uranium content for the entire member averages approximately 0.0015 percent (Kepferle, 1959). Uranium-rich zones lie just above the uppermost thick bentonite bed or disconformably above the Niobrara chalk in the absence of bentonite. The uranium is held in the phosphatic fossil fish and carbonized plant remains. The member also contains a suite of trace elements in which arsenic, boron, chromium, copper, molybdenum, nickel, selenium, and vanadium are conspicuous (Tourtelot, 1956). Up to 25 feet thick (Curtiss and Waddel, 1951a; Petsch and Fairbanks, 1952; Wing and Gries, 1941).
	Niobrara Formation	200	Crops out as vertical cliffs of light colored chalk along the Missouri River below Big Bend Dam. Physically amorphous. Contains foraminiferal and flocculent material. Impurities include clay, organic matter and small amounts of iron sulfide in the form of pyrite pellets. Unweathered chalk is predominantly very dark gray to black. Weathers buff and bleaches white near the surface (Rothrock, 1931; Petsch, 1946).

THE NIOBRARA IS THE OLDEST OF THE ROCK UNITS EXPOSED ON THE RESERVATION.

	Carlile Shale	140-325	Light-blue or light-gray to black shale, generally non-calcareous; contains one or more sandstone or sandy intervals in the top half. Marine (Howells, 1974).
	Greenhorn Limestone	50-100	Buff to bluish, white, or gray, highly calcareous shale; commonly marly and fossiliferous. May be inerbedded with thin limestone layers Marine (Howells, 1974).
	Graneros Shale	150-320	Medium to dark-gray non-calcareous shale. Calcareous concretions and pyrite and marcasite crystals common. Locally the formation may contain thin lenses and beds of sandstone and may be sandy or silty at the base. Along the crest and slopes of the Sioux uplift, basal beds of sandstone or sandy and silty shale may exceed 100 feet in thickness. Marine (Howells, 1974),
Lower Cretaceous	Newcastle Sandstone (the Dakota Sandstone of some authors (Darton, 1951)	280-350	White, tan, or light-gray sandstone, very fine to coarse-grained, loose to tightly cemented; interbedded with dark-colored

			shale. Deltaic or near-shore deposits (Howells, 1974).
	Skull Creek Shale	0-130	Dark bluish-gray shale. Marine (Howells, 1974).
	Inyan Kara Group [Includes Fall River Sandstone (the Dakota Sandstone of most previous reports), Fuson Shale, Minnewaste Limestone and Lakota Sandstone (Darton, 1951)]	0-80	White to light-gray or tan sandstone, fine to medium grained; contains beds of gray to black and reddish to buff shale and siltstone. Continental to marginal marine deposits (Howells, 1974).
Jurassic	Sundance Formation	0-90	White, buff, dark-pink, or red sandstone, medium fine-grained; may be glauconitic in some areas; contains layers of red to brown, green, and gray shale. Marine (Howells, 1974).
Permian and Pennsylvanian	Minnelusa Formation	0-250(?)	White to yellow, buff, or red sandstone interbedded with anhydrite, brick-red to orange, green, or black shale, and white to brown to gray limestone and dolomite. Continental to marine (Howells, 1974).
Mississippian	Madison Group [Pahasapa Limestone and Englewood Limestone (Darton, 1951)]	0-100(?)	White to tan, brown, and gray limestone and dolomite. Locally may contain shale or anhydrite beds, Marine (Howells, 1974).
Devonian	Undifferentiated	0-50(?)	Red, green, gray, and black shales interbedded with anhydrite, red to gray, medium to fine-grained sandstone and siltstone, and gray to brown limestone and dolomite. Marine (Howells, 1974).
Transgressive	"basal wash"	0-50	White and buff to pink to light reddish-purple sandstone, generally coarse-grained but ranges from fine-grained to gravelly. May be arkosic. Reflects the lithology of underlying or nearby Precambrian rocks. A coarse clastic facies that overlies the Precambrian surface throughout much of South Dakota (Howells, 1974).
Precambrian	Sioux Quartzite	?	Pale maroon, pink, red or purple, hard, dense, orthoquartzite. Locally white, locally friable. Contains a few beds of catlinite (pipestone) (Howells, 1974).
	Igneous and metamorphic	?	Various colored granite, gneiss, schist, and other rocks igneous and metamorphic rocks (Howells, 1974).

A simplified geologic map (Figure 4) shows the distribution of Quaternary sediments, the widespread Cretaceous Pierre Shale, and the limited outcrop of the Niobrara Formation along the Missouri River.

The Pierre Shale underlies all of South Dakota west of the Missouri River with the exception of the Black Hills and restricted areas of the Missouri river Valley where the formation has been removed by erosion (Searight, 1937). In the Missouri River

Valley, the Pierre Shale is a thick body of shale and clay that has been divided into eight members. From the base up these include the Sharon Springs, Gregory, Crow Creek, DeGrey, Verendrye, Virgin Creek, Mobridge, and Elk Butte Members. With the exception of the Elk Butte, all of the members crop out on the reservation. The total thickness of the Pierre is as much as 360 feet on the reservation.

> "The shale commonly contains 65-80 percent clay minerals, 15-25 percent quartz, a few percent feldspar, and small amounts of calcite, dolomite, biotite, pyrite, gypsum, jarosite, clinoptilolite, and organic matter.Cristobalite is abundant in many but not all siliceous shales. Typically, the clay-mineral fraction contains about 5 percent each of kaolinite and chlorite, 15 percent illite, 35 percent montmorillonite, and 40 percent mixed-layerillite-montmorillonite. Principal variations from this average composition are:(1) a more montmorillonitic phase that comprises the frothy-weathering units, and (2) a montmorillonite-poor phase, commonly with unusually large amounts of kaolinite and no chlorite, mainly in the lower part of the Pierre shale. Almost all bentonite beds of the Pierre are composed largely or exclusively of montmorillonite, rarely a little kaolinite, variable but usually small amounts of feldspar and biotite, and little or no quartz; the most abundant mineral in a few bentonite beds near the base of the Pierre shale is clinoptilolite"(Schultz and others, 1960, p. 2041).

Water Resources

> "Shallow ground water is not obtainable in much of the area and where it is found, it often is of poor quality. Surface water, with the exception of the Missouri River reservoirs, though a valuable and widely distributed resource, is undependable because of scanty and erratic precipitation. Therefore, some people have drilled deep artesian wells for their basic water needs. Because of the expense of drilling artesian wells, most people will continue to use surface water and shallow ground water, as available, particularly for livestock supplies.
>
> "The best chemical quality and largest volume supply of water available within the reservations is from the Missouri River reservoirs. Development of some of the more than 17 million acre-feet of annual flow in the Missouri appears to be an attractive solution to water shortage and a boon to economic improvement, particularly for irrigation. However, financial cost of such development probably will restrict it to large projects or to individual users within a mile or so of the reservoirs; in general, the greater the distance from the reservoir, the higher the cost and the larger the area that probably should be developed.
>
> "Surface runoff is widely developed for livestock supplies. Although evaporation losses are high, as much as 38 inches a year, dams and dugouts are comparatively inexpensive way to hold snowmelt and

storm runoff for later use at widely dispersed sites. Use of this type of water resource will continue to grow because of its many advantages.

"Shallow ground water of fairly good quality is available in only a few areas. In most of these areas well yields will be less than 20 gpm, although two areas will support well yields greater than 50 gpm. Most future development of shallow ground water probably will be for stock and domestic wells in the few favorable areas. Water quality, of great importance in considering any possible source of supply, is of particular concern for shallow wells because of the ease of pollution from surface sources, possible high nitrate, and the known possibility of high selenium content." (Howells, 1974)

MINERAL RESOURCES

The following sections summarize available information about energy, metallic, and nonmetallic mineral resources that occur, or that may possibly occur, within the Lower Brule Indian Reservation. The commodities discussed include identified as well as undiscovered mineral resources, according to the classification adopted by the U. S. Bureau of Mines and the U. S. Geological survey (1980) and used in this report.

Mineral production from the reservation has been limited to sand and gravel. There are no leases for oil and gas or for other minerals on Indian tribal trust or allotted lands on the reservation, but three permits were issued for removal of gravel from a pit in the SE¼ sec. 16, T. 108 N., R. 73 W. in 1979 (U. S. Bureau of Indian Affairs, 1979a). Recently, companies have indicated interest in obtaining oil and gas leases if they should be offered.

Energy Resources

Petroleum and (or) natural gas, uranium, and geothermal energy resources may occur on the reservation, although they are not known there now. Low-grade oil shale occurs in the Sharon Springs Member of the Pierre Shale; a few thin beds may yield as much as 8 gallons of oil per ton (Kepferle, 1959, p. 581; Swanson, 1960, p. 19). Development of oil shale on the reservation seems unlikely.

Petroleum and Natural Gas

No wells have been drilled for oil or gas on the reservation. Several exploratory or wildcat wells have been drilled nearby, however, to the south, west, and north of the reservation (Petroleum Information Corp., various dates);all were dry holes.

Natural gas has been produced from artesian water wells in central and eastern South Dakota for many years. According to Henkes and Gries (1963, p.16).

"Numerous artesian water wells drilled in the vicinity of the Missouri River have produced natural gas along with the water. In a few cases this gas is produced from the Niobrara shale, but most comes from the

Dakota sand. The quantity of gas is small and generally is allowed to flow into the air or is burned as a flare; some farmers and ranchers, however, have piped the gas into their homes and used it for heating and cooking. Gas was found in an artesian well drilled in 1893 at the Pierre Indian School at the east edge of Pierre, but it never was used and the well was plugged in 1939 (Gries, 1940).

"In 1894, a hotel in Pierre drilled a water well to 1,300 feet where a strongflow of water and gas was obtained. The volume of gas was sufficient for cooking and for heating and lighting the hotel, and a surplus was piped to another company. In the same year, the city of Pierre drilled a water and gas well that produced enough gas to supply "...practically every home and business house in the city for cooking, heating, and lighting. All streets in the city we relighted by gas lights.. " Subsequently, five more wells were drilled for gas. Only one, drilled in 1910 at the State capitol, reported any specific gas quantity or pressure; this well initially produced 84,960 cubic feet per day at a pressure of about 165 psi, but by 1916 production had diminished to about 15,100 cubic feet per day at 30 psi. No cumulative gas production figures are available, but in 1930 one well had an indicated annual production of 14,000,000 cubic feet (Gries, 1940)."

Recent studies indicate that the potential for natural gas from shallow, porous, low-permeability reservoir rocks, such as some chalks, sandstones, and siltstones of Cretaceous age in the Great Plains, is more significant than was formerly thought (Rice and Shurr, 1978, p. 891-892; 1980, p. 969-987; Scholle, 1978, p. 892; Shurr and Rice, 1979, p. 256). Near the Sioux uplift, moreover, these rocks show facies changes and local unconformities that may influence natural gas accumulation. Improvements in logging and well--completion techniques also enhance the potential for natural gas production from these rocks.

While several factors lessen the prospects for discovery of oil or gas on the reservation (Henkes and Gries, 1963, p. 17; Miller, 1971, p. 706-717), the area does have some potential for oil and, especially, for natural gas. Production of limited quantities of gas from the nearby Pierre gas field, coupled with a very low density of exploratory drilling, possible favorable structure (Petsch, 1942), and substantially higher prices for oil and gas, all indicate that further exploration for these commodities is warranted. Moreover, contrary to earlier opinions, recent mapping by Howells (1974) shows that favorable Paleozoic formations underlie at least part of the reservation. Wells, including water wells, drilled to the Niobrara or deeper should be tested carefully for gas production. Even though the output may be small, flows of gas sufficient for local use may be obtained.

Uranium

Investigations by Tourtelot (1956), using surface exposures and gamma-ray logs of holes drilled for oil, showed that the Sharon Springs Member of the Pierre Shale is radioactive in the subsurface of southern South Dakota. At a road-cut near Oacoma, thin beds of shale were found to contain as much as 0.01 percent uranium. Additional work by Kepferle (1959) confirmed that the Sharon springs Member is anomalously rich in uranium over a wide geographic area in south Dakota and northeastern Nebraska. Uranium in the Sharon Springs is too low in grade, however, to be recovered commercially at present.

Although the potential for discovery of uranium ore deposits on the reservation seems low, local concentrations of uranium may exist either in Sharon Springs or in other favorable sedimentary horizons.

Geothermal Energy

The reservation is on the fringe of an area in south-central South Dakota where thermal gradients measured in wells and test holes are generally above normal and where some wells may produce low-temperature geothermal water from the Dakota Sandstone (Adolphson and LeRoux, 1968; Schoon and McGregor, 1974). Such warm waters may have a potential use in space heating and agriculture on a local basis. Insufficient data are available to determine the significance of this resource on the reservation.

Metallic Mineral Resources

Large deposits of low-grade manganese resources are pre-eminent among metallic mineral resources on the reservation. Iron occurs with the manganese, but its recovery would depend on manganese production. Several authors have mentioned the Pierre Shale as a possible non--bauxitic source of aluminum (Gries, 1942, p. 64-66; Rothrock, 1944, p. 65-66; Miller, 1959, p. 26). Many alternate non-bauxitic sources of aluminum, however, are far more promising.

Manganese

Interest in the vast resources of low-grade, manganese-bearing material in the Pierre Shale along the Missouri River below Pierre has risen and fallen in the 50-year period since their discovery. For a concise overview of the history, geology, mining, and beneficiation of these deposits, the following information taken from Gries (1975, p. 107-108).

> "History of exploration.--Concretions that weather out of the DeGrey Member of the Pierre Shale form a continuous black band along the Missouri River breaks in central South Dakota. Mr. Albert Amundsen of Lake Andes, S. Dak., discovered in 1927 that these concretions, or nodules, were unusually high in manganese. This aroused the interest of the John A. Savage Co., of Duluth, and of Mr. K. M.Leute of Minneapolis, who sponsored a program of test pitting and sampling of the manganese-bearing beds both north and south of Chamberlain. D. F. Hewett of the U. S. Geological Survey analyzed this test pit data and concluded that the manganese concretions underlying 9 townships near Chamberlain contained an estimated

102,000,000 tons of metallic manganese (Hewett, 1930).

"Stratigraphic studies in 1934-35 indicated that the manganese-bearing zone formed a laterally continuous member of the Pierre Shale formation, and a systematic program of section measuring, mapping, trenching, and sampling was conducted by the South Dakota Geological Survey in 1940 and 1941 (Gries and Rothrock, 1941).

"The U. S. Bureau of Mines inaugurated an extensive evaluation of the manganese deposits of the Missouri Valley in 1940. A pilot plant was built on the outcrop 8 miles west of Chamberlain in 1941. Experiments in mining and transportation of concretion-bearing shale, and in separating nodules from shale, continued from 1941 to 1947 (Pesonen and others, 1949; Zinner and Grosh, 1949).

"In the late 1950's the Pittsburgh Pacific Co. became interested in the concentration of manganese nodules in terrace gravels along the Missouri River north of Fort Thompson, Buffalo County. An experimental plant was built to devise methods of separating the gravel into (1) a manganese nodule concentrate,(2) gravel, and (3) waste substances.

"Description of the deposits.--The DeGrey Member consists of dark gray shale, numerous thin bentonite beds, and abundant iron-manganese concretions. It is underlain by the thin, light-colored marl of the Crow Creek Member and overlain by the dark, gumbo-forming shale of the Verendrye Member.

"The nodules occur in distinct layers parallel to the bedding of the enclosing shale. The average nodule has the size and shape of a large potato. Nodules may be widely separated or so closely spaced as to form a nearly continuous pavement. The Bureau of Mines has recognized three types of concretions: (1) hard concretions having a hardness of 4.0 to 5.0 on Moh's scale, which are the most abundant, (2) soft concretions that have a hardness of 2.5 to 3.5 and that may be soft throughout or may have a hard core and (3) still softer nodules that grade into shale and are as likely to have fractures going through a concretion as around it. Types 1 and 2 easily break free of the enclosing shale.

"Fresh unweathered concretions of the hard variety are medium gray to olive. Weathered nodules have a gray center surrounded by a rusty brown halo and a purplish-black outer crust. The soft varieties are ordinarily white to cream colored when fresh and light brown after weathering. The concretions are mostly carbonates of manganese, iron, calcium, and magnesium. The non-carbonate constituents are mainly silica and alumina, probably present in the form of clay. A typical nodule contains 14 to 17 percent manganese and 6 to 10 percent iron.

"The Bureau of Mines conducted an intensive sampling program along both sides of the Missouri River from T. 102 N.

to T. 107 N., and up the White River as far as T. 104 N., R. 74 W. The concretion zone ranged in thickness from 12 feet at wheeler Bridge, Charles Mix County, to 72 feet near the Big Bend of the Missouri river. The average thickness used in tonnage estimates was 40 feet. Samples from bucket drill holes were dried and hand sorted to separate the concretions from the shale. Concretions range from 2.45 percent by weight near Big Bend to 6.11 percent near Oacoma, Lyman County; the average, over all areas drilled, is 4.85 percent of the dry material in the zone. If minus one-half inch material is excluded, the percentage drops to 3.19.

"The average composition of concretions in 9 of the 10 areas drilled is 15.68 percent manganese and 8.7 percent iron. For the plus one-half inch concentrate, the percentages increase to 16.09 and 10.26 respectively.

"Experimental mining indicated that the concretion zone could be mined in a single bench, using a 3-yard or larger shovel. Mining and hauling would be difficult in periods of continued wet weather.

"A two- or three-stage wet jigging process appeared to be the most satisfactory method of separating the nodules from the shale. Methods that resulted in a shale-free concentrate yielded an appreciably smaller percentage of the total manganese than methods that permitted a small percentage of shale to remain in the concentrate. Zinner and Grosh (1949) noted that it would be desirable to devise a metallurgical process that could handle a concentrate with no less than 10 percent shale."

The literature on manganese deposits of the Missouri Valley is extensive. It may be divided into reports primarily about: (1) the geology and distribution of the manganese-bearing rocks, (2) mining and beneficiation (concentration) of the resource, and (3) metallurgical processing of a manganese nodule concentrate. Few of these studies concern deposits on the Lower Brule Reservation specifically, but many are still applicable to its manganese resources.

Compared with other domestic manganese resources, the Missouri Valley deposits are large but very low in grade. Pesonen and others (1949, p. 87)calculated "that an outcropping and lightly covered manganiferous zone 523 miles in peripheral length and 365 feet wide contains approximately 12,000,000 tons of manganese in 77,700,000 tons of concretions, ..."

Of the 523 miles of outcrop, Henkes and Gries (1963, p. 23) estimated that about 25 percent, or 131 miles, lies within the limits of the Lower Brule Reservation and that 3 million tons of manganese is contained therein. Manganese resources in the DeGrey Member were mapped by Gries and Rothrock (1941), Rothrock (1943), and Pesonen and others (1949). Figure 1 shows the approximate location of these deposits on the reservation. At two places west of Lower Brule, manganese deposits were drilled and sampled in detail by USBM (Pesonen and others, 1949, fig. 10; 1949a, p.

55-58, 61-63), but additional sampling will be needed to determine accurately the extent and grade of manganese resources on the reservation. Manganese nodules are also present in terrace gravels along the Missouri River (Rothrock, 1944a); on the reservation, these deposits are not a manganese resource. A small part of the manganese-bearing beds is within the taking area for Lake Sharpe (Van Sant, 1960, p. 5-6).

Two reports summarize extensive work by USBM on mining and beneficiating the Missouri Valley manganese deposits in the DeGrey Member (Dupuy and others, 1946; Zinner and Grosh, 1949). Briefly, they found that mining and processing a full thickness of the manganese-bearing zone probably would be required to sustain large-scale commercial operations. The nodules in this material would be notably more difficult to concentrate than altered or weathered nodules in surficial deposits. Wet jigging methods showed the most promise in treating the fresher material, but the jigging tests still did not produce a clean nodule concentrate, yield a high-grade product, or recover most of the manganese (Zinner and Grosh, 1949, table 7).

Metallurgical studies (Knickerbocker and Miller, 1942; Jacobs and Hunter, 1946; Torgeson and others, 1946) are pertinent only because they show that it is technically feasible to produce manganese metal, ferromanganese, or other commercial products using raw materials from the Missouri Valley deposits, and because they indicate specifications required of the beneficiated product for various metallurgical processes.

The conclusions of Henkes and Gries (1963, p. 25) regarding Manganese resources on the reservation appear to be valid today:

> "At present there is no market for the manganese nodules. It is technically possible to use the nodules directly in the production of basic pig iron, or to produce manganese metal by an electrolytic process. Neither use is economically feasible at present. Manufacture of ferromanganese by complex pyrometallurgical processes, or recovery of manganese by leaching and chemical processes is also technically possible, but completely uneconomic in the foreseeable future.
>
> "Barring a national emergency, the prospects for developing manganese from the Pierre shale are remote. The greater accessibility of the outcrops in the Chamberlain-Oacoma area suggest that when development does come, it will be in that area. With the tremendous tonnages available close to the railroad, development would be slow to extend far to the north or south."

A comprehensive, authoritative report about the recovery of manganese from low-grade domestic resources, which places the Missouri Valley deposits in a national perspective, ranks these deposits far down on the list (National Materials Advisory Board, 1976, p. 17, 54-55). This report and a recent commodity profile on manganese by USBM (DeHuff and Jones, 1979, p. 7) paint a similar, pessimistic picture for development of the Missouri Valley deposits.

Manganese deposits on the reservation are a demonstrated, subeconomic resource at present. The Missouri Valley deposits are far too low in grade to be competitive today. Moreover, a major obstacle to their eventual development is the lack of a proven, efficient, economical method to separate the nodules from the shale host rock (DeHuff and Jones, 1979, p. 7).

Cobalt, Copper, and Nickel

Unlike some of the manganese-bearing nodules that occur on the sea floor, which have been recently sought for their cobalt, copper, and nickel content, the manganese deposits of the Missouri Valley do not contain significant concentrations of cobalt or nickel (Schlain, 1946; B. H. Clemmons, written common., 1962). Two spectrographic analyses of the nodules show only 0.01 percent copper (Pesonen and others, 1949, p. 59).

Nonmetallic Mineral Resources

Nonmetallic mineral resources of the Lower Brule Reservation include sand and gravel, clay, and shale. The Niobrara Formation, formerly a source of chalk for building stone, lime, and cement rock in southeastern South Dakota, underlies the reservation. Unfortunately, the most accessible deposits that cropped out along the Missouri River are now covered by the waters of Lake Sharpe and Lake Francis Case. The occurrence of a zeolite mineral (clinoptilolite) may point to a potential resource on the reservation.

Sand and Gravel

Large deposits of sand and gravel occur in terraces along the Missouri River in south-central South Dakota. These terrace deposits consist mostly of glacial outwash materials carried by streams from melting glaciers; however, some local materials, such as manganese-bearing nodules, are also present.

Rothrock (1944a) has compiled an inventory of major sand and gravel deposits along the reach of the Missouri that borders the reservation; the following data are taken from his report. In addition, the Materials and Tests Laboratory of the Division of Highways, South Dakota Department of Transportation, in Pierre maintains a file of data about sand and gravel deposits used or tested for use by the department.

Four terrace deposits, containing an estimated 200 million cubic yards of sand and gravel, lie within the reservation (Figure 1). La Roche terrace, in the east half of T. 109 N., R. 76 W., near the mouth of La Roche Creek, has been dissected into several parts by erosion. Remnants of the terrace contain about 30 million cubic yards of fairly clean sand and gravel (mostly sand). Small amounts of material have been produced from pits in the NE¼ sec. 27, T. 109 N., R. 76 W. by a government/ contractor operation.

The Medicine Creek terrace covers one-half square mile in sec. 33, T. 108 N.,R. 74 W., and sec. 4, T. 107 N., R. 74 W., just east of Iron Nation. No estimate of volume was made for this small deposit.

A large terrace occupies about 11 square miles inside the loop of the Big Bend of the Missouri

River. Most of this terrace contains only sand; however, about l square mile at the southern end is underlain by gravel. The gravel-bearing part, in secs. 16, 17, and 21, T. 108 N., R. 73 W., contains about 28 million cubic yards of material, while the rest of the terrace is estimated to have at least 110 million cubic yards of sand. Gravel has been produced from a pit in the SE¼ sec. 16, T. 108 N., R. 73 W.; in 1979, three permittees produced about 11,000 cubic yards of sand and gravel from this pit (U. S. Bureau of Indian Affairs, 1979a).

The Fort Hale terrace is on the west side of the Missouri River and south of Muddy Creek in the west half of T. 106 N., R. 71 W. About 3 miles long and 1 mile wide at its widest part, the deposit contains an estimated 37.5 million cubic yards of sand and gravel.

Many factors, such as quality and quantity of the deposit, demand, and especially transportation costs, would affect the use of sand and gravel resources of the reservation. Existing use of the surface also is an important factor. Some of the terrace deposits are within the small part of the reservation now dedicated to irrigated land, a use that may preclude recovery of underlying resources such as sand and gravel.

Clay and Shale

Several investigators have discussed clay and shale resources in the Pierre Shale along the Missouri River in South Dakota; however, these resources apparently have not been studied in detail on the reservation. Parts of the Pierre may contain material suitable for making structural clay products or lightweight aggregate.

The USBM investigated clay and shale deposits in North and South Dakota to determine if any were suitable for bloating to make lightweight aggregate (Cole and Zetterstrom, 1954; Zetterstrom and Cole, 1956). They found, as did Karsten (1956), that the Pierre Shale contains suitable material at several of the places tested along the Missouri, including Fort Pierre and Chamberlain; suitable material conceivably may occur on the reservation as well. Because available resources are so large and widespread, potential marketing areas and transportation facilities are perhaps as important as geologic characteristics in locating a lightweight aggregate pit and plant.

Common clay, suitable for making brick, tile, and other structural clay products, is also widespread and abundant in the State (Rothrock, 1944). It is reported at Pierre and Chamberlain (Patterson and Harked, 1975, p. 128) and probably occurs on the reservation. Again, the chance of developing common clay resources on the reservation, rather than at Pierre where a local market and good transportation network exist, is remote unless deposits of exceptional quality are found.

Bryson and others (1947) indicate that bentonite crops out above the pierre-Niobrara contact on the reservation. According to Gries (1942, p. 68), thin beds of bentonite are common in the Sharon Springs Member, but they seldom exceed 1 foot in thickness. Bentonites in the Pierre are the nonswelling type; such bentonite has been used to filter and purify oils, much like fuller's earth, and to bond foundry sands. Bentonite from the reservation probably cannot compete with similar deposits more favorably situated elsewhere.

Geologic studies and sampling might reveal clay or shale resources that could be developed on the reservation. Detailed economic feasibility studies, however, would be needed to determine if these deposits could compete successfully with abundant and widespread resources outside the reservation.

Zeolites

Recently, much attention has been directed toward the zeolites because this group of minerals has many new-found industrial and agricultural applications, and substantial deposits of zeolites have been found in certain sedimentary rocks. Zeolites have been reported from several localities in South Dakota, mostly in altered tuffaceous rocks of Tertiary age but also at two sites in the Pierre Shale (Sheppard, 1975, p. 157).

Clinoptilolite, a zeolite mineral, occurs in the Pierre Shale along the Missouri River as a minor constituent of no value in some beds and as a major component of others (Schultz and others, 1960, p. 2041). Near the mouth of Crow Creek, 11 miles north of Chamberlain, an altered bed of bentonite is composed almost entirely of clinoptilolite (Schultz, 1963, p. 173). Schultz (oral common., 1979) found beds of zeolitic bentonite, ranging from less than 1 inch to 10 inches in thickness, at several places close to the reservation along the Missouri River north of Chamberlain.

The occurrence and economic significance of zeolites on the reservation are not known.

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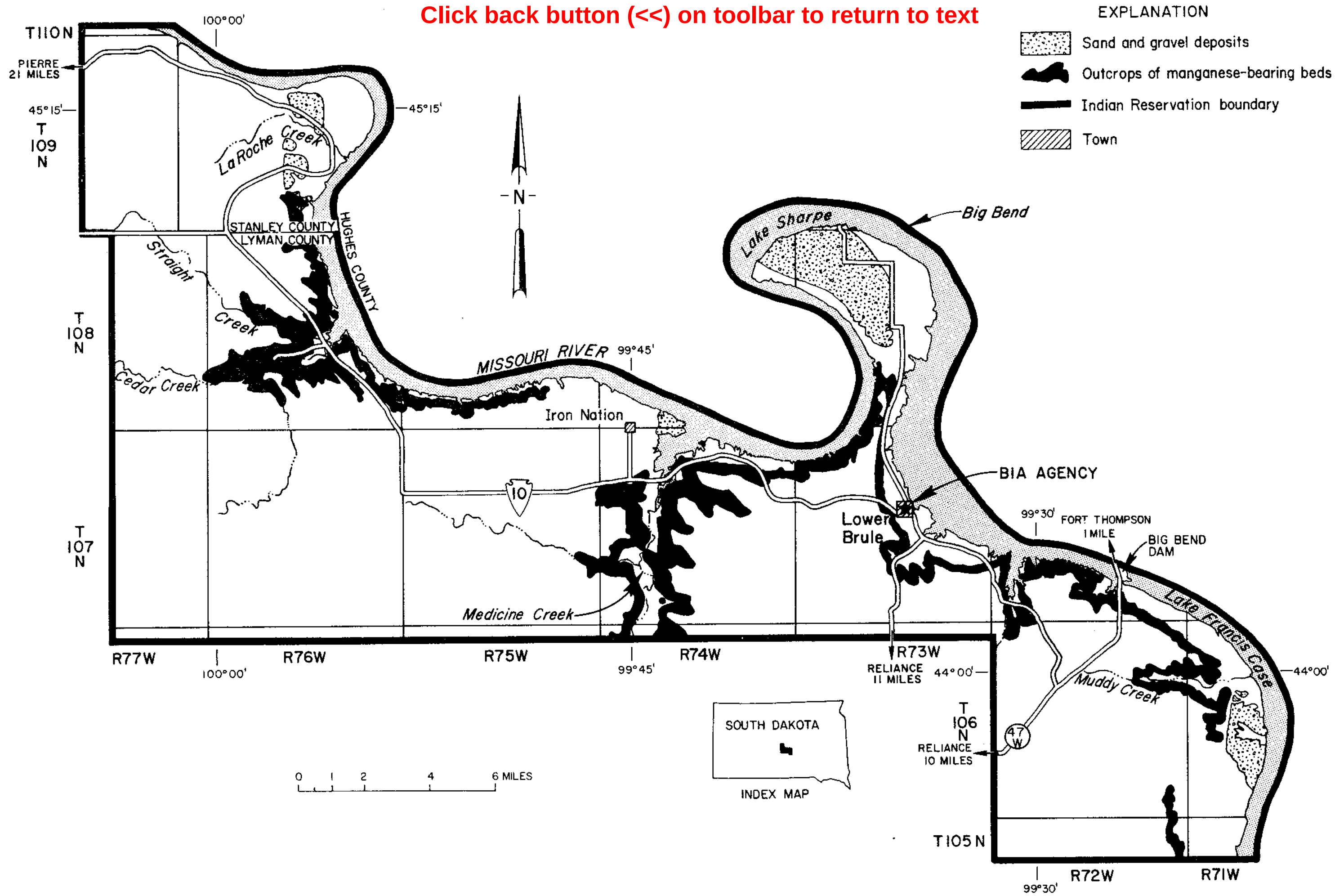

Figure 1. Map of the Lower Brule Indian Reservation, Lyman and Stanley Counties, South Dakota. (Mineral resource data from Pesonen and others, 1949; and Rothrock, 1944a).

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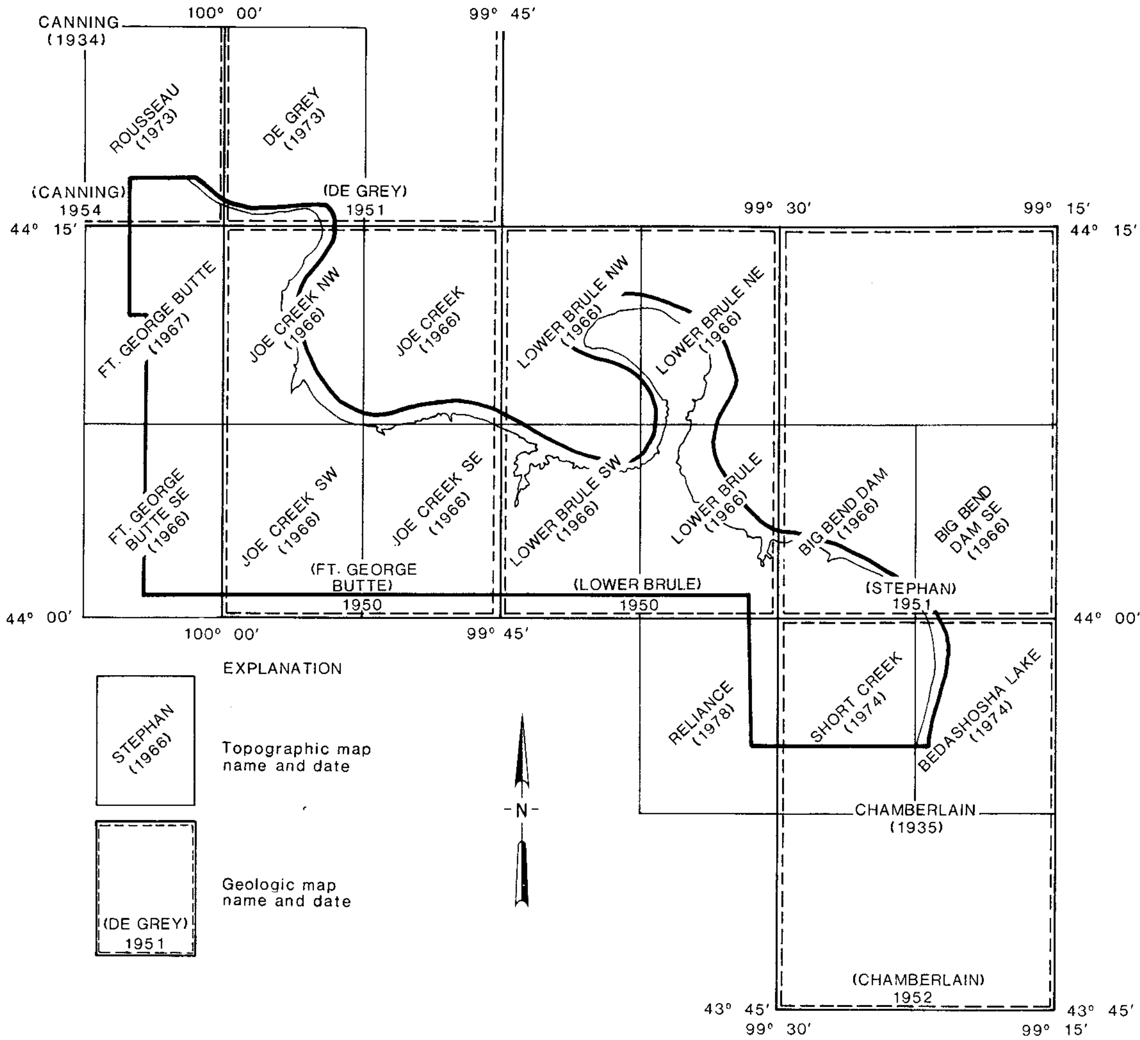

Figure 2. Index to topographic and geologic mapping, Lower Brule Indian Reservation, South Dakota.

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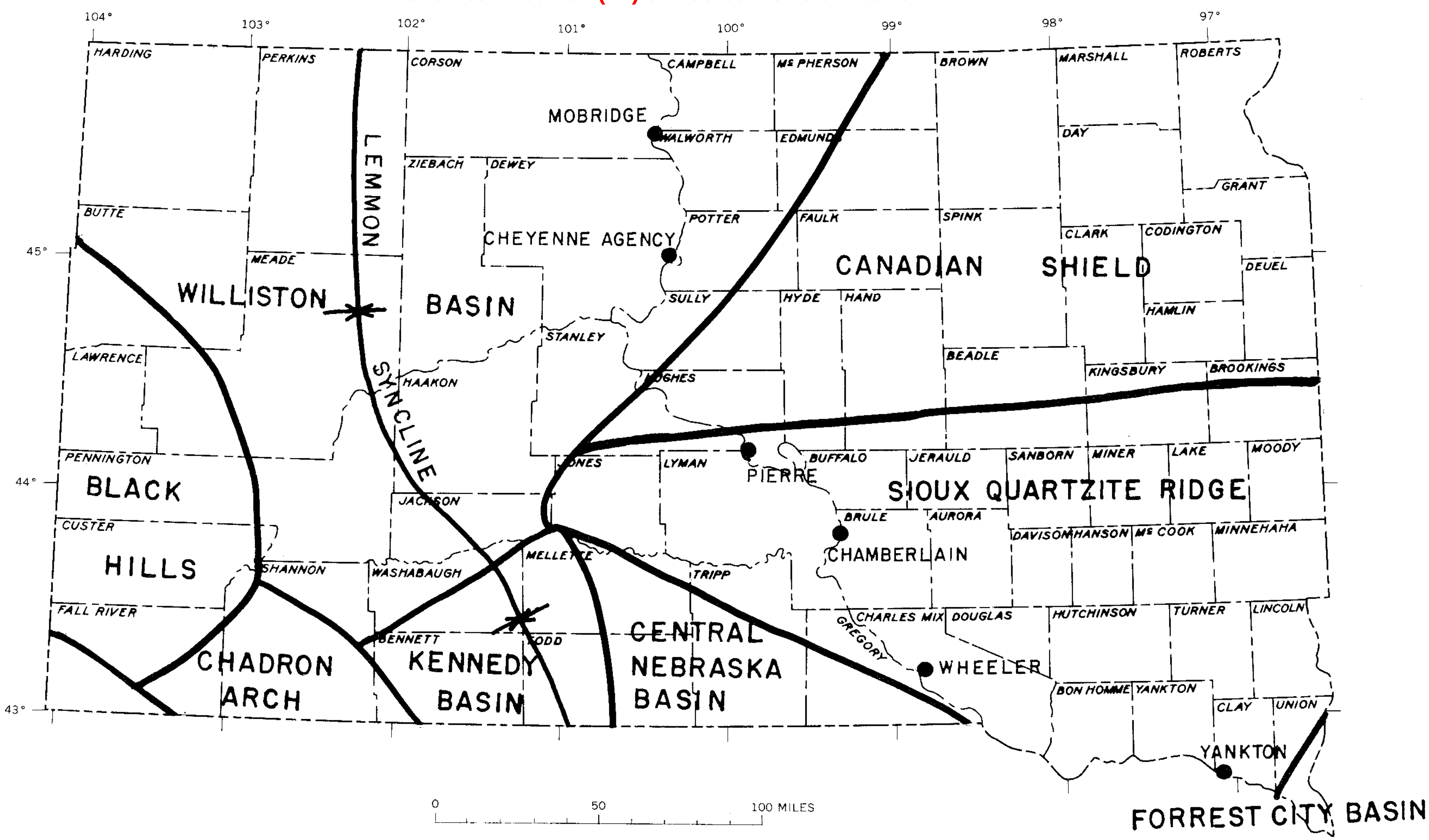

Figure 3. Major structural features of South Dakota. Map adapted from Wing and Gries (1941), Rothrock (1944), Petsch (1946), and Steece (1975).

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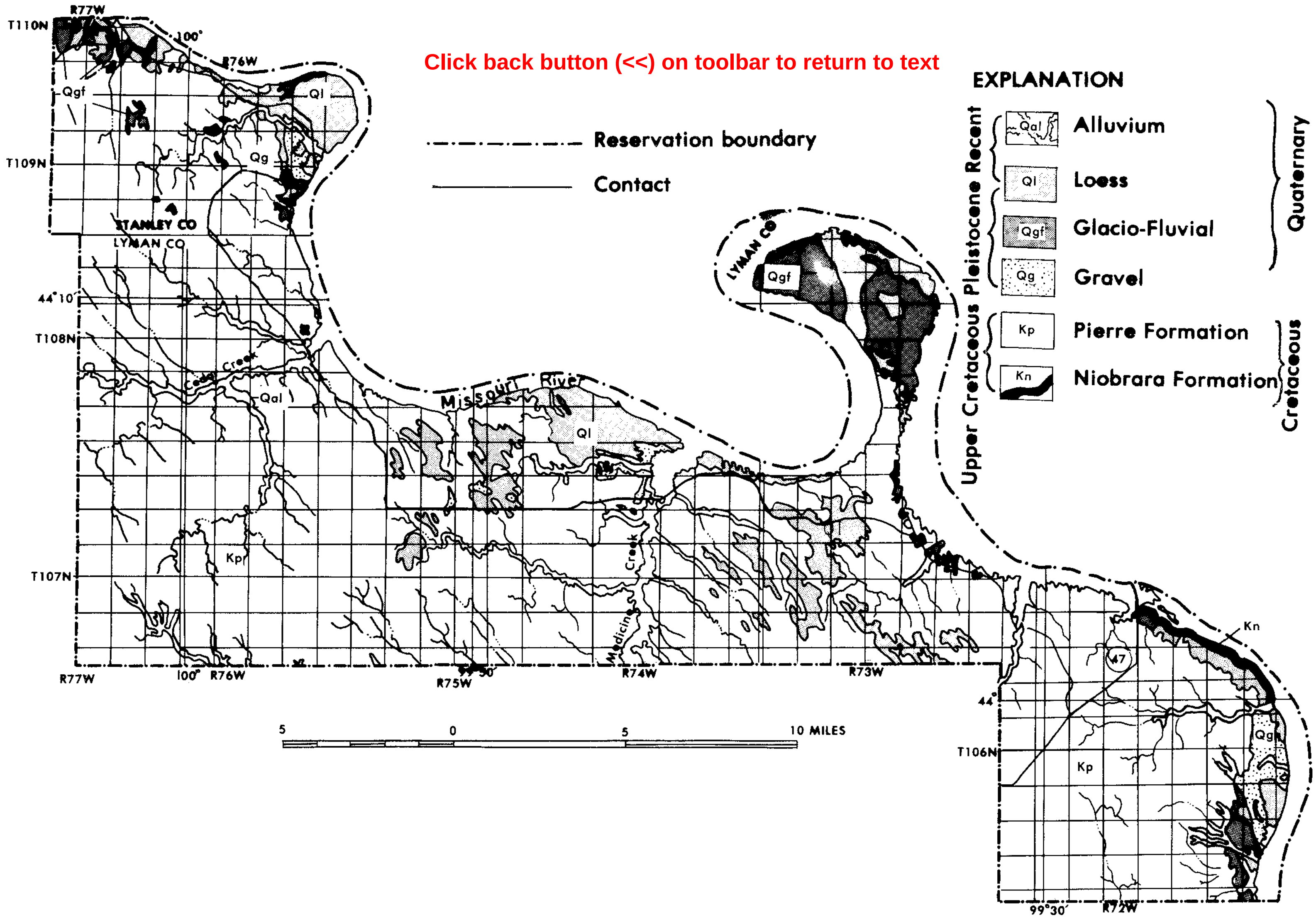

Figure 4. Geologic map of the Lower Brule Indian Reservation, South Dakota. Modified from Howells, 1974.