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STATE OF SOUTH DAKOTA  
George T. Mickelson, Governor

STATE GEOLOGICAL SURVEY  
E. P. Rothrock, State Geologist

REPORT OF INVESTIGATIONS  
No. 63

A PRELIMINARY REPORT ON THE SIOUX QUARTZITE

by  
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Vermillion, South Dakota  
January, 1949

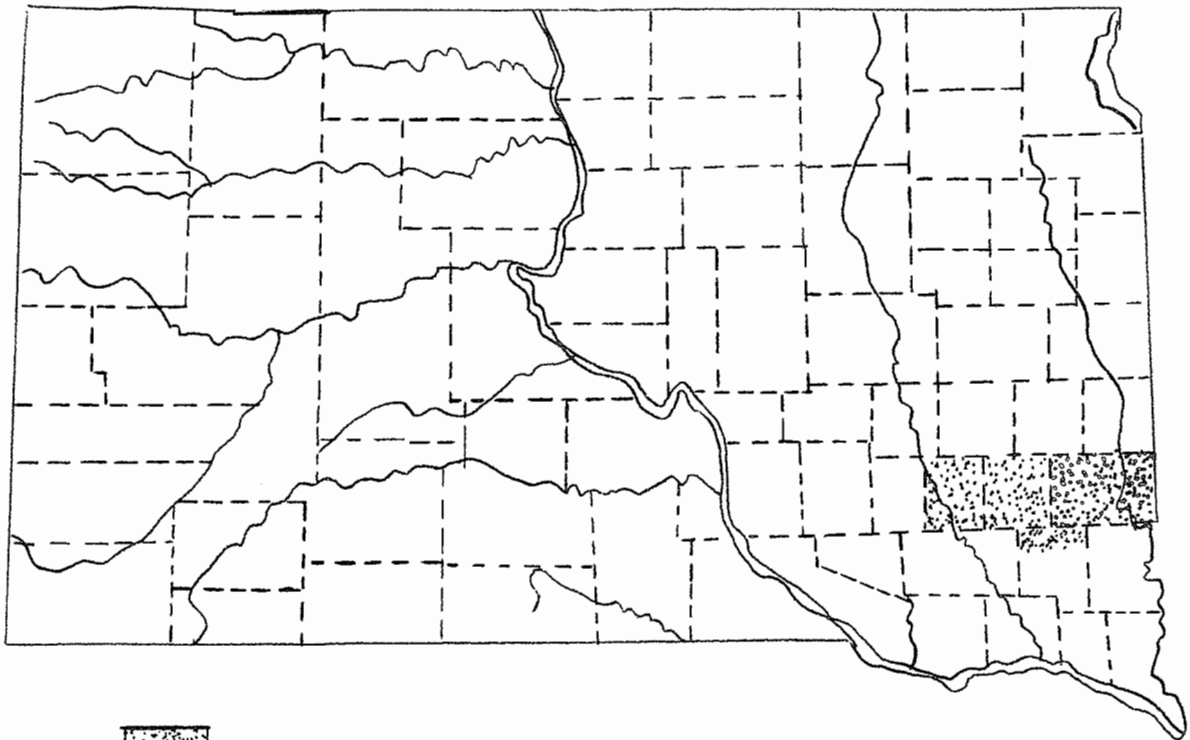
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INDEX MAP



Area covered in this report.

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# A PRELIMINARY REPORT ON THE SIOUX QUARTZITE

## INTRODUCTION

### PURPOSE

The Sioux quartzite, which is locally called the "Sioux Falls granite", is actually a sedimentary formation of a pink, well-cemented sandstone, consisting of 97 to 99% silica. Its hardness, uniformity, and attractive appearance have lent themselves to a number of uses, including building stone, crushed rock, gannister, and riprap, and they suggest other uses. The formation is exposed in the southeastern corner of South Dakota and in southwestern Minnesota, in addition to minor exposures in the very northwest corner of Iowa, just south of Rowena, South Dakota. During two and a half months of the summer of 1947 a reconnaissance study of the exposures of the Sioux formation in South Dakota was made by the writer for the State Geological Survey. The purpose of the study was to map the important variations in sedimentation and structure of the formation in order to aid and promote economic development of the rock.

### PREVIOUS WORK

The Sioux quartzite has been mentioned in the literature for more than a hundred years, but there has been no report that attempted to get an integrated picture of the formation. Earlier reports of some importance include the following:

N. H. Winchell's descriptions of the Minnesota exposures in 1872-1882 (10)\*

S. W. Beyer's Ph.D. thesis, which was a study of the diabase intrusive and other rocks exposed near Corson, S. D., and which was published in 1896 (3)

J. E. Todd's summary of his observations on the Sioux quartzite in South Dakota, published in 1903 (9), and more recently

E. L. Berg's microscopic and X-ray study of the quartzite and pipestone outcropping at Pipestone, Minnesota, published in 1937 and 1938 (1,2).

In addition to these reports, details of geology are mentioned in many scattered bulletins, annual reports, and scientific proceedings. The present report attempts to summarize what is already known about the formation and to add some new data which

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\*Numbers in parentheses refer to bibliography.

should give a better picture of the formation and its economic possibilities. The past summer's work was the first step towards a complete and thorough study of the Sioux quartzite.

#### ACKNOWLEDGEMENTS

The writer wishes to acknowledge the considerable aid and cooperation he has received in accumulating data and in writing the report. Dr. E. P. Rothrock, State Geologist, gave the writer permission and encouragement to study the Sioux quartzite. The field map for Dr. Rothrock's 1926 study of the sand and gravel deposits of Minnehaha County was most helpful to the writer in locating known exposures. C. L. Baker, of the State Geological Survey, offered many constructive suggestions regarding the geology, and many of the ideas and interpretations presented here were at least influenced by discussions with him. Mrs. Helen L. Davenport drafted Figures 1 and 2 for the report and most of the routine work of publishing the report has been done by other members of the office staff of the State Geological Survey; their efforts are greatly appreciated.

In the field the writer was aided by the local residents, who directed him to many exposures, saving much time and in some instances pointing out exposures that had not been reported previously. Their consideration and helpfulness are hereby acknowledged.

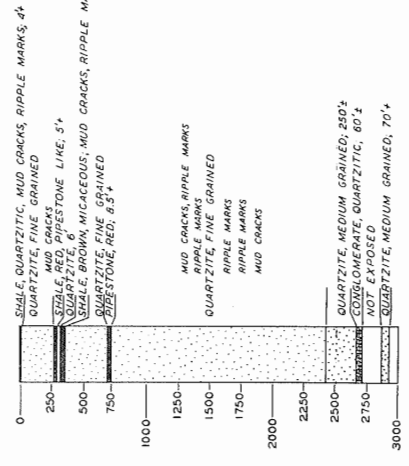
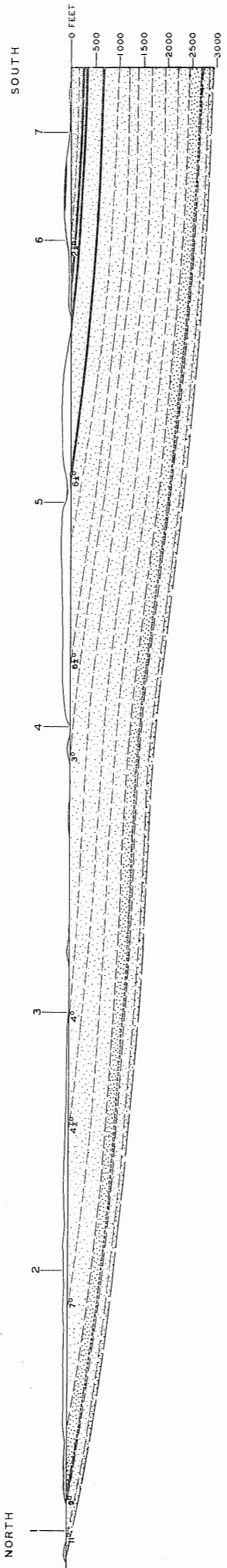
#### EXPOSURES IN SOUTH DAKOTA

The known exposures in South Dakota are in Minnehaha, Lincoln, Turner, McCook, and Hanson Counties. Information from water wells in these counties indicates that the formation underlies the entire region between the limiting exposures. The approximate areal extent of the exposures in this state is shown on the outcrop map (Fig. 1), and covers a belt some 70 miles long in an east-west direction and about 30 miles wide in a north-south direction. The western-most outcrops are in Hanson County, five miles east of Mitchell; the eastern-most is in Minnehaha County near Sherman, where Split Rock Creek crosses the South Dakota-Minnesota state line. The southern-most outcrop is near Parker in Turner County and the northern-most is at Dell Rapids in Minnehaha County.

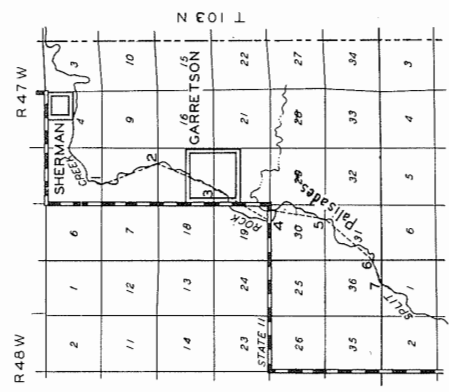
Most of the exposures are in Minnehaha County, either in the vicinity of the Big Sioux River or along Split Rock Creek. The outcrops at Dell Rapids are large and are well-known for their picturesque beauty. South of that city along the Big Sioux River the next significant outcrop is west of Sioux Falls, where the quartzite lies a few feet below the flood plain and is exposed in

# GENERALIZED STRATIGRAPHIC SECTION

## ALONG SPLIT ROCK CREEK, NEAR GARRETSON, SOUTH DAKOTA



COLUMNAR SECTION



INDEX MAP



GEOLOGY BY  
BREWSTER BALDWIN  
DRAFTED BY  
HELEN L. DAVENPORT

FIGURE 2

two quarries. Much of the pink rock is exposed at the falls and in other outcrops and quarries north and east of the business district. The quartzite outcrops again six miles east of the city at East Sioux Falls, where it is found on either side of State Highway 38 at the crest of the hill sloping towards the river. The presence of a number of exposures just east of the river in vicinity of Rowena indicates that a ridge of quartzite underlies a large part of the southeastern area of the township.

Along the course of Split Rock Creek exposures may be found from the state line downstream to Corson. For a distance of six miles the exposures are good and nearly continuous. Devil's Gulch, in the city of Garretson, is cut in the pink quartzite by a tributary of Split Rock Creek, and the Palisades, another well-known scenic feature, is a steep-walled gorge some sixty feet deep where Split Rock Creek has entrenched itself. Other broad outcrops may be found west of Garretson, not related to any main drainage.

West of the Big Sioux River exposures are scarce. In Minnehaha County there are small exposures at Ellis on Skunk Creek and a few larger ones north of Ellis and north of Hartford. In Turner County and southeastern McCook County the quartzite is exposed in a number of small patches along the East Fork of the Vermillion River for a distance of 11 or 12 miles. In the rest of McCook County the only known exposures are on Wolf Creek. One exposure is three miles southwest of Bridgewater and the other is an extension of the large exposure southwest of Spencer. In Hanson County the outcrops are found along Wolf Creek (southwest of Spencer), Plumb Creek (southwest of Emery), Pierre Creek (between Alexandria and Farmer), Johnson Creek (at Fulton), Rock Creek (northeast of Mitchell), Enemy Creek (southeast of Mitchell), and along the James River (north of Enemy Creek and at Rockport Colony).

#### OUTCROP MAP

The black areas on the outcrop map (Fig. 1) indicate the approximate location of the outcrops. These areas are of necessity considerably generalized in order to be shown on a map of this scale, and so they include far more than the exact area of outcrop. The outcrops along Pierre Creek between Alexandria and Farmer, for example, are not so impressive as the outcrop map might suggest. From the gentle topography and the intermittent nature of exposures, however, it may be assumed with fair certainty that the bedrock can be revealed over a far wider area by removing a thin layer of cover or overburden. The same applies to the intermittent outcrops around Sioux Falls, East Sioux Falls, and Rowena. The surface of the quartzite is not a smooth one,



however, because pre-glacial streams established drainage patterns on the rock which have been almost completely obscured by glaciation. Therefore, if a quarry is to be opened in an area where the exposures are poor the thickness of overburden should be checked rather carefully with auger or drill holes.

## GEOLOGY

### SEDIMENTATION

#### Cementation

The Sioux quartzite is a sedimentary formation that consists predominantly of pink-coated, fine grains of quartz sand cemented to a non-porous quartzite by silica. The rock has characteristic greasy luster due to the fact that it breaks through the quartz grains instead of around them. This characteristic of breaking identifies the rock as a quartzite and is a result of the excellent cementation of quartz grains by silica. Since both the grains and cement are made of silica, the rock is homogeneous, tough, hard, and pure.

In some exposures and quarries it will be noted that the silica cement is not present. In such cases one can rub off the sand grains and rarely one can find patches where all the cement is gone and the sand is loose. Some of the more striking examples of this may be found in the southern half of Sec. 8, T. 103 N., R. 47 W., on either side of Split Rock Creek; in Sioux Falls at the southeast corner of the small quarry east of Weber Avenue, just south of the Morrell Packing Plant; and in the small quarry just north of the road in Sec. 4, T. 102 N., R. 59 W., southeast of Mitchell.

The absence of cement is probably due to weathering processes, which have locally removed the silica cement. In some cases it may be due to non-deposition of the cement. In comparison with the total amount of quartzite exposed at the surface, the volume of rock from which the cement has been leached is insignificant. Even in the localities mentioned the volume of weathered quartzite is small compared to the total volume exposed. One can study a number of exposures in detail before finding weathered patches. By and large, the leaching and removal of cement is restricted to the walls of the joints or cracks in the rock, where surface water has seeped through and been channelized. It is not known to what extent the cement has been leached below the surface. In all the quarries and exposures observed the leaching tended to be either more abundant at the surface than several feet down or unrelated to the surface; no downward increase in leaching effects has been noted in the hundred feet or so of maximum relief on the quartzite.

### Color and Impurities

The color of the quartzite is commonly pink or red, but it can vary over a considerable range. Some exposures are nearly gray or white, with only a faint pinkish cast, and others are nearly black. A dark reddish purple is common, and in some places the fresh rock has an orange tint. Study of the rock under the microscope shows that the color of the quartzite is due to the presence of thin films of iron oxides coating the grains of quartz (4). Slight variations in the amount and nature of the coating can result in noticeable variations in the color of the rock. Chemical analyses of the quartzite show that the iron forms less than 3% of the rock and commonly about 1-2% (8, p.151).

Some horizons of the quartzite contain relatively large amounts of alumina. Winchell (10, p.198) quotes an analysis of a sample taken from the quartzite at Pipestone, Minnesota:

Table 1

SiO <sub>2</sub>	84.52%	CaO	0.31%
Al <sub>2</sub> O <sub>3</sub>	12.33%	MgO	Trace
Fe <sub>2</sub> O <sub>3</sub>	2.12%	K <sub>2</sub> O	0.11%
H <sub>2</sub> O	2.31%	Na <sub>2</sub> O	0.34%

The alumina is present as an aluminum silicate, and according to Berg (2, p.267), who studied in detail samples from the same quarry, the quartzite probably originally contained many grains of detrital feldspar in addition to the quartz grains. Feldspar is an alkalic aluminum silicate and is an important component of granites; therefore, the feldspar grains in the quartzite would indicate erosion of a granite mass. Feldspar is the probable source of much of the aluminous impurities in the Sioux formation, but an original clayey sand would also give a quartzite high in alumina. Feldspathic beds are exposed along the East Fork of the Vermillion River, particularly in Sec. 35, T. 101 N., R. 53 W., and are perhaps not uncommon in other outcrops west of Minnehaha County. The great bulk of the Sioux quartzite is not feldspathic but is essentially pure silica with some iron oxide.

### Conglomeratic Beds

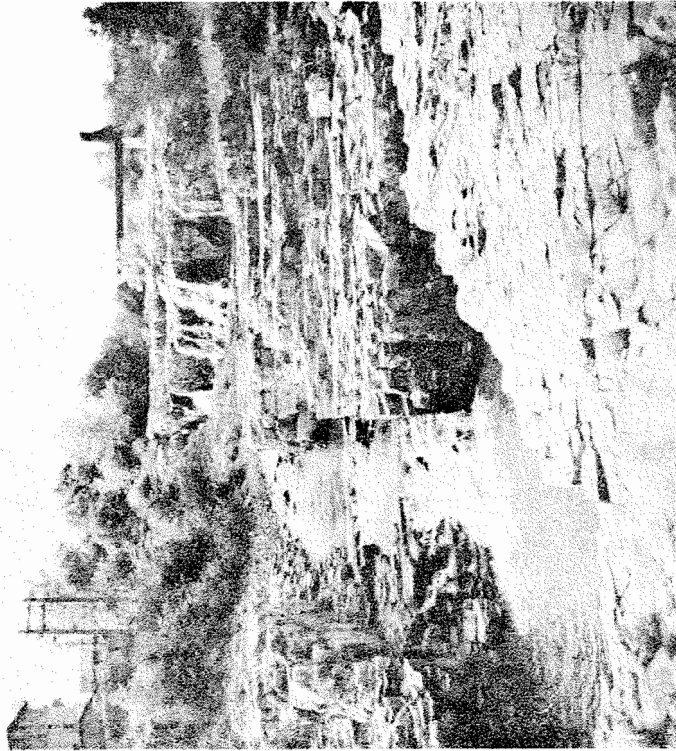
Although the greater part of the Sioux formation consists of fine-grained quartzite, a number of outcrops show seams and beds of coarse-grained quartzite. These beds represent the accumulation of coarse sands and gravels.



**Figure 3 B**

**MUD CRACKS**

**A BEDDING SURFACE AT THE FALLS,  
SIOUX FALLS.**



**Figure 3 A**

**THE FALLS AT SIOUX FALLS**

**LOOKING SOUTH. BEDS DIP 4° SOUTH.  
NOTE THE BLOCKY JOINTING.**

In the series of exposures from Sherman southward to Garretson along Split Rock Creek, one can observe much coarse-grained quartzite. In the northwest quarter of Sec. 8, T. 103 N., R. 47 W., for instance, the larger particles are 1/3 to 1/2 inch in diameter. This is the coarsest grained material outcropping in South Dakota. White and colorless crystalline quartz forms most of the pebbles, but some pebbles consist of altered cherty material and a very few are pebbles of fine-grained siliceous sandstone or quartzite. The pebbles are generally subangular in shape. They form about half of the rock, the matrix being fine-grained silica-cemented sandstone and quartzite. In the southern half of the section the rock is fine- to medium-grained with a few seams of coarse-grained sand. The remainder of the beds that are exposed along the course of the creek are fine-grained, with a few thin coarser-grained seams.

In other areas besides the Garretson section, coarse-grained beds and seams have been noted. Some of these include the exposures near Dell Rapids in the southeast quarter of Sec. 11, T. 104 N., R. 49 W.; the exposures along the East Fork of the Vermillion River from Sec. 14, T. 101 N., R. 53 W. south to the south half of Sec. 28, T. 100 N., R. 53 W.; and the exposures in western Hanson County in Secs. 4 and 9, and in Sec. 21, T. 102 N., R. 59 W.

#### Shale and Pipestone Beds

During the general period of deposition of thick beds of fine- to coarse-grained quartz sand there were several times when clay and silty clay were deposited. These very fine-grained layers have been hardened and perhaps altered to form shale, and in some instances pipestone, in layers varying from less than an inch to about thirty feet in thickness. These beds are characteristically thin-bedded and soft. They range from pure quartz siltstone to pure clay pipestone. Most of the beds have at least a small amount of quartzose silt, which may be detected by a very fine gritty feel between the teeth. The pipestone-like quality of several of the shale beds seems to be due to a chemical alteration of somewhat unusual sediment containing much alumina. The following analyses indicate the composition of pipestone or "catlinite". Sample 4 was taken at the Palisades, South Dakota, and the other samples were taken at Pipestone, Minnesota. Sample 1 is the original "catlinite", collected by George Catlin in 1837.

	1	2	3	4	5
SiO <sub>2</sub>	48.20	57.43	58.25	50.40	49.01
Al <sub>2</sub> O <sub>3</sub>	28.20	25.94	35.90	33.30	35.17
Fe <sub>2</sub> O <sub>3</sub>	5.00	8.70	-----	2.80	3.06
FeO					none
MgO	6.00	-----	-----	0.17	0.23
CaO	2.60	-----	-----	0.60	0.05
Na <sub>2</sub> O					.06
K <sub>2</sub> O	-----	-----	-----	4.10	5.62
MnO	0.60	-----	-----	-----	
H <sub>2</sub> O $\neq$	8.40	7.44	6.48	9.60	5.63
H <sub>2</sub> O —					0.24
TiO <sub>2</sub>					0.44
Ig, less total H <sub>2</sub> O					0.24
	-----	-----	-----	-----	-----
	99.00	99.51	100.63	100.97	99.91

Analyses:

- 1-4, Geology of Minnesota, Vol. 1, page 542.  
5, Berg, E. L., American Mineralogist,  
Vol. 23, 1938, page 261.

The color of the shale and pipestone beds ranges from red to purple and blue and is due to finely disseminated iron oxide. In zones next to joints and cracks water has leached out the iron oxide and bleached the color to cream or white. Circles of bleaching  $\frac{1}{4}$  inch or less in diameter give the rock a somewhat spotted appearance.

The shale and pipestone beds are soft and do not form prominent outcrops. For this reason, outcrops are few and it is difficult to determine whether any two outcrops are parts of the same horizon. At least four different horizons have been found in the Palisades section of Split Rock Creek (Fig. 2). The lowest one outcrops on the southeast bank of the creek, a

few hundred feet south of the bridge, in the northeast quarter of Sec. 31, T. 103 N., R. 47 W. This bed is probably the one represented by Analysis 4, above. The shale is of pipestone quality, red in color, but commonly bleached to cream. Its thickness is at least 8.5 feet and perhaps several times that much. A water well drilled on the hill above went through quartzite to a depth of 94 feet and ended at 106 feet in 12 feet of pipestone. This horizon is overlain by a thick ledge of quartzite which forms the lower Palisades. Downstream less than half a mile, in the middle of the section, a second thick bed of shale overlies the quartzite. This second shale is red-brown to bluish in color. It is sandy and contains shiny flecks of white mica, which led prospectors to dig a shaft for silver. Mud cracks, ripple marks, and other sedimentary features indicate a shoreline and shallow-water environment. The shale is more than 30 feet thick and is overlain by a six-foot ledge of quartzite, which is in turn overlain by another pipestone-like horizon with a minimum thickness of 5 feet (7, p.11). The fourth layer of shale is found along the railroad embankment in the southeast corner of Sec. 36, T. 103 N., R. 48 W. This shale is about 4 feet thick, and is characterized by shallow-water features, such as ripple marks, mud cracks, and clay galls. Much of the shale is quartzitic, and some seams contain no clay at all.

Shale and pipestone beds also outcrop in other parts of Minnehaha County. Northeast of Hartford near the center of Sec. 11, T. 102 N., R. 51 W., a minimum of eight feet of gritty, blue to purple, "spotted" shale is exposed on the east bank of Skunk Creek. In Sioux Falls shaly beds are exposed on Cliff Avenue, a few hundred feet south of Rice Street, and thin seams of shaly quartzite were found in the sewer ditches three or four blocks southeast of the athletic park. A mile south of East Sioux Falls and a few hundred feet north of the south edge of Secs. 28 and 29, T. 101 N., R. 48 W., non-gritty purple-red shale at least 7 feet thick outcrops in a gully. North of Corson, in the southeast quarter of Sec. 10, T. 102 N., R. 48 W., a blue-gray, hard silty shale at least 8 feet thick forms the north bank of Split Rock Creek. Shale beds outcrop in Minnesota, the best known being the horizon quarried by the Indian tribes at Pipestone, Minnesota.

#### Age

The age of the Sioux quartzite cannot be determined directly because no fossils have been found in the formation, and the relationship with other formations is obscured by glacial debris. A well in Stanley County encountered the Sioux quartzite directly under the St. Peter sandstone (C. L. Baker, personal communication), which is lower Middle Ordovician. Therefore the Sioux

formation is Lower Ordovician or earlier; no other direct evidence is known. On indirect evidence the formation is probably pre-Cambrian in age. On the basis of lithology, absence of fossils, and gentle structures the formation has been correlated by some geologists with the Baraboo quartzite in Wisconsin, which is overlain directly by upper Cambrian sediments. Most writers have called the Sioux and the Baraboo quartzites Huronian in age. but the evidence for any assignment in age is very weak.

### Environment

The Sioux quartzite evidently accumulated as a series of water-laid sands that were deposited near the shore of an ancient shallow sea or large lake. The evenness in grain size of any one bed and the absence of anything but quartz grains indicate that the sands that accumulated were worked for a long time by water before being covered by more sands. No channeling, such as would be expected in stream deposits, has been noted, and the various primary features observed point to a marine or lake environment rather than a land environment.

Ripple marks are plentiful and they indicate that currents along the bottom of the water body were strong enough to pile up the sand grains in periodic tiny ridges and valleys, in much the same way as wind will pile up fine sand into ripples and dunes. Cross-bedding is also common. It indicates that currents were strong enough to transport a considerable amount of sand particles for a short distance, only to let the sand pile up on 20° to 30° slopes as the currents slowed down. Cross-bedding is usually limited to single beds a few inches to a foot thick, and these cross-bedded layers tend to be beveled on the top by another erosion surface on which sedimentation is horizontal rather than cross-bedded. Many individual cross-bedded layers may be traced for a hundred feet or more, if exposures permit, but due to the homogeneous character of the beds, it is difficult to follow a certain horizon for any distance on a good exposure. No attempt was made to determine if there is a preferred direction of the cross-bedding, although there does seem to be considerable variation in adjacent beds.

Mud cracks form a third type of primary sedimentary feature. These are shrinkage cracks that result from the drying out of mud or very fine sand. They are preserved by being filled with a coarser or finer textured sediment. Mud cracks thus suggest an environment in which the sediments were first under water and then exposed to the air and finally submerged under water again. This sort of environment might include a tidal flat or other shore zone location, with the mud cracks being formed at low tide. Mud cracks are difficult to preserve because, with the re-advance of water over a mud cracked surface, waves are apt to erode the



surface instead of filling the cracks. Only the deeper cracks will be preserved, and these only by favorable conditions. Yet some ten or twelve sets of mud cracks have been found in Minnehaha County. Three sets can be found southwest of Garretson in the southeast quarter of Sec. 19, T. 103 N., R. 47 W. The mud cracks occur on three separate bedding planes in the outcrop a hundred yards north of the road and on the east side of Split Rock Creek. Another set of mud cracks occurs at the falls in Sioux Falls, on the west side of the small gorge, just south of the telephone line.

## STRUCTURE

### Warping

The sediments are laterally extensive and have been gently warped and tilted and jointed at some period in the past. The amount of dip of the beds varies from 11 degrees at some exposures to flat-lying at others, but averages about 3 or 4 degrees. The direction of dip is even more variable. In the northeast part of Sec. 29, T. 101 N., R. 48 W., the beds dip south, but in the southeast corner of the same section the beds dip to the north. In the western part of Sec. 28, the dips are generally westward, showing that the structure here is a gentle trough plunging to the west. The directions of dip of the beds in other exposures in the area emphasize the pattern. In sections 14 and 15 the beds dip south, but at Rowena the dips are west-northwest, and south of Rowena, in sections 34 and 35, the dips are to the north-northwest. This sort of mild warping characterizes the structure of the quartzite, although in the area west of Skunk Creek in Minnehaha County the exposures are too poor to show integrated patterns.

Along Split Rock Creek, near Garretson, the Sioux formation is better exposed than in any other part of South Dakota. Considerable time was spent in studying the exposures along the creek between the southern part of Sec. 5, T. 103 N., R. 47 W. and the northern part of Sec. 1, T. 102 N., R. 48 W. Figure 2 is a stratigraphic section, which shows the main variations in the types of sediments exposed and which shows the general structure of the Sioux formation in this area.

The variations in types of sediments have been described in the preceding part of the report. The relationship of the various strata is shown in the columnar section in Figure 2. The thickness of the fine-grained quartzite units is estimated from the stratigraphic section, and the thickness of the other units was estimated and measured crudely in the field. The total thickness exposed along the creek is approximately 3000 feet, as deter-

mined from the cross-section. Since more beds possibly overlie those at the south end of the section and more beds probably underlie those at the north end, the thickness of the Sioux formation is probably considerably more than 3000 feet. It will be noted that about five-sixths of the part of the formation exposed near Garretson consists of fine-grained quartzite, and that, of the other units, the coarser beds are near the base of the section and the finer-grained shaly beds are near the top. The approximate levels at which mud cracks and ripple marks were found have been noted in the columnar section. These features probably occur at other levels, but the writer's impression is that they are rare or absent in the lower third of the section.

The structure was determined by a study of the attitude of the beds in the surface exposures. Several readings of the amount and the direction of dip of the beds were taken in each quarter or half mile of the creek's course. These readings were averaged to give the prevailing attitude of the beds for each mile section traversed by the creek. More than fifty readings were taken. The stratigraphic section was drawn along a line parallel to the direction of dip in each section. The beds in sections 8 and 17 dip nearly due south. The exposures in sections 20 and 19 are poor. Below section 19 the beds dip southwest. The amount of dip is recorded on the stratigraphic section, and in constructing the section the beds were projected below the surface parallel to these dips.

The Sioux quartzite forms a ridge that has an east-west trend and rises above the bedrock that occurs north and south of the quartzite. The distribution of exposures shows the east-west trend. Studies of the depth at which water wells encountered the quartzite were made by J. E. Todd (9) and his maps show that the quartzite bedrock surface slopes rather strongly northward down to the bedrock surface formed on granite and slopes more gently to the south. The direction of dip of the outermost exposures is toward the center of the exposure area. At Dell Rapids the dip is to the south and southwest, and at Parker the beds dip north. The beds in the western-most exposures, along the James River valley, dip to the east. North of Luverne, Minnesota, the quartzite dips west. These dips suggest that the ridge is a partly buried erosional remnant of a gently down-warped portion of the Sioux quartzite, which has been more resistant than the flanking bedrock. If this interpretation is true, the Sioux quartzite structure is an east-west trending syncline or group of synclines and can be compared with the well-known synclinal pattern of the Baraboo quartzite in Wisconsin.



Figure 4 A

PALISADES, SOUTH OF GARRETSON  
IN SEC. 31, T. 103 N., R. 47 W. LOOK-  
ING NORTHWEST. BEDS DIP 6° SOUTHWEST.  
NOTE THE PROMINENT VERTICAL JOINTING.



Figure 4 B

CONCRETE MATERIALS COMPANY QUARRY  
AT WEST SIOUX FALLS. VIEWED FROM  
THE WEST. BEDS DIP 5° SOUTH.

### Jointing

The quartzite is broken into blocks by well-developed jointing. Study of the joint trends in the area of exposures gives three trends: north 75-45° west; north 10° west to north 15° east; and north 55-70° east. These trends seem to maintain for the entire exposure area, although most of the readings were taken in Minnehaha County. The great majority of joints noted are within a few degrees of vertical, but a few oblique joints were noted. In addition, the quartzite breaks along nearly horizontal planes; most of these are bedding planes, but some are probably horizontal joints. In some outcrops there is no pattern to the joints, the distribution of directions being irregular. The joint pattern for any one outcrop can not be predicted on the basis of present information but must be determined in the field. The origin of the vertical joints is probably related to regional stresses and to the warping which gave rise to the gentle dips.

The spacing of joints is of prime importance to those interested in quarrying the quartzite, since it determines the maximum size of blocks available. The size of blocks obtainable is in many instances controlled by the number of trends in an area. Thus the presence of three directions of jointing should result in smaller blocks than the presence of only one or two directions. As observed in the field during the summer's preliminary study of exposures, the spacing of joints varied over considerable ranges. The quarries themselves tend to have the most closely spaced joints, evidently the result of shattering by dynamite during quarrying operations. There the joints may be a few inches apart up to a foot or two apart. Occasional large blocks measuring several feet in each direction may be seen on quarry floors. Exposures of quartzite may have joints every few inches, and commonly every foot or so.

### OVERBURDEN

#### Loess

The southeastern part of South Dakota is covered with a layer of loess, which is very fine-grained, wind-blown silt. Loess forms good soil. The thickness can vary from nothing to more than ten feet. No attempt was made in the last summer's reconnaissance to distinguish loess from glacial drift, and for purposes involving quarrying of quartzite, loess and glacial drift form similar types of overburden.

## Glacial Drift

In the area bounded by the known exposures the Sioux quartzite is covered by a varying thickness of glacial drift. Glacial drift consists of boulders, gravel, sand, and clay which were deposited as an uneven blanket or moraine when the ice sheets melted. Much of the surface of the quartzite is marked by glacial scratches. These were made by rocks in the ice sheet being dragged across bed rock and so they indicate the direction of glacial movement. The great majority of striations trend south 10-30° east.

Two ice sheets are known to have invaded this region (5). The older glacier, which has been called Kansan in age, presumably covered the entire area and when it melted some 100,000 years ago (5) the boulders, gravel, sand, and clay incorporated in the ice were left as a blanket of unconsolidated, unsorted glacial drift which obliterated the pre-glacial drainage. A long period of time elapsed, during which the drift was weathered to a soil, and streams succeeded in establishing a new drainage pattern, in places removing much of the drift. Long after the retreat of the older glacier a second ice sheet advanced over much of the same area. This younger glacier, Wisconsin in age, did not advance over the region east of Skunk Creek (Fig. 1). The Wisconsin ice melted some 20,000 years ago, leaving its blanket of glacial drift, which also obliterated former drainages. One can readily notice the difference between the area covered by the younger glacier and that covered only by the older. In the latter case, there is good drainage, no swamp land, and rather well-exposed bedrock. In the former area, however, the streams have not yet had time to etch a new drainage pattern nor to drain the swamps, and bedrock outcrops may be found only along some of the creeks.

From the blanket-like nature of glacial drift, one can feel safe in assuming that where a number of outcrops occur in a limited area, the glacial cover is thin. In the areas where outcrops are few and small, the depth to bedrock can be found by auger holes or drill holes.

## Pre-Glacial Overburden

In at least two areas another formation or type of material was deposited on top of the Sioux quartzite before the glacial drift. Along the East Fork of the Vermillion River, in southeast McCook County, white chalk is exposed. Outcrops of chalk may be seen just north and south of Highway 16, where it crosses the river. The chalk is probably the same formation that is exposed in Yankton. It is soft rock that readily rubs off on one's clothing and hands. It is made of calcium carbonate and so it will

react readily with hydrochloric acid to give off bubbles of carbon dioxide. Chalk is a variety of limestone and it may contain impurities of clay and quartz sand. As overburden it would be more of a problem than glacial drift because it is more compact.

In the vicinity of Corson in Minnehaha County there are three different formations of uncertain age that overlie the quartzite and underlie the glacial drift. A light gray semi-plastic gritty clay with occasional iron-stained and black patches may be found in a few small outcrops. In the northwest quarter of Sec. 23, T. 102 N., R. 48 W., in a gully just east of the railroad bridge, a minimum of five feet of clay directly overlies the quartzite. In the northeast quarter of Sec. 22, T. 102 N., R. 48 W., nearly a foot of gray clay overlies weathered diabase (3) and in turn is overlain by a white, siliceous, chalky-looking rock.

This white formation has been called a chalk (3, p.74), but a brief microscopic study suggests that the Corson "chalk" is a volcanic ash bed; its age is unknown. It rubs off readily on one's hands, as does the Niobrara chalk at Yankton but can be distinguished from chalk by two characteristics. First, it does not react with hydrochloric acid to give off bubbles of carbon dioxide. Second, it feels very gritty between the teeth, while true chalk has very little or no grit. Chemical analysis of the volcanic ash shows a very high silica content and low calcium content; this is in marked contrast with the Niobrara chalk at Yankton (7, p.13).

Table 3

	Yankton Chalk	Corson "Chalk"
SiO <sub>2</sub>	6.22%	80.5%
Al <sub>2</sub> O <sub>3</sub>	3.56	6.56
CaO	48.25	?
MgO	2.00	?
CO <sub>2</sub>	36.23	0.00

The volcanic ash is found in Secs. 22, 23, and 26, T. 102 N., R. 48 W. In the diabase area of section 22, as has already been mentioned, the ash overlies the clay and diabase. Farther downstream the ash is exposed in the southern third of section 23, where it is at least 12 feet thick, although in its upper part it grades into a denser, cherty rock. In the middle of section 26, both the ash and the overlying chert are exposed for a distance of some 700 feet on the east bank of the creek. The transition zone

here is about a foot wide and is marked by an indentation in the low cliff.

The chert is a compact, structureless, hard, light gray to white rock, marked by small holes and pits; it is composed of silica. South of the diabase outcrop in section 22, chert with a minimum thickness of 4 feet can be found on the west bank of the creek. In section 26 a minimum of four feet is exposed over the ash horizon. The origin of the chert is not known. The field occurrence of the chert, however, suggests that it is related to, and perhaps is an altered phase of, the ash.

The chert and the chalky-looking volcanic ash bed have an unknown lateral distribution. The chert would be a problem wherever it occurs as overburden, because it is abrasive and compact; the volcanic ash bed is softer and could be more easily handled. However, these two materials have been found only in the immediate vicinity of Corson, and quartzite exposures are poor in this area.

It is not expected that the overburden materials other than glacial drift will present a significant problem to those interested in quarrying the Sioux quartzite. Where exposures are poor, the thickness and nature of overburden should be ascertained by drilling before selection of a site for quarrying Sioux quartzite.

## ECONOMICS

### CHARACTERISTICS

Four quarries are producing quartzite on a large scale in South Dakota. The Concrete Materials Company is operating a quarry west of the city of Sioux Falls. The Dell Rapids Quarry Company is intermittently working a quarry on the southwest corner of Dell Rapids. On the east edge of Dell Rapids the L. G. Everist Quarry is producing quartzite. The Spencer Quarries, Inc., is in operation just southwest of Spencer. Quartzite has also been produced in the past 60 years and more from other quarries in South Dakota. The chemical and physical characteristics of the quartzite, although not unique, are unusual enough to warrant consideration of the many uses to which the quartzite has been and could be put.

The greatest bulk of the quartzite is composed of nearly pure silica, with less than three per cent of ferruginous and aluminous impurities. Three analyses show the uniformity of composition of the quartzite now being quarried (8, p.151).

Table 4

	1	2	3
Moisture	---		
Ignition loss	.03		
Silica (SiO <sub>2</sub> )	97.58	99.14	97.82
Alumina (Al <sub>2</sub> O <sub>3</sub> )	.31	.28	} 2.12
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> )	1.20	.50	
Calcium oxide (CaO)	.14	trace	
Magnesia (MgO)	.10		
Sulfur trioxide (SO <sub>3</sub> )	.13		
Soda (Na <sub>2</sub> O)	.10		
Potash (K <sub>2</sub> O)	.03		
Manganese oxide (MnO)		trace	
Total	99.62	99.92	99.94

1. Quartzite from Wisconsin Granite Co. Quarries, Sioux Falls, S. D., analysis by U. S. Bureau of Roads
2. Quartzite from Dell Rapids, S. D., analysis by U. S. Bureau of Roads
3. Quartzite from Spencer, S. D., analyzed by State Chemical Laboratory, Vermillion, S. D., by Guy G. Frary.

Since silica is soluble only in hydrofluoric acid and in strong alkaline solutions the rock is chemically inert and insoluble for most practical purposes. Silica is refractory and is the hardest common substance. The quartzite is formed of well-sorted quartz grains and cemented with silica, and it is therefore homogeneous, tough, non-porous, refractory, and highly resistant to abrasion. It has an attractive color and luster. Jointing has broken the rock into more or less rectangular blocks that vary in size over wide extremes. Crushed fragments of quartzite have an irregular angular shape. The following table indicates some of the physical characteristics of the rock: (8, p.149)



Table 5

	1	2
Specific Gravity	2.73	2.66
Weight per cubic foot in pounds	170.	166.
Water absorbed per cubic foot	.18% (.30 lbs.)	.04% (.07 lbs.)
Per cent of wear	2.3	2.5
French coefficient of wear	17.4	16.0
Hardness	18.7	18.7
Toughness	17.0	20.
Cementing value	36.380	-----
Crushing strength (lbs. per sq. in.)	-----	51,700

1. Quartzite from Wisconsin Granite Quarry, Sioux Falls, South Dakota
2. Quartzite from L. G. Everist Quarry, Dell Rapids, South Dakota

Tested by U. S. Bureau of Public Roads; A. T. Goldberg,  
Engineer of Tests

In the field one can readily observe the durability of the Sioux quartzite. The scratches made by boulders in the Wisconsin and older ice sheets are well preserved on many of the outcrops of fresh quartzite. This evidence indicates that there has been no appreciable weathering of the rock surface since the time the scratches were made. The Wisconsin ice sheet began to melt back from the area under discussion some 20,000 years ago. In the area east of Skunk Creek there was no younger glaciation, and so the glacial scratches in this area are much older and may have lasted for 100,000 years or more. Much of the time there may have been a cover of glacial debris protecting the quartzite surface from intense weathering, but none the less one must be impressed by the durability of the stone. This resistance to weathering is important in quarrying the quartzite. Glacial overburden may have to be removed, but no waste due to weathering should be encountered in the upper few feet of the quartzite.

It has been pointed out (2) that some beds in the Sioux formation contain considerable amounts of alumina, due to clay or to feldspar grains in the original sediment. Beds containing feldspar grains and those containing clay occur in South Dakota, but they do not form a large part of the formation. The chemical and physical properties of quartzite with aluminous impurities are in-

DETAILS OF THE CONGLOMERATIC BEDS NORTH OF GARRETSON  
NW  $\frac{1}{4}$  SEC. 8, T. 103 N., R. 47 W.

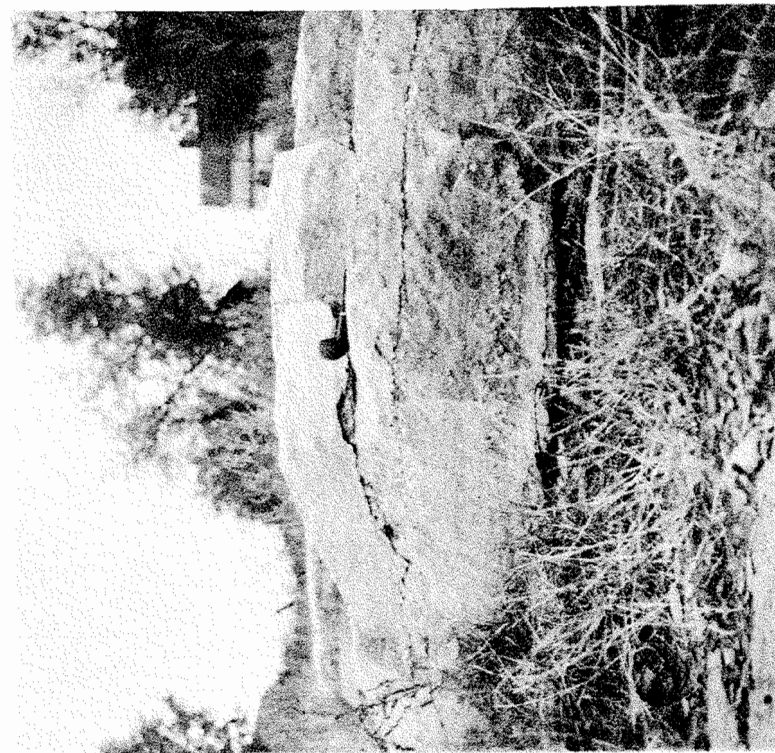


Figure 5 A

A VERTICAL SURFACE AT RIGHT ANGLES TO BEDDING. SHOWS THE CONCENTRATION OF PEBBLES IN THIN SEAMS. VIEWED FROM THE NORTH. BEDS DIP 90° SOUTH.



Figure 5 B

VIEW OF BEDDING SURFACE. MAJORITY OF THE PEBBLES ARE  $\frac{1}{2}$  INCH OR LESS IN DIAMETER, AND ARE COMPOSED OF QUARTZ AND CHERT.

ferior to those of pure quartzite. The uses of the impure quartzite are limited to rip-rap and possibly concrete aggregate. The following discussion of uses of the Sioux quartzite refers to the purer form of quartzite such as is being quarried at present.

## USES

Most stone products are cheap commodities that are used in large volumes, and so shipping and handling charges form a large part of their cost. Therefore a stone industry tends to have its local markets protected from competition by outside industries, even though it may be difficult for its products to compete in outside markets. The importance of the transportation charges is particularly great in something like concrete aggregate and rip-rap. In these two products the Sioux quartzite has a market that is large in area, since competing material must come from Minnesota, Wisconsin, Missouri, central Iowa, or the Black Hills. For stone products that are characterized by quality, such as gannister, grinding pebbles, and tube mill liners, transportation costs are a smaller factor, and so the Sioux quartzite can compete with outside markets on the basis of quality of product.

The uses of the Sioux quartzite can be divided into two main groups: the first group involves quartzite used in blocks of large or small size; the second group involves quartzite that has been crushed and sized.

### Quartzite Blocks

Blocks of quartzite that may or may not be trimmed to desired shapes and sizes have been used as building stone, paving blocks, monumental stone, tube mill liners, grinding pebbles, and rip-rap.

### Building Stone

The Sioux quartzite has been used extensively in the past for building purposes. At the end of the 19th Century, many stone cutters came from Great Britain to aid in quarrying and trimming the blocks. Much of the building stone came from the now-abandoned quarries at East Sioux Falls and Rowena. The homogeneity, attractive appearance, and extreme resistance to weathering have made this a popular building stone in the past, and many buildings in eastern South Dakota and neighboring states are made of the quartzite. N. H. Winchell (10, p.199) rates a sample of impure quartzite from the Pipestone Quarry in Pipestone, Minnesota as 87%, compared with the various relative assets of other Minnesota building stones, and only three Minnesota stones rated higher

(90%). The principal disadvantage of the quartzite as a building stone is the difficulty of trimming blocks to the desired shape. The rock is too hard to permit sawing to desired dimension. Even where jointing is favorable, some trimming is needed to supply dimension stone. With the competition of softer types of building stone and with rise in the cost of labor, Sioux quartzite has fallen into disfavor as a building stone.

### Paving Blocks

At one time quartzite paving blocks were produced for use in many of the large cities in the central United States. The durability of the rock in the face of both chemical and physical attack made the quartzite well-suited for the purpose. With the increased use of concrete for road surfacing, paving blocks have become a thing of the past, although some streets paved with the quartzite are still being used after 40 years.

### Ornamental Stone

Minor amounts of quartzite are used in monumental work. The extreme resistance to weathering and the appearance are favorable properties. The quartzite will take a high polish and has been used successfully as monumental stone, polished corner stones, wainscotting, and turned pillars.

### Tube mill liners and grinding pebbles

The quartzite is well suited for uses as lining blocks and grinding pebbles in tube mills because it is composed almost entirely of silica, which is less soluble and harder than any other common substance. The quartzite is tough and homogeneous and so it wears by attrition rather than by chipping. Thus quartzite grinding pebbles for use in ball mills have a long life and do not contaminate the material being pulverized.

None of the rock quarried in South Dakota is being used for this purpose, but the Jasper Stone Co. in Jasper, Minnesota, has been operating successfully for years producing both linings and grinding pebbles. These products are used in tube mill operations for grinding ores, cement, feldspar, and other materials.

### Rip-rap

Rip-rap consists of large, more or less regularly shaped blocks of rock and it is used to face bridge abutments, earth dams, river banks, railroad embankments, and other surfaces where erosion by rapid currents is a problem. In view of the present construction of the long earth dam at Fort Randall, South Dakota, and in view of the proposals for construction of other earth dams

along the Missouri River, the possibility of using Sioux quartzite for rip-rap must be considered seriously. Great volumes of rip-rap are needed to cover and protect an earth dam against erosion and against slumping due to lowering of the water level.

The quartzite has several advantages and one disadvantage. The disadvantage is that in most of the outcrops the maximum size of blocks is limited by the jointing to one or two feet on a side. However in some outcrops, such as at Dell Rapids, jointing is more widely spaced, permitting removal of blocks several feet on a side. The advantages of using the quartzite for the Fort Randall dam, and possibly other dams in the state include the durability, the rectangular shape of the blocks, and the short transportation necessary. Jointing commonly is rectangular, and so regularly shaped blocks can be obtained. These will be easier to fit together than irregular blocks from other types of rock. In addition, the quartzite is essentially indestructible; erosion and weathering do not affect the rock. The most important advantage of the quartzite is its nearness to the Fort Randall dam site. Rock outcrops in Hanson County are 60 miles from the dam site, those at Sioux Falls are 100 miles away, and those at Dell Rapids are 120 miles from Fort Randall. The nearest exposures of other types of rock are 200 miles away (Milbank granite) or more (Black Hills granites). Out of state rip-rap would have to come far greater distances, from Minnesota, Wisconsin, Missouri, central Iowa, or the Rocky Mountains. Thus transportation costs will be a strong factor in determining the source of the rip-rap used at Fort Randall and other earth dams along the Missouri, and the use of Sioux quartzite for at least the Fort Randall dam is greatly favored by its location. Rip-rap for uses other than earth dams can be in smaller blocks. The South Dakota quarries supply abundant rip-rap for local use.

### Crushed Products

Crushed and sized quartzite has many uses. The most important ones are listed below, with the requirements for each. It will be seen that for most of these uses the quartzite is very well suited, and that for glass sand, the quartzite comes very close to the requirements.

#### Crushed Stone

Crushed stone is being produced in considerable amounts for concrete aggregate, road metal, and railroad ballast. The size desired varies with the exact use and specifications from coarse sand to pieces two inches in diameter. The crushed quartzite is hard, tough, sized, and generally durable.

### Filter Beds

The quartzite is excellent for filter beds in water supply or sewage disposal plants because it is insoluble, clean, can be properly sized, and is lasting.

### Engine Sand

Crushed quartzite can be used for engine sand to provide traction for locomotives, trolleys, trucks, and busses, because it is hard, tough, angular, and can be screened to the desired size.

### Abrasives

Sand used for sand-blasting, stone-polishing, and other abrasive work should be very hard, tough, sized, and sharp. Crushed and screened quartzite meets all these requirements.

### Poultry Grit

The hardness and angularity of crushed and sized quartzite make it a good material for poultry grit, and being insoluble it has an advantage over limestone grit.

### Foundry Sand

Foundry sand must be sized, refractory, cohesive, and permeable. Crushed and sized quartzite bonded with controlled amounts of clay will make excellent foundry sand.

### Filler

Pulverized quartzite will make an admirable filler for many products. It is inert and will add weight, hardness, and toughness to such products as plastics, asphalt, plaster, and roofing materials.

### Silica Brick

Silica brick or "gannister" is used as a refractory lining in copper reverberatory and refining furnaces and in acid metallurgical furnaces. It must be highly resistant to temperatures above 1500°C., it must not react with the material being heated, it must be strong enough to bear the weight of the charge, and it must be capable of being molded into bricks. Crushed quartzite bonded with small amounts of lime has been used for this with success.

## Ferro-Silicon

Ferro-silicon is used in considerable quantities in the steel industry to deoxidize and degassify the melt and to improve the quality of the steel. The silicon content in 1944 (6, p.573) ranged from 9 to 95% and averaged 31.2%. Coke and electricity are required in large amounts to produce ferro-silicon. Sioux quartzite has been shipped to Keokuk, Iowa, where hydroelectric power is available for the production of ferro-silicon.

## Glass Sand

Glass sand requires a high degree of purity, and the more important sources in the United States run above 99% SiO<sub>2</sub>. The impurities, particularly iron and aluminum, must be low. The quality of the quartzite approaches the required grade closely enough to warrant consideration of its use as a glass sand. The impurities in the Sioux quartzite are the very ones that are considered harmful, however, and so it would probably have to be purified somewhat before being acceptable.

## POSSIBLE QUARRY SITES

### Selection of Quarry Sites

The selection of a good site for a quarry in the Sioux quartzite should be dependent on several factors: the quality of the rock, the geology, the location, the market for the products, and the kinds of products.

The quality of the rock must be determined by chemical and physical tests, but a general idea of the quality can be obtained by examining exposures. The quartzite should be fine-grained and even-bedded, and no shaly beds should be present. Any one bed will tend to remain constant in composition, so samples for analysis should be taken in the successive beds to be quarried rather than in any one bed. Iron will probably analyze about 1-2%, but alumina should be less than 1% in all beds if the rock is to be used for chemical or refractory purposes.

Physical tests should be made on the rock, but inspection of exposures will ordinarily suffice to tell whether the rock is suitable. If the rock is well-cemented, it will have high crushing strength, high resistance to abrasion, and low porosity. If the rock is poorly cemented, quarrying and crushing is easier, but, although a large proportion of fine sand can be produced, the production of coarser materials is limited.

A study of the structure of the exposures will give information on the spacing of jointing and on the dip of the beds. Widely spaced and poorly developed joints are best for rip-rap or dimension stone, and closely-spaced joints are best for most other products. The dip of the beds can perhaps be used to advantage. By working up the dip, water will drain away from the working face. In addition, the dip could be used to aid in removing large blocks with a minimum of explosives. The disadvantage of working up the dip is that in most places this requires more capital at the start, since the quarry pit must be worked downward before a working face is made. The simplest method of beginning a quarry is to quarry a ledge that is naturally exposed and to work into a hill. This method gives a working face from the start, but it ordinarily requires working down-dip.

Overburden may be a problem in two ways. The exposures may be poor, in which case the chemical and physical nature of the quartzite must be determined largely from drill holes, and the nature of the jointing can not be determined. In addition, removing the overburden may be costly. Even where the overburden is thin or has been removed, it would be advisable to wash the working face and surface with water to remove the clay impurities in the overburden. This will ensure the purity of all sizes of crushed products, permitting the fines to be produced for gannister and ferro-silicon.

Topography is important both in regard to ground water and to accessibility of the quarry. Where the working face extends below the level of ground water, water will seep in, presenting a problem unless the quarry is self-draining. A quarry opened by a stream may also have this problem of flooding. If the quarry is opened in a low area flanked on all sides by hills, it may be costly to get the products to the railroad, whereas a quarry located in a flat area will not have this problem. The location in relation to the railroad and to the markets is important, because transportation charges form much of the cost of stone products.

The main kinds of products to be obtained from a quarry and their markets should be established in advance, because in some instances the quality of the quartzite is important, and the market and competition will be strong economic factors in determining the success of the industry. Perhaps the best plan would be to produce the largest blocks possible for rip-rap, putting the waste through crushers and screens to obtain all sizes of crushed quartzite. Even the finest material could be used as filler, a filter sand, gannister and perhaps ferro-silicon.

The following description of exposures is made in an attempt to indicate the more likely quarry sites. The descriptions include: the size of the exposure; the thickness of the beds





Figure 6 B

VOLCANIC ASH OVERLAIN BY CHERT

CENTER OF SEC. 26, T. 102 N., R. 48 W.  
THE NOTEBOOK IS AT THE CONTACT. HEIGHT  
OF THE EXPOSURE IS ABOUT 8 FEET.



Figure 6 A

SHALE OUTCROP

COOLEY FARM, CENTER OF SEC. 31,  
T. 103 N., R. 47 W. LOOKING SOUTH-  
WEST. BEDS DIP 6° SOUTHWEST. LOW-  
EST 10 FEET OF SECOND SHALY HORIZON.

exposed; the jointing, if it is significant; mention of impure or shaly beds; the distance to the nearest railroad; the approximate amount of overburden; and other factors that may have a bearing locally. The descriptions of the exposures are taken up in order by counties, which are divided into ranges, going from east to west. The ranges are in turn subdivided into townships going from north to south. The townships are treated by sections or by groups of exposures, and in some instances there is also a summary description of the exposures in any one area or township.

### Minnehaha County

#### Range 47 West

##### Township 103 North

Split Rock Creek--The quartzite is exposed along Split Rock Creek from the state line east of Sherman in section 3 to the west side of section 31. In section 3 there is one exposure within a hundred yards of the state line. Downstream there are scattered intermittent exposures in sections 3, 4, and 5. The exposures in sections 8, 17, 19, 20, 30, and 31 are in the valley of Split Rock Creek and have been described in the discussion of the geology. Many good quarry sites are available. Coarse-grained quartzite is exposed in a gully in the northwest corner of section 16. The quartzite exposed in the middle of section 8 is poorly cemented, at least at the surface, and a large volume of easily crushed material is available for finely crushed silica products. The G. N. RR. runs parallel to the creek and so the distance to the railroad is a half mile or less.

Section 18--In the northwest quarter of this section, quartzite is exposed in a field. The outcrop rises nearly ten feet above the level of the field and is perhaps a hundred feet in diameter.

##### Township 102 North

Section 8--Quartzite is exposed in the northwest quarter of the section along the creek for a distance of about 500 feet. It is well jointed, and twenty feet or more of beds are exposed.

Section 21--Quartzite is well exposed in the center of the section for a distance of 500 feet, with more than 20 feet of beds exposed. Some pipestone fragments were found here and so it would be advisable to determine by drilling whether shaly beds are present below the surface before opening a large quarry. The outcrop is  $1\frac{1}{2}$  miles west of the G. N. RR.

Section 22--There is a small outcrop with little relief at the center of the west edge of the section. It is 1 mile west of the G. N. RR.

Range 48 West

Township 103 North

Sections 1 and 12--Quartzite is exposed along West Pipestone Creek where the creek crosses the road between sections 1 and 12. The length of outcrop is about  $\frac{1}{4}$  mile. The creek bed slopes approximately with the dip of the beds and so only a few feet of beds are exposed.

Section 9--Four or five small isolated outcrops with five feet of relief occur in the southwest corner of the section.

Section 11--Quartzite is exposed in a small outcrop with five feet of relief in a farmyard in the center of the east edge of the section. Quartzite is also exposed in the southwest quarter of the section and extends into the northwest quarter of section 14. The topography slopes with the dip of the beds and so only a few feet of beds are exposed. The outcrop area in these two sections is approximately 100 acres. Joints are well developed and close.

Section 12--Quartzite outcrops in the creek and in very small patches in the southeast corner. Relief is about 5 feet. (See section 1.)

Section 14--Quartzite is exposed in the northwest quarter and is an extension of the exposure in the southwest quarter of section 11. In addition, quartzite is exposed in the southwest quarter of section 14 in an intermittent outcrop less than a hundred yards long, in the creek bottom.

Section 15--Quartzite is exposed on the dry creek bottom in the northeast quarter of the section. The exposure extends about 200 feet into section 10. The length of exposure is about half a mile. Jointing is close and well-developed.

Section 16--Quartzite is exposed intermittently for a distance of half a mile in the creek in the southeastern quarter of the section. The relief is about five feet.

Section 23--Quartzite is exposed in the northeast quarter just south of the road and again in the southeast corner along the creek, and in intermittent patches in the western half of the section.

Section 35--A very small patch of shaly quartzite occurs on the section line road in the middle of the north edge of section 35.

Section 36--Part of the Split Rock Creek section occurs in the southeastern corner of this section. (See T. 103 N., R. 47 W.)

Summary--There are many exposures in sections 9, 10, 11, 12, 14, 15, 16, and 23. Even though few exposures are large in area the number of exposures in these 8 sections indicates that the overburden is thin. The topography slopes to the south as do the beds, and so the thickness of beds exposed is not great. Therefore, a drill hole would be necessary to determine the nature and quality of the quartzite before opening a quarry. In this area there are three well-developed trends of jointing and the joints are closely-spaced.

Rip-rap may not be available. The average distance to the G. N. RR. is about 3 miles.

#### Township 102 North

Section 1--The southern end of the Split Rock Creek exposures described earlier in the report and above in T. 103 N., R. 47 W. lie in the northern part of the section. The quartzite is evidently very close to the surface along the creek in the southern part of the section.

Section 11--A few very small patches of quartzite are exposed along the creek in the southwest corner of the section.

Section 10--Shale forms the north bank of the creek in the southeast corner of the section.

Section 15--Diabase is exposed intermittently along the creek.

Section 14--Quartzite is exposed along the railroad tracks in the southwest quarter. It is well-jointed, and about 30 feet of beds are exposed.

Section 22--Diabase, volcanic ash, and chert are exposed along the creek in the northeast quarter of the section.

Section 23--Quartzite is exposed along the creek in the northwest quarter and in the southern half of the section. Overburden includes clay, volcanic ash, and chert.

Section 26--Volcanic ash overlain by chert outcrops along the creek in the southern half of the section.

Summary--The only good quarry site in the township is in the southwest quarter of section 14. Overburden is limited to a thin cover of glacial drift and loess. The railroad tracks cross the outcrop. Drilling would be required to determine whether there are shale beds near the surface, because shales occur a mile north in section 10. Elsewhere in the township the quartzite is exposed only in small patches, and the overburden consists of several different types of material in addition to glacial drift and loess.

#### Township 101 North

Sections 14 and 15--Quartzite forms an east-west ridge  $1\frac{1}{2}$  miles long in the southern third of these sections. The beds dip south about  $8^\circ$  and are exposed on the north flank of the ridge. About 60 feet of beds are exposed. Joints are widely spaced and poorly developed. It may be possible to utilize the dip of the beds and the topographic relief to aid in removing large blocks with minimum use of black powder. This outcrop could supply large amounts of rip-rap. It is 2 miles from the I. C. RR., and overburden is thin.

Section 26--Quartzite has been quarried just west of Rowena. The quartzite is well jointed and has thin shaly seams.

Sections 34 and 35--Quartzite is exposed for about a mile in the southern half of these sections, just south of a dry creek. The outcrop is evidently part of a high area of quartzite that has very thin cover. The outcrops in section

26 and those in the corner of Iowa are evidently part of the same high area.

Sections 20, 28, and 29--Quartzite has been quarried extensively at East Sioux Falls in the very southeastern corner of section 20 and in the northeast corner of section 29. The same outcrop extends into the western half of section 28. The quartzite is exposed intermittently in the south part of sections 28 and 29 on either side of the section line, and a bed of pipestone-like shale can be seen below the quartzite. The quartzite in these sections is well jointed. The I. C. RR. tracks are less than a half mile from the quarries.

#### Range 49 West

##### Township 104 North

Section 11--Coarse-grained quartzite is exposed in the south part in a gully. Overburden seems to be thick. The outcrop has a poor topographic location and is not near a railroad. Outcrops in the vicinity of Dell Rapids are far more accessible.

Section 15--Quartzite is poorly exposed in two shallow gullies in the northeastern quarter of the section, less than 20 feet above the level of the Big Sioux River. Relief is low.

Sections 9 and 16--Quartzite is exposed over the north half of section 16 and in the southern part of section 9. The Dells, the two branches of the Big Sioux River, are cut deeply into the quartzite, with about fifty feet of quartzite exposed in some places. Overburden is thin to absent. The Dell Rapids Quarry Co. is working intermittently in the northwest corner of section 16. The C. M. St. P. and P. RR. passes around the quarry.

Section 10--The L. G. Everist Quarry is located in the south half of the section. Overburden is thin to absent, and jointing is closely spaced. The quarry is served by a short spur of the C. M. St. P. and P. RR.

Section 18--Quartzite is exposed for a distance of 1500 feet in a dry creek in the northwest quarter of the section. About 10 feet of beds are exposed. The railroad is nearly 2 miles east.

Section 32--Quartzite is poorly exposed at the town of Baltic. It immediately underlies the dam on the Big Sioux River. It is also exposed just east of town in a small gully that crosses the section line road between this section and section 5, township 103 north. The outcrop extends for two or three hundred feet north and south of the road. Overburden is thick. The railroad is less than a half mile west.

##### Township 103 North

Section 5--(See T. 104 N., section 32)

Township 101 North

West Sioux Falls--Quartzite is exposed in many small patches over much of the Big Sioux River flood plain. The overburden consists of river silts only a few feet thick. Two quarries, owned by the Concrete Materials Company, are located just west of the river at the bend in state highway 38. One quarry is in the southeast corner of Sec. 12, T. 101 N., R. 50 W., and the other is in the northwest corner of Sec. 18, T. 101 N., R. 49 W. In addition, there are small exposures in the southwest corner of Sec. 7 and in the southeast corner of Sec. 7. Several small outcrops can be seen along the south edge of Sec. 8, within the limits of the Airbase and at Covell Lake.

Sioux Falls--North and east of the business district there are several large exposures in the vicinity of the falls, and two quarries have been worked by the Wisconsin Granite Company. Although railroad facilities are excellent, real estate values discourage reopening any of the quarries.

Range 50 West

Township 104 North

Section 12--Quartzite is exposed for a third of a mile in a dry creek in the western half of the center of the section. The relief in the quartzite is about 10 feet. The overburden is perhaps as much as ten feet thick. The outcrop is about 4 miles from the C. M. St. P. and P. RR.

Township 102 North

Section 27--Quartzite is exposed in two or three small patches about 20' in diameter in the northwest quarter of the section.

Section 28--Quartzite is well exposed in a dry creek extending 1500' northwest from the center of the section. The rock is well-jointed and closely jointed in part. The outcrop is less than 3 miles from the C. St. P. M. and O. RR.

Township 101 North

Section 10--During the dry seasons a number of small patches of quartzite are exposed in Willow Creek, just east of Ellis and north of the railroad. The exposures are poor.

Sections 12 and 13--(See T. 101 N., R. 49 W., the description of the exposures of West Sioux Falls.)

Range 51 West

Township 103 North

Section 33--Two or three very small patches of quartzite appear in the west branch of Skunk Creek just north of the south edge of the section. Relief is less than 2 feet. The railroad is 4 miles south.

Township 102 North

Section 11--Quartzite and shale are exposed along Skunk Creek in the middle of the section. Shale forms part of the east bank, and the creek flows on bare quartzite. It appears that the soft shaly beds have been stripped from the quartzite by stream action. West of the creek the quartzite is exposed in patches isolated by a very thin cover of river silts. Jointing is not well developed. There is little or no relief on the quartzite and so a drill hole would be required to determine the nature of the underlying beds before this site could be chosen for a quarry. All quarrying operations would be below the level of Skunk Creek and this might present a serious water problem. The railroad is about 2 miles south.

Turner County

Range 53 West

Township 100 North

Section 7--Quartzite is exposed in a number of small patches along the East Fork of the Vermillion River. The largest outcrop is in the southeast quarter of the southwest quarter of the section where the quartzite is coarse-grained and probably analyzes high in alumina.

Section 28--Coarse-grained quartzite, probably high in alumina, outcrops for a quarter of a mile along the river in the south part of the section. It is evidently cross-bedded.

Township 99 North

Section 10--Quartzite is exposed in a small quarry or artificial reservoir in the southwest quarter of the section. The diameter of the shallow pit is about 40 feet, and the quartzite is exposed in only a small part of it.

Section 11--Quartzite is poorly exposed by the East Fork of the Vermillion in at least two places in the south half of the section.

Section 15--Quartzite is exposed for 600 feet on the banks of the West Fork of the Vermillion River in the northeast quarter.

Summary of Turner County--There are no good quarry sites in Turner County. Quartzite is poorly exposed along the East and West Forks of the Vermillion River. In several outcrops the quartzite seems to be high in alumina and therefore unsuitable for many uses of crushed quartzite products. The exposures are within a few feet of the river level and so quarrying would be complicated by water. The C. M. St. P. and P. RR. and the C. and NW. RR. serve Parker; and the distance to one or the other of these railroads is from less

than a half mile to over three miles.

### McCook County

#### Range 53 West

##### Township 101 North

Summary--Quartzite is exposed only along the East Fork of the Vermillion River. In section 14 a patch of medium to coarse-grained quartzite outcrops in the northern part near the road. A similar outcrop occurs in the southwest quarter of section 23. Quartzite outcrops in fields on either side of the road in section 26 and section 35. Both outcrops are small. The quartzite is medium- to coarse-grained and probably high in alumina. The outcrops are 3 to 5 miles from the C. and NW. RR. No good quarry sites were noted here, because of the evidently poor grade of quartzite, the poor exposures, and the problem of flooding by river water.

#### Range 56 West

##### Township 103 North

Section 19--(See section 24, T. 103 N., R. 57 W.)

##### Township 101 North

Section 21--Quartzite is well exposed in the center of the section along Wolf Creek. It is fine- to medium-grained and cross-bedded. It contains some clay and so probably will analyze high in alumina. Some of the rock is weathered and soft. About 30 feet of beds are exposed. The C. M. St. P. and P. RR. passes through the town of Bridgewater three miles east of the outcrop. This exposure does not offer a good quarry site because of the poor quality of the quartzite. The overburden, however, is thin over a rather large area.

### Hanson County

#### Range 57 West

##### Township 103 North

Sections 19 and 30--Quartzite is exposed in Pierre Creek for a quarter mile north and south of state highway 38. Overburden is very thin over a wide area, but there is little relief in the outcrop. A drill hole would be needed to determine the nature of the underlying beds before quarrying could be started.



Section 24--The Spencer Quarries Inc. is operating in the quartzite exposed in the northeast quarter of the section. It is served by a spur which joins the C. St. P. M. and O. RR. at Spencer. The quarry produces crushed rock and riprap. Overburden is very thin, and quartzite is exposed over a wide area, not only in the northeast quarter of section 24, but also in the northwest quarter of section 19, T. 103 N., R. 56 W.

Sections 25 and 26--Quartzite is exposed in Wolf Creek in the southeast quarter of section 26 and on the west edge of section 25. The exposures are not large, and less than 5 feet of beds are exposed. Overburden is probably thin between these exposures and those in section 24.

#### Township 101 North

Section 4--Quartzite is exposed in Plumb Creek.

#### Range 58 West

##### Township 103 North

Section 8--Quartzite is well exposed in Johnson Creek just northeast of Fulton, in the eastern half of the section. About 30 feet of beds are exposed and the overburden is thin. The C. St. P. M. and O. RR. is 1 mile south.

Section 15--Quartzite is exposed in four patches in the north half of the section. Each outcrop is small with less than 5 feet relief. This is the only group of exposures known west of Skunk Creek that is not related to a main drainage line.

Section 36--Quartzite is exposed in Pierre Creek for nearly a half mile in the northwest quarter of the section. There is no relief on the rock surface, and so drilling would be advisable before planning a quarry. Water would be a problem.

##### Township 102 North

Section 14--Quartzite is well exposed on the east side of Pierre Creek in the northwest quarter of the section, southeast of Alexandria. Jointing is rather widely spaced. Water would be a problem in quarrying. The C. M. St. P. and P. RR. is a quarter mile north.

##### Township 101 North

Sections 5, 6, and 8--Quartzite is widely exposed in these sections on the southwest flood plain of the James River south of Rockport Colony. The exposures cover nearly a quarter section in area and the relief is at least ten feet. The overburden is probably thin over at least another half section. The nearest railroad is 6 miles north.

Range 59 West

Township 103 North

Section 4--A small exposure less than 30 feet in diameter and with five feet of relief can be found in Rock Creek in the northeast quarter of the section. The quartzite is fine to medium-grained.

Township 102 North

Section 4 and 9--Medium to coarse-grained quartzite has been quarried in several pits in the southwest quarter of section 4 and in the northwest quarter of section 9. The quartzite is well-exposed in these sections, some 20 to 40 feet above the James River level. The alumina content of the quartzite might be appreciable, and so a chemical analysis should be made. Some of the quartzite is poorly cemented.

Section 21--In the northwest quarter of the section coarse-grained quartzite is exposed intermittently along Enemy Creek for nearly half a mile. The location is poor for a quarry site because the hills rise sharply on either side of the creek. Water would be a problem. The railroad is at least 6 miles away by road.

Summary of Hanson County--Quartzite exposures have little relief in this county, except for the outcrops at Fulton. For this reason drilling would be required prior to opening a quarry to determine the nature and quality of the quartzite below the surface. The exposures in Range 59 West are medium to coarse-grained and may contain harmful amounts of alumina for chemical uses. Because most of the exposures are along drainage lines, water in the quarry might be a real problem.

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