UNIVERSITY OF MINNESOTA

Minnesota Geological Survey

George M. Schwartz, Director

Summary Report No. 9

HIGH-SILICA SANDS OF MINNESOTA

by

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There are a number of pure silica sandstones associated with the sedimentary rock formation in east-central and southeastern Minnesota. They are interbedded with the limestones, dolomites and shales that characterize the subsurface geology of these areas. The sandstones are exposed extensively along the valley walls of the Mississippi, Minnesota and St. Croix Rivers and their major tributaries. Several of the sandstone formation crop out also on the divides between major drainage lines or they are covered with no more than a thin mantle of glacial sediments. Their composition and texture indicate that the silica sands of which they are composed could be used for various industrial purposes.

CLASSES OF HIGH-SILICA SANDS

Sands and sandstones may be classified many different ways. In industry they are generally classified according to use. The following classification of high-silica sands is adapted from that of R. W. Stone of the U.S. Geological Survey.

Blasting sand is clean, tough, sized sand with angular grains, used by means of compressed air for such purposes as cleaning metal castings and dressing or carving stone.

Brass sand is an exceedingly fine sand used in making molds for casting aluminum, brass, and bronze on which a very smooth surface is desired.

Burnishing sand is a clean fine-grained, tough silica sand with rounded and spherical grains. It is used in rolling down and burnishing gold decorations on chinaware and porcelain.

Core sand is a coarse molding sand used to make a solid form, usually porous to be placed in a mold, about which the metal is poured.

Facing sand is a molding sand used to make the face of the mold.

Filter sand is clean silica sand in sorted sizes, used for sand beds in water filtrations plants.

Fire sand is a highly refractory silica sand for lining furnaces and ladles used to contain molten metal.

Glass sand is the major constituent of glass, consisting from 52 to 65 percent of the original mixture. High-grade glass sands are over 99 per cent silica of medium fineness.

Grinding sand and polishing sands are sharp, tough, hard sands. They are generally sized and are used in sawing, cutting, and polishing stone and for grinding and etching glass.

Molding sands vary in testure and composition depends upon the kind of metal to be poured. They should be high-silica to be sufficiently refractory to withstand the heat of the poured metal.

There are many other uses for high-silica such as in pottery, porcelain, tile, etc.

TABLE 1. Ground sand and sandstone sold or used by producers in the United States in 1953, by uses

Use	Short tons	Value	
		Total	Average per ton
Abrasive:			
Cleansing and scouring compound	166,590	$1,296,908	$7.79
Other	7,275	46,306	6.37
Enamel	30,281	244,593	8.08
Filler	75,170	591,247	7.87
Foundry	84,927	759,594	8.94
Glass	9,503	90,489	9.52
Pottery, porcelain, and tile	263,810	2,488,638	9.43
Other uses[1]	32,471	266,283	8.20
Use reported, total	670,027	5,784,058	8.63
Use unspecified	110,614	1,029,343	9.31
Grand total	780,641	6,813,401	8.73

[1]-includes filter, paint, plaster, roofing, and sliding.

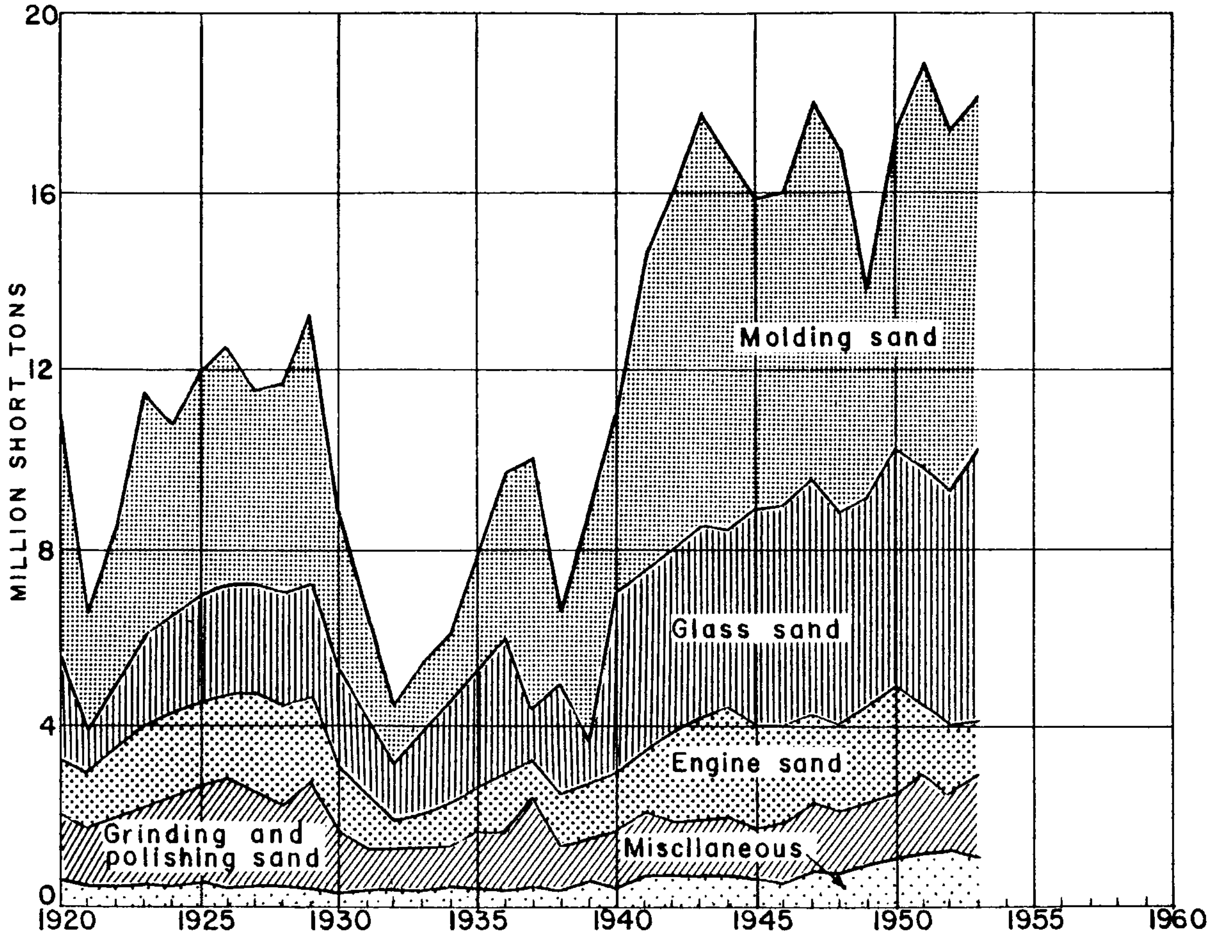


Fig. 1. Production of industrial sands in the United States, 1920-1953. Bureau of Mines Mineral Yearbook.

PHYSICAL PROPERTIES AND TESTS

For many of the uses listed above, specific physical and chemical properties are very important. The most essential properties may be listed as follows:

Color is an index of purity. Pure silica sand is white.

Cleanners refers to the relative freedom from clay, salt, and organic matter.

Grain size as determined by sizing on a series of standard sieves. Standard screen-opening ratios and methods of testing are specified for sands for various uses.

Effective size is the term used to denote the grain size of a sand in which 10 per cent of the grains are smaller and 90 per cent are larger than that size. The effective size is used in determining the uniformity coefficient and it serves also as an index of the coarsness of a sand.

Uniformity Coefficient expresses variation in grain size of a sand. It is determined from a cumulative percentage curve by finding the grain size compared with which 60 per cent of the grains are smaller and 40 per cent are larger. This grain size is then divided by the effective size and the result is the uniformity coefficient. If the coefficient is near 1.0 it indicates that nearly 50 per cent of the grains are of the same size, whereas, a coefficient of 5 or 6 indicates poor sorting.

Shape of grain varies from very sharp and angular to almost perfectly spherical. It is important for many uses.

Specific gravity of pure quartz sand is about 2.60 to 2.65. A lower or higher specific gravity denotes impurities.

Porosity depends upon the shape of grains. The relative proportion of grains of different sizes and the degree of compaction.

Refractoriness enables a sand to undergo high temperatures without fusing or breaking down. It is lowered by the presence of such fluxes as lime, magnesia, the alkalies and iron oxides.

SANDS FOR SPECIFIC USES

Glass Sands

Sand used in the manufacture of different grades of glass may range from high-silica sand containing but a very small percentage of iron oxide, to material with a lower percentage of silica and as much as 1 per cent of iron oxide. Proposed chemical requirements for various grades of glass as formulated by the American Ceramic Society are given in the accompanying table. For high-grade glass the sand must consist of pure quartz grains free from clay, organic matter and other impurities. The sand must be uniform in chemical composition and in size and shape of grains. It must not be coarser than 20 to 30 mesh nor finer than 100 to 120 mesh.

A minimum of iron oxide is desirable because of its coloring effect on the glass. Calcium and magnesium oxides are not objectionable if their content is small and the amount uniform. Alumina in the form of feldspar minerals may be present in small amounts. In fact as much as 0.25 per cent may be added if none is present in the original sand.

TABLE NO. 2. Proposed Chemical Requirements for Glass Sand (specification formulated by the American Ceramic Society in conjunction with the Bureau of Standards)

	Silica SiO_2 Tolerance	Silica SiO_2 Min.	Alumina Al_2O_3 Max.	Alumina Al_2O_3 Tolerance	Iron Oxide Fe_2O_3 Max.	Iron Oxide Fe_2O_3 Tolerance	Calcium and Magnesium CaO + NgO Max.	Calcium and Magnesium CaO + NgO Tolerance.
First Quality, Optical glass	± 0.1	99.8	0.1	± 0.05	0.02	± 0.005	0.1	± 0.05
Second Quality, Flintglass Containers and tableware	±0.5	98.5	0.5	±0.1	0.035	±0.005	0.2	±0.05
Third Quality, Flint glass	±1.0	95.0	4.0	±0.5	0.035	±0.005	0.5	±0.1
Fourth Quality, Sheet Glass, rolled & Polished plate.	±0.5	98.5	0.5	±0.1	0.06	±0.005	0.5	±0.1
Fifth Quality, sheet glass, rolled & Polished plate.	±1.0	95.0	4.0	±0.5	0.06	±0.005	0.5	±0.1
Sixth Quality, green glass, containers & window glass	±1.0	98.0	0.5	±0.5	0.3	±0.05	0.5	±0.1
Seventh Quality, green glass	±1.0	95.0	4.0	±0.5	0.3	±0.05	0.5	±0.1
Eighth Quality, amber glass containers	±1.0	98.0	0.5	±0.5	1.0	±0.1	0.5	±0.1
Ninth Quality, amber glass	±1.0	95.0	4.0	±0.5	1.0	±0.1	0.5	±0.1

TABLE NO. 3. Chemical Composition of Glass Sands.*

Source	Per cent					
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Ign. loss
1	99.405	0.21	0.075	0.072	0.068	0.17
2	99.82	0.12	0.017	Trace	Trace	
3	99.81	0.17	0.014	0.00	0.00	
4	99.607	0.16	0.021	0.05	0.03	0.08
5	98.6	0.17	0.230	---	Trace	

1. Crystal City, Mo.
2. Mapleton, Pa.
3. Hancock, W. Va.
4. Ottawa, Ill.
5. West Vienna, N.Y.

*U.S. Bureau of Mines Bull. 226.

Filter Sand

Sand is used by many municipalities to remove suspended mineral matter, bacteria and other organic matter from the public water supplies. The sand is placed in uniform layers over layers of sized, crushed stone or coarse gravel. High-silica sands are regarded as the best. The grains may be rounded or angular. Flat and cylindrical grains are undesirable. The sand must be free of dust and it should not contain more than 1 per cent finer than 0.13 mm and more coarser than 5 mm in diameter. A good filter sand should not contain more than 2 per cent by weight of lime and magnesium carbonates.

Foundry or Molding Sand

Foundry sand is an inclusive term for molding, core and steel sands. The sands may vary greatly in chemical composition and in grain size, uniformity, grain shape, and other physical characteristics, depending upon the mode of utilization. Entirely different types of sand are needed for the casting of brass, aluminum and steel. The principal requisites of a molding sand are cohesiveness, refractoriness, texture, permeability and durability.

Texture or size of grain is an important quality in foundry sand for it affects the cohesiveness and permeability as well as determining to some extent the size and weight of the casting that can be made and the character of the surface produced. Many foundry sands are designated by a grain fineness number which is the screen mesh that all the grains would pass if they were of uniform size. It is the weighted average fineness. The classification of sands by this method is given in the accompanying table.

TABLE 4. Grain Fineness Classification

Grain class	Sands with Grain Fineness Number
No. 1	200 to and including 300
No. 2	140 to but not including 200
No. 3	100 to but not including 140
No. 4	70 to but not including 100
No. 5	50 to but not including 70
No. 6	40 to but not including 50
No. 7	30 to but not including 40
No. 8	20 to but not including 30
No. 9	15 to but not including 20
No. 10	10 to but not including 15

At present less emphasis is placed on getting a perfact natural molding sand for each purpose. Sands for specific foundry practices are mixed to obtain the required size distribution and the bonding properties desired are obtained by adding calculated amounts of bentonite or other suitable bonding clays.

There are scores of ther used for high-silica sands. For a tabulation of many uses and the specifications, if any, for the sand, the reader is referred to Bulletin No. 53 of the Illinois State Geological Survey, by J.E. Lamar.

TABLE 5. Screen Scale Commonly Used In Industry

No.	Mesh	Opening in Microns	Opening in Inches	Approx. opening in Millimeters
20	20	840	.0331	.8
30	28	590	.0232	.6
40	35	420	.0165	.4
50	48	297	.0117	.3
70	65	210	.0083	.2
100	100	149	.0059	.15
100	Pan	-149	-.0059	-.15

STRATIGRAPHIC POSITION OF HIGH-SILICA SANDS

The high-silica sandstones of Minnesota are associated with the sedimentary rocks of Keweenawan, Cambrian and Ordovician ages. The following simplified classifications shows their positions in the succession of formations. (The oldest at the bottom).

Ordovician
- Maquoketa formation (shale and limestone)
- Galena formation (shale and limestone)
- Decorah formation (shale)
- Platteville formation (limestone)
- St. Peter sandstone (high-silica sands)
- Shakopee-Oneota formation (limestone)

Cambrian
- Jordan Sandstone (high-silica sands)
- St. Lawrence formation (shale, silt and sandy dolomite)
- Franconia formation (impure silica sands and silts)
- Dresbach formation (high-silica sands and silts)

Keweenawan
- Hinckley sandstone (high-silica sands)
- Fond du Lac beds (red sandstone and shales)

PHYSICAL CHARACTERISTICS OF SILICA SANDS OF MINNESOTA

Hinckley Sandstone

The geologically oldest high-silica sandstone in Minnesota is the Hinckley formation of Upper Keweenawan age. It crops out at many places along the Kettle River both to the north and south of the city of Sandstone in Pine County. The formation is approximately 150 feet thick and a vertical section of more than 100 feet is exposed in the old quarries in the banks of the Kettle River.

The quarry floor is higher than water level and drainage is therefore perfect and rock removal easy.

Section of Hinckley Sandstone in Quarries
West Bank of Kettle River, Sandstone, Minnesota

HINCKLEY SANDSTONE		Thickness (feet)
10.	Sandstone, very coarse, light yellow to buff and brown, cross-bedded, massive or thick beds.	10.0
9.	Sandstone, massive and coarse like that above, but with some fine-grained, thin beds. Good quarry stone.	10.0
8.	Sandstone, salmon-colored to brown, thin-bedded, ripple-marked massive, coarse, and cross-bedded at the base.	13.3
7.	Sandstone, thin-bedded, hard, fine-grained, red to yellow.	2.7
6.	Sandstone, massive, medium-grained, pink to buff and red. Good quarry stone.	18.0
5.	Sandstone, fine to coarse, pink to reddish. A 2-foot and 4-foot bed.	6.0
4.	Sandstone, massive, cross-bedded, light yellow to pink.	10.0
3.	Sandstone, coarse-grained, well-cemented, pink.	15.0
2.	Sandstone, massive to thin-bedded, ripple-marked, pink to buff.	8.0
1.	Sandstone, partly covered to level of Kettle River.	8.0
	Total	101.0

The sandstone is coarse to fine, mostly medium grained, yellowish to salmon pink and red, or nearly white. Textural analyses show that its sands are fairly well sorted. Table 6 gives a summary of its textural characteristics as determined on channel samples from the quarry face at Sandstone, Minnesota.

TABLE NO. 6. Summary of the Textural Characteristics of the Hinckley Sandstone

Stratigraphic Position (feet from top)	Textural Characteristics: Median Diam. in mm.	Coef. of Sorting	Coef. of Skewness	Effective size in mm.	Uniformity Coef.
0-10	0.290	1.40	0.97	.150	2.17
10-20	0.260	1.39	0.96	.140	2.15
20-30	0.385	1.25	0.95	.245	1.68
30-40	0.305	1.36	0.93	.145	2.37
40-50	0.315	1.37	0.88	.150	2.40
50-60	0.260	1.41	0.96	.140	2.15
60-70	0.315	1.36	0.99	.160	2.22
70-80	0.275	1.36	0.99	.140	2.21
80-90	0.310	1.17	1.02	.180	1.94
Average	0.302	1.40	0.97	.161	2.14

The sandstone is well cemented. The cementing material is principally silica and many of the quartz grains of the original rock have been enlarged by secondary quartz showing crystal faces. The rock, however, is still granular and upon crushing breaks along the faces of the grains instead of through them. The subangular shape of the grains and their roughened surface offer good attachment for the bonding materials used in foundry practices.

The Hinckley sandstone is not exposed at the surface in the area south of Kanabec and Pine Counties and to the south of the Twin Cities it is deeply buried under the Cambrian and Ordovician rocks. Deep wells have penetrated it as far south as Rochester and Mankato.

Dresbach Sandstone

The Mt. Simon sandstone is the basal member of the Dresbach formation. It is a coarse to white to pink and brown sandstone with some quartz pebble horizons. Thi member is from 75 to 250 feet thick. Along the Mississippi River from Winona southward this sandstone generally rests on the Precambrian granites and related rocks, but northward and westward from Winona it lies on the Hinckley sandstone. Its outcrops in Minnesota are confined to the valley of the St. Croix River and its tributaries above St. Croix Falls. In the area north and south of Mankato, where the younger Cambrian and Ordovician rocks have been removed by erosion, the Mt. Simon is covered by a thick mantle of glacial drift. Its textural composition is shown in Table No. 7.

TABLE 7. Summary of the Textural Characteristics of the Mt. Simon Sandstone

Stratigraphic Position (feet from top)	Textural Characteristics				
	Median Diam. in mm.	Coef. of Sorting	Coef. of Skewness	Effective size in mm.	Uniformity Coef.
		Well No. 1*			
325-331	0.37	1.26	1.31	0.214	1.64
331-370	0.29	1.47	1.07	0.203	1.42
490-520	0.34	1.19	0.97	0.241	1.27
520-525	0.24	1.31	0.87	0.142	1.41
525-527	0.34	2.30	2.21	0.103	3.78
527-530	0.24	1.42	1.03	0.101	2.47
530-531	0.31	1.68	0.96	0.179	1.03
531-535	0.31	1.48	1.00	0.164	1.37
535-630	0.25	1.37	0.98	0.141	1.08
630-670	0.33	1.52	0.77	0.224	1.43
670-693	0.23	1.42	0.95	0.104	1.12
Average	0.295	1.49	1.09	0.165	1.63

* From drill cuttings, Montrose city well.

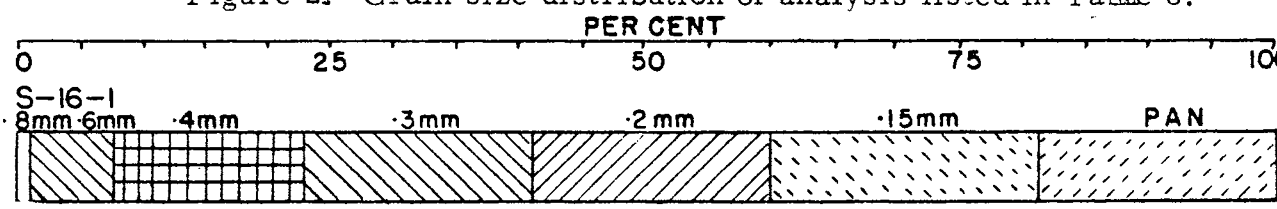
The name Eau Claire is given to the middle member of the Dresbach formation. It is a fine-grained, gray to greenish-gray buff sandstone with beds of green to reddish shale. This portion of the formation is from 25 to 250 feet thick. It crops out in Winona and Houston counties along the Mississippi River and its tributaries. Several exposures were sampled for textural analyses.

1. Near Hokah in the south wall of Root River valley, a channel sample was taken 1/2 mile downstream from the stock-yard and freight depot. This sample represents the lowest part of the Eau Claire exposed in the Hokah-La Crescent area. A summary of the textural analysis is given in Table 8. This sample from the Eau Claire is somewhat coarser grained than those taken from nearer the top of this unit of the Dresbach formation.

TABLE 8. Screen Analysis of Eau Claire Sandstone Near Hokah, Minn. one mile east of Mt. Tom.

Feet above base of outcrop	Percentage by weight retained on sieves						
	No. 20	No. 30	No. 40	No. 50	No. 70	No. 100	∠ No. 100
0-5	1.00	6.50	15.10	18.20	19.10	21.10	19.20

Figure 2. Grain size distribution of analysis listed in Table 8.



2. At the village of Dakota in southeastern Winona County, the Eau Claire member of the Dresbach formation crops out as a cliff 10 to 15 feet high along the tracks of the Milwaukee Railroad where it parallels Highway No. 61, but at a lower level, the cliff is between the highway and the railroad tracks. Here the sandstone is well cemented with quartz and carbonates and it is difficult to get an accurate textural analysis. Microscopic studies indicate that it is much finer grained than both the Mt. Simon and Galesville members of the formation. In fact many thin layers of silt and clay are interbedded with the sandstone.

Neither of the locations where the Eau Claire sandstone was sampled are favorable sites for the excavation of a large tonnage of sand. At all the exposures investigated this member of the Dresbach formation has a thick overburden of younger formations.

The Galesville sandstone is the upper member of the Dresbach formation. It is medium and coarse yellow to white, poorly cemented high-silica sandstone. It crops out at numerous places along the lower portion of the Mississippi River bluffs from Winona southward. A good exposure occurs a short distance south of La Crescent beyond Pine Creek, in Sec. 15, T104N, R4W. Here a vertical section of 30 feet is exposed in the highway cut. The sandstone occurs as a broad terrace with only a few feet of alluvium as overburden. A railroad and a highway skirt the toe of the terrace which has extensive acreage. From an industrial standpoint, this is the best location found for the utilization of this sandstone.

Table 9 and Figure 3 summarize the textural characteristic of Galesville sands near La Crescent.

TABLE No. 9. Screen Analyses of Galesville Sandstone
La Crescent, Pine Creek Section.

Feet from	Percentage by weight retained on sieves						
top	No. 20	No. 30	No. 40	No. 50	No. 70	No. 100	/ No. 100
0-5	0.10	1.00	5.00	13.60	17.00	19.40	43.90
5-10	0.40	0.70	3.40	17.80	31.60	27.00	18.20
10-15	0.10	0.50	2.10	7.50	12.40	18.40	57.90
15-20	0.40	2.10	8.60	19.30	31.60	25.20	12.80
20-25	0.10	1.30	7.90	15.40	22.70	23.90	28.60
25-30	0.60	2.60	2.60	13.40	17.50	21.10	37.20

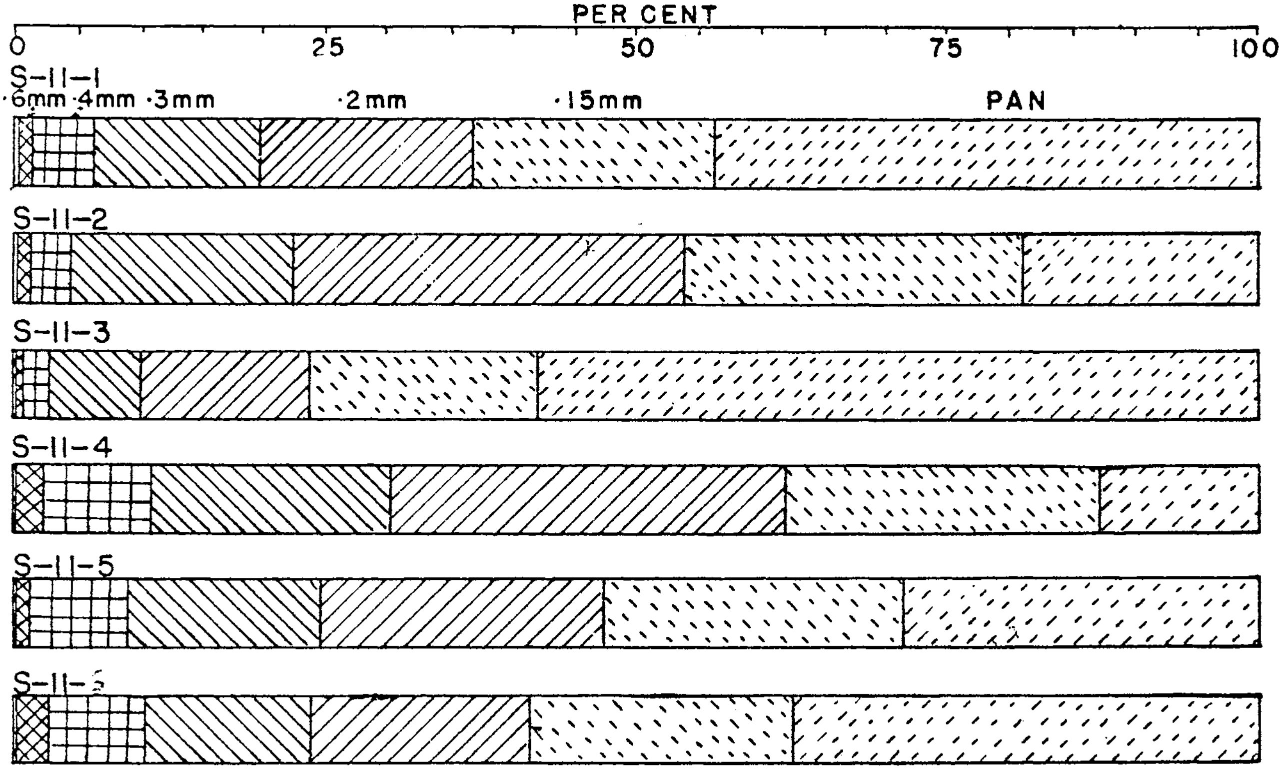


Figure 3. Grain size distribution of analyses listed in Table 9.

A chemical analysis of a representative composite sample of the Galesville sandstone at the above location by Eileen H. Oslund of the Rock Analysis Laboratory, University of Minnesota, showed the following composition: (laboratory No. R. 2341)

SiO_2---	98.61	Na_2O----	.02
Al_2O_3---	.69	K_2O------	.06
TiO_2---	.018	Li_2O----	.00
Fe_2O_3---	.111	H_2O----	.00
MgO ---	.02	Loss on ignition	.13
CaO ---	.01		
			100.4

The same sandstone is exposed in a street cut in Winona a short distance down the hill from the campus of St. Mary's College. A sample taken from this exposure has the textural characteristics indicated in Figure 4. This is not a favorable location for a processing plant.

The Franconia Formation

The rocks of the Franconia formation are highly variable in composition and in texture. Most of the sandstone members are very fine grained and contain a high percentage of silt and clay. The only high-silica unit ia a thin bed at the base, resting on the Galesville sandstone. This is very similar in composition to the Galesville. Table 10 gives its textural characteristics.

TABLE NO. 10. Screen Analysis of Ironton Sandstone
Winona, Hillside street cut below St. Mary's College

Feet from top	Percentage by weight retained by sieves No. 20	No. 30	No. 40	No. 50	No. 70	No. 100	Thru 100
0-5	5.50	16.40	17.60	18.50	15.60	9.50	16.70
5-10	7.00	21.70	22.40	16.40	9.10	7.10	15.30

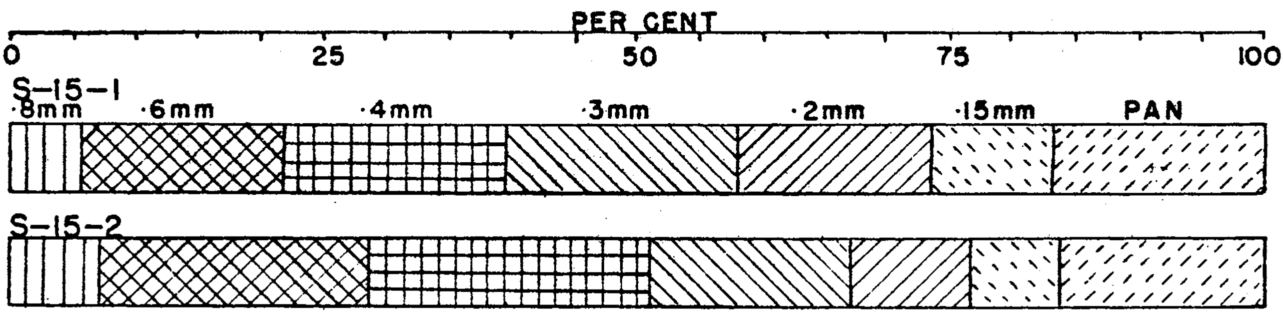


Figure 4. Grain size distribution of the Galesville sandstone at Winona.

The Jordan Formation

The Jordan sandstone is a loosely cemented medium to coarse grained white, high-silica sandstone. It ranges from 75 to nearly 175 feet in thickness and is exposed in the valleys of the Minnesota River and its tributary streams and in the bluffs of the Mississippi and St. Croix Rivers and their major tributaries. Elsewhere in southeastern Minnesota it is deeply buried under younger rocks.

The upper ten or fifteen feet of the formation are considerably coarser than the middle and lower portions. At many places these upper beds have sand grains on which the faces of the crystals have been partly or completely restored by secondary growth. Such grains have sharp edges and points and are therefore, ideal blasting sands. A number of pits have been opened in this portion of the Jordan and the sands are sized to the desired grades.

The formation has been sampled at various places in its outcrop area and its physical and textural characteristics are summarized below.

1. Red Wing, Minnesota. Sand mine in the southwestern part of the city. In that area the sandstone consists of the following units:

Jordan Sandstone	Thickness in feet
Sandstone, yellow, massive, in hard layers with thin, friable layers between. Some fucoidal beds.	32.6
Sandstone, yellow, massive, with hard lenses and lumps.	7.0
Sandstone, white, massive, medium-grained, cross-bedded. Scattered pebbles the size of peas occur in the sand, also thin seams and lenses of argillaceous green shale, with a few hard lenses near the top.	17.0
Sandstone, white medium-grained, with thin lenses and seams of argillaceous green shale. Fossils occur in the shale.	33.0
Sandstone, white to yellow, fine-grained.	

Samples from the upper 25 feet taken at the mine have the following textural characteristics:

TABLE NO. 11. Screen Analyses of Jordan Sandstone
Sand Mine in Southwest Red Wing

Feet from	Percentage by weight retained on sieves						
top	No. 20	No. 30	No. 40	No. 50	No. 70	No. 100	an / No. 100
0-5	2.90	14.25	32.10	38.90	10.70	0.50	0.40
5-10	2.00	9.10	21.20	42.50	22.30	1.80	1.20
10-15	4.15	12.70	31.15	34.20	12.10	3.30	1.70
15-20	1.60	15.30	45.50	31.50	5.00	0.80	0.30
20-25	5.00	20.28	.00	25.20	6.20	2.00	1.00

Averages:

Median diameter	0.408 mm.
Coefficient of sorting	1.60
Coefficient of shewness	1.09
Effective size	0.26
Uniformity Coefficient	2.83

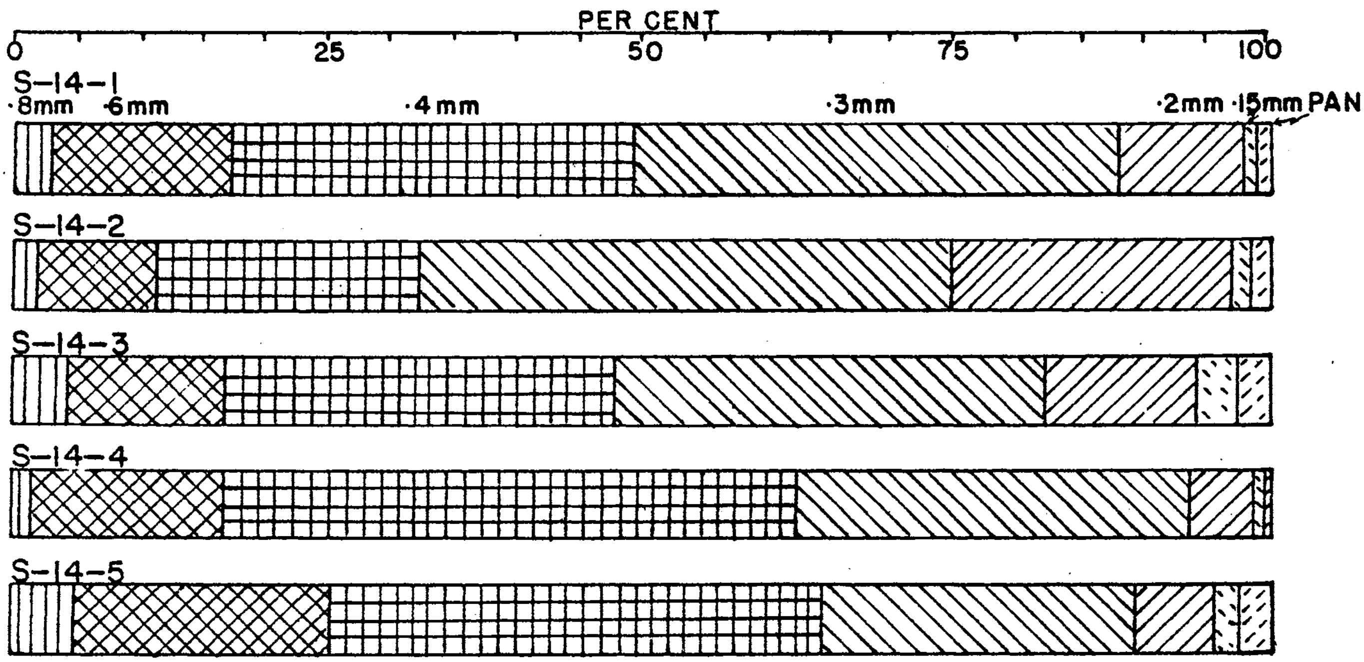


Figure 5. Grain size distribution of analyses listed in table 11.

In the region of Red Wing the Jordan sandstone is exposed in the walls of all the deep gullies and ravines. Southeast of the city it occurs in the high bluffs along the Mississippi River. In that area it is capped by 20 to 50 feet of the Oneota dolomitic limestone. Any large scale industrial operation in that area would be obliged to use tunneling methods rather than an open pit for excavating the silica sand.

2. Ottawa, Minnesota, at the pit of Gopher State Silica, Inc.

In the region of Ottawa the Jordan sandstone underlies a broad, flat terrace of the Minnesota River Valley. This terrace extends for several miles both north and south of the village of Ottawa. At most places there is no more than a thin cover of residual blocks and boulders of the Oneota dolomite over the sandstone. The terrace stands approximately 30 feet above the water level in the river and consequently the upper part of the formation can be excavated without ground water seepage into the pit. The Chicago, St. Paul and Omaha Railroad Co. has its tracks on the terrace. A siding serves the plant of Gopher State Silica, Inc. This Company produced 150,000 tons of processed sand in 1956 and hope to produce at least 2000,000 tons in 1957.

Table 12 summarizes the textural characteristics of the upper part of the Jordan sandstone in the Ottawa area.

TABLE NO. 12. Screen Analyses of Jordan Sandstone at Pit of Gopher State Silica, Inc. Ottawa, Minn.

Feet from top	Percentage by weight retained on sieves						
	No. 20	No. 30	No. 40	No. 50	No. 70	No. 100	< No. 100
0-5	2.00	10.0	26.20	28.10	10.50	8.50	14.70
5-10	1.90	9.35	26.25	42.70	12.35	2.60	4.80
10-15	1.37	10.15	39.70	44.16	4.00	0.45	0. 15
15-20	3.60	15.23	33.30	32.72	8.82	4.20	2.10
20-25	6.20	17.90	32.50	26.00	10.00	4.80	1.60
25-30	5.43	19.00	33.30	26.60	9.75	4.95	1.00

Average Median diameter	0.450 mm.
Coefficient of sorting	1. 37
Coefficient of skewness	0. 97
Effective size	0.190 mm.
Uniformity coefficient	2.10 mm.

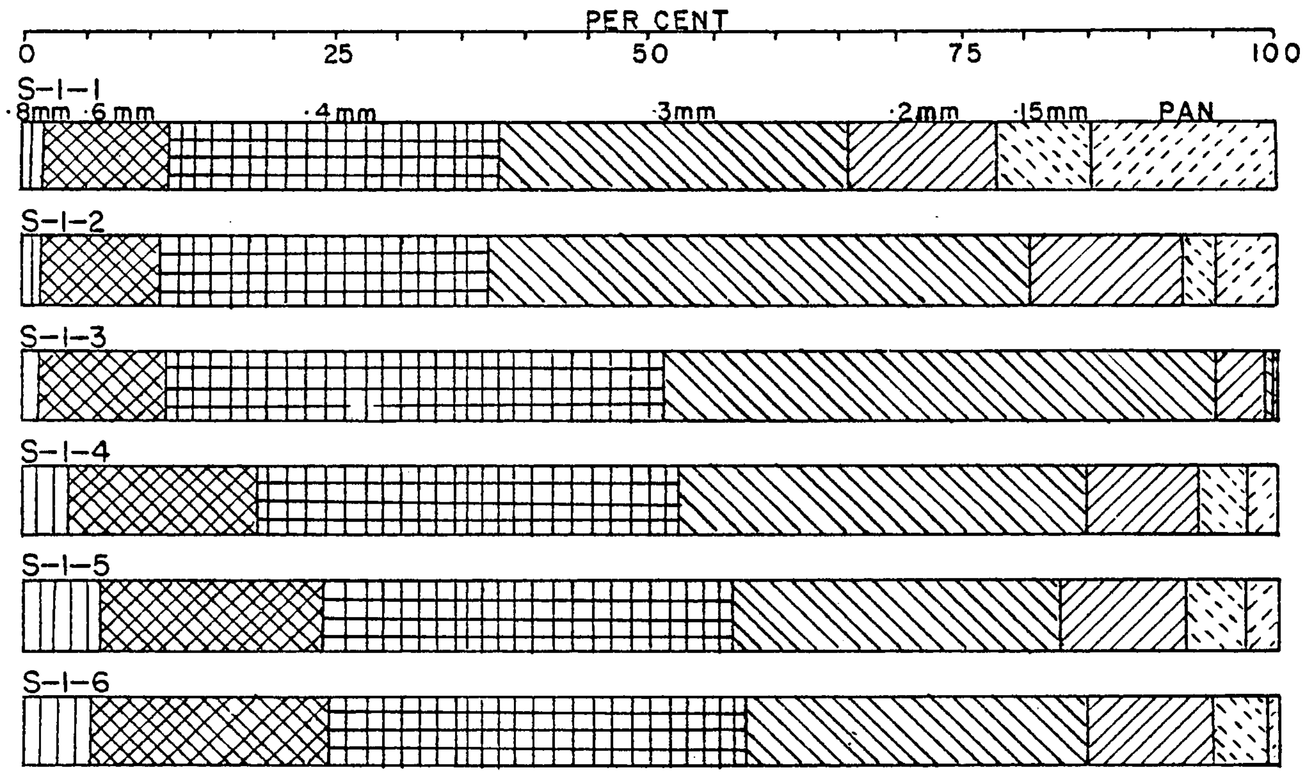


Figure 6. Grain size distribution of the analyses listed in table 12.

3. Jordan, Minnesota. Approximately 4 miles north of the City on west side of Highway No. 169.

A rock terrace similar to that at Ottawa occurs in the Minnesota Valley between Jordan and Shakopee. Near Shakopee as much as 50 feet of dolomite overlies the Jordan sandstone. This overburden becomes thinner toward the south and wedges out to zero about 4 miles north of the city of Jordan. There the sandstone crops out over a number of acres. The tracks of the Chicago, St. Paul and Omaha Railroad skirt the west margin of the outcrop area and a siding has been built to serve the Minnesota Quartz Co. which operates a small plant near the southwest margin of the outcrops.

TABLE NO. 13. Screen Analyses of Jordan Sandstone
Minnesota Quartz Co. Pit 4 miles north of Jordan

Feet from top	Percentage by weight retained on sieves No. 20.	No. 30	No. 40	No. 50	No. 70	No. 100	Thru No. 100
0-5	1.60	15.00	42.00	35.00	5.60	0.50	0.20
5-10	3.30	21.40	44.10	26.20	4.40	0.40	0.10
10-15	0.90	12.00	51.00	31.55	3.70	0.40	0.45
15-20	1.00	7.20	19.70	24.40	19.70	15.10	12.85

Averages:

Median diameter---0.443mm.
Coefficient of sorting ---1.290
Coefficient of skewness---1.070
Effective size----0.082
Uniformity Coefficient----2.070

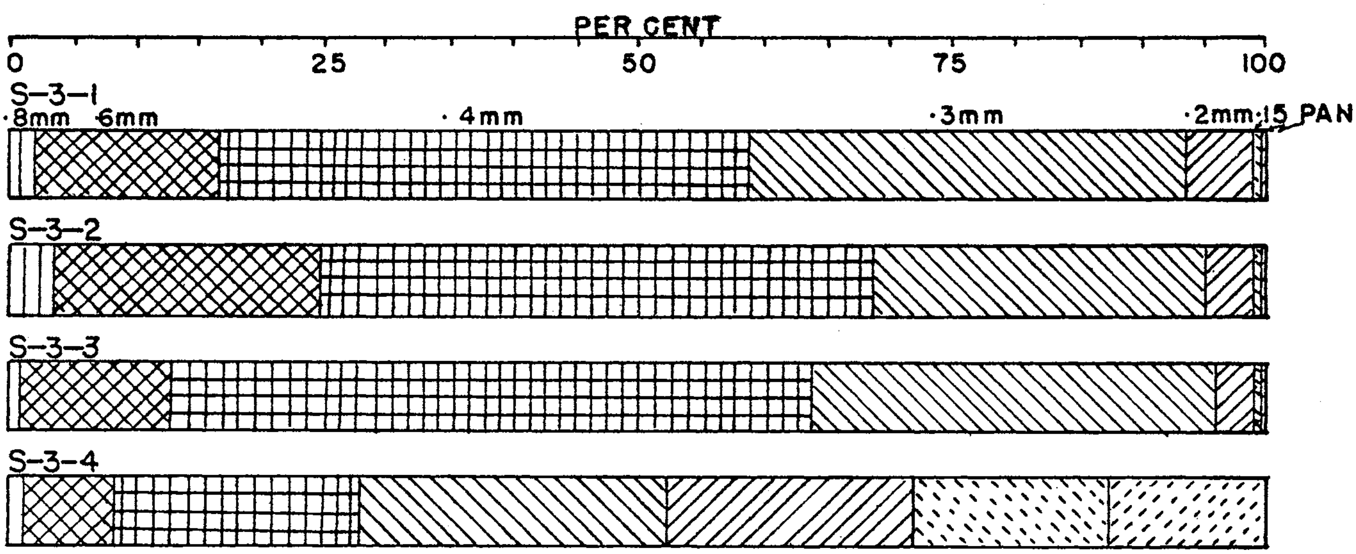


Figure 7. Grain size distribution of the analyses listed in Table 13.

4. North Mankato opposite Sibley Park.

The Jordan sandstone is exposed at many places in the north wall of the Minnesota Valley from North Mankato northwestward toward Judson. There are no locations favorable for the industrial development of its high-silica sand in that region because of its very thick overburden of dolomite and glacial drift. It was sampled, however, to compare its textural and other physical characteristics with those of the Jordan sandstone as exposed in the valley in the regions of Ottawa and Jordan.

The following table is a summary of screen analyses on samples 30 to 40 feet below the top of the formation.

TABLE NO. 14. Screen Analyses of Jordan Sandstone.
North Mankato opposite Sibley Park

Feet from top	Percentage by weight retained on sieves. No. 20	No. 30	No. 40	No. 50	No. 70	No. 100	Thru No. 100
30-35	3.30	15.20	39.45	24.55	8.80	5.00	2.10
35-40	4.50	14.90	41.60	27.10	5.60	3.00	3.10

Averages:

Median diameter	0.436mm
Coefficient of sorting	1.61
Coefficient of skewness	1.07
Effective size	0.24
Uniformity Coefficient	1.62

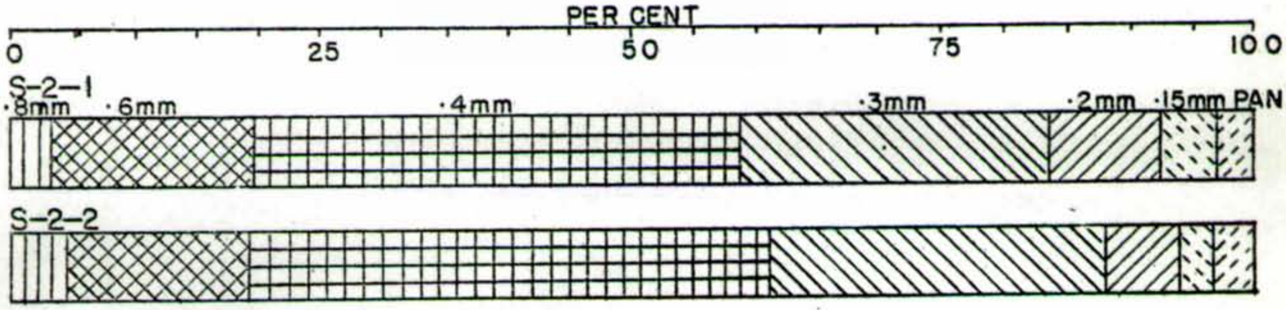


Figure 8. Grain size distribution of the analyses listed in table 14.

5. Wabasha, Minnesota, road cut along Highway No. 60 up the hill west of the city.

Nearly the entire thickness of the Jordan sandstone is exposed in the road cut blasted into the hillside along Highway 60 west of the city.

Nearly the entire thickness of the Oneota dolomite overlies the Jordan sandstone in this area and consequently it could not be excavated profitably by the open pit method.

The basal 20 feet of the formation is much finer grained then the upper beds. The following table summarizes its textural variations.

TABLE NO. 15. Screen Analyses of Jordan Sandstone Near Wabasha along Highway 60 west of the city.

Feet from top	No. 20	No. 30	No. 40	No. 50	No. 70	No. 100	Thru No. 100
	Percentage by weight retained on sieves						
0-5	2.80	13.80	30.00	29.00	14.20	5.30	4.00
5-10	3.60	11.80	28.00	28.60	11.90	3.80	12.60
10-15	2.50	11.90	29.85	30.80	10.10	3.55	11.20
15-20	0.40	1.60	11.00	23.80	24.40	20.40	10.40
20-25	1.00	4.20	11.90	20.00	21.80	24.30	16.70
40-45	1.80	5.90	9.60	11.50	12.20	21.70	37.20
45-50	0.80	2.80	7.90	22.00	27.30	19.40	19.50
50-55	2.00	2.50	2.40	8.70	19.50	22.10	41.70
55-60	0.20	0.40	1.60	4.00	8.50	16.70	68.00
60-65	0.60	1.00	1.40	3.40	6.70	12.80	74.00
65-70	0.50	0.60	2.30	3.00	6.70	14.60	72.80
70-75	0.20	0.20	1.20	7.30	28.40	34.80	22.80

Average median diameter	.374
Average coefficient of sorting	1.76
Average coefficient of skewness	1.10
Average effective size	0.156
Average uniformity coefficient	2.16

6. St. Croix River Valley, near west end of Osceola bridge.

The Jordan sandstone is exposed at a number of places along the valley of the St. Croix River from a short distance south of Taylors Falls to its junction with the Mississippi River near Hastings. In some areas most of the Oneota dolomite has been eroded and no more than a thin mantle of glacial drift covers the Jordan sandstone.

On the Minnesota side of the valley, near the west end of the bridge at Osceola, Wisconsin, the upper part of the Jordan was cleared of its overburden during grading operations for the approach to the bridge. Samples from the upper 15 feet of the sandstone have the textural characteristics tabulated below.

The lower part of the formation was sampled in the highway cut at the east (Wisconsin) end of the bridge.

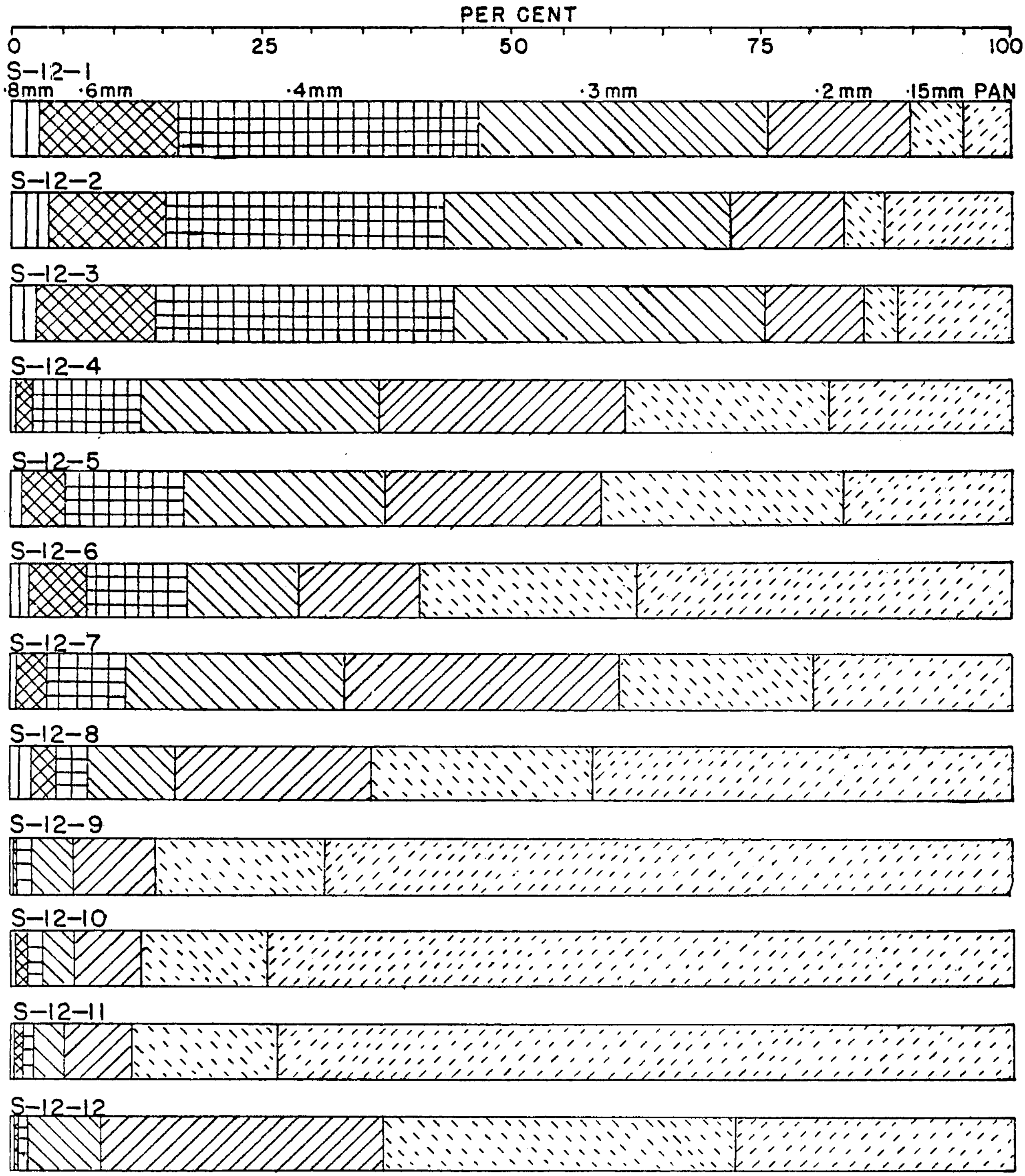


Figure 9. Grain size distribution of the analyses listed in Table 15.

TABLE NO. 16. Screen analyses of Jordan Sandstone
Minn. end of Osceola Bridge over the St. Croix River

Feet from top	No. 20	No. 30	No. 40	No. 50	No. 70	No. 100	Thru No. 100
	Percentage by weight retained on sieves						
0-5	1.20	6.40	23.30	40.00	20.40	5.30	6.30
5-10	0.60	9.00	31.00	39.20	16.30	2.60	1.70
10-15	0.60	7.00	20.30	28.70	23.50	12.50	6.40
60-65	0.60	1.80	3.20	7.40	38.20	41.20	7.50
65-70	0.70	4.50	5.70	9.80	36.80	33.00	9.30

Averages:	Upper 15 ft.	Bottom 10 ft.
Median diameter	0.353	0.140
Coefficient of sorting	1.72	1.75
Coefficient of skewness	1.04	2.24
Effective size	0.24	0.12
Uniformity coefficient	1.53	1.52

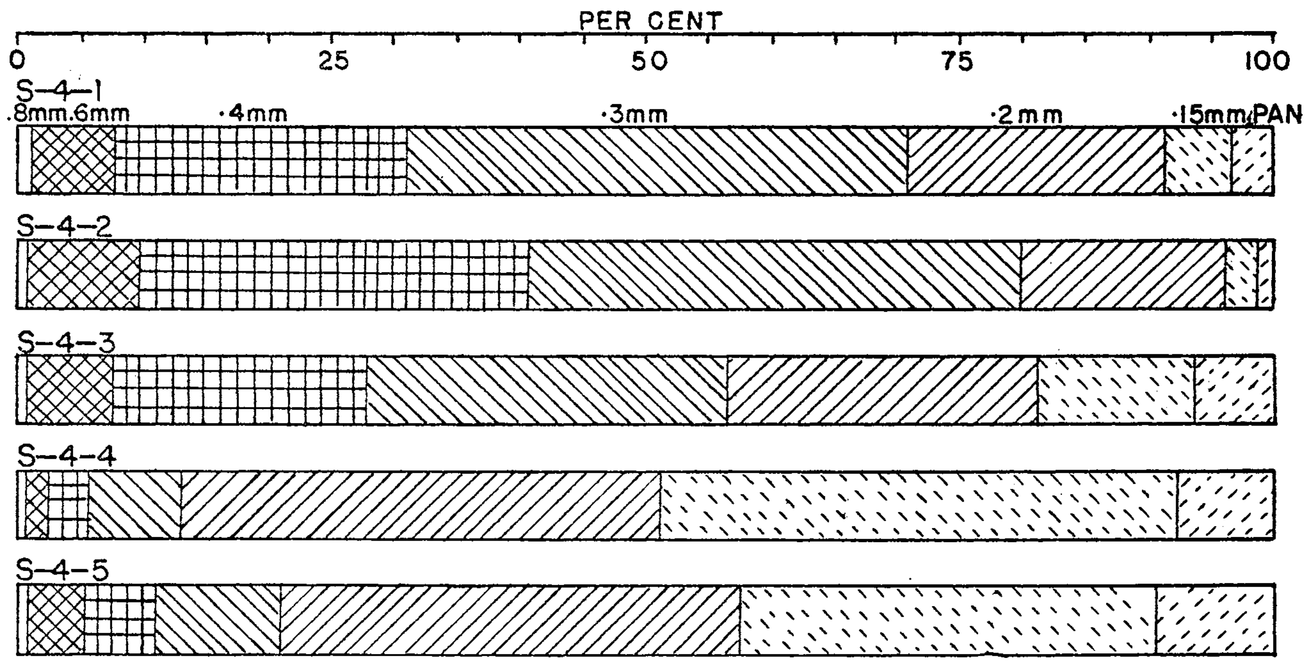


Figure 10. Grain size distribution of the analyses listed in Table 16.

A partial chemical analysis of a representative composite sample of the upper 25 feet of the sandstone gave a total iron content of 0.29%.

7. Stillwater, Minnesota, Boom Hollow highway cut.

The entire thickness of the Jordan formation occurs in the west wall of the St. Croix River at Stillwater. However, it is overlain by the basal beds of the Oneota dolomite and a thick mantle of glacial drift. It is exposed as a cliff sixty feet high along the main street of Stillwater in the southern part of the city and also at the north margin and northwestward along the highway up Boom Hollow.

The textural variations in the upper part of the formation are listed below.

TABLE NO. 17. Screen Analyses of Jordan Sandstone
Stillwater, Boom Hollow section.

Feet from top	No. 20	No. 30	No. 40	No. 50	No. 70	No. 100	/No. 100
			Percentage by weight retained on sieves				
0-5	0.00	0.40	50.00	25.20	9.40	9.40	5.80
5-10	0.00	0.50	50.00	24.20	10.40	8.40	6.80
10-15	0.00	0.40	48.00	22.80	11.40	9.90	8.45

8. Village of Afton, south of Bayport.

The total thickness of the Jordan sandstone is exposed in a gully wall a short distance southwest of Afton, near a bridge over the small stream that made the gully. Ten to twenty feet of the Oneota dolomite occur over the sandstone. The topography of the area near the exposure is not suitable for a sand processing plant.

The textural characteristics of the sand are shown in Tables 18 and 19.

TABLE NO. 18. Screen Analyses of Jordan Sandstone
Afton, Minnesota

Feet from top	1 mm 1.0	1/2 mm 0.5	1/4 mm 0.25	1/8 mm 0.12	1/16 mm 0.0625	/-1/16 mm / 0.0625
			Percentage by weight retained on sieves			
0-5	1	11	49	37	1	1
5-10	1	2	34	57	5	1
10-15	1	14	61	22	1	1
15-20	1	21	60	16	1	1
20-25	2	9	48	38	2	1
25-30	2	25	50	20	2	1
30-35	2	27	43	24	3	1
35-40	1	9	52	34	3	1
40-45	1	3	31	43	19	3
45-50	1	2	21	52	22	2
50-55	1	2	23	48	24	2
55-60	1	2	23	49	22	3
60-65	1	1	16	39	30	13
65-70	0.5	0.5	9	35	20	35
70-75	0.5	0.5	10	27	53	9
75-80	0.0	1.0	8	11	36	44
80-85	0.0	1.0	3	10	38	48

TABLE NO. 19 Textural Relationships of the Jordan Sandstone
Afton, Minnesota

Feet from top	Median Diameter	Effective Size	Coefficient of Sorting	Coefficient of Skewness	Uniformity Coefficient
0-5	.270	.180	1.29	1.25	.250
5-10	.240	.142	1.25	0.98	.225
10-15	.310	.190	1.33	1.14	.275
15-20	.330	.205	1.34	1.12	.300
20-25	.265	.170	1.25	1.17	.250
25-30	.350	.175	1.44	1.07	.375
30-35	.365	.155	1.55	0.95	.310
35-40	.300	.145	1.45	0.93	.260
40-45	.195	.090	1.54	1.06	.165
45-50	.180	.080	1.40	0.94	.155
50-55	.180	.080	1.46	0.94	.152
55-60	.175	.080	1.43	1.04	.150
60-65	.135	.047	1.56	1.08	.115
65-70	.105	.010	2.15	0.67	.075
70-75	.105	.065	1.51	1.02	.090
75-80	.075	.010	1.81	0.71	.060
80-85	.065	.010	1.91	0.78	.050

9. Near Houston in Houston County.

The entire thickness of the Jordan sandstone is exposed in the cut along the highway a short distance northeast of the city of Houston. It is overlain by the Oneota dolomite. The textural characteristics of its sands are shown graphically in Figure 11.

TABLE NO. 20. Summary of the Textural Characteristics of the Jordan Sandstone.

Location	Median Diam. in mm.	Coef. of Sorting	Coef. of Skewness	Effect. Size	Unif. Coef.
		Upper 30 ft.			
Ottawa	0.450	1.37	0.97	0.190	2.10
Long Lake Well	0.380	1.69	1.26	0.108	3.49
Stillwater	0.406	1.43	0.85	0.098	3.04
Afton	0.310	1.36	0.95	0.141	3.12
Red Wing	0.408	1.60	1.09	0.262	2.83
Wabasha	0.374	1.76	1.10	0.156	2.16
Jordan	0.443	1.29	1.32	0.320	1.34
Mankato	0.436	1.61	1.07	0.240	1.62
Osceola bridge	0.353	1.72	1.04	0.211	1.53
		Middle 40 ft.			
Long Lake	0.162	2.07	1.16	0.082	2.07
Stillwater	0.147	1.34	0.85	0.063	1.81
Afton	0.185	1.37	1.93	0.042	1.76
Wabasha	0.213	2.26	2.20	0.132	1.34
Osceola	0.221	1.75	1.80	0.161	1.71
		Lower 20 ft.			
Long Lake	0.071	1.82	1.37	0.037	1.26
Stillwater	0.086	1.41	1.03	0.043	2.03
Afton	0.065	1.42	1.87	0.043	1.94
Wabasha	0.181	1.57	1.26	0.131	1.38
Osceola	0.140	1.75	2.24	0.120	1.52

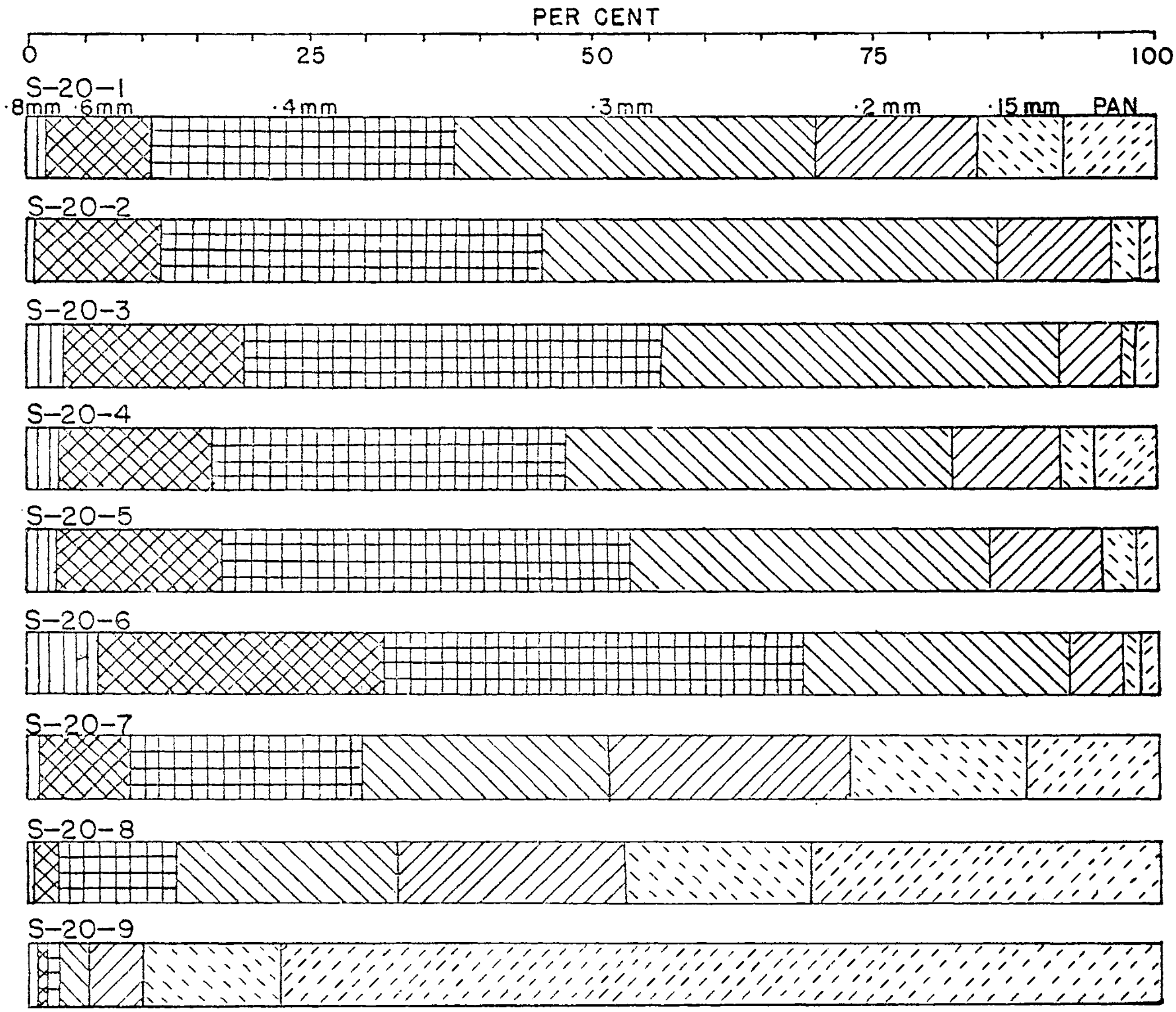


Figure [illegible]. Grain size distribution of the Jordan Sandstone near Houston in Houston County.

The St. Peter Sandstone

The St. Peter sandstone is one of the most widely recognized formations of the central part of the United States.

It is a friable high-silica sandstone consisting mainly of remarkably white and well-sorted quartz grains. Much of the whiteness is due to the frosted surfaces of the grains. Locally the formation is stained yellow, brown, pink or red by iron oxide. These may follow certain horizons in the sandstone, but more commonly the color is in erratic bands and represents an infiltration of iron-bearing water from overlying strata.

In Minnesota the St. Peter underlies the greater part of the area between the Minnesota and Mississippi rivers and much of Ramsey, Washington, Anoka and Hennepin counties. It varies from 75 to 175 feet in thickness. It is thickest in the area of the Twin Cities, where an average of 57 well logs show a thickness of 158 feet. It becomes thinner toward the south. At Owatonna and southward from that city, the St. Peter is only 100 feet thick.

Texturally and mineralogically the St. Peter is remarkably uniform, indicating that its sands were well sorted prior to and during deposition. Most of the quartz grains are from one-eighth to one-half of a millimeter in diameter. It will all pass a No. 20 sieve with openings approximately 0.8 mm. in diameter, and the amount that is as fine as silt and clay ($\pm$ 250 mesh) is no more than a fraction of one per cent.

Table 21 shows the uniformity of the St. Peter sands over a large area in the Upper Mississippi Valley.

TABLE NO. 21. Summary of the Textural Characteristics of the St. Peter Sandstone

Geographic Location	Textural Characteristics				
	Median Diam. in mm.	Coef. of sorting	Coef. of Skewness	Effective Size in mm.	Uniformity Coef.
Caledonia	0.241	1.39	1.02	0.165	2.12
Castle Rock	0.192	1.31	1.17	0.106	1.64
Chatfield	1.239	1.42	1.01	0.124	2.39
Chimney Rock	0.309	1.45	1.26	0.107	2.24
Decorah, Iowa	0.233	1.45	0.99	0.117	2.34
Mendota	0.235	1.41	1.09	0.142	1.99
N. Minneapolis	0.235	1.48	0.96	0.107	2.65
St. Paul Park	0.178	1.32	1.20	0.119	2.28
Zumbrota	0.201	1.32	1.06	0.114	2.00
Preston	0.225	1.47	0.97	0.119	2.23
S. Minneapolis	0.219	1.55	0.94	0.098	3.02
Rochester	0.207	1.38	1.12	0.121	2.00
St. Paul	0.197	1.37	1.07	0.121	1.92
Washington County	0.281	1.27	1.11	0.175	3.66
Blue Mound, Wis.	0.235	1.33	1.04	0.125	2.38
Average	0.228	1.39	1.07	0.124	2.32

Where free of secondary infiltrated iron, the sandstone is very pure silica. The following chemical analysis is typical.

TABLE NO. 22. Chemical Analysis of St. Peter Sandstone. Mendota, Minnesota from valley wall at Junction of Mississippi and Minnesota Rivers. Composite sample, upper 50 feet.

SiO_2	98.91	CaO	0.02
Al_2O_3	0.62	MgO	0.01
Fe_2O_3	0.09	K_2O	0.02
		Na_2O	0.01
		Loss on Ign.	0.27

A. Willman, analyst.

The St. Peter formation crops out almost continuously in the banks of the Mississippi River from north of Minneapolis, through the Twin Cities and for a number of miles south of St. Paul. There are several pits and undergroud operations in the Twin Cities where the sandstone is excavated for foundry sand, blasting sand, filter sand, etc. It is readily available also, with very little overburden, at numerous locations to the south and southwest of the cities. Some of these locations are near railroads and good highways.

The formation has been sampled at various places in its outcrop area and its physical and textural characteristics are summarized below.

1. Castle Rock Road Cut--Highway 65--South of Farmington.

The highway between Farmington and Northfield crosses the south rim of the Twin Cities artesian basin. In that region the Platteville and younger formations are completely eroded off from the sandstone over an area of several square miles. There the only overburden is a thin mantle of glacial drift. See Table 23 and Figure 12.

TABLE NO. 23. Screen Analyses of St. Peter Snadstone
Castle Rock Road Cut South of Farmington.

Feet from	Percentage by weight retained on sieves						
top	No. 20	No. 30	No. 40	No. 50	No. 70	No. 100	No. 100
0-5	0.00	0.10	3.20	21.20	24.00	24.60	27.20
5-10	0.00	0.00	2.00	25.85	29.00	21.20	22.00
10-15	0.00	0.00	2.20	25.40	26.65	20.65	25.10
15-20	0.00	0.10	0.70	15.00	26.00	27.70	30.50
20-25	0.00	0.10	0.60	16.00	29.80	23.40	30.00
25-30	0.00	0.10	0.50	13.00	30.20	30.80	25.30

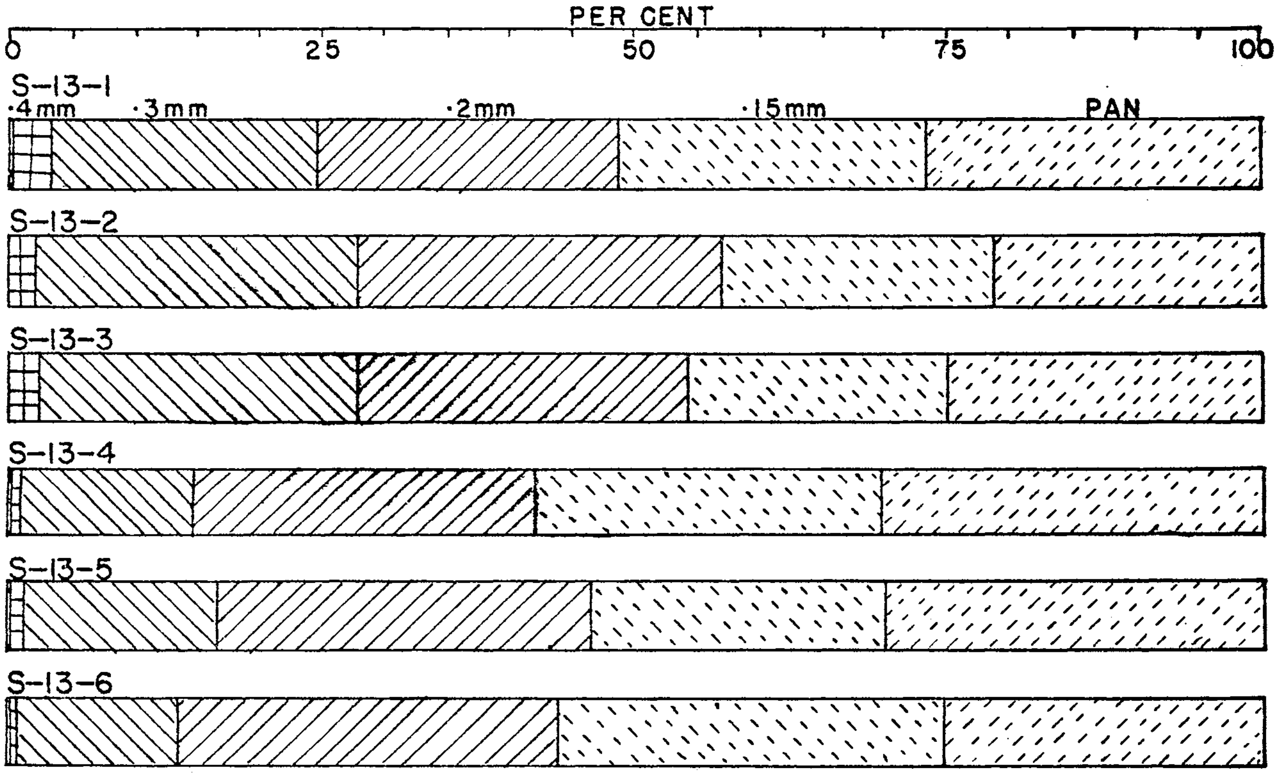


Figure 12. Grain size distribution of the analyses listed in Table 23.

A detailed chemical analysis of a representative, composite sample of the St. Peter sandstone in this area, by Eileen H. Oslund of the Rock Analysis Laboratory, University of Minnesota showed the following composition: (Laboratory No. R. 2342).

SiO_2	98.74	Na_2O	.007
Al_2O_3	.70	K_2O	.03
TiO_2	.048	Li_2O	.00
Fe_2O_3	.127	H_2O	.00
MgO	.04	Loss on ignition	.29
CaO	.00		99.98

2. Along Highway 56 between Stanton and Wangs in Goodhue County.

In this region many hills and ridges are capped by the basal beds of the Platteville limestone which rest on the St. Peter sandstone. This thin overburden could be stripped off easily and large open pits excavated in the sandstone. Table 24 and Figure 13 summarize the textural characteristics of the silica sand.

TABLE NO. 24. Screen Analyses of St. Peter Sandstone
Highway cut between villages of Stanton and Wangs in Goodhue County.

Feet from top	Percentage by weight retained in sieves. No. 20	No. 30	No. 40	No. 50	No. 70	No. 100	/_ No.100
0-5	0.00	0.10	2.30	25.00	30.00	24.00	18.90
5-10	0.00	0.10	2.10	23.40	28.40	24.80	21.20
10-15	0.00	0.00	1.20	23.40	30.80	24,80	19.10
15-20	0.00	0.10	1.00	21.20	29.70	24.50	23.40
20-25	0.00	0.10	1.10	17.50	29.30	30.00	22.20

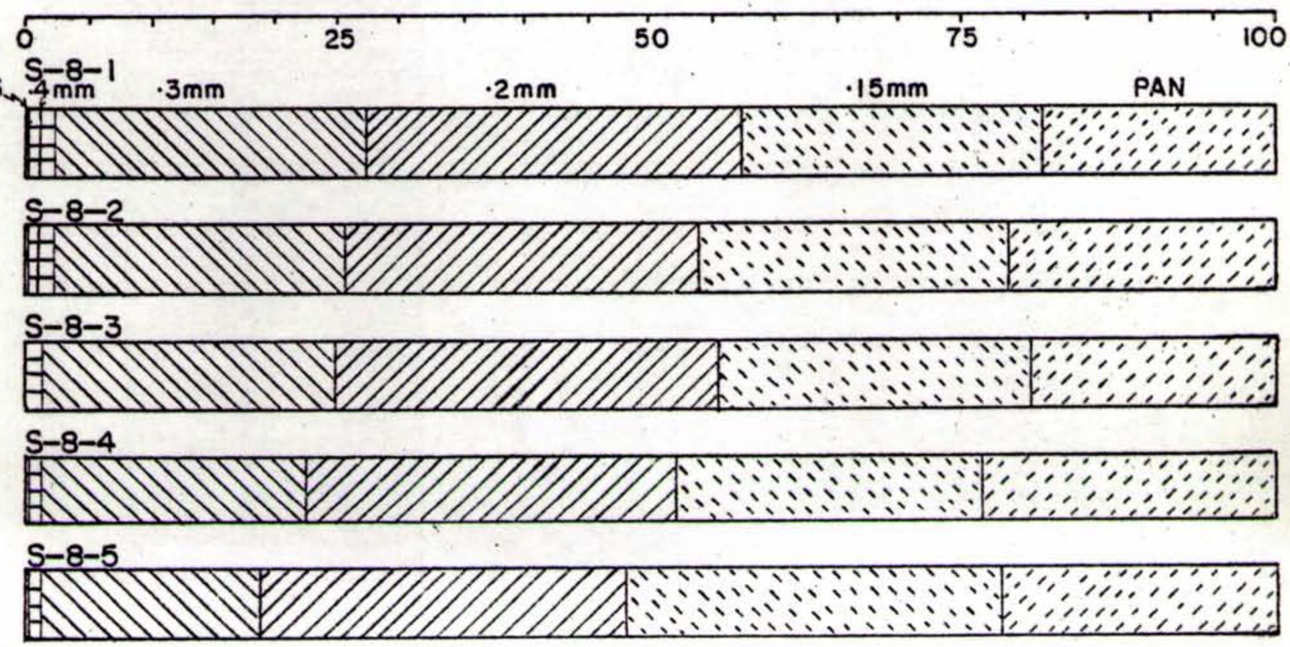


Figure 13. Grain size distribution of the analyses listed in Table 24.

3. South of Highway 12 (the Hudson Road), east of St. Paul in sections 7 and 8. Township 28 North, Range 21 west.

In this region there are low buttes in the topography that are outliers of the Platteville limestone and the St. Peter sandstone. On several of such hills the sandstone has very little overburden. It is an ideal location for open pit operations in the silica sand.

4. Dover, Minnesota, Olmsted County. One mile east of village along U. S. Highway No. 14.

The upper 20 feet of the St. Peter sandstone is exposed in the road cut. The overburden consists of a thin mantle of loess and the lower beds of the Platteville limestone. This is an exceptionally favorable location for an open pit operation. The upper 30 feet of the sandstone could be excavated without serious ground water seepage. A railroad parallels the highway.

Table 25 and Figure 14 summarize the textural characteristics of the silica sand.

TABLE NO. 25. Screen Analyses St. Peter Sandstone
Dover, Minnesota. One mile east of town on U. S. Highway No. 14.

Feet from top	Percentage by weight retained on sieves						
	No. 20	No. 30	No. 40	No. 50	No. 70	No. 100	∠ No. 100
0-5	0.10	1.90	19.00	26.60	17.10	18.50	16.40
5-10	0.00	0.10	11.00	26.00	17.70	22.00	23.00
10-15	0.00	0.10	4.80	25.65	22.10	17.65	28.70
15-20	0.00	0.10	3.40	21.00	26.80	24.00	23.80

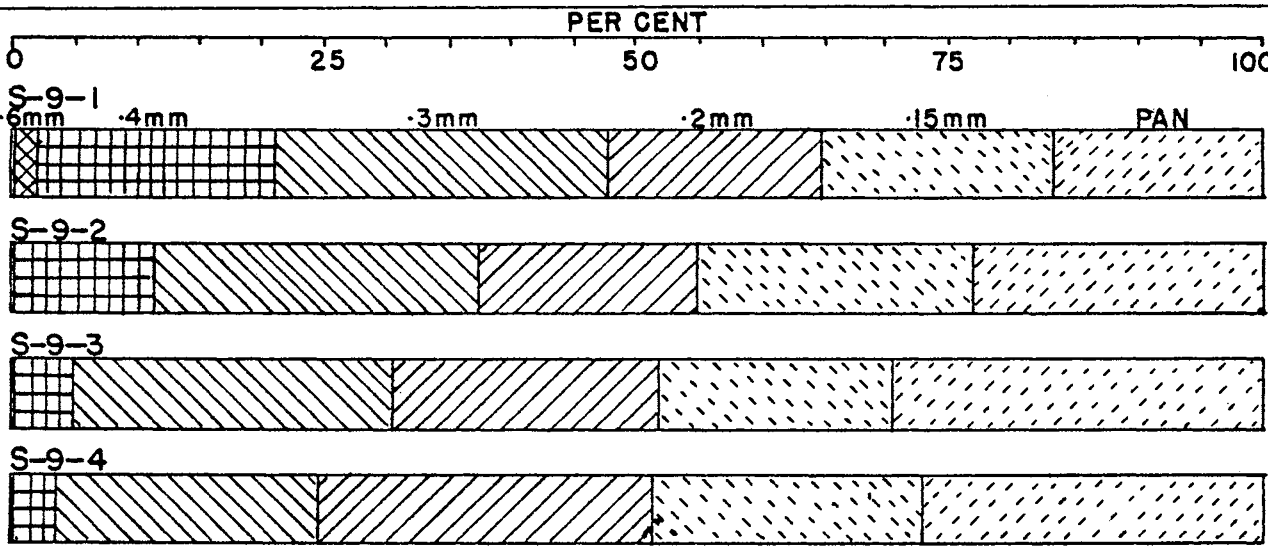


Figure 14. Grain size distribution of the analyses listed in Table 25.

5. West of Miesville in Dakota County, a short distance east of the junction of Highway 61 and 20.

At this location the overburden on the St. Peter sandstone is no more than a thin mantle of soil. This favorable relationship appears to exist over a very large area. The subsurface structure of this region is an eastward extension of the structural high between Farmington and Northfield.

Table 26 and Figure 15 summarize the textural characteristics of the sandstone.

TABLE NO. 26. Screen analyses of St. Peter Sandstone
Near Miesville. Short distance east of Junctions of Highway 61 with 20.

Feet from top	Percentage by weight retained on sieves.						
	No. 20	No. 30	No. 40	No. 50	No. 70	No. 100	∠ No. 100
0-5	0.00	0.02	1.15	6.70	36.10	38.80	17.00
5-10	0.00	0.30	1.00	6.30	38.65	32.55	22.10

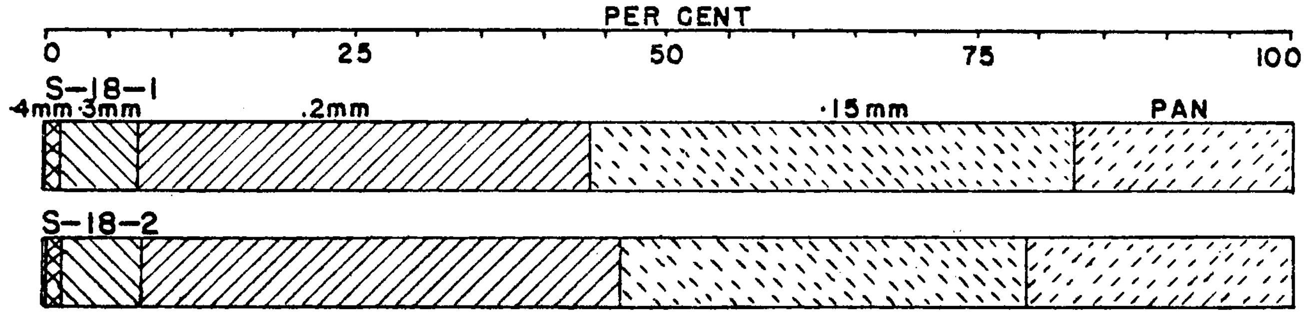


Figure 15. Grain size distribution of the analyses listed in Table 26.

,6. North Minneapolis, east of the Fridley Filtration Plant.

The St. Peter sandstone is exposed along the east margin of the Northern Pacific Railroad Company's yards. Here the upper 30 feet of the formation occur above the level of the tracks, and the Helm sand pit has been opened in the clean, white silica sand that is excavated and screened for various grades of foundry sand. The overburden consists of 4 to 6 feet of Platteville limestone and several feet of glacial drift.

Table 27 and Figure 16 summarize the textural characteristics of the sand.

TABLE NO. 27. Screen analyses of St. Peter Sandstone
Helm Sand Pit. North Minneapolis

Feet from top	Percentage by weight retained on sieves. No. 20	No. 30	No. 40	No. 50	No. 70	No. 100	Thru No. 100
0-5	0.00	1.35	31.00	41.40	10.85	6.10	9.40
5-10	0.00	0.20	6.00	29.20	19.40	17.10	28.00
10-15	0.00	0.00	5.20	36.60	16.70	15.80	26.00
15-20	0.00	0.10	2.90	29.00	22.30	20.00	25.00
20-25	0.00	0.00	0.60	31.70	32.50	15.30	19.60
25-30	0.00	0.00	0.80	18.00	29.80	25.00	26.30
30-35	0.00	0.00	1.00	13.80	31.40	29.40	24.00

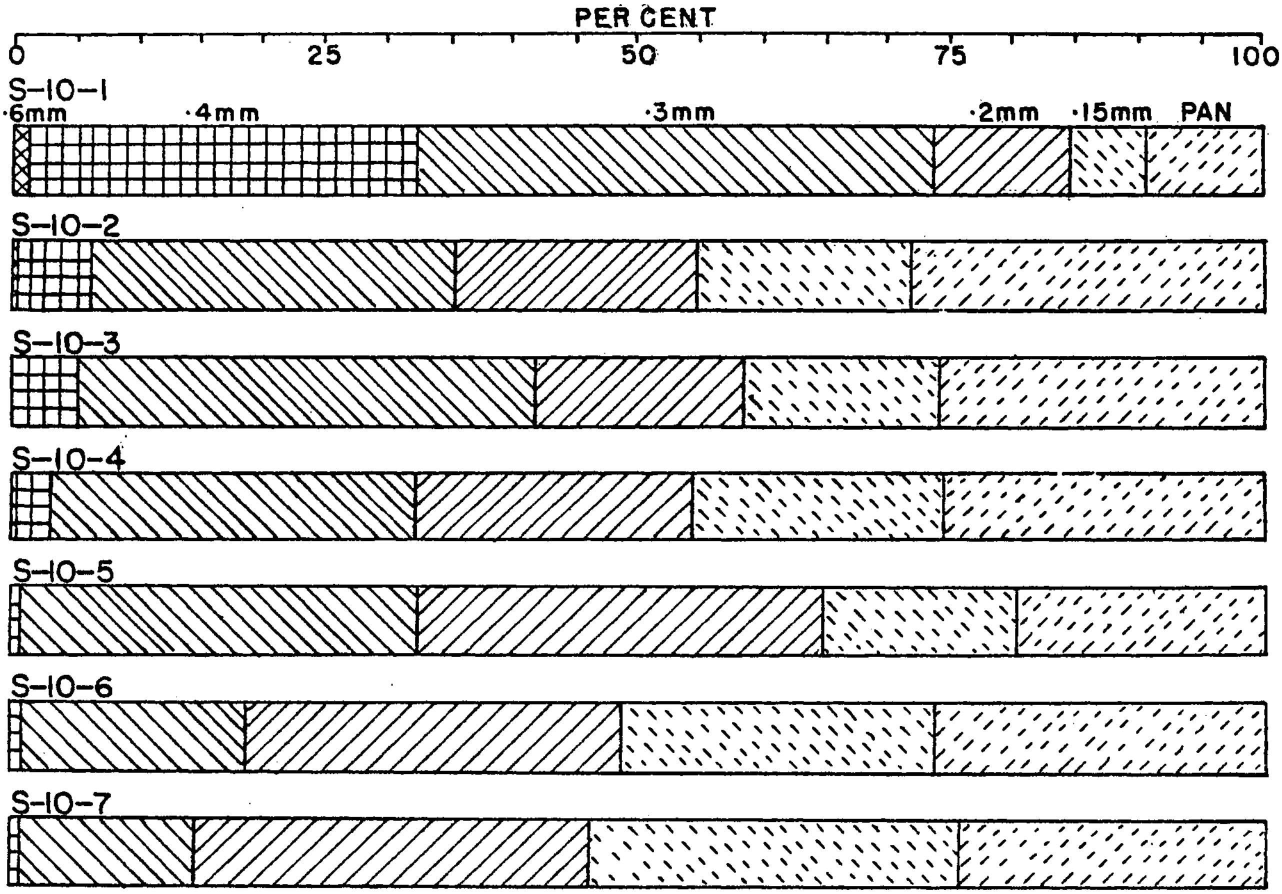


Figure 16. Grain size distribution of the analyses listed in Table 27.

A detailed chemical analysis of a representative composite sample of the St. Peter sandstone at the Helm pit in north Minneapolis by Eileen H. Oslund of the Rock Analysis Laboratory, University of Minnesota, showed the following composition: (Laboratory No. R. 2340).

SiO_2 --------	99.12	Na_2O -------	.006
Al_2O_3 -------	.50	K_2O --------	.06
TiO_2 --------	.050	Li_2O --------	.00
Fe_2O_3 ------	.053	H_2O --------	.00
MgO --------	.02	Loss on ignition -------	.20
CaO --------	Tr.		
			100.04

7. Houston County, west of Caledonia.

In Township 102 north, Range 6 west, there are elongated ridges on which the St. Peter aandstone crops out extensively. The only overburden is a few feet of soil and subsoil which is composed, for the most part of loess and, therefore, easily removed.

A series of samples from that area represent the upper 50 feet of the sandstone formation. The textural characteristics of the white silica sand from the top of the formation downward, are shown in Figure 17.

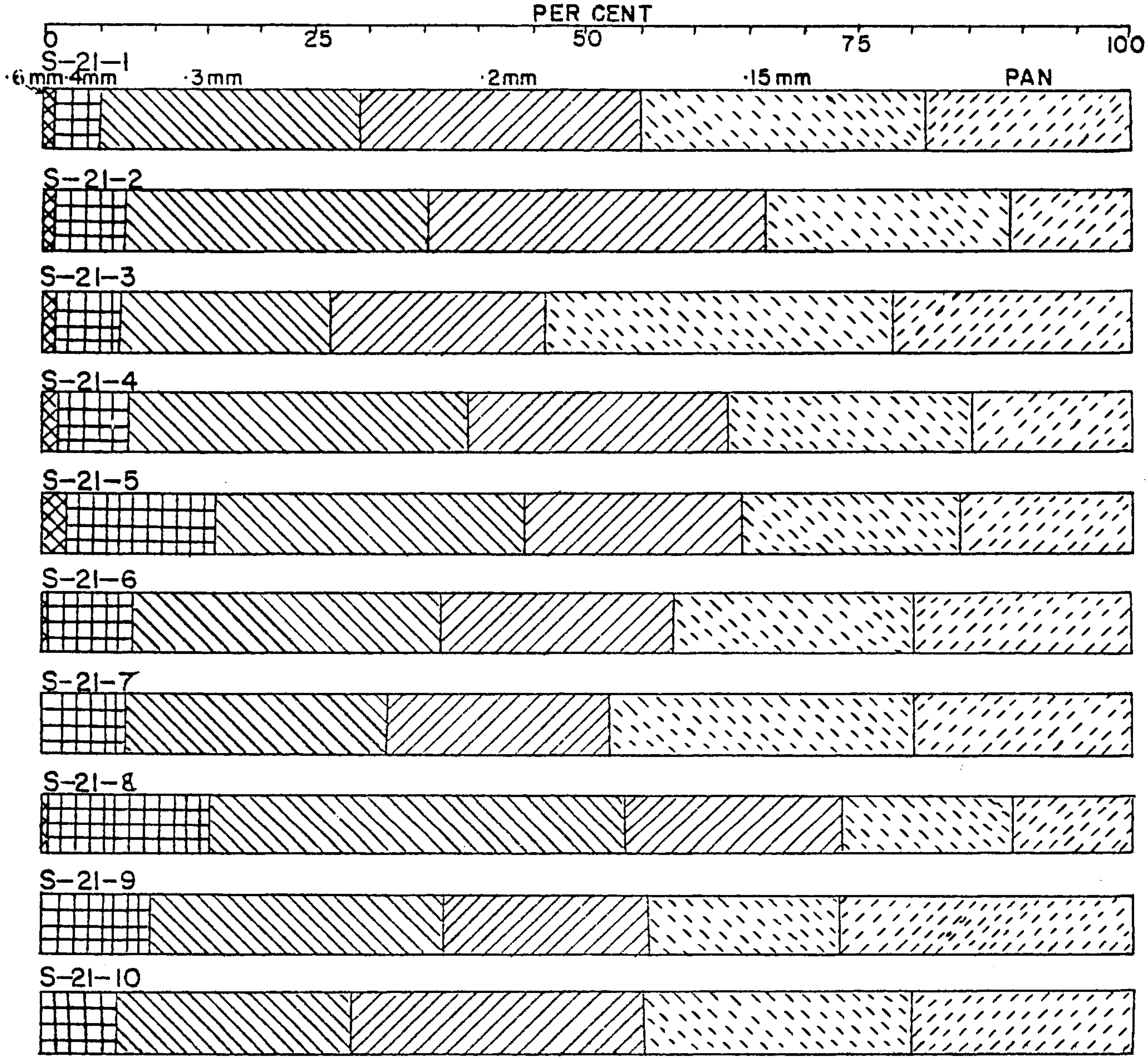


Figure 17. Grain size distribution of the St. Peter sandstone near Caledonia.

A partial chemical analysis of a representative, composite sample of the St. Peter sandstone in this area showed a total iron content of Fe as Fe_2O_3 of 0.09%.

Summary of St. Peter Sandstone Formation

There are several locations near the Twin Cities where large open pits could be excavated in the St. Peter sandstone. At these locations there is very little overburden and the topography is such that underground water would not be a problem in the upper 30 to 40 feet of the formation. Such conditions exist at the following locations.

1. In Washington County east of St. Paul, and south of Highway No. 12 in Township 128N. Range 18W.
2. In Dakota County west of Miesville near the Junction of Highway No. 61 with Highway 21. (See Fig. 15).
3. In Dakota County south of Farmington, a short distance north of the Castle Rock road intersection with Highway 65. (See Fig. 12).
4. In North Minneapolis along the N. P. railroad yards.

Each of the above locations is on or near a good highway and not far from railroad transportation.

Root Valley Sandstone

In the southeastern counties of Minnesota there is a sandstone 30 to 40 feet in thickness, lying between the upper portion of the Oneota dolomite and below the Shakopee dolomite. In the older geologic literature this horizon was known as the New Richmond sandstone. It is typically exposed along the highway west of Lanesboro, along the river bluffs at Preston, in Whitewater State Park and in many other places in that part of the State. The formation becomes thinner toward the north and west and in the regions of Mankato, Red Wing, Hastings and the Twin Cities it is only a few feet thick and consequently of little, if any, value as a source of high silica sand for industrial uses. In the southeastern counties, however, it could be excavated by tunneling into the hillsides. See Figure 18 for its textural characteristics.

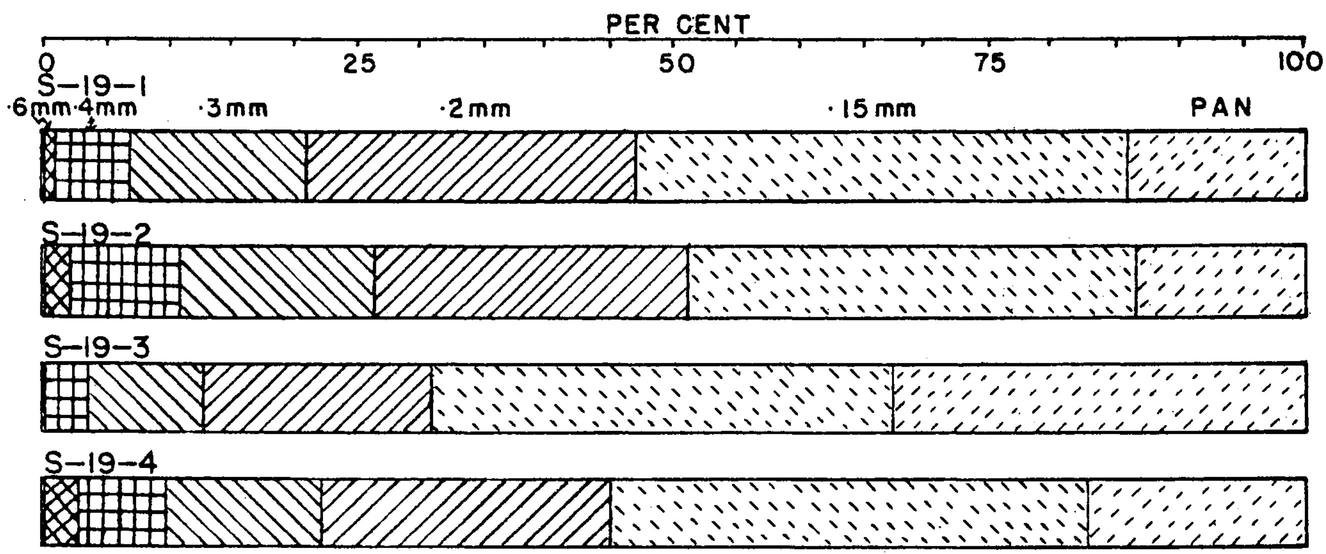


Figure 18. Grain size distribution of the Root Valley sandstone in Whitewater State Park.