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THE STRUCTURAL AND ORNAMENTAL STONES OF MINNESOTA

BY

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THE STRUCTURAL AND ORNAMENTAL STONES OF MINNESOTA.

By OLIVER BOWLES.

INTRODUCTION.

The building and ornamental stones of Minnesota, though far less valuable than the iron ores, rank second in value in the mineral output of the State. The growth of the industry has been gradual and has been subject to many fluctuations, due to decreasing demand for certain products and to increasing demand for others. Certain localities where quarrying once flourished have found other industries more remunerative and abandoned pits at such places bear witness to the former existence of the industry; other places, more favored geographically or possessing stone better adapted to meet the prevailing demands, have become centers for marketing.

In this bulletin the history of the industry is summarized, the rocks of Minnesota and their constituent minerals are described, and an outline of the geologic history is given. A brief account of the properties essential to the usefulness of stones is followed by a general discussion of the crystalline rocks of Minnesota. Detailed descriptions of the quarries, of their products, mode of operation, equipment, ownership, and means of transportation, form the main body of the report. As a guide for prospective operators undeveloped outcrops as well as quarries are described.

The writer takes this opportunity to acknowledge his obligation to Prof. F. F. Grout, of the University of Minnesota, for many valuable suggestions and for aid in the field work, mapping, collection of data, and criticism of manuscript; and to Mr. E. K. Soper for field work in some of the southeastern counties. Thanks are due to Mr. George S. Nishihara for preparing sketches and diagrams, and to Mr. E. F. Burchard, of the United States Geological Survey, for supplying statistics which it would have been impossible for the writer to obtain elsewhere. Mr. H. C. Whitaker, formerly editor of The Stone Trade, supplied valuable figures, showing the present demand for different types of stone. Mr. J. J. Cleveland, of St. Cloud, assistant engineer, determined the location of certain points the position of which it was necessary to fix for mapping. The tests of crushing strain and transverse strength were made by the experimental engineering department of the University of Minnesota under the direction of Prof. W. H. Kavanaugh. Acknowledgments are due to

Mr. Alfred W. Gauger for chemical analyses of various limestones and for some of the tests of specific gravity and porosity. The quarrymen throughout the State have cooperated in the work most cordially. Thanks are due particularly to Messrs. L. C. Brown, W. J. Holes, A. M. Simmers, and C. L. Atwood, of St. Cloud, and Mr. M. M. Williams, of Little Falls. Frequent reference has been made to the work of the late N. H. Winchell [1] on the building stones of the State.

Since the study of the stone resources of Minnesota was completed an agreement has been entered into between the United States Geological Survey, the Bureau of Mines, and the Bureau of Standards for a cooperative study of the stone resources and industry of the United States. Other bulletins like this, to be published by the United States Geological Survey, will therefore be prepared by that Survey in cooperation with these bureaus and with the geological surveys of the States that may be interested. In general the agreement provides that the United States Geological Survey shall gather data concerning the classification, extent, and geology of undeveloped and quarried deposits and the statistics of quarry output; that the Bureau of Mines shall gather quarrying, mining, and technologic data, with special reference to safety, efficiency of operations, and prevention of waste; and that the Bureau of Standards shall make all physical and chemical tests necessary to determine the value of the stone for structural use and for making concrete.

Since this cooperative arrangement became effective the author of this bulletin has represented the Bureau of Mines as quarry technologist.

DEVELOPMENT OF STONE QUARRYING IN MINNESOTA.

Rocks useful for structural or ornamental purposes outcrop in many parts of Minnesota. Limestones were the first to be utilized, partly on account of their easy workability as compared with granites and similar rocks and partly because they were situated in more populous regions.

LIMESTONES.

The first limestone quarry in Minnesota was opened in 1820 to build part of old Fort Snelling. The second quarry, so far as is known, is the one in Mendota from which limestone for Gen. Sibley's house was taken in 1835. (See Pl. XVII, *A*, and pp. 159, 160.) The Carli quarry, in Stillwater, now operated by the city of Stillwater, was opened in 1847 and another large quarry in 1854. The first quarry in Winona was opened in 1854 and was followed a few years later by several others. Three quarries were reported in Mankato at an early date, the first in 1853. The first quarry in Mantorville began

[1] Final report on the geology of Minnesota: Minnesota Geol. Survey, vol. 1, pp. 142–203, 1884.

GRANITE QUARRIES
Active (a)
Inactive (i)

STEARNS COUNTY

1. C. D. Schwab (i)
2. Monarch Granite Co. (a)
3. Black Diamond Granite Co. (i)
4. Black Diamond Granite Co. (a)
5. Granite City Granite Co. (a)
6. National Quarry Co. (a)
7. Simmers & Campbell (a)
8. Melrose Granite Co. (i)
9. Melrose Granite Co. (a)
10. Melrose Granite Co. (a)
11. Melrose Granite Co. (i)
12. Melrose Granite Co. (a),
13. St. Cloud Granite Works (a)
14. Frick & Borwick Granite Co. (a)
15. S. A. Jones (i)
16. Pioneer Granite Co. (a)
17. Holes Bros. (i)
18. Melrose Granite Co. (a)
19. Empire Quarry Co. (a)
20. Empire Quarry Co. (a)
21. C. L. Atwood (i)
22. Holes Bros. (i)
23. Holes Bros. (a)
24. Robinson Bros. (a)
25. J. B. Robinson (i)
26. John Doerner (a)
27. Morgan Flaherty & Son (i)
28. Northwestern Granite Co. (a)
29. Granite City Granite Co. (i)
30. Black Diamond Granite Co. (i)
31. Robert Graham (i)
32. L. E. Noreen (a)
33. L. E. Noreen (a)
34. Streitz Bros. (a)
35. St. Cloud Granite Works (a)
36. Robert Graham (a)
37. Melrose Granite Co. (a)
38. United Granite Co. (a)
39. Rockville Granite Co. (a)
40. Clark & McCormack (a)
41. Homer Tenney (i)

SHERBURNE COUNTY

42. August Erickson (i)
43. August Erickson (a)
44. John Kellas (a)
45. Reformatory (a)
46. Reformatory (i)
47. East St. Cloud Granite Co. (a)
48. Hilder Granite Co. (a)
49. Old Rock Island (i)

BENTON COUNTY

50. Fischer's quarry (a)
51. Sauk Rapids Granite Co. (a)
52. Sauk Rapids Granite Co. (a)
53. Sauk Rapids Granite Co. (a)
54. Sauk Rapids Granite Co. (a)
55. Coates quarry (a)
56. Swanson & Hagstedt (a)

MAP OF THE ST. CLOUD REGION, MINNESOTA, SHOWING ROCK OUTCROPS AND QUARRIES

Scale 1/62,500

1 ½ 0 1 2 3 MILES

1917

LEGEND

Red granite — Gray granite — "Rockville" granite — Diorite — Gabbro

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

operations in 1856, and two others between 1865 and 1870. The rock from these quarries was hauled to neighboring towns before railways were constru ted. By 1856 the quarry industry in the State had become acti e.[1]

Excavations were begun on Barn Bluff, Red Wing, in 1865 and at the Kasota quarries in 1868. Between 1870 and 1900 stone was quarried more or less extensively at Caledonia, La Crescent, Brownsville, Whalen, Rushford, Fountain, and a number of other southern towns, and also in Minneapolis and St. Paul.

CRYSTALLINE ROCKS.

The quarrying of crystalline rocks in Minnesota began about 1867. The first granite quarry recorded was opened near the center of Sauk Rapids village. It was first owned by F. A. Fogg.[2] A quarry opened by Breen & Young in East St. Cloud in 1868 supplied stone for the corners, steps, and trimmings of the United States customhouse and post office at St. Paul. Other quarries near Sauk Rapids were opened a little later. Several quarries in both the red and the gray granites in the neighborhood of St. Cloud were opened between 1870 and 1885. Between 1880 and 1890 the industry prospered. Between 1890 and 1900 the output fluctuated considerably but on the whole grew slowly. From 1900 to the present time the growth of the granite-quarrying industry has been strong and steady, and the organization of at least three new companies in the St. Cloud region in 1913 gives promise of further expansion. (See Pl. I.) Detail maps (Pls. II and III) show the active quarries in St. Cloud and Haven townships. During the last 10 to 15 years certain outlying districts, the rocks of which appear to be related to those at St. Cloud, have been exploited to some extent. Several quarries have been worked in Morrison County, though none of them are now active. In Kanabec County, at Warman, a beautiful gray granite was first worked in 1907 and is still being quarried. The granites farther north have been but little used. About 1890 a quarry was opened at Hinsdale siding, but it ceased operation about two years later. A little red granite was quarried many years ago at Beaver Bay, on Lake Superior.

In the upper Minnesota River valley crystalline rocks, including diorites, granites, and gneisses, occur at several places between New Ulm and Ortonville, and have been excavated at Morton, North Redwood, Granite Falls, Montevideo, and Ortonville. At Ortonville active quarrying was begun in 1898 and was continued for several years. The beautiful deep-red stone quarried there is particularly attractive. Later the rock was used only for crushing, and work in these quarries is entirely suspended.

[1] Many of the dates given are taken from Winchell, N. H., Final report on the geology of Minnesota, vol. 1, pp. 142-203, 1884.

[2] Idem, vol. 2, p. 433, 1888.

Quarrying was begun at North Redwood in 1898 and has been carried on successfully ever since. At Morton the Saulpaugh Co. employed about 300 men from 1884 to 1887. Subsequently John Anderson operated on the same bluff, and in 1898 the present Anderson Granite Co. was formed.

Between North Redwood and Ortonville a number of small excavations were made, but the rock is of inferior quality and none of these quarries are now being worked. (See pp. 69–72.)

The gabbros of Minnesota have been quarried extensively only in the neighborhood of Duluth. About 1896 active quarrying was carried on at a number of points in the bluff west of the city. The large quarry now operated by the Duluth Crushed Stone Co. was opened in 1903. A quarry in diabase has been operated for a number of years at Two Harbors. The diabase area at Taylors Falls was excavated to furnish crushed stone for the big dam of the General Electric Power Co. but has not been further developed. In fact the gabbro is but little quarried except to obtain riprap or crushed stone.

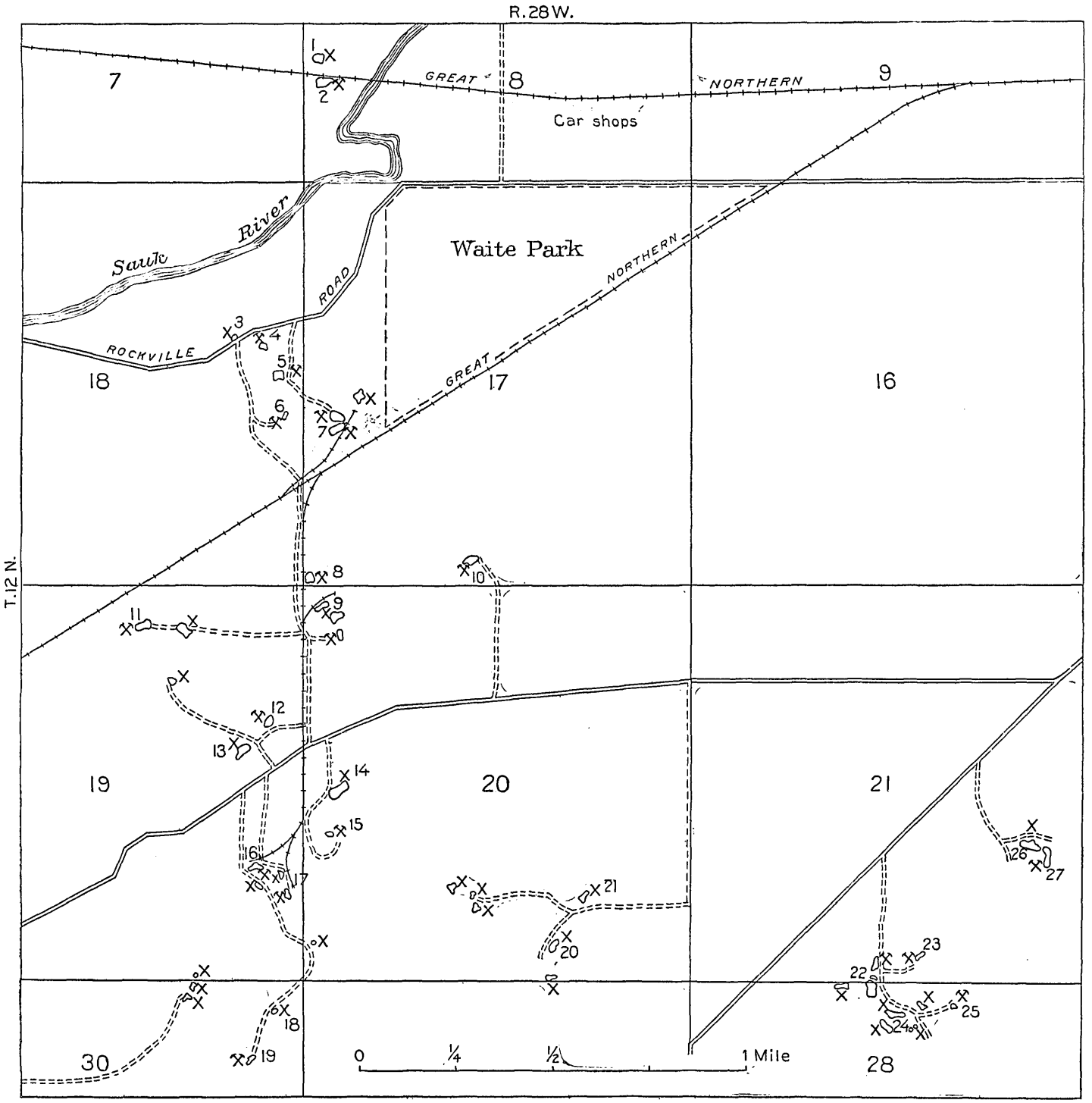
SANDSTONES.

Sandstone was quarried at Sandstone, Pine County, in 1885, and was hauled to Hinckley by teams. Some quartzite was quarried near Courtland in 1859 and near Luverne and Pipestone a few years later. The Fond du Lac quarries supplied "brownstone" for many structures built between 1870 and 1900.

USES OF STONE.

As may be inferred from the number and distribution of quarries, the rapidly growing population of Minnesota used stone extensively in early days for structural use. Nearly all the stone quarried was employed for building bridges, culverts, foundations of houses and barns, for erecting dwellings, churches, and public institutions, and for making lime. Comparatively little ornamental stone was quarried before 1890. The conditions to-day, however, are very different from those of 30 to 40 years ago, when building stone constituted almost the entire product. A large and ever-increasing share of the quarry output is crushed stone, part of which is used for concrete and part to supply the present widespread demand for better roads and streets. Curbstone and paving blocks are also in great demand.

The use of concrete for foundations, bridges, culverts, curbing, footings, and other structures has markedly reduced the demand for building stone and for lime. The use of concrete has the advantages of ease in transportation and economy in time and labor and has consequently reduced the demand for the rougher grades of building stone and has greatly increased the demand for crushed stone. The stone men are to-day brought into keen competition with the advocates of concrete. If properly employed, concrete may be used to



LEGEND

Quarry excavation

Quarry, active

Quarry, inactive

QUARRY OWNERS OR OPERATORS

1. C. D. Schwab
2. Monarch Granite Co.
3. Black Diamond Granite Co.
4. Black Diamond Granite Co.
5. Granite City Granite Co.
6. National Quarry Co.
7. Simmers & Campbell
8. Melrose Granite Co.
9. Melrose Granite Co.
10. St. Cloud Granite Works
11. Melrose Granite Co.
12. Frick & Borwick Granite Co.
13. S. A. Jones
14. Holes Bros.
15. Melrose Granite Co.
16. Empire Quarry Co.
17. Empire Quarry Co.
18. Holes Bros.
19. Holes Bros.
20. C. L. Atwood
21. C. L. Atwood
22. Streitz Bros.
23. St. Cloud Granite Works
24. L. E. Noreen
25. L. E. Noreen
26. Robert Graham
27. Melrose Granite Co.

MAP SHOWING LOCATION OF GRANITE QUARRIES IN WEST-CENTRAL ST. CLOUD TOWNSHIP, STEARNS COUNTY, MINN.

advantage for many purposes, but it lends itself more readily than stone to dishonest practices by unscrupulous builders. The concrete contractor may make profits on low bids by using lean mixtures, whereas the stone contractor must use all stone. Inferior concrete work, however, undoubtedly reacts in favor of stone.

As a consequence of the changed conditions indicated many quarries that were once active are now idle, and many that were worked for the rougher grades of structural stone now produce crushed rock only.

On the other hand, the increased purchasing power of the people has led to a demand for the better grades of structural and ornamental material. A considerable area of the State has passed beyond the pioneer stage, and more commodious and permanent structures are built. Civic pride demands the finest stone for public buildings, and every year more and more costly monuments and spires are added to cemeteries and public squares.

To-day the inactive quarries of the State are chiefly those that formerly produced rubble and lime. The demand for riprap is still great, as it is used extensively for river improvement and harbor protection. The demand for crushed rock is also great and is becoming greater year by year. The market for high-grade structural and ornamental stone is constantly becoming better. Cities are becoming larger—and more smoky; and as soot adheres but slightly to polished surfaces, polished stone is used more and more for monuments, pillars, columns, and panels. On account of its greater permanency granite is now more widely used for monuments. The industry has made its greatest advances in producing the better grades of structural stone and in increasing its output of crushed stone.

PRODUCTION.

In connection with the history of Minnesota stone quarrying, figures showing the production of stone are of interest. The following table, compiled from volumes of "Mineral Resources" of the United States Geological Survey, illustrates the progress of the industry from early years and indicates its present proportions:

Value of stone quarried in Minnesota for various years.

1880	$255,818
1890	1,101,008
1900	930,938
1910	1,997,145
1911	1,702,525
1912	1,845,746
1913	1,952,686
1914	1,513,039
1915	1,492,341

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The output at 10-year intervals shows remarkable fluctuations. In 1900 the value was less than it was 10 years before, but by 1910 it had more than doubled. The highest production was reached in 1910. In value of production Minnesota in 1915 ranked seventeenth among the States.

In the following tables [a] the stone produced in Minnesota is classified (by value) as to kind, uses, and sources (geologic formations). The rocks are divided into four great groups, granite, basalt (including gabbro), limestone, and sandstone (including quartzite).

Value of stone produced in Minnesota in 1915.

Granite	$841,943
Basalt (gabbro)	80,640
Limestone	395,763
Sandstone and quartzite	173,995
	1,492,341

If the value of lime burned from Minnesota stone should be added, the value of the limestone would be increased to $491,953.

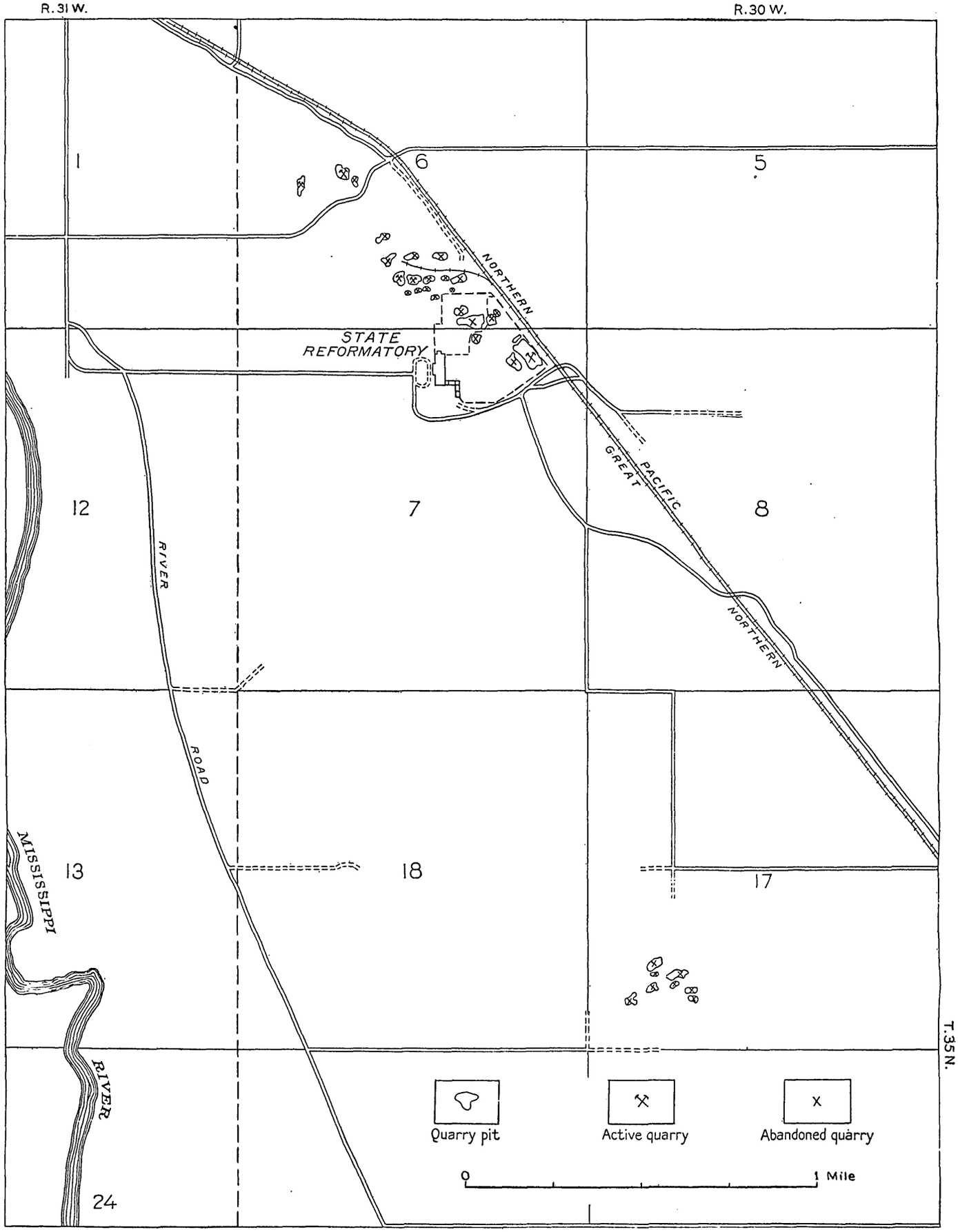
Kinds of stone produced in Minnesota in 1915, tabulated by uses.

	Granite.	Basalt (gabbro).	Limestone.	Sandstone and quartzite.	Total.
Building or trimming:					
Rough	$2,560	.....	$34,738	$430	$276,336
Dressed	117,017	.....	80,937	40,654	
Rubble	3,714	$4,165	22,198	5,291	35,368
Monumental:					
Rough	68,558	.....	.....	.....	573,169
Dressed	504,611	.....	.....	.....	
Paving blocks	123,940	.....	.....	38,771	162,711
Curbing	100	.....	.....	25,241	25,341
Flagging	.....	.....	140	.....	140
Riprap	2,295	350	58,697	1,990	63,332
Crushed:					
For road making	15,540	11,305	4,218	26,223	329,039
Railroad ballast	.....	.....	.....	.....	
Concrete	.....	64,820	177,093	29,840	
Sugar refining	.....	.....	2,100	.....	2,100
Ore flux	.....	.....	664	.....	664
Other uses	3,608	.....	14,978	5,555	24,141
	841,943	80,640	395,763	173,995	1,492,341

Quantity, value, and uses of granite produced in Minnesota in 1915, by counties.

County.	Number of plants.	Building (rough and dressed).		Monumental (rough and dressed).		Paving blocks.		Crushed stone.		Other value.	Total value.
		Quantity.	Value.	Quantity.	Value.	Number of blocks.	Value.	Quantity.	Value.		
Benton, Lac qui Parle, Redwood, and Renville	6	*Cu. ft.* 17,517	$23,231	*Cu. ft.* 23,379	$43,349	527,715	$40,826	*Short tons.*	.....	$4,119	$111,525
Sherburne	5	25,108	30,399	14,727	32,166	585,000	44,750	12,950	$15,540	4,429	127,284
Stearns	19	27,802	65,947	181,285	497,654	747,000	38,364	.....	.....	1,169	603,134
	30	70,427	119,577	219,391	573,169	1,859,715	123,940	12,950	15,540	9,717	841,943
Average price	.....	.....	1.70	.....	2.61	.....	[b]66.64	.....	1.20	.....	.....

[a] Prepared by E. F. Burchard, of the United States Geological Survey. [b] Per thousand.



MAP SHOWING LOCATION OF GRANITE QUARRIES IN HAVEN TOWNSHIP, SHERBURNE COUNTY, MINN.

Grouped by geologic systems, the total value of the product given for each division is as follows:

Value of stone produced in Minnesota in 1915, by geologic systems.

Devonian; Mower County, all made into lime.	
Ordovician:	
Galena; Dodge County	$8,320
Platteville; limestone of Hennepin, Olmsted, Ramsey, and Rice counties	183,646
Shakopee; limestone of Washington County	3,720
Oneota; limestone of Blue Earth, Fillmore, Goodhue, Houston, Le Sueur, Nicollet, and Winona counties	200,377
Cambrian; sand and sandstone, no production.	
Keweenawan; the granites of Sherburne, Benton, and Stearns counties; gabbro of Lake and St. Louis counties; and the sandstone of Pine County.	1,019,655
Huronian; quartzite of Nicollet, Pipestone, and Rock counties	63,982
Laurentian; granites of Lac qui Parle, Redwood, and Renville counties	12,641
	1,492,341

Lime burned from Minnesota stone in 1915 was valued at $96,190, most of which sum must be credited to the Oneota formation and the remainder to the Shakopee and Devonian.

A list of the buildings in which Minnesota stone has been used is given on pages 211–213.

ROCK MINERALS.

PHYSICAL PROPERTIES.

Rocks are made up of minerals—small crystalline bodies firmly joined together—but a detailed discussion of the minerals that compose the stones of Minnesota is not within the scope of this bulletin. Anyone who desires to read a comprehensive discussion of this subject can find it in one of the many standard works on mineralogy.[1]

Many minerals can be identified by their physical properties as observed with the naked eye or with the eye aided by a small pocket lens. Others can be identified by grinding down a small fragment of the rock in which they occur until it is transparent and then studying it with a microscope. Minerals may also be identified by chemical tests.

The principal physical properties by which a mineral can be identified are its color, streak, hardness, cleavage, form, and specific gravity.

The color of a mineral is the property that most readily appeals to the eye; and color, though somewhat variable in the same mineral, is useful in identification. Variations in color are usually due to the presence of impurities. Thus, the smoky color of some quartz grains is caused by minute grains of carbon or other dark inclusions, and the pink color of orthoclase by small particles of hematite.

[1] Dana, J. D., Manual of mineralogy, New York, 1912. Kraus, E. H., Descriptive mineralogy, Ann Arbor, Mich., 1911. Phillips, A. H., Mineralogy, New York, 1912.

By streak is meant the color of the fine powder which, for the harder minerals, is best obtained by rubbing the mineral on a plate of unglazed porcelain, or which, for the softer minerals, may be obtained by scratching the surface with a pocketknife. With most minerals streak is more constant than color.

Minerals differ greatly in hardness. A "scale of hardness" has been devised to express this property numerically. In this scale 1 is applied to minerals that can be scratched easily with the finger nail, such as talc or clay; 2 to those that can be scratched with the finger nail with greater difficulty, such as gypsum; 3 to those that can be scratched easily with a knife, such as calcite (limestone); 4 to those that can be scratched with greater difficulty with a knife, such as fluorite; 5 to those that can be scratched with very great difficulty with a knife, such as apatite; 6 to those that can be scratched with a file but not with a knife, and that will scratch glass, such as feldspar; and 7 to those that can not be scratched with a file, such as quartz. Minerals harder than 7 are not of common occurrence in building stones.

Cleavage is defined as the tendency of a mineral to break in certain definite directions, the breakage yielding more or less flat surfaces that have brightly reflecting faces. If a piece of granite is held between the observer and a source of light at a level below the eye, the bright faces that may be observed are the cleavage planes of the crystals of feldspar. As some minerals show such planes and others do not, cleavage thus becomes a useful means of identifying certain minerals. Under favorable conditions, such as are afforded by protected cavities, many minerals may grow as crystals having plane surfaces. In rocks, however, most of the crystal faces are destroyed by the intergrowth of crystals, which form a crystalline mass. But though the crystal form may be variable or may be entirely obliterated by intergrowth, cleavage remains constant. The rectangular cleavage fragments of feldspar and the cleavage angles of hornblende (56° and 124°) are characteristic.

The specific gravity of a mineral is its weight compared with the weight of an equal volume of water. Some minerals, such as calcite or quartz, are light, being little more than $2\frac{1}{2}$ times as heavy as water; others, such as iron ores, are heavy, being about 5 times as heavy as water. With practice, one can estimate specific gravity fairly well with the hand. Most rocks, however, contain so many different minerals that they can not readily be identified by their weight.

The minerals that occur commonly in Minnesota building stones are briefly described below.

SILICATES.

Kaolinite.—Kaolinite, kaolin, or clay is a hydrous silicate of aluminum and is the chief constituent of shales and slates. It has a characteristic earthy odor and a tendency to absorb water. Such

absorption promotes disintegration in shales and argillaceous sandstones. Kaolin is produced chiefly by the decomposition of feldspar in granites and allied rocks; the clay particles, in separating out, cloud the feldspar, and the degree of cloudiness indicates the extent to which decomposition has progressed.

Feldspar.—There are several kinds of feldspar, which are distinguished by differences in composition and crystallization. The principal varieties are orthoclase, microcline, and plagioclase. There are several kinds of plagioclase, but their distinction without a microscope is difficult and likely to be inaccurate, and no attempt will here be made to indicate methods of distinguishing them.

The feldspars are important constituents of granites and certain other igneous rocks, and consequently form one of the chief groups of minerals in building stones. Though less resistant than quartz, they withstand weathering remarkably well. On alteration by weathering they form chiefly clays. The beauty and permanence of the structures made from the granites of Minnesota quarries are due largely to the attractive colors, susceptibility to polish, and resistance to weathering of the feldspars in the rock.

Orthoclase is a silicate of aluminum and potassium. It has a hardness of 6, a specific gravity of 2.5, and a perfect cleavage, which may be recognized by the brilliant reflection of light shown by its crystals when viewed at certain angles. Its color is usually some shade of pink but may be gray or white. Orthoclase is an essential constituent of most granites, commonly forming nearly half the mass of the rock. Much of the orthoclase in Minnesota granites is remarkably intergrown with stringers of quartz or with other feldspars (see p. 51), but these stringers can be seen only with the microscope. Orthoclase is more resistant to weathering than plagioclase.

Microcline, though having the same composition as orthoclase, crystallizes differently. In rocks it is practically impossible to distinguish microcline from orthoclase without the use of a microscope. It is very common in the granites of Minnesota, and in some of them it is the most abundant feldspar.

The plagioclase of most common occurrence is a silicate of aluminum, calcium, and sodium, and is commonly called lime-soda feldspar. In hardness, specific gravity, and cleavage it is similar to orthoclase, but its color is characteristically light gray or dark gray rather than pink. In many medium or coarse grained rocks it may be distinguished from orthoclase by the lines or striations on its cleavage surfaces. It occurs in different amounts in most granites and is the characteristic feldspar in the darker rocks, such as the diorites, diabases, or gabbros. Plagioclases are more easily altered than orthoclase or microcline. By surface weathering they form chiefly clay, but by deep-seated hydrothermal alteration they may form sericite or zoisite.

Mica.—There are two common types of mica—muscovite, or white mica (improperly called "isinglass"), and biotite, or black mica. Muscovite is a hydrous silicate of potassium and aluminum and is sometimes called potash mica. Biotite contains magnesium and iron in addition to the constituents of muscovite. Both varieties have very perfect cleavage in one direction, being made up of thin, easily separable elastic plates piled one upon another.

The hardness of mica is 2 to 3. Biotite is more common than muscovite and forms the dark grains or specks in many granites. Muscovite appears in a few granites in the form of small silvery plates. Biotite alters to chlorite, quartz, iron oxide, and carbonates. Muscovite is more stable.

Hornblende.—The most common member of the amphibole group of minerals is hornblende, a complex silicate of calcium, magnesium, iron, and aluminum. It is very dark green to pitch black in color, has a hardness of about 6, and a perfect prismatic cleavage. It has two cleavages, which make angles of about 56° and 124° with each other, but in grains exposed on rock surfaces it commonly shows only one. It resembles biotite, but it will not split into thin plates, and it is much harder—so hard that while unaltered it can not be scratched with a knife, whereas mica can be scratched easily. Hornblende is the most common dark mineral in granites and diorites and is present in many schists and gneisses. By surface weathering it alters to quartz, carbonates, and iron oxides. It is regarded as a fairly stable mineral, one that resists atmospheric decomposition better than most dark minerals, and hence its presence is not undesirable in a building stone. Its alteration to chlorite or epidote, if pronounced, results in green stains.

Augite.—Though it is placed in another group—the pyroxenes—augite is similar in composition to hornblende. The two minerals are often confused. Some features that distinguish augite from hornblende are its less brilliant cleavage surfaces, the difference in its cleavage angles which approach 90° rather than 60°, and in some varieties its somewhat metallic luster. Its hardness and color are similar to those of hornblende. It is a characteristic constituent of the dark igneous rocks, such as diabase and gabbro, though occasionally it is a minor constituent of granite or diorite. Its most common associates are plagioclase feldspar, olivine, and magnetite. The alteration of augite to hornblende has been frequently noted. This type of alteration may take place at great depth and does not necessarily diminish the value of the rock as a building stone. Augite is less stable than hornblende; it weathers somewhat readily, giving the same alteration products. Its presence is not desirable in structural stone that is to be exposed to the weather.

Chlorite.—Chlorite is a hydrous silicate of aluminum, iron, magnesium, and rarely manganese. It has a hardness of about 2 and generally a dark-green color. It is formed by hydrothermal alteration and also by weathering of the original constituents of a rock, commonly by the alteration of hornblende, augite, or biotite. Chlorite gives the characteristic color to "greenstones," which are dense, basic igneous rocks that have undergone alteration. Its presence in building stones generally indicates surface weathering.

Epidote.—The mineral epidote is a hydrous silicate of calcium, aluminum, and iron. In igneous rocks it is usually an alteration product. Its hardness is 6 to 7, its specific gravity 3.3 to 3.5, and its color yellowish green. It forms "green lines" and stains in many granites, and in some is sufficiently abundant to give the whole rock mass a bright yellow-green color. It alters to an earthy iron-stained material.

Olivine.—In chemical composition olivine is a silicate of iron and magnesium. It has a hardness of 6.5 to 7, a specific gravity of 3.2 to 3.6, and an olive-green color. It occurs as glassy grains in basic rocks, such as diabase, gabbro, or basalt. It alters readily to serpentine, talc, or chlorite.

Talc.—Talc is a hydrous silicate of magnesium. It has a hardness of 1, a soapy or greasy feel, and an apple-green to white color. It is a product of the decomposition of hornblende, augite, or olivine. It is often called soapstone or soap rock. Much of what is designated "soap rock" by quarrymen, however, is clay or a mixture of limestone and clay and contains no talc.

Sphene.—Titanite or sphene is a silicate of calcium and titanium. It is a hard brown mineral occurring in many granites as wedge-shaped crystals which, however, are generally too small to be recognized with the unaided eye. It is a common microscopic accessory mineral in "St. Cloud gray" granite. Its presence does not impair the quality of the stone.

Zircon.—Zircon is a silicate of zirconium. It occurs as microscopic tetragonal crystals, usually in or near biotite or hornblende. In the granites of central Minnesota the crystals of zircon, which occur in biotite, are commonly surrounded by dark rings known as "pleochroic halos." They can be seen only with the microscope.

Garnet.—Common red garnet is a silicate of iron and aluminum. It has a hardness of about 7, poor cleavage, white streak, and red color. It appears as perfect crystals, generally with diamond-shaped faces, or as irregular granular masses of different sizes, the largest one-fourth to one-half inch across. Garnet is usually found in metamorphic rocks, such as gneisses or schists, though occasionally it is found in granites. It occurs in certain schist inclusions in the granites of central Minnesota.

CARBONATES.

Calcite.—Calcite is calcium carbonate ($CaCO_3$). It has a hardness of 3. In most Minnesota occurrences it is white to yellow, but in the marbles of some other States and of certain foreign countries it is red, blue, green, and other colors. Calcite crystals show perfect cleavages in three directions, meeting at angles of about 75°. In limestones, however, calcite is commonly in granular form and shows no cleavage. It effervesces in cold dilute hydrochloric acid. It is very abundant in nature, forming the chief part of many limestones and occurring as interstitial filling in some sandstones. It is not common in igneous rocks and its presence in them practically always indicates alteration. Calcite dissolves slowly in water containing carbon dioxide.

Dolomite.—Dolomite is a carbonate containing calcium and magnesium ($CaMg(CO_3)_2$). It has the same hardness, color, and cleavage as calcite, from which it may be distinguished by the fact that it will not effervesce in cold dilute acid. It is common in most of the limestone beds of Minnesota.

OXIDES.

Quartz.—Quartz is silicon dioxide (SiO_2). It has a hardness of 7 and so is the hardest of all the common minerals in rocks. It is generally clear and glassy but may be smoky, milky, or blue. In open spaces it may form beautiful hexagonal crystals, but in rocks it appears as rounded or irregular grains. It has no cleavage, is insoluble in all common acids, and has a specific gravity of 2.6. It commonly forms the glassy grains in granites, and is the chief part of most sandstones. It is important in building stones from the fact that it resists weathering better than other common minerals. It is abundant in the red granites of Minnesota but is less plentiful in the gray granites. It constitutes almost the entire mass of the sandstones of Kettle River and of the quartzites of Rock and Pipestone counties.

Magnetite.—Magnetite is an oxide of iron (Fe_3O_4). It is a hard black mineral, makes a black streak, and is readily attracted by a weak magnet. It occurs in basic igneous rocks, commonly in grains large enough to be seen with the naked eye. It is less abundant, though almost as widespread, in the siliceous rocks. It is present in small grains in practically all granites, though generally recognizable only with the microscope. It is a stable oxide and does not readily alter to forms which cause stains when exposed to the weather. Some grains that appear to be magnetite may be ilmenite ($FeO.TiO_2$), a mineral which is similar in appearance but which is not so readily attracted by the magnet.

Hematite.—The mineral hematite is an oxide of iron (Fe_2O_3). It is red to black in color and has a red-brown streak. It occurs as a hard mineral of metallic luster or as a soft earthy aggregate and is the chief iron ore in Minnesota. In many building stones it occurs as microscopic grains. The color of the red granites of Minnesota is largely due to fine microscopic inclusions of hematite, mostly in orthoclase or microcline. It also forms a large part of the cementing material in some sandstones. It alters slowly to limonite.

Limonite.—Limonite is a common oxide of iron, having the same chemical composition as hematite except that it contains also water. The hard varieties are brown to black in color and have a yellow-brown streak. Earthy varieties are yellow and soft. It results from the decomposition of pyrite and other minerals that contain iron, such as hornblende, biotite, or augite. Limonite gives a buff or yellow color to many limestones and sandstones. The yellow "Kasota" marble and many of the buff limestones in southeastern Minnesota owe their rich color chiefly to the fine grains of limonite that are scattered through them. Occasionally limonite forms unsightly stains on the surfaces of building stones.

SULPHIDES.

Pyrite.—Pyrite is a sulphide of iron (FeS_2). It is brass-yellow in color, has a hardness of 6 to 6.5, and occurs as little crystals or grains in many rocks. By weathering, pyrite oxidizes more or less rapidly to limonite. Some authors have stated unreservedly that rock containing pyrite will stain readily by weathering, but many structures made of stone containing an abundance of pyrite have stood exposed to the weather for 75 or 100 years without staining. If the pyrite is pure and in the form of nonporous crystals, it is usually resistant. If it is mixed with marcasite, it will rapidly oxidize and produce stains.[1]

Marcasite.—Marcasite has the same chemical composition as pyrite but differs from it in crystal form. Its physical properties are similar to those of pyrite, and it is usually difficult to distinguish the two minerals. Marcasite may also occur as scattered grains in building stones but is less common than pyrite. By weathering, it oxidizes to limonite. It alters more readily than pyrite and must, on that account, be regarded as a more serious impurity in structural stone designed for exterior use. Minnesota building stones are remarkably free from both pyrite and marcasite.

PHOSPHATES.

Apatite.—Apatite is a phosphate of calcium. It occurs in building stones, generally as microscopic prismatic crystals that form inclusions in other minerals. Its presence has practically no influence on the quality of the stone.

[1] For a complete discussion of sulphide decomposition see Bowles, Oliver, The technology of marble quarrying: Bur. Mines Bull. 106, pp. 30-32, 1916.

ROCKS.

CLASSIFICATION.

Rocks are classified, according to their origin, into three great groups—igneous, sedimentary, and metamorphic. Only rocks that may be used as building stone are described in this bulletin.

Igneous rocks are those which originated from a molten mass or magma that cooled and solidified. Differences in the conditions of solidification produce rocks of different textures. Magmas that cooled very slowly at great depth commonly formed coarse-grained rocks, such as granite or gabbro; those that cooled rapidly commonly formed fine-grained rocks, such as basalt. The igneous rocks of economic importance in Minnesota are mostly granite, but include also smaller amounts of diorite, gabbro, basalt, and diabase.

Sedimentary rocks are sometimes referred to as "stratified," for they are formed of sediments that were laid down in successive strata or layers. Most of the materials of which they are formed have been derived from igneous rocks through disintegration. The process of rock decay or disintegration, though apparently very slow, is continuous and produces results of immense magnitude. Alternate frost and heat open innumerable fractures in rocks, chemical constituents of the atmosphere and of rain water penetrate these fractures and dissolve out parts of the rocks; and rain, streams, waves, or tides break loose the shattered fragments, grind them up, and transport them far from their source. Wind, too, is an agent of transportation. Millions of tons, even cubic miles of rock, are thus disintegrated and carried away to oceans or lakes where they are deposited as sediment. In addition to the products of rock decay, myriads of organisms that inhabit the ocean secrete calcium carbonate from the sea water to form their shells, which on the death of the organisms add to the accumulations of rock-forming material. Thus three great processes—rock disintegration, transportation, and redeposition—are now at work and have been at work for ages; and these processes, aided, as indicated, by organic agencies, have formed most of the sedimentary rocks. Four great types of rocks are thus formed—conglomerate, sandstone, shale, and limestone or dolomite.

Metamorphic rocks are rocks of either igneous or sedimentary origin which have been profoundly altered by dynamic, chemical, or thermal processes. The chief agencies that produce such changes are pressure, heat, and chemical reaction. Under great pressure and high temperature rocks deep in the earth may become plastic and by earth movement may become tilted or folded into complex forms. Pressure may cause recrystallization, and thermal waters may dissolve, transport, and reprecipitate many minerals. Thus new rocks may be formed whose texture and composition are entirely distinct from those of the unaltered igneous or sedimentary rocks.

IGNEOUS ROCKS.

Granite.—Granite is a completely crystallized rock consisting of distinctly visible grains and is regarded as originating at considerable depth below the surface. It was once liquid, but on cooling its constituent minerals slowly crystallized out, the crystals interlocking with one another. The chief minerals in granite are orthoclase, microcline, plagioclase, quartz, and mica or hornblende. These are usually accompanied by magnetite, apatite, zircon, pyrite, or sphene. All the essential constituents of granite except mica are as hard as or harder than steel, so that it is hard to cut and dress.

The color of granite depends largely on the color of the feldspar it contains; and, as feldspar is red, pink, or some shade of gray or white, granites are red, pink, or gray. If hornblende or biotite is abundant and is evenly scattered through it in fine grains the rock may be almost black. The granites of the upper Minnesota River valley are mostly red or pink; those of central Minnesota are red, gray, or black, and occur in many complex and interesting relations. (See pp. 54–57.)

Granites are classified as fine grained, medium grained, or coarse grained. Medium-grained granites are those in which the feldspar crystals average about one-fourth of an inch in diameter. A granite in which some of the crystals of feldspar are much larger than the others is called a porphyritic granite. In building or ornamental stone uniformity of texture is desirable. Granites are named from the most abundant ferromagnesian mineral they contain, being called, for example, biotite granite or hornblende granite.

Some quarrymen desire to know the depths to which granite may extend and whether there is danger that a body of the rock may run out. In this respect granites and other deep-seated igneous rocks differ notably from sandstones, limestones, or other sedimentary rocks. The sediments were laid down originally as nearly horizontal beds and may be of relatively slight thickness, so that in a given area they may in time be quarried out. Granite, on the other hand, comes up from below; its depth is unknown but in general is very great and may be measurable even in miles. The depth to which it may be quarried is generally governed by the position of the ledges worked and the ease of extraction.

The lateral extent of granite, like its depth, is usually great. Where all its outcrops are of similar rock over a considerable area (as, for example, in Stearns County, Minn.), they are probably not separate individual rock masses but are parts of one great body or mass of granite that underlies the whole area or even the whole region. Most of this mass is covered with glacial drift, through which the granite projects here and there in knobs or ridges that rise from it like islands from a sea, and all these projections are, to continue the

simile, united at the sea floor. In most areas of granite the mass of rock is almost unlimited, and the supply available for quarrying depends on many considerations, such as ease of transportation and stripping, and quality of stone.

Aplite.—Aplite is a name given to a fine-grained light-colored granite that usually occurs in dikes.

Syenite.—Syenite consists essentially of orthoclase feldspar and some dark mineral, such as hornblende or biotite. It differs from granite in containing no free quartz.

No true syenite is quarried in Minnesota. Winchell [1] calls many of the crystalline rocks quarried in the St. Cloud region syenite, a designation quite in accord with his definition, for he states that "Syenite differs from true granite in containing the mineral hornblende instead of mica, both being otherwise alike composed of quartz and feldspar"; [1] but this definition is quite different from that given above.

Quartz monzonite.—Quartz monzonite is similar to granite except that the orthoclase and plagioclase are approximately equal in amount. They can scarcely be distinguished from granites except with the microscope.

Diorite.—Typical diorite consists of abundant plagioclase feldspar, with subordinate orthoclase or microcline, together with hornblende, augite or mica, and no quartz. If quartz is present the rock is called quartz diorite, though in ordinary field classification such rocks are usually called granites, as one can not readily discriminate the different feldspars. The origin and texture of diorite is similar to that of granite. It is usually much darker and is therefore not so desirable as a structural stone.

Granodiorite.—Granodiorite is intermediate in composition between quartz monzonite and quartz diorite; it contains less orthoclase than quartz monzonite and more orthoclase than quartz diorite.

Gabbro.—Gabbro consists essentially of plagioclase feldspar and augite. Common accessory minerals are olivine, biotite, hornblende, and magnetite. It is usually dark gray or green or nearly black. It is a deep-seated rock, like granite, and has the same texture. On account of its very dark color and the fact that it weathers more readily than granite, it is generally not a desirable building or ornamental stone. It is excellent for crushing or for riprap. Much of the rock in the gabbro area near Duluth consists almost entirely of plagioclase and is called "anorthosite."

Basalt.—Basalt has the same composition as gabbro but is much finer grained. The molten magma from which it was formed was poured out in great surface flows or sheets, and its rapid cooling

[1] Winchell, N. H., Geology of Minnesota, vol. 2, p. 431, 1884.

produced the fine-grained texture. Though more difficult to crush than granite or gabbro it is well adapted to road building or concrete construction.

Diabase.—The composition of diabase is similar to that of gabbro and basalt, and in texture the rock is intermediate between them. Typical diabase is rather fine grained and contains needle-like or lathlike crystals of feldspar. It is commonly a dike rock—that is, it has been intruded into cracks or fissures in preexisting rocks. It is dark green or black and is used as riprap or crushed rock.

SEDIMENTARY ROCKS.

Conglomerate.—Water may sort the material it carries according to size and weight and deposit it in more or less uniform beds. Coarse pebbles and boulders are deposited near a shore, and when cemented together they form rock called conglomerate. The pebbles of a conglomerate may be of various kinds and colors, but nearly all of them are well rounded by the action of water and the spaces between the large pebbles are filled with smaller pebbles, sand, clay, iron oxide, or calcium carbonate. Through long ages of intense pressure, aided by the deposition of cementing material, the whole mass has become firmly consolidated. By elevation of the sea floor and by erosion of the overlying material the conglomerate may appear at the surface of the earth. Conglomerates are not abundant in Minnesota. One ridge of beautiful jasper conglomerate, which lies across the river from New Ulm, in Nicollet County, has been quarried to some extent. If their pebbles are nearly uniform in hardness and are firmly cemented conglomerates may form useful building stones.

Sandstone.—Pebbles and boulders are dropped near the shore but sand grains are carried farther out and deposited in deeper water. By the same processes of consolidation that form the conglomerates the sands are cemented into a more or less coherent mass known as sandstone. Nearly all sandstones are composed chiefly of quartz, but they contain other minerals in small and markedly different proportions; the "Fond du Lac" sandstone contains much feldspar and mica, whereas the St. Peter and Jordan sandstones are 95 to 99 per cent quartz. The economic value of a sandstone depends largely on its state of aggregation. Many sandstones are poorly cemented and for this reason are termed friable or incoherent. The degree of coherence depends on the amount of cementing material and the nature of the cement. The cement is deposited from mineral-bearing waters that percolate through the minute spaces between the sand grains and gradually fill them by precipitation. As a consequence the nature of the cement depends on the composition of the solution. The most common cements in sandstone are clay, silica,

calcium carbonate, and iron oxide. Calcareous cement is not desirable, for it dissolves in water containing carbon dioxide and allows the sand grains to fall apart. Iron oxide is not very desirable, as some forms of it alter and stain the rock. It also makes a weak cement, which is not even so durable as the calcareous. It gives a brown or reddish color to the rock. The best and most durable cement is silica in the form of quartz. In some sandstones the intergranular spaces are so completely filled with quartz that the original sand grains have lost their identity and the whole rock looks like massive quartz. Such a rock is termed a quartzite. This is probably the most enduring of all building stones, but its hardness makes it so difficult to cut and trim that it is not used extensively. The most valuable sandstone is that in which a proper balance is attained between workability, which governs the cost of production, and degree of induration, which governs strength and durability.

Shale.—The finest particles transported by streams are naturally carried the farthest from shore and are deposited in deeper water in the form of beds of clay, which, when firmly cemented and hardened, form a rock called shale. Shales are of no economic value for direct use as structural material, but certain shales of Minnesota and other States are used for making brick, and in some States shale is used as an ingredient of Portland cement.

Limestone and dolomite.—Pure limestone consists of the mineral calcite (carbonate of calcium, $CaCO_3$), and pure dolomite consists of carbonate of magnesium and calcium ($CaMg(CO_3)_2$). The term limestone commonly includes both calcite and dolomite or mixtures of these in variable proportions. Most limestone is formed from shells of marine organisms, but a small portion results from the chemical precipitation of calcium or magnesium carbonates. The shells may be so broken as to produce a fine-grained mass, in which, however, many well-preserved shells remain. The mass of shells or finer material is consolidated by pressure or by the addition of cementing material. It may so happen that the carbonate materials are deposited simultaneously with sand grains or mud, forming sandy or clayey limestones. Furthermore, deposits of lime, sand, and clay may be formed in succession, resulting in alternate beds or lenses of limestone, sandstone, and shale. By elevation of the sea floor extensive beds of limestone may form land surface.

The limestones of Minnesota are practically all dolomitic, and some are pure dolomites. These highly dolomitic limestones can not be used for making cement, but they are excellent structural materials. Dolomite is less soluble and more enduring than calcite. The limestones, as a group, whether pure or dolomitic, are attractive and durable. They dissolve slowly in water containing carbon dioxide. When shaly they disintegrate more readily.

METAMORPHIC ROCKS.

Gneiss.—Intense unequal pressure resulting from earth movement or from the flow of a magma during its crystallization may give to granites or related rocks a banding due to the parallel arrangement of the constituent minerals. Such rocks are called gneisses. Many gneisses are more permeable and hence less resistant to weathering than the corresponding unchanged granites. They have also less transverse strength, especially in the direction parallel with the banding. This is true of some gneisses near Montevideo, Minn., though the Morton gneiss, both in permeability and strength, is apparently in no respect inferior to a granite. Most gneisses are less uniform in texture than granites.

Schist.—Schists are finely banded metamorphic rocks, which are seldom quarried for structural uses. On account of their lamination most of them are weak and are permeable to water and therefore disintegrate rapidly. No schists are quarried in Minnesota.

Quartzite.—By metamorphism a sandstone may be changed to a quartzite (see p. 202), and by intense mechanical deformation clayey sandstone may be converted to a quartz schist.

Slate.—The metamorphism of a shale results in the formation of numerous closely spaced cleavage planes, most of which cut across the bedding planes in flat-laying beds and thus are vertical or nearly so. The resulting rock is slate, which in thin sheets may be used for roofing. Near Carlton, Minn., there are great masses of slate, which, however, are as yet but little exploited.

Marble.—The metamorphism of a limestone or dolomite produces a recrystallized form known as marble. Marble takes a good polish and is used chiefly as ornamental stone. As it is a product of metamorphism it is usually found in mountainous regions, notably in the Appalachian belt of the Eastern States. The limestones of Minnesota have undergone little or no folding and have not been affected by igneous intrusion, so that no true marble deposits are likely to be found in the State. Some of the beds at Kasota, however, though practically undisturbed since their formation, are somewhat recrystallized and when polished are sometimes termed "marble." Certain of the recrystallized beds extend into the Mankato quarries, but no other marbles are known in the State. Serpentine rock, or "verd antique," which is used for decoration, is classed with marbles, as it is a commercial substitute for true marble. No serpentine marble is quarried in Minnesota.

ROCK STRUCTURES THAT AFFECT QUARRYING.

TYPES.

The work of quarrying building stone includes the excavation of blocks of specified sizes and shapes. Ordinarily this work involves two steps—the breaking loose of larger blocks and the reduction of

these blocks to proper dimensions. The rock structures that are of prime interest to quarrymen in connection with the first step are the natural open seams that divide the rock into rhomboidal masses; the structures that are of interest in connection with the second step are those that permit the rock to be split with greater ease in certain directions than in others. Quarrymen recognize two kinds of open seams—vertical or nearly vertical seams, called joints, and horizontal seams, which, if they occur in igneous rocks, are called sheeting planes, or, if they occur in undisturbed sedimentary rocks, are called bedding planes. As bedding planes are planes of stratification they may stand at any angle in folded beds. Planes of cleavage, along which the rock splits with greater ease, are known as "the rift" and "the run." In many eastern quarries "grain" is used instead of "run."

JOINTS.

Most of the joints in the igneous rocks of Minnesota are nearly vertical. Several parallel joints constitute a "system." Joints generally occur in two prominent systems that meet at an angle of about 90°, but at many places a third or fourth system may appear. Those of the most persistent and continuous series are known as major joints or master joints; those that continue for only short distances are known as minor joints. Buckley's classification[1] recognizes these two types only, but in many of the quarry descriptions given in this bulletin a third term, secondary, is applied to joints that are intermediate between major and minor. In many quarries, especially granite quarries, the joints occur mainly in two systems, one more prominent than the other, termed major and secondary. Other less pronounced systems are termed minor. A fourth type of joints, known to quarrymen as dry seams or blind seams, consists of incipient joint planes or closed joints, which are invisible or appear only as faint lines in the undisturbed rock but which readily open when the rock is shattered by a blast. In many places they pass obliquely through blocks marked out by major or secondary joints.

Joints are now regarded as due to compressive or torsional strain, a single force producing two sets of joints that intersect at an angle of about 90°, and each set makes an angle of 45° with the direction of strain.[2]

The angles of intersection and the spacing of the joints are of great importance to quarrymen. If the joints are too closely spaced (only a few inches apart), the blocks are too small to be useful and the rock is valuable only for crushing. If they are too widely spaced (50, 75, or 100 feet apart), quarrying is difficult. If they meet at acute angles, much rock is wasted. (See also p. 62.)

[1] Wisconsin Geol. Survey Bull. 4, p. 457, 1898.

[2] Dale, T. N., The granites of Connecticut: U. S. Geol. Survey Bull. 484, p. 37, 1911.

In sedimentary rocks jointing is generally complex. At many places two prominent systems cross at nearly a right angle, and secondary or minor systems may meet them at oblique angles. Most of the joints are nearly vertical. Joint systems may show remarkable continuity over considerable areas.

SHEETING PLANES.

Sheeting planes in igneous rocks are generally more closely spaced near the surface than they are far below it. Most of them are nearly horizontal and in general conform with the rock surface. Inclined sheets are common but may be related to joints rather than to sheets. According to Dale,[1] the chief factor in producing sheets is compressive strain aided by expansion under solar heat.

The presence of sheeting planes greatly facilitates the removal of blocks. Where they are absent or are spaced too far apart artificial sheets are formed by discharging blasts in horizontal holes, known as "lift holes."

BEDDING PLANES.

Bedding planes are parallel with the planes of stratification in sedimentary rocks and are generally more regular and more closely spaced than sheeting planes. They may be open fractures or they may be seams of different material, such as clay seams in limestone. Close bedding and jointing are undesirable in quarries where building stone or only riprap or crushed rock is produced. The blocks are too small for building stone, and blasting for the production of riprap or crushed stone is not very effective, as much of the explosive force is disseminated in the cracks.

RIFT AND RUN.

Many granites split with greater ease in some directions than in others. The direction of easiest splitting or the fracture system that makes the splitting possible is called the rift. In some granites a second direction of easy splitting or fracture system stands at right angles to the rift, but this system is less strongly marked. In many eastern quarries this system is called the "grain." Throughout Minnesota, however, the term "run" is generally employed by quarrymen for this system, and is therefore the term used in this bulletin. The direction at right angles to both rift and run is called the "hardway" or "head grain." In this direction the rock does not split readily. Throughout central Minnesota the rift is horizontal and the run is generally north and south, though in a small area of granite in secs. 17 and 20, St. Cloud Township, Stearns County, it is east and west. The rift is apparently independent of the sheets;

[1] Dale, T. N., op. cit., p. 29.

in certain quarries where the sheets dip 30° or more the rift is horizontal.

Neither rift nor run is at all pronounced in Minnesota granites. Skilled stonecutters can detect them easily but others can not. The ability to recognize them is indispensable to the success of the quarryman, especially of cutters of paving blocks, which must be blocked out and trimmed according to the natural planes of splitting. (See Pl. VI, *A*, p. 60.)

There is great diversity of opinion regarding the cause of rift and run. According to Dale,[1] who cites the opinions of others and adds the results of his own investigations, they are due principally to mineral orientation—that is, the arrangement of the rock minerals in lines or planes; to incipient jointing caused by strain; and to microscopic faults or fractures. In an earlier publication Dale[2] shows that a probable relation exists between rift and run and the fluidal cavities in minerals. He gives a number of illustrations from New England granite quarries which indicate that rift is independent of flow structure.

That rift and run in the granites of central Minnesota have their origin in mineral orientation is rather definitely indicated by two facts:

1. The rift surface is smoother than other surfaces. A skilled paving-block cutter, when blindfolded, can detect the rift by the feel of the surface. A predominance of feldspar cleavage planes parallel with a surface would manifestly produce greater smoothness or uniformity.

2. The statement of some quarrymen that they recognize the direction of rift by "the direction in which the grains point" is significant. They appear to base their observations rather on the dark than on the light-colored minerals.

Rift and run are noticeable in sedimentary rocks. Planes of stratification are planes of weakness, even if they are not open, so that massive blocks may be readily split from certain beds along some particular horizontal plane. Such splitting is comparable with the "rift" of igneous rocks, though the planes of fracture are of different origin. Such a plane is known among limestone quarrymen as "capping." It is probably due to a slight change in sedimentation—to the deposition of a thin layer of material that differs from that deposited before or merely to a temporary cessation in deposition, either of which might form a smooth surface that would permit little or no interlocking of grains with the bed next laid down. The run is much less pronounced than the rift but is of considerable importance, especially in sandstone from which paving blocks are made.

[1] Dale, T. N., op. cit., p. 26.

[2] Dale, T. N., The chief commercial granites of Massachusetts, New Hampshire, and Rhode Island: U. S. Geol. Survey Bull. 354, pp. 42–47, 1908.

PROPERTIES OF STONE.

OUTLINE OF PROPERTIES.

The adaptability of a stone to structural or ornamental use is governed mainly by its inherent physical, chemical, and mineral properties. The properties required for different uses differ greatly, depending on the purpose for which the stone is to be employed. For bridge rock great strength is required, for monuments or other outdoor structures appearance and resistance to weathering are of more consequence, and for interior decoration attractive color and adaptability to carving and polishing are the chief requisites. Some of the important properties of stone are its composition (mineral or chemical), hardness, texture, color, strength, porosity, and specific gravity or weight.

METHODS OF STUDY.

As is pointed out by Buckley and Buehler [1] these properties may be determined by three different methods—by studying the stone in the quarry or in exposures, by examining structures made from the stone, and by laboratory tests. Several of the properties may be studied by all three methods, others by two of them. If possible, the results obtained by one method of investigation should be verified by comparing them with the results obtained by others.

The data recorded in this report were obtained mainly by studying the rocks in quarries and in natural exposures. All active and many abandoned quarries were visited and the surface indications at many undeveloped outcrops were examined.

The stone buildings and other structures in Minnesota are very youthful in comparison with many in the Old World, and a study of their endurance is of relatively less value than a study of structures in lands where civilization is older, but all information that could be gained by this method of study has been recorded. The laboratory work done involved investigations of crushing strength, transverse strength, porosity, specific gravity, and weight per cubic foot, as well as chemical analyses and microscopic examinations.

BRIEF DESCRIPTIONS OF PROPERTIES.

Full discussions of the properties of stone are given in other reports,[2] so that only the more salient features are here noted.

Composition.—A rock consists of one or more minerals, and the minerals are made up of elements combined in definite proportions. By chemical analysis these elements and the proportion of each may

[1] Buckley, E. R., and Buehler, H. A., The quarrying industry of Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 2, p. 30, 1904.

[2] Buckley, E. R., and Buehler, H. A., op. cit. Merrill, G. P., Stones for building and decoration, 3d ed., 1903. Ries, H., Building stones and clay products, 1912. Parks, W. A., Building and ornamental stones of Canada, vol. 1, 1912.

be determined, and by microscopic study the individual minerals may be identified. The value of chemical analyses of building stone is often overestimated. The analysis of a granite may give little indication of its adaptability to structural uses. Simple qualitative tests may, however, be very useful. For example, it is much more desirable to know whether the iron in a granite is present in the ferrous or ferric state than to know its exact amount. An analysis of a limestone discloses its value for certain uses. The proportion of magnesium it contains directly affects its value for making cement; the proportion of aluminum usually indicates the proportion of clay mixed with the calcium or magnesium carbonates; a knowledge of the proportion of insoluble matter is important if the limestone is to be used as a fertilizer; and the presence of sulphur probably indicates that it contains pyrite. Much useful information that was formerly obtained almost exclusively by chemical methods, or was not obtained at all, is now gained by the use of the petrographic microscope, study with which is quicker, cheaper, and for most purposes more effective than chemical investigation. By the microscope we may observe and identify the minerals in a rock and may note their state of aggregation, freshness, relative abundance, impurities, and texture, and may to some extent interpret the history of the rock and learn what influences have been at work to improve or impair it for structural uses. In the preparation of this bulletin about 300 thin sections of Minnesota stones were studied with the microscope. (See reports on particular quarries, pp. 68–147.)

Hardness.—The hardness of a rock, or its resistance to abrasion, depends directly on the hardness and texture of its component minerals. Most of the constituents of granite are as hard as or harder than steel, and the rock is therefore difficult to tool. Granites in which the proportion of quartz is large are harder than those in which it is small, for quartz is their hardest essential constituent. Limestone consists of minerals that can be scratched easily with a knife and it is consequently worked with comparative ease. Sandstone may be worked with ease or difficulty according to the nature of its cementing material and its state of aggregation. Siliceous sandstones or quartzites are the most difficult to cut.

Texture.—The term "texture," as applied to a rock, means the size, uniformity, and arrangement of its constituent mineral grains. In rubble, riprap, or crushed stone texture is of little moment, but in stone of ornamental grades it is of vital importance. Uniformity in size of grain and in distribution of minerals is demanded in monumental and the best structural stone. Fossiliferous limestones are subject to differential weathering, which destroys their originally uniform surfaces.

Color.—Rocks are of many colors, and the choice of color for a building stone depends on individual taste or prevailing fashion. For monumental stone there is a demand for rock of practically all colors. For building stone, red, gray, brown, or white rocks are widely employed, and dark-gray or black rocks are used but little. The buff or yellow colors of many limestones and sandstones and the red or pink shades of many granites are due to the presence of minute grains of iron oxides. Surface stains are serious blemishes and are generally due to the presence of small crystals of pyrite, marcasite, or siderite, which oxidize by weathering, or to soluble iron salts in the quarry water.

Strength.—Most building stones, when unweathered, are sufficiently strong for all ordinary structural uses. Bridge piers and supporting columns in large buildings must sustain great pressures, but even in such structures the strength of ordinary stone far exceeds the requirements of safety. It is, however, generally conceded that rock disintegrates and tends to weaken more readily when under severe stress, and a factor of safety of 20 is therefore usually demanded—that is, the stone must be able to resist a crushing stress 20 times as great as that to which it will be subject when placed in a wall. For ordinary uses a stone that will sustain a crushing strength of 5,000 pounds to the square inch is considered satisfactory. Most fresh granites will sustain a pressure of 20,000 to 35,000 pounds to the square inch, and many limestones will sustain a pressure nearly as great. Sandstones differ widely in strength, but their probable strength can be judged from the state of aggregation of their constituent minerals. Crushing tests are not particularly useful except those made on stone that is to be employed for some purpose that demands exceptionally great strength. Tests made to show transverse strength—that is, the strength required to sustain a load applied at the middle of a bar of stone that is supported at the ends—is of more importance, for it shows the adaptability of the stone to use as window caps, door caps, and the like. The number of broken caps that may be observed in buildings indicates that sufficient care has not been taken in selecting stone for such uses.

Tests to show both the compressive and the transverse strength of a number of Minnesota rocks were made under the direction of W. H. Kavanaugh, of the University of Minnesota. Both kinds of tests were made on a number of samples from each of the quarries, in order to get fair average results. In making crushing tests the compression surfaces of the cubes were bedded in a thin layer of plaster of Paris to insure an even bearing. The transverse tests were made by arranging the specimen on well-rounded supports 10 inches apart and applying the load in the center of this span through a similarly well-

rounded bearing. In computing the modulus of rupture the well-known formula $p=\frac{PLe}{4I}$ was used, in which p = modulus of rupture in pounds per square inch; P = breaking load at center in pounds; L = span in inches; e = maximum fiber distance; I = moment of inertia of the cross section at the break, computed from the formula $I=\frac{bh^3}{12}$, in which b is the width of and h the depth of the specimen.

The compression tests were made on sawn cubes of approximately 2½-inch edge, and the transverse tests on blocks 2½ by 2½ by 12 inches, the supports being 10 inches apart.

Porosity.—Porosity affects the durability of a stone by permitting the infiltration of water which may contain solvents and which may freeze in the pores. Many tests have been made to determine the percentage of pore space in rocks. Early writers have stated that the danger due to frost is directly proportional to the percentage of pore space, but Buckley [1] has pointed out that the important factor to consider is the facility with which the stone gives up water; that as rocks with small pores give it up less readily, rocks with fine pores suffer most seriously from the action of frost. Parks [2] determined the permeability of many rocks and found that it bore no relation to percentage of porosity or to the effect of frost. It is apparent, however, that the solvent effect would be greater in rocks of greater permeability.

Specific gravity and weight per cubic foot.—The specific gravity of a stone is its weight compared with the weight of an equal volume of water. It may be expressed as apparent specific gravity or true specific gravity. The apparent specific gravity of a rock is obtained when its pore spaces are filled with air throughout the determination. The true specific gravity is obtained when pore space is eliminated, either by filling the pores with water or by determining specific gravity from the rock powder. The latter method was employed in all the determinations here recorded.

The specific gravity of common rocks ranges from 2.2 to 2.7, and the weight per cubic foot ranges from 150 to 190 pounds, depending on the weight and relative abundance of the constituent minerals and upon the porosity. The weight per cubic foot is useful in calculating the weight which a superstructure imposes upon its base.

PHYSICAL TESTS.

The following table shows the results of recent physical tests of the several Minnesota building stones. The results of earlier tests have been published by Winchell.[3]

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[1] Buckley, E. R., The building and ornamental stones of Wisconsin, p. 22, 1898.

[2] Parks, W. A., Report on the building and ornamental stones of Canada, vol. 1, p. 62, 1912.

[3] Winchell, N. H., op. cit., vol. 1, pp. 196-203.

Results of recent physical tests of Minnesota building stones.

Rock.	Locality.	Quarry.	Crushing strength.		Transverse breaking strength; modulus of rupture.	True specific gravity.	Pore space.	Weight.
			First crack.	Final collapse.				
			Lbs. per sq. in.	*Lbs. per sq. in.*	*Lbs. per sq. in.*		*Per cent.*	*Lbs. per cu. ft.*
Granite (red)....	Ortonville.....	Consolidated Granite Co.	12,772	23,722	3,098.2	.....	.....	.....
Granite (pink)..	North Redwood.	North Redwood Granite Co.	12,308	21,236	4,526	2.690	0.6	167.1
Granite (gneiss).	Morton.....	Anderson Granite Co.	8,600	20,340	3,042	.....	.....	.....
Granite (pale pink).	Rockville.....	Clark & McCormack.	10,574	17,294	2,048	.....	.....	.....
Quartz diorite (gray).	St. Cloud.....	Robert Graham...	15,080	21,000	2,979	2.761	.37	171.9
Granite (red)...	.....do.....	Melrose Granite Co.	9,733	19,101	2,291	.....	.....	.....
Do.....	.....do.....	J. B. Robinson....	.....	.....	.....	2.643	.32	164.6
Do.....	.....do.....	Pioneer Granite Co.	9,395	15,712	2,596	.....	.....	.....
Granite (gray)..	East St. Cloud..	August Erickson..	11,426	16,996	.....	.....	.....	.....
Do.....	Warman.....	Warman Creek Granite Co.	9,996	17,246	3,159	.....	.....	.....
Marble (pink)..	Kasota.....	.....	4,469	5,439	1,129	2.823	6.78	164.5
Marble (yellow).	.....do.....	.....	.....	.....	.....	2.580	7.74	148.8
Limestone (bridge ledge).	Mankato.....	Fowler & Pay....	8,882	11,390	2,167	2.902	6.78	169.1
Limestone.....	Hastings.....	O. Carlson.....	.....	.....	.....	2.626	9.31	148.8
Do.....	Frontenac.....	Frontenac Stone Co.	6,874	8,017	1,367	.....	.....	.....
Do.....	Ottawa.....	.....	.....	.....	.....	2.836	9.75	160.0
Do.....	Rochester.....	Donohue Bros....	.....	.....	.....	2.788	3.04	169.0
Do.....	Faribault.....	Eberhart Kaul....	.....	.....	.....	2.788	3.59	168.0
Do.....	St. Lawrence....	.....	.....	.....	.....	2.814	9.99	158.3
Do.....	Plainview.....	Abe Leatherman..	.....	.....	.....	2.885	9.96	162.3
Do.....	St. Charles.....	Fred Wolter.....	.....	.....	.....	2.608	8.29	149.5
Quartzite.....	Pipestone.....	.....	10,429	20,277	6,583	.....	.....	.....
Sandstone.....	Sandstone.....	Kettle River.....	.....	12,295	.....	.....	.....	.....
Do.....	.....do.....	.....do.....	.....	12,799	.....	.....	.....	.....

CONSIDERATIONS IN SELECTING STONE.

The chief considerations in selecting stone are durability, appearance, and cost.

Durability.—Stone that is to be used for exterior work, particularly in a climate like that of Minnesota, should be able to withstand weathering. Its durability will depend chiefly on its mineral composition and texture. Limestones dissolve slowly in water that contains carbon dioxide, porous rocks disintegrate by freezing, and granites may be fractured by unequal expansion of their constituent minerals. These processes are, however, very slow and uncertain. It is difficult to judge the weathering qualities of a stone by examining its constituents and texture. Many careful laboratory tests have been made and the results have been recorded in the literature. Such tests are important, and the results are worthy of much attention.

A very practical method of determining the resistance of a rock to weathering—a method which may be used in conjunction with laboratory tests—is to observe the rock where it has been long subjected to the elements and to study the visible effects of weathering. This

study may consist of careful scrutiny of structures built many years ago or of the stone as it occurs in the quarry.

For certain uses, as for flagging or steps, resistance to weathering is of course necessary, but resistance to wear is of even more importance.

Stone in buildings may be subjected to intense heat by a conflagration. The ability of different rocks to resist the effects of high temperature has been studied by observation of burned buildings and by laboratory tests. W. E. McCourt [1] has shown that limestones, up to the point of calcination, withstand the effects of fire better than any other stones. Next in order are sandstones, next fine-grained crystalline rocks, and last the coarser crystalline rocks. As a rule, the finer grained and more compact the stone and the simpler its mineral composition the better will it resist the damaging effects of extreme heat.

Appearance.—Color and texture are the controlling factors of appearance. Individual tastes differ greatly as to colors or textures, but there are certain general principles bearing on appearance to which practically all will subscribe. White or very light colors are undesirable for structures in manufacturing or railroad centers, where soot and smoke blacken building stone. The blackening may to some extent be prevented by polishing the stone, as soot adheres less readily to a polished than to a rough surface, but the cost of polishing is high.

A very desirable feature of color is uniformity, and this may be hard to obtain. Different beds may have different shades of color, and for architectural unity it may be necessary to obtain all the stone from a single bed. Lack of uniformity may be due to unequal distribution of different-colored minerals, such as are seen in areas of pegmatite in granites or in the varied banding of gneisses.

Generally speaking, permanence of color is requisite to attractiveness. Unequal oxidation may cause some parts of a rock surface to become darker than others, and bleaching may cause some parts to become lighter. The presence of alkali salts may result in the formation of unsightly efflorescent coatings. Crystals of pyrite, marcasite, or siderite may by oxidation cause rusty stains, such as may be observed in many structures in Minneapolis on blocks of limestone obtained from local Platteville beds. For selecting stone free from such blemishes careful microscopic examination is recommended.

Under certain conditions, however, change of color may not detract from the appearance of a structure. Limestones and sandstones may become darker through lapse of time, by chemical changes—for example, the oxidation of iron carbonate. If all the stone in a structure changes uniformly the resulting color may be as attractive

[1] New Jersey Geol. Survey Ann. Rept. for 1906.

as the original. On some stones richer and more pleasing tones of color develop after prolonged exposure.

Uniformity of texture is desirable in stone designed for certain structures, such as monuments, carved objects, and exterior building blocks, but variations in texture may add to the attractiveness of large columns or panels. Thus a coarsely banded gneiss may be very attractive in a large column but would not look well in a polished monument, especially in a small one.

Cost.—The factors that govern the cost of stone are quarry conditions, workability, and situation with respect to the means of transportation.

One important element in quarrying is the thickness of soil or waste rock that covers the beds to be quarried. Drainage is also important, as pumping increases the expense of quarrying. The angle of intersection and the proximity of joints and sheeting planes have much to do with the ease of removal of the rock and the shape of the blocks obtained. Acute angles of intersection result in undesirable angular fragments, and wide spacing makes quarrying more difficult. The presence of defects increases the cost, for the expense of handling rejected blocks must be added to the price of the finished product. Skill in quarrying tends to reduce the cost of stone. The situation of the quarry opening with respect to the attitude of inclined sheets, the use of modern machinery, the position and depth of drill holes, and the size of the charge employed, are all factors in the cost of production. The utilization of waste material is one of the important economic problems in stone quarrying.

The workability of stone depends partly on the hardness and texture of its constituent minerals and partly on the rift and run. The ease with which a stone can be tooled, sawed, or polished depends chiefly on its hardness and texture. The ease with which it can be split or trimmed into blocks with even surfaces depends on the natural directions of splitting, and the cost depends both on the skill of the cutter and his knowledge of the inherent peculiarities of the stone.

A block of granite 2 feet square and 3 feet long weighs about a ton. The cost of transportation may be the chief item of expense. Stone may be transported by team and wagon, by railroad, or by water, transportation by water being the cheapest.

PHYSIOGRAPHY.

Taken as a whole the surface of Minnesota is a moderately undulating plain, marked at intervals by belts of uneven topography, where hills of rock or glacial drift are interspersed with undrained depressions, and by some extensive lake beds, the most notable of which are in the Red River valley, a basin that was once occupied by the glacial Lake Agassiz.

Southern Minnesota is for the most part a plain of moderate elevation. An area in the southeastern part of the State, known as "Coteau des Prairies," rises about 500 feet above the remainder of southern Minnesota and extends westward into the Dakotas. The highest part of southern Minnesota, exclusive of the coteau, or divide, just described, lies in the southeastern part of the State, in Mower County, where the rocks are bowed into a flat dome, the apex of which reaches an elevation of 1,400 feet above the sea. This dome has an exceedingly gentle slope, but it constitutes a very important feature of the topography of the southern part of the State. Where streams have cut channels on the eastern slope of this upland as they flowed to Mississippi River they have formed deep gorges with precipitous walls. Along the Minnesota River valley rounded rock masses outcrop at many places. In the southeastern part of the State the glacial drift is very thin or absent, and rock outcrops are more common. The harder rocks find topographic expression in flat-topped mounds, although most of the surface is covered by a veneer of dustlike clay or loess whose thickness ranges from 1 to 12 feet or more and averages about 5 feet. This loess tends to smooth over any small irregularities of the surface. It reaches its maximum thickness in stream valleys and depressions, and it is thin or absent on higher knolls and rolling prairies.

Northern Minnesota has a more varied topography. Its northwestern part, which was once covered by glacial Lake Agassiz, is as flat as a floor except for a series of low gravel ridges that represent former beaches of the lake. Its north-central and northeastern parts are more undulating and contain many hilly belts or glacial moraines. In the southern part of Otter Tail County three morainic belts converge to form what are known as the Leaf Hills, which rise 250 to 300 feet above the general elevation of the surrounding land. In the extreme northeastern part of the State the topography is rather rough and the highest point in the State is found. Here several low "mountain ranges" of pre-Cambrian rock, trending approximately N. 70° E., rise about 1,800 feet above the sea.

The principal drainage system is that of Mississippi River and its intricate net of tributaries, but in the northwestern part of Minnesota Red River of the North is the main drainage line, and in the northeastern part a considerable area is drained to Lake Superior.

GEOLOGY OF THE BUILDING STONES.

The rocks of all the great geologic periods from the earliest Archean granites and schists to Recent alluvium are represented in Minnesota. The columnar section given in Plate IV shows the principal formations, in order of age, with the oldest formations at the bottom.

Era.	System and Series.	Formation.	Section.	Approximate Maximum Thickness (feet).	Character of Strata.	Value for Building Stone.
Cenozoic.	Quaternary. Recent.				Lake and river silt.	No building stone.
	Quaternary. Pleistocene.			600±	Glacial drift and loess.	Glacial boulders; used chiefly for rough wall stone.
Mesozoic.	Cretaceous.	Benton shale.		550	Clays and shales.	Of no value as building material.
		Dakota sandstone.			Sandstones and in a few places limestone.	
Paleozoic.	Devonian.			100	Sandstones and sandy limestones.	Quarried in Mower, Fillmore, and Faribault counties.
	Ordovician.	Maquoketa shale.		100	Shales and limestones.	Of no value for building.
		Galena limestone. Decorah shale. Platteville limestone.		230	Shales and limestones.	Quarried in Hennepin, Dakota, and some of the southeastern counties.
		St. Peter sandstone.		200	Sandstone with a little shale.	Too friable to be of value for building.
		Shakopee dolomite.		100	Sandy dolomite.	Some available building stone in Scott and Washington counties.
		Oneota dolomite.		200	Buff to reddish dolomite.	Furnishes most of the limestones and marbles quarried in southeastern Minnesota.
	Cambrian.	Jordan sandstone.		200	White to brown sandstone.	Too friable to be of value except a little quarried in Chisago and Scott counties.
		St. Lawrence formation.		200	Buff dolomite with green shale and sandstone.	A little dolomite in Scott County.
		Franconia sandstone.		100	White sandstone and green sand.	Too friable to be of value for building.
		Dresbach sandstone and underlying shales and sandstones.		450	White sandstone with interbedded shales and limestones.	For the most part very friable; has been quarried only near Dresbach, in Winona County.
Proterozoic.	Algonkian (?).	Red clastic series of southeastern Minnesota and probably contemporaneous sandstones to the north.		2,250	Red sandstones and shales, shaly layers especially abundant near the base.	The so-called "Kettle River" sandstone (known locally as Hinckley sandstone) of Pine County, and the sandstones near Duluth, in St. Louis County (both probably contemporaneous with the red clastic series), afford valuable building material.
	Algonkian. Keeweenawan.	Conglomerate and sandstone.		500	Conglomerate and sandstone.	Of little value for building.
		Eruptives.		Unknown.	Granites, gabbros, and diabases.	The granites of central Minnesota, notably those of Stearns, Benton, and Sherburne counties, furnish superior building and ornamental stones. The gabbros and diabases of Lake, St. Louis, and Chisago counties are utilized for road material, concrete aggregate, and riprap.
	Algonkian. Huronian. Upper Huronian (Animikie group).	Acidic and basic intrusives.		Unknown.		Of little value for building.
		Virginia and other slates.		3,000±	Slates.	The Virginia slate has no value as building material. The slates of Carlton County may be used for roofing.
		Biwabik and Gunflint formations.		800±	Taconite, iron ore, ferruginous chert and paint rock.	Of no value as building material.
		Pokegama quartzite.		200	Quartzite, quartz slate, and conglomerate.	The Pokegama quartzite of St. Louis County and the possibly contemporaneous Sioux quartzite of Nicollet, Pipestone, and Rock counties are used chiefly for crushed stone.
		Giants Range and other intrusive granites, granite porphyry, and dolerites.		Unknown.	Gray and pink granite, granite porphyry dolerites, and lamprophyres.	The Giants Range granite of St. Louis County affords fair building material.
	Algonkian. Huronian. Lower middle Huronian.	Slate, graywacke, and conglomerate.		5,000	Green to gray slates, graywackes, and conglomerates.	Of little value as building material.
	Archean. Laurentian.	Residual clay.		Unknown.	White residual clay.	
		Granites, gneisses, and porphyries.			Granites and porphyries in part altered to schists.	Great masses of granite northwest of Lake Superior are mostly inaccessible. The granites of Minnesota River valley from Big Stone Lake to New Ulm have been used for buildings and monuments.
	Archean. Keewatin.	Soudan formation.		Unknown.	Banded cherts and red jaspers.	Of little value as building material.
		Schists and porphyries and Ely and other greenstones.			Greenstones, green schists, porphyries and iron ore.	Of little value as building material.

GEOLOGIC COLUMN OF MINNESOTA.

ARCHEAN.

The Keewatin was a period of great volcanic activity, during which lava flows, both subaqueous and subaerial, were poured out. Small amounts of sediments were deposited, especially near the close of the Keewatin. The volcanic rocks of this period are mainly basalts but include also some slate, jaspilite, and dolomite. The rocks that underlie these lavas are not known. The basalts over much of the area have been profoundly metamorphosed and converted into so-called green schists, which now crop out in much of the northern part of Minnesota. The gneisses of the southwest and central part may be of the same or nearly the same age.

In Laurentian time siliceous granitoid and gneissic masses were intruded into the Keewatin rocks, mostly as great batholiths. Their relation to the Keewatin is complex, some outcrops indicating that the granite magma may have stoped and absorbed parts of the basic rock. The Laurentian crops out prominently in two areas, in one of which, northwest of Lake Superior, there are enormous masses of granite and gneiss, which, on account of poor transportation facilities, are now unavailable for use as building stone. Another Laurentian area is in southwest Minnesota along Minnesota River valley from Big Stone Lake to New Ulm. This area has been correlated less certainly with the Archean.

ALGONKIAN.

Contrasted with the Archean the Algonkian was a period of sedimentation, though at times in that period igneous activity was pronounced. Two series of Algonkian rocks, each of considerable thickness, are recognized in Minnesota, the lower the Huronian and the upper the Keweenawan.

The lower-middle Huronian sediments in Minnesota consist of slates and graywackes (dark-gray sandstones containing angular fragments of shale and other materials), with which are associated several kinds of igneous rock. The slates, which overlie the Archean unconformably, extend from northeastern Minnesota westward in a belt that lies in the main south of the Archean outcrop. In the region farther west they are covered by drift and Cretaceous formations.

The upper Huronian (Animikie group) rests unconformably on the middle Huronian. It consists of thin conglomerate and sandstone and, above these, of the iron formation of the Mesabi Range and the slates that overlie it. The upper Huronian is much less altered than the earlier formations but has been invaded and in central Minnesota somewhat metamorphosed by large intrusive igneous masses, most of which are probably Keweenawan. The quartzite near New Ulm, Pipestone and Luverne may belong to this group.

The Keweenawan consists of conglomerates, sandstones, and shales, interbedded with flows of diabase and other igneous rocks. The sediments are relatively thin, and most of them, from their red color, poorly sorted materials, and alternation with lava flows, may be classed as land deposits. The middle and upper Keweenawan derived most of their sediments from the dominantly basic Keweenawan igneous rocks. They lie unconformably above the Huronian, but their exact relation to the Cambrian is uncertain.

Igneous activity was pronounced in early or middle Keweenawan times, and granites which are probably referable to this period occur in central Minnesota. These granite intrusions were followed by basic intrusion and extrusion.

The Lake Superior basin was developed about this time by subsidence of the area now occupied by the lake, the synclinal nature of the basin being shown by the lavas, which dip under the lake on each side. The large area on the north shore is of special interest on account of the great gabbro laccolith (Duluth gabbro) and the series of flows and intrusions that are so prominent along the shore cliff. Diabases of probably the same age extend southwestward to central Minnesota near Little Falls, and diabase dikes that extend as far as the Minnesota River valley are assigned to this epoch. Later Keweenawan times were marked by sedimentation.

The red sandstones found in deep-drilled wells in the region around Minneapolis and St. Paul are tentatively included in the Keweenawan. The sandstones of Sandstone and Fond du Lac are probably of late Keweenawan age, though possibly they may be early Cambrian.

PALEOZOIC.

Paleozoic rocks outcrop at several places in southeastern Minnesota over an area comprising about one-eighth of the State. Structurally they form a shallow synclinal basin.

CAMBRIAN.

The Cambrian rocks, consisting of shales, limestones, and sandstones of marine origin, rest unconformably on the earlier tilted rocks.

Dresbach sandstone and underlying shales and sandstones.—The lower part of the Cambrian in Minnesota includes the Dresbach sandstone, of Upper Cambrian age, which outcrops near the town of Dresbach. Thicknesses of 50 to 100 feet are shown in drilled wells in southeastern Minnesota. At Taylors Falls the Dresbach contains marine fossils and lies in contact with tilted Keweenawan lavas. In other parts of the State it is separated from the pre-Cambrian rocks by older sandstones and shales.

Franconia sandstone.—The Franconia sandstone, consisting of 100 or more feet of white micaceous sandstone, with greensand at the

base in some areas, overlies the Dresbach and is typically exposed at Franconia, in Chisago County.

St. Lawrence formation.—Above the Franconia sandstone is the St. Lawrence formation, 100 to 200 feet thick. It consists of a somewhat sandy and porous buff magnesian limestone and layers of green shale and white and green sandstone. It outcrops near Judson and St. Lawrence siding, on Minnesota River, and at many points along the Mississippi bluffs from Red Wing to the Iowa line.

Jordan sandstone.—Above the St. Lawrence is a white to yellow incoherent sandstone, 75 to 200 feet thick, consisting of medium to coarse well-rounded grains. It appears along the valleys of Minnesota and Mississippi rivers and a number of their tributary streams.

ORDOVICIAN.

The Ordovician rests conformably on the Cambrian. The lowest rocks included in the Ordovician are the Prairie du Chien group, which consists mainly of dolomites and is divided into the Oneota dolomite below and the Shakopee dolomite above.

Oneota dolomite.—The Oneota dolomite, which is 75 to 200 feet thick, occurs in heavy uniform beds of buff color, and is somewhat porous in its upper part. It outcrops at Kasota and Mankato in the Minnesota River valley and almost continuously along the Mississippi and many of its tributaries from Red Wing to the Iowa line. Most of the limestone quarries of the State are in this formation.

Associated with the dolomite of the Oneota or the Shakopee is a bed of white calcareous sandstone, sometimes called New Richmond, which reaches a maximum thickness of 40 feet, though in many places it is much thinner. It is useless as quarry rock on account of its friability.

Shakopee dolomite.—The Shakopee dolomite is similar to the Oneota. It ranges from 25 to 75 feet in thickness, is buff in color, fine grained, and somewhat sandy. Outcrops occur along Minnesota River, notably at Shakopee, and on the bluffs of Mississippi River between St. Paul and Hastings. It is quarried at a few places in Scott and Washington counties.

St. Peter sandstone.—Above these dolomites is the St. Peter sandstone. It is 80 to 200 feet thick, white to yellowish in color, and consists of very pure quartz in well-rounded grains. It is very friable and is useless for structural purposes. It outcrops along the Mississippi near the Twin Cities and at many points throughout the southeastern counties. At its top is 3 to 6 feet of blue shale.

Platteville limestone.—The Platteville limestone, which is 12 to 30 feet thick, contains a smaller proportion of magnesium carbonate than the underlying Shakopee and Oneota, and is blue rather than buff in color. Outcrops are prominent in Minneapolis and St. Paul, where

it was quarried extensively in earlier years for structural use, and it caps many hills in the southeastern counties at some distance from the large rivers. Numerous shaly layers, one-fourth to one inch thick, alternate with the beds of limestone. In the southern part of Minnesota these layers are several inches thick.

Decorah shale.—Above the Platteville limestone is the Decorah shale, which has been traced through several counties southeast of St. Paul. It has a maximum thickness of about 100 feet and an average of about 50 feet. It is not useful as a building material except as it is employed in the manufacture of brick.

Galena limestone.—The Galena limestone, which overlies the Decorah shale, reaches a maximum thickness of 70 to 80 feet in Minnesota and is represented at only a few places. The most prominent outcrops are in Dodge, Mower, and Fillmore counties, where it supplies quarry rock of good quality. It is a somewhat sandy, buff to bluish magnesian limestone.

Maquoketa shale.—Above the Galena limestone is the Maquoketa shale, a dolomitic shale and sandstone having a thickness of about 100 feet.

DEVONIAN.

After a period of erosion 50 to 100 feet of Devonian sediments were deposited. These constitute the northern part of a large area that outcrops principally in Iowa. In Minnesota the main portion of the rock is limestone, interbedded with shales at the base and grading into sandstone at the top. Small areas appear in Mower, Fillmore, and Faribault counties, where they supply limestone for structural purposes.

POST-DEVONIAN EROSION.

The era of erosion following the formation of Devonian rocks must have been long and the weathering widespread and profound. No rocks between Devonian and middle Cretaceous are represented in Minnesota. No important diastrophic movements are indicated, and it is not probable that the elevation above sea level was great nor that the topography was rugged. Archean granites and gneisses, extending over many counties, are kaolinized to depths of 10 to 100 feet, and are now covered and protected by Cretaceous rocks, which shows that the extensive weathering took place in pre-Cretaceous time.

MESOZOIC.

CRETACEOUS.

Cretaceous clays and sands (rarely some limestone) lie unconformably over Archean, Algonkian, and Paleozoic rocks, having a maximum thickness of about 500 feet. They contain marine fossils of Dakota or Benton age. The southwestern quarter of Minnesota is

almost entirely covered with such sediments, which surround the older prominent quartzite knobs, which probably represent islands in the Cretaceous sea. The Cretaceous beds are only partly consolidated and are not suitable for structural purposes.

CENOZOIC.

PLEISTOCENE EPOCH.

Just before the glacial epoch, in Pleistocene time, the larger features of the topography were much the same as now. The great ice sheets advancing over the State scoured some valleys, filled others, and on melting left 200 to 300 feet of drift over large areas, entirely changing the details of the topography and drainage.

Glaciation has had an important bearing on the building-stone problem. The moving ice ground away the superficial decayed part of the rock and thus simplified the problem of rock stripping in many quarries. Glacial drainage had a similar effect in the Minnesota River valley, where the great glacial River Warren, which drained Lake Agassiz, cleared away all débris from the "Morton" and "North Redwood" gneiss. Glacial drift or glacial-lake deposits have completely covered and rendered unavailable all the hard rocks of many counties.

CRYSTALLINE ROCKS OF MINNESOTA.

AGE AND GENERAL DISTRIBUTION.

Crystalline rocks include granites, gneisses, diorites, gabbros, and related rocks. In geologic age they fall into two groups, the granites and gneisses of Archean age, and the granites, diorites, gabbros, and related rocks of Keweenawan and Huronian age.

The Archean rocks occur in two widely separated localities. They outcrop prominently in Bigstone, Chippewa, Yellow Medicine, Renville, and Redwood counties, in the upper Minnesota River valley, and in the northern part of the State, notably in the vicinity of the Vermilion Range.

Crystalline rocks, probably of lower Keweenawan age, outcrop in many parts of central Minnesota, notably in Stearns, Sherburne, Benton, Morrison, Mille Lacs, and Kanabec, with small outcrops of doubtful age in Todd and Aitkin counties.

Granites of middle Huronian age are found in the Giants Range and its eastward extension in St. Louis County, and gabbros and diabases of Keweenawan age occur in St. Louis, Lake, and Chisago counties.

ARCHEAN ROCKS OF MINNESOTA RIVER VALLEY.

In the upper Minnesota River valley, from New Ulm to Ortonville, are numerous outcrops of granite and gneiss, much of which is of excellent quality for structural or ornamental purposes.

Thousands of years ago the glacial river Warren evidently reached such notable proportions as to cover almost the entire valley, in places about 2 miles wide. In its passage it swept away all decayed and weathered débris, leaving fresh rock at the surface. This extensive erosion, which was accomplished by the immense volume of water derived from melting ice sheets and from rainfall over an area that may almost be termed continental, has a direct bearing on the availability of good rock in the Minnesota River valley. In the narrow and somewhat precipitous valleys of tributary streams, such as Birch Cooley and Redwood River, conditions are quite different. No great volume of water has ever passed down here, and the ancient surface is not deeply eroded. The Archean rocks, protected from glaciation by a Cretaceous covering, are decayed almost beyond recognition, and their abundant outcrops offer no available rock for structural or ornamental purposes. Erosion, which prepared the rock for quarrying in the Minnesota River valley by clearing away all the waste material, failed to do similar work on tributary streams.

Much valuable stone has been obtained from masses that outcrop near Ortonville, North Redwood, and Morton. The "Ortonville" stone is a medium-grained biotite granite or granite gneiss, which has an attractive deep-red color and takes a good polish. (See Pl. IX, *C*, p. 68.) Under the microscope it is seen to consist of orthoclase, microcline, quartz, and biotite mica. The feldspars are intergrown as in microperthite, the quartz is abundant, and the mica appears as scattered flakes. Near Montevideo the rock is more gneissic in texture, less uniform in grain size, and less attractive in coloring than at Ortonville.

Knobs and domes of biotite gneiss in the Minnesota River valley near North Redwood supply two types of attractive and valuable monumental and structural stone. One type is a beautiful greenish-gray medium-grained biotite gneiss—a "sap rock," or one that occurs near the surface and shows change of color due to surface alteration. The other type is a gray to pale-pink medium-grained granite or quartz diorite, consisting chiefly of much gray to pale-pink feldspar, some clear quartz, and small grains of black mica. Both rocks are even grained and are exceptionally attractive. The only imperfections observed are a few dikes of aplite (fine-grained granite). A great quantity of high-class monumental stone is available.

Thin sections of the green granite under the microscope show the following characters: Quartz is prominent. The feldspars are orthoclase and subordinate microcline. The small proportion of dark mineral is chiefly biotite, some of it secondary as an alteration product of hornblende, which appears in a few places as cores in the center of the biotite grains. A few grains of magnetite are present. The

rock has altered considerably to fine granular kaolinite and chlorite, the latter giving the green color.

The pale-pink granite is a medium-grained, even-textured biotite granite. The feldspars are orthoclase and plagioclase in about equal amount and a little microcline. Quartz is abundant. The only dark minerals present are a few grains of biotite and magnetite. The red color is due to small grains of hematite, confined chiefly to minute cracks between mineral grains. No other alteration seems to have taken place, the stone being exceptionally pure and fresh.

At Morton conditions are similar to those at North Redwood. The rock occurs in a higher and larger dome, the bare rounded bluffs forming a prominent landmark in the Minnesota River valley. The "Morton" rock is a medium to coarse grained biotite granodiorite gneiss. The feldspars are red, and the dark minerals occur mostly in streaks and bands. In places the rock is porphyritic. Feldspars constitute the larger share of the rock, orthoclase and plagioclase being most abundant and microcline subordinate. Considerable quartz is present. The chief dark mineral is biotite, with a small amount of hornblende and a few grains of magnetite.

The Archean rocks of the Minnesota Valley are marred by certain structures and textures which it is desirable to avoid in quarrying. Some of the rocks, particularly the "Ortonville," contain at irregular intervals oblong masses 1 inch to 2 feet in diameter consisting of quartz and large orthoclase crystals, some 2 or 3 inches across. In other places these masses assume the form of irregular, indistinctly bounded dikes. They evidently represent the final stage of a rock consolidate, when the surface was solid and the lower part of the eruptive mass still molten. Such masses are known as pegmatites. They do not, as a rule, form lines of weakness, as the large crystals are interlocked firmly with the surrounding finer-grained rock. For pillars or columns these areas are very attractive, as they add contrast and variety. For monument work, however, where even-grained texture is demanded, they are undesirable. Even in wall rock, as observed in the walls of a small jail behind the Bigstone County courthouse in Ortonville, these coarse-grained patches can be regarded only as blemishes.

Another defect consists of black knots of two types—long, irregular streaks that give the rock a gneissic texture, and oblong knots of different sizes, the largest observed being about 2 inches in diameter. They apparently consist almost entirely of black mica. They are not as numerous as the pegmatite masses.

Extensive outcrops of Archean rocks occur in northern Minnesota, but on account of their inaccessibility they have not been studied in the preparation of this report.

KEWEENAWAN ROCKS OF CENTRAL MINNESOTA.

ROCKS SHOWN ON THE MAPS.

Keweenawan rocks of several types occur abundantly in central Minnesota and constitute a valuable resource. They outcrop in many places, particularly in the neighborhood of the city of St. Cloud.

The outcrops and quarries in the St. Cloud region are shown on Plate I (p. 14), which represents an area of about 200 square miles about the city of St. Cloud. In the construction of this map the surveyed section lines and corners were used as a base and the outcrops were located with the plane table. The average magnetic declination for the region is 8° 30′ east of true north. Five types of rock—"St. Cloud red" granite, "St. Cloud gray" granite, "Rockville" granite, gabbro, and diorite—are marked with distinguishing symbols. Large-scale groups of active quarries, one in St. Cloud Township and the other in Haven, are shown on Plate II (p. 16) and Plate III (p. 18). Many quarries outside these areas are of equal importance but are too widely scattered to be included in a detail map.

GRANITES AND RELATED ROCKS.

The rocks of greatest economic value in central Minnesota are the granites and related rocks, which are quarried extensively in Stearns, Benton, and Sherburne counties. Most of the region is covered with drift, the rock appearing as low knobs or ridges, few of which rise more than 20 to 30 feet above the surrounding fields.

PROMINENT ROCK TYPES.

The granites quarried in the St. Cloud region are of three main types. In trade they are known as the "St. Cloud red," "St. Cloud gray," and "Rockville" granites.

"ST. CLOUD RED" GRANITE.

Throughout western St. Cloud Township, in Stearns County, the red granite is the most abundant. In secs. 8, 17, 18, 19, and 20 the exposures are almost entirely of red granite, and in secs. 29, 30, and 32 they are of red granite associated more or less intimately with gray granite. Red granite crops out sparingly on the east side of Mississippi River, the largest exposure being in sec. 17, Haven Township, Sherburne County. Other outcrops, some of considerable size, appear in western Benton County.

The red granite is medium to coarse grained, the feldspar crystals averaging about one-fourth of an inch in diameter. The chief minerals are feldspar and quartz, with minor amounts of hornblende, biotite, and magnetite. The feldspars (75 per cent) are mostly red or pink with subordinate gray. Orthoclase and microcline are more

abundant than plagioclase. They are usually intergrown with plagioclase and quartz, forming micrographic granites or microperthites. The quartz (15 to 20 per cent) occurs in coarse glassy grains. Hornblende and biotite together form 5 to 10 per cent of the rock. Magnetite appears in minute scattered grains. An average of the analyses of three typical "St. Cloud red" granites, analyzed by G. H. Hammond,[1] W. W. Willard,[2] and F. F. Grout,[3] gives the following result:

Average of analyses of three typical "St. Cloud red" granites.

SiO_2	71.17
Al_2O_3	13.30
Fe_2O_3	3.52
MgO	.30
CaO	1.56
Na_2O	3.85
K_2O	4.33
H_2O	.64
CO_2	.21
TiO_2	.23
P_2O_5	.23
	99.34

The carbon dioxide (CO_2) shown by these analyses is noteworthy. It probably indicates the presence of calcite due to alteration of the feldspars, and it would appear therefore that surface-weathered specimens had been analyzed. Calcite has not been noted in thin sections of the "St. Cloud red" granite ordinarily quarried.

"ST. CLOUD GRAY" GRANITE.

The largest exposures of gray granite and those least associated with other rock types in Stearns County are in secs. 21 and 28, St. Cloud Township. Numerous exposures occur in secs. 29, 30, 32, and 33 of the same township, but are more or less invaded or intimately associated with red granite, although a number of them are of good quality. Gray granite of commercial quality is more abundant than red granite in Sherburne County, particularly in secs. 6 and 7, Haven Township, in or near East St. Cloud. Scattered outcrops appear in western Benton County.

The gray granite (monzonite) is somewhat finer grained than the red, the feldspars averaging about one-eighth to three-sixteenths of an inch in diameter. The only minerals distinguishable in the hand specimen are gray feldspars and black hornblende or mica and here and there a grain of quartz. The microscope reveals, in descending

[1] Specimen obtained 1,750 paces north and 500 paces west of the southeast corner of sec. 32, T. 124 N., R. 28 W.

[2] Specimen obtained 1,250 paces north and 1,000 paces west of the southeast corner of sec. 21, T. 125 N., R. 28 W.

[3] Analysis made in 1883, specimen obtained at "Hartman's quarry," 1,670 paces north and 385 paces west of the southeast corner of sec. 29, T. 124 N., R. 28 W.

order of abundance, orthoclase, plagioclase, hornblende, quartz, microcline, biotite, magnetite, sphene, apatite, and zircon. In many specimens quartz is more abundant than hornblende, but it is never very prominent. The feldspars are rarely intergrown, as in the red granites. The most notable difference is in the quartz, which is never abundant and appears always to have been the last mineral to crystallize, filling the cracks and crevices between the other crystals. Hornblende shows intergrowth with biotite or alteration to biotite, and in some rocks exhibits cores of augite. Sphene is almost invariably present, another respect in which the gray granite differs markedly from the red, in which sphene is absent or appears only as very small and almost colorless grains.

An analysis of the most typical "St. Cloud gray" granite by F. F. Grout[1] shows the following composition:

Analysis of typical "St. Cloud gray" granite.

SiO_2	64.40
Al_2O_3	14.93
Fe_2O_3	1.63
FeO	3.13
MgO	3.05
CaO	4.18
Na_2O	3.31
K_2O	3.95
H_2O (above 100° C.)	.15
H_2O (below 100° C.)	.07
CO_2	.18
TiO_2	.57
ZrO_2	.07
P_2O_5	.57
S	.12
MnO	.09
BaO	.05
	100.45

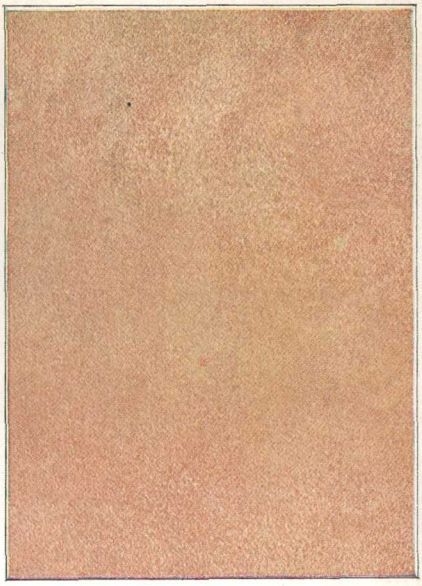
The smaller proportion of quartz in the gray granite as compared with the red is shown in the analysis by the lower percentage of silica; the larger proportion of sphene accounts for the increase in titanium dioxide. The "St. Cloud Red" and "St. Cloud gray" granites are shown in Plate V, *A* and *C*.

"ROCKVILLE" GRANITE.

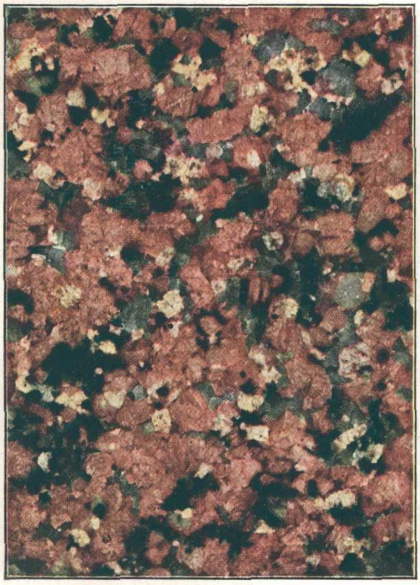
The third important granite is that which is quarried most abundantly at Rockville and hence is called the "Rockville" granite. Other outcrops of "Rockville" granite are in secs. 24 and 26, St. Joseph Township, and secs. 19 and 20, St. Augusta Township, Stearns County.

[1] Specimen obtained 1,500 paces north and 100 paces west of the southeast corner of sec. 28, T. 124 N., R. 28 W.

(A)



(B)



(C)

(D)

A. "ST. CLOUD GRAY" GRANITE
B. "KASOTA PINK" MARBLE
C. "ST. CLOUD RED" GRANITE
D. "HINSDALE" GRANITE

The "Rockville" granite (see Pl. XIII, *B*, p. 118) is much coarser grained than the "St. Cloud red" granite, the feldspars being one-half to three-fourths of an inch across. It is pinkish-gray and, as observed in hand specimens, consists of pale-pink feldspars, quartz, and black mica. By microscopic determination the chief feldspar is orthoclase, but considerable microcline and a little plagioclase also appear. Quartz is abundant in large glassy grains. Small grains of magnetite, apatite, and sphene are accessory.

A chemical analysis by F. F. Grout shows the following composition:

Analysis of "Rockville" granite.

SiO_2	69.63
Al_2O_3	13.85
Fe_2O_3	.54
FeO	4.01
MgO	.83
CaO	2.58
Na_2O	2.32
K_2O	4.33
H_2O (above 100° C.)	.23
H_2O (below 100° C.)	.10
TiO_2	.33
P_2O_5	.28
	99.03

Like the "St. Cloud gray" granite the "Rockville" contains sphene, but in its abundance of quartz and microcline and its coarse crystallization it resembles the "St. Cloud red" granite. (See Pl. V, *C*, p. 52.)

PORPHYRITIC GRANITE.

Porphyritic granite has been noted in two localities in Stearns County. In sec. 33, St. Cloud Township, about 8 rods south of John Doerner's quarry, it intrudes gray granite as a dike about 15 feet across, which spreads out into a larger mass. The contact is sharp; and near the gray rock, where cooling was rapid, a fine-grained granite porphyry resulted, while at a distance it is a coarse porphyritic granite. In thin section the granite porphyry consists of phenocrysts of quartz, orthoclase, and biotite in a fine-grained groundmass of the same minerals. In the porphyritic granite, at a distance from the contact, the phenocrysts are orthoclase and quartz, with an occasional microcline crystal, and the groundmass is of medium-grained quartz, feldspars, hornblende, and biotite.

A second outcrop of porphyritic granite in the NW. ¼ sec. 2, St. Cloud Township, near the west end of Sauk Rapids Bridge, shows interesting relationships and probably represents the latest igneous intrusion in the St. Cloud region. For 30 yards from the south of the exposure granite porphyry appears. It consists of a fine-grained

groundmass of quartz, orthoclase, and plagioclase, with subordinate hornblende, biotite, and magnetite, in which are embedded crystals of quartz and orthoclase. North of this for 40 yards is a fine-grained gray granite, consisting of gray feldspar and both biotite and hornblende. The dark minerals are not uniformly distributed and quartz is not abundant. The chief feldspars are orthoclase and microcline, with subordinate plagioclase. The rock resembles the typical "St. Cloud gray" granite, both in mineral content and texture. The presence of sphene, which is so characteristic of the latter, completes the similarity. The gray rock is cut by a diabase dike 4 inches wide, with trend N. 75° W., and by several red aplite dikes. Joints are about 2 feet apart and strike N. 10° W. North of this for 64 yards is granite porphyry, bounded on the north by a 3½-foot diabase dike with trend N. 75° E. Joints in the porphyry strike N. 5° E. and N. 20° W. Near the dike the texture of the porphyritic rock shows a notable change, the matrix becoming a very fine grained typical rhyolite porphyry. Not much change is seen in the size of the phenocrysts. Stringers of the porphyry cross the diabase; three from one-fourth to one-eighth of an inch wide and clearly connected with the porphyry were observed. The diabase dike is bordered on the north side by the gray granite, which extends 5 yards farther north. From these relationships it is evident that the gray granite is the oldest of the three rocks, being intruded by diabase dikes, and the granite porphyry the youngest, for it intrudes the diabase dikes. (See fig. 1.)

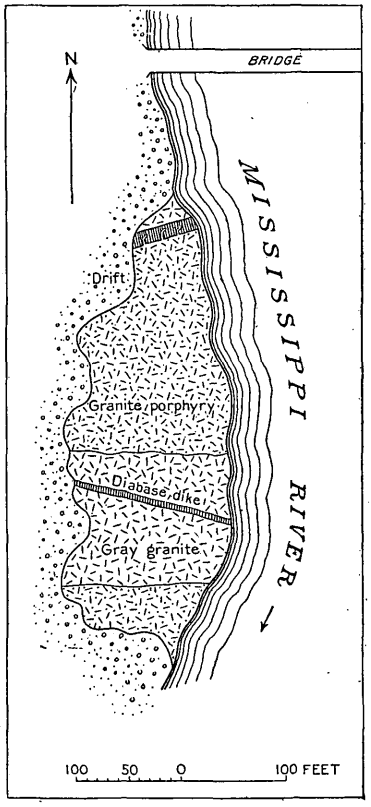


FIGURE 1.—Sketch map showing relations of rocks south of Sauk Rapids Bridge, sec. 2, St. Cloud Township, Stearns County, Minn.

AGE OF THE GRANITES.

In the absence of known contacts with rocks of determined age the geologic age of the granite can not be accurately stated. Diabase dikes, probably related to the great gabbro intrusion in the Lake Superior region, cut the granite in many places. As the gabbro is Keweenawan, it is inferred that the granite is early Keweenawan or

older. No contacts of the granite with more ancient rocks have been observed. Numerous rock inclusions in the granite have been studied, and the results throw a little light on the problem, though they are not conclusive. A garnetiferous schist inclusion found in the gray granite of sec. 29, St. Cloud Township, Stearns County (pp. 60, 111), is very similar in mineral composition to schists occurring near Little Falls, about 30 miles north. The latter are described as upper Huronian, and thus the petrographic evidence suggests that the granite is post-Huronian—that is, early Keweenawan.

At some places in the St. Cloud region large areas of red granite and gray granite occur without contact with each other, but at other places the two types are in intimate contact that affords a means of judging their relative ages. Many outcrops show clearly that the red granite is younger than the gray.

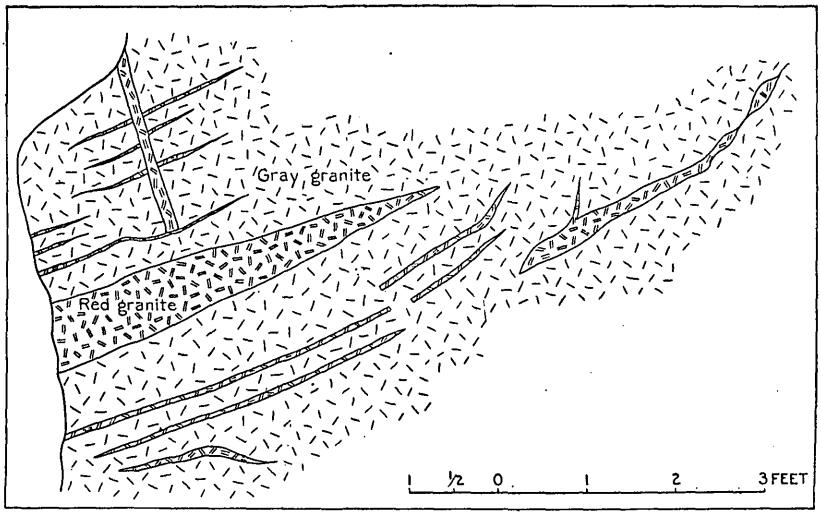


FIGURE 2.—Sketch showing relation of red granite and gray granite at the center of the west side of sec. 29, St. Cloud Township, Minn.

At the center of the west side of sec. 29, St. Cloud Township, the red granite is clearly younger, as it forms dikes and stringers in the gray granite. (See fig. 2 and Pl. VII, *B*.) Another place where the relations of the rocks are clearly shown is at an exposure whose center is 222 rods north and 78 rods west of the southeast corner of sec. 29, St. Cloud Township. The rock in the eastern part of this exposure is a medium-grained red granite, and that in the western part is a gray granite. Near the contact the texture of the red granite becomes finer. Numerous fine red dikes pass from the red area into the gray. At one point an inclusion of biotite schist occurs in the gray rock, and both the schist and gray granite are cut by a red granite dike. (See fig. 3.) The inclusion may be a fragment of the upper Huronian schist, such as occurs near Little Falls.

In the Monarch Granite Co.'s quarry, in sec. 8, St. Cloud Township, an interval evidently elapsed between the times of the solidification of the two magmas. After the gray granite magma became firm enough to be shattered it was intruded by dikes of white aplite (fine-grained granite). As the red granite is not cut by the white aplite it was evidently injected later. Considerable time was no doubt required for the solidification of the gray granite magma and for the injection and solidification of the aplite dikes.

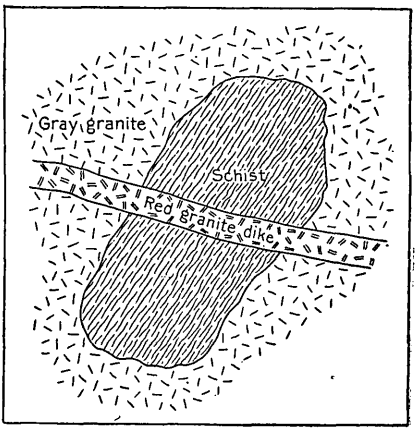


FIGURE 3.—Sketch showing relations of rocks in outcrop 222 rods north and 78 rods west of the southeast corner of sec. 29, St. Cloud Township, Minn.

At the west end of an exposure whose center lies about 300 rods north and 96 rods west of the southeast corner of sec. 32, St. Cloud Township, the red and the gray granite are in contact. As observed in an abandoned quarry the line of contact is gradational over a space of several inches and the two rocks are evidently nearly contemporaneous. Dikes of the red, however, occur in the gray at several places, and the converse is nowhere seen, the relation indicating the later intrusion of the red granite.

Near the center of the north line of sec. 21, St. Cloud Township, an outcrop divides into two ridges, the eastern end of each being of red granite and the remainder of gray granite.

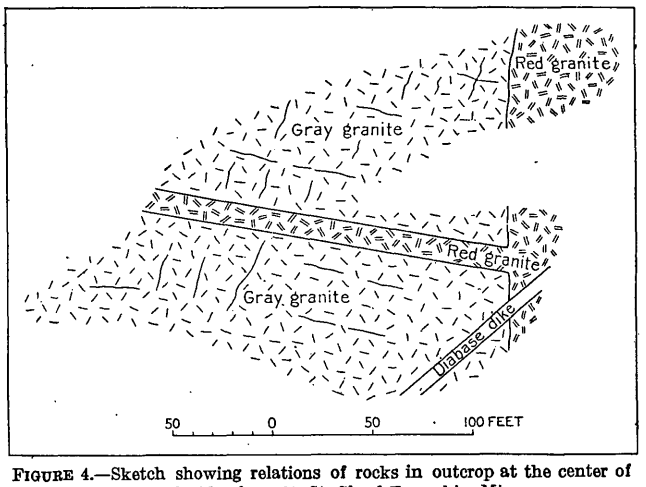


FIGURE 4.—Sketch showing relations of rocks in outcrop at the center of the north side of sec. 21, St. Cloud Township, Minn.

In the southern ridge a 10-foot dike of red granite in the gray, traced to its source, is found to connect definitely with the larger mass of red granite. It trends N. 80° W. through the gray rock and disappears beneath the drift at the eastern side of the outcrop. A number of

smaller red dikes are present. The large dike and most of the small dikes follow the direction of major jointing in the gray rock (N. 80° W.). A 6-foot diabase dike, striking N. 50° E., and a 5-foot dike striking N. 40° E., cut both red and gray rock. (See fig. 4.)

In an outcrop at the center of the north line of sec. 32, St. Cloud Township, several red granite dikes injected into gray granite follow the direction of the major joints in the gray rock, indicating that jointing systems were developed before the injection of red magma.

In most places, however, the contacts are gradational, the one rock merging into the other as though nearly contemporaneous. The same relationship of red to gray granite exists in Morrison County.

ROCK DEFECTS.

Occurrence and character.—The defects observed in the "St. Cloud" granites at different places are more fully discussed on pages 75–136. This is done not with any intent to give undue prominence to these imperfections but in order to explain their origin and the nature of their occurrence and if possible to formulate rules that may aid the quarryman in obtaining rock free from blemish. The occurrence of defects does not prevent the production of excellent stone, as is proved by the nation-wide reputation of "St. Cloud" granites, but it does increase the expense of quarrying.

The interpretation of defects is a matter of considerable difficulty, for the evidence in many places is meager and much of it is not understood. Nevertheless, a few general principles may serve in some measure to guide prospective quarrymen.

The chief defects which the quarryman should endeavor to avoid are mixtures of red and gray granite, trap dikes, aplites, hair lines, black knots, irregular and close jointings, and surface alterations.

Mixtures of red granite and gray granite.—Considerable areas of red and of gray are found, each of them comparatively free of the other, but in many places the types are greatly mixed, and one can never be sure that he will not find inclosed masses of gray rock in a red quarry and dikes and intruded masses of red granite in a gray quarry. If the stripped outcrop is of sufficient size to permit fairly extensive observation the presence or absence of dikes or masses of foreign material at the surface will fairly indicate what must be expected at depth. In this connection one fact is worthy of note: Near the surface of each of at least eight different red quarries, some of them several miles apart, a mass of gray granite 15, 20, or even 50 feet across, but nowhere more than 10 to 20 feet deep, was observed. Most of these masses contain more quartz than the larger areas of gray granite and in other

respects also are of somewhat different type. They may be masses of the typical gray granite, modified by diffusion of material from the more siliceous red granite. They are usually lacking in uniformity and useless as quarry rock.

It is undesirable to attempt quarrying near known contacts of the red with the gray, for in many places the gray granite is cut by numerous dikes of the red, and the red is inclined to show uneven texture, pegmatitic areas, and inclosed masses of gray granite. Also the shattered nature of the rock near the contact results at many places in the presence of fine quartz veins filling cracks.

Study of the map (Pl. I) will indicate in a general way the type of rock to be expected in a given area. For example, sec. 29, St. Cloud Township, contains numerous outcrops of both red and gray granite but no considerable area of the one without more or less of the other. Such irregular distribution is unpromising; mixed types prevail, dikes and inclusions are common, and the texture lacks uniformity.

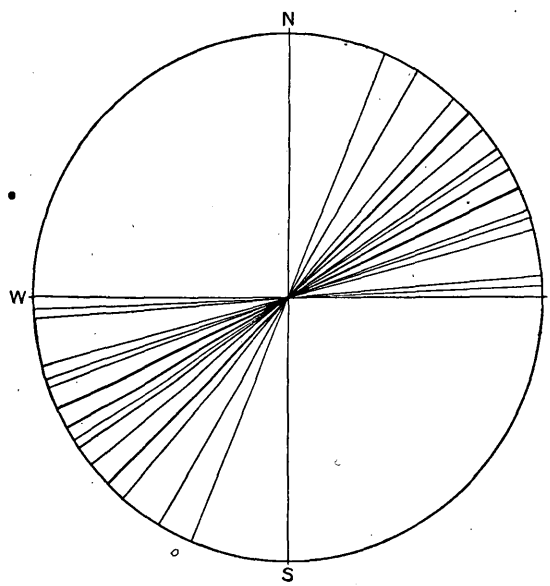


FIGURE 5.—Strike of diabase dikes in the St. Cloud region.

Diabase or trap dikes.—Diabase dikes are common throughout the region. They range in width from a small fraction of an inch to 4, 6, or even 8 feet. It is noteworthy[1] that the dikes observed in the St. Cloud region (see fig. 5) point in general toward the Duluth region the center of Keweenawan igneous activity.

The contact effect of the diabase on the granite is slight, altering it to a depth of 1 to 2 inches only from the contact, but the dikes are disadvantageous because of the waste of time and labor required to remove them, because of the waste of the granite penetrated by the smaller dikes, and because of the presence of incipient fractures which commonly accompany the formation of the larger dike-filled fissures. It has been observed at several places that the rock near dike contacts is somewhat unsound, but several good quarries close

[1] Grout, F. F., unpublished manuscript on the granites of Stearns County, Minn.

to dikes have been noted. Where unsound rock borders on dikes it is evident that the shattering which formed the open fractures undoubtedly formed at the same time numerous fine cracks which seriously mar the strength and appearance of the rock near by. Some of the minor fractures are also filled with diabase and are known among quarrymen as "hair lines," though not all hair lines are of this origin. Some of those that are closely associated with the dikes contain the same minerals as the diabase; others contain only alteration products of these minerals, such as epidote and chlorite, but preserve the diabasic texture. However, some quarries close to dikes show no hair lines. Their presence can best be determined by a careful scrutiny of the stripped surface, preferably on a rainy day.

Aplites.—Dikes of aplite (fine-grained granite) are common, especially in the East St. Cloud gray granite quarries, and their presence results in an undesirable amount of waste rock. In the red granite they are less common. A noteworthy characteristic is the prevailing red color of the aplites that occur in red granite, and the gray color of those in gray granite; apparently they are later intrusions of the magma that formed the rock in which they occur. Lack of system—that is, great divergence in trend among the aplites (see fig. 6), is an additional fact which sustains this hypothesis. At many places they are so irregular that no attempt was made to record their direction.

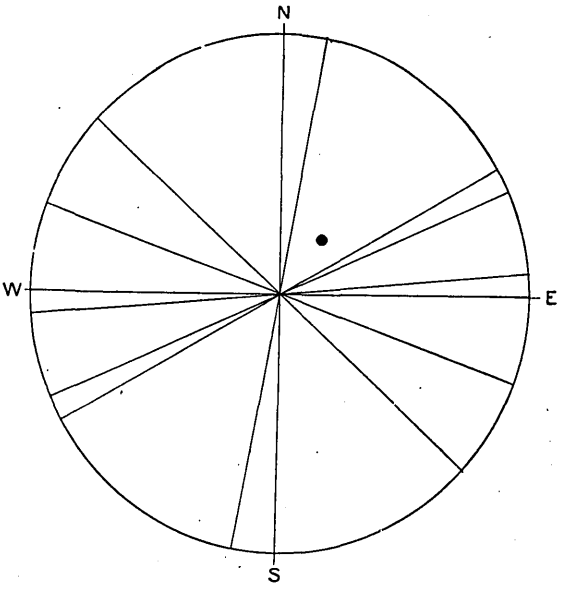


FIGURE 6.—Strike of aplite dikes in the St. Cloud region.

Hair lines.—The term "hair lines" is applied to all fine lines of discoloration, whether black or green. Some hair lines are dikes; some of them are minute quartz veins, which appear black if the quartz is dark or "smoky." Such veins are most common near the contacts of two rock types where movement or shattering has taken place.

Hair lines of green color are very common. These are epidote veinlets, many of them following joints, in which case they are not serious. Others follow no definite direction but wander irregularly throughout the rock mass and mar much of the stone. Green lines

occur in many places in parallel or interlacing groups, probably because rock shattering follows zones rather than single lines, and epidote has filled the minute fractures. As a rule they run east and west and are more common near the surface than deep down in quarries. Plate VI, *B*, shows the hair lines as they appear on the rock surface.

Black knots.—"Black knots," when in the gray granite, constitute its most serious blemish. Some of them are segregations—gathering together in spots of the dark minerals during the process of cooling and solidification. Others are inclosed fragments caught up by the molten gray rock and held within it until the whole mass solidifies. Most of these fragments are somewhat angular in shape and consist of material different from the rock in which they are inclosed. The most common are inclusions of gray granite in the red, the converse having never been observed. Such inclusions are serious blemishes in the red granite and are naturally of more frequent occurrence near contacts of the gray and the red rocks.

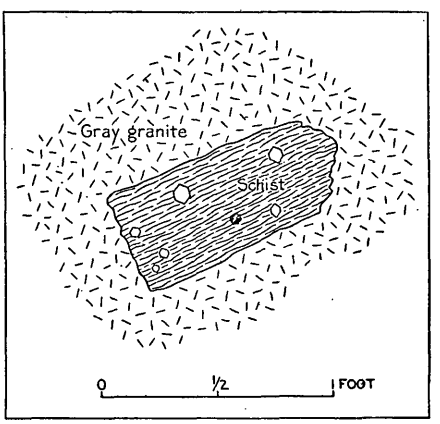
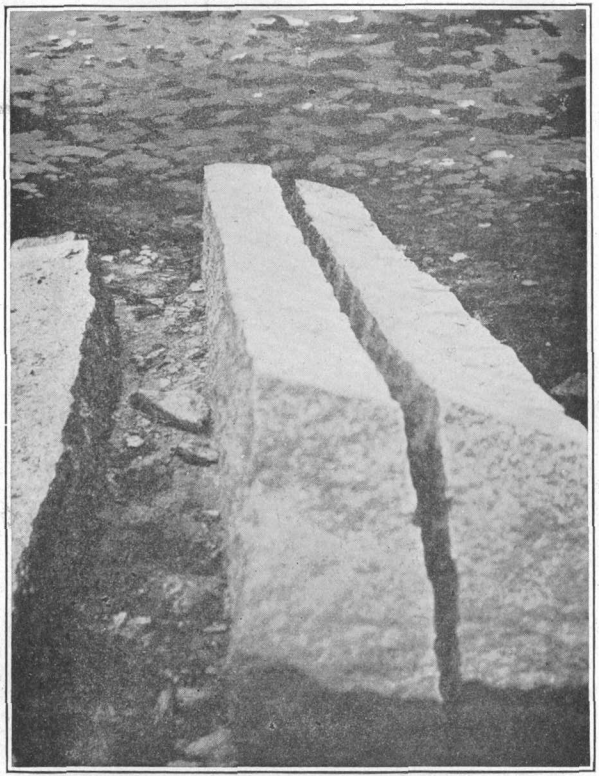


FIGURE 7.—Inclusion of garnetiferous mica schist in gray granite 173 rods north and 236 rods west of the southeast corner of sec. 29, St. Cloud Township, Minn.

Inclusions of foreign material picked up by the molten rock have been noted in several places. One, which occurs in a granite outcrop about 200 rods north and 224 rods west of the southeast section corner of sec. 29, St. Cloud Township, is an irregular fragment (see fig. 7) a foot long and 5 inches thick, of a finely laminated biotite schist, containing many large and small garnets, some of which are half an inch across. Under the microscope dynamic action is apparent in the granular nature of the quartz and the presence of many parallel cracks. The schist consists of biotite, hornblende, hypersthene, and garnet, and a few grains of plagioclase and magnetite. It resembles the garnetiferous schists which occur in the Mississippi River valley, about 30 miles to the north. An inclusion of fine-grained diabase containing much magnetite was also observed.

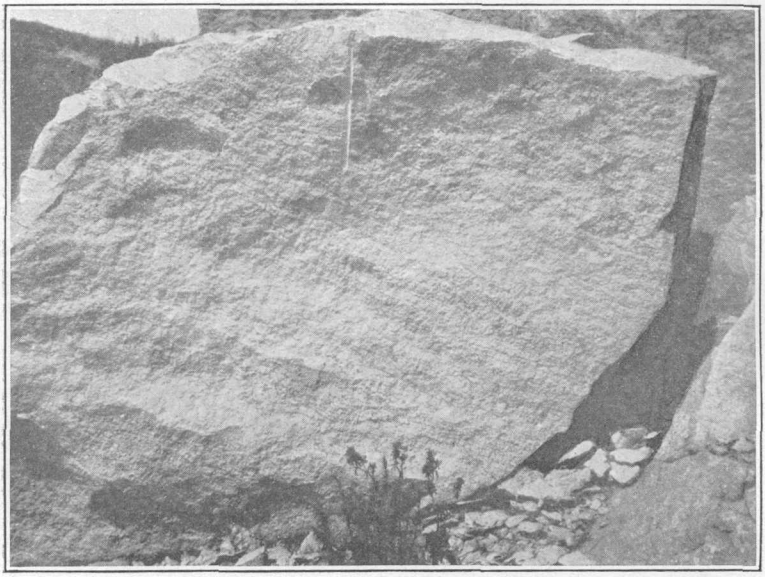
Garnetiferous norite (a variety of gabbro) inclusions have also been noted. An inclusion of biotite schist in gray granite is shown in figure 2 (p. 55).

Both the origin and distribution of segregations are difficult to explain. No general conclusion has been reached regarding their occurrence, and their presence or absence in any locality is a matter of mere speculation.



A. GRAY GRANITE SPLIT ALONG THE RIFT, ROBERT GRAHAM'S QUARRY, ST. CLOUD TOWNSHIP, STEARNS COUNTY, MINN.

B. HAIR LINES AS THEY APPEAR ON THE GRANITE SURFACE.



A. EVEN SURFACE MEASURING 12 BY 15 FEET OBTAINED BY A SINGLE BLAST IN A 3-FOOT REAMED DRILL HOLE, ANDERSON GRANITE CO.'S QUARRY, MORTON, MINN.

B. DIKES OF RED GRANITE CUTTING GRAY GRANITE IN SEC. 29, ST. CLOUD TOWNSHIP, MINN.

As knots of the inclusion type occur more commonly near contacts, by avoiding known contacts one may hope to find fewer knots. On the other hand, knots of the segregation type, so far as may be inferred from evidence in Minnesota quarries, are liable to occur anywhere. Hence an interpretation of the origin of knots is a matter of some importance. A specific example will illustrate the method of interpretation.

In the "Mora" granite knots of the two types occur. The one consists of orthoclase, plagioclase, quartz, and biotite, the same minerals that occur in the surrounding rock, though the proportion is different, biotite being in excess. These minerals show the same peculiarities as corresponding minerals in the main rock mass; for example, the biotite contains apatite and zircon inclusions (the zircon having pleochroic halos), a condition characteristic of the "Mora" granite. Such knots are segregations. The other type of knot consists of quartz and biotite, with no feldspar. The mica flakes show parallel orientation and do not exhibit apatite or zircon inclusions. The minerals have different characteristics from corresponding minerals in the surrounding rock mass, and the knots are probably inclusions of biotite schist. The shape of many knots is indicative of their origin, angular knots being inclusions, and ellipsoidal or spherical knots being more probably segregations.

It is advisable for prospective quarrymen to strip the outcrop for a considerable area, if it is not already bare, and then to examine it very carefully, preferably on a rainy day, before spending any money on development work or equipment. A careful scrutiny of the outcrop surface will reveal the probable proportion of knots, hair lines, streaks, dikes, and veins, as well as the direction and spacing of joints in the underlying rock.

Joints.—Joints in the "St. Cloud" granite are spaced sufficiently far apart at most places to permit the quarrying of large blocks. Many quarrymen regret the wide spacing of joints, as it increases the difficulty of quarrying. If, however, joints were closely spaced the rock would probably be decayed to a considerable depth and the cost of its necessary removal would probably more than offset the increased facility of quarrying. In one quarry in East St. Cloud two joints occur 3 feet apart and the rock between them is so stained and decayed as to make it useless to a considerable depth, this being but one illustration of the general rule that close jointing permits water percolation in a greater number of places and thus hastens rock decay.

Compass readings were taken of the direction of joints in all the quarries and outcrops of the region. All the results obtained for major and secondary joints are combined in the accompanying dia-

gram (fig. 8), in which joint directions are represented as radii of concentric circles.

It is noteworthy that most of the major joints strike north or a little west of north, and most of those remaining, a little south of west. On the other hand, most of the secondary joints strike a little south of west. A feature of economic importance is the tendency of joint systems to run at approximately right angles. This is best appreciated by holding the diagram at some distance from the eye, the light and dark quadrants then appearing to better advantage. This is a matter of first importance to quarrymen, as joints intersecting at acute angles result in angular blocks and consequent undesirable waste of both labor and stone.

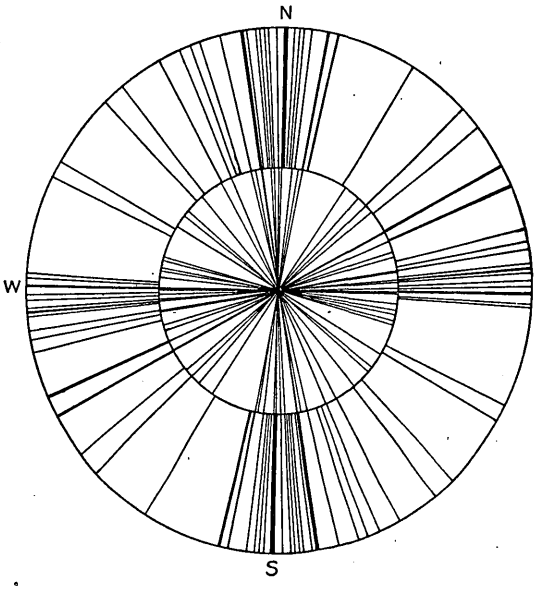


FIGURE 8.—Strike of major and secondary joints in granites of the St. Cloud region, Minn. Outer circle, major joints; inner circle, secondary joints.

Sheeting planes.—Sheeting planes in granites lie parallel to the ground surface and are consistently closer together near the surface than at depths. In many New England granite quarries sheeting planes are more closely spaced than joints. A remarkable feature of the St. Cloud region, however, is the scarcity, or even the entire absence, of sheets in both red and gray granite, some quarries 60 feet in depth showing no sheeting planes. Where present they are almost invariably more widely spaced than joints. Quarrymen who have worked first in New England and later in St. Cloud describe the rock of the latter region as "standing on end." The scarcity or absence of sheets makes quarrying difficult, as it is necessary to force artificial sheets by means of "lift holes."

Surface alteration.—Bare outcrops rising several feet above the surrounding level are not desirable places on which to open quarry pits when only monumental stone is desired. It has been found, especially in the case of red granite, that bare exposures result in deep weathering. In certain quarries, however, it was observed that the depth of surface weathering is influenced by the proximity of sheeting planes. Where no sheets occur the rock is usually weathered to a

greater depth than where they are present. If a sheeting plane lies 4 to 8 feet below the rock surface, especially if it is inclined, the rock above is usually greatly decomposed and that below is practically unaltered. The open seam permits the surface water to drain away, and the lower rock, being protected from frost and heat, is unfractured and offers maximum resistance to surface decomposition. It is unfortunate in this connection that sheeting planes are so far apart. In many quarries of red granite opened in exposed outcrops stained "sap rock" is found to a depth of 10 to 20 feet; and in other places, where a covering of soil has served as protection, only the upper foot or 2 feet shows stain. Even where stains due to weathering are invisible the rock to a depth of 15 to 20 feet beneath bare exposures may be bleached, the feldspars having lost a large part of their attractive and desirable red color. Such rock, though suitable for building blocks, is unsalable as monumental stone. A mantle of 2 or 3 feet of soil seems sufficient to prevent such bleaching.

If it is desired to produce both structural building blocks and monumental stone, quarries on exposed bluffs may work to advantage. Blocks that are unstained, though faded, make excellent structural material, and their removal is usually easy. Thus the stripping of faded material is conducted with profit and good monumental stone is reached in time. The bleaching and staining of exposed bluffs have been observed in so many places that the rule may be given as almost universal.

The gray granite, however, apparently has a more stable color, which is not so readily affected by the elements. Bare exposures are rarely affected to a depth of more than 3 feet.

NATURE OF THE PRODUCT.

On account of the attractive appearance and susceptibility to polish of the red and the gray granites, both are well adapted for ornamental structures such as monuments, spires, and columns. A large part of their output is monumental.

The rock is equally well adapted for building purposes, though it has not been used as extensively in this way on account of the lack of equipment of many of the companies for handling large contracts. However, many attractive buildings are made entirely or partly from "St. Cloud" stone.

One of the important minor uses of the stone is for the production of paving blocks, of which several millions have been employed in city street construction. They are made exclusively from the gray granite. Crushed rock for roads and concrete is produced in several places, and rubble is supplied for rough masonry and foundation work. Much waste rock was supplied in past years for railroad ballast and filling, but of late years the demand for it has been less.

GABBROS AND DIORITES.

Certain gabbro areas occur in St. Wendall and Le Sauk townships in Stearns County. They have been quarried but little and are not of great economic importance. Their structural relations are, however, noteworthy. They are cut by siliceous intrusives, which in places are similar to the typical "St. Cloud red" granite and may be a part of the red granite intrusion. If they are part of this mass, the gabbro intrusion antedates that of the red granite. Evidently this gabbro is not related in age to the diabase dikes which cut the granites of St. Cloud Township. The presence of red granite dikes in the gabbro, and the absence of diabase dikes in the vicinity, indicate that basic intrusives in the St. Cloud region are of two periods.

In Watab Township, Benton County, extensive and prominent outcrops of dark diorite have been quarried in a few places.

TECHNOLOGY.

QUARRY METHODS.

Stripping.—The gravel, sand, or clay which overlies a rock deposit may be removed in several ways. It is doubtful if any granite quarries in Minnesota are extensive enough to justify the use of a steam shovel. On level or moderately inclined surfaces stripping may be done with teams and scrapers. On less accessible surfaces the soil is loaded into boxes and removed with the quarry derrick. It is imperative that the overburden be removed to a sufficient distance to insure that it will not impede present or future operations, and it may be necessary to load it on small cars for farther removal.

Plan of operation.—The positions of all joints, hair lines, knots, or other imperfections should be carefully noted and the most favorable location selected for the quarry opening. The walls of the excavation should be made to conform in direction with the more prominent structures, such as joints, hair lines, or rift. By taking such precautions the number of angular blocks and of blocks marred by diagonal hair lines may be reduced to a minimum.

The ordinary method of procedure is first to blast out a hole to get a quarry face or bench. Drill holes are then placed some distance back from the face and masses of rock broken loose by powder shots. If a sheeting plane provides a floor opening, quarrying is easier and less wasteful. If sheeting planes are absent artificial ones must be produced by blasts in horizontal "lift holes." The larger masses are reduced to convenient sizes by wedging in drill holes.

The shape of the opening is governed by quarry conditions. If stripping is heavy it may be advisable to excavate a small area to

considerable depth. In some deposits too the quality of the rock improves with depth. In most quarries the cost of removing stripping and inferior surface rock is so high that wide and shallow quarries are not justified. On the other hand, the high cost of hoisting will probably discourage quarrying to depths greater than 80 or 90 feet. The quarryman should endeavor to attain a proper balance between stripping cost and hoisting cost and at the same time obtain a maximum supply of high-grade rock.

Drilling.—In most Minnesota quarries drills are steam driven. In some quarries, few but increasing, compressed air is used. The first cost of compressed-air equipment is higher than that of steam, but it is generally considered to be more convenient and economical.

Blasting.—The Knox system of blasting is commonly employed in the granite quarries of Minnesota. It involves the use of a reamer or flanged tool which, when driven into the drill hole, cuts grooves about one-fourth of an inch in depth on opposite sides of the hole. Care is taken to cut the grooves exactly in line with the desired direction of splitting. A plug of cotton or other material is placed in the hole some distance above the powder charge and the hole is tamped above the plug. The air space above the charge permits the explosive force of the powder to be distributed over a comparatively wide surface and the grooves promote straight splitting. The explosion is more effective by the Knox system than otherwise, and smaller charges may be used, resulting in a smaller proportion of waste by shattering.

The effectiveness of the method is well illustrated in a "Morton" gneiss quarry, in which a plane even rock surface 15 by 12 feet was obtained by means of a single reamed drill hole only 3 feet deep. (See Pl. VII, *A*). Many years ago in the same quarry the Saulpaugh Co., in order to make an even break of the same magnitude, projected five unreamed drill holes 8 feet deep. Single holes are usually fired by fuse. If more than one hole is required for a single fracture an electric firing machine is used to give a simultaneous discharge.

Wedging.—The large blocks separated from the quarry ledge by blasting are reduced in size by the "plug and feather" method. Shallow holes are drilled in rows a few inches to several feet apart, the distance depending on the ease with which the rock splits. In crystalline rocks the necessary holes are made by hand drills in the smaller quarries and by compressed-air plug drills in those better equipped. In each of the holes is placed two half-round steel plugs with an iron wedge between them. By driving in the wedges a fracture is formed. If the holes are so placed that splitting may be done in directions of rift and run straight and even breaks are obtained with greater ease than if these directions are disregarded. Wedging may also be employed to remove the larger irregularities

from the blocks, the final trimming being accomplished with a hand hammer and tool.

Hoisting.—The common type of derrick consists of a vertical mast, commonly of wood, held in place by steel cables. The swinging boom is commonly of wood also. Steel derricks are used in a few quarries. Hoisting is accomplished by horse, steam, or electricity. Additional yard derricks are used at some quarries for loading.

Finishing.—Cutting and polishing shops are located close to a few quarries, but most of them are at St. Cloud or near-by towns. The cutting, polishing, and carving of granite into monuments is an important industry, which employs several hundred men. A complete list of the finishing plants is given on page 218.

Blocks of the sizes desired for monuments are first placed beneath a surfacing machine, which removes the larger irregularities from the surface. Most machines are operated by compressed air. A bar which holds a tool having blunt projections strikes the rock surface rapid blows and chips off fragments of rock.

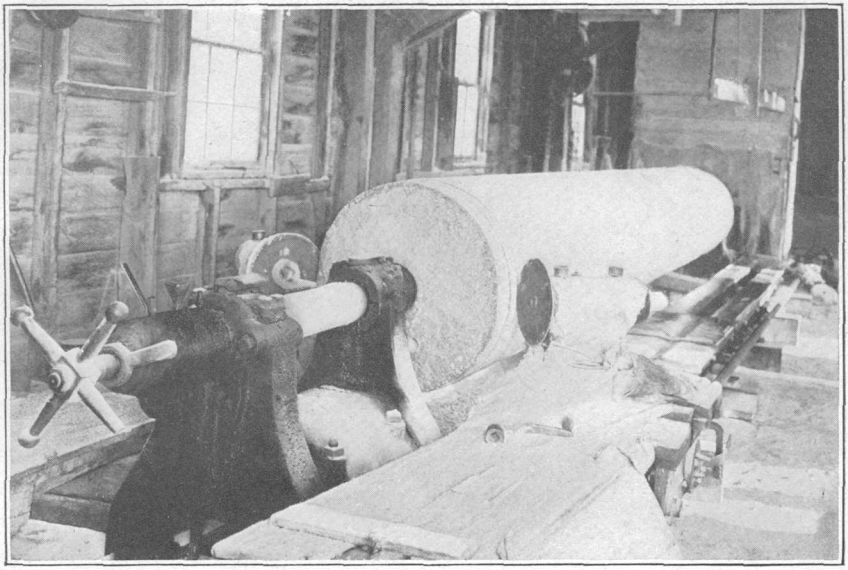
Eight or ten surfaced blocks are placed on a timber bed with their upper surfaces on an even plane. The entire group of blocks is surrounded by a wooden box, the bottom of which is a little lower than the rock surface. All cracks in the box and between the blocks are filled with plaster of Paris. Coarse steel shot is placed on the rock and a stream of water directed upon the surface. A revolving head driven by machinery is guided over the surface and grinds it down. Different sizes of shot are employed, and finally the surface is thoroughly cleaned and then polished with "putty powder," which is usually tin oxide. An experienced polisher can completely polish a bed of 60 to 100 square feet in a 10-hour day.

Carving and lettering are done with hand tools driven by a hammer or operated by compressed air.

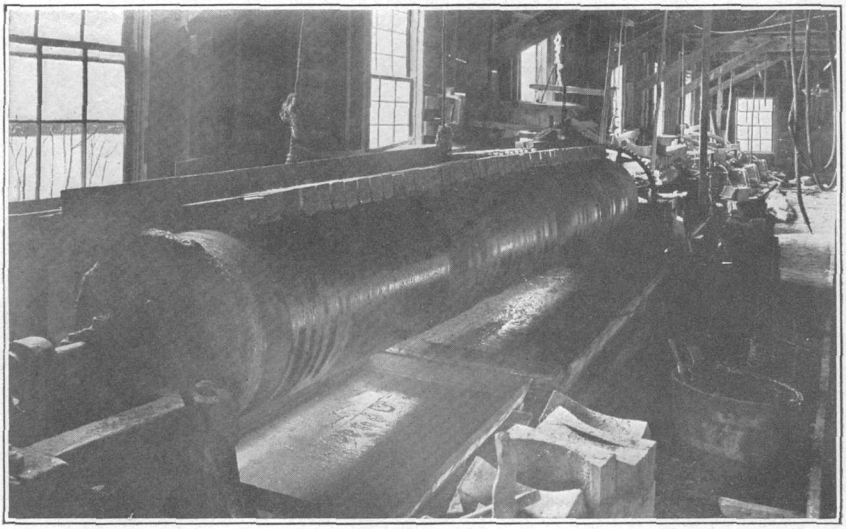
Some shops are equipped with turning lathes for turning down and polishing granite columns.

Two very large lathes are operated in the Rockville Granite Co.'s shops in Rockville. As the column rotates small steel cutting disks set at angles of about 45° to the axis of the lathe trim down the column to desired evenness and uniformity. (See Pl. VIII, *A*.) For polishing, the column (See Pl. VIII, *B*) is rotated and the abrasive held against it. Chilled steel shot is used as a coarse abrasive, then corundum and emery powder, and finally tin oxide. The pads consist of wooden blocks curved to fit the column and lined with felt or other soft texture.

Rock transportation.—All the granite quarries of Stearns County are 2½ to 5 miles from St. Cloud, where most of the shops are situated. A number of the quarries in Benton and Sherburne counties are also some distance from the finishing plants. On this account



A. GRANITE COLUMN QUARRIED BY THE PIONEER GRANITE CO., IN THE LATHE OF THE ROCKVILLE GRANITE CO., ROCKVILLE, MINN.



B. SIMILAR COLUMN IN THE POLISHING LATHE.

transportation of rock from quarry to shop is an item of considerable expense. Railway sidings (see Pls. II and III) reach most of the quarries, but some haul their rock with teams and wagons.

WASTE.

It is remarkable that so little of the waste rock in the region is used for crushing. G. J. Hilder & Son, the State reformatory, and the Sauk Rapids Granite Co. have the only crushers. The Hilders manufacture paving blocks, and the small chips resulting are easy to crush. Discarded blocks from monumental stone workings are large and unwieldy and require so much labor to reduce them to convenient size that the operation is generally regarded as unprofitable. Some of the waste material is sold for rubble, but most of it is unused. The disposal of waste material is a problem still awaiting solution in the St. Cloud region. The expense of excavating and handling inferior rock is great, and the heaps of discarded blocks in many places cover up rock which might otherwise be quarried to advantage. Many of the blocks marred only by small black knots or inconspicuous hair lines could be utilized for building if the quarries and shops were provided with suitable equipment for dressing and handling them and sufficient capital to handle building contracts. The enlargement of operations to include production of both monumental and building stone from the same quarries may at least partly solve the problem.

ECONOMIC CONDITIONS.

Both the red and the gray granites are beautiful in appearance and are in great demand. They are well known throughout the country and to some extent in Canada and Mexico. Approximately 95 per cent of the total output of monumental stone is sold beyond the borders of Minnesota, a condition which reflects credit on the industry and points to prosperity and continued expansion. Most of the companies, however, are small and have moderate facilities, few being qualified to bid on large contracts. The organization of larger companies would result in a more rapid development of the industry.

Market price of "St. Cloud" granite in 1913.

Gray base stock, per cubic foot	$0.80
Gray die or polish stock, per cubic foot	1.25
Red base stock, per cubic foot	1.00
Red die or polish stock, per cubic foot	1.25
Paving blocks, per thousand f. o. b.	76.50
Rubble, per cubic yard	0.60–0.70

GRANITES.

GRANITES AND GNEISSES OF ARCHEAN AGE IN THE MINNESOTA RIVER VALLEY.

BIG STONE COUNTY.

DISTRIBUTION AND CHARACTER OF THE ROCKS.

Available rock in Big Stone County is found only in the Minnesota River valley from Ortonville southeastward to the neighborhood of Odessa and Correll. Near Ortonville there are numerous outcrops, some of which rise 30 or 40 feet above the general level of the valley. Two large quarries have been operated here—one by the Consolidated Granite Co. and the other by the Aberdeen Granite Co. Other smaller quarries are the Union, now owned by the Consolidated Granite Co.; a quarry owned by F. L. Cliff; the St. Paul quarry, which has not been operated for a number of years; and the Light quarry, now owned by the Aberdeen Granite Co.

No stone is at present quarried in Big Stone County. Robert Hunter operates a polishing shop in Ortonville, employing two cutters, but all the stock used is shipped from a quarry in South Dakota, not far from Milbank.

The "Ortonville" stone is a biotite granite or granite gneiss. At Ortonville, as at North Redwood, the gneissic texture is not nearly so pronounced as at Montevideo and other points on the lower Minnesota River valley. The rock is deep red in color, takes an excellent polish, and is one of the most attractive stones in the State. (See Pl. IX, *C*). For a microscopic description of the rock see page 48.

The "Ortonville" stone has certain defects which must be avoided as far as possible in quarry operations. The chief of these are pegmatite masses, black knots, and close jointing.

The pegmatite masses consist of coarsely crystallized feldspars and quartz which appear in streaks or knots. They give the rock an uneven texture which destroys its attractiveness for many purposes.

The black knots are masses of dark minerals, either hornblende, black mica, or a mixture of the two, which mar the surface like blots on a sheet of paper.

The joints in many places are only a few inches apart, and are commonly irregular and meet at sharp angles, but in the better material they are 3 to 8 feet apart and intersect approximately at right angles. The close spacing of the joints accounts for most of the waste material lying in heaps beside the quarry pits.

In quarrying it has proved possible to avoid the defective material, and much rock of good quality in large blocks has been quarried near Ortonville. Four large columns of "Ortonville" stone occupy prominent positions in the State Capitol Building at St. Paul.

(A)

(B)

(C)

A. "MORTON" GRANITE GNEISS
B. "SAUK RAPIDS LIGHT-GRAY" GRANITE
C "ORTONVILLE" GRANITE

Under crushing tests "Ortonville" granite cracked under a pressure of 12,772 pounds per square inch and collapsed under 23,722 pounds. Under transverse stress its modulus of rupture proved to be 3,098.2 pounds per square inch.

CONSOLIDATED GRANITE CO. QUARRY.

The Consolidated Granite Co.'s quarry is about 1½ miles from Ortonville, in sec. 22, T. 121 N., R. 46 W. Work began in 1898, and for some years one ledge supplied very large blocks of excellent quality for monument manufacture. Sufficient stone was quarried at one time to keep busy a polishing shop in Ortonville that operated three polishing machines and employed twelve cutters. Later it became more difficult to obtain blocks of such quality, and the industry was directed toward the production of crushed stone, great quantities of which were used for road material. For this purpose a large and well-equipped crushing plant was erected at a cost of about $30,000. It has not operated since 1911. A small amount of rubble was also produced.

Quarry conditions are fair. The rock rises in a bluff about 30 feet above the general drainage level and outcrops over an area of about 2 acres, with other outcrops in the vicinity. The top of the bluff is bare of soil, requiring only the removal of about 4 feet of partly decayed rock. The Chicago, Milwaukee & St. Paul Railway tracks are about three-fourths of a mile distant.

ABERDEEN GRANITE CO. QUARRY.

The Aberdeen Granite Co.'s quarry is in secs. 15 and 16, T. 121 N., R. 46 W., about three-fourths of a mile from Ortonville and one-third of a mile from the Chicago, Milwaukee & St. Paul Railway tracks. It was formerly known as the Baxter quarry. Great masses of structural rock were excavated here and shipped to distant points. The Hennepin County courthouse, in Minneapolis, was built of rock from this quarry. The rock is similar in texture, color, and defects to that just described. The quarry has not been worked for several years.

CHIPPEWA COUNTY.

Exposures of Archean granite and gneiss in Chippewa County are confined to the valley of Minnesota River. Outcrops are numerous for several miles along the valley near Montevideo and also near Granite Falls, whence they extend almost continuously to Minnesota Falls, at the southeastern extremity of the county. All the outcrops are of red granite, except at Montevideo, where a body of gray granite is worked.

MONTEVIDEO AREA.

Rock outcrops in the Montevideo area in two localities—one of 1 or 2 acres about half a mile south of Montevideo, in sec. 19, T. 117 N., R. 40 W., and the other about 2 miles southeast of Monte-

video, in secs. 20 and 29. Several small openings have been made in past years, one of which is now being worked.

The rock south of Montevideo is a gray gneiss or banded granite which rises in a dome 30 or 40 feet above the general level. A thin section shows that it consists mainly of quartz in clear small grains, feldspars, both orthoclase and plagioclase, and a little biotite. A small portable crusher is supplying a small quantity of this rock for road construction.

At several places about 2 miles southeast of Montevideo, in secs. 20 and 29, small quarries were opened about 1900. These were operated intermittently, supplying stone for foundations, until about 1909. The rock, whose surface is marked at many places by potholes, is a red granite gneiss, which differs from the "Ortonville" stone chiefly in having a more distinct gneissic banding. This detracts somewhat from its value, for between these gneissic bands are planes of schistosity or partings, which are commonly so closely spaced that blocks only a few inches in thickness may be obtained.

Near Carleton Lake a small excavation shows that blocks 3 to 6 feet across and of fair quality may be procured, but close to the railroad the gneiss breaks into uneven angular blocks of smaller size. Here the dark minerals are more abundant and form dark streaks in the rock. Water percolation along the planes of schistosity has resulted in the partial decomposition of the dark minerals and the consequent formation of reddish stains which penetrate to considerable depths. The quality of the rock improves toward Carleton Lake, the schistosity is less distinct, and dark minerals are less abundant.

The rock, as shown by the microscope, is a medium-grained granite gneiss with very little biotite. The chief feldspar is microcline, orthoclase and plagioclase being subordinate. Considerable quartz is present and is graphically intergrown with the orthoclase and microcline. The red color is due to small hematite grains scattered throughout the feldspars and bordering the quartz grains. The feldspars show a little alteration to clay.

The rock has been used for foundations of a number of structures in Montevideo.

Owing to black knots of biotite, stains, quartz veins, pegmatite areas, and, most of all, the marked gneissic texture, none of the rock is of monument grade. It is serviceable for foundations and wall rock and for crushing.

GRANITE FALLS AREA.

About one-fourth of a mile from the Chicago, Milwaukee & St. Paul Railway station, in sec. 34, T. 116 N., R. 39 W., is a cliff which has supplied stone for foundations in Granite Falls. The rock is the best in quality of any seen in the district around Granite Falls. It is a dark diorite, consisting of hornblende, plagioclase, garnet, small grains

of magnetite, and some chlorite, which last indicates incipient weathering. It is not as schistose as the rock at Montevideo, and jointing planes are sufficiently spaced to give blocks 3 feet in length. In color the rock is too dark to be attractive for entire structures, but it appears to be substantial for foundation purposes.

Rock crops out almost continuously along Minnesota River from Granite Falls to about a mile beyond Minnesota Falls as irregular humps and ridges, moss covered, and somewhat decayed. Half a mile below Minnesota Falls the rock is a quartz diorite, rather dark in color, containing biotite and a little quartz. It is very much altered by weathering.

YELLOW MEDICINE COUNTY.

The granites and gneisses of Yellow Medicine County outcrop in three areas—in the Minnesota Valley in the vicinity of Granite Falls, as small patches north of Echo and Wind Lake, and midway between Canby and Chatfield.

GRANITE FALLS AREA.

A small quarry was opened by the Granite Falls Stone Co. in 1897 about half a mile from the Great Northern Railroad, where it approaches Granite Falls station from the west, in sec. 32, T. 116 N., R. 39 W., on the steep face of a 50 to 60 foot bluff overlooking the marshlands northeast of Minnesota River. The rock is a dark biotite gneiss. The gneissic texture is very marked, and the planes of schistosity or easy splitting, though in a few places 1 to 3 feet apart, are commonly so closely spaced that the rock is useless. In the back part of the quarry firm rock, suitable for ordinary foundation work, may be obtained. The foundation of the Yellow Medicine County courthouse in Granite Falls was made from this rock and is apparently durable.

About half a mile south of Granite Falls, in sec. 4, T. 115 N., R. 39 W., is an area of garnetiferous gabbro,[1] described by W. S. Bayley, which is not suitable for structural purposes.

Outcrops of granite gneiss are numerous in and about Granite Falls. Most of the rock dips 60° to 80° and is so deeply decomposed that the erosive action of the great glacial river was not sufficient to remove it as completely as at Morton and North Redwood. Postglacial decomposition has doubtless increased the amount of decay, and the chances for finding good rock in this vicinity are not encouraging. However, fairly fresh and solid rock may be obtained in Chippewa County, on the opposite side of the river. (See p. 70.)

Granite Falls is favorably situated for the production of crushed rock. The river has a fall of 14 feet and has a potential energy of about 1,000 horsepower, 500 of which is now used to supply light and

[1] U. S. Geol. Survey Bull. 150, p. 282, 1898.

power to Granite Falls and Maynard. The close proximity of rock, power, and railroad transportation is noteworthy.

RENVILLE COUNTY.

DISTRIBUTION OF THE ROCK.

The only rock of economic importance in Renville County outcrops along Minnesota River and in the lower parts of the larger tributary streams. Exposures along the bluffs of the river are all more or less decomposed. Tributary valleys, such as Beaver Creek and Birch Cooley, cut into the Archean, and here, also, decomposition is great.

The best rock occurs in outlying masses in the main river valley, where river erosion has cleared away all but the firm fresh rock. Prominent domes of this sort occur at North Redwood and Morton, the latter covering many acres and reaching an elevation which affords from its summit an extensive view of the river basin.

The stripping away of waste material by river erosion is marked in this locality. The remarkable state of preservation, even after the many seasons of rain and drought, of heat and frost, since glacial times indicates the ability of the rock to resist weathering.

NORTH REDWOOD GRANITE WORKS.

The North Redwood Granite Works quarry is situated about 1½ miles from North Redwood station, in sec. 20, T. 113 N., R. 35 W. Outcrops occur near the center of the broad river basin in a thickly wooded district. River erosion has swept away all the decayed rock, and silt has partly covered the low domes, permitting an extensive growth of vegetation, the mold of which has added to the mantle of earth which now hides most of the granite. These domes cover many acres.

Quarrying was first begun about 1887. March 1, 1912, a company was formed known as the North Redwood Granite Works. Quarrying operations are intermittent. The quarry supplies one shop in North Redwood employing one or two cutters.

Small pits are opened in several places. On the vertical wall of the largest, which is about 15 feet deep, horizontal sheeting planes are spaced about 6 feet apart. Nearly vertical joints are far apart, none appearing on this wall, which is 12 to 15 feet wide, and consequently blocks of very large size may be obtained. The rock has an indistinct gneissic texture.

There are two types of rock—a medium-grained biotite gneiss of greenish-gray color and a pale-pink biotite granite. These rocks are more completely described on page 48.

On the southeast side of the granite area are many immense boulders, most of which resemble the bedrock in composition and structure, though some are porphyritic in texture, having large

feldspar crystals. Monumental stone of good quality has been obtained from a number of them.

Physical tests of the pink granite show: True specific gravity, 2.690; pore space, 0.6 per cent; weight per cubic foot, 167.1 pounds. Under crushing stress the first crack developed under 12,308 pounds per square inch, and the rock finally collapsed under 21,236 pounds. Under transverse stress the modulus of rupture proved to be 4,526 pounds per square inch.

Though the rock is largely made up into high-grade monuments, it is also used for structural purposes, for which it is well suited. The Redwood Falls Public Library, High School, Granite Block, and the North Redwood Bank Building are examples.

ANDERSON GRANITE CO. QUARRY.

A prominent dome of biotite granodiorite gneiss in the Minnesota River valley near Morton has been quarried in eight or more places. It was worked extensively from 1884 to 1887 by the Saulpaugh Co., which employed about 300 men. Subsequently quarrying was carried on by John Anderson until 1908, when the Anderson Granite Co. was formed. The company now operates at several places on the bluff, in sec. 31, T. 113 N., R. 34 W. Some rock is obtained from immense boulders.

The rock is distinctly gneissic (banded) but is very firm and does not permit ready percolation of water. In places it is porphyritic. (See also p. 49 and Pl. IX, *A*, *B*, p. 68.) Sheeting planes are 12 to 20 feet apart and dip 5° to 15°, always toward the margin of the area, showing a domal structure. This probably has a direct bearing on the excellent preservation of the rock, as the sheeting planes act as watersheds. Major joints are 6 to 30 feet apart, and, where observed, meet approximately at right angles, their directions being southwest and southeast. A few minor joints meet the major joints at about 20°. Rock masses of great size may be obtained. During the summer of 1912 the Hans Neilson Hauge monument was made for Concordia College, Moorhead, Minn. The base of the monument is 5 by 4 by 3 feet, and the column consists of a single piece 18 by 3 by 2 feet. Though the rock is variable in texture, it is attractive when polished. Some light-colored and some red dikes are present, but apparently they do not weaken the rock, and do not noticeably detract from its appearance. It is a very handsome stone, especially for large structures. Rock containing black knots and streaks consisting chiefly of biotite is avoided by quarrymen as much as possible.

At least half of the rock may be polished for monuments and the remainder used for bases, range rock, trimming, curbing, and bridge work. The rock is well adapted for the latter purpose, for it is strong and can be quarried in blocks whose size is limited only by the means of transportation.

In addition to the Hans Nielson Hauge monument at Moorhead and many smaller monuments this rock has supplied material for the range rock and trimming for the Catholic Church, Waconia, for bank buildings at Gibbon, and Fairfax, and for curbing at Gibbon, Arlington, and Morton.

Physical tests obtained at the University of Minnesota showed that under crushing stress the first crack came at 8,600 pounds per square inch and the rock collapsed at 20,340 pounds. Under transverse stress the modulus of rupture was found to be 3,042 pounds per square inch.

Quarry conditions are excellent. The bluff is high and can be worked everywhere in shelf quarries. The outward dipping of the sheeting planes not only insures perfect drainage but facilitates greatly the removal of blocks from the quarry.

The Minneapolis & St. Louis Railroad tracks are about 15 rods from the nearest quarry. The Saulpaugh Co. had a siding right at the quarry, but this has since been abandoned. The Anderson Granite Co. has a well-equipped shop a few rods from the railroad.

REDWOOD COUNTY.

On the opposite side of the river, in Redwood County, rock outcrops are numerous in the valley of Redwood River. A covering of Cretaceous rocks protected them from glaciation, and stream erosion has not been sufficient to clear away the decayed portion. As a consequence the river bluffs are decayed to great depth, and fresh material is not available. The rock has been used to some extent at Redwood as crushed stone for concrete aggregate.

NICOLLET COUNTY.

Granite was quarried many years ago in the extreme northwest of the county for the construction of Fort Ridgely, 1½ miles to the east. The rock is porphyritic and has a gneissic texture. A second outcrop occurs 4 miles lower down Minnesota River. It is a pale-red granite of uniform texture. No granite quarries are now operating in Nicollet County.

KEWEENAWAN GRANITES OF CENTRAL MINNESOTA.

QUARRIES AND UNDEVELOPED OUTCROPS.

In the detailed discussion of the rocks of central Minnesota the quarries and the undeveloped outcrops are considered separately. The line between developed and undeveloped outcrops is drawn somewhat arbitrarily. In its strictest sense any outcrop on which test pits or drill holes have been made is developed. For the purposes of the present discussion all the active and many of the more

prominent inactive quarries are considered "quarries," and all the less important abandoned excavations and test pits, especially those that represent only a small part of an outcrop, are considered "undeveloped" exposures.

The quality of outcrops on which no development work whatever has been done can be judged from surface observations only. The nature of the fresh underlying rock must be inferred from the appearance of the decayed and stained surface material and from conditions in near-by developed quarries. The results of such observations are not always reliable. Jointing systems, dikes, hair lines, and other structural features may be judged with a fair degree of accuracy, but surface observations are often misleading, for weathered rock is almost invariably stained or bleached. The judgments on such outcrops expressed in this bulletin are based on comparisons of surface and deep rock in many quarries.

The quarries and outcrops are described in the alphabetic order of the townships.

STEARNS COUNTY.

ASHLEY TOWNSHIP (T. 126 N., R. 35 W.).

A small isolated outcrop of epidote granite lies in northwestern Stearns County, about 8 miles west of Sauk Center, in the SW. ¼ NW. ¼ sec. 17, Ashley Township. It is reddish gray to green in color, and its megascopic minerals are pale-pink feldspar with the coloring matter very unevenly distributed. Granular quartz and epidote are abundant. The epidote occurs as a replacement or alteration product of some original dark material which is now unrecognizable in the hand specimen, but which in thin section proves to be augite. Under the microscope epidote appears in abundance. Quartz, orthoclase, plagioclase, and augite are the essential constituents. It is evident that the rock was originally an augite granite. Pegmatite areas are common, and the texture is very uneven. The most prominent joints strike N. 23° W. and are very close, 1 inch to 1½ feet apart; minor joints strike S. 85° W. Epidote is so abundant that certain areas are green. The rock is probably useless.

Frank Minette reports a black granite, probably a gabbro, on his property in sec. 18.

LE SAUK TOWNSHIP (T. 125 N., R. 28 W.).

UNITED GRANITE CO. QUARRY.

Near the middle of the east side of sec. 17 a red granite quarry owned by the United Granite Co., of St. Cloud, outcrops over an area of about 26 rods east and west and 16 rods north and south. The main opening is at the eastern end and a smaller one is near the north side. The main excavation is about 50 by 30 feet in extent and is 15 feet deep.

The rock is a medium-grained biotite granite of pleasing color. The texture is not uniform, an uneven distribution of light and dark minerals resulting in an irregular banding. In places, also, the grain is not uniform, pegmatite masses or veins occurring here and there. Both red and gray feldspars are present. Observation with a hand lens shows that the red color is distributed unevenly, but from a distance of 2 feet or more it appears uniform. Quartz is abundant; some is smoky and some colorless. A few grains of pyrite are present. Microscopic examination shows that microcline is the most abundant feldspar, and that many of its crystals are surrounded by bands of secondary feldspar. Quartz is abundant in grains, whose maximum diameter is about one-fourth of an inch. The dark minerals are biotite and magnetite in small amounts and specks of hematite arranged along cracks and crystal boundaries.

Joints strike N. 5° E. and N. 80° E. They are unevenly spaced; in one place those striking N. 5° E. are about 2 feet apart and those striking N. 80° E., 6 to 8 feet apart. In other places areas of 15 to 20 feet are without open joints.

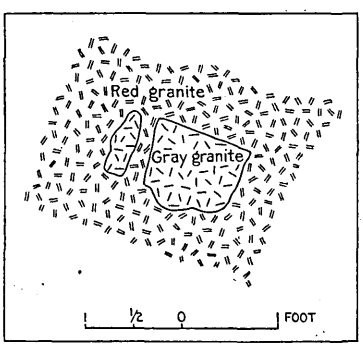


FIGURE 9.—Fragments of gray granite inclosed in red granite (drawn to scale), United Granite Co.'s quarry, sec. 17, Le Sauk Township, Stearns County, Minn.

A few gray knots appear, but they are not nearly so numerous as in the smaller quarry. Some reddish inclosed fragments look like fine-grained masses of the same material as the main quarry rock. No hair lines or trap dikes occur. Reddish stains follow seams in places. At one point the characteristic concentric lines of flowage of a viscous magma were very distinct. The presence of pegmatite masses and bands, indistinctly defined masses of red granite inclosed in red, and concentric flowage lines, all indicate that the rock in this area was in motion at the time of solidification.

At the smaller excavation inclusions of gray granite are sufficiently abundant to impair much rock. (See fig. 9.) The gray rock is a hornblende-biotite granite made up of fine-grained quartz in abundance, some orthoclase, plagioclase, and hornblende, and a little magnetite and sphene. As sphene is almost invariably present in the "St. Cloud gray" granite and absent in the red, the inclusions appear to be fragments of the typical gray granite of St. Cloud caught up by the red magma, which solidified before it dissolved them. The excess of quartz may be due to diffusion from the surrounding red granite.

The rock quarried here was hauled to St. Cloud, where the United Granite Co. operates a polishing shop; the 6-mile haul is a serious

drawback in the development of the area. No stripping is needed. Pumping is required to remove accumulated water in the quarry pit. Though operated during the early part of 1912, the workings are now idle.

UNDEVELOPED ROCK OUTCROPS.

Rock outcrops of diverse types appear in several widely separated localities in Le Sauk Township. Red and gray granite, gabbro, norite, and diorite are represented.

In secs. 5 and 6 extensive outcrops of gabbro somewhat similar to that near by in secs. 12 and 13, St. Wendall Township, probably represent parts of the same intrusion. The largest outcrop observed extends more than a quarter of a mile westward from a point near the center of the SW. ¼ sec. 5. This rock consists essentially of abundant augite, plagioclase, and a remarkably large proportion of quartz, this mineral being more abundant than in the "St. Cloud gray" granite. It is an unusual species—an augite granite. The rock is coarse grained and greatly decayed. Augite is extensively altered to biotite.

Near the eastern end of the area are two small knobs of coarse-grained pale-red biotite granite. Near these granite areas the augite granite is cut by two dikes of biotite granite, one an inch wide and the other 3 inches wide. Through the central part of the ridge no biotite granite was seen, but near the western end numerous red granite dikes 3 inches to 1 foot in diameter cut the augite granite at different angles. The relative durability of the two rocks is well illustrated, for at one point the gabbro is rotted to a gravelly, incoherent mass, leaving the granite dikes standing 10 to 12 inches above it in a fairly fresh though shattered condition. The dike consists of abundant orthoclase, considerable plagioclase, and quartz, and a small amount of biotite and magnetite. It shows reddish stains along a series of parallel cracks and on crystal boundaries.

About 152 rods north and 160 rods west of the southeast corner of sec. 5, a prominent knob of granite a few square yards in outcrop rises about 15 feet from a level field of scattered standing timber and underbrush. The rock, which is pale red and porphyritic and contains pale-red feldspars one-half to three-fourths of an inch long, consists of orthoclase, abundant quartz, subordinate plagioclase and microcline, biotite in numerous small flakes, and garnets. Some has been quarried.

About 64 rods south of the center of sec. 6 are two small outcrops, one of gabbro and the other of fine-grained red augite granite. The latter consists essentially of abundant orthoclase, less prominent plagioclase, augite showing remarkable zonal alteration to hornblende or biotite, and quartz in scattered grains. Rusty cracks and crystal borders give evidence of advanced decomposition. Grains of magnetite, apatite inclusions, and one crystal of sphene were observed.

Near the center of the south line of sec. 8, just east of Watab Lake, on the farm of D. L. Baker, is a small outcrop of gray granite. Where exposed, it is medium grained and even grained. Joints strike north and south and are 2 to 4 feet apart. It is cut by a few pegmatite dikes. The outcrop covers but a few square feet, but the owner states that for 8 rods to the east the rock surface is scraped in plowing the land.

About 296 rods north and 280 rods west of the southeast corner of sec. 10, near Mississippi River, is an outcrop of dark augite-diorite porphyry similar to the massive ridge on the opposite side of the river in Benton County. It is fine-grained and nearly black in color, but contains scattered phenocrysts of feldspar one-fourth to one-half of an inch long. Microscopic study reveals the following minerals in order of abundance: Plagioclase, hornblende, biotite, and some augite, with occasional phenocrysts of feldspar and quartz. Though the rock shows very little alteration, it is too dark to be of value for building stone and too variable in texture for monumental purposes. It may be used as crushed stone or rubble.

The diorite is literally riddled with dikes and masses of granite that include many fragments of the diorite. The intruded rock is a gray biotite granite, consisting of orthoclase, plagioclase, a very little microcline, abundant quartz, biotite, and subordinate hornblende, magnetite, and sphene.

The dark color and the closely spaced intrusives render the diorite unfit for anything but rubble or crushed rock. It has been quarried to some extent—generally in the wintertime, for the rock bluff forms a prominent point on the river shore, and transportation over the ice is convenient.

An outcrop of red granite, on property owned by C. D. Schwab in the S. ½ SE. ¼ NW. ¼ sec. 21, Le Sauk Township, is similar to that quarried by the Monarch Granite Co. in the SW. ¼ sec. 8, St. Cloud Township, being porphyritic with a dense matrix. It is a hornblende granite in which the hornblende shows considerable alteration to biotite. The phenocrysts are orthoclase or microperthite, and the groundmass is mainly of quartz and orthoclase. A specimen taken at the surface exhibits considerable alteration to kaolin. The red color is due to the presence of numerous fine inclusions of hematite. Though the individual grains show considerable diversity in size, the feldspars being prominent, on the whole the rock is fairly uniform. It has a good red color and is free from knots, hair lines, and, so far as seen, from trap dikes. Some has been quarried but not at sufficient depth to show the quality of the unweathered product. Two outcrops occur about 32 rods apart. One is small and rises but little above the surrounding country. Another, about 30 rods to the west, rises as a ridge 15 feet high, 10 rods long, and 3 rods wide.

Joints are closely spaced and intersect at right angles. Three systems were noted; one N. 4° E., another N. 40° E., and another N. 45° W. (See fig. 10.)

The joints are closely spaced and, one system being oblique to the other, dissect the rock into angular blocks. The rock is free of blemishes and is of good color.

Just north of this, in the N. ½ SE. ¼ NW. ¼ sec. 21, on the property of Michael Jabs, are two outcrops of gray granite. The eastern and larger outcrop, which covers an area of about 100 square yards, is medium grained and of even texture. It is cut by a few dikes of red granite, which trend toward the area of red granite last described and are probably related to it. Some of this rock was quarried many years ago for bridge work. The joints are not so close as

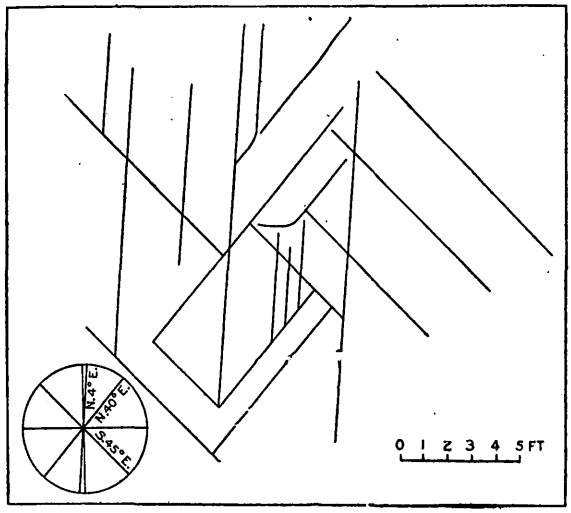


FIGURE 10.—Sketch showing structure of rock in outcrop of red granite, S. ½ SE. ¼ sec. 21, Le Sauk Township, Minn.

in the red rock. Two distinct systems appear, north-south and N. 87° W. These are spaced 3 to 10 feet apart.

The rock is a medium-grained biotite granite, the pale-gray feldspars and black mica giving it a mottled appearance. The quartz grains are brown in color and are prominent—a noteworthy fact, for the typical "St. Cloud gray" granite contains but a small amount of quartz and that in minute clear grains. It differs also from the typical "St. Cloud gray" granite in being of a lighter gray and in having more abundant biotite. The rock is somewhat weathered near the surface, and what appears to be secondary epidote is prominent in the upper one-fourth of an inch. With the microscope, most of the feldspar was determined as plagioclase, identifying the rock a quartz diorite rather than a granite.

The nearest railway station is Sauk Rapids, about 5 miles distant.

A granite outcrop in the SW. ¼ SE. ¼ sec. 21, on Watab River, about one-fourth of a mile upstream from the road at Sartel, rises 3 or 4 feet above the water for about 5 rods on the south bank of the river immediately below the second dam and then disappears beneath the drift. The granite consists of red feldspar, white or transparent quartz, black mica, and hornblende in small grains that give the rock a spotted appearance. It is not very uniform in texture, being pegmatitic in places, and also is cut by dikes of red granite. In places, also, the distribution of minerals is variable, the hornblende being more abundant. Feldspars are paler in some masses, and so it lacks the pleasing deep red color that is so desirable in monumental granite.

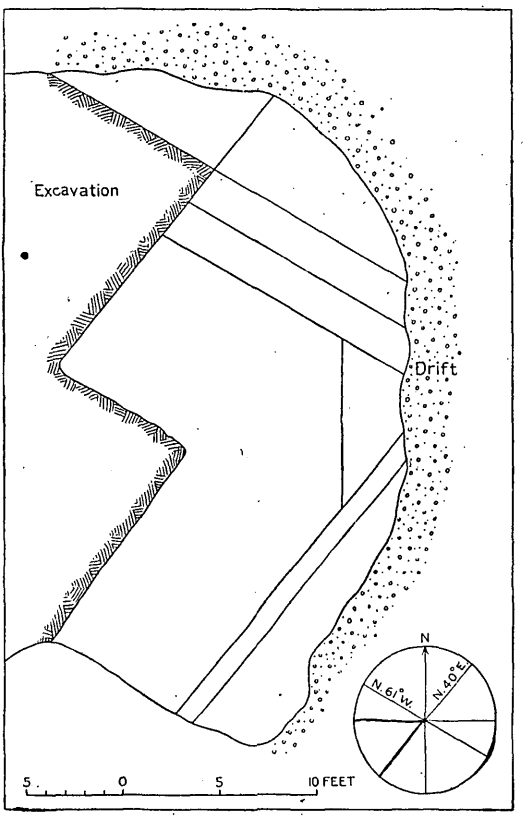


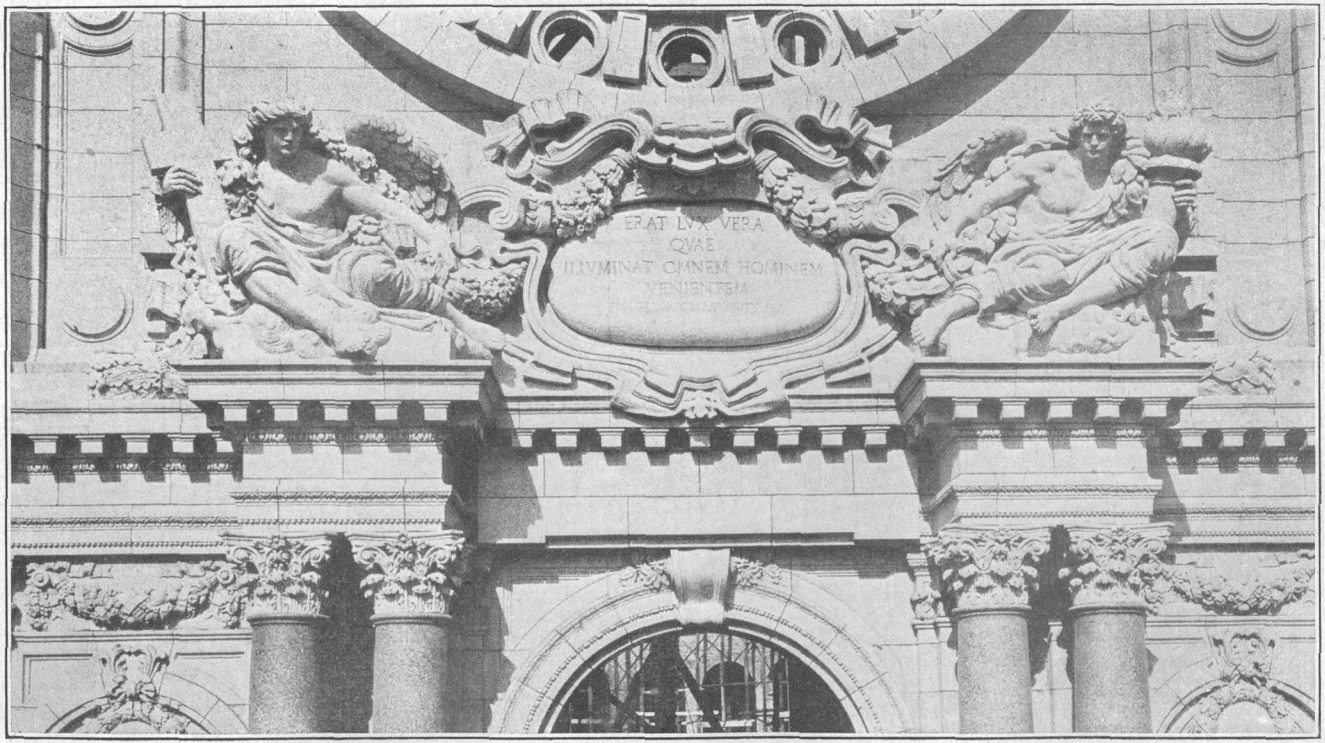
FIGURE 11.—Sketch showing structure of rock in gray granite outcrop near St. Augusta, NW. ¼ SE. ¼ sec. 19. Lynden Township, Minn.

With the microscope, both orthoclase and microcline were observed. The feldspars are, for the most part, confused perthitic intergrowths. Quartz is abundant but is not evenly distributed. The chief dark mineral is hornblende, though magnetite and biotite are also present. Jointing or sheeting planes could not be observed on account of the smallness of the outcrop. The material observed is not of monument grade.

LYNDEN TOWNSHIP (T. 122 N., R. 27 W.).

Not far from St. Augusta, on the farm of J. H. Moeller, in the NW. ¼ SE. ¼ sec. 19, Lynden Township, granite outcrops over an area about 12 rods long in a northeasterly direction and 2 to 4 rods wide. The rock probably continues near the surface beneath a ridge, which curves to the east for about 400 yards. This is an isolated exposure, the nearest outcrops being at Luxemburg, 6 miles to the west, and at the Northwestern Granite Co.'s quarry, 7 miles to the north.

CLARK & McCORMACK'S QUARRY AND SHOPS, ROCKVILLE, MINN.



CARVING IN ROCKVILLE GRANITE OVER MAIN ENTRANCE OF CATHEDRAL, ST. PAUL, MINN.

The rock is an even-grained gray granite but differs from the typical "St. Cloud gray" chiefly in the color of its feldspars, which are a clear greenish gray, much lighter in color than those of the typical "St. Cloud" stone. They afford a more distinct contrast between dark and light minerals. Both hornblende and biotite are present and form approximately a fourth of the rock mass. Quartz is not abundant. The black and greenish-white mottling is very attractive. In thin section, orthoclase appears to be the most abundant feldspar, with plagioclase nearly equal in amount. Microcline is subordinate. Quartz is present in small scattered grains, and sphene, magnetite, and apatite are accessory constituents.

Some granite has been quarried, and in the 5 feet of vertical exposure no sheeting planes appear. Joints strike N. 61° W. and S. 41° W. (See fig. 11.) Very few black knots are visible. The rock is uniform and attractive and is apparently suitable for high-grade monumental work. It has been used only for a barn foundation. The Great Northern Railway passes about half a mile distant.

MELROSE TOWNSHIP (T. 126 N., R. 33 W.).

A small outcrop of coarse red granite, reported to be inferior in quality, on Sauk River at Melrose is now covered by a mill and can not easily be examined.

ROCKVILLE TOWNSHIP (T. 123 N., R. 29 W.).

CLARK & McCORMACK QUARRY.

At Rockville, 10 miles from St. Cloud, two granite quarries are operated by Clark & McCormack and by the Rockville Granite Co. The Clark & McCormack quarry, the largest in the State for the production of structural granite, was opened in 1907. During 1912 it employed an average of about 85 men and had a daily output of about 300 to 400 cubic feet of finished stone. The rock is transported from the quarry by handcars on tracks to shops equipped with eight surfacing machines. (See Pl. X.)

The "Rockville" stone is uniform and exceptionally coarse grained, the angular feldspar crystals being one-half to three-fourths of an inch in diameter. It consists of pale-pink feldspar, quartz, and black mica, the combined effect on a hammered surface being pinkish gray. (See Pl. XIII, *B*, p. 118.) No pyrite or other minerals which would cause stain or blemish are present. Observed with the microscope the rock is a biotite granite. The chief feldspar is orthoclase. Considerable microcline, a little plagioclase, and abundant quartz also appear. Small grains of hornblende, magnetite, inclusions of apatite, and fairly large crystals of sphene are accessory constituents. An analysis of the rock is given on page 53.

Physical tests made at the University of Minnesota show that under crushing stress the first crack came at 10,574 pounds per square inch and final collapse at 17,294 pounds. Under transverse breaking strain the modulus of rupture proved to be 2,048 pounds per square inch.

Gray knots in the form of lenslike masses occur but are not common. The rock is exceptionally pure and even grained; on the freshly exposed quarry wall the eye can not detect the slightest change in its appearance except where surface stained. Such uniformity of texture and color are properties greatly in demand.

The rock rises in a great dome which is exposed over at least an acre. On the exposed surface, careful observations of joints could be made. Open joints are far apart and are somewhat irregular in direction; the most prominent strike S. 70° E. and others N. 45° E., S. 55° E., and N. 10° W. This irregularity, if joints were closely spaced, would result in much waste rock, but here, where they are spaced 20, 40, and even 100 feet apart, the irregularity is of little consequence. In fact, quarrying would be easier if they were more closely spaced. Sheeting planes are also few in number. Where quarrying is now carried on none are present, and beds have to be forced by "lift holes." On the northwest side of the dome, where the rock has been stripped, a drill hole was projected and an open seam found at a depth of 22 feet. Blocks of immense size are obtainable, much larger than can be handled by derrick. Large blocks are broken loose by blasting and are subdivided by plug and feather.

Weathering has produced a reddish stain in the upper 18 inches of the rock, and similar stains occur 18 inches to 2 feet on each side of the open seams. The rock becomes a little lighter in color at depth.

A noteworthy feature of the quarry is the small waste heap. Almost all the stone quarried is used, and the actual output in cubic feet is very much greater than in the St. Cloud quarries.

The most important building in which "Rockville" stone has been used is the new cathedral at St. Paul, still unfinished, in which it is employed for the outer structure, including the lower part of the central dome. This noble edifice, of modern Renaissance type, will, when completed, cost $1,750,000. Clark & McCormack supplied the 250,000 cubic feet of stone required at a contract price of more than half a million dollars. The completed edifice will be about 300 feet high, and its lofty position on the heights will make it one of the most prominent structures in the State.

In the finished structure one of the admirable qualities of the stone is apparent. Many granites are rather dead in appearance, exhibiting the same dull, unvaried look from all viewpoints. The "Rockville" stone is made up largely of coarsely crystallized feldspars, showing brilliant cleavage faces, which on the hammered surfaces

give a glittering reflection. Thus, in moving past any point, there is no monotony but constant change. The rock has a tone, an individuality, like many of the finest marbles.

The remarkable adaptability of the stone for carving is seen in the magnificent sculpture work above the main entrance. The central group, entitled "Christ blessing and instructing the apostles," surmounts the pediment or gable above the large round window. It was designed by Leon Hermant, the actual carving being done under the guidance of John Garatti, of Venice, Italy. All the carving was done after the 72 stones, weighing 400 tons, had been placed in the arch. Some idea of the size of these figures may be gained from the fact that the mass of rock from which the head of Christ was carved weighed 9 tons. The figure of Christ is in the center, 116 feet above the main floor level. The carving over the main doorway and the Corinthian caps of the columns (see Pl. XI) also are of more than ordinary interest.

ROCKVILLE GRANITE CO. QUARRY.

The quarry of the Rockville Granite Co. is about one-fourth of a mile north of the Clark & McCormack quarry, on the north side of the railroad track. It was opened in 1891. Much structural stone was obtained here in past years. The stone is the same as that of the Clark & McCormack quarry. Joints are far apart, the most prominent running east and northeast. In connection with the quarry is a stone-cutting and polishing shop, equipped with the largest lathes for turning and polishing columns to be found in the Central States. (See Pl. VIII, p. 66.)

ABANDONED QUARRIES AND UNDEVELOPED OUTCROPS.

South of Rockville, near the mill pond, on property owned by Homer Tenney, is a deserted quarry that has been idle for about 20 years. Several undeveloped rock exposures in the vicinity of Rockville are all of the same general type. With an unlimited supply of first-class stone, uniform, attractive, and adapted for the best and most artistic structural purposes, there is the possibility of a great development of the industry.

ST. AUGUSTA TOWNSHIP (T. 123 N., R. 28 W.).

In the NE. ¼ NW. ¼ sec. 30, St. Augusta Township, on the property of Katherine Hanson, a small outcrop, close to the road, is 8 by 5 rods in extent and rises about 3 feet above the surface. The rock is a coarse-grained biotite granite of the "Rockville" type, consisting chiefly of large pale-pink feldspars and abundant quartz. The minerals, in descending order of abundance, are microcline, plagioclase, orthoclase, biotite, hornblende, magnetite, and apatite.

Alteration is not pronounced, even in a specimen from the surface. Irregular open joints strike N. 78° E. and N. 25° W. and are spaced 8 to 12 feet apart. In the eastern part of the outcrop two joints close together trend N. 22° E., and parallel with them are four dikes, three of them about half an inch wide and the fourth a quarter of an inch wide. The centers of the dikes consist of large quartz crystals and the margins of feldspars so interlocking with the crystals of the surrounding rock that their borders are indistinct. A diabase dike 5 feet thick crosses the outcrop in direction N. 65° E. Lithologically this dike rock is one of the most interesting in Minnesota. It is a quartz diabase porphyry, containing many large crystals of feldspar and quartz. One gray knot about 6 inches across was seen. Apparently the rock is a good building stone, though probably not useful for monumental purposes. As it is several miles from a railroad, its extensive development is not probable.

Near the center of sec. 19, on Stephen Zenner's farm, one-third of a mile from the road that passes the Luxemburg church, a second more prominent outcrop covers an area about 22 rods north and south and about 6 rods wide. The rock extends westward near the surface; according to Mr. Zenner, the plow touches it in many places. The ridge is about 20 feet high and drops off abruptly to a marsh on the east side. The rock is a coarse-grained hornblende biotite granite of the "Rockville" type, about three-fourths of which is of feldspar in large crystals half an inch to an inch across. Pale-pink feldspar is abundant, and a subordinate amount of pale-green feldspar is present. Biotite and hornblende are about equally abundant, and quartz in small grains is plentiful. As observed under the microscope, orthoclase with subordinate microcline and smaller though numerous quartz crystals form the light portion of the rock. Very little perthitic intergrowth was observed. Scattered grains of hornblende, biotite, and magnetite form the darker part.

The most prominent joints at the southern end of the outcrop strike N. 22° W. and N. 60° E. and are 4 to 10 feet apart. At the north end of the outcrop joints of three systems, N. 70° W., N. 50° W., and N. 85° W., divide the rock into angular masses. Here also epidote veins are more numerous and when traced for a distance give place to numerous interlacing green hair lines. A few gray knots contain feldspar crystals similar to those in the surrounding rock and hence appear to be segregations.

The rock makes very attractive structural blocks or columns. It compares favorably with the "Rockville" stone, but poor railroad facilities will probably discourage its development. Some stone was quarried on the eastern side of the ridge and used locally, but none has been excavated for a number of years.

ST. CLOUD TOWNSHIP (T. 124 N., R. 28 W.).

ATWOOD QUARRIES.

The Agate Granite Co. operated quarry pits in the W. ½ SE. ¼ sec. 20, St. Cloud Township, until 1912, when it ceased business. Its property is now owned by C. L. Atwood, president of the Security State Bank, St. Cloud. The rock in the larger excavation is a red hornblende granite, consisting chiefly of flesh-red feldspars, with subordinate greenish feldspars scattered throughout. Quartz is abundant in medium-sized transparent glassy grains. Hornblende crystals vary in size; in places they are larger than in any other red granite quarry of the region. With the microscope the chief feldspar was identified as orthoclase. Microcline is prominent and plagioclase subordinate. The feldspars are intergrown as in perthite, and all are altered to some extent. Hornblende shows considerable alteration to biotite.

Segregations composed largely of hornblende form black knots and gneissic bands. A sample taken from one of these bands shows fine-grained black hornblende and biotite with lenslike areas of feldspar. The bands contain magnetite, biotite, hornblende, and pyrite. The hornblende is fibrous and borders the light minerals or is intergrown with them.

Narrow veins of clear or smoky quartz were observed in a few places. Large masses of rock are, however, quite free of these streaks and knots. Joints are somewhat irregular. Two well-defined systems strike S. 45° E. and S. 5° E. and are intersected by minor systems. They are sufficiently spaced to allow excavation of large blocks. Sheeting planes are better developed in this quarry than in most Minnesota occurrences; near the top of the quarry they are 2 to 4 feet apart and the spacing increases at depth. They dip slightly to the north. Their presence makes quarrying comparatively easy.

At the southwest side of the quarry near the top is a mass of gray granite which appears to be almost contemporaneous with the red, but which is much finer grained. Feldspars are of two kinds, pale pink and pale green, and quartz is abundant in small grains. As observed with the microscope the minerals present are microcline, orthoclase, quartz, plagioclase, biotite, hornblende, sphene, magnetite, and apatite, in order of abundance. The dark minerals are unevenly distributed, and as a whole the minerals are intimately intergrown and show less clear and definite boundaries than those of the typical "St. Cloud gray" granite. A 2-foot diabase dike crosses the pit in direction N. 55° E.

The rock is attractive in color and the quarry is in good condition for further development, being equipped with a large derrick and modern hoisting and pneumatic machinery.

At 100 yards to the north, almost on the section line south of sec. 20, another pit, from which considerable rock has been removed, exhibits surface alteration by weathering to a depth of 6 to 8 feet. The pit is now partly filled with water. The granite is cut by a diabase dike 2½ feet wide which trends N. 65° E.

About one-third of a mile north of these pits the rock rises in a prominent dome about 20 feet above the general level. An abandoned excavation at the north side of the outcrop is about 200 feet long and 75 feet wide. Open joints are somewhat irregular, the most prominent systems being E., N. 15° W. and N. 60° E. They are spaced 2 to 10 feet apart. On the top of the dome south of the quarry a series of parallel quartz veins appears. They are one-eighth to three-fourths of an inch across and run northeast, their direction being different from that of the joints. The presence of sheeting planes 2 to 6 feet apart greatly facilitates excavation. The rock is an even-grained red granite of good quality.

Transportation is by team and wagon to St. Cloud, about 3½ miles distant.

BLACK DIAMOND QUARRIES.

The Black Diamond Granite Co. operates a red granite quarry in the SE. ¼ NW. ¼ sec. 18, St. Cloud Township. The quarry was opened in 1909. The red granite is of two types, coarse grained and fine grained, the fine grained occurring near the contact of a mass of dark-gray granite at the western side. Both are adapted for monumental use, the fine grained being the more attactive. The red rock consists of microcline graphically intergrown with feldspar and quartz and of orthoclase, plagioclase, quartz, and a very little green hornblende. Joints are approximately at right angles and 3 to 20 feet apart.

The dark gray is a hornblende granite, the feldspar of which is chiefly orthoclase, with subordinate plagioclase and microcline. Hornblende with a little biotite and magnetite form the dark part of the rock. No sphene is present. The rock differs materially from the typical "St. Cloud gray" granite.

Geologic relationships are rather complex in this quarry. (See fig. 12.) The finer-grained texture of the red granite near the contact and the presence of red dikes in the dark granite prove that the latter is the older. Both rocks are cut by dikes, some of them in the form of minute hair lines (*a*), which are shown by microscopic examination to be of granite similar to the larger mass of dark-gray rock. In rough-dressed blocks they are difficult to see unless water is thrown on the surface, but when polished they appear as thin dark lines on an otherwise uniform surface and are thus undesirable. Water is thrown over the blocks, and those to be hauled to the shops for final dressing and polishing are carefully selected.

The dark-gray rock would be valuable if it were not invaded by foreign material. In this quarry, however, it is so cut up by pale-red granite dikes that uniform blocks are not readily obtained.

Steam and pneumatic drills and steam hoists are employed. Transportation is by team and wagon to St. Cloud, about 4 miles distant. The St. Cloud Street Railway runs to Waite Park, only a short distance from this and several other quarries. If some suitable arrangement could be made with this company, the cost of transportation over 3 miles of bad road might be reduced. In this connection, it may be of interest to the St. Cloud quarrymen to know that stone from a quarry at Rockport, Maine, is transported about a mile over an electric railway that maintains a regular half-hour passenger service without causing any demoralization in the traffic.

About 32 rods northwest of this quarry, on the opposite side of the Rockville road, is a deserted pit in the dark-gray rock. It is a biotite-hornblende granite, somewhat finer grained than the red granite.

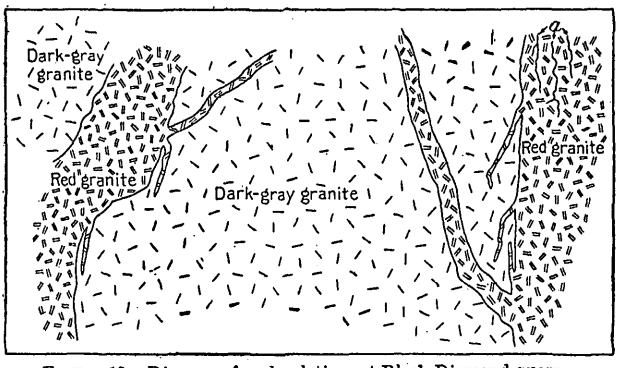


FIGURE 12.—Diagram of rock relations at Black Diamond quarry.

It is somewhat porphyritic in places with white feldspar crystals one-fourth to one-half inch across. Quartz is abundant in small grains. In places the white feldspar is fine grained and sufficiently abundant to give the rock a light-gray color. The rock is invaded by dikes of red granite, though not so seriously as in the larger quarry. It takes a good polish, presenting a rich blue-black color where free of the porphyritic crystals of light feldspar.

The company also operates a quarry in gray granite in the SE. ¼ SE. ¼ sec. 27. The rock is an even-grained uniform granite, about three-quarters of which consists of light-colored minerals, chiefly gray feldspar. The presence of some pale-pink feldspars gives the rock a reddish tinge. A few small grains of pyrite were observed. A number of hair lines proved to be quartz veins under the microscope.

Joints are far apart and strike N. 10° W. and N. 80° E. The quarry was inactive in 1913 and the excavation full of water, so that observation of sheeting planes could not be made. One diabase dike 3 feet

wide trends N. 65° E. Some black knots were seen. The rock splits with ease and is well adapted for monument stock, paving blocks, or curbing. Transportation is by team and wagon to St. Cloud, about 4 miles distant.

DOERNER QUARRY.

John Doerner has made two excavations in a prominent dome of gray granite or quartz monzonite in the NW. ¼ NW. ¼ sec. 33, St. Cloud Township. The outcrop measures abont 48 rods east and west and 40 rods north and south. The eastern quarry was worked first and is now deserted. At this point the rock is a very dark gray, almost black in color, owing partly to an abundance of fine-grained hornblende and biotite and partly to the dark-gray color of the feldspars. It is a hornblende granite, with subordinate biotite and a little quartz. The gray rock is cut by a number of red dikes which appear to be a fine-grained dike phase of the typical "St. Cloud red" granite. Under the microscope the chief minerals which appear in the dike rock are orthoclase, plagioclase, microcline, and quartz. The feldspars are microperthitic, as they are in most of the typical red granite. The dark minerals are biotite and magnetite. Lithologically the rock is similar to the typical "St. Cloud red" granite. Scattered grains of hematite give the red color. Feldspars are partly altered to kaolin and calcite.

Nearer the road at the western end of the outcrop is the newer quarry, which is now operating. The rock is a hornblende-biotite granite, which is reddish-gray, owing to the presence of grains of pale-red feldspar along with the more abundant gray type. The microscope reveals orthoclase as the chief feldspar, with subordinate plagioclase and microcline. Quartz is more abundant than in most of the "St. Cloud gray" rocks. Hornblende, biotite, magnetite, and sphene constitute the remainder of the mass, the latter in many places surrounding magnetite grains. Minute apatite crystals inclosed in the other minerals are common. The feldspars appear dusty by alteration to clay.

The rock of this quarry is cut by light-colored aplite dikes and contains dark knots, some of which are very angular and appear to be included fragments rather than segregations.

In the northern undeveloped part of the outcrop red dikes are present. A band of dikes half an inch to an inch wide, scattered over a space 10 feet in width, may be traced N. 10° E. for 8 rods. It is crossed by larger dikes at various angles. The quarry is about 4 miles from St. Cloud.

EMPIRE QUARRY CO. QUARRIES.

The Empire Quarry Co. began operations in 1912 on the site of the quarry formerly operated by Hennessey & Cox, of St. Paul, in the NE. ¼ SE. ¼ sec. 19, St. Cloud Township. The rock rises in a dome

about 25 feet above the general level of the surrounding country, and its upper part may be worked as a shelf quarry.

The rock is a medium-grained red hornblende granite, a little paler in color than that worked by the same company in an adjacent quarry. (See below.) Major joints strike north and south and are spaced 10 to 30 feet apart.

Near the top of the quarry at the south side is a mass of very tough gray biotite granite. The combination of fine-grained light gray feldspar and black mica gives it a speckled pepper and salt appearance. Clear quartz is visible with a hand lens, and is more abundant than in the typical "St. Cloud gray" granite.

The rock in thin section exhibits a fine-grained uniform texture. It consists of orthoclase, microcline, quartz, plagioclase, biotite, and a few grains of magnetite. The toughness of the rock is occasioned by the interlocking of the feldspar and quartz grains. Its contact with the red shows in places a gradual transition over an interval of 6 inches or more. Smaller masses of gray are inclosed in the red near the contact.

A 1½-inch pegmatite dike passes through the red granite. It is fine grained near the margin, then coarser, light-colored feldspars appear graphically intergrown with quartz; a central band about one-fourth of an inch across consists of clear quartz and black mica with no feldspar.

Stone used in the construction of the St. Paul post office was obtained from this pit many years ago, the quarry at that time being operated by John Clark, now of the firm Clark & McCormack, of Rockville.

On the same rock dome, about 60 rods southeast of the pit last described, a new excavation was opened in 1912. The rock is a medium-grained red hornblende granite. Most of the feldspar is pink with a few scattered greenish-gray grains. It is chiefly microcline, graphically intergrown with quartz and considerably altered to kaolin. Quartz is abundant, part being clear and part smoky. Joints which are rather uneven strike N. 5° W. and N. 87° E., 2 to 12 feet apart. Sheeting planes are uneven and indistinct, the highest being about 8 feet from the surface. The rock is stained and decayed down to the first sheeting plane but not beyond it.

A peculiar pegmatite area passes northeast through the quarry. It is very irregular and enlarges to a mass 6 to 8 feet across. It is composed of pink feldspar in crystals 1 to 4 inches long, quartz, a small amount of pyrite, and bladed interlacing crystals of brown mica, some of which are 2½ inches in length. A small amount of pyrite is present. Under the microscope the feldspars appear as perthitic intergrowths. The pegmatite area does not affect the quality of the rock beyond its own borders.

The outcrop is cut by a few small irregular diabase dikes, stained green where exposed at the surface. A zone of "green lines"—epidote veinlets bearing a little pyrite—passes N. 80° E. through the quarry.

A few lenticular inclusions of fine-grained gray granite, the largest 18 inches long and 4 inches wide, were observed. Other masses appear to be fine-grained segregations, containing both pink and gray feldspar.

Fortunately, the imperfections noted are confined to certain definite areas. Uniform attractive rock is obtained in large quantities. The color is somewhat deeper red than in the older quarry and is therefore better adapted to monumental purposes.

Electric power transmitted from the Mississippi at St. Cloud operates the air compressor, and hoisting is done by steam. Transportation is by a railway siding so conveniently situated that the quarry derricks are used for loading cars. The siding passes north on the section line and joins the Great Northern track from St. Cloud to Rockville, about a mile distant.

FLAHERTY BROS. QUARRY.

Flaherty Bros. operated a small quarry several years ago in the NW. ¼ NW. ¼ sec. 33, St. Cloud Township. The rock, which appears to be a gray hornblende granite, is in reality a diorite. The feldspars are gray to very pale pink, and consist of abundant plagioclase with subordinate orthoclase and microcline. Very little quartz is present. The hornblende is unusually fine grained. Magnetite, sphene, and apatite are accessory.

The gray rock is cut by a number of pale-red aplite (fine-grained granite) dikes. Some of the gray granite is spotted with red crystals, as though the two granites were nearly contemporaneous and somewhat mixed at the contact. This conforms with the general relationship of the red granites and gray granites in the St. Cloud region. A few black knots but no diabase dikes were seen. The quarry is 4 miles from St. Cloud, where the firm operates a well-equipped monument shop.

FRICK & BORWICK GRANITE CO. QUARRY.

The Frick & Borwick Granite Co. began operations in 1906 on the site of the old Minnesota Granite Co's. quarry in the SE. ¼ NE. ¼ sec. 19. The rock is red hornblende granite of uniform texture and attractive appearance. Most of the feldspar is red, but numerous greenish-gray crystals are scattered throughout. Small hornblende crystals appear as inclusions in some of the larger feldspars. Some clear and some smoky quartz appears. As observed under the microscope the rock consists almost entirely of microcline and quartz, with subordinate orthoclase, hornblende, and biotite. The feldspars show

little alteration. The rock is deeper pink in color at the bottom of the quarry than near the surface. The entire absence of sheeting planes, though the pit is now 60 feet deep, is noteworthy. Joints strike N. 30° E. and N. 80° E. and are so spaced that blocks of large size may be obtained. Epidote occurs as a filling in some open seams. A mass of gray biotite granite, which occupies the south end of the quarry near the surface, consists, in descending order of abundance of orthoclase, quartz, microcline, biotite, magnetite, and apatite. Quartz is more plentiful than in the typical "St. Cloud gray" granite, though in other respects the two rocks show marked similarity. Masses of fine-grained gray hornblende granite occur in the red as inclusions. One fragment observed was 20 inches long and 5 inches wide, with square corners.

The rock splits more easily in direction of run than rift. Though this is contrary to the definition of rift, the rift is so uniformly horizontal that the term is reserved among the quarrymen for the horizontal direction of splitting, irrespective of ease or difficulty of cleavage. As at the St. Cloud Granite Works, about two-thirds of a mile northeast, the run is east and west. Two large derricks with steam hoist are employed, and drilling is done by steam and compressed air. Transportation is by team and wagon or railway. A loading derrick stands at the siding about 100 yards from the quarry.

GRAHAM QUARRY.

A quarry is operated by Robert Graham in the NE. ¼ SE. ¼ sec. 21. The rock is a gray, even-grained hornblende-quartz diorite. The feldspars are mostly gray, though some grains are pale pink. Quartz is not prominent, though scattered grains of considerable size appear, some having a blue color. The dark minerals are fine-grained and very evenly distributed, giving the rock a uniform texture. With the microscope the most abundant feldspars were identified as plagioclase with subordinate orthoclase and microcline. Hornblende is prominent and biotite subordinate in amount. A section from the bottom of the quarry exhibits distinct cores of augite in the center of hornblende crystals. Grains of magnetite and sphene are common.

Physical tests show: True specific gravity, 2.761; pore space, per cent, 0.37; weight per cubic foot, dry, 171.9 pounds. Under crushing strain the first crack came at 15,080 pounds per square inch and final collapse at 21,000 pounds. Under transverse breaking stress the modulus of rupture proved to be 2,979 pounds per square inch.

Joints strike north and east and are 6 to 20 feet apart. Though the pit is now nearly 60 feet deep no sheeting planes have been reached, a circumstance that makes quarrying difficult. The rock is very uniform and free from blemish. The few black knots present appear under the microscope to be segregations. The rock is well

adapted for making paving blocks and curbing on account of its pronounced rift and run. (See Pl. VI, *A*, p. 60.) It is used for trimming, window sills, paving blocks, curbing, and monument stock. Stripping requires the removal of about 2 feet of sandy soil.

A stone-dressing shop is situated at the quarry. Steam power is employed for hoisting, and steam and pneumatic drills are used in rock excavation. The quarry is in every respect well equipped and turns out large quantities of excellent stone. Transportation is by wagon to St. Cloud, about 2 miles distant.

GRANITE CITY GRANITE CO. QUARRIES.

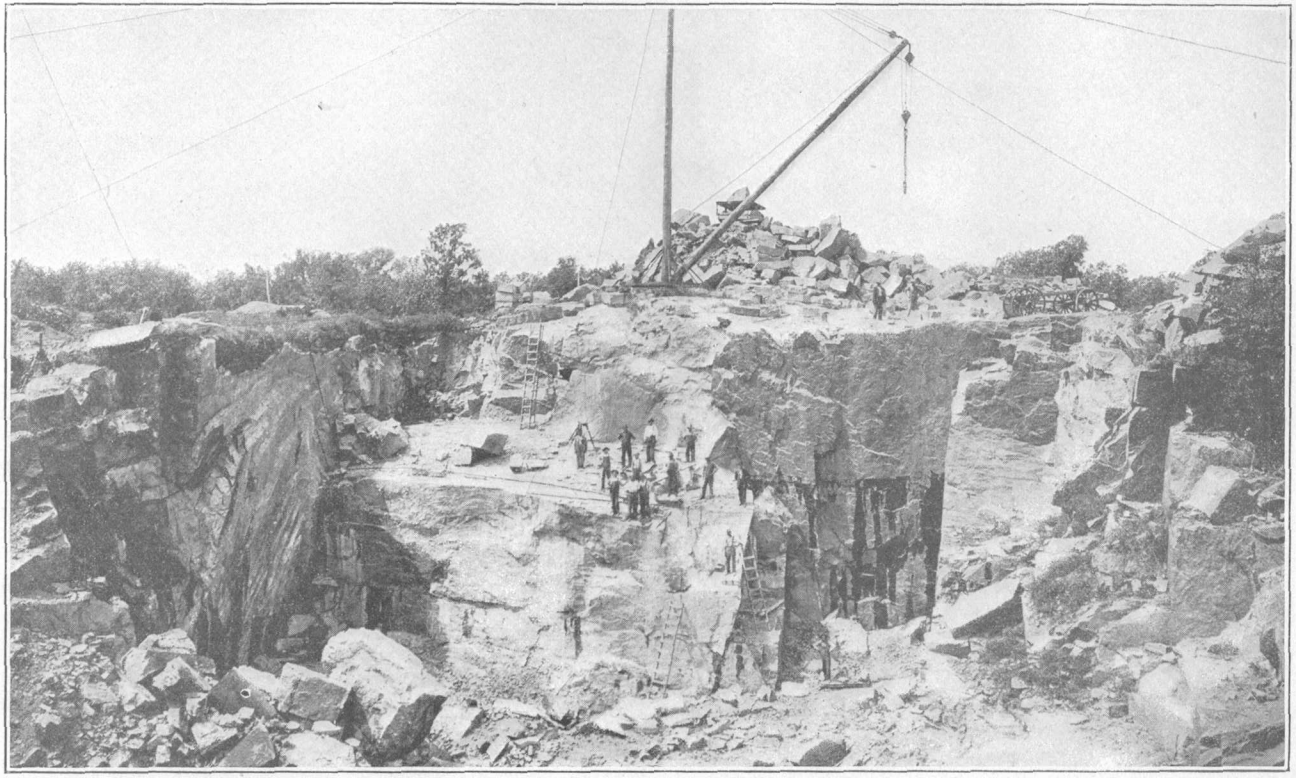
The Granite City Granite Co. operates in the NE. ¼ SE. ¼ sec. 18, St. Cloud Township, a quarry (Pl. XII), which was first operated by James Murray, the present company being organized in 1900. The rock is a medium to coarse grained red granite, becoming a little deeper red at the bottom of the quarry. Major joints strike north and south. In several places joints occur close together and then for a space of 10 to 20 feet none appear. The only sheeting plane visible at the present stage is about 20 feet from the top and is horizontal, the remaining 35 feet of quarry wall having no natural sheeting planes. This makes quarrying somewhat difficult, requiring blasting in horizontal holes (lift holes) in order to create artificial sheeting planes. Blocks of almost any desired size may be obtained. One spire supplied from this quarry is 1 foot 10 inches square and 17 feet 2 inches long. Steam and pneumatic drills are employed and hoisting is done by steam. Transportation is by team and wagon to St. Cloud, about 5 miles distant, where the company operates a large monument shop.

The Granite City Granite Co. also operates at times a gray granite quarry in the SW. ¼ SW. ¼ sec. 28. It is about 50 yards from a gray quarry operated by the Black Diamond Granite Co. (See p. 87.)

HOLES BROS.' QUARRIES.

Holes Bros. are pioneers in the quarrying industry of St. Cloud. They first quarried at Sauk Rapids in 1875. In 1885 they began excavation in the west-central part of sec. 20, St. Cloud Township, and continued until 1912. The rock is medium grained and attractive in appearance, becoming a deeper red in the bottom of the quarry.

Unfortunately several large trap dikes pass through the quarry, and associated with them are numerous hair lines, or small trap dikes, together with certain bands of bleached or faded rock, known among the quarrymen as "jasper bands," which greatly mar the polished rock. In consequence of the dikes the expense of removing waste rock became so great that the quarry was abandoned. The old quarry pit is very large. The derrick was the tallest in the St. Cloud region and was a prominent landmark for many miles.



GRANITE CITY GRANITE CO.'S QUARRY, ST. CLOUD TOWNSHIP, STEARNS COUNTY, MINN.

In 1912 a new quarry was opened in the NE. ¼ NE. ¼ sec. 30, St. Cloud Township. The rock is a medium-grained red granite of attractive appearance. About three-fourths of the feldspars are red and one-fourth pale green. Quartz is abundant in both clear and smoky grains. Under the microscope the chief feldspar was identified as microcline showing microperthitic intergrowth with other feldspars. A little orthoclase and plagioclase, abundant quartz, and hornblende in large scattered crystals constitute the remainder of the rock.

Sheeting planes are 8 to 16 feet apart, some horizontal and others dipping 10° to 15° N. Joints are irregular and in part of the quarry the rock is badly broken up. The rift is horizontal, and the run north and south.

Two bands of interlacing green lines about 20 feet apart run east and west through the quarry. They consist mainly of epidote and are entirely independent of joints. Other epidote veins follow the joints, some of which, when traced for a distance, gradually become closed seams and finally die out. Green lines that follow joints impair only a little rock, but those that run in interlacing bands obliquely through the blocks cause considerable waste.

At the present stage of development hand drilling is employed and hoisting done by horsepower. Transportation is by team and wagon to St. Cloud, about 5 miles distant, where the firm operates a monument shop equipped with stone cutting and polishing machinery and lathes for turning columns and pillars. The finished rock is sold under the trade name of "Red Rock granite."

About 35 rods northeast of their new quarry, in the NE. ¼ sec. 30, St. Cloud Township, the firm has excavated in gray biotite granite to some extent. The rock consists of abundant gray feldspar, quartz in small glassy grains, biotite, and a little hornblende. It is even grained and somewhat finer in texture than the typical "St. Cloud gray" granite. It has a greenish tinge near the surface, due to alteration by weathering. It differs from the typical "St. Cloud gray" granite in containing more quartz and plagioclase and no sphene. It closely resembles the masses of gray rock occurring in several red granite quarries, notably those of the Empire Quarry Co., Agate Granite Co., and St. Cloud Granite Works. The quality does not justify further development.

JONES QUARRY.

The Jones quarry, formerly the Emery, which has not operated for about 20 years, is a short distance southwest of the Frick & Borwick Granite Co.'s quarry, in the SE. ¼ NE. ¼ sec. 19, St. Cloud Township. It was purchased in 1913 by S. A. Jones, who operates a monument shop in East St. Cloud.

The rock is a red granite similar to others in this region. Three diabase dikes, each several feet in diameter, pass through the quarry

running northeast, and associated with them are numerous hair lines. A mass of gray granite occurs at the southwest end. The contact is very indistinct; many masses of red are inclosed in the gray and some dikes of gray occur in the red. In one spot a pegmatite mass several inches across contains coarsely crystallized brown mica. As the rock rises in a prominent dome at this point, quarrying may be conducted with ease. Reopening the quarry is contemplated.

MELROSE GRANITE CO. QUARRIES.

The Melrose Granite Co. owns a quarry of gray granite in the E. ½ SE. ¼ sec. 21, St. Cloud Township. This quarry was opened in 1910 and much rock has been removed, considering the short time since quarrying began. It is hornblende granite, consisting chiefly of gray feldspar, prominent hornblende, and blue quartz in scattered grains. A few grains of pyrite are visible, and are confined mainly to the walls of seams. Study of a typical specimen with the microscope shows the minerals present in order of abundance to be orthoclase, plagioclase, microcline, quartz, hornblende, mica, magnetite, and sphene. It is a fresh, uniform rock.

The excavation is about 250 feet long, 75 feet wide, 6 to 10 feet deep at the north end and about 20 feet deep at the south, where work is now begun on the second sheet. At the south end of the quarry the rock outcrops at the surface, and at the north end the removal of 6 to 10 feet of soil is necessary. A covering of soil protects the rock from decay. Where exposed at the surface, the rock is stained and partly decayed or shattered to a depth of 2 to 6 feet; but where protected by the mantle of soil it is affected to a depth of a few inches only. Sheeting planes are 2 to 10 feet apart, and are nearly horizontal, though somewhat undulating. Major joints are 4 to 6 feet apart and strike north and east. A few minor joints cross the major joints at acute angles. The rock is uniform, medium grained, and of attractive color. It splits easily and is well adapted for making paving blocks or curbing.

Three diabase dikes, each about a foot in diameter, and a few smaller ones were observed. Their trend is northeast and they are nearly vertical. The rock is altered to a reddish color for 1 to 5 inches on each side of the larger dikes. The contact effect of diabase dikes on the granite is very slight. Crystals are fractured and feldspars show evidence of considerable kaolinization for 3 or 4 inches from the contact. Reddish stains occur for about an inch on each side of the major joints. Black knots are scarce.

The quarry is well equipped with machinery. An unusually large derrick is operated with steam hoist, and a yard derrick by electric power. A shed for stone dressing is situated near the quarry. Dressed blocks are hauled by teams to the siding near the red quarry

at the west line of sec. 17, from which point they are shipped to large and well-equipped polishing shops at St. Cloud.

The company also quarry in red granite in the southwest corner of sec. 17 and the northeast corner of sec. 20. Of the two pits in sec. 20, the one farthest to the north is abandoned and full of water.

In the southern excavation the rock is a hornblende granite, consisting of pink feldspar, hornblende, subordinate biotite, and abundant quartz, both clear and smoky. The chief feldspar is microcline, with subordinate orthoclase and plagioclase. It is an exceptionally deep red attractive rock. Distinct joints strike north and east. Sheeting planes are few and uneven. One trap dike 3 feet wide trends east and west. In the northwest part of the quarry many black and green lines occur, the latter in interlacing bands 4 or 5 inches wide, running east and west. With the microscope they seem to be epidote veins, filling minute fractures. A few gray knots were found on examination to be gray granite inclusions.

Under crushing stress the first crack came at 9,733 pounds per square inch, and final collapse at 19,101 pounds. Under transverse breaking strain the modulus of rupture proved to be 2,291 pounds.

A second quarry now in operation is in the extreme southwest of sec. 17. Joints in this quarry are northwest and southwest, and sheeting planes, two of which are 15 feet apart, dip 30° SW., the northwest joints dipping to make right angles with them. The rift is horizontal, and therefore when the rock is split on the rift, acute-angled blocks are formed with a consequent high percentage of waste. The rock is stained red along the joints. The quarries are well equipped with steam and pneumatic drills and steam hoist. By means of a siding from the Great Northern Railway, all the rough dressed blocks are transported to the shops at St. Cloud.

The Melrose Granite Co. opened up a new quarry in 1913 in the NW. ¼ SW. ¼ sec. 20, St. Cloud Township, a short distance east of the quarry operated by the Empire Granite Co. The rock is a red hornblende granite of good color and uniform texture. The feldspars are flesh red with a few scattered grains of greenish gray. The chief feldspar is microcline, with subordinate orthoclase and plagioclase, all the feldspars being perthitic. Clear, transparent quartz is prominent and hornblende is present in small amount. As this is a new quarry and has attained only slight depth, the feldspars in the rock so far excavated show considerable alteration.

Jointing is somewhat irregular. The open joints trend N. 60° E., N. 60° W., and N. 20° W. Blocks 3 to 8 feet across are obtainable between these open seams. Closed seams, however, are present and in places are close together. They permit water percolation with consequent reddish stains. Sheeting planes are also uneven, but so little excavation has yet been accomplished that their general

character could not be observed. Unless fewer and more regular joints are found with continued excavation it is probable that this pit will prove unprofitable. Steam and pneumatic drills and steam hoists are employed.

Another quarry was opened by the same company in 1913 in the NW. ¼ NE. ¼ sec. 19. The rock is a medium-grained red hornblende granite of excellent quality. Feldspars are mostly pink, with subordinate pale green. Quartz is abundant and hornblende in fairly large grains is uniformly distributed. Most of the feldspar is microcline and is much intergrown with stringers of other feldspars and quartz.

Major joints strike north and south, and secondary joints in several directions. All are well spaced for quarrying. Sheeting planes are more abundant than in most quarries of the region, and this facilitates excavation. Two sheets 8 to 10 feet thick, now visible, dip about 10° NW. The rock ridge rises about 20 feet above the low marshy ground, and at the present stage the quarry is of the shelf type. The northwestward dip of the sheeting planes being toward the front of the excavation greatly assists the removal of blocks. With the exception of one small diabase dike trending N. 51° E., no defects were observed. Steam and air drills are employed and blocks are handled by a derrick with a steam hoist. Transportation is by team and wagon to the siding near the northeast corner of sec. 19, about half a mile from the quarry.

MONARCH GRANITE CO. QUARRY.

South of the Great Northern tracks and west of Sauk River, in the W. ½ SW. ¼ sec. 8, a large quarry, opened in 1906 and formerly owned by J. Lilliquist, is now operated by the Monarch Granite Co., which was organized in 1912.

The best rock quarried is a medium-grained red hornblende granite of attractive appearance. The feldspar is almost all pink in color, showing a few grains of the greenish gray so prominent in some localities. Smoky quartz is abundant.

Joints are 2 to 8 feet apart and form two prominent systems, north-south and east-west. Horizontal sheeting planes are 3 to 12 feet apart. An open seam dips about 30° to the bottom of the quarry at about 35 feet, where it becomes horizontal. This has permitted water percolation and resulted in extreme weathering of the granite for several inches on each side of the seam. The appearance of granite decayed to kaolin and mixed with loose grains of quartz and feldspar in the bottom of the quarry, with firm rock both above and below is remarkable, and has not been observed elsewhere in the region.

A mass of gray rock 8 to 10 feet in thickness where observed, and of unknown lateral extent, occurs at the northwest side of the excavation. This gray rock is medium grained and consists of gray feldspar, black hornblende, and mica, with scattered grains of both clear and smoky quartz. Orthoclase and microcline are together a little more abundant than the plagioclase. Quartz is prominent, and biotite and hornblende form the rest of the rock. It is cut by numerous aplite dikes one-fourth to one-half of an inch across. The dikes are somewhat porphyritic as seen under the microscope, consisting of abundant quartz and a few microcline phenocrysts in a fine-grained groundmass of quartz and feldspars.

Near the contact the red rock is very porphyritic, with reddish-white feldspars and black hornblende embedded in a dense fine-grained matrix. Undoubtedly this change in texture is due to the molten red granite magma meeting the solid gray granite, and consequently cooling more rapidly near the comparatively cold rock. Dikes of red granite in the gray also indicate that the red was injected after the solidification of the gray.

Near the contact the shattered nature of the rock and its lack of uniformity make it undesirable. At some distance from the contact, however, the rock is even grained and very attractive, becoming a little darker red at depth. A few dark hair lines were noted, and also some red streaks where the feldspars were crowded together. Part of the rock outcrops, and the maximum stripping is about 5 feet of sand and gravel.

The quarry is equipped with pneumatic drills, and a large derrick with steam hoist. Though the Great Northern Railway passes within 25 yards of the quarry, no siding has been built. The rock is hauled by teams to St. Cloud, 4 miles distant, where the company has a well-equipped stone dressing and polishing shop. Pumping is required to remove accumulated surface water. The finished product in the form of monuments, columns, and the like is advertised widely under the trade name "Monarch red."

NATIONAL QUARRY CO. QUARRY.

The National Quarry Co. began operations in 1913 in the NE. ¼ SE. ¼ sec. 18. An even-grained red hornblende-biotite granite of good quality is obtained. It consists of pink feldspar, clear to smoky quartz, and a small proportion of hornblende and biotite. With the microscope the chief feldspar was determined as microcline microperthite. Quartz is abundant. Hornblende, biotite, and a few grains of magnetite form the dark part of the rock. Hornblende is shredded in appearance and somewhat altered. A few minute hair lines were found to be veins of smoky quartz. The rock is remarkably fresh, considering the limited depth of the excavation.

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As the excavation is small, only one sheeting plane appears. It is about 10 feet from the surface. Joints strike N. 30° E. and N. 30° W. Blocks of large size, remarkably free of flaws, are obtainable. The appearance of rock of such good color near the surface is promising.

A mass of very dark gray rock appears near the west side of the excavation. As observed in the quarry it is somewhat similar to that which is found in the Black Diamond quarry, a short distance to the north, but is darker in color. Under the microscope, however, it is a type apparently unrelated to the Black Diamond dark-gray rock. It is an augite-hornblende-biotite granite, the three dark minerals appearing in about equal amount. The feldspars are orthoclase and plagioclase, and quartz is abundant. Owing to the presence of augite the rock would probably stain easily by weathering if employed where exposed to the elements. It is also too dark in color to be attractive, except for contrast with light-colored stone.

Hoisting was first done by horsepower, steam machinery being installed in the autumn of 1913. Transportation is by wagon to St. Cloud, 4 miles distant.

NOREEN QUARRIES.

L. E. Noreen has made several excavations in the NW. ¼ NE. ¼ sec. 28. All the old pits are practically abandoned, and two new ones were opened in 1913.

The rock in all the excavations is similar. It is a medium-grained even-textured granite of the typical gray color. Approximately three-fourths of the rock is gray feldspar, and the remainder is made up of black hornblende, with a little biotite and fine-grained quartz. A few minute grains of pyrite are visible. Microscopic determination proves the rock to be a hornblende-biotite-quartz monzonite. Orthoclase and plagioclase, which are present in nearly equal amount are the most abundant minerals. Quartz is more prominent than in most gray granites of central Minnesota. Hornblende, biotite, magnetite, sphene, and inclusions of apatite form the remainder. Feldspars are somewhat altered but not sufficiently so to impair the quality of the rock. A few dark-green knots are present and appear to be segregations of biotite and hornblende partly altered to chlorite.

About 4 rods west of the middle point of the north section line of sec. 28 and immediately south of the line is an abandoned excavation approiximately 225 by 120 feet and 15 to 25 feet deep. Open joints are in two prominent systems, north and N. 77° E., and are spaced 10 to 30 feet apart. Sheeting planes are horizontal and 8 to 12 feet apart. The rock is a little rusty near the surface. Two types of dikes appear on the quarry wall; small, straight, nearly vertical white aplites, about one-fourth of an inch wide; and curved, wavy, red dikes, 1 inch to 2 inches wide with very distinct borders.

Irregular patches of red granite, 6 inches to 2 feet across, also appear in places. Black knots from the size of a walnut to 6 inches wide are present but are infrequent. They appear to be segregations composed largely of hornblende. The rock is in bare outcrop, requiring no stripping whatever. The quarry is abandoned and the derrick removed.

About 32 rods farther south is a second excavation which has two large derricks. No rock was excavated in 1913. Joints strike N. 10° W., N. 10° E., and N. 50° E., and are spaced 10 to 25 feet apart. No sheeting planes appear on the 20-foot quarry face. Some black knots and fine red dikes are present. On a bare outcrop southwest of the quarry the joints are much closer and more irregular. Several other abandoned excavations in the vicinity are of similar type.

Active operations are carried on in two small excavations, one south and the other southeast of the abandoned pits. The rock appears to be of excellent quality and free of blemish. The rift is horizontal and the run north and south. Close observation discloses many acute-angled crystals of hornblende pointing north and south in an indistinct parallelism which may account for the run of the rock.

Horsepower is employed for hoisting in both quarries. A compressor run by a gasoline engine supplies compressed air for pneumatic drills. Transportation is by wagon to St. Cloud, about 2½ miles distant.

NORTHWESTERN GRANITE CO. QUARRIES.

The Northwestern Granite Co. operates two quarries on opposite sides of the road, one in the NW. ¼ sec. 34 and the other in the NE. ¼ sec. 33, T. 124 N., R. 28 W. The one in sec. 34, on property owned by Mrs. Fischer, was opened in 1890, and great quantities of rock have been excavated. It is an even-grained gray hornblende-biotite granite, very free from defects. It consists of light-gray feldspar, black hornblende, and mica, and scattered grains of blue quartz. It is uniform in texture and color.

The overburden of soil varies from 3 to 13 feet. Sheeting planes lie 10 to 16 feet respectively from the surface and dip about 10° S. Open joints trending N. 60° E. are 6 to 20 feet apart; others trending N. 10° W. are farther apart, 30 to 40 feet in places. Blind seams occur at intervals between them. One diabase dike 3 to 4 feet in width runs N. 85° E. through the quarry. A few black knots occur.

The quarry in sec. 33, on property of John Kermeier, is similar to that in sec. 34. The most prominent joints are N. 65° E.; others are curved and very irregular. An overburden of 4 to 10 feet of soil has protected the rock from weathering. The diabase dike exposed in the quarry in sec. 33 forms the south wall of this quarry, but it

impairs the quality of the rock for a few inches only. A few black knots were noted. Rock is excavated for monument stock and curbing, and a small amount of it is employed as building stone.

The quarries are equipped with steam derricks, steam and pneumatic drills, and are conveniently situated for transportation, the main road passing between the excavations. St. Cloud is about 4 miles distant.

ROBINSON QUARRY.

A quarry owned by J. B. Robinson in sec. 32 began operations in 1883 and ceased in 1909. The rock rises in a great dome 25 or 30 feet above the general level and covers several acres. It is a coarse-grained hornblende granite, consisting of pale-pink feldspars, transparent quartz somewhat less abundant than in most St. Cloud red granite, black hornblende, and biotite.

Under the microscope the feldspars show the effect of weathering by dusty or cloudy surfaces. Both orthoclase and microcline are present and are graphically intergrown with quartz; hornblende with inclusions of magnetite and quartz forms but a small proportion of the rock.

There are two prominent jointing systems which trend N. 65° E. and N. 25° W. Joint planes are 8 to 20 feet apart. Very distinct open horizontal sheeting planes are 12 to 16 feet apart and are distinctly advantageous both in blasting and in the removal of blocks.

Owing to the domelike structure the upper part of the rock may be worked as a shelf or bench quarry, the present excavation being of this type. The effects of weathering below the upper 6 or 8 feet are not sufficient to impair the strength of the stone, but, as in many other places where rock surfaces are exposed, the rock is bleached to considerable depth, and lacks the deep-red color so much desired in "St. Cloud" granite for monumental purposes. Owing to the open sheeting planes and the domelike nature of the outcrop the quarry is admirably adapted for excavation of building stone.

The color is probably darker red at depth, as in other red-granite quarries. In a small excavation at the base of the dome, where the rock is protected by soil, the color is deeper red. It seems probable that if deeper quarrying were pursued the upper portion could be employed for building stone and the lower for monumental purposes.

Two distinct dikes and a few hair lines were observed. The rift is horizontal, the run east and west, and the head grain north and south. The rock takes a fine polish but does not show a good contrast between polished and hammered surfaces. A polishing shop, operated jointly by J. B. Robinson and Robinson Bros., is situated near the southeast corner of sec. 29. St. Cloud station is 4 miles distant, and transportation is by wagon. The quarry supplied stone

for the St. Cloud post office and the lower part of the old Minneapolis post office.

Physical tests made at the University of Minnesota geologic laboratory show: True specific gravity, 2.643; pore space, per cent, 0.32; weight per cubic foot, dry, 164.6 pounds.

ROBINSON BROS.' QUARRY.[1]

Robinson Bros. began excavation of red granite in the SE. ¼ NE. ¼ sec. 31, St. Cloud Township, in 1909. The excavation is about 30 by 50 feet in extent and is 15 feet deep. The rock is exposed as a prominent ridge, and the surface rock is consequently pale, becoming deeper red at depth.

The rock consists chiefly of pink feldspar with a subordinate amount of pale green. Microcline is abundant, constituting fully three-fourths of the total mass, the other fourth being hornblende and clear grains of quartz. The rock is medium grained, of uniform texture, and is fairly free from blemish. The rock quarried in 1913 shows evidence of surface alteration but will probably improve in quality on deeper excavation.

Joints trending east-west are prominent and are 10 to 12 feet apart. Few joints in other directions are visible. No sheeting planes have been reached. Two diabase dikes 2 feet wide and 3 feet apart trend N. 60° E. and dip 60° SE. Black hair lines near the dikes are probably fine dikes of diabase. In the vicinity of the dikes the rock is decayed and stained to a much greater depth than in other parts of the excavation. A few dark knots are scattered throughout the quarry.

The equipment consists of an air compressor, operated by steam power, and a quarry derrick and yard derrick, both operated by horsepower.

Robinson Bros. operate a monument shop about a mile from the quarry at the southeast corner of sec. 29. The shop is about 4 miles from St. Cloud.

ST. CLOUD GRANITE WORKS QUARRIES.

The St. Cloud Granite Works operates a red granite quarry in the SE. ¼ SW. ¼ sec. 17. The excavation is about 75 feet deep.

The rock is a medium-grained hornblende-biotite granite, consisting of pink feldspar with a small admixture of pale-green feldspar, black hornblende, and subordinate biotite, together with both clear and smoky quartz. The chief feldspar is microcline. In places grains of hornblende and quartz form inclusions in the larger feldspar crystals. The rock is similar to that excavated at the Empire Quarry Co.'s new quarry.

[1] In 1915 the company was reorganized as the Keystone Granite Co.

Major joints strike N. 10° W. and N. 80° E. and are widely spaced. A few minor joints cross these obliquely. The first sheeting plane is about 10 feet from the surface, and the rock, except where protected by a covering of soil, has been altered down to this plane. On the other hand, where a depth of 6 feet or more of soil protects the surface the rock is unaltered.

One band of partly decayed rock runs N. 80° E. through the quarry, and is useless even to the bottom of the quarry, being stained and decayed by water percolation in open joints. Two diabase dikes, the largest of which is 3 feet across, pass N. 55° E. through the quarry. A few hair lines trend generally east and west. At the west end of the quarry a mass of gray granite is in sharp contact with the red. The run is east and west instead of north and south, as it is in most quarries. An abundance of high grade rock is produced and the quarry is in good condition for further development.

Steam and pneumatic drills are employed, and two large derricks are operated by steam power. The rock is transported by wagon for about 3½ miles to St. Cloud, where the company operate a very large shop equipped with stone dressing and polishing machines and lathes.

The St. Cloud Granite Works also owns a gray granite quarry in the SW. ¼ SE. ¼ sec. 21, St. Cloud Township. The rock is made up chiefly of gray feldspar crystals, some of which show distinct striations, but contains a few reddish feldspars, which give it a faint red tinge when observed closely. Scattered grains of blue quartz constitute a rather unusual feature of the rock. Hornblende and biotite constitute the darker portion.

With the microscope orthoclase was observed as the most abundant feldspar, though plagioclase is prominent. Sphene, magnetite, apatite, and zircon are accessory constituents. The rock has suffered little alteration. Black knots are numerous and appear to be segregations of hornblende and biotite. "White knots" in the form of large white feldspars appear in places, but otherwise the rock is even grained and uniform in color.

SCHWAB QUARRY.

A quarry operated a number of years ago in the W. ½ SW. ¼ sec. 8, north of the Great Northern tracks and west of Sauk River, is owned by C. D. Schwab, president of the Farmers' State Bank of St. Cloud. A pit about 50 feet in diameter is now nearly full of water so that observations were confined to the upper portion of the excavation, the stripped outcrop, and the waste heap. Both red and gray rock were quarried.

The red rock is a hornblende granite, red feldspar forming more than half the mass, the remainder being chiefly quartz and horn-

blende. Orthoclase and plagioclase are both present and are very much intergrown, forming a microperthite. Small grains of magnetite and inclusions of apatite are common. The rock is medium grained, the crystals being one-half to one-fourth of an inch in diameter.

The gray rock consists chiefly of greenish gray feldspar, which forms more than half the rock; quartz, roughly estimated at 20 per cent, hornblende, and biotite, the biotite being more abundant than in the red rock. The gray is finer grained than the red, the crystals averaging one-sixteenth to one-eighth of an inch in diameter.

North-south joints are vertical and 8 to 20 feet apart. East-west joints are similarly spaced and dip about 20° S. The texture is fairly uniform, but a number of cavities and small pegmatite masses are found. Small quantities of pyrite (FeS_2), pyrrhotite (FeS), and fluorite (CaF_2), all of which are uncommon in the St. Cloud region, are mingled with the quartz, feldspar, and mica.

Throughout a considerable area the red and gray types are mixed. Indistinct dikes of the red occur in the gray, and masses of gray are inclosed in the red. Boundaries between the two are very indistinct, and in places a gradual transition can be traced from one to the other, the mixed zone ranging in width from a few inches to several feet. In consequence of this, masses of rock occur which are neutral in color and can be placed with neither type. At some distance from the contact red rock of good quality may be obtained. A few black hair lines were observed. Although the quarry is close to the railroad no siding has been constructed. St. Cloud is about 4 miles distant.

SIMMERS & CAMPBELL QUARRIES.

Simmers & Campbell are pioneer granite workers of the St. Cloud region. A. M. Simmers formerly operated a quarry in Rockville. Present operations are in the NW. ¼ SW. ¼ sec. 17, St. Cloud Township, where three large excavations have been made. The one farthest east is 96 feet deep and is now abandoned and full of water. Work is now carried on in two excavations which are close together and will shortly be united into a single opening. The rock, a red granite, rises in a dome about 40 or 50 feet above the general level.

In thin section microcline is the chief feldspar, with orthoclase and plagioclase subordinate. The latter, from its small extinction angle, appears to be oligoclase. The feldspars show characteristic microperthitic intergrowth. Quartz is abundant. A small amount of hornblende, biotite, and a few grains of magnetite form the darker portion of the rock. Though the specimen was taken from about 55 feet below the surface, the feldspars show kaolinization, though not sufficiently to impair the quality of the stone.

Vertical major joints strike N. 2° W., and a second series dipping 85° to 88° N. strikes N. 85° W. Joints are spaced 6 to 10 feet apart. Sheeting planes are spaced about 20 feet apart and dip about 30° N. A small mass of gray granite occurs near the north side of the pit. A few dark knots appear and are more plentiful near the surface than at depth. Hair lines are numerous, though fortunately they are confined to one band of rock about 20 feet across. They contain, as identified with the microscope, epidote, needle-like crystals of plagioclase, and a very few crystals of olivine. Evidently they are diabase dikes altered almost beyond recognition and are probably offshoots of the larger dikes.

A dull rusty gray streak several inches in width, known locally as a "jasper band," passes diagonally through the quarry and appears,

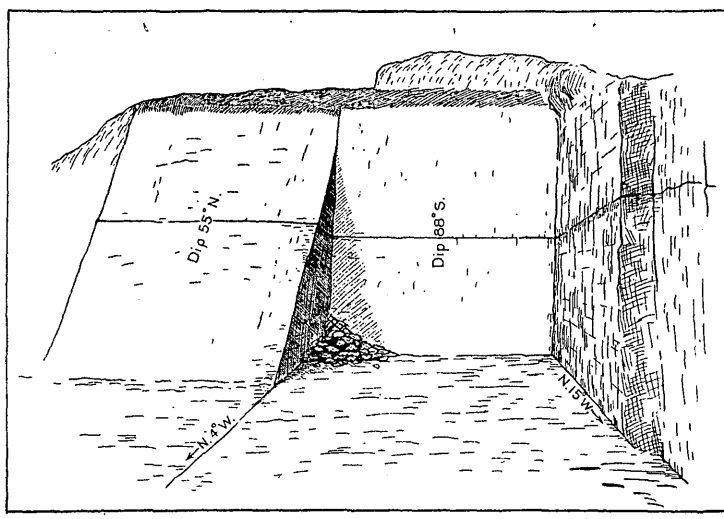


FIGURE 13.—South wall of Simmers & Campbell quarry showing an inclined joint on one-half of the quarry face and a nearly vertical joint on the other half.

from microscopic evidence, to be a band of stained rock due to weathering by water percolating along an oblique incipient seam. A 4-foot dike running N. 85° E. forms the south wall of the pit. A few pyritiferous smoky quartz veins with crushed zones of country rock along their borders appear in places.

The smaller excavation was opened up more recently on the north side of the steep rock bluff. Though now worked down somewhat below ground level, it presents the appearance of a shelf quarry.

An unusual occurrence of joints is shown in figure 13. The eastern half of the quarry wall follows an inclined joint dipping 55° N., and the western half a joint dipping about 88° S. The eastern plane is probably related to the system of inclined sheeting planes in the adjacent quarry. Vertical joints range from N. 4° W. to N. 15° W. and are spaced 15 to 20 feet apart at the east and 2 to 6 feet apart at

the west side of the pit. The rock in this quarry is free from dikes and "jasper bands" and is of good quality.

Steam and pneumatic drills and a steam hoist are employed. Transportation is facilitated greatly by a siding from the Great Northern Railway, which is so conveniently placed that the rock may be loaded directly on the cars by the quarry derrick at the larger excavation. A large polishing shop is situated in St. Cloud City. The rock is placed on the market under the trade name "North Star granite."

STREITZ BROS. QUARRY.

Streitz Bros. operate a gray granite quarry in the SE. ¼ SW. ¼ sec. 21. The excavation is about 150 feet long and 60 feet wide. At the north end the rock outcrops at the surface, but at the south end 4 to 8 feet of soil is removed.

The rock is uniform and of attractive appearance. It is a hornblende-biotite-quartz monzonite, consisting of orthoclase and plagioclase, with subordinate microcline; hornblende, biotite, and a few scattered grains of magnetite, and quartz in small amount filling intergranular spaces. Apatite inclusions are common. The feldspars are slightly kaolinized.

The chief joints strike north and east and are far apart, 40 or 50 feet in places. One sheeting plane appears on the 15-foot quarry face. Near the south end of the excavation a number of small parallel aplite dikes strike N. 60° E. Two diabase dikes about 2 feet wide trend N. 60° E. Steam is employed for pumping and running the air compressor, and hoisting is done by horsepower. Nearly all of the waste rock is sold for rubble. Transportation is by wagon to St. Cloud, about 2½ miles distant.

Southwest of the quarry, on the south line of sec. 21, a prominent ridge of gray granite was excavated many years ago. Aplite dikes, black knots, and irregular seams are numerous. North of the ridge the rock surface drops to the level of the fields and outcrops in several places. Here, as far as could be observed, it is of excellent quality, and promises well for future development.

UNDEVELOPED OUTCROPS.

The outcrops (see Pl. I) are described in the numerical order of the sections.

Sec. 2.—In the NW. ¼ sec. 2, about 7 rods south of the Sauk Rapids Bridge, an outcrop of gray granite is cut by diabase dikes and granite porphyry. The rock appears along the river margin at the base of the steep bluff and juts out beneath the river, forming a rapid. On account of the heavy overburden of drift and the lack of uniformity in texture, this rock is probably of little economic importance.

Sec. 8.—A few rods south of the Great Northern Railway bridge across Sauk River a patch of granite rises a little above the ground level and then disappears beneath the river. Its area is about 6 square rods. The rock is red granite, similar to that excavated by the Monarch Granite Co., 40 rods farther west. It lies at so low a level and is so close to the river that it would be difficult to keep it drained, especially in seasons of high water.

Sec. 17.—About 280 rods north and 252 rods west of the southeast corner of sec. 17, close to Sauk River, granite rises about 15 feet above the water. Its western part, a little of which has been quarried, is a gray granite, somewhat porphyritic in texture, with phenocrysts of microcline. Quartz is not prominent. Biotite, which is the more abundant dark mineral, appears to be secondary from alteration of hornblende. The texture is not very uniform. A north-south system of joints is spaced 3 inches to 6 feet, and a N. 88° E. system is spaced somewhat more widely. On account of close jointing and lack of uniformity in color and texture further excavation is unlikely.

About 10 rods to the northwest is a similar outcrop about 2 rods across.

About 11 rods farther south an outcrop of red granite approximates 12 by 8 rods in extent. Major joints striking N. 10° W. are closely spaced; secondary joints, N. 80° E., are few in number A few oblique minor joints were noted. The rock is thus divided into small and irregular blocks which can not be quarried to advantage. It is uneven in texture and is intruded by red aplite (fine-grained granite) dikes.

Sec. 18.—North of the railroad, near the junction of the Simmers & Campbell spur track, there is an outcrop about 8 rods wide of mixed coarse red and fine gray granite, closely jointed, and consequently of little use for monumental purposes.

About 92 rods north and 40 rods west of the southeast corner of the section a prominent dome 48 by 24 rods in extent rises about 30 feet high. The northeastern third is a fine-grained red granite, and the remaining two-thirds a medium-grained gray granite. A 6-inch pegmatite dike, which runs irregularly through the gray, consists of quartz and coarse crystals of feldspar, together with yellow-green epidote, probably of secondary origin. In the red granite also is a pegmatite dike consisting mainly of feldspar. Joints in the red strike N. 10° W. and N. 80° W. In the gray a prominent system strikes N. 15° W., and cross joints, few in number, strike irregularly. In both rocks they are closely spaced. Some of the gray rock has been quarried.

About 40 rods to the southwest is the edge of an outcrop covering several acres, the largest in the section. Rocks of four distinct ages

occur. The oldest is a typical "St. Cloud gray" granite, which is intruded by typical coarse-grained "St. Cloud red" granite, this in turn by red aplites, and all three by a diabase dike. The Great Northern Railway crosses the southwestern end of the granite in a cutting about 10 feet deep.

At the northern part of the outcrop a deserted quarry pit, known as the Drake quarry, was once connected with the railroad by a spur track. At the pit the rock is a uniform gray granite of good quality, consisting, in descending order of abundance, of orthoclase, plagioclase, quartz, microcline, hornblende, biotite, and magnetite. Feldspars show considerable alteration to kaolin. Joints strike N. 20° W. and N. 65° E. and are 6 to 20 feet apart. A 2-foot diabase dike, running parallel with the second set of joints, forms the southern wall of the excavation. The rock is intruded by a few granite dikes, which are more abundant near the surface than at the bottom of the pit. A few black knots appear. The excavation is approximately 120 by 60 feet in area and is 15 to 20 feet deep.

The remainder of the outcrop west of the pit is chiefly of red granite, though its northern part contains a little gray rock. The main mass is coarsely even-grained granite of the characteristic "St. Cloud red" type. Intruded into this are masses and dikes of red granular aplite, which, under the microscope, is seen to consist of orthoclase, plagioclase, microcline, quartz, hornblende, biotite, and magnetite. The quartz is granular in rounded grains with distinct boundaries like the quartz of a sandstone. Inclusions of apatite are abundant. There is some evidence of flow structure. The fine-grained aplite is cut by numerous joints with different trends, so closely spaced that only small diamond-shaped pieces could be obtained. Joints in the coarse red rock are widely spaced, and some of it has been quarried. The presence or absence of aplites will probably decide whether quarrying will be profitable or unprofitable.

About 24 rods north and 40 rods west of the southeast corner of the section, south of the railroad, is an outcrop of mixed red and gray granite with numerous joints.

About 25 rods north and 170 rods west of the southeast corner of the section a small though prominent outcrop of coarse red granite rises about 20 feet above a level field. On account of its exposed position, its joints are forced open by frost, and the rock, so far as visible, has reached an advanced stage of decay. The character of the unaltered rock can not well be judged.

Sec. 19.—A conspicuous dome surrounded by cultivated fields rises about 92 rods east of the Pioneer Granite Co.'s quarry in the NW. ¼ SW. ¼ sec. 19. The rock is a pale-pink granite porphyry consisting of feldspars a quarter to a half inch across, embedded in a fine-grained granite groundmass. With the microscope the

phenocrysts are seen to be of orthoclase and the groundmass an intergrowth of orthoclase and plagioclase (a microperthite) together with a very little hornblende, biotite, quartz, and magnetite. The rock is not attractive in appearance.

About a fourth of a mile to the north, close to the railroad, part of the smaller of two small outcrops of similar rock was quarried many years ago.

About 144 rods north and 212 rods west of the southeast corner of the section is an outcrop of red hornblende granite. In texture it lacks uniformity, the feldspars being so large as to be almost porphyritic in places. It has reached such an advanced stage of decay that the quality of the fresh rock can not be ascertained without development work. Orthoclase, plagioclase, microcline, quartz, hornblende, biotite, magnetite, and apatite are the minerals present, in order of their relative abundance.

A small outcrop appears close to the railroad 292 rods north and 121 rods west of the southeast corner of the section. It is of the typical red type and is intruded by a few red aplites. A few green and black hair lines appear. Joints strike N. 83° E. and N. 15° W. and are 3 to 7 feet apart.

An area of red granite occurs with the center of the outcrop approximately 252 rods north and 93 rods west of the southeast corner. It is separated by a ravine from the prominent area to the north where the Melrose Granite Co. opened up a new red granite quarry in 1913. The rock is even grained and is free from diabase dikes and hair lines. The intrusion of fine-grained red granite dikes 6 to 20 feet across constitutes the most serious impediment to successful quarrying. Microscopic observation of the intrusive dikes exhibits the same minerals as occur in the coarse red granite, viz, orthoclase, microcline, quartz, hornblende, and a subordinate amount of plagioclase and biotite. The dark minerals are scattered throughout in fine grains.

Before opening up a new quarry in this area extreme care should be taken to ascertain the probable extent of rock free of aplite dikes. Undoubtedly areas of sufficient size may be found. In the area to the north the red dikes also occur, but the Melrose excavation reveals a mass of exceptionally pure and flawless rock.

Sec. 20.—A long outcrop crosses the south section line at its center and extends about 65 rods north and 50 rods southwest of the line. The rock rises as a bare bluff facing the east and is wooded and drift-covered to the west. Where observed the rock is similar to that excavated by the Agate Granite Co. a short distance to the east. No attempt has been made to investigate the quality of the rock at depth.

About 224 rods west of the southeast corner is a rugged dome of granite about 50 feet high, extending 40 rods to the north. Its

summit affords an excellent view of the rough, rocky, and wooded country which extends 1½ miles to the south and southeast. The rock is a medium-grained red hornblende granite. Unlike most of the "St. Cloud red" granites, in which more or less greenish feldspar is present, almost all of the feldspar of this rock is red. The remaining constituents are abundant glassy quartz and black hornblende. The deep-red color and uniform texture are attractive characteristics. Major joints striking N. 10° W. are 3 to 10 feet apart, and secondary joints, striking N. 65° E., are spaced 4 to 18 feet apart. Irregular minor joints were noted. In the eastern part of the outcrop a number of fine-grained red aplite dikes range in width from half an inch to 8 inches. Near the north end a small pit was made, but at this point the rock is pale in color. Apparently rock of fine quality is available in the southern part of the outcrop, but its inaccessibility is a serious drawback.

An outcrop of gray granite 266 rods west of the southeast corner is intersected by numerous red dikes. A 2-inch diabase dike runs northeast.

About 144 rods north of the southwest corner is a small outcrop of red granite close to the section line. The rock is of fair quality, though some hair lines appear. A little stripping has been done.

Two quarry pits were worked at one time on a bluff 40 rods north and 213 rods west of the southeast section corner. The quarry pits are near the top of the bluff and are visible for a long distance to the east. The rock is red granite similar to that quarried at Holes Bros'. old quarry.

Sec. 28.—About 208 rods north and 321 rods west of the southeast corner are two small abandoned quarry pits in an outcrop of gray granite on property owned by Robert Graham. The exposure is about 50 rods in diameter. The rock is somewhat porphyritic, containing many relatively large hornblende crystals. Joints strike north and N. 80° W. and are 3 to 8 feet apart. Sheeting planes are 12 feet or more apart. The rock is intersected by reddish-white aplites. Black knots in the form of hornblende segregations half an inch to an inch wide appear in places.

A smaller outcrop appears in a thickly wooded area 224 rods north and 86 rods west of the southeast section corner. A small excavation has been made near the north end. The rock is a fairly uniform gray granite cut by a number of aplite dikes.

About 213 rods north and 186 rods west of the southeast corner of the section is a ridge of medium-grained gray granite 65 rods long and rising about 15 feet high. Joints are irregular in direction, though favorably spaced. The rock is cut by irregular aplite dikes one-fourth to one-half inch across and by a 6-inch red granite dike. A 3-inch diabase dike cuts the granite ridge with a trend northeast.

In the NW. ¼ sec. 28 are two small outcrops of coarse-grained gray granite. Some of the western mass has been quarried.

Sec. 29.—A larger area of rock is exposed in sec. 29 than in any other section in the township, and transportation is not a serious problem; but the unfortunate intrusion of red granite in the gray and the later intrusion of red aplites add greatly to the uncertainty of quarrying. There are a great many outcrops but no working quarries.

Twenty-four rods north of the southeast corner, the road, which here follows the section line, crosses an outcrop about 32 rods north and south at its widest point and 52 rods long. Observed in a small quarry pit close to the road the rock is dark gray in color, medium grained, and of uniform texture. A few black knots are present. Numerous dikes of red granite cut through the gray. (See Pl. VII, *B*, p. 61.) Some of them are fine grained near their borders and pegmatitic in the center. (See fig. 14.) The dikes range from one-fourth of an inch to 6 inches across and are very irregular both in direction and distribution.

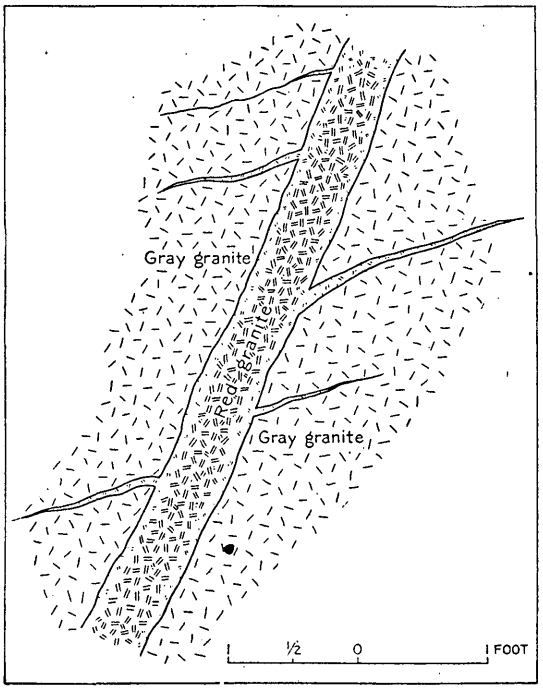


FIGURE 14.—Characteristic red granite dike in gray granite 47 rods north of southeast corner of sec. 29, St. Cloud Township, Minn.

Southwest of this lies a second ridge, 52 rods long and 26 rods wide, of a red granite, medium grained and apparently of good color, though observation could be made only of weathered surfaces.

The center of a third outcrop is 38 rods north and 128 rods west of the southeast corner. The rock is a gray granite similar to that 24 rods north of the southeast corner. Major joints strike north and east and are 2 to 15 feet apart. A minor system strikes N. 50° W. The exposure is traversed by irregular dikes of red granite. Several small outcrops adjoining this are of similar type.

A prominent though small dome of red granite is 108 rods north and 80 rods west of the southeast section corner. It rises about 25 feet above the surrounding cultivated fields. Irregular joints are numerous.

At the center of the section an outcrop of gray granite 32 by 58 rods in extent has been successively intruded by red granite, red aplite, and diabase. The eastern part of the area is red granite, medium grained, and apparently of good color. Joints strike N. 25° W. and N. 80° W. and are well spaced. It is probable that good quarry rock could be obtained here. Farther west a gray granite is traversed by a mosaic of red dikes and consequently is quite useless as a monumental stone. Near the contact masses of gray rock are inclosed in the red. At one point the mass of coarse red granite is cut by a red aplite dike which shows concentric flow lines, indicating viscosity in the magma at the time of injection. It probably represents the final stage of red magma intrusion. The whole mass is cut by a 2½-foot diabase dike running northeastward.

The center of a large outcrop of gray granite is approximately 200 rods north and 224 rods west of the southeast section corner. The area is about 64 by 48 rods in extent, and is domelike in structure, rising to a considerable height in the center. A scrubby forest growth covers a large part of the area, with numerous patches of bare rock appearing.

The rock is an even-textured gray biotite granite, cut by numerous dikes of red granite. It is medium grained, the feldspar crystals being one-eighth to one-fourth of an inch across. Very little quartz is present. Near the north side of the area a red aplite shows curved flow lines. Many years ago paving stones were quarried in the southeastern part of the dome. The rock at the abandoned pit is intersected by red granite dikes and quartz epidote veins. In the southwest part of the outcrop two large deserted quarry pits show a gray granite composed of orthoclase, plagioclase, microcline, hornblende, biotite, quartz, magnetite, and sphene. Numerous dikes of red granite mar the rock for monumental purposes. Pegmatites are of common occurrence. They consist of coarse feldspars, quartz, and brown mica in lathlike crystals. Black knots are numerous; most of the smaller ones appear to be biotite segregations, but some of the larger are angular inclusions of garnetiferous biotite schist, caught up by the gray granite magma which solidified around them. (See fig. 7, p. 60.) The rock is suitable for paving blocks or building stone but not for monumental purposes.

A small outcrop 100 rods north and 300 rods west of the southeast corner is of mixed red granite and gray granite of inferior quality.

The section line crosses a small outcrop 116 rods north of the southwest corner. The southern part is gray granite intersected by red dikes and the northern part is red granite. Major joints striking N. 30° W. are very close, 1 to 3 inches apart; those of a secondary system, striking N. 60° E., are 4 inches to 1 foot apart. Two 4-inch diabase dikes trend N. 65° E. and N. 22° E.

From the middle of the west section line a ridge extends 128 rods northeast. The eastern end of the ridge is gray granite cut by red dikes, the two types being so mixed that uniform rock could not readily be obtained. A little west of this, and continuing through the central portion of the ridge, red granite only appears. Farther west the rock is of mixed red and gray, intersected by close joints. The best rock is in the central part of the ridge, but the occurrence of gray granite close at hand both to the east and west, makes the outlook poor for successful operation.

A steep dome of rock rises about 30 feet above a slough 272 rods west of the southeast section corner. Both red and gray rock occur and are probably too greatly mixed to be of value, though possibly considerable areas of each could be found fairly free of the other.

The final area to be described in sec. 29 is about 40 by 24 rods in extent and its center lies at a point approximately 222 rods north and 28 rods west of the southeast section corner. The western part is of gray granite cut by many red granite dikes and quartz veins and containing schist inclusions. The eastern part is of red granite, variable in texture. Two diabase dikes, one 3 feet wide, and the other narrower, trend N. 40° E. The wider dike narrows to a point toward the southwest and disappears. The diabase is later than both the red and the gray granite. On account of the unfortunate mixing of the two types, the lack of uniformity in texture, the close jointing, and the quartz veins the area is probably of little value for quarrying.

Sec. 30.—About 64 rods north and 64 rods west of the southeast section corner an outcrop covering an acre rises about 15 feet above the surrounding region, which on all sides for about a third of a mile is covered with scrub oak and a second growth of willow and poplar. The eastern part is a medium-grained red granite of attractive color. Joints are in one system only, N. 85° E. The following spacing between joints was observed from south to north, near the east end of the outcrop: 3, 3, 2, 12, 12, and 15 feet. The rock is remarkably free from defects, no hair lines, dikes, or knots appearing. The western part of the ridge is of gray granite, the actual contact between it and the red being covered by a strip of drift, near which the red granite is very fine grained. Surface conditions indicate that good monumental red granite may be obtained in the eastern part of the ridge.

About 175 rods north of the southeast section corner a small outcrop extends from the section line 8 rods to the west. It consists of gray granite intruded by numerous dikes of red granite.

The center of an extensive outcrop of coarse red granite falls about 160 rods north and 64 rods west of the southeast corner. Major joints 6 inches to 1 foot apart strike N. 40° W. Secondary joints striking N. 40° E. are 3 to 8 feet apart. Close jointing is a serious imperfec-

tion. Quartz veins about one-fourth of an inch across follow the open joints in some places. Several smaller outcrops in the same neighborhood are of similar type.

A small outcrop near the center of the SW. ¼ sec. 30 is a very pale red hornblende-biotite granite, greatly decayed. It consists of orthoclase, plagioclase, a little microcline, quartz in rounded grains with a somewhat granular texture, hornblende, biotite, and magnetite.

About 250 rods north and 213 rods west of the southeast corner about one-half mile west of Holes Bros.' new quarry a large dome of granite covers several acres. The northern part is a light-gray fine-grained granite, and the southern part a red granite of fair quality, though the color is pale. The color will probably improve with depth.

On the north section line, 92 rods west of the northeast corner, a dome of red granite about 20 feet high was quarried in several places many years ago by Frick & Borwick. The color is paler red than most of the "St. Cloud" stone, and for this reason operations ceased. It is probable that the exposed nature of the bluff has resulted in bleaching.

Sec. 32.—A small outcrop of red granite occurs close to the section line 234 rods north of the southeast section corner. Joints strike N. 10° W., N. 30° W., and N. 60° E., and are closely spaced. The rock is cut by numerous east-west epidote veins.

Several small outcrops to the north and others to the southwest are so much decayed that no definite conclusions could be reached regarding their quality.

The center of a prominent exposure lies about 300 rods north and 96 rods west of the southeast corner. The ridge is about 64 rods east and west, 16 rods wide, and rises about 20 feet high. It is mainly of gray hornblende-biotite granite. Major joints strike N. 10° W.; others are very irregular, and all are spaced far apart. Dikes of red granite and aplite are common. The color is not attractive. The western end is a mass of red granite, which while fairly uniform and free from defects is rather pale in color.

From the center of the north line of sec. 21 an extensive outcrop runs about 56 rods southwest. Toward the east it divides into two ridges, the eastern end of each being a medium-grained red granite and the remainder gray. Major joints in the red rock average 5 or 6 feet apart and strike N. 10° E. A few secondary joints cross at irregular intervals and in various directions. A 6-foot diabase dike striking N. 50° E. and a 5-foot diabase dike striking N. 40° E. cut both red and gray rock. The rock is probably of little economic value.

About 292 rods north and 220 rods west of the southeast corner is a small ridge which was excavated for a short time and then abandoned. The rock is a medium to coarse grained pale-red hornblende

granite. Feldspars form the greater part of the rock and are of two distinct kinds, the most prominent being flesh-red and the other which is present in considerable amount, being pale green. Under the microscope the prominent feldspars are orthoclase and microcline with subordinate plagioclase. Quartz is abundant. Hornblende, biotite, and magnetite form a very small portion of the total volume. The presence of the magnetite is not detrimental, for it is a stable oxide, not likely to cause stains. The rock is intersected by many irregular open joints. Stains occur along the joint planes, and in places penetrate the rock for several inches. The most serious imperfection is the presence of blind seams, known among quarrymen as "slick seams," which run obliquely to the main joints and are invisible in the undisturbed rock mass. On blasting, however, they open up, forming many small angular fragments. Some hair lines and a few dark knots occur. In the western part of the outcrop numerous diabase dikes, half an inch to 6 inches across, trend approximately N. 65° E. Eighteen dikes were counted in a distance of 20 feet. They are confined to one band of rock, the southern part of the exposure being free of them.

About 24 rods to the south is a small outcrop, a little of which is excavated. A large diabase dike passes N. 70° E. along one side of the pit, and near it are numerous hair lines. The rock is pale-red granite, but it probably improves in color with depth. Microscopic examination exhibits two prominent minerals, microcline and quartz forming nearly all of the rock, with subordinate orthoclase, biotite, and hornblende. The microcline is perthitic.

About 40 rods south of the northeast section corner a ridge of red granite runs from the section line 32 rods east. Near its eastern end is an area of gray granite, near which the red rock is much finer grained. The rock is of fair quality though rather pale. A small quarry pit was made at the western end.

South of this are several small outcrops of gray granite that are seriously injured by the presence of several diabase dikes.

Sec. 33.—There are few outcrops in sec. 33. A quarry is operated by the Northwestern Granite Co. near the center of the eastern section line and quarries owned by John Doerner and Morgan Flaherty & Son are located on rather prominent outcrops in the extreme northwest.

Gray granite about 100 feet across outcrops 268 rods north and 40 rods west of the southeast corner of the section. As observed in a small excavation the rock is a gray hornblende-biotite granite, similar to that quarried by the Northwestern Granite Co. It consists of orthoclase, subordinate plagioclase, a little blue quartz, hornblende, biotite, and numerous grains of magnetite and sphene. The feldspars are slightly kaolinized and about half of them are pale

pink, giving the rock a reddish tinge. The rock is of good quality as far as could be observed. Some of it has been quarried.

A second outcrop is about 8 rods south of that on which John Doerner's quarries are situated in the NW. ¼ NW. ¼ of the section. It is a gray granite intruded by granite porphyry. The porphyry is cut up into small angular blocks by numerous joints. Major joints strike N. 5° E. and secondary joints N. 53° W. and N. 65° E., the three systems thus meeting at about 60°. The rock in this outcrop is probably of little economic value on account of its different textures, close jointing, and intrusions.

Sec. 34.—An outcrop of gray granite covering 50 square rods is situated 240 rods north and 296 rods west of the southeast corner. Joints strike N. 85° W. and N. 10° E. and are spaced 3 to 10 feet apart. The rock appears to be of good quality.

About 14 rods farther west is a very small exposure of similar rock.

ST. JOSEPH TOWNSHIP (T. 124 N., R. 29 W.).

PIONEER GRANITE CO. QUARRY.

On the site of the old Baxter quarry in the NE. ¼ SE. ¼ sec. 24, the Pioneer Granite Co. began operations in 1913. The rock is a coarse-grained red granite, paler than the typical "St. Cloud red" but deeper red than the "Rockville" granite. It is of the latter type. A few dark knots consist of both red and greenish feldspar and abundant hornblende and biotite. They are much finer grained than the main quarry rock. Feldspar forming about three-fourths of the rock is mainly pink with a subordinate amount of greenish-white.

Under the microscope the minerals present in the typical granite are, in order of abundance, microcline, quartz, orthoclase, hornblende, biotite, and plagioclase. The feldspars show considerable microperthitic intergrowth. Hornblende and biotite are in large flakes and grains, which are much broken up and contain many inclusions of quartz and feldspar. Some of the feldspars contain inclusions of dark minerals. The knots are segregations of hornblende and biotite.

Three prominent jointing systems occur: N. 5° E., N. 60° E., and N. 60° W. Minor joints cross in different directions. The jointing planes are widely spaced and permit the quarrying of large blocks. One diabase dike about 3 inches wide was observed to trend N. 30° E. A few black to greenish hair lines were determined under the microscope to be veins of epidote and chlorite.

Physical tests showed that under crushing stress the first crack came at 9,395 pounds per square inch and final collapse at 15,712 pounds. Under transverse breaking strain the modulus of rupture proved to be 2,596 pounds per square inch.

The rock is excellent for building purposes, being strong, durable, and attractive. It takes a good polish and as joints are far apart long pieces for columns or spires may be obtained. Two columns, each 19½ feet long and 22 inches in diameter, were obtained in 1913 for the Zapp State Bank, St. Cloud. (See Pl. VIII, *A* and *B*, p. 66.) The turning and polishing were done at the Rockville Granite Co.'s shops in Rockville.

Stone from this quarry was used for the basement and approaches of the State Capitol, St Paul. During 1913 and 1914 rock was supplied for the steps of the Gateway Park Building and trimming for the Ford Motor Works, Minneapolis, for the basement of the Menominee post office, Wis., and the Olympia Building, Winnipeg.

Steam power is employed for hoisting and deep drilling. A siding from the Great Northern Railway greatly facilitates transportation.

UNDEVELOPED OUTCROPS.

One outlying outcrop of considerable extent is situated in the NE. ¼ NE. ¼ sec. 26, St. Joseph Township, on land owned by John Undersander. It is close to the Great Northern Railway connecting St. Cloud with Rockville. The rock rises about 20 feet above the track and covers about an acre. It is medium to coarse grained and is pale pink in color. It consists of pale-pink feldspar, hornblende, biotite in small flakes and masses, and abundant quartz in medium-sized clear glassy grains. The feldspars contain many inclusions of quartz, biotite, and hornblende, large enough to be seen with the naked eye. In thin section the largest feldspars are seen to be microcline; orthoclase and plagioclase are subordinate in amount. Hornblende and biotite are the prominent dark minerals, the latter associated with magnetite grains. Apatite crystals are common and of unusually large size. In uniformity of texture, size of grain, and color the rock is similar to the "Rockville" stone. Though it has not yet been quarried its similarity to the "Rockville" stone and the excellent facilities for its railroad transportation suggest its use for structural purposes.

ST. WENDALL TOWNSHIP (T. 125 N., R. 29 W.).

There are no active quarries in St. Wendall Township, and all the outcrops are of gabbro or closely related types.

Near the center and in the SE. ¼ sec. 12 and the NE. ¼ sec. 13 several short ridges of medium to coarse grained olivine gabbro rise a few feet above the general level. The most prominent of these is near the southeast corner of sec. 12, on the property of C. L. Atwood, of St. Cloud. It reaches an elevation of about 40 feet above the surrounding fields and covers an area of at least an acre. In a small quarry

excavation observation of fairly fresh rock shows that the most abundant minerals are plagioclase and augite. A little green hornblende and considerable biotite appear to be alteration products of the augite. Olivine and magnetite grains are numerous, and a few quartz grains appear in places. The presence of quartz grains in a rock containing olivine bears with it a strong presumption that the quartz is secondary. The rock is dark green in color and takes a good polish.

Jointing planes are very irregular and the rock is greatly decomposed to a depth of 4 to 5 feet. The upper part of the ridge includes masses of decayed porphyritic and schistose rocks. Similar rock appears in smaller outcrops to the west.

An outcrop 48 rods east of the center of sec. 12 is a quartz norite, consisting of plagioclase, hypersthene, a little monoclinic pyroxene, quartz, and a few flakes of secondary biotite. The quartz is not abundant and appears to be secondary.

A small area of gabbro about 40 rods south of the center of sec. 12 is cut by two red-granite dikes, which resemble in general character the typical "St. Cloud red" granite. A pegmatite area about a foot in diameter was observed in the same outcrop. It consists of large crystals of red orthoclase graphically intergrown with quartz.

Though rocks containing so large a proportion of iron-bearing minerals usually alter much more readily than granite, the area may have some economic value. For interior decoration the dark-green polished surface would be attractive for panel work in contrast with lighter rock. Gabbro is valuable in the form of crushed stone for macadam or concrete.

SAUK CENTER TOWNSHIP (T. 126 N., R. 34 W.).

Southeast of Sauk Center, near the railway, is a small exposure of pale-pink medium to fine grained biotite granite highly altered by weathering. It contains many inclusions of coarse-grained gneissic granite and patches of pegmatite and is traversed by close and uneven joints. Some of it has been quarried for foundations, but it is useless for monuments.

WAKEFIELD TOWNSHIP (T. 123 N., R. 30 W.).

Though several outcrops representing different types of rocks occur in Wakefield Township no quarries were active in 1913. The only reported granite quarry in this vicinity was found on examination to be an excavation in a huge boulder of granite almost buried in the drift.

Within the town of Cold Spring an extensive exposure of granite rises along the river front as a bluff about 20 to 30 feet high. It is a pale-pink hornblende granite, in which the minerals are unequally

distributed, the quartz grains occurring massed together in places. Green epidote is common. Lack of uniformity and pale color make the rock unprofitable to quarry except for crushing or rubble. Much of it has been quarried for foundation stone.

Close to the Richmond road, about a mile west of Cold Spring, in the NW. ¼ sec. 21, is a small outcrop of coarse-grained hornblende granite. Though only decayed rock is visible, the deep red color of the feldspars is attractive. A small outcrop of similar type occurs about a third of a mile to the west, near the railroad crossing.

Two prominent ridges of coarse red biotite granite, one in the SW. ¼ sec. 20 and the other in the NW. ¼ sec. 29, covers each at least an acre and rise about 40 feet about the level of the road. Biotite is present in small flakes and quartz in large glassy crystals. The most prominent constituent, however, is feldspar in large deep red crystals 1 to 1½ inches across. Only surface rock, in which the feldspars are rusty along cracks and crystal boundaries, could be observed, but the probability of great improvement in color below the zone of surface alteration makes investigation of this area desirable. In texture and color the rock resembles the "red Waupaca" granite of Wisconsin.[1] As observed in thin section the feldspar is mostly microcline. Quartz is present in large grains. Biotite, magnetite, and a little hornblende constitute the relatively small amount of dark mineral. Joints are uneven and are several feet apart. At the south side of the outcrop in the SW. ¼ sec. 20 is a mass of dark fine-grained diorite which is older than the granite, for the latter intrudes it as a dike at one point.

At the western end of the outcrop in sec. 20 is a patch of very attractive fine-grained deep-red granite, whose contact with the adjacent coarse red granite is covered by drift. It occurs on property owned by Henry Osendorf, who states that it was first uncovered by the plow. An excavation about 15 feet across and 10 feet deep has been made. As the lower part of the pit is filled with water, observations could be made only of the upper 2 feet of rock, which is covered by a mantle of 4 or 5 feet of soil.

The rock is one of the most attractive in Minnesota. It is a binary granite, consisting of red feldspars and smoky quartz. It is fine grained, crystals being one-eighth to one-sixteenth of an inch in diameter, and is uniform both in color and texture. It takes a beautiful polish (see Pl. XIII, *C*), and is deep red, being similar both in color and texture to the "Montello" granite of Wisconsin.[2] The feldspar is microcline with subordinate orthoclase. Quartz is abundant. A few small grains of biotite, hornblende, and magnetite can

[1] Buckley, E. R., Building and ornamental stones of Wisconsin: Wisconsin Geol. Survey Bull. 4, p. 126, pl. 12, 1898.

[2] Buckley, E. R., op. cit., p. 96, pl. 6.

(A)

(B)

(C)

(D)

A. "WARMAN CREEK GRAY" GRANITE
B. "ROCKVILLE" GRANITE
C. "RICHMOND RED" GRANITE
D. "MORRISON COUNTY GRAY" GRANITE

be detected with the microscope. The rock shows some effects of surface weathering.

As far as could be observed the rock is badly broken by joints, though better conditions may exist at depth. The rock excavated was employed in building a barn foundation. If blocks of considerable size free from seams could be found they would undoubtedly be valuable for monumental purposes. The Great Northern Railway is about half a mile distant.

In the western part of sec. 19, south of the main road from Cold Spring to Richmond, are outcrops of dark tough diorite, which is medium to coarse grained and greenish gray. With the aid of the microscope it was determined to be an augite diorite, consisting of large crystals of plagioclase and hornblende, many of the latter containing augite cores. This condition suggests that the rock was probably a gabbro originally, and that the augite is gradually changing to hornblende. Some of the rock has been quarried in two places for barn foundations and is serviceable. Its dark color makes it undesirable for all except the most ordinary structural purposes. Its usefulness for road construction or concrete has not been investigated.

SHERBURNE COUNTY.

CHARACTER AND DISTRIBUTION OF THE ROCKS.

The larger part of Sherburne County is deeply drift covered and has no outcrops of bedrock. The northwestern part, however, is more thinly covered, granites being exposed in the SW. ¼ sec. 17, the NE. ¼ sec. 7, and the S. ½ sec. 6, Haven Township, each of which contains a number of active quarries. The granites are assumed to be of early Keweenawan age. Gray granites predominate, though red granites and a few intermediate varieties are present. In general the rocks of Sherburne County present a greater number of different types in a given area than those of Stearns County. The gray rock has a more or less distinct horizontal rift and a north and south run. Partly on this account and partly because the numerous aplite dikes would cause too great waste if monument stock were produced, the chief production is paving stones. The close proximity of two railway lines is a factor of great economic value.

QUARRIES.

OLD ROCK ISLAND OR SAULPAUGH QUARRY.

The most southerly outcrop in Sherburne County is in the SW. ¼ sec. 17, Haven Township. It rises in a rounded dome 4 or 5 acres in extent about 15 feet above the general level. Rock was first quarried on this outcrop in 1879 by Daniel Burns, who supplied stone for the Chicago, Milwaukee & St. Paul Railway bridge over

the Mississippi on the short line between St. Paul and Minneapolis. In 1881 it was leased to Saulpaugh & Co., of Rock Island, Ill., who supplied 7,000 cubic yards of stone for the Northern Pacific Railway bridge over the Missouri at Bismarck. Part of the stone was obtained from this quarry and part from quarries at Watab in Benton County.[1] Since the completion of this contract, the quarry has remained idle.

The main mass is a coarse pinkish-gray quartz monzonite, having about the same texture as the "St. Cloud red" granite, though not so uniform. The dark minerals, biotite and hornblende, are very abundant. Feldspars are of two kinds, pale pink (orthoclase or microcline) and pale greenish gray (plagioclase) in about equal amounts. The quartz, some of which is smoky, is not plentiful. The rock shows little alteration, even under the microscope.

In the northwestern part of the outcrop a smaller mass of finer-grained granite contains very few of the pale-pink feldspars. The dark minerals, the chief of which is biotite, are present in fine, scattered particles, whose combined effect deprives the rock of the attractive color that characterizes many of the "St. Cloud gray" granites.

A few sheeting planes occur near the surface but none at depth. The chief joints strike N. 65° E. and secondary joints N. 1° E. Joints are spaced far apart, 40 to 50 feet in places. The area is intersected by numerous pale-red and gray aplite dikes trending about N. 70° W. Toward the eastern end of the outcrop several bands of a medium-grained gray granite cut through the coarser rock. Their boundaries are indistinct. A diabase dike 4 feet thick crosses the outcrop in direction N. 70° E.

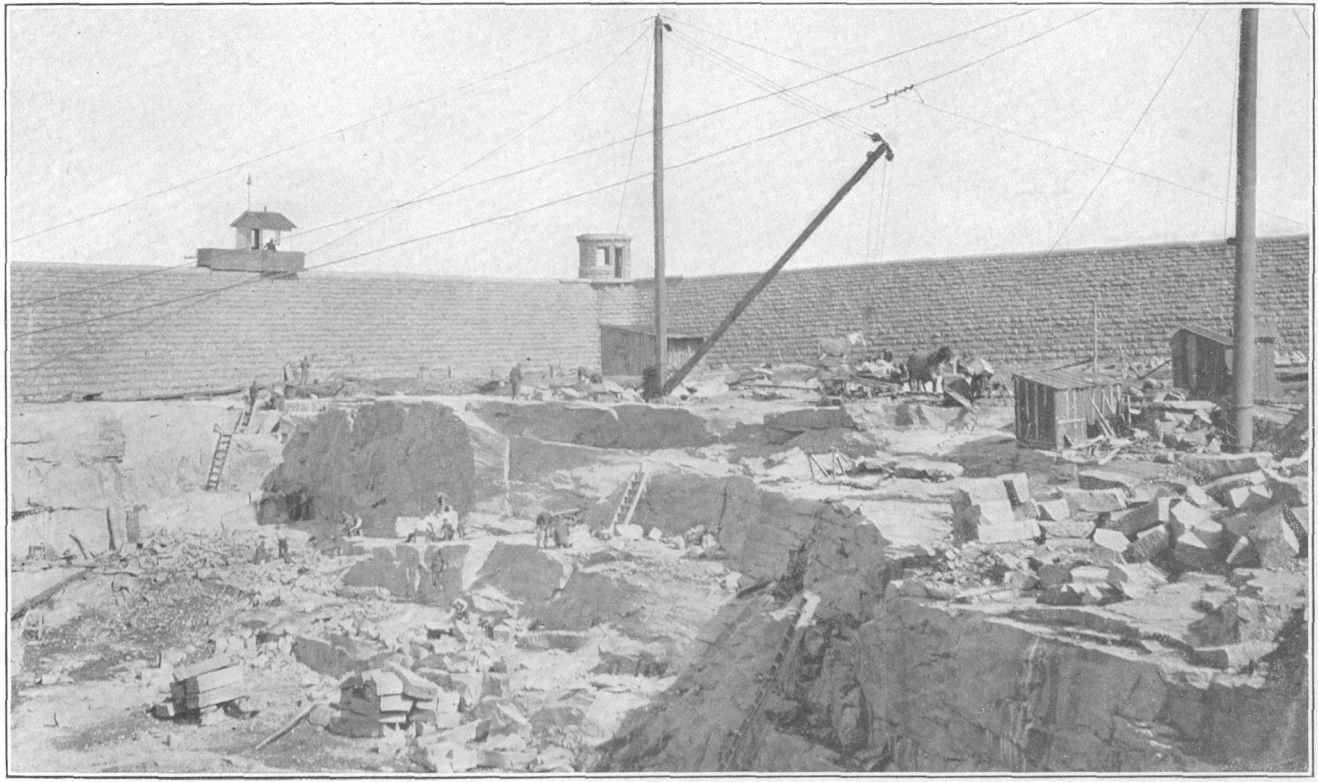
On account of the unattractive color and, above all, the varying types within a limited area the rock is not to be recommended for monumental purposes. It is, however, an excellent structural stone, being strong and durable. The nearest railway stations are Reformatory or Haven, each about 2 miles distant.

MINNESOTA STATE REFORMATORY QUARRIES.

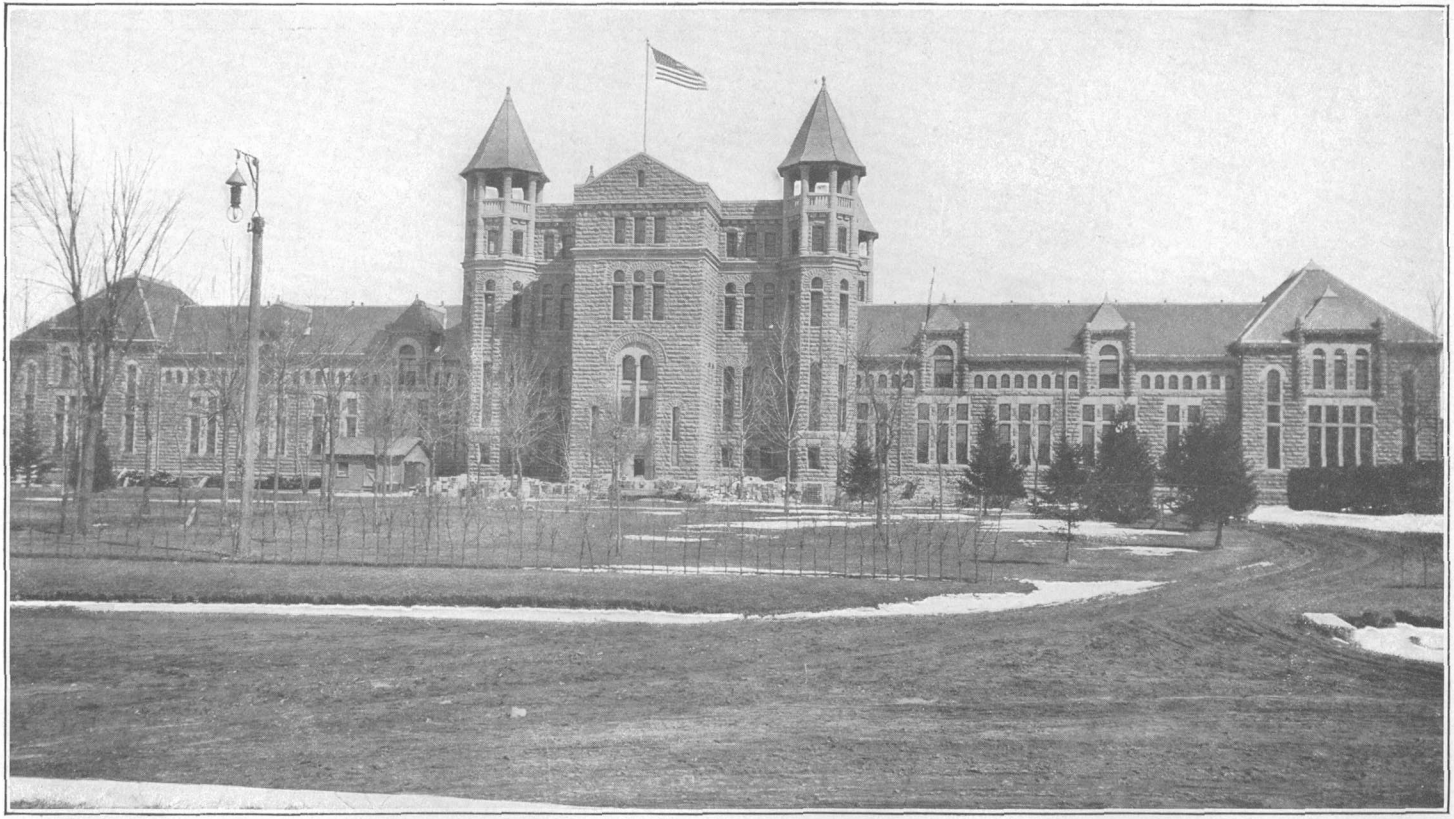
The State Reformatory grounds are in the NE. ¼ sec. 7 and SE. ¼ sec. 6, Haven Township, about 3 miles from the center of St. Cloud city. The inmates have excavated rock since 1889 and have made several large pits, some inside the walls and some outside.

The rock is a medium-grained gray hornblende-quartz monzonite, consisting of gray feldspars, black hornblende, mica, and a little quartz. As observed with the microscope, orthoclase and microcline together are a little in excess of the plagioclase. The remainder of the rock mass consists of hornblende, biotite, and a small amount

[1] Winchell, N. H., Final report on the Geology of Minnesota: Minnesota Geol. Survey, vol. 2, p. 432, 1888.



REFORMATORY QUARRY, EAST ST. CLOUD, MINN.



MAIN BUILDING OF ST. CLOUD REFORMATORY.

Constructed of gray granite obtained from the reformatory quarries.

of quartz, sphene, magnetite, and apatite. The rock shows but slight alteration by weathering.

In the larger excavation within the walls (see Pl. XIV) major joints strike N. 88° E., secondary joints N. 22° E., and a few of minor importance N. 36° W. and N. 86° W. They are 3 to 14 feet apart. In excavations farther north, two of which are outside the walls and three within, major joints strike N. 88° W. and secondary joints N. 5° E. Sheeting planes are very indistinct and far apart, a circumstance which makes quarrying difficult. A number of black knots, most of which are rather small, half an inch to 2 inches across, appear to be segregations of dark minerals; but others are angular and are probably fragments of a dark rock inclosed at the time of consolidation. White to reddish aplite dikes, half an inch to 2 inches in diameter, are common. The rock is fairly uniform and shows little change at depth, though it is said by quarrymen to be a little harder in the bottom of the quarries.

The output is building blocks and crushed stone. At present about 200 carloads of crushed rock are supplied annually to the State highway commission. In early years a great deal of wall rock was sold, the maximum yearly output being about 250 carloads. A siding from the Great Northern Railway enters the grounds.

About 1903 the building stone quarried was used in constructing new reformatory buildings and walls. The main building (Pl. XV) shows the adaptability of the stone to structural work. In 1902 the construction of a wall 4 feet thick at the base, 2½ feet at the top, and 22½ feet high about the reformatory grounds was begun. (See Pl. XIV.) In 1913 over three-fourths of a mile had been built, and it was estimated that about 8 years more would be required to complete it. In 1912 an octagonal water tower, 30 feet across the base and 115 feet high, was completed.

Just outside the reformatory wall is the deserted pit where Breen & Young began work in 1868. It has been inactive for many years.

EAST ST. CLOUD GRANITE CO. QUARRY.

About one-eighth of a mile north of the reformatory grounds and close to the Great Northern and Northern Pacific railways are three excavations made by the East St. Cloud Granite Co. The quarries were opened about 1900 and have been worked continuously ever since. Both red and gray granite are quarried. The red quarry is the second from the railroad, and lies between two gray quarries, whose rock is almost identical with that from the reformatory quarries. The red is a medium to coarse grained hornblende granite similar to the typical "St. Cloud red" granite of Stearns County. The feldspars are chiefly red, a few crystals of greenish gray occurring

in places. Quartz is abundant in glassy grains and hornblende is subordinate.

Major joints strike N. 75° E. and secondary joints N. 13° W. All are nearly vertical and 1 to 15 feet apart. In the gray quarry two sheeting planes lie 5 and 12 feet, respectively, from the surface, but with increasing depth the spacing increases considerably. In the red quarry indistinct planes appear near the surface, though none occur in the lower 40 feet of quarry wall. The gray granite contains a number of black knots which are probably segregations. Large masses of the gray rock form inclusions in the red. The red rock turns brown on weathering. About half the output is paving blocks, the remainder consisting of building stone, monument stock, and curbing. The nearest station is Reformatory, half a mile distant.

HILDER GRANITE CO. QUARRY.

A gray-granite quarry immediately west of the East St. Cloud Granite Co.'s pits was first operated by the Hilder Granite Co. under lease in 1886 and was bought in 1912. It has been worked continuously since first opened.

The rock is a fine-grained gray hornblende-biotite granite containing a larger proportion of dark minerals than most of the gray granites on the opposite side of the river in Stearns County. Feldspars are mostly gray with a subordinate number of pale-pink crystals. In order of abundance they are orthoclase, plagioclase, and microcline. Quartz is fairly abundant in clear glassy grains. Hornblende and biotite are about equal in amount; both contain numerous inclusions of apatite and zircon, the latter surrounded by pleochroic halos. Sphene and magnetite grains are numerous, but the magnetite, being a stable oxide, is unlikely to cause stains by weathering.

Major joints strike N. 84° E., secondary joints N. 10° W., and a subordinate system N. 40° W. This would result in the production of undesirable angular blocks if the joints were not so very widely spaced—20, 30, and in some places 40 feet. At the western side of the excavation two parallel joints are 2½ feet apart, and the rock between them is greatly decomposed, showing that close jointing tends to hasten rock decay. Sheeting planes are horizontal and 6 to 16 feet apart.

Black knots are common in places, but certain large masses are almost free of them. The rock is stained to some extent along joint planes. White aplite stringers half an inch to 2 inches wide and one narrow red dike traverse the rock irregularly. The red dike is probably related to the coarse red granite which occurs in the near vicinity and which, wherever observed, is younger than the gray. One vertical open joint about half an inch wide contains a

peculiar "dike" of fairly coherent pure white sandstone. It is probably a remnant of a white sandstone, possibly of Cambrian age, which rested immediately upon the granite at one time, but which was later swept away by glaciation.

A few small vugs occur, in one of which a crystal of purple fluorite was observed.

Some odd types of rock occur in this outcrop, among them a reddish-gray granite with green patches about 30 rods northeast of Hilder's main quarry. Red granite outcrops about 300 yards to the west but is as yet undeveloped.

Good monument stock may be obtained from this quarry, but during 1912 and 1913 a contract to supply the Twin City Lines of St. Paul and Minneapolis with a million paving blocks compelled a concentration of labor on that line of work and a consequent decrease in production along other lines. During the summer of 1912 about 24 stonecutters were employed on an average, producing about 3,000 paving blocks a day. In 1910 a stone crusher was installed. The small rock chips resulting from the trimming of paving blocks are very easily crushed. A siding from the Great Northern Railway to the quarry greatly facilitates transportation. Modern steam and pneumatic drills and steam hoists are employed.

ERICKSON QUARRY.

A quarry in the NE. ¼ SW. ¼ sec. 6, Haven Township, was first opened in 1883 to supply stone for the stone-arch bridge in Minneapolis. It then remained idle for 15 years, after which it was worked for a year by G. J. Hilder. It was bought by August Erickson in 1908 and has been worked continuously ever since.

The main type is a medium-grained uniform gray hornblende granite. Its determination with the microscope places it rather with the quartz monzonites, for in it orthoclase and microcline together are about equal to plagioclase. Quartz is not very abundant and was evidently the last mineral to crystallize. Hornblende with subordinate biotite, sphene, and magnetite form the darker part of the rock. It is remarkably fresh, showing very slight alteration. A second type, more easily worked, is a finer-grained pinkish-gray granite with a sloping contact, which is exposed in the bottom of the quarry on the north side.

Compression tests were made on nine cubes of the gray granite. On the average the first crack came at 11,426 pounds per square inch and final collapse at 16,996 pounds.

Chief joints strike N. 6° W. and secondary joints N. 80° E., thus meeting approximately at right angles. Minor joints strike N. 58° E. and N. 42° W., also approximately at right angles. They are 5 to 20 feet apart. Sheets are distinct and 4 to 15 feet apart. Some

are horizontal and others oblique, thus wedging out. Black knots are scarcer than in most gray quarries on the east side. White aplite dikes, however, are very numerous and run at all angles. Stripping requires the removal of 4 to 5 feet of soil.

The quarry is of the pit type and is about 40 feet deep. Its chief output is paving blocks, a very little monument stock being produced. It is about half a mile from the reformatory and 1½ miles from East St. Cloud. Transportation is by wagon.

A short distance to the southeast is Erickson's abandoned pit, in which the rock is similar to that just described. Jointing systems, however, show some variation. Chief joints strike N. 25° W. and secondary joints N. 61° E.

KELLAS QUARRY.

A little west of Erickson's quarry in the NW. ¼ SW. ¼ sec. 6, Haven Township, a quarry, opened by John Kellas in 1906, yields a fairly uniform dark-gray hornblende granite. Microscopic examination shows some variation in relative amount of the various minerals in different parts of the quarry. Plagioclase and quartz appear to be the most variable constituents. Orthoclase and microcline together form the greater portion of the feldspar mass in most places, though plagioclase is prominent. Hornblende and subordinate biotite form a larger share of the rock than they do in the typical gray granite of Stearns County. A few magnetite grains and abundant apatite inclusions are accessory constituents. The feldspars show a little alteration to kaolin.

Major joints strike N. 65° W. and secondary joints N. 3° W. They are nearly vertical and are widely spaced. Sheets are distinct, 4 to 20 feet apart, and wedge out in places as in Erickson's quarry. A few black knots occur, and white to pale-pink aplite dikes are numerous. Part of the quarry has no overburden, and the maximum stripping at the present time is about 10 feet. The chief output is paving blocks, though some monument stock is produced. Transportation is by wagon, and the nearest station is Reformatory, three-fourths of a mile distant.

BENTON COUNTY.

CHARACTER AND DISTRIBUTION OF THE ROCKS.

In Benton County the only rocks available for structural or ornamental purposes are the granites and related rocks of lower Keweenawan age. Outcrops are more numerous than in Sherburne County. They are most abundant in Sauk Rapids and southwestern Watab townships, and occur also in southwestern Minden, Gilmanton, and Mayhew Lake townships near the center of the county, and in Granite Ledge, on Rum River, in the northeast.

The rocks of Benton County are less uniform and present greater diversity of types than those of Sherburne or Stearns counties. Nevertheless, good quarry rock outcrops in many places, the most extensive areas being in secs. 27 and 34, Watab Township. The rock is principally a dark diorite, which is not particularly attractive even where uniform. The exposures of highest commercial value, so far as known, are in secs. 1, 11, 13, and 14, Sauk Rapids Township, and sec. 31, Minden Township.

QUARRIES.

FISCHER CO. QUARRY.

In the E. ½ SW. ¼ sec. 31, Minden Township, the Fischer Co. has operated a red-granite quarry since 1909. The rock is medium to coarse grained hornblende granite of the typical "St. Cloud red" type. Pink feldspar forms about three-fourths of the rock, and the remaining fourth is about three parts quartz and one part hornblende. The texture is uniform and the color fairly attractive, though much paler than most of the red granites of Stearns County. Under the microscope the feldspar is seen to be microcline. The hornblende is fringed with biotite in some places. Feldspars show considerable alteration to kaolinite. Such alteration affects the rock seriously for structural purposes only where excessive, as along joints or in "sap rock" near the surface.

Major joints strike N. 87° E., and a second system N. 60° E. The joints are nearly vertical and 2 to 15 feet apart. Indistinct horizontal sheeting planes are spaced 2 to 10 feet apart. Some hair lines are present, and two narrow diabase dikes cross the quarry in the direction of the chief joints, N. 87° E.

Building stone and curbing are the chief products. Large uniform blocks are easily obtained. The Gordon & Ferguson glove factory in St. Cloud was made of stone from this quarry. The nearest station is East St. Cloud, a mile distant.

A gray rock just east of this quarry was opened about 1883 and worked on a small scale by J. O. McConnell. The quarry has been inactive for a number of years. The rock is similar in texture and color to that farther south, in Sherburne County. It was used in building the Friedland German Church at St. Cloud.

COATES QUARRY.

The Coates quarry, in the NE. ¼ NW. ¼ sec. 13, Sauk Rapids Township, is on an outcrop 32 by 8 rods in extent. It was first worked about 1893 and thereafter was idle many years. Active operations were renewed in the spring of 1913.

The rock is pale pinkish gray in color but in texture and constituent minerals is of the "St. Cloud red" granite type. It is medium

to coarse grained and consists of a very pale pink feldspar, quartz, and scattered crystals of hornblende. Microscopically the feldspars were determined as plagioclase, orthoclase, and microcline. Quartz in small grains fills spaces between the other minerals. Both hornblende and biotite are present, and associated with them are scattered grains of magnetite. Sphene is common, and its presence, together with the character of the quartz, places the rock rather with the gray granites, although in the hand specimen it resembles the typical red.

Major joints strike N. 84° E. and secondary joints N. 10° E., and are 10 to 20 feet or even farther apart. The joints are all vertical. Indistinct sheeting planes are 5 to 6 feet apart and dip slightly to the north.

The rock weathers somewhat more readily than the "St. Cloud gray" granite and is stained reddish-brown to a depth of several feet. Similar stains extend half an inch to an inch from the few joints. No dikes appear except some narrow aplites in the undeveloped part of the outcrop. Where still hard and firm, the brown rock is utilized for curbing, and the unaltered rock is used extensively for building. Stone was supplied during 1913 for the courthouse at Grand Forks, N. Dak.

No stripping is necessary. Pumping is required at intervals to remove water from the pit. The Sauk Rapids Granite Co.'s spur track is half a mile distant but is not used. The nearest station is Sauk Rapids, about 2½ miles distant.

SAUK RAPIDS GRANITE CO. QUARRIES.

The Sauk Rapids Granite Co. purchased four locations and began operations in 1914. Two of the quarries, in secs. 11 and 14, Sauk Rapids Township, were formerly operated by the Western Granite Co.; a third is on a previously undeveloped outcrop known as the Beall property, in the northern part of sec. 11, same township, and the fourth is on a previously undeveloped outcrop in sec. 35, Watab Township.

In 1884 a quarry pit was opened in the NE. ¼ sec. 14, Sauk Rapids Township, and was first known as the Arnold quarry. In 1906 it was sold to the Western Granite Co., of Sauk Rapids, who operated it until 1911, after which it was idle until 1914, when it was purchased by the Sauk Rapids Granite Co.

Prominent outcrops occur over an area of about 30 acres, the rock rising in places 35 feet above the adjacent swamps.

Both red and gray rock occur, and the quarry is situated at a contact of the two. The red is a hornblende granite, though somewhat paler in color than the typical "St. Cloud red" granite. Near

the contact of the gray rock the color becomes a paler pink and the texture finer. Though the line of contact is fairly distinct, the rocks are somewhat mixed, both pink and gray feldspars appearing in each type. The age relation of the two rocks was not determined.

The gray rock is a hornblende granite, somewhat finer grained than the red and containing less quartz. Major joints strike N. 20° E. and dip about 80° W. Several minor joints intersect them at various angles.

The most serious imperfection is the shattered nature of the rock. Two large diabase dikes 3 to 4 feet across run N. 55° E. through the quarry, and it seems reasonable to suppose that the shattering which accompanied their injection started incipient fractures in the surrounding rock. The faded color of the red granite and the mixing of the two types near the contact also results in considerable waste.

A few rods to the north a small pit has been made in the red rock, which at this point exhibits a fine deep color. A quarry away from both dikes and contacts would yield a better quality of stone, accompanied by much less waste. Working conditions, however, are better than at most quarries of the region, as the rock may be worked as a shelf or bench quarry to a depth of about 25 feet.

The present company operates this quarry for the production of crushed rock exclusively. The crushing plant is equipped with No. 6 and No. 3 gyratory crushers and a 24-inch disk crusher. A siding 2 miles long connects with the Northern Pacific Railway at Sauk Rapids.

About a third of a mile northeast of this quarry, in the SE. ¼ SE. ¼ sec. 11, Sauk Rapids Township, is another, formerly owned by the Western Granite Co., which was also purchased in 1914 by the Sauk Rapids Granite Co. Both red and gray granite occur.

The former is a deep-red hornblende granite of uniform texture, one of the most attractive red granites observed in the St. Cloud region. The feldspars, forming about 70 per cent of the rock mass, are red, with the exception of a few scattered grains of greenish color. Quartz, forming about 20 per cent of the rock, is in large transparent grains, and black hornblende forms the remainder. Close to the contact with the gray granite the rock is somewhat lighter in color.

Under the microscope the chief feldspar is seen to be orthoclase, intergrown with plagioclase as a microperthite.

Major joints strike N. 5° W. and secondary joints cross them at right angles. They are all vertical and 3 to 15 feet apart. Three nearly horizontal sheets appear at intervals of 20, 18, and 7 feet. A few dark streaks were noted where the dark minerals were aggregated in lines, giving the rock an indistinct gneissic appearance. A very few hair lines, but no dikes, were seen. A few inclusions of gray rock occur in the red.

This quarry represents one of the few observed cases where good rock is obtained close to contacts. As a rule the color of the rock near contacts is unattractive, and hair lines, fractures, and inclusions are numerous.

The gray rock, which has been quarried less extensively, is a fine-grained hornblende granite that exhibits streaks and has somewhat uneven texture. The quarry is equipped with two 30-ton electric derricks, one of which has two speeds for the boom lift and two speeds for the fall. An air compressor supplies air for drilling.

Rock is quarried for monumental stone, building blocks, and curbing, and much material that would otherwise be wasted is used for paving stones.

A third quarry was opened up on an extensive undeveloped outcrop of red granite covering several acres in the W. ½ NE. ¼ sec. 11, Sauk Rapids Township. It rises as a ridge of sufficient height to permit bench quarrying to considerable depth. Pink feldspar forms about two-thirds of the rock mass. It is chiefly microcline, though some orthoclase and plagioclase also appear. The feldspars are microperthitic, as in the red granite of Stearns County. Quartz is abundant in large glassy grains. Hornblende with subordinate biotite and magnetite constitute the remaining portion.

Joints are very irregular but are widely spaced. Major joints strike N. 2° W. and N. 72° E., and minor joints N. 55° W., N. 82° W., and N. 88° W. One area, 80 by 110 feet, is without open joints. Quarrying would be easier if joints were more numerous. Two narrow diabase dikes follow the major joints N. 72° E., and the rock close to them is intersected by numerous hair lines, which probably are minute dikes. The quarry is equipped with a 30-ton quarry derrick and a piling derrick, both electric driven, and with an air compressor of 450-feet capacity to supply drills. The quarry is served by a siding extended from the quarry last described. The rock is used for monuments, building, curbing, and paving stones.

The fourth quarry, situated near the center of sec. 35, Watab, is in light-gray granite. The equipment consists of two steam derricks and steam-operated drills. The company operates a well-equipped finishing plant in Sauk Rapids.

It may be noted that this company is producing a good deal of building stone and is gradually increasing its equipment so as to be able to handle large building contracts without difficulty. In 1914 the railway siding was extended from the southeast corner of sec. 11, Sauk Rapids Township, to the third and fourth quarries described above.

SWANSON & HAGSTEDT QUARRY.

In the NW. ¼ NE. ¼ sec. 1, Sauk Rapids Township, A. F. Swanson and John Hagstedt began quarrying about 1896 and continued till 1909, when they ceased operations.

The rock is a very pale pink or almost gray hornblende granite, which, like the rock from the Coates quarry (p. 125), has the texture of the "St. Cloud red" granite. It is quite uniform. The feldspars are orthoclase, microcline, and plagioclase. They are perthitic and exhibit considerable alteration. The hornblende shows alteration to biotite.

Major joints strike N. 80° E. and secondary joints N. 8° E. They are widely spaced. Sheeting planes are horizontal, distinct, and 2 to 6 feet apart, being much closer and more distinct than in most of the quarries of the region. As a consequence slabs of large size may be easily obtained. One block lying in the quarry was 10 feet 8 inches by 6 feet 6 inches and 14 inches thick.

The rock contains a few small dark knots and a number of larger green patches, probably inclusions, some of which are a foot in diameter.

No stripping is required. The quarry is worked to a depth of only 8 to 10 feet as a bench quarry. Deeper excavation would require pumping. The rock is not to be recommended for monumental purposes but is well adapted for paving stones, building blocks, flagging, door sills, and steps. The quarry is about 5 miles from Sauk Rapids.

A noteworthy feature of this as well as of most other quarries in the St. Cloud region on the east side of the Mississippi is the absence of a waste heap. This is partly due to the fact that more structural stone and paving blocks and less monumental stone are produced, and partly because the Northern Pacific Railway has used the waste material for filling on its lines.

SAUK RAPIDS QUARRY.

The Sauk Rapids quarry has not been worked for many years and will probably never be worked again, but in past years it was the center of a great industry. It is close to the business district of Sauk Rapids, where real estate is now too high priced to permit its reopening. It was opened by F. A. Fogg in 1867 and worked by him until 1871, when excavation was continued by Collins, Mitchell & Searle, of St. Cloud. Later it was worked by Burns, Reeder & Robinson. Stone from this quarry was used in several structures of note: In Minneapolis for the towers of the suspension bridge and trimming of the city hall; in St. Paul for the store occupied by Nicols & Dean; in Milwaukee for the polished front of the Mitchell Bank; and in Des Moines for trimming for the Iowa State capitol.[1] It takes a good polish and is suitable for monumental work.

UNDEVELOPED ROCK OUTCROPS.

The undeveloped or slightly developed outcrops are described in the alphabetic order of townships, and in the numerical order of sections within each township.

[1] Winchell, N. H., Final report on the geology of Minnesota: Minnesota Geol. Survey, vol. 2, p. 433, 1888.

GRANITE LEDGE TOWNSHIP (T. 38 N., R. 28 W.).

In the northeastern township of Benton County, in the NE. ¼ NW. ¼ sec. 20, an outcrop of red granite is intersected by a diabase dike running N. 30° E. South of the dike the rock is coarse grained, similar to the typical "St. Cloud red" granite. Joints are far apart. North of the dike the rock is much finer grained and is intersected by numerous closely spaced joints.[1]

On the west branch of Rum River, in the NW. ¼ sec. 24, and extending westward into sec. 23, a prominent outcrop of red granite forms a ridge across the river and causes a waterfall about 4 feet

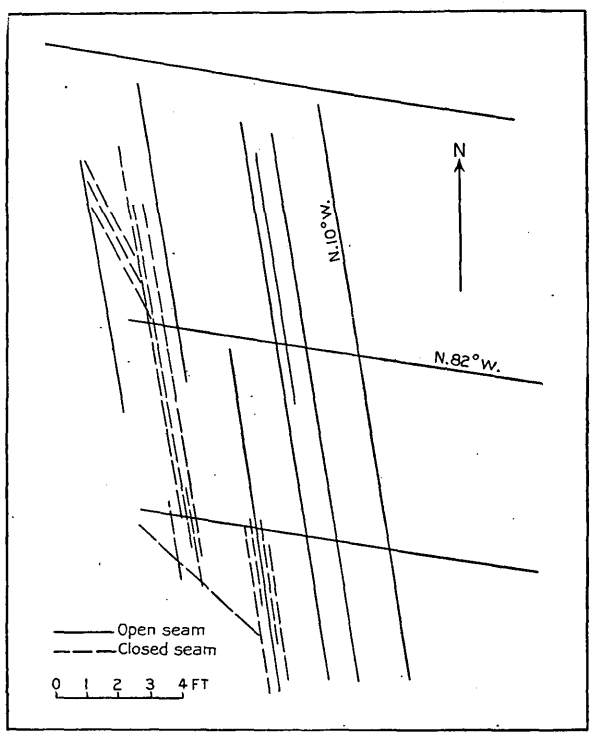


FIGURE 15.—Sketch showing structure of rock in sec. 24, Granite Ledge Township, Minn.

high. The largest exposure is 5 rods wide and 10 rods long. Surface rock only is observable, and little is known regarding the quality of the unweathered granite. The stone is a medium to coarse grained red hornblende granite. The feldspars, which average one-fourth of an inch in diameter, form approximately three-fourths of the rock, the remainder being chiefly quartz with subordinate hornblende. At a depth of a few inches the rock is rusted to a somewhat deeper red than normal. This is somewhat misleading, as it might cause a superficial observer to expect a deeper red color in

[1] Winchell, N. H., op. cit., p. 436.

the main mass than actually exists. The normal color seems to be about the same as the average red granite of Stearns County. The texture is uniform.

Under the microscope orthoclase is observed as the chief feldspar, appearing in large crystals which are microperthitic, though not as pronouncedly so as in most of the red granites of Stearns County. Scattered crystals of plagioclase and microcline appear, and quartz is abundant in large clear grains. The hornblende shows an advanced stage of alteration to biotite. In surface specimens the feldspars are highly altered to clay.

Chief joints strike N. 10° W. and are spaced very irregularly—from 1 to 18 feet. Subordinate joints strike N. 82° W. and are 6 to 10 feet apart. (See fig. 15.) In the western part of the outcrop numerous blind seams parallel the major joints and a few cut across at various angles. The eastern part of the level area west of the river bed is apparently free of blind seams. No diabase dikes, knots, or pegmatites were observed. A red aplite dike about a foot wide runs east-west across the stream bed.

Drainage would be difficult, for the rock rises only 2 or 3 feet above normal level of the river. Transportation is also a serious matter; Foreston is about 6 miles distant, and the roads are poor. Rum River is now bridged, and a road is being opened southward on the section line between secs. 23 and 24. When this is completed rock could be hauled almost due south to Estesbrook siding, about 4½ miles distant.

GILMANTON TOWNSHIP (T. 37 N., R. 29 W.).

In the SW. ¼ sec. 13, about three-fourths of a mile east of the outcrop on Elk River in Mayhew Lake Township, red granite outcrops near the road in an exposure not more than 8 rods across. The rock is a red hornblende granite similar to that in Granite Ledge Township. The texture is quite even. Joints are irregular but not close together. Blocks 10 feet across could be obtained.

MAYHEW LAKE TOWNSHIP (T. 37 N., R. 30 W.).

An outcrop about 8 rods across, in the S. ½ sec. 13, rises about 10 feet above the water in the channel of Elk River. The rock is a somewhat porphyritic hornblende granite, consisting of feldspar crystals one-fourth to one-half inch across, embedded in a fine-grained groundmass of feldspar, quartz, and hornblende. The color is an attractive pink, but the texture lacks uniformity.

SAUK RAPIDS TOWNSHIP (T. 36 N., R. 31 W.).

Sec. 1.—About 44 rods south of Swanson & Hagstedt's quarry in the NE. ¼ sec. 1 is a small outcrop of very pale red granite.

An outcrop of red granite occurs 224 rods north and 180 rods west of the southeast corner of the section. Some has been quarried for local uses both from the ledge and from a large boulder a little west of it. Joints are spaced 5 to 30 feet apart. Major joints strike N. 3° E. and secondary joints N. 88° W., the two intersecting approximately at right angles. Several outcrops to the north and the south are of the same type.

Another group of small granite outcrops occurs in the vicinity of a point 128 rods north and 216 rods west of the southeast corner.

Sec. 2.—A small outcrop of red granite occurs 106 rods north and 128 rods west of the southeast corner of sec. 2. Major joints strike N. 85° E. and secondary joints N. 41° W. They are 2 to 10 feet apart. The rock is intersected by aplite dikes which follow the major joints. A small excavation has been made.

A small flat outcrop of red granite occurs a little south of the section line and 36 rods west of the northeast corner.

Sec. 11.—Red granite, a little of which has been excavated, outcrops 92 rods north and 128 rods west of the southeast corner of sec. 11. Major joints strike N. 5° E., secondary joints N. 53° W., and a few minor joints N. 79° W. The major and secondary joints are 2 to 5 feet apart.

In the S. ½ NW. ¼ of the section are a few small field outcrops of red granite. Joints are 2 to 5 feet apart and strike north and south.

A small outcrop, 300 rods north and 268 rods west of the southeast corner, was quarried to a small extent years ago. The rock lacks uniformity, containing many complex intrusions and inclusions. The main mass is a dark-gray hornblende granite, intruded by a coarser pale-red granite and containing scattered crystals of red orthoclase. In thin section it is somewhat porphyritic with large crystals of orthoclase and plagioclase in a finer, though still medium-grained groundmass of feldspar, quartz, hornblende, biotite, and sphene. Quartz is more abundant than in the "St. Cloud gray" granites and much finer grained than in the red. The hornblende contains very many quartz inclusions. Joints trending N. 9° W. are 2 to 4 feet apart. They are not vertical, but dip either eastward or westward and are in places so nearly horizontal that they resemble sheeting planes.

Sec. 13.—An exposure about 120 feet across in the SW. ¼ SW. ¼ sec. 13 consists of a fine-grained gray granite, composed of orthoclase, plagioclase, microcline, quartz, hornblende, biotite, magnetite, and sphene. The quartz is not plentiful, and appears in small grains occupying the crevices and irregular spaces between the other minerals. The hornblende shows distinct cores of augite. At the west end of the outcrop a mass of red granite of the typical "St. Cloud red" type consists of pink feldspar, abundant quartz, and black

hornblende. The contact runs about N. 30° E. Dikes of the red rock cut the gray. Joints are very irregular and 2 to 8 feet apart.

Sec. 14.—All the exposures in sec. 14 are in the NE. ¼. Most of the rock has already been described. (See pp. 126–127.)

An outcrop about 40 rods long has its center about 234 rods north and 24 rods west of the southeast section corner. Two smaller outcrops are close to its western end. Red and gray rock alternate repeatedly even over small areas and probably preclude the finding of any considerable quantity of uniform rock.

Major joints run due north and cross contacts of red and gray without change of direction. They are nearly vertical and 1 to 5 feet apart. Secondary joints strike N. 80° E. Aplite dikes trending N. 66° E. and N. 48° W. intersect both red and gray rock. Near contacts the red granite sends dikes from the main mass into the gray in directions parallel with the aplites. Several diabase dikes trending N. 60° E. are confined to the gray rock. The rock is too defective to encourage development, although a little has been quarried for local building.

A small exposure of red granite appears 277 rods north and 50 rods west of the southeast corner.

Sec. 23.—An outcrop, mostly of gray granite, near the east end of Sauk Rapids bridge, is of fair quality though badly weathered. Major joints strike N. 10° W., secondary joints N. 70° E., and a few minor joints N. 5° E. Major and secondary joints are 1 to 8 feet apart. Aplite dikes intersect the mass in direction N. 78° W. It is unlikely that the area could be successfully developed as the land is too high priced.

Sec. 24.—In the NW. ¼ SW. ¼ sec. 24 there are three outcrops on property owned by A. E. Hagquist, of Sauk Rapids. The most northerly exposure covers about 200 square rods and consists of mixed red and gray granites, invaded by aplite and quartz porphyry dikes. Major joints strike N. 87° W. and secondary joints N. 42° W. The joints of both systems are 2 to 5 feet apart.

The next outcrop to the south is a gray hornblende-biotite granite of fair quality, which was first quarried by L. Mayo in 1892 and was idle in 1913. The rock is medium to fine grained and is fairly uniform in texture. The chief feldspar is orthoclase, with subordinate plagioclase and microcline. Quartz occurs scantily in small grains. The hornblende shows distinct alteration to biotite, and some crystals have cores of augite. Sphene is plentiful and is generally associated with grains of magnetite. A few grains of zircon were observed. The feldspars, especially the orthoclase, show alteration to kaolin.

A specimen of fresh material quarried at considerable depth has a specific gravity of 2.782, a pore space of 0.45 per cent, and weighs 172.8 pounds per cubic foot.

Joints at right angles, N. 5° W. and N. 85° E., are quite distinct and are 3 to 10 feet apart. One sheeting plane is 8 feet beneath the surface and horizontal. Observations could not be made at greater depth, as the pit is full of water. Some aplite stringers, the largest an inch wide, intersect the granite from east to west; others are very irregular. Black knots are numerous. "White knots," in the form of large light-colored feldspar crystals, appear in places and are said to be of less frequent occurrence in the bottom of the pit. The stripped surface shows distinct glacial striations pointing northeast.

The rock is well adapted for making paving stones, base stock, or building blocks.

The third outcrop, which is 44 rods to the south, is of red granite.

Sec. 25.—In the W. ½ SE. ¼ sec. 25 several abandoned quarry pits are sunk on outcrops of a medium-grained hornblende-biotite granite of uniform texture. As determined with the microscope, plagioclase is the most abundant feldspar, and the rock is more properly a quartz diorite than a granite. Quartz, biotite, and hornblende are prominent; magnetite and sphene are accessory in small amount; and some secondary epidote is present. The rock is otherwise fresh and of good quality.

Joints are rather irregular. Major joints strike N. 84° E., are nearly vertical, and are 2 to 6 feet apart. A pale-pink granite intrudes the gray, and fragments of the gray are inclosed within it. Four diabase dikes cross the outcrop in direction N. 57° E.

Sec. 26.—A small outcrop in the extreme northwestern part of the section near the east end of Sauk Rapids Bridge is similar to the outcrop in sec. 23.

WATAB TOWNSHIP (T. 37 N., R. 31 N.).

Sec. 26.—A group of small exposures in the W. ½ NW. ¼ sec. 26, Watab Township, have never been quarried, and are not likely to be. Diabase, felsite, fine-grained quartz diorite, coarse red granite, and porphyritic gray granite all appear and are greatly mixed. Major joints strike N. 87° E. Further investigation is hardly advisable.

Sec. 27.—Outcrops are numerous in sec. 27, an almost continuous line of them beginning near the center of the section and extending southward on the east side of the main wagon road to where it crosses the south section line. The largest outcrop is a little east of the center and is more than a quarter of a mile long and an eighth of a mile wide. Though extensive, the rock is to be recommended only for rough masonry or crushing. It lacks uniformity in texture and, like that in sec. 26, consists of a confused mass of various types. Close to the railroad the rock is a felsite (a fine-grained light-colored igneous rock); farther west a rather coarse red granite appears, followed by quartz diorite porphyry and beyond by a shattered diabase.

Grains of pyrite are numerous. Other exposures in the ridge are similarly lacking in uniformity and are chiefly of diorite.

A point 192 rods north and 223 rods west of the southeast corner marks the center of the most extensive outcrop in the county. It is 106 rods north and south, 64 rods east and west, and rises as a prominent hill. The rock is a fine-grained dark-gray quartz diorite porphyry, having a structure almost like that of a diabase. Though uniform both in color and texture, strong, and probably durable, it is too dark to be attractive either for decorative or structural work.

Sec. 34.—The ridge in sec. 27 continues southwestward through the NW. ¼ sec. 34. The rock is mainly dark quartz diorite.

An exposure about an eighth of a mile long occurs with its center at a point 288 rods north and 180 rods west of the southeast corner, close to the Northern Pacific Railway track. The western part of the outcrop is a shattered quartz diorite and the eastern a porphyritic gray granite of fair quality. It is not as desirable in color or texture as the "St. Cloud gray" granite but would make attractive building blocks. Major joints strike N. 3° E., secondary joints N. 84° E., and minor joints N. 26° W. Major and secondary joints are 1 to 6 feet apart and are rather irregular.

A small outcrop of red granite occurs in the NE. ¼ of the section.

Sec. 35.—In the SW. ¼ sec. 35 are three small outcrops of the typical "St. Cloud red" granite of fair quality. Joints strike north and east, are nearly vertical, and spaced 3 to 6 feet apart.

An abandoned pit in an outcrop of mixed red and gray granite is about 170 rods north and 74 rods west of the southeast corner. A second pit is at a contact of red and gray granite. The red rock becomes finer grained near the contact and is evidently the younger. It underlies the gray, the dip of the contact being about 70° W. and the strike N. 5° W. This quarry was first opened by H. D. Gurney, of St. Paul, in 1874, and leased to Saulpaugh & Co. in 1881, who quarried extensively, employing from 50 to 100 men. The stone was used in the construction of the Northern Pacific Railway bridge at Bismarck.[1] The gray rock is lighter in color and coarser in texture than the typical "St. Cloud gray." With the microscope it appears to be a quartz diorite rather than a granite, plagioclase being more abundant than orthoclase. Quartz is in small scattered grains. Hornblende, biotite, magnetite, and sphene form the dark part. Chief joints strike N. 6° E. and N. 73° E. and are 2 to 10 feet apart. Minor joints strike N. 67° W. "Hair lines," composed chiefly of epidote, are numerous. The rock is attractive in appearance.

The eastern quarry is in red hornblende granite consisting of feldspar (microperthite), quartz in large grains, and hornblende. In texture it is similar to the "St. Cloud red" granite, the feldspars

[1] Winchell, N. H., op. cit., p. 435.

being one-eighth to one-fourth inch across. It is of fair quality, though somewhat pale. Hair lines of epidote are numerous.

A group of outcrops in the NW. ¼ of the section contain two small excavations made by Talcott, Castle & Co. in 1871. The stone quarried was shipped to Chicago.[1] The main type is a light-gray biotite granite, consisting of orthoclase, plagioclase, microcline, quartz, biotite, and hornblende, with accessory zircon and epidote inclusions. It is lighter in color and coarser in texture than the "St. Cloud gray" granite. It is somewhat porphyritic, with white feldspar crystals about half an inch across. It weathers nearly white. Jointing systems are so diverse that many angular blocks result. Major joints strike N. 12° E. and secondary joints N. 75° W. Minor joints follow diverse directions, among which N. 86° E., N. 70° E., and N. 45° E. were noted. They are nearly vertical and are 1 to 10 feet apart. A green phase of the rock occurs. Inclusions of diorite schist or gneiss are common. The stone is variable, both light and dark gray occurring and grading the one into the other.

On one of the southern outcrops of light-colored gray granite the Sauk Rapids Granite Co. located a quarry in 1914.

The most northerly outcrops in this group are of dark quartz diorite like that in sec. 26.

Sec. 36.—A line of boulders near the south section line just north of Swanson & Hagstedt's quarry may represent an outcrop a little disturbed by glaciation. A small outcrop of red granite occurs close to the road, near the middle of the west section line.

GRANITES OF MORRISON, KANABEC, AITKIN, CASS, MILLE LACS, AND ST. LOUIS COUNTIES.

MORRISON COUNTY.

Rocks of several types, such as mica schists, staurolite schists, slate, diorite, and granite, occur in Morrison County. Of these the slates and schists are of little use for structural purposes. Diorite has been quarried to some extent near Little Falls and granite in a number of widely separated localities.

WILLIAMS QUARRY.

The most important outcrop of diorite is on land owned by M. M. Williams in the NE. ¼ NE. ¼ sec. 13, T. 129 N., R. 30 W. The outcrop is a dome covering about 2 acres and rising 6 to 8 feet above the surrounding fields. Most of it is thinly coated with soil and part of it is wooded, but the rock appears at the surface in a number of places. Two distinct types occur; one fine grained and nearly black, and the other coarser and gray in color. The black rock

[1] Winchell, N. H., op. cit., p. 435.

appears, from its fine-grained contact, to be intrusive into the gray, but no dikes were found extending from one to the other.

The dark fine-grained rock was determined microscopically to be an augite diorite. It consists of numerous lathlike crystals of plagioclase, biotite, green hornblende, and almost colorless augite, the augite forming the central portion of many hornblende crystals which are evidently alteration products. The rock shows slight effects of surface weathering. In some sections very little hornblende or biotite is present, though augite is abundant.

Major joints strike N. 82° E. In part of the exposed rock the joints are 6 inches to 2 feet apart, and in other places they attain a maximum spacing of 6 feet. Sheeting planes are 2 to 4 feet apart. Large blocks are obtainable. In some places the rock is porphyritic, with large biotite crystals or crystal aggregates, and in other places close by is much finer grained. However, considerable masses of even-grained dark rock are available. Specimens have been polished with good results. The gray rock is less uniform in texture than the black.

Several excavations have been made, the largest of which is about 30 by 20 feet and 10 feet deep. The dark rock, which has been quarried more than the gray, was opened up in 1888 and has been worked at different times since then for local uses. The bulk of the rock quarried was used in making foundations of mills and other structures in Little Falls, about 2 miles distant. The Little Falls and Dakota branch of the Northern Pacific Railway runs within half a mile of the quarry.

FISH LAKE QUARRY.

A granite outcrop which has been quarried to some extent is in the SE. ¼ sec. 13, T. 40 N., R. 31 W., on the farms of Mrs. McMeyer and Joseph Rausch. It covers about half an acre and rises about 6 feet above the surrounding fields. It is known locally as the "Fish Lake quarry," owing to its proximity to a small lake of that name. Quarrying began here about 1906, some of the stone being used locally for bridge abutments and foundations and some shipped away for monuments and bases. No work has been done since 1911. The excavation measures about 50 by 30 feet and is 8 feet deep. Drainage is good, no pumping being required down to the present level.

The rock is an even-grained biotite granite of very light gray color, which becomes almost white on the bush-hammered surface. It consists of light gray to almost white feldspars in grains a thirty-second to a sixteenth of an inch across, forming over half the rock mass; pale-yellow transparent quartz grains, the largest of which are about the size of a pin's head; and flakes of black mica about one-sixteenth of an inch across. The minerals are very evenly dis-

tributed, and the resulting speckled "pepper and salt" effect is very pleasing. The rock is much finer grained and much lighter in color than the "St. Cloud gray" granite. By microscopic determination the chief feldspar is orthoclase, with some microcline and a very little plagioclase, all slightly kaolinized. A few small grains of hornblende, biotite, and magnetite, with included apatite crystals, constitute the remainder of the rock.

Joints are 2 to 8 feet apart, and in the quarry excavations are vertical and appear in one system only, striking N. 82° W. On the wall of the excavation there are four sheeting planes, about 2 feet apart, a condition that greatly facilitates quarrying. Near the south side of the outcrop the sheeting planes are 1 to 2 feet apart and dip about 15° S.; and the joints, though following the same compass direction as in the excavation, are not vertical but dip about 75° N. at right angles with the sheeting planes. The rock is free of defects, containing no dikes, streaks, nor hair lines and only a few small black knots, segregations of biotite, one-fourth to one-half of an inch across. It is well adapted for monumental purposes.

The nearest railway station is Pierz, on the Minneapolis, St. Paul & Sault Ste. Marie Railway, 1½ miles distant.

DAVIDSON & DAVIDSON QUARRY.

Quarrying began years ago on an outcrop covering several acres in the SW. ¼ sec. 24, T. 41 N., R. 31 W., on the property of Davidson & Davidson, of Little Falls. No work has been done since 1907. The quarry excavation is about 30 by 20 feet and is 12 feet deep to the surface of the water which fills its lower part. The quarry supplied building blocks and monument stock.

The rock is a dark-gray, medium-grained, and fairly even grained hornblende-biotite granite that in places shows a distinctly gneissic texture. It consists of light-gray feldspar and bluish-white quartz grains that together form a little more than half the rock mass, the remainder being formed of a mixture of hornblende and biotite.

With the microscope the feldspars were determined as orthoclase and subordinate plagioclase. Quartz appears in numerous though small grains. The feldspars appear exceptionally fresh and unaltered.

Joints are at right angles, their direction at the quarry excavation being N. 35° E. and N. 55° W., and are favorably spaced for quarrying. No sheeting planes appear on the 12-foot quarry wall. Lenses, dikes, and masses of pale-red to white granite are intruded into the gray. A few of these appear in the old quarry excavation, but they are more abundant in other parts of the rock ridge. Those in the quarry wall consist chiefly of quartz, with subordinate amounts of white feldspar, black mica, and scattered red garnets. In places fragments of gray rock are inclosed in the red, which is undoubtedly

a later intrusion. The presence of these intrusions in many parts of the ridge indicates that much rock, otherwise of monument grade, is probably marred by injected bands. Areas of considerable size, however, are comparatively free from such intrusions, the old quarry location being one spot where dikes are less numerous. Few black knots were observed, and aside from the later granite injection the rock is free of imperfections. A slab of this stone observed in the wicket of the First National Bank, Little Falls, is attractive in appearance and takes excellent polish. Transportation is a rather difficult problem, for the quarry is 7 miles from Pierz, the nearest station on the Minneapolis, St. Paul & Sault Ste. Marie Railway, and is 10 miles from Little Falls.

WHITNEY QUARRY.

In sec. 18 and the south part of sec. 17, T. 41 N., R. 30 W., both red and gray granites outcrop. The gray, which is probably of the greater economic value, outcrops near the road and extends about a third of a mile northward, beyond which it gradually gives place to the red rock. About 7 rods north of the road an excavation known as the Whitney quarry, which has been idle for two years, contains a dark-gray biotite granite. Orthoclase is the most prominent feldspar, though plagioclase is also present in relatively large amount. Quartz in not very plentiful and is in small grains. Apatite, as exceptionally large inclusions, and scattered grains of magnetite are accessory minerals. The presence of sphene in fairly large grains is a respect in which the rock closely resembles the "St. Cloud gray" granite.

The hornblende crystals show in places cores of augite and fringes of biotite, illustrating the progressive alteration, augite to hornblende to biotite. In this respect also the rock is similar to the "St. Cloud gray" granite, but it contains much more of the dark minerals. The rock is medium grained and is very uniform, both in size of grain and distribution of minerals. It is similar to the rock occurring in sec. 24 (p. 138), but it is somewhat coarser grained and lacks the gneissic texture. It is even grained and uniform throughout the whole quarry.

At the quarry joints strike N. 53° W. and N. 10° W. and are 4 to 12 feet apart, so that large blocks are available. The systems, however, are not continuous, for a short distance north of the excavation joints appear with direction N. 45° W. and N. 75° E. No sheeting planes appear on the 4 feet of quarry wall above water level.

In quality the rock is of exceptional purity, having few black knots and no hair lines or dikes, though it is cut by red granite dikes farther north.

About 64 rods north of the pit red granite intrusions appear and become more and more abundant toward the north. About 120 rods

north of the pit a mass of red biotite granite, covering about 50 square rods in outcrop, is attractive in appearance, having the lively red color so much in demand for monumental purposes. It is somewhat finer grained than the "St. Cloud red" granite. The most prominent mineral present is a red feldspar, in grains about one-eighth of an inch across. The feldspar is chiefly orthoclase with subordinate plagioclase, and is perthitic in texture. Its deep red color is due in part to surface oxidation and probably pales at depth. Glassy transparent quartz is almost as abundant as the feldspar and would probably make the rock hard to cut and dress. Black mica forms approximately one-sixth of the mass. A little hornblende, magnetite, and apatite are accessory. Reddish stains in cracks and crystal boundaries and the dusty appearance of the feldspars show the effects of surface weathering.

Joints strike N. 45° W. and N. 40° E., and are 4 to 12 or 15 feet apart. Three fine-grained red aplite dikes 1 to 2 inches wide trend N. 10° E. In places a few masses of gray granite occur as inclosed fragments caught up by the red magma at the time of intrusion. As far as could be observed, no very large area of red granite occurs, though stripping might uncover greater masses. Inclosed fragments of gray granite and unevenness of texture, which is usually found near contacts, are the most serious imperfections to be expected.

The entire outcrop, including both red and gray, is nearly half a mile in length and 8 to 24 rods in width. Much of this area may not properly be termed an outcrop, for a thin covering of soil supporting a growth of scrub underbrush covers much of it; but rock appears in many places, and the general conformity of the surface points beyond doubt to the presence of a low ridge of rock with slight covering.

The nearest railroad station is Belle Prairie, about 7 miles westward. The roads are fair, for though the region is somewhat rolling no large hills are to be crossed.

KANABEC COUNTY.

DISTRIBUTION OF GRANITE.

Numerous outcrops of granite occur in Kanabec County, but are for the most part inaccessible. Two railroads pass through the county in a northeasterly direction, one near the south and the other toward the north. Nearly all the outcrops of granite are between these lines, and most of them at a considerable distance from either.

The best-known granite in Kanabec County is that quarried at Warman post office, 14 miles north of Mora, in secs. 5 and 6, T. 41 N., R. 23 W. The rock outcrops in several places over an area of about 80 acres. Quarries were opened in 1907 by the Warman Creek Granite Co., and the Pike-Horning Granite Co. The two quarries are about one-fourth of a mile apart.

REYNOLDS GRANITE CO. QUARRY.

The Reynolds Granite Co. is at the time of writing operating the Pike-Horning property under lease. The rock is a medium to fine grained biotite granodiorite, which in general appearance closely resembles the granite of Barre, Vt. (See Pl. XIII, *A*.) It consists essentially of quartz, feldspar, and mica. Quartz is abundant and exhibits many liquid, gas, and apatite inclusions. The feldspars are both orthoclase and plagioclase, the latter being somewhat more abundant. Some crystals show zonal structure. Biotite is abundant and contains microscopic apatite and zircon inclusions. The constituent minerals are uniform in size and distribution. The rock is free from pyrite and similar minerals that might cause stains by weathering.

A chemical analysis by F. F. Grout shows the following composition:

Analysis of granodiorite from the Reynolds Granite Co's. quarry, Warman, Minn.

SiO_2	69.55
Al_2O_3	15.52
Fe_2O_3	.14
FeO	3.29
MgO	1.61
CaO	3.67
Na_2O	3.79
K_2O	2.12
H_2O (above 100° C.)	.40
H_2O (below 100° C.)	.10
Ti_2O	.44
ZrO_2	.02
P_2O_5	.07
Cr_2O_5	.01
	100.73

As observed on the stripped rock surface at the north side of the Reynolds quarry, joints strike N. 33° W., N. 32° E., and N. 78° E., thus following three systems at approximately 60°. Actual conditions as to spacing and direction of joints are shown in figure 16. The angles are acute and the spacing close.

All the joints are not vertical; those trending N. 32° E. dip 70° to 80° W. In addition to the open seams some incipient jointing planes, known to the quarrymen as "dry seams" and recognizable only as rusty lines, parallel the adjacent jointing planes and are 6 inches to 5 feet apart. Vertical dry seams are more pronounced than horizontal seams. Sheeting planes are distinct, somewhat uneven but generally horizontal, and are 2 to 6 feet apart. The quarry wall, especially near the surface, is badly cracked in places, undoubtedly by powder shakes due to too heavy blasting. Exam-

ination of the quarry wall near the bottom shows fewer dry seams. Blocks 5 feet in length are easily obtainable in parts of the quarry, and it seems probable that larger blocks may be obtained at greater depth.

A few black knots are of biotite schist and are therefore inclusions in the granite. Others apperar to be segregations, as their constituent minerals show peculiarities similar to those of corresponding minerals in the main rock mass. There are no diabase dikes and no hair lines, but two pegmatite dikes, each about 3 inches in diameter, consisting of quartz and coarsely crystallized orthoclase, were observed.

The granite of this quarry shows a little variation in color. As a whole the rock is a little darker gray at the bottom of the quarry than at the top. Areas of varying lighter and darker gray, however, occur without any definite relation to depth. The difference is very

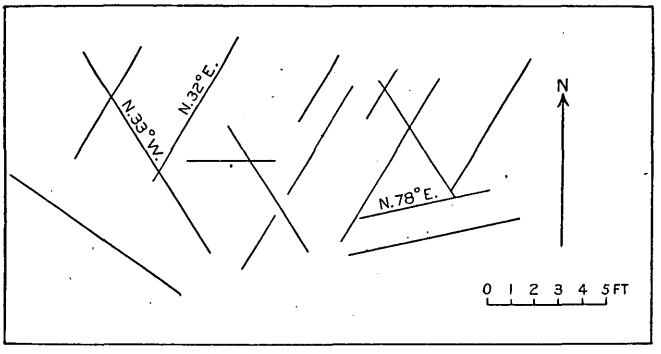


FIGURE 16.—Sketch showing structure of rock at Reynolds quarry, Warman, Kanabec County, Minn.

slight and can be detected only by careful scrutiny. Microscopic examination of the lighter variety shows numerous fine aggregations of earthy material, probably kaolin formed as a result of surface weathering, along cleavage cracks of the feldspars. The presence of similar earthy material, though in smaller amount, in the quartz, a mineral which is not subject to such alteration, leads to the supposition that probably at least part of it is in the form of minute inclusions. In other localities where gray granite occurs it has been noted that in general the effect of surface weathering is to make the rock a lighter gray.

WARMAN CREEK GRANITE CO. QUARRY.

In the Warman Creek Granite Co.'s quarry the joints are much more regular. They belong to two prominent systems, N. 30° E. and N. 30° W., meeting at 60°, and are spaced irregularly from 6 inches to 4 feet. Figure 17, drawn to scale, represents the joints on the rock surface where stripping had been done east of the quarry.

Only one joint shown is at variance with the two well-defined systems.

The joints tend to be bunched at intervals. (See fig. 17.) Several occur close together; then for 12 or 14 feet they are 2 to 4 feet apart; then they are again closely spaced.

Some aplite dikes one-fourth to one-half inch wide follow the joints, and others trend more irregularly. Where present they mar the uniformity of the rock and result in considerable waste. A very few black knots and indistinct pegmatite dikes occur.

Physical tests of the granite gave: Crushing strength, first crack at 9,966 pounds per square inch; final collapse at 17,246 pounds per square inch. Transverse breaking strength, modulus of rupture, 3,159 pounds per square inch.

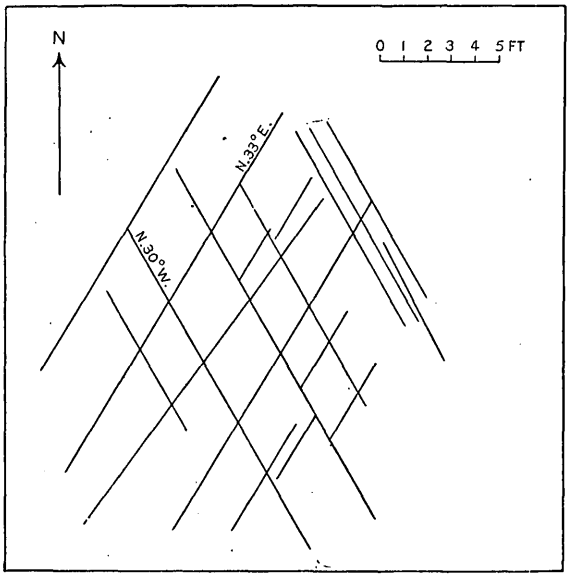


FIGURE 17.—Sketch showing structure of rock at Warman Creek Granite Co.'s quarry, Warman, Kanabec County, Minn.

The nearest railroad station is Red Top on the Minneapolis, St. Paul & Sault Ste. Marie Railway, 8 miles distant, but the stone is now hauled 14 miles by wagon to Mora, over a road that is good throughout. It is to be hoped that the industry and enterprise of the present operators will be rewarded by a railway line in the near future.

The stone is marketed under the trade name "Mora gray." It commands a high price and gives good satisfaction as a monument stone.

UNDEVELOPED OUTCROPS.

Several exposures of granite cross the road in the NE. ¼ sec. 8, T. 40 N., R. 24 W., and extend generally northeast and southwest. The main type is a fine-grained uniform light-gray granite, consisting of

light-gray to white feldspar, abundant glassy quartz, and scattered flakes of black mica. The surface phase of the rock is reddish.

Outcrops are reported from Ann River[1] in sec. 30 of this same township. The rock is described as a light-gray fine-grained uniform granite.

In the SW. ¼ sec. 13, T. 42 N., R. 24 W., fine-grained gray hornblende granite was exposed in excavating for a dam on Hay Creek. The feldspars are gray to pale pink and vary greatly in size. Prominent pale-pink feldspars give the rock an undesirable porphyritic appearance in places.

Extensive outcrops occur at the Upper and Lower Falls of Snake River in T. 42 N., R. 23 W. According to description[2] the rock is of little value except for rough structural purposes. It lacks uniformity in texture, is invaded by dikes and quartz veins, and is associated with schistose rocks.

AITKIN COUNTY.

The only rock outcrops reported in Aitkin County are near McGrath station on the Minneapolis, St. Paul & Sault Ste. Marie Railway, where a coarse-grained gray granite occurs. According to report the rock is a good building stone but is inferior for monumental purposes.

CASS COUNTY.

The only rock outcrop known in Cass County is in the extreme southwestern corner in the E. ½ NW. ¼ sec. 28 and the SE. ¼ sec. 21. It is a ridge of gray to greenish-gray granite which extends about one-fourth of a mile east and west, and rises 5 or 6 feet above a sparsely wooded sandy region. The rock is a medium-grained, fairly even textured hornblende granite with indistinct gneissic texture. The feldspars are pale red and are somewhat granular. The dark mineral, forming about one-third of the rock, was apparently originally hornblende but is now altered to chlorite and epidote. Quartz is abundant in small glassy grains. Alteration to kaolin and epidote is so extreme that the original minerals are scarcely recognizable with the microscope. The rock is cut by a number of diabase dikes, the largest of which is 60 feet across and runs N. 75° W., parallel with one of the two prominent jointing systems. Evidently the diabase magma was injected into one of the open joints. The second jointing system strikes N. 10° W. Joints are 1 to 5 feet apart. Green epidote veins in some places follow the joints and at others are very irregular. Some of the rock has been quarried for local uses, as foundations of barns and houses. If the excavation were carried

[1] Winchell, N. H., Final report on the Geology of Minnesota: Minnesota Geol. Survey, vol. 2, p. 617, 1888.
[2] Idem, p. 618.

below the zone of surface alteration the rock would probably be better, though it is improbable that it would be of monument grade. The stone is serviceable for rough masonry. The nearest station is Staples, 10 miles distant by wagon road.

MILLE LACS COUNTY.

Outcrops of red granite occur on the west branch of Rum River in secs. 29 and 19, T. 38 N., R. 27 W., about 5 miles west of Milaca. The rock is similar to that occurring about 2 miles to the west in Granite Ledge Township, Benton County. (See pp. 130–131.)

At the south end of Mille Lacs Lake, in the NW. ¼ T. 42 N., R. 26 W., a cutting on the Minneapolis, St. Paul & Sault Ste. Marie Railway exposes igneous rocks covered by about 15 feet of drift. Two types, gray and black, are considerably mixed, the gray being probably intrusive into the black, though this is not established. The dark rock is a medium-grained mica diorite; the gray appears to be a lighter phase of the same type, exhibiting large flakes of biotite in a finer groundmass of feldspars, from which it derives its color. Neither rock is attractive.

On the upper part of the main branch (East Branch) of Rum River, in sec. 18, T. 41 N., R. 26 W., several outcrops of different or differently described rock (syenite, hornblende rock, gneiss, granite, and greenstone) are recorded.[1]

Outcrops[2] in sec. 29, T. 41 N., R. 26 W., consist chiefly of a medium to coarse grained hornblende-biotite granite, which is somewhat porphyritic in texture. The most prominent mineral is feldspar, chiefly orthoclase, in crystals one-fourth to one-half inch long. Quartz is abundant in small grains, and fine-grained mica and hornblende are scattered throughout. The color is not attractive for high-grade work, but the rock would probably make a good building stone. It is cut by fine-grained red granite dikes of microcline, orthoclase, plagioclase, quartz, biotite, and muscovite.

ST. LOUIS COUNTY.

GIANTS RANGE.

In St. Louis County, in the Mesabi iron-mining region, granites of lower middle Huronian age form the Giants Range, which rises as a prominent bluff, constituting the backbone of the iron range. The rock is a medium-grained granite of gray or pale-pink color, invaded by pegmatites in places. About 1½ miles north of Kinney it consists of pale-pink feldspar, clear quartz, and scattered flakes

[1] Winchell, N. H., *op. cit.*, p. 617.

[2] Examined by F. F. Grout.

of muscovite or white mica. With the microscope the chief feldspar is seen to be orthoclase. Plagioclase is nearly as abundant, though in smaller crystals, and the rock may therefore be classed as a quartz monzonite. Quartz is in small grains and is not prominent as in the "St. Cloud red" granite. Hornblende and biotite are present in small grains and are somewhat altered to chlorite. Joints form a very distinct system, trending N. 30° E. and are 1 to 6 feet apart. East-west joints are rare. Surface rock only could be observed. The color of the stone is not sufficiently attractive to make it desirable for monumental purposes. As a structural stone it would probably be useful, but on account of local conditions it may not be used for many years. Though exceedingly abundant and well placed for shelf quarrying, it is 2 to 6 miles from towns and railroads. Moreover, near many of the range towns, notably Chisholm, the ground is strewn with innumerable boulders, mostly of granite, which are quite fresh and suitable for building purposes, and which will probably supply the demand for foundation stone for many years to come.

HINSDALE QUARRY.

An eastward extension of the Giants Range was at one time quarried near Hinsdale siding, about 2 miles north of Mesaba station on the Duluth & Iron Range Railroad. The quarry, which was opened about 1891, is about 100 yards from the siding near the top of a bluff that rises about 75 feet above the railroad. Consequently it is of the shelf or bench type. The excavation is about 40 feet wide at the center and 125 feet long, and the wall is about 40 feet high.

The rock (see Pl. V, *D*) is a somewhat porphyritic granite with pink feldspar crystals about half an inch across. The general color effect at some distance is a pinkish gray. Closer observation shows that the feldspars are of two types, large scattered porphyritic pale pink and abundant greenish gray, the latter forming the bulk of the rock. Quartz is in fine grains and is not at all conspicuous. Most of the hornblende is in small grains, with a few larger ones, so lined up as to give the rock an indistinct gneissic texture. Microscopic study proves that the most abundant feldspar is orthoclase, and that microcline and plagioclase are subordinate. Biotite, hornblende, and magnetite form the dark part of the rock. Crystals of sphene, in most places associated with the magnetite grains, are even more abundant than in the "St. Cloud gray" granite. Apatite inclusions are numerous. On account of the small amount of quartz present the rock should be comparatively easy to dress.

On the exposed rock surface west of the quarry three joint systems trend N. 20° W., N. 70° W., and N. 55° E. The western edge of the

quarry is a prominent open joint running N. 32° W. The joint structure is shown in figure 18.

Though most of the joints are vertical a system near the north end of the quarry striking N. 5° E. dips about 50° E. Eight such joints 2 to 8 feet apart were observed. The acute angles of intersection of these joints with the vertical systems result in blocks of undesirable shape.

Sheeting planes are well spaced. From the top of the quarry downward they appear at approximate intervals of 8, 8, 10, 4, and 10 feet. Near the surface they dip slightly west, the dip increasing with each successively lower plane, the floor of the quarry dipping 20° W. It is therefore evident that a serious mistake was made in opening a quarry facing the east, for in it the beds dip toward the back of the pit, resulting not only in poor drainage but in great difficulty in removal of rock. It is comparable with an attempt to remove shingles from a roof, beginning at the eaves rather than the ridge. Northwest of the present quarry a ravine opens through the bluff, making it possible to open a quarry in which the beds would dip toward the side rather than toward the back wall, a condition which would facilitate rock removal.

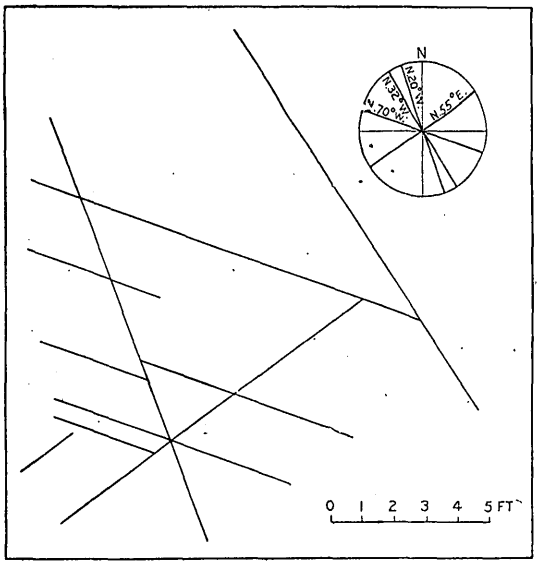


FIGURE 18.—Sketch showing structure of rock at Hinsdale quarry, St. Louis County, Minn.

Near the north end of the quarry a large number of aplite dikes appear. Some dark knots seem to be inclosed fragments of hornblende schist. The central and southern parts of the quarry are fairly free of defects, though the presence of lenticular masses of black hornblende 1 inch to 2 feet in length mars considerable rock for monumental purposes. Aside from such knots the rock is even-grained, uniform, and attractive. The siding only 100 yards from the excavation makes transportation simple, especially as the quarry floor is so much higher than the track.

GABBROS AND DIABASES.

LAKE, ST. LOUIS, AND CHISAGO COUNTIES.

LAKE COUNTY.

The only quarry now operating in Lake County is the Two Harbors Rock Crushing Plant. Diabase is excavated, and practically the entire output is crushed. During 1913 part of this was sold to the Duluth & Iron Range Railroad for concrete construction such as station platforms and walks, and the remainder was used for street construction in Two Harbors.

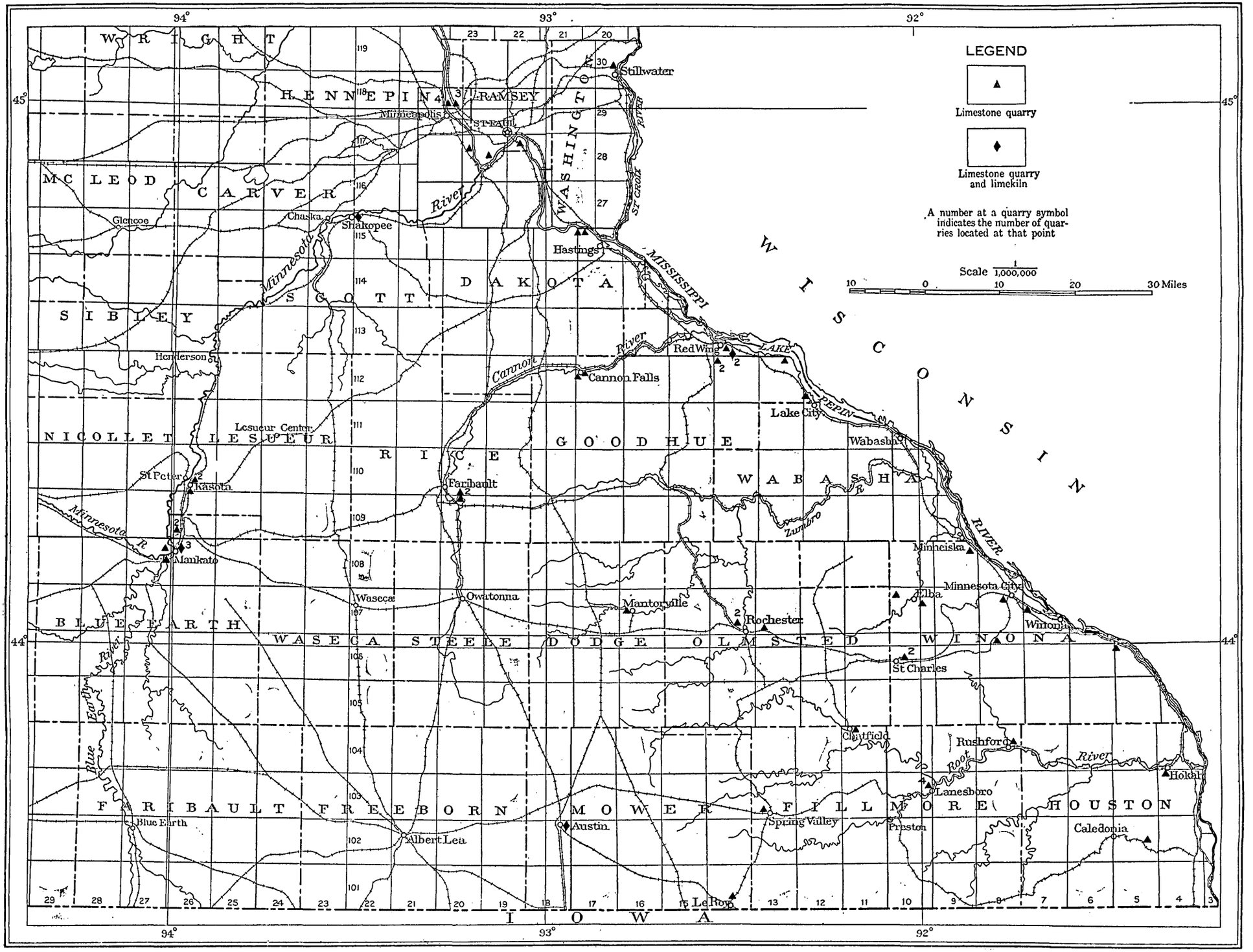
ST. LOUIS COUNTY.

The Duluth gabbro of Keweenawan age occupies a large area near the head of Lake Superior, rising to a bold bluff many feet high in the neighborhood of Duluth. The rock is for the most part a coarse-grained gabbro. In some localities it is a typical gabbro, containing plagioclase and augite, in others it contains considerable olivine. In West Duluth it is composed almost entirely of plagioclase feldspar and is called anorthosite.

DULUTH CRUSHED STONE CO. QUARRY.

The gabbro has been quarried for many years in several places, but the only extensive recent excavation is that done by the Duluth Crushed Stone Co., which began work in the anorthosite of West Duluth in 1903. The rock is a typical anorthosite, consisting almost entirely of plagioclase crystals, half an inch to an inch in length, prominently striated parallel to their long axes. Small amounts of augite are present in places. In color the rock is dark brown to almost black. Jointing and sheeting planes are very irregular, the rock being broken up in many directions and into rather small fragments. No definite systems are exhibited. In places crevices between sheeting planes are filled with a red mineral which is probably laumontite. A large fault plane passes diagonally through the quarry showing distinct slickensides. Along the fault plane the rock is altered to a mixture of chlorite and clay. A few calcite veins appear, the largest seen being about an inch across. The rock is decayed to a depth of 6 inches on either side of the vein.

Steam drills are employed. As the quarry is of the shelf type, rock handling is comparatively easy. The fragments are loaded into cars on tracks and transported to powerful crushers situated close to the railroad tracks. Heavy blocks for riprap are handled by derricks. In general, the output is about evenly divided between crushed rock and riprap, with subordinate amounts of rubble for foundations and retaining walls. The crushed rock is used for road construction and concrete work, and the riprap for harbor protection. During the summer of 1913 rock was supplied for a breakwater at Ashland, Wis.



MAP SHOWING LOCATION OF THE LIMESTONE QUARRIES IN MINNESOTA.

OTHER QUARRIES.

The Duluth city quarry, near Eleventh Avenue West and Superior Street, was in operation during the summer of 1913. The whole output was employed in improvements upon the Superior breakwater.

Charles Hokanson, of West Duluth, has quarried in the same gabbro ridge in past years for the production of curbing and occasionally for a little monument stone.

About 1896 rock was quarried in several places along the bluff to supply stone for lining the city water reservoir. The entire lining, requiring 34,000 cubic feet, was made of the Duluth gabbro. The rock at the top of the bluff is better adapted for trimming and cutting than that at the base, which is very tough and has a much less perfect rift. The upper ledges have a definite horizontal rift and a north and south run, properties which greatly facilitate splitting.

The Duluth gabbro is well adapted for riprap for shore protection and filling, and gives excellent service as crushed stone for concrete or road construction. It is used successfully, though not very extensively, for curbing. Much of it, however, is too dark and somber and weathers too easily to make it desirable for buildings or monuments. Merrill[1] states, however, that the "Duluth anorthosite" takes a beautiful polish and is well adapted for ornamental slabs and columns.

CHISAGO COUNTY.

Near Taylors Falls, on St. Croix River, rugged exposures of diabase and basalt form the picturesque Dalles of the river. The rock is tough, black, and massive and is somewhat amygdaloidal in places. It was quarried and crushed for concrete work in the construction of the Minneapolis General Electric power dam at St. Croix. According to report, the rock is, on account of its toughness, very hard to crush. No rock was excavated subsequently until 1913, when the Taylors Falls Trap Rock Co. established a crushing plant near the town of Taylors Falls. The Minneapolis Trap Rock Co. plans extensive excavation on the Wisconsin side of the river, where a $150,000 plant is now under construction. Crushed rock of this type is of excellent quality for concrete construction, and will probably be greatly in demand in the Twin Cities.

LIMESTONES AND MARBLES.

DISTRIBUTION AND CHARACTER.

Limestones are confined to the southeastern portion of the State. Plate XVI shows the location of all the limestone quarries in Minnesota that produced stone during 1912 or 1913.

Practically all the limestones of Minnesota are dolomitic and many of them are nearly pure dolomite. Though nearly flat lying and

[1] Merrill, G. P., Stones for building and decoration, 3d ed., p. 114, 1903.

showing little deformation they are more or less recrystallized—in certain beds so much so that the rock takes a good polish. Limestone suitable for many purposes is obtained. Polished or unpolished slabs for wainscoting and flagging; carvings for interior or exterior decoration; cut stone, range rock, and rubble are all obtained in large amounts. Riprap is quarried extensively, and the production of crushed stone for macadam and concrete is increasing year by year. Lime is manufactured in several places, and a limited amount of stone is quarried for cement, for sugar refining, iron-ore flux, and fertilizer.

COLOR.

Many of the beds are nearly pure white. Such limestones under the microscope are seen to consist of pure calcite or dolomite, with the possible admixture of clay or sand grains. Others are yellow to buff, from rocks containing minute particles of iron oxide. Certain beds, such as the lower bridge ledge at Mankato, are blue when first quarried but rapidly turn buff on exposure, probably from the oxidation of iron originally present in them in carbonate form; the Platteville limestone is blue where unweathered but is yellow along joint planes. In some of the blue ledges, however, the color is more permanent. This is well shown in a farmhouse in Dakota County (p. 161), which has stood for 47 years, and still retains the distinct blue color.

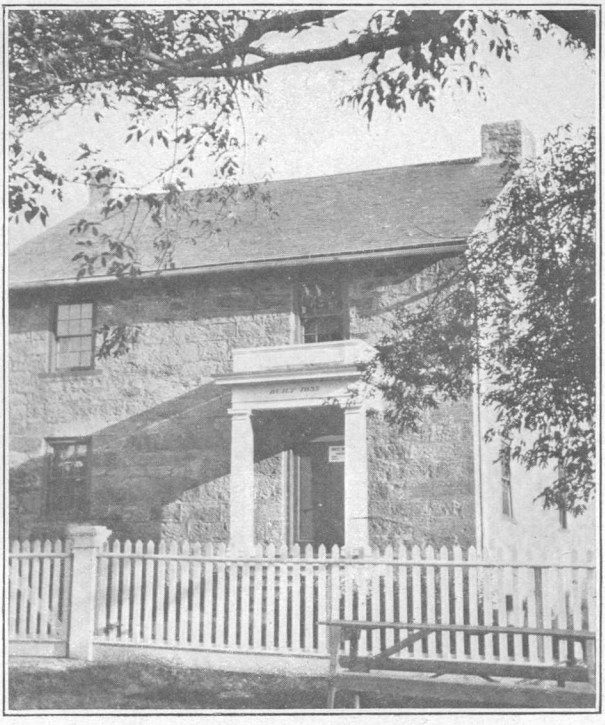
At Ottawa, St. Peter, and Kasota, near Minnesota River, the color of the Oneota dolomite in different beds ranges from deep yellow to pink. Winchell [1] states that the dark color of the "Kasota" stone is probably due to the absorption of material from the waters of Minnesota River, when it flooded the terrace now being excavated.

The alternation of pink and yellow beds is peculiar and a chemical and microscopic investigation to determine its cause was made in the laboratory at the University of Minnesota by A. W. Gauger. As iron is the common impurity giving pink, buff, or yellow colors to limestone, careful determinations were made of total iron and also ferrous iron, it being thought that the degree of oxidation might affect the color. In determining the ferrous iron the samples were crushed, but not ground, to pass through an 80-mesh sieve and were decomposed and dissolved in an atmosphere of CO_2 according to the method of W. F. Hillebrand.[2] Total iron was determined by the Reinhart-Zimmerman method: [3]

[1] Winchell, N. H., Final report on the geology of Minnesota: Minnesota Geol. Survey, vol. 1, p. 165, 1888

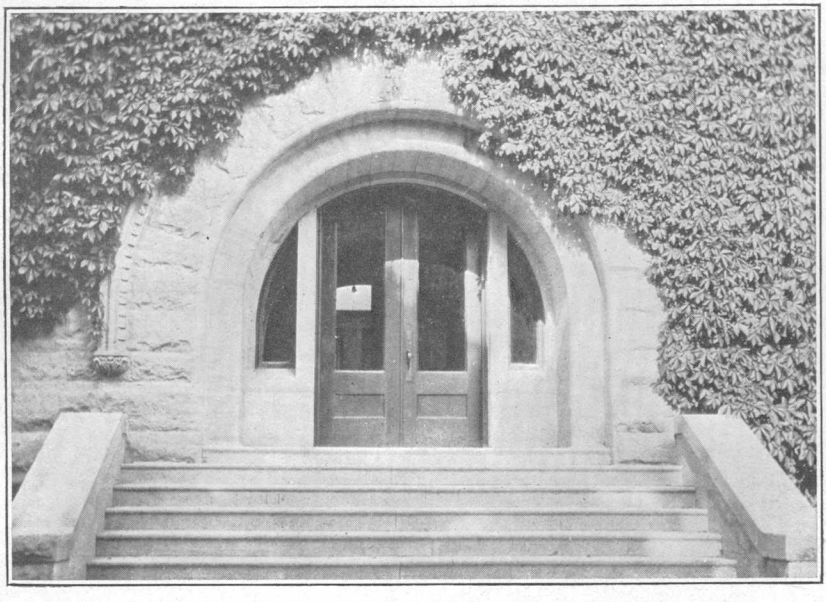
[2] U. S. Geol. Survey Bull. 422, p. 223, 1910.

[3] The process of determining total iron as FeO was as follows: Solution in HCl, addition of H_2SO_4, evaporation to drive off HCl, solution in water, reduction of iron by H_2S (see U. S. Geol. Survey Bull. 422, pp. 107-108), expulsion of H_2S by CO_2 and titration by N/50 $KMnO_4$ which had been standardized against a known Bureau of Standards solution. The ferrous iron was determined from a crushed (not ground) sample (idem, p. 21) by J. P. Cooke's method (idem, p. 169).



A. GEN. SIBLEY'S HOUSE, MENDOTA, MINN.

Built of Platteville limestone in 1835.



B. ENTRANCE OF LIBRARY BUILDING, CARLTON COLLEGE, NORTHFIELD, MINN.

Constructed of "Kasota" stone.

Percentage of total and ferrous iron in pink and yellow "Kasota" stone.

	Pink.	Yellow.
Total iron determined as FeO	0.708	0.504
Ferrous iron oxide (FeO)	.250	.152

It may be questioned whether so small an amount of iron could give so deep a color, but many specimens of red orthoclase colored by minute inclusions of hematite (Fe_2O_3) have been analyzed and found to contain less than 1 per cent of iron. The ratio of ferrous iron in terms of FeO to total iron in terms of FeO is practically the same in each specimen tested, 0.35 to 0.30, making it evident that neither the difference in total amount of iron nor the difference in the degree of oxidation is great enough to account for the marked change in color.

Thin sections of both rocks were made and studied under a magnification of 740 diameters. In each section, when thus magnified, the main mass was gray in color. In the one were minute red specks, evidently of hematite (Fe_2O_3), and in the other yellow grains which appeared to be limonite ($2Fe_2O_3.3H_2O$). It appears, therefore, that the variation in color is due rather to the degree of hydration than to oxidation of the iron. An attempt to estimate the amount of water combined with the iron appeared impracticable on account of the small percentage of iron and the large percentage of clay.

DURABILITY OF ARGILLACEOUS LIMESTONE.

Certain of the Platteville beds at St. Paul and Minneapolis contain thin bands of shale which disintegrate readily, destroying the uniformity of the surface and seriously weakening the rock. Thus in many buildings in St. Paul and Minneapolis alternating horizontal ridges and depressions are conspicuous. About 4 miles west of St. Paul, at Mendota, the Platteville limestone used in the construction of Gen. Sibley's house (Pl. XVII, *A*) has stood for 79 years with almost no sign of disintegration; it appears therefore to be much purer than the stone at St. Paul. Chemical analysis shows, however, that the stone at Mendota contains 26.66 per cent insoluble matter, in which kaolin greatly predominates. In the stone at St. Paul and Minneapolis the clay is concentrated in beds and interstratified with limestone, whereas in the stone at Mendota it is uniformly distributed throughout the mass, a condition which results in a more stable and permanent rock structure. Apparently, then, the percentage of clay present has little influence on the durability, the manner of distribution being of more importance.

ECONOMIC CONDITIONS.

The general conditions of the trade in building stone are outlined on page 117. Many small limestone quarries are now idle and several new ones are being opened. In many places quarries have been opened to obtain stone for some specific structure, on completion of which the quarry has become inactive. Many others have a large supply of very handsome and durable rock but are kept in idleness by the high price of labor, the expense of transportation, and the adaptability of concrete as a substitute, especially for rubble. Concrete foundations for barns and houses have been noted within a few yards of quarries. On the other hand, the growing desire for attractiveness, permanence, and dignity, which massive stone masonry can alone supply, provides a steady demand for the fine-grained, uniform, buff or yellow limestones and dolomites that are found at so many places in southeastern Minnesota. Greater enterprise on the part of many quarry owners would widen their markets. Some of the most beautiful limestones in the State are unknown outside the villages or townships where they are located.

QUARRY METHODS.

In quarries where structural blocks are obtained large masses are marked out by rows of drill holes, the depths of the holes being governed by the thickness of the beds. Steam drills are usually employed for deep drilling. Drill holes are commonly grooved with a "reamer" to insure straight splitting, and where this is done fewer holes are required. Small powder blasts, exploded simultaneously by electricity, break the whole mass loose. If it is desired to break the rock at a joint, the drill holes are placed 6 inches or a foot back of the joint; the intervening rock acts as a cushion and prevents shattering of the block. Often a large block is separated by a single drill hole. Some limestone quarries employ the Knox system, by which the drill hole is grooved with a reamer and a plug of cotton or similar material placed 1 to 2 feet above the light powder charge and tamped with earth. The air space above the charge distributes the explosive force and causes a more effective break and at the same time prevents the shattering likely to occur when the whole energy of the charge is concentrated at one point. Vertical channeling machines are employed at Kasota only.

When large blocks are loosened further splitting in vertical directions is accomplished by the plug and feather method. (See p. 65.) In most limestone quarries the drilling for plug and feather is done by hammer and short hand drills. In a few places long drills without hammers are employed, the weight of the drill when raised and dropped being sufficient. Pneumatic drills are not used extensively.

Further splitting of blocks in the horizontal plane is accomplished by wedging where bedding planes are sufficiently open to allow wedges to enter and by the plug and feather method where the planes are too close. Horizontal channeling machines are not used in Minnesota.

Where riprap or rubble are produced the rock is shattered by blasting and is further divided by crowbar, wedge, and stone hammer. Such methods are used chiefly in thin-bedded rocks.

Where stone for crushing is quarried, heavy charges of dynamite are used, as the purpose is to break the rock up as much as possible.

Derricks consist of tall masts, usually of wood, held in place by steel cables. The movable booms as a rule are also of wood. In small quarries horsepower is employed for hoisting and in larger ones either steam or electric power.

QUARRY DESCRIPTIONS.

ANOKA COUNTY.

The Platteville limestone outcrops at the extreme south of Anoka County in Fridley Township. This outcrop represents the most northerly exposure of the Platteville on Mississippi River. Some of it was quarried in sec. 34 many years ago.

BLUE EARTH COUNTY.

GENERAL FEATURES.

The following formations outcrop in Blue Earth County along the valley of Minnesota River and its larger tributaries, the Blue Earth and the Little Le Sueur:

Pleistocene: Drift.
Cretaceous: Clay and sand.
Ordovician: Oneota dolomite.
Cambrian:
  Jordan sandstone.
  St. Lawrence limestone.

The Oneota and St. Lawrence are the only formations from which building stone may be obtained.

The St. Lawrence limestone outcrops only at Judson, where it was quarried many years ago. In quality it is inferior to the Oneota dolomite, being thinly bedded, closely jointed, and lacking in strength. As the beds are low lying, quarrying conditions are unfavorable and the rock is not quarried in Blue Earth County.

The Oneota dolomite outcrops in a number of places along the tributary streams as far as Garden City and Rapidan. Years ago it was quarried to a considerable extent, mainly for local buildings, but for a number of years operations have practically ceased.

Outcrops are also numerous along the Minnesota River valley. The Kasota terrace (see p. 175) continues to Mankato, and rock appears in many places, especially along stream-eroded valleys. On account

of the large blocks obtainable, their uniformity, high tensile strength, and attractive appearance the limestone of Blue Earth County is noted for its adaptability to heavy masonry and bridge construction. Smaller building blocks and crushed stone for concrete construction are important secondary products. Riprap and waste material are used for railroad ballast and for filling in low places in the city. The quarries now operating in the county are those owned by the Mankato Limestone & Fuel Co., the T. R. Coughlan Co., Fowler & Pay, James McClure, the Widell Co., and the Carney Bricklayer's Cement Co. Other quarries were formerly worked but are now idle. Near Bradley's crossing, at the northern extremity of the county, Fowler & Pay opened a quarry in 1887 and worked it for a short time. J. R. Beatty & Co. operated a quarry in sec. 20, Lime Township.

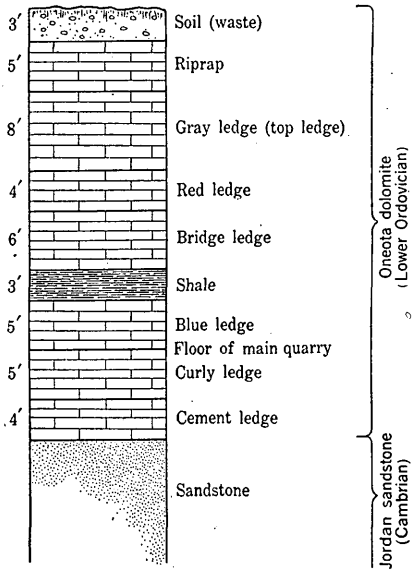


FIGURE 19.—Vertical section of the Widell Co. quarry, Mankato, Minn.

BRADLEY QUARRY.

On the property of G. R. Bradley, of Mankato, in the NW. ¼ sec. 20, T. 109 N., R. 26 W., a deep stream-cut valley exposes the rock in several places. The outcrops are on the same terrace and at approximately the same level as the Kasota quarries. Two shallow excavations and one diamond-drill boring were made. Unfortunately the boring was too near the edge of the bluff to obtain a fair section, for rock alteration or even displacement of the beds might extend some distance from the valley. One of the excavations was badly caved and concealed the lower beds. In the other the removal of 1 to 3 feet of soil and several feet of broken rock disclosed fairly good ledges. The rock contains some vugs filled with calcite crystals, but these, according to observations made in other quarries, are probably confined to the surface layers. Some deep yellow but no pink rock occurs in the pits. The drill core, however, shows some pink rock that takes good polish.

An average of analyses by F. F. Grout of three samples from this locality shows calcium carbonate 52.62 per cent and magnesium carbonate 38.78 per cent. The remainder, chiefly aluminum and iron, estimated by difference, is 8.6 per cent. The aluminum indicates the presence of a little clay; the iron is coloring matter.

Economic conditions are favorable. The presence of the ravine permits shelf quarrying and facilitates removal of waste rock. The

Chicago, St. Paul, Minneapolis & Omaha Railway is near by, and a siding from it has been built to the larger excavation. Rock owned by Morgan Brooks, on adjoining property to the south and west, has been quarried and polished and is of good quality. This section of the terrace seems worthy of investigation.

M'CLURE AND WIDELL QUARRIES.

About 3 miles northeast of Mankato, James McClure and the Widell Co. have extensive quarries, which are similar in essential features. The Widell Co. has excavated to a depth of 35 feet (see fig. 19) in a buff-colored dolomitic limestone, most of which is somewhat too porous to take good polish and is best adapted for heavy masonry.

The so-called "curly ledge" is the probable continuation of the "H. & D." ledge at Kasota, being at the same approximate horizon and like the "H. & D." ledge, containing knots and having irregular uneven bedding. The bridge ledge is the most valuable, supplying large blocks of good quality for bridge abutments and culverts. Parts of the red ledge are crystalline and take a good polish and therefore may be classed as marble. The beds dip to the south about 5 feet in 100. Bedding planes are 2 to 6 feet apart, and joints are vertical, 4 to 15 feet apart. Two jointing systems run east-west and north-south. Drainage is poor, springs occurring in every ledge but chiefly at the shale bed shown in figure 19.

These companies, which have operated for many years, have sidings from the Chicago, St. Paul, Minneapolis & Omaha line, and have provided stone for such structures as the State Capitol at St. Paul, the Minnesota State Prison at Stillwater, and a number of bridges on the Chicago & Northwestern Railway, notably at Boone and Cedar Rapids, Iowa.

According to strength tests made by W. H. Kavanaugh, of the University of Minnesota, in 1907 the rock is very strong and is thus suitable for any sort of bridge work where great crushing strength is required.

A chemical analysis by F. F. Grout of a dry sample of the rock from the bridge ledge shows the following composition:

Analysis of rock from bridge ledge, McClure & Widell Co. quarries, Blue Earth County, Minn.

Silica (SiO_2)	7.35
Alumina (Al_2O_3)	4.51
Iron oxide (Fe_2O_3)	.96
Titanium oxide (Ti_2O_3)	.08
Calcium carbonate ($CaCO_3$) [1]	48.26
Magnesium carbonate ($MgCO_3$) [2]	38.67
Phosphorus oxide (P_2O_5)	.06
	99.89

[1] Calculated from CaO=27.05 per cent. [2] Calculated from MgO=18.50 per cent.

JEFFERSON AND WILLARD QUARRIES.

About 1½ miles northeast of Mankato a stream tributary to Minnesota River has cut a steep-walled ravine in a perpendicular limestone bluff. On the northeast side of this ravine and on the neighboring bluff of Minnesota River are quarries owned by A. Jefferson & Son and by M. G. Willard, and on the southwest side is a quarry owned by the Chicago & Northwestern Railway. None of these were in operation in 1912. The rock is similar to that obtained in the McClure and the Widell quarries. The upper ledges contain numerous cavities filled with calcite and quartz crystals. A section of the Jefferson quarry shows beds almost identical with those at the Widell Co.'s quarry, despite the fact that the two quarries are more than a mile apart.

Section in the Jefferson quarry, Blue Earth County, Minn.

Top.	Feet.
Limestone	6–7
Building stone	3½
Red ledge	4
White stone that takes polish	5
Bridge ledge	5
Shale	2½
Blue ledge, flagging stones	5
Cement stone, burns to cement	6–8
Jordan sandstone.	

QUARRIES IN MANKATO.

General features.—The remaining quarries of Blue Earth County are within the limits of the city of Mankato. A prominent bluff, the exposed part of the preglacial rock terrace, begins three-fourths of a mile north of the railway station, and stretches continuously for nearly half a mile in full view of travelers who enter Mankato by rail from the north. The horizontal beds and the vertical joints give the cliff face the appearance of heavy artificial masonry. A buff dolomitic limestone is excavated by three companies on the same bluff. (See fig. 20.)

The 3½ foot "red ledge" and the 4-foot "cream ledge" are the only beds adapted for cutting and polishing. They may be classed as marble. With the microscope the rock appears to be a somewhat crystalline, fairly even grained limestone, containing a few yellow grains of limestone and a little carbonaceous matter. Other beds are porous, many of the cavities being filled with ocher. The Mankato quarries are best known by the rock derived from the "bridge ledge." The general color tone is buff; the bottom ledge is blue but turns slowly buff by oxidization of the iron which it contains. The rock is very tough, strong, and durable. It is shipped to distant points to construct buildings, bridges, and culverts.

Physical tests of a sample from the bridge ledge gave: True specific gravity, 2.902; percentage of pore space, 6.78; dry weight per cubic foot, 169.1 pounds. Under crushing stress the first crack came at 8,882 pounds per square inch and final collapse at 11,390 pounds. Under transverse breaking stress the modulus of rupture proved to be 2,167 pounds per square inch.

Joints are far apart—even 20 to 30 feet in the bridge ledge. This permits the excavation of very large blocks.

Quarry conditions are excellent. Sidings are built level with the quarry floor. Water, which enters only below the bridge ledge, is easily drained off toward the river. The larger masses are broken loose by light blasting, and plugs and feathers are employed for further vertical breaks.

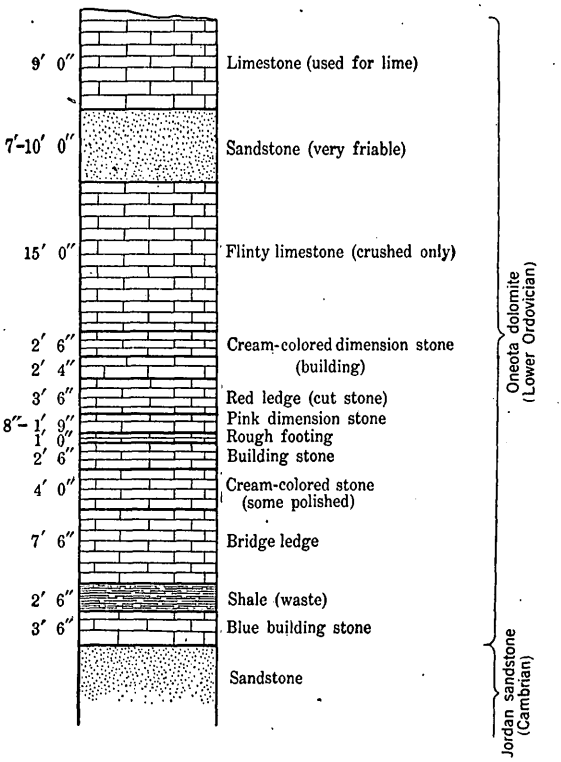


FIGURE 20.—Vertical section of T. R. Coughlan Co. quarry, Mankato, Minn.

Chicago & Northwestern Railway quarry.—That part of the bluff nearest the river is occupied by the Chicago & Northwestern Railway quarry. It was operated extensively in past years but was idle in 1912.

Fowler & Pay quarry.—Fowler & Pay occupy the section of the bluff adjacent to the Chicago & Northwestern Railway quarry, where they carry on extensive quarrying. Rock has been excavated here for over 20 years. The present output is chiefly building stone and bridge rock, with subordinate quantities of riprap, crushed rock, and lime, a brown hydraulic type of which is made only from the shell rock at the top of the bluff. A sawing machine produces cut stone. As will be seen from the description of the ledges (p. 156), only certain beds are adapted for polishing. The total output ranges from 1,500 to 1,800 carloads annually.

Fowler & Pay operate also at Austin and Le Roy and have offices at Minnesota Transfer and Minneapolis.

T. R. Coughlan Co. quarry.—The T. R. Coughlan Co. has excavated rock from the third section of the bluff for the last 26 years. The chief products are bridge rock, building stone, crushed rock, riprap, lime, and a minor amount of cut stone. Bridge rock was supplied from this quarry for the Cedar River Bridge, Menominee Junction, Wis., and building blocks for the Mother House and Academy, Mankato.

Mankato Limestone & Fuel Co. quarry.—Two blocks east of the Coughlan Co. quarry an excavation in the same bluff, is owned by the Mankato Limestone & Fuel Co. The rock is of the same type as that in the Coughlan quarry, but the bed above the cream ledge is of somewhat better quality. Poor drainage prevents the quarry from being worked below the top of the bridge ledge. Transportation is by team and wagon. Rock from this quarry was employed in the construction of the Le Sueur Center jail and sheriff's house and in the basement of the Mankato post office.

Carney Bricklayer's Cement Co. quarry.—In southwest Mankato, on both sides of Blue Earth River, stone is quarried for the manufacture of Carney's bricklayer's cement. This cement is not recommended for concrete construction, but, as the name implies, is used for laying brick. It sets slowly, becomes very hard, and is said to be superior to lime. The output is about 1,000 barrels a day. It sells in Mankato at 50 cents for a barrel of 240 pounds.

DAKOTA COUNTY.

Rock outcrops are numerous in Dakota County and represent a number of geologic formations, as follows:

Pleistocene: Drift.
Ordovician:
- Decorah shale.
- Platteville limestone.
- St. Peter sandstone.
- Shakopee dolomite.
- Oneota dolomite.

Cambrian: Jordan sandstone.

The Cambrian sandstones, which outcrop only along the Mississippi between Hastings and Nininger, are friable and are useless for structural purposes. The Oneota formation, exposed at Hastings and Nininger, supplies dolomite for riprap.

O. CARLSON QUARRY.

About 1905 a small excavation was made in the Oneota dolomite at Hastings by Mr. O. Carlson. The rock is gray in color and though the pores are large it is apparently durable. It has a specific gravity of 2.626, a pore space of 9.31 per cent, and weighs 148.8 pounds per cubic foot.

Joints strike N. 70° E. but are indistinct and far apart. Open beds are 3 to 6 feet apart and dip 5° E. Stripping requires the removal of 1 to 2 feet of soil and 6 to 8 feet of broken rock. Rock could be quarried without pumping only to a depth of about 10 feet, for greater depth would bring the excavation below the level of the river. Work was carried on but a short time and the excavation is scarcely large enough to show the quality of the unaltered stone. The product was used for local building of foundations. The railway station is about half a mile distant.

GENTZKOW & MOGREEN QUARRY.

About three-fourths of a mile west of Nininger, which is 3 miles northwest of Hastings, extensive quarrying is now carried on by Gentzkow & Mogreen, who also operate at Minneiska, in Winona County. As at Minneiska the Nininger quarries are operated under contract for the United States Government for river improvement. Quarries were operated in this locality about 50 years ago and at different times since then. The present company began operations in 1913.

The rock is a yellow to white limestone, for the most part too porous to make a desirable building stone, but it is suitable for riprap, which constitutes the entire output. A 10-foot ledge near the top, however, is fairly free from pores and excessive jointing and is well adapted for building blocks. The stripping consists of 4 to 10 feet of soil. Open bedding planes are 8 to 14 feet apart. The quarry is well equipped with steam and pneumatic drills, and modern machinery for handling the stone. The high bluff excavated is close to the river, and the rock is carried to the water by cars on tracks. The loaded skips are hoisted from the car trucks by a derrick and dumped onto the scows without further handling. About 25 men are employed. It is planned to excavate approximately 20,000 cubic yards annually for at least five years.

BLOMSTRAND & OLSON QUARRY.

At Nininger a quarry similar to that of Gentzkow & Mogreen is operated by Blomstrand & Olson under contract for the United States Government. Most of the rock is yellow and very porous. About 11 men are employed, and it was planned to excavate 10,000 cubic yards during the summer of 1913. The rock is transported by scows to the vicinity of St. Paul, where it is used in river protection.

MENDOTA QUARRIES.

The Platteville limestone outcrops abundantly in the northwestern townships and forms the upper part of the bold bluffs which flank Mississippi and Minnesota rivers. It has been quarried in several

places, the most notable of which is Mendota. On the bluff where St. Peter's Church stands and on property now owned by the church is an abandoned quarry which is probably the second opened in the State. (See fig. 21.) A thickness of only 8 feet of rock can be used, but the area available is very extensive.

The beds near the top are 1 to 4 inches thick, but lower ones are progressively thicker, the lowest measuring 8 to 14 inches. Joints are irregular, but blocks 1 to 2½ feet long are obtainable. The rock is blue, becoming yellow upon exposure. Fossils are present but do not appreciably affect the quality. Some shale layers occur but are not so prominent as in the rock quarried at St. Paul. The rock, as shown by a partial chemical analysis, contains calcium carbonate, 45.77 per cent; magnesium carbonate, 24.75 per cent; insoluble in hydrochloric acid, 26.66 per cent; and is therefore a highly dolomitic limestone. In thin section it is seen to be very uniform and granular, showing much clay, a few rusty streaks, and very few quartz grains.

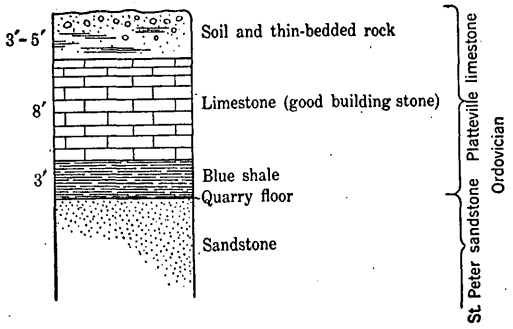


FIGURE 21.—Vertical section of Mendota quarry.

This quarry supplied the stone for Gen. Sibley's house, which was built at Mendota in 1835 and is probably the oldest stone building in Minnesota. The exterior of the house has never been altered and is still excellently preserved (see Pl. XVII, *A*, p. 150), though it has turned yellow or reddish yellow by oxidation.

The old Faribault House, a short distance west of Gen. Sibley's house, once a famous roadhouse but now utilized for grain storage, is also of solid stone. Two of its walls, still in excellent condition, were built of stone from the Mendota quarries and two of St. Peter sandstone. (See pp. 210–211.)

The Platteville limestone is exposed in many parts of the county and has been quarried in numerous small openings for local buildings.[1] Most of the quarries are now idle or are operated only at intervals, as occasion demands. Quarries are situated in Burnsville, Lakeville, Eureka, Sciota, Castle Rock, and Empire townships, but as conditions are similar in all of them only one is described.

AIKEN QUARRY.

In sec. 24, Lakeville Township, about 2½ miles northwest of Farmington, a quarry was opened about 50 years ago by Daniel F. Aiken.[1]

[1] Winchell, N. H., Final report on the geology of Minnesota: Minnesota Geol. Survey, vol. 2, p. 83, 1888.

and is now owned by his heirs. It has been worked intermittently for about 30 years. It is on a hillside and is of the shelf or bench type. It shows the following vertical section:

Section at Aiken quarry, Dakota County, Minn.

	Feet.
Soil	2
Thin-bedded rock	4
Good stone	6

The amount of overburden to be removed would increase greatly if the quarry were worked back into the hill. The rock is yellow by surface weathering but was originally blue, as is shown by the blue cores of the larger blocks. Bedding planes are horizontal and are very close together in the upper part but lie farther and farther apart as the depth increases until at 12 to 14 feet they are 6 to 14 inches apart. Some beds are more claylike than others and disintegrate more readily. Thin clay seams appear but are not so pronounced as in the stone at St. Paul. The durability of the stone is well illustrated in a farmhouse not far from the quarry, which was built in 1866 and is still excellently preserved. The process of oxidation is evidently slow, as the larger blocks still exhibit clearly the characteristic blue cores.

The fire-resisting properties of the stone are well shown in the foundation of a barn that was burned in 1886. The heat turned the stone red and crumbled it a little on the inner side of the wall but evidently did not appreciably affect its strength.

DODGE COUNTY.

GENERAL FEATURES.

Rocks of Ordovician age outcrop along branches of Zumbro River in the northeastern part of Dodge County. The following formations appear:

Pleistocene:
- Drift and loess.

Ordovician:
- Galena limestone.
- Decorah shale.
- Platteville limestone.
- St. Peter sandstone.
- Shakopee limestone.

The Platteville limestone was quarried many years ago near Concord, on North Middle Branch of Zumbro River. The best quarry rock, however, is the Galena limestone near Wasioja and Mantorville, on South Middle Branch of Zumbro River. The rock is a yellow to buff dolomitic limestone, though blue where not exposed to weathering agencies. It is pitted in places. Several

large quarries were operated many years ago but are all abandoned and overgrown at present. The following section at one of them is quoted from N. H. Winchell's report:[1]

Section at old quarry in Dodge County, Minn.

	Ft.	in.
1. Loose fragments	4	0
2. Beds of vesicular magnesian limestone, almost free from iron, measuring from 6 to 20 inches	30	10
3. Thin, slaty, argillo-magnesian beds	1	6
4. Good heavy beds of magnesian limestone, same as No. 2	11	6
5. Thinner shaley beds	5	0
6. Heavy beds of buff limestone with considerable shale	20	0
	72	10

M'DONOUGH QUARRY.

All the old quarries are idle, but one more recently opened on rock of the same type is in operation. In general the beds are 2½ to 3 feet thick, and in consequence massive blocks suitable for heavy bridge work may be obtained. Major joints strike N. 56° E. and are 2 to 3 feet apart. Secondary joints strike N. 25° W. and are 5 feet or more apart. The rock is used for local structural purposes, mainly for foundation work. It is strong, durable, and attractive.

FILLMORE COUNTY.

GENERAL FEATURES.

Fillmore County is drained almost entirely by Root River, the main channel and tributaries of which have cut deep ravines with many precipitous exposures. The relief is great and the following geologic formations are exposed:

Pleistocene: Drift and loess.
Cretaceous: Conglomerates.
Devonian: Limestone.
Ordovician:
- Galena limestone.
- Decorah shale.
- Platteville limestone.
- St. Peter sandstone.
- Oneota and Shakopee dolomites.

Cambrian: Jordan sandstone.

The building stones are the Oneota, Platteville, Galena, or Devonian limestones. The Devonian outcrops only on hilltops in western Fillmore County and is quarried in only one place, all other quarries being in the Platteville and the Oneota, of Ordovician age.

Winchell,[2] in 1884, mentioned many quarries in different parts of the county, but a number of them have been idle for many years

[1] Winchell, N. H., op. cit., vol. 1, p. 373.
[2] Idem, pp. 280-307.

and are not mentioned here. The most promising rock is in the Oneota formation, which lies in the hilltops near Rushford and neighboring towns.

BLY QUARRY.

Devonian rocks occur only on hilltops in western Fillmore County and at present are worked only in a quarry about three-fourths of a mile east of Spring Valley station, about 50 feet higher than the track at Spring Valley station, and about 1,308 feet above sea level. The quarry was opened about 1878 and was worked intermittently until 1908, when the present owner, T. M. Bly, obtained possession. Since that time it has been worked to some extent every year. All the rock excavated during the early period was from the upper craggy and porous ledge. When the present owner began operations he excavated the next lower bed, which is about 5 or 6 feet thick and is of much better quality, being almost free of cavities. The rock is known locally as "sandstone," though in reality it is a highly fossiliferous sandy limestone. It is pale yellow in color with wavy red streaks, and is strong and durable. Chemically it is a highly magnesian limestone, containing 56.50 per cent calcium carbonate, 40.27 per cent magnesium carbonate, and 1.39 per cent (probably silica) insoluble in hydrochloric acid.

Joints are very irregular but are sufficiently far apart to allow fair-sized blocks. Quarrying is easy, as very little stripping is required. It is intended to begin operations on the next lower bed in the near future. This at present can not be examined, but if the quality holds or improves the quarry promises to be desirable. One steam drill is now employed. The rock is good for foundations or for entire structures and, being within easy hauling distance of Spring Valley, can be laid down there more cheaply than rock from other quarries.

CAREY QUARRY.

Platteville and Galena limestones outcrop as prominent bluffs along several streams in the county; and the Platteville has been quarried along the bluffs of Bear and Deer creeks north of Spring Valley.

The quarry in the Platteville which has been worked the longest and most extensively is that owned by W. H. Carey, 4 miles north of Spring Valley in the bluff of Deer Creek. It is admirably situated for excavation and easy loading, the quarry wall rising as a vertical cliff about 40 feet high from about the level of the wagon road. By aneroid reading the base of the quarry is 50 feet below the level of the Chicago, Milwaukee & St. Paul tracks at Spring Valley and is about 100 feet lower than that of the Bly quarry, in the Devonian formation.

The Carey quarry shows the following vertical section reading downward:

Section in the Carey quarry, Fillmore County, Minn.

	Feet.
Broken and nodular limestone	6
Porous limestone, some cavities ½ to 1 inch across	12–14
Thick-bedded limestone with few cavities	16–18

The beds are 2 to 4 feet thick. Open vertical joints meet nearly at right angles and are far apart—in one place 25 feet apart—and large blocks of good solid stone are available. Like the Platteville in many other localities the rock is blue at a distance from the seams and yellow where exposed to oxidation. Microscopic study shows it to be fine grained and uniform though somewhat porous. It contains very little coloring matter. Chemically it consists of 76.44 per cent calcium carbonate, 20.45 per cent magnesium carbonate, and 1.96 insoluble in hydrochloric acid. It was quarried extensively many years ago, both for building blocks for local use and for lime (said to be somewhat hydraulic), which was manufactured and shipped away in great quantities. At present no lime is made, partly on account of the decreased demand owing to extensive concrete construction and partly because fuel is much more expensive than in former years. Although this is a good stone for building purposes, its distance from railways will probably prevent its employment for all but local uses. None was taken out in 1913.

A mile upstream is a quarry owned by George Wilbrecht. The rock is much the same but in thinner beds. It has not been worked for several years.

OTHER QUARRIES NEAR SPRING VALLEY.

About 8 miles farther northeast, in sec. 36, Sumner Township, are numerous outcrops along the bluffs of Bear Creek. Quarries in these ledges are owned by H. A. Palmer and W. W. Reynolds. The Palmer quarry, close to Washington, is a sandy limestone of good building quality, but has been little excavated of late years. The Reynolds quarry was opened in 1912 to supply rock for constructing a bridge over Bear Creek. The rock is less sandy and is good for bridge, culvert, or foundation construction.

Farther east, in a quarry owned by Edward Rath in the same formation, the rock is similar and is quarried for local purposes only. Near the town of Fillmore is a quarry owned by Charles Shultz from which much rock was taken in 1912 for road construction.

CLAYTON QUARRY.

Many of the low hills in the vicinity of Chatfield in the extreme north of Fillmore County, are capped with the Platteville limestone, and on one of these hills, about half a mile from the Chicago & Northwestern Railway station at Chatfield, a quarry, now operated by

E. L. Clayton, was opened about 40 years ago. The rock is a dense, fine-grained, bluish-yellow limestone.

Major joints strike N. 63° E. and are vertical and 4 to 5 feet apart. Secondary joints strike north and N. 70° W. and are 2 to 3 feet apart. Beds are distinct and 4 to 18 inches in thickness. The rock splits easily. There is considerable variation in the color and texture of the rock in different beds. Interbedded shales, fossils, and cherty or limy concretions appear in places. Stripping requires the removal of 4 to 5 feet of soil. No rock is shipped, the whole output being used in Chatfield as range rock or foundation stone. It is attractive in color and quite durable.

QUARRIES NEAR LANESBORO.

Eastward from Spring Valley the Chicago, Milwaukee & St. Paul Railway follows the valley of Root River. It drops rapidly from the high level of the Devonian rocks to the Galena and Platteville formations, and then to that of the Ordovician sandstone, which outcrops between Fountain and Isinours. Ordovician limestone appears west of Isinours and continues prominently for many miles eastward. The Oneota is quarried at Lanesboro for local purposes. Quarries are owned by George Ness, Ole Ensrud, and the village of Lanesboro. Rock is excavated at irregular intervals as required for foundations, culverts, and bridges, etc., in the vicinity.

QUARRIES NEAR WHALEN AND PETERSON.

At Whalen and Peterson towering cliffs of Oneota dolomite along the river bluff are quarried by O. E. Tew, of Peterson, for barn and house foundations. H. A. Bertrand and Ole Hogen operate quarries 4 and 5 miles, respectively, from Peterson, also for local use.

AKRE & DAHL QUARRY.

The Akre & Dahl quarry, about a mile northeast of Rushford station, was opened many years ago and was formerly known as the "Old Highland quarry." The quarry floor is approximately 225 feet above the railroad tracks, at the top of a steep and winding road, down which the rock is hauled by teams.

The upper portion of the quarry wall, 10 to 20 feet thick, consists of soil and broken stone, beneath which is a ledge 6 to 15 feet thick. Beneath it is a solid bed 12 to 14 feet thick of one of the purest and best limestones in Minnesota.

In thin section the limestone is seen to be extremely fine grained and pure, the only foreign material being a very few grains of carbonaceous matter and rarely a speck of iron oxide. As shown by chemical analysis the rock consists of 51.50 per cent calcium carbonate; 38.98 per cent magnesium carbonate; and 6.34 per cent

insoluble in hydrochloric acid. The proportion of magnesium is a little lower than that required for a dolomite. The insoluble portion is probably clay.

Open joints filled with clay are spaced irregularly but at considerable distances apart, and blocks of any desired size may be obtained. The fine-grained uniform texture of the stone, combined with its pale yellow to milky-white color, make it exceedingly attractive. A few reddish streaks run parallel with the bedding, and occasionally a small cavity appears; these, however, are rare.

So far the stone has been used in local buildings only. During the summer of 1912 the Masonic Temple of Rushford was built of it. The Lutheran Church, built in 1906, and the Rushford School are other representative structures. The uniformity of the stone, its freedom from blemish, and its attractive color should gain it a wide market.

NELSON QUARRY.

On a neighboring bluff a similar quarry owned by Charles Green is operated at times by Martin Nelson. It is not developed as extensively as the one described above, and was not operating in 1913.

GOODHUE COUNTY.

GENERAL FEATURES.

A number of valuable stone quarries in Goodhue County promise long-continued production. The following geologic formations outcrop:

Pleistocene: Drift and loess.
Cretaceous: Shale and clay.
Ordovician:
- Platteville limestone.
- St. Peter sandstone.
- Shakopee limestone.
- Oneota dolomite.

Cambrian:
- Jordan sandstone.
- St. Lawrence limestone.

Near the Mississippi the quarries are in the Oneota formation and in the southwestern part in the Platteville.

The chief center of the stone industry in Goodhue County is at Red Wing, near which are five active quarries, all in similar stone.

The base of all the quarries is approximately at the same level, about 300 feet above the railroad at Red Wing station. The beds used form a total thickness of 25 to 45 feet. The rock is pale yellow to white, of uniform texture, and, though somewhat porous, is enduring, as shown in structures which have stood for many years. Some flinty layers are present and a little iron stain appears in places.

Open bedding planes are 2 to 6 feet apart, and closed seams assist greatly in splitting the beds into more suitable thicknesses. Most of the jointing planes are indistinct and irregular but are spaced sufficiently far apart to permit the excavation of large blocks. All the quarries have the same shaly floor and the same 4½-foot basic layer of yellow rock with flattened ocher-filled cavities, above which lies the white to pale-yellow rock. An average specimen of the stone which is used for structural purposes has a true specific gravity of 2.644, a porosity of 10.46 per cent, and a dry weight of 148 pounds per cubic foot.

The rock is employed for foundation stone, even-course cut stone, riprap, and lime. Several important structures in Red Wing were made of "Red Wing" stone. The Swedish Evangelical Lutheran Church was built of it in 1895, the Evangelical Lutheran Church in 1905, and the Methodist Church in 1908. They are all beautiful structures, both in architectural design and in attractiveness of material. The rock is durable.

BJORK QUARRY.

Near East Seventh Street, Red Wing, a quarry owned by Johannes Johnson is operated by A. Bjork. Riprap, range rock, and lime are produced. With the microscope the rock appears as a fine-grained, even-textured dolomite, containing a few quartz grains. Chemical analysis shows that it consists of 50 per cent calcium carbonate, 39.79 per cent magnesium carbonate, and 6.02 per cent insoluble in hydrochloric acid. Calcium and magnesium carbonates are present almost in the proportion in dolomite. The quarry is about half a mile from the Chicago, Milwaukee & St. Paul Railway track.

DAHL QUARRY.

A. M. Dahl has operated a quarry in East Red Wing since 1904. No lime is made. The chief output is building stone, little riprap being produced on account of the 1½-mile haul by team and wagon. The Red Wing Methodist Church was built of this stone.

LILLYBLAD QUARRIES.

Close to the Dahl quarry is one owned by Fred Glover and operated under lease by Gust Lillyblad. It is quarried extensively for lime, with a small production of riprap and building stone. Cable cars convey the stone down the hill and beneath Seventh Street to lime kilns beside the railroad track.

On Bond Street, about 2 miles south of the Chicago, Milwaukee & St. Paul station is a quarry owned by Gust Lillyblad, which, according to Winchell,[1] was formerly owned by Mr. Berglund, and was

[1] Winchell, N. H., op. cit., 160.

opened in 1868. Some ledges are almost pure white and the rest yellow. Lime was manufactured here at one time, but none is now made. Some riprap is shipped to St. Paul, though the chief output is range rock for local use. The rock is porous, especially in the upper layers, where many geodes of calcite and quartz occur.

HAGLUND QUARRY.

Across the road from the Lillyblad quarry is one owned by Andrew Haglund. It was first operated by Andrew Donaldson over 40 years ago. Some riprap is taken out in winter, but the chief product is building stone.

Other quarry areas in Goodhue County are near Frontenac, Cannon Falls, and Pine Island.

FRONTENAC STONE CO. QUARRY.

The Frontenac stone quarry, in the Oneota formation about 2 miles northeast of Frontenac station, was opened many years ago. After three years of inactivity it resumed operations in 1913. The quarry floor is approximately 260 feet above the railroad level. A bed of high-grade stone about 8 feet thick is excavated with some difficulty owing to greatly increased overburden when the quarry is worked back into the face of the hill. Much rock is available, however, by working along the face of the hill. The stone is pale yellow to white, with uniform texture and though porous is well adapted to work requiring bush-hammered surface. A partial analysis shows 52.50 per cent calcium carbonate, 41.24 per cent magnesium carbonate, and 4.27 per cent insoluble in hydrochloric acid. Under crushing stress the first crack came at 6,874 pounds per square inch and final collapse at 8,017 pounds. Under transverse breaking stress the modulus of rupture proved to be 1,367 pounds per square inch.

The stone is employed both in interior and exterior structural work or trimming. The Lake City High School and the Girls' College of the Red Wing Training School were made from it, and it was used also to some extent in the old capitol at St. Paul. Stone is now being supplied for part of the interior work of the Cathedral of St. John the Divine, in New York City. Better railroad facilities would probably increase production.

JOHNSON (G. P.) QUARRY.

The most important quarry in the Platteville of Goodhue County is that owned by G. P. Johnson at Cannon Falls. It was opened many years ago and was bought by the present owner in 1891. It is on a high bluff about half a mile from the Chicago Great Western Railway tracks. About 2 feet of stripping is required, below which the quarry face is about 10 feet high. The color is at first blue but

weathers yellow. Beds are 3 to 10 inches thick and have no apparent dip. Joints are very irregular and meet in places at acute angles; the most prominent are N. 45° W. and N. 70° E. Shale beds are confined to spaces between the solid thick beds of limestone and are easily disposed of as waste material. In this respect the stone at Cannon Falls is of higher quality then that in the same formation at St. Paul and Minneapolis, where thin-bedded shales are scattered throughout the building-stone beds. The stone at Cannon Falls is attractive, durable, and has no serious blemishes. The First Congregational Church, built in 1907, the old schoolhouse, and several business blocks are made from this rock. It is well adapted for even-course building stone.

JOHNSON (BERT) QUARRY.

Bert Johnson owns a small quarry south of Cannon Falls in the Platteville limestone. The quarry was idle in 1911, but in 1912 it supplied stone for a new wing of the Cannon Falls schoolhouse. The rock is similar in every respect to that just described.

DUTCHER QUARRY.

Several quarries at one time worked in the vicinity of Pine Island are at present inactive. About half a mile northeast of the town is a small pit once operated by D. L. Dutcher. The rock is the Platteville, and, like the stone at Cannon Falls, weathers from blue to yellow buff. Beds are 2 to 8 inches thick and dip 5° N. Major joints strike north and east, the former vertical and the latter dipping 10° S.; and secondary vertical joints strike N. 75° E. and N. 35° W.; they are spaced 6 to 15 feet apart. The rock is fairly durable but has some shaly layers and contains a number of calcite geodes. The pit has not been operated for many years, concrete being used exclusively for foundations at Pine Island at the present time.

HENNEPIN COUNTY.

GENERAL FEATURES.

Rock outcrops in Hennepin County are confined to the vicinity of Mississippi River from Fort Snelling to the Anoka County line and are consequently chiefly within the limits of the city of Minneapolis. The Platteville limestone (Middle Ordovician) and the St. Peter sandstone (Lower Ordovician) are the outcropping rocks.

Active quarrying is now conducted in northeast Minneapolis, east of Johnson Street and between Johnson Street and Central Avenue, near Fifteenth Avenue. Three companies operate large modern crushing plants, supplying in all 150,000 to 200,000 cubic yards of crushed stone annually. An area of about 60 acres supports this

industry, but a considerable part of it is now worked out. An average of 10 feet of stripping is required over the whole area. The upper beds are argillaceous and are termed "soap rock" by the quarrymen. The lower 12 or 14 feet is a hard, dense high-calcium blue limestone, containing little clay. The lower beds are suitable for the production of rubble and range rock, but none is now produced. The beds dip about 3° E.

UNIVERSITY OF MINNESOTA CAMPUS QUARRY.

The Platteville limestone furnishes the only structural stone in the county. It has been quarried very extensively in past years for basements and retaining walls, as well as for a considerable number of entire structures. A section of the rock bluff near the university in southeast Minneapolis shows the following beds:

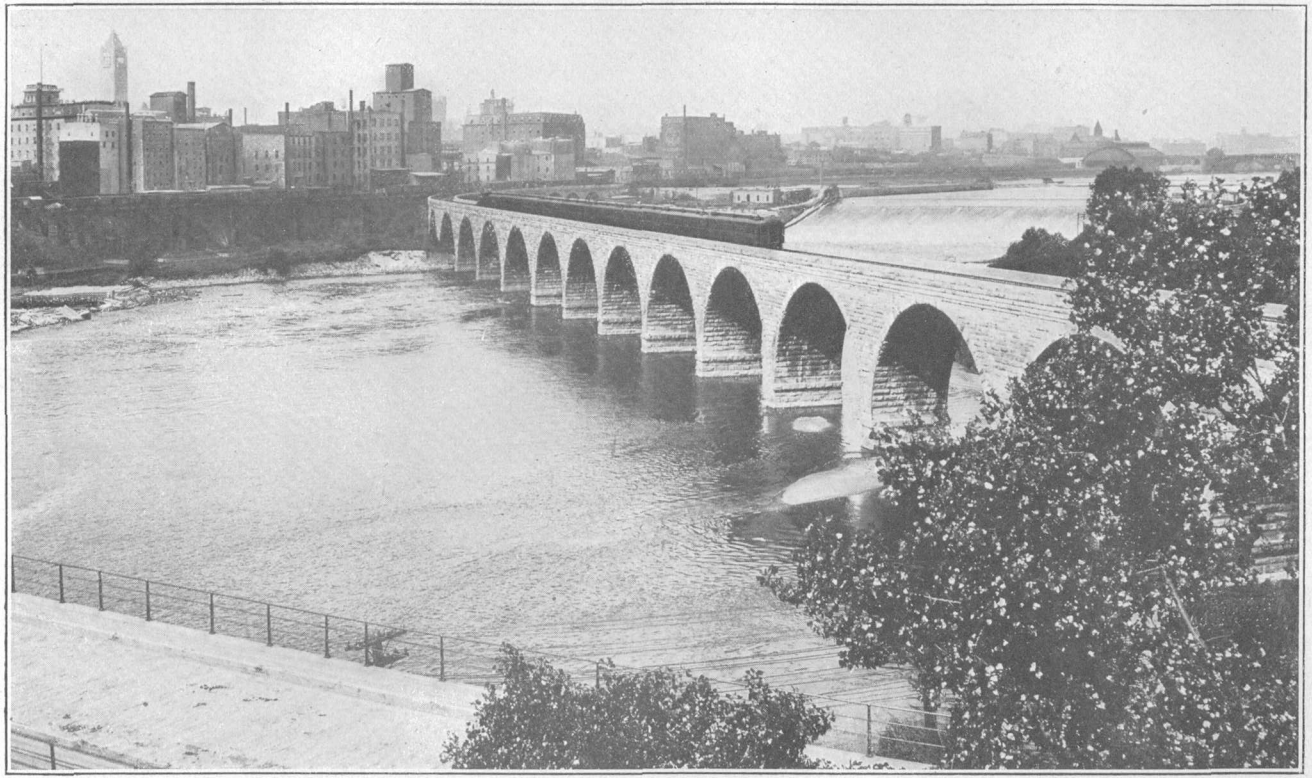
Section of rock bluff near the university, in Minneapolis, Minn.

	Feet.
Limestone, impure, bluish, fossiliferous, in thin beds, becoming more shaly near the bottom	10
Shale, green, becoming more calcareous toward the bottom and top	7
Limestone, argillaceous	15
Shale, blue	2
St. Peter sandstone.	

The third bed is the one most widely used for structural purposes. The argillaceous matter is not in regular laminations but in shaly spots and lenses, giving the rock a mottled or blotched color, and is too abundant for the rock to be a good building stone. The clay masses disintegrate readily, causing the rock to crumble. Where unexposed to weathering it is durable and strong and consequently is serviceable for backing. Pyrite crystals are present in some of the lower beds. In many structures in Minneapolis certain blocks are stained by oxidation of the pyrite; others which contain no pyrite retain their original blue color for some years and then gradually turn buff.

At two places near the Minneapolis, St. Paul & Sault Ste. Marie Railroad bridge, and also near Twenty-ninth Avenue S., rubble and range rock were quarried extensively until about 1911, when operations ceased. Rock was quarried many years ago on property now included in the new campus of the university in southeast Minneapolis. Through a ruling of the park board it is unlikely that any further excavation will be attempted at any point along the river bluffs within the city.

Near the foot of St. Anthony Falls limestone was quarried and used for certain parts of the Great Northern Railway stone-arch bridge (see Pl. XVIII), which was built during 1882 and 1883. As described by John A. Bohland, bridge engineer, the bridge consists of two segmental arches of 43.8 feet spans and 25 feet radius; one segmental arch of



GREAT NORTHERN RAILWAY STONE ARCH BRIDGE, MINNEAPOLIS, MINN.

40 feet span and 40 feet radius; 16 semicircular arches of 80 feet span and 4 segmental arches of 98.7 feet span and 50 feet radius, together with piers and abutments. Its total length at grade line is 2,100 feet. The work was carried out under the direction of C. C. Smith, chief engineer. The material is granite from the east bank of Mississippi River near Sauk Rapids, native limestone from quarries near the bridge site, and magnesian limestone from Mankato, Minn., Stone City, Iowa, and Bridgeport, Wis. Granite was used in the piers above the footing courses. The arches and spandrel walls are magnesian limestone backed with native limestone.

MINNESOTA CRUSHED STONE CO. QUARRY.

The Minnesota Crushed Stone Co. has a large excavation east of Johnson Street, near Fifteenth Avenue NE. A depth of 6 to 10 feet of soil is removed by large dump cars which are loaded by a steam shovel. The upper 4 feet is thin-bedded yellow limestone, followed by 6 feet of blue gray and 14 to 18 feet of hard blue limestone. An analysis of a composite sample taken from top to bottom of the quarry shows that the rock has the following composition:

Analysis of composite sample of rock from the Minnesota Crushed Stone Co.'s quarry.

$CaCO_3$	70.30
$MgCO_3$	13.54
Al_2O_3	.84
FeS	2.13
Insoluble	12.50
	99.31

The low percentage of alumina shows that the sample contained very little clay. The rock is shattered by heavy blasting, loaded into cars, and hauled to the crusher up an inclined track by cable and drums. The crushed rock is delivered directly into cars on a siding. A new crusher was installed in 1914.

MINNEAPOLIS STONE CO. QUARRY.

Between Johnson Street and Central Avenue large excavations have been made by the Minneapolis Stone Co. About 10 feet of sandy soil is stripped. At the east side the upper 3 to 4 feet of the rock is yellow, but at the west all of it is blue. The total thickness of the beds is 14 to 18 feet. An analysis follows:

Analysis of composite sample from Minneapolis Stone Co.'s quarry.

$CaCO_3$	80.00
$MgCO_3$	6.10
Al_2O_3	1.32
Fe_2O_3	1.95
Insoluble	9.00
	98.37

The whole output is crushed stone, which is used extensively for concrete and road construction. The quarry is equipped with all modern machinery. A railway siding facilitates transportation.

BLUE LIMESTONE CO. QUARRY

Near the corner of Central Avenue and Fifteenth Avenue NE. the Blue Limestone Co. owns 10 acres, most of which is now worked out. Ten feet of soil and 3 feet of thin-bedded yellow limestone overlie 11 feet of the dense blue limestone. The chemical composition of the average product is shown by the following analysis by A. W. Gauger:

Analysis of composite sample from Blue Limestone Co.'s quarry.

$CaCO_3$	82.06
$MgCO_3$	3.72
Al_2O_3	1.04
Fe_2O_3	.71
Insoluble	11.90
	99.43

Modern machinery is employed for quarrying, transportation, and crushing. The Blue Limestone Co. operates a large plant near the corner of Broadway and K Street NE. for crushing boulders and washing sand and gravel.

ANDERSON QUARRY.

North of the excavation made by the Blue Limestone Co. A. P. Anderson quarries similar rock for rubble. The rock is of excellent quality for foundations.

JOHNSQN QUARRY.

At 1131 Fourth Street NE., about a mile west of the Anderson quarry, L. P. Johnson excavates limestone from a city lot 40 feet front and 100 feet deep, about half of which is now worked out. The rock is covered by 2 feet of soil. The upper 3 feet is thin bedded and used only for filling, but the remaining 6 feet is of good quality. It is blue when fresh but stains buff along joints. Three joint systems are equally prominent. One system strikes N. 74° E., a second N. 17° E., and a third N. 30° W. They are straight, vertical, and spaced 15 to 20 feet apart. Rubble is supplied for house foundations.

ROGERS QUARRY.

A similar quarry is operated now and then by Andrew Rogers near the corner of Third Street and Thirteenth Avenue NE. Joints strike N. 37° W., N. 18° E., and N. 73° E. and are 10 to 20 feet apart. The best beds are 6 inches to 1 foot thick. Available stone covers an area of about half a city block. Rubble only is produced.

HORTENBACH QUARRY.

A larger quarry, operated by R. Hortenbach at the corner of Fifth Avenue and Fifth Street NE. was opened in 1911 on an available area of half an acre, about half of which is now exhausted. After stripping 7 feet of soil 13 feet of good rock is available. The upper beds are thin, but from the lower part blocks as much as 10 inches thick may be obtained. Major joints strike N. 30° W. and N. 21° E. and are 10 to 20 feet apart. A minor system strikes N. 75° W. Rubble only is produced. The quarry is equipped with a horsepower derrick.

UNITED STATES GOVERNMENT QUARRY.

The United States Government operates a quarry near Minnehaha Park on the Mississippi River bluff. The quarry was first opened in 1907. It was idle for two or three years but was reopened in 1912 and was worked extensively in 1913. The rock is covered with 18 feet of glacial till. Its upper 6 feet consists of thin-bedded, alternating layers of limestone and shale, resting upon blue limestone beds that have a total thickness of about 30 feet. The rock contains many calcite-filled cavities and many fossils. The entire output is crushed stone, all of which is employed in the new high dam of reinforced concrete now under construction.

Rock fragments are transported by cars to a crusher below the level of the track, are elevated by buckets on an endless chain to a bin on the top of the bluff, and are hauled thence by teams about 300 yards and sent down a chute to skips, which are carried across the river by overhead cable. About 18 men excavate 125 to 140 cubic yards daily.

HOUSTON COUNTY.

GENERAL FEATURES.

Abundant rock exposures in Houston County range from Cambrian to Middle Ordovician. The following formations outcrop:

Pleistocene: Drift.
Ordovician:
- Platteville limestone.
- St. Peter sandstone.
- Shakopee limestone.
- Oneota dolomite.

Cambrian:
- Jordan sandstone.
- St. Lawrence limestone.

The county is rough and hilly, being deeply intrenched by Root River, by Crooked and Winnebago creeks, and by numerous tributaries. The Oneota supplies the only profitable quarry rock in the county. Many years ago a somewhat friable sandstone was quarried

from the top of a bluff near Hokah and used to some extent for building foundations. It is too friable, however, to endure and it has not been employed for many years. A little of the Platteville was quarried near Spring Grove years ago.

The Oneota dolomite has been quarried in several places along the valley of Root River. Between Hokah and La Crosse a house and a three-story brewery, built of stone quarried from the near-by hills, are still well preserved and of attractive appearance. Near Hokah two quarries are worked occasionally.

BALDWIN QUARRY.

The larger of two quarries near Hokah, owned by Charles Baldwin, is a mile southwest of the town. The floor of the quarry is 310 feet above the railroad. The quarry shows the following vertical section:

Section in the Charles Baldwin quarry, southwest of Hokah, Minn.

	Ft.	in.
Soil	2–3	
Limestone, thin bedded, yellow	8	0
Limestone, yellow, porous; with many holes ¼ to ½ inch across in horizontal lines partly or completely filled with cherty or crystalline quartz	2	0
Limestone, yellow, porous	2	6
Same		6
Limestone, yellow, with many flinty patches	2	0
Limestone, yellow, with few pores and little flint	3	6
Limestone, gray		8
Limestone, gray, porous, sandy	2	6
Limestone, gray, sandy	4	0

Of the two grades of stone the gray is somewhat sandy and friable and is of poorer quality than the yellow, though it may be used for foundation work. Under the microscope the gray rock is somewhat crystalline and contains a few grains of quartz. Where observed in foundation walls it is durable and attractive.

PILGER QUARRY.

Louis Pilger owns a quarry in the same formation on an adjoining bluff, from which similar stone may be obtained. It has not operated for a number of years.

DUFFY QUARRY.

Near Caledonia several quarries have been worked extensively and have provided stone for many foundations and a number of complete structures. Caledonia lies at an altitude higher than Hokah. The railroad drops with a heavy grade toward Reno and passes near available outcrops of Oneota dolomite 2 or 3 miles east of Caledonia.

Two miles east of Caledonia a quarry owned by James Duffy is close to and almost at the level of the track, which is, by aneroid read-

ing, 275 feet lower than at Caledonia station. Stone was obtained from this quarry for the Houston County courthouse built in 1883 and for the Houston County jail built in 1875, but it has not been worked for many years. Beds and joints are sufficiently far apart to allow blocks of good size. Sandy beds and flinty layers occur, and also lines of cavities filled in places with flint, crystalline quartz, or with calcite.

HOSCHEIT QUARRY.

Three miles east of Caledonia an abandoned quarry close to the railroad almost at the level of the track is owned by John A. Hoscheit. The St. John's Catholic Church and St. Peter's Catholic Church, in Caledonia, were made of stone from this quarry, the former in 1899 and the latter in 1873 or 1874. Beds are 6 inches to 2 feet thick, the blocks for the former church being even coursed and 12 inches thick. The rock contains sandy and flinty knots and a few friable beds one-eighth to one-fourth inch thick which weather out, leaving grooves. Some beds are porous and others free of pores.

GENGLER QUARRY.

Four miles east of Caledonia a quarry owned by J. P. Gengler furnished, during the summer of 1913, 200 cords of riprap for the Chicago, Milwaukee & St. Paul Railway. The quarry floor is about 50 feet above the railroad, which at this point is 315 feet lower than at Caledonia station.

MINOR QUARRIES.

Lars E. Hange owns a quarry 6 miles east of Caledonia which supplies a small amount of stone for local purposes. William Henslin also supplies a small local demand.

Rock like that in the Houston County courthouse is durable and attractive, and much of it is available, but no serious effort has been made in Houston County to develop the industry.

LE SUEUR COUNTY.

GENERAL FEATURES.

Rock outcrops in Le Sueur County at Kasota, St. Peter, and Ottawa in the Minnesota River valley. Only the Oneota dolomite (lower Ordovician) and the Jordan sandstone (Cambrian) are seen.

KASOTA AREA.

GENERAL FEATURES.

The Oneota dolomite is a valuable structural and ornamental stone, supplying, from the Kasota quarries, the only "marble" quarried in the State. Kasota is on a rock terrace 15 feet above the river and 1½ miles in width, which extends to Mankato, 8 miles distant, though

interrupted in places by tributary channels. The beds dip eastward at a low angle and are covered with a coating of 4 to 6 feet of drift and river gravel.

Erosion cavities filled with clay, sand, gravel, or boulders are common in the marble beds. In the Hugunin estate quarry a large clay pocket 20 feet deep branches into well-rounded chambers 2 to 6 feet in diameter. In the Babcock & Willcox quarry a pothole

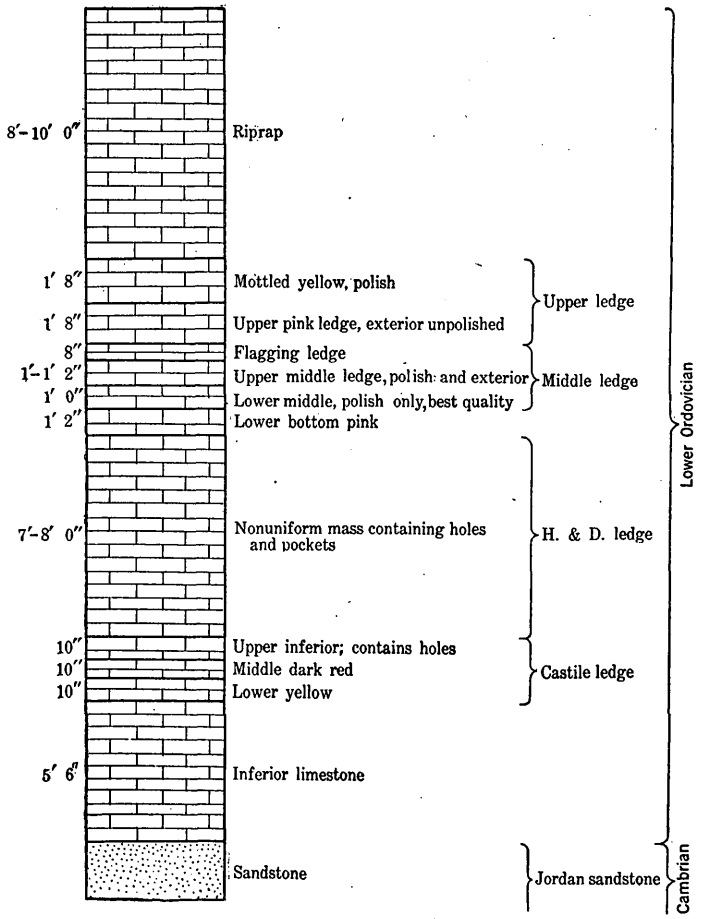


FIGURE 22.—Vertical section in Breen Stone Co. quarry, Kasota, Minn.

about 10 to 12 feet in diameter is filled with sand, gravel, and boulders. On the opposite side of the quarry an irregular V-shaped pocket contains clay in the lower portion, sand, gravel, and boulders above, and a 1-foot level layer of white sand near the top. Many similar cavities and cracks in other quarries contain brown and yellow clay, pure white clay, sand, gravel, and granite boulders. Rock adjacent to the pockets is stained to a depth of a few inches.

The marble from Kasota, widely known as "Kasota stone," is used in many States, and also in Canada and Mexico. It is attractive, takes a good polish, and consequently is suitable for interior decoration. The chief types are a uniform pink (see Pl. V, *B*) and a mottled yellow.

A vertical section of the deepest quarry, that owned by the Breen Stone Co. (fig. 22), has at the top 8 to 10 feet of broken rock, which is used only for riprap, crushed stone, and rubble. Below this is the "upper ledge" of two layers, each 1 foot 8 inches thick; the upper layer of a mottled yellow color is polished, and the lower is used for unpolished exterior work. The "middle ledge" is made up of three layers of pink rock; the upper, 8 inches in thickness, is termed the "flagging ledge" from its adaptability for such work; the next, 1 foot to 1 foot 2 inches thick, is called the "upper middle ledge," and is used both for polishing and for exterior work; the third, 1 foot thick, called the "lower middle ledge," is used entirely for polishing and is of fine quality. Below the "middle ledge" is a layer 1 foot 2 inches thick, called the "lower bottom pink."

Most of the quarries stop at the "lower bottom pink," but the Breen Stone Co. went deeper in order to learn the quality and extent of the lower rock. Immediately below the "lower bottom pink" the "H. & D." ledge, 7 to 8 feet in thickness, was penetrated. It has an uneven rolling upper and lower surface and shows a variable texture and color throughout its mass. It contains many pockets and holes, and, though parts of it have been polished and show beautiful variegated colors, in the Breen quarry it is mostly waste rock. Moreover, the uneven bedding planes make it difficult to quarry without horizontal channeling machines. A point of lithologic and stratigraphic interest is the occurrence in the Widell and Jefferson quarries near Mankato, about 7 miles distant, of a "curly ledge," which shows the same uneven texture and lies at about the same horizon relative to the underlying Jordan sandstone. The "H. & D." ledge has been used to some extent in both the Breen and in the Babcock & Willcox quarries, but its quality is too variable and its uneven bedding too great an impediment to make its use profitable. In the Hugunin estate quarry, however, it is of a more uniform and even texture, and is excavated to a considerable extent.

Below the "H. & D." ledge is the "castile ledge" of three 10-inch layers. The uppermost is inferior on account of holes; the second is a dark-red stone of good quality; and the lower is a yellow stone, also of good quality. The "castile ledge" is but little used on account of its inaccessibility. It is to be seen only at the lowest point in the quarry. Below the "castile ledge" 5½ feet of limestone rests upon the Jordan sandstone.

Between the stripping and the sandstone there is about 32 feet of rock, which falls into well-defined sections. The upper 8 to 10 feet may be classed with the stripping, as its removal is primarily for the purpose of reaching the better rock, though its lower part yields riprap, crushed stone, and rubble. The next 7 to 10 feet comprise the best "Kasota" marble. The remainder of the ledge is mostly inferior and is little quarried.

CHEMICAL AND PHYSICAL CHARACTERS OF "KASOTA" STONE.

An analysis of "Kasota" stone by S. F. Peckham[1] shows the following composition:

Analysis of "Kasota" stone.

$CaCO_3$	47.904
$MgCO_3$	35.227
Fe_2O_3, Al_2O_3	1.490
Insoluble, chiefly silica	13.850
Undetermined	1.529
	100.000

The remarkable alternation of red and yellow beds is discussed on pages 150–151.

Physical tests of pink marble showed that under crushing stress the first crack developed at 4,469 pounds per square inch and final collapse at 5,439 pounds. Under transverse breaking stress the modulus of rupture was found to be 1,129 pounds per square inch; the true specific gravity is 2.823, the per cent of pore space 6.78, and the dry weight 164.5 pounds per cubic foot. For the yellow marble the true specific gravity is 2.589, the per cent of pore space 7.74, and the dry weight 148.8 pounds per cubic foot.

TECHNOLOGY.

The Breen Stone Co. and Babcock & Willcox employ Wardwell channeling machines. The large blocks are broken loose by wedging and are reduced in size by plugs and feathers. The Hugunin Estate Co. has no channeling machines but uses blasting and feather and plug methods. Stripping is done in winter and late in summer. No good stone is quarried later than October 15, as it must have at least a month to dry before frost; otherwise the freezing of the "quarry water" destroys the rock. Stripped areas are covered with straw during the winter. Enough rock is quarried early in summer to keep the shops employed during the entire season. Abandoned quarries are used for rock storage, and thus the old derricks are utilized for loading and unloading.

The Breen Stone Co. and Babcock & Willcox have large and well-equipped shops where much of the labor is done by machinery.

[1] Winchell, N. H., op. cit., p. 638.

Sawing machines are employed to cut thin slabs for wainscoting, flagging, etc. The saws are long blades of iron, several of which are held in parallel position in large vibratory frames. A stream of water and sand constantly flows over them. They wear their way slowly through a large block, converting it to a number of thin slabs. It is a very slow process, the saws sinking only about three-fourths of an inch an hour. They are kept running continuously day and night.

Many of the slabs thus obtained are marketed without further treatment, but a large number are polished. In addition to machine sawing and polishing, hand cutting and carving for trimming and interior finish are carried on extensively.

Some cut stone is produced, but the chief output consists of flagging squares, large slabs for wainscoting, both polished and unpolished, carved work, and trimming required for interior decoration. The size and strength of the slabs obtainable are worthy of note. Twenty-five slabs, each 7 feet by 7 feet 2 inches, were prepared by the Breen Stone Co. for St. Thomas College, St. Paul. Though only seven-eighths of an inch thick, the polishing on both sides, which required a great deal of handling, resulted in the cracking of only one.

The stone in all the Kasota quarries is similar. Some riprap and crushed stone are produced.

For exterior work "Kasota" stone was employed in the post office buildings at Aberdeen, S. Dak., Aurora, Ill., Cedar Rapids and Davenport, Iowa, and Faribault and Mankato, Minn., in the courthouse and county jail at St. Paul; the Kasota Block at Minneapolis; the Administration Building, State School for the Blind, Faribault, and the Library Building, Carlton College, Northfield, Minn. (See Pl. XVII, *B*, p. 150.) It was used for interior decoration in the Masonic Temple, State Capitol, and St. Paul Hotel, St. Paul; the State Capitol, Madison, Wis.; Union Depot, Kansas City, Mo.; Woodward Building, Washington, D. C.; St. Mark's Episcopal Church and the Gateway Building, Minneapolis, and many other structures.

BREEN STONE CO.

According to N. H. Winchell,[1] quarrying began at Kasota in 1868. A quarry owned by Brackenridge, Stewart & Buttars was operated by Messrs. Breen & Young, to whom the present Breen Stone Co. is successor. The company, which has offices in Kasota and St. Paul, operates two quarries which supply large and well-equipped shops. A siding from the Chicago, St. Paul, Minneapolis & Omaha Railway line facilitates transportation of the finished product.

[1] Winchell, N. H., Final report on the geology of Minnesota: Minn. Geol. Survey, vol. 1, p. 165, 1884.

BABCOCK & WILLCOX QUARRY.

One of the first quarries opened in the county was owned by J. W. Babcock. Quarries and shops are equipped with modern machinery, and have the same facilities for transportation and quarry extensively in the same type of rock as the Breen Stone Co.

HUGUNIN ESTATE CO. QUARRY.

The Hugunin Estate Co. began operations in 1911. It excavates and supplies stock but has no shops. The quarry is about half a mile from the quarries just described and has rock of about the same character, except that the "H. & D." ledge is more uniform.

MINOR AREAS.

HIX QUARRY.

At Ottawa Oneota dolomite somewhat similar to the "Kasota" stone overlies the Jordan sandstone. Several small quarries in it have operated intermittently for many years, producing a little stone for local foundations. In a typical quarry owned by Charles Hix the excavation is about 13 feet deep and shows the following vertical section:

Section in Charles Hix's quarry, Le Sueur County, Minn.

	Ft.	in.
Soil and thinly bedded rock	7	0
Yellow to pale pink rock with many holes and lime pits	2	0
Yellow rock, less porous	1	4
Pink with some yellow intermixed near the bottom, somewhat porous	2	6

The bedding is variable, planes being 1 inch to 3 feet apart. A ledge may appear firm in one plane and a few feet away it may split up into numerous beds 1 to 2 inches thick. The rock shows numerous lime pits at all levels. It has a true specific gravity of 2.836, a pore space of 9.75 per cent, and a weight of 160 pounds per cubic foot when dry.

All the quarries are shallow, and it is possible that deeper excavation would uncover better rock. Lime was once manufactured, but no kilns are now in operation.

LIVINGSTONE QUARRY.

The only outcrop noted in the neighborhood of St. Peter is on the farm of Fred Livingstone, in sec. 21, T. 110 N., R. 26 W. The outcrop occurs close to the Chicago, St. Paul, Minneapolis & Omaha Railway, about half a mile south of St. Peter station. Rock was first quarried about 20 years ago and intermittently since that time, and the excavation is now 12 to 15 feet in depth. Most of it is buff

to yellow in color, but one bed, 14 inches thick, near the bottom of the pit is an attractive pink rock of good quality. Further excavation might uncover a larger supply of this type of rock.

MOWER COUNTY.

GENERAL FEATURES.

The rocks of Mower County are similar to those found in the western part of Fillmore County, but exposures of the Cretaceous are more prominent. The following geologic formations outcrop:

Pleistocene: Drift.
Cretaceous: Conglomerate, sandstone, and clay.
Devonian:
  Argillaceous sandstone.
  Dolomitic limestone.
Middle Ordovician: Galena and Platteville (dolomites and shales).

The only formation from which quarry rock can be obtained is the Devonian. The upper beds of dolomitic limestone have been quarried on Woodbury Creek in Lyle Township in the extreme southwest, on Deer Creek in Frankford Township in the east, and on Upper Iowa River in Le Roy Township in the southeast corner.

In Lyle Township a rough, cavernous, magnesian limestone outcrops along Woodbury Creek in beds aggregating about 18 feet in thickness, with a gentle southward dip. It is suitable for that type of rough masonry for which concrete is now largely substituted. It was quarried to some extent many years ago, though not recently.

In Frankford Township, on Deer Creek, about 10 feet of yellowish buff limestone, similar to that near Washington (p. 164), was quarried many years ago for local bridge abutments and foundations.

At Le Roy very little of the porous rough limestone appears, as it is overlain by a later fine-grained uniform Devonian limestone, nearly white in color. It occurs more abundantly to the south in Iowa. Near Le Roy its maximum thickness is not more than 15 feet, and it is interbedded with thin bands of shale. It is of much better quality than the underlying beds, being quite free of pores and very attractive in color. It has been quarried at a number of points in the vicinity of Le Roy, but only one quarry is now in operation.

FOWLER & PAY QUARRY.

Rock is at present excavated for the production of lime only. Ledges of uniform fine-grained limestone, well adapted for interior decoration and polished work, lie close to the railway but are as yet undeveloped.

The upper shaly sandstone, which outcrops along Cedar River near Austin, is fine grained and fairly uniform. Its color is blue, except where oxidation has turned it red along joints and near the surface.

Cavities filled with quartz or ocher are common. It fractures easily and is cross-bedded in places, and in consequence wedges out in undesirably angular blocks. Some of the rock has been quarried by Fowler & Pay for lime burning.

NICOLLET COUNTY.

GENERAL FEATURES.

The surficial rocks of Nicollet County are confined to the valley of Minnesota River, where they outcrop in the following order:

Pleistocene: Drift.
Cretaceous: Shale and sandstone.
Ordovician: Oneota dolomite.
Cambrian:
  Jordan sandstone.
  St. Lawrence limestone.
Huronian: Quartzite.
Archean: Granite and gneiss.

The Archean granites and gneisses of the county are discussed with the crystalline rocks and the quartzite with the sandstones.

A little of the St. Lawrence limestone has been quarried at Hebron and in the southwest corner of Faxon Township. Its quality is inferior and the quarries were long ago abandoned.

The Oneota dolomite crops out at St. Peter and North Mankato. Within the city of St. Peter rock was quarried along the river bank and used for structural purposes for many years. As it lacks the ornamental qualities of the "Kasota" stone, it has gradually been displaced by concrete construction and the quarries are abandoned. Near the asylum, about 2 miles southwest of St. Peter, stone of good quality was quarried years ago but is now unused.

NORTH MANKATO STONE QUARRY CO.

In North Mankato the Oneota dolomite has been excavated in several quarries, only one of which is still active. The North Mankato Stone Quarry Co. first began operations in 1907 and has quarried continuously since that time. The rock is a buff-colored dolomite similar to the stone at Mankato. As no sidings are available, heavy bridge rock can not be handled, and the chief output is rubble, though crushed rock is also produced. The quarry floor is about 20 feet above the river flats, a condition that favors drainage and transportation.

OLMSTED COUNTY.

GENERAL FEATURES.

Rocks from Cambrian to Upper Ordovician age are represented in Olmsted County, though only certain beds are useful for building purposes. The following formations outcrop:

Pleistocene: Drift and loess.
Ordovician:
Maquoketa shale.
Galena limestone.
Platteville limestone.
St. Peter sandstone.
Oneota dolomite.
Shakopee limestone.
Cambrian:
Jordan sandstone.
St. Lawrence formation (limestone, sandstone, and shale).

The St. Lawrence formation outcrops only in the valley of Zumbro River, in the northeastern part of the county. Lime was burned from it at one time, but for many years it has not been used.

The Shakopee and Oneota, which together constitute the Prairie du Chien group, are not easily distinguishable from each other in Olmsted County. Each is from 40 to 60 feet thick along Whitewater, Zumbro, and Root rivers and each consists of sandy limestone interbedded with bands of shale. Both are useless for building purposes.

The Platteville formation is the only rock now quarried. It is widespread over the county but is worked only in the vicinity of Rochester, where all the active quarries in the county are grouped.

ROCHESTER STATE HOSPITAL QUARRY.

A quarry about a mile from Rochester, in sec. 31, T. 107 N., R. 13 W., is owned by the State of Minnesota and is operated under the supervision of W. M. Weeks, superintendent of the Rochester State Hospital. It was opened about 1878. Most of the quarrying is done by hospital inmates, 25 to 40 working at one time. The rock is blue at depth but is yellow along joints and near the surface. Beds are 3 inches to 2 feet thick, and joints are 10 to 20 feet apart. About 2 feet of soil is stripped, and the quarry is worked to a depth of about 30 feet. The quarry is situated on a high bluff, and the crusher is placed at a lower level than the quarry floor. The entire output in 1912 was crushed rock, which was employed in the concrete work of a new sanitarium at the hospital.

DONAHUE BROS. QUARRY.

About a mile northwest of Rochester a quarry, now owned by Donahue Bros., was opened about 50 years ago and has been worked very extensively. The rock is much the same as that at the hospital quarry but is said to withstand weathering better. It has a true specific gravity of 2.788, a pore space of 3.04 per cent, and a dry weight of 169 pounds per cubic foot.

Beds are 3 inches to 3 feet thick and are horizontal. Open joints 6 to 20 feet apart strike east, N. 30° E., N. 20° W., N. 70° E.

Joint walls in many places are coated with calcite. The output is crushed rock and some rubble.

WALDEE QUARRY.

In the same bluff as the Donahue Bros. quarry is one owned by George Waldee. The rock is the characteristic yellow-buff limestone which caps the low hills around Rochester. Bedding planes are 2 inches to 3 feet apart, averaging about 10 inches. Joints striking N. 50° E. are 12 to 15 feet apart; those striking N. 25° W. are 10 to 20 feet apart; and a few minor joints strike N. 25° E. Fossils and cherty or limy concretions are of common occurrence. Some beds crack into thin slabs when exposed to the weather.

Quarry conditions are good as regards drainage, and bench excavation makes quarrying easy. The overburden is 4 to 8 feet of soil and loose rock. An excellent road leads a mile to Rochester, in and around which most of the rock is used. Rochester is abmirably situated to supply surrounding towns with stone and the local demand is good. Much rock is available.

RAMSEY COUNTY.

GENERAL FEATURES.

Bedrock exposures are confined to the Mississippi River bluffs in the southern part of Ramsey County, where outcrops of Decorah shale, Platteville limestone, and St. Peter sandstone, all of Ordovician age, were seen.

The Platteville formation is the only structural rock in the county. It outcrops almost continuously along the river bluff and has been quarried at numerous points. In general, it falls into three rather distinct parts that have fairly constant characters: An upper layer, 6 to 10 feet thick, of drab to buff magnesian limestone, containing many fossils and masses of crystalline calcite, a bed of about the same thickness of argillaceous limestone or shale, and at the bottom a 12 to 15 foot layer of blue limestone, interbedded with thin shale bands, which has supplied most of the structural stone in and around St. Paul. The weathering out of the shale layers causes the hard layers to stand out in relief and thus to form the characteristic horizontal ridges so prominent in all the old stone walls of the city. On this account the rock is not very durable. A bed of blue shale 3 to 6 feet thick lies between the blue limestone and the underlying St. Peter sandstone. The only quarries now actively engaged are in South St. Paul and near the Fort Snelling Bridge on the north side of the river.

BIELENBERG QUARRY.

The South St. Paul quarry, near East George Street, has been operated by C. Bielenberg since 1904. The rock is variable in its different beds.

Two distinct types of stone, an upper yellow and a lower blue bed, are quarried. The 3-foot bed of porous yellow rock is used for structural purposes. Immediately below this are two contiguous beds, 5½ and 6 inches thick, which are of high quality. The rock is a uniform, fine-grained, yellow limestone, containing many small grains of crystalline calcite. A partial analysis gives calcium carbonate, 55.57 per cent; magnesium carbonate, 29.11 per cent; insoluble in hydrochloric acid, 13.54 per cent. The rock is therefore a magnesian limestone. The insoluble portion is probably mostly clay, but the presence of clay distributed uniformly throughout a rock mass has little effect on its durability. (See p. 151.) The rock is a beautiful structural stone and it is a matter of regret that only about half an acre of it is now available.

In the quarry from which the yellow stone is obtained, argillaceous limestone, called "soap rock," is so thick that no attempt is made to quarry the underlying blue limestone, which is now excavated from an adjacent quarry, where a thickness of 12 to 14 feet is available. There are three beds, each 17 inches thick, and others 6 to 14 inches. Joints are so spaced that blocks 6 feet in length may be obtained. The rock is used mainly for basement construction. The foundation of the owner's house is made from this stone, and 15 years of weathering has had no apparent effect on it.

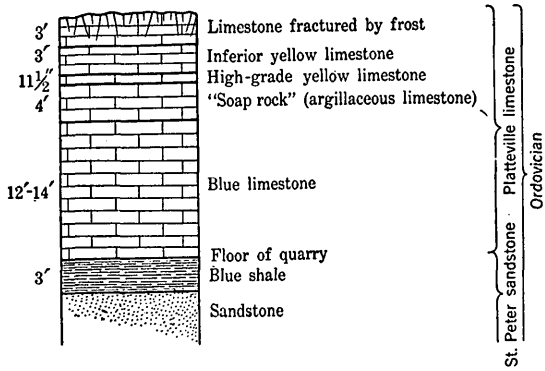


FIGURE 23.—Columnar section of C. Bielenberg's quarry, South St. Paul.

An adjoining quarry of similar rock, owned by John Fischer, is now nearly worked out.

ROBBINS QUARRY.

On the north side of the river, not far from the Fort Snelling Bridge, J. B. Robbins operates a large rock-crushing plant. The limestone, whose total thickness is about 10 feet, is blue to yellowish, thin bedded, and inferior for any purpose except crushing. Beneath it are 6 to 10 feet of blue shale overlying the St. Peter sandstone. An area of about 60 acres is still available. Practically the entire output is used for street construction in St. Paul. Transportation is by team and wagon. Crushed rock from this quarry was used in the construction of the concrete piers of the Fort Snelling Bridge, and is said to have been very satisfactory.

RICE COUNTY.

GENERAL FEATURES.

The rocks of Rice County are all of Ordovician age. Rock outcrops along the valleys of Cannon and Straight rivers and in the northeastern townships along the bluffs of Prairie Creek and caps the hills at some distance from streams. The Galena limestone, Decorah shale, Platteville limestone, St. Peter sandstone, and Shakopee dolomite outcrop successively.

The Platteville and Shakopee formations have furnished all the structural stone of the county. The Platteville is the more accessible, appearing as prominent bluffs along Cannon River and Prairie Creek. Near Faribault it lies in massive beds about 15 feet in thickness beneath the green Decorah shale. Active quarrying is now confined to a small area on Straight River and its tributary, Fall Creek, about 2 miles east of Faribault. The quarries are in sec. 33, Cannon City Township (T. 110 N., R. 20 W.), and extend southward into sec. 4, Walcott Township (T. 109 N., R. 20 W.).

CROMER QUARRY.

The quarry on Fall Creek was opened by Philip Cromer in 1865,[1] and since 1909 has been operated by J. A. Cromer The workable ledge is 11 feet thick and the stream flows over the quarry face. Below the stripping of 6 inches to 6 feet of soil four beds, 12, 8, 10, and 9 inches in thickness, may be used for the manufacture of lime, being reported to contain 97 per cent of the combined calcium and magnesium carbonates. The remaining 8 feet of the ledge is a good building stone, blue to drab in color, free from imperfections, and attractive. Joints striking N. 62° W., N. 80° W., N. 70° E., and N. 5° E. are vertical and 6 to 10 feet apart. A little iron stain observed originates in the bedding planes of the upper strata. Part of the rock used in the construction of buildings connected with the Minnesota School for the Deaf at Faribault was obtained from this quarry, but in 1912 the entire output was shipped away and used as a flux in blast furnaces. The nearest railroad station is Faribault, where the Chicago, Milwaukee & St. Paul, the Chicago, Rock Island & Pacific, and the Chicago Great Western railways intersect.

LIEB QUARRY.

About half a mile south of the Cromer quarry, on the Straight River bluff, George Lieb began operations in 1907. (See fig. 24.)

The thickness of stripping required, approximately 30 feet, makes quarrying rather expensive. The stripping is a shale which could be

[1] Winchell, N. H., op. cit., p. 171.

utilized for the manufacture of brick, and the operation of a brick plant in combination with the quarry might be profitable.

The upper thin limestone beds are uniform and nearly white. If the iron-bearing bed is included in structural blocks it causes serious rusty stains, as may be seen in certain blocks in the basement of the Brunswick Hotel, Faribault. The so-called "marble" ledge is of exceptional purity and takes a good polish. The upper limestone beds, excluding the clayey and iron layer, supply stone for the Minnesota Sugar Co at Chaska for use in refining sugar, about 900 cords a year being shipped for this purpose. The massive lower bed, which is gray to drab in color, is made into even-course building blocks of high quality. Buildings connected with the Shattuck School, School for the Blind, School for the Feeble-Minded, and School for the Deaf are made of stone from this quarry or others in the near vicinity. As observed in these structures, the Faribault stone is attractive in color, durable, and free from blemish where the iron-stained bed is not employed. Of late years, however, Bedford, Ind., stone has been employed for water tables, for it is more easily cut and carved.

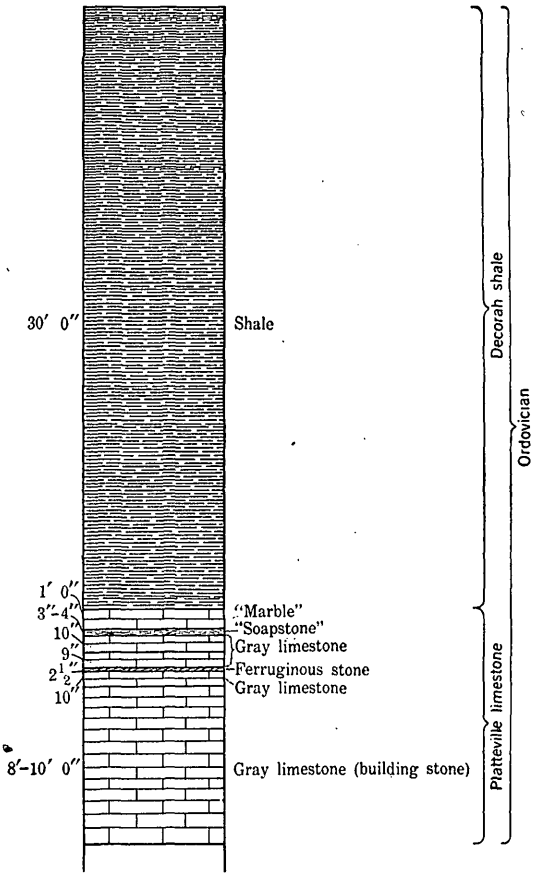


FIGURE 24.—Vertical section of George Lieb's quarry, Faribault, Minn.

KAUL QUARRY.

A short distance north of the Lieb quarry, in sec. 33, Eberhart Kaul operates a quarry on the same ledge. It was worked many years ago for local buildings and was purchased by the present owner in 1901. It is quarried extensively for structural work, a subordinate part of the product being employed for riprap and sugar refining. The rock is blue to drab in color in the lower beds and nearly white

in the upper part. Under the microscope it appears to be a fairly even grained fossiliferous limestone. A few grains of pyrite are associated with the fossils and may be of organic origin. The rock has a true specific gravity of 2.788, a pore space of 3.59 per cent, and a weight of 168 pounds per cubic foot when dry.

The vertical section is similar to that in the Lieb quarry except that little of the stripping exceeds 12 feet. Drainage is perfect, as the stone is worked as a bench quarry with the floor higher than the river bed. The average production is about 1,000 cords a year. The construction of an addition to the School for the Deaf at Faribault during 1912 required 650 cords.

MINOR QUARRIES.

The city of Faribault owns a quarry which is nearly worked out and has not been operated for years. Its product was crushed rock, for which gravel has now been substituted.

The Platteville limestone has been quarried extensively along Prairie Creek and also near Dundas on Cannon River. The product has been used extensively in Northfield, where Willis Hall, of Carleton College, was built in 1872—the main structure of "Dundas" stone and the trimmings from Faribault. It was burned in 1879 and rebuilt with the same walls. As observed in this building the "Dundas" stone contains sandy and shaly pits and layers which disintegrate into holes and seams much as in the "St. Paul" stone. The trimming is much better but has turned red, perhaps partly from the fire. The bulkheads of the entrance steps are made of blocks with the bedding vertical. They are badly cracked and are disintegrating much more rapidly than the steps or the main structure.

A small quarry in the Platteville formation is worked on a hilltop near St. Olaf's College at Northfield. The rock is thin bedded and contains shale layers, and is useful only for foundation work.

The Shakopee formation appears in the Cannon River valley from Dundas to the Dakota County line. It is interbedded with sand and shale layers and is porous. It underlies Northfield, and has been excavated for foundations.

SCOTT COUNTY.

GENERAL FEATURES.

Surficial rocks in Scott County are confined to a few places in the Minnesota River valley. The following formations outcrop:

Pleistocene: Drift.
Lower Ordovician:
  Shakopee dolomite.
  Oneota dolomite.
Cambrian:
  Jordan sandstone.
  St. Lawrence limestone.

The sandstone quarries at Jordan are described on page 210. The Oneota dolomite, which outcrops over a considerable area close to the railway, near Merriam Junction, has not been quarried.

SCHROEDER BRICK & LIME MANUFACTURING CO. QUARRY.

Some stone is quarried by the Schroeder Brick & Lime Manufacturing Co. in the town of Shakopee. Most of it is used for lime burning and is said to make a very strong brown lime. The quarry face, 12 to 15 feet deep, shows a series of distinct but uneven beds 6 to 8 inches thick. Most of the rock is dolomite but is interbedded with layers of sandstone, which are used locally for foundations. Though it is useful for this purpose probably it would not pay to excavate it except as a by-product in the manufacture of lime. Both rocks are very porous and show irregular jointing planes.

ST. LAWRENCE QUARRY.

About a mile from St. Lawrence siding, midway between Jordan and Belle Plaine, an old quarry was opened 40 or 50 years ago but has not operated for about 15 years. The rock belongs to the St. Lawrence formation. It is a reddish dolomite with green specks. Its true specific gravity is 2.814, its pore space 9.99 per cent, and its weight per cubic foot 158.3 pounds when dry. It is flat, lying in beds 4 to 10 inches thick. Joints are irregular and 3 inches to 2 feet apart. The quarry has been worked to a depth of 6 or 7 feet over an area of about an acre. The old St. Lawrence Hotel, a prominent road house in stage-coach days, built from this stone 40 years ago, is badly cracked in places, but several houses on near-by farms, built of this rock, are still in good repair and are attractive.

STEELE COUNTY.

Steele County is almost completely drift covered, bedrock appearing only in the vicinity of Owatonna.

In the bed and along the banks of Straight River, in secs. 28 and 33, Clinton Falls Township, are rather extensive, though low, outcrops of limestone which probably belong to the Galena formation of the middle Ordovician. In past years, when stone was so much in demand for foundation work, this rock was quarried extensively and hauled many miles. The wall of an abandoned quarry now owned by D. R. Lindesmith, shows 2 to 6 feet of drift and 1 to 10 feet of thin-bedded limestone, the bottom of which is at normal water level. Below the water level 4 feet of thick-bedded limestone is reported, and below this a useless shaly limestone. Near the surface the beds are 1 to 3 inches thick, but lower ones are progressively thicker, reaching a maximum of about 8 inches at water level. Joints are

very irregular and closely spaced. Drainage is poor, the best beds occurring below water level. The rock is blue, turning slightly yellow by weathering, is uniform, and free of defects. It was used in Owatonna and the surrounding country in the foundations of many structures, whose present preservation shows that it is durable. The quarry is close to the Chicago, Milwaukee & St. Paul track and is 3½ miles from Owatonna station. It has not been worked for the last 4 years, except for an occasional load of thin slabs from the river bed for well curbing or foundations.

WABASHA COUNTY.

GENERAL FEATURES.

Rock outcrops in Wabasha County are continuous all along Mississippi River, along Zumbro River through the center of the county, and in Elgin and Plainview townships at the south. The range of elevation from the Mississippi River level to the tops of the inland hills is about 600 feet. Quarry rock may be obtained from the Platteville, Oneota, and St. Lawrence formations. The important quarries are the Burkhardt, in the Platteville limestone, south of Plainview, and the First National Bank, John Beaver, Jewell Nursery, and Claus Bremer quarries in the Oneota dolomite along Mississippi River near Wabasha and Lake City. Cambrian rocks were quarried to some extent years ago.

The following rock formations are exposed in Wabasha County:

Pleistocene: Drift and loess.
Ordovician:
- Platteville limestone or dolomite.
- St. Peter sandstone.
- Shakopee dolomite.
- Oneota dolomite.

Cambrian:
- Jordan sandstone.
- St. Lawrence formation (limestones, sandstones, and shales).

BURKHARDT QUARRY.

The only quarry of importance in the Platteville is that owned by Alfred Burkhardt on the bluff of Whitewater River, about 3 miles south of Plainview. The rock is a gray to white crystalline limestone having a true specific gravity of 2.880, a pore space of 1.02 per cent, and a weight of 178.2 pounds per cubic foot when dry. Beds are 3 inches to 3 feet thick and dip 5° to 10° E. Joints are very irregular, but blocks of fair size may be obtained. The quarry is of the bench type and is easily accessible by road. The rock is covered with 2 to 6 feet of soil. The upper beds were burned for lime several years ago in a kiln near the quarry. Later, building stone and crushed rock were quarried, the latter being employed for street construction in Plainview. There was no production in 1912.

Three small quarries were once operated near Mazeppa in the extreme west of the county but are now inactive. Another small quarry was once worked near Millville. They are all in the Oneota formation.

FIRST NATIONAL BANK QUARRY.

In sec. 24, Pepin Township, near Reads Landing, a quarry owned by the First National Bank of Wabasha was opened about 1888 and operated at intervals until 1900. The rock is a fine-grained, though somewhat porous, buff Oneota dolomite, similar to the "Frontenac" stone of Goodhue County. Some ledges of excellent quality are obtainable. Distinct bedding planes are 6 inches to 3 feet apart and are horizontal. Vertical joints 2 to 3 feet apart strike N. 80° E. and N. 5° W. The upper 15 feet contains many cavities, but the lower 40 feet is of good quality. About half the rock is suitable for building stone. As a rule the thicker beds are more uniform. The rock is bare in places; elsewhere the maximum overburden is about 20 feet of soil and broken rock. The quarry floor is 290 feet above the railroad tracks. Some of the waste rock was used by the United States Government during 1913 for shore protection along Mississippi River.

BEAVER QUARRY.

A small quarry owned by John Beaver near the First National Bank quarry has had a similar history. No rock has been excavated for many years.

JEWELL NURSERY CO. QUARRY.

A quarry owned by the Jewell Nursery Co. of Lake City is 1½ miles from Lake City station on the Chicago, Milwaukee & St. Paul Railway. It was opened in 1909 and is worked in the winter time only. The rock, which is of Oneota age, is a buff sandy dolomite, locally known as sandstone. Bedding planes are distinct and 4 inches to 3 feet apart, averaging about 1 foot. Major joints striking north-south and secondary joints east-west are about 4 feet apart and are vertical. The vertical quarry wall of about 30 feet shows an alternation of hard and soft beds, the latter being of inferior grade. Calcite-filled vugs and cherty inclusions are common, and some beds are too thin to be of use. The overburden so far is about 6 feet but will increase greatly with wider excavation. The rock is suitable for foundation construction. Most of it is used for structures connected with the nursery, but some is sold.

BREMER QUARRY.

Claus Bremer opened a small excavation in 1912 in sec. 6, Lake Township, about 3 miles from Lake City. The rock is a dense, fine-grained, buff Oneota dolomite, of better quality than most of the

rock seen in Wabasha County. Joints are similar in direction and spacing to those of the Nursery quarry. Bedding planes are 6 inches to 1 foot apart. The overburden is variable, the minimum being 3 or 4 feet of soil. Very little work has been done here, and the quarry is now abandoned.

MINOR QUARRIES.

The Beckman quarries, now abandoned and overgrown, are the oldest in the region and supplied most of the structural stone used in Lake City. They are in Goodhue County but are near the Wabasha line.

Other abandoned small quarries, such as the Singer quarry, at Reads Landing, and the Baker quarry, near Wabasha, are in the St. Lawrence formation. The Singer quarry is in a buff, thin-bedded, sandy dolomite, with interbedded shales, and is too friable for structural purposes. The Baker quarry is in a buff to bluish sandy dolomite, which was used many years ago as foundation stone.

WASHINGTON COUNTY.

GENERAL FEATURES.

The bedrock formations of Washington County are of Cambrian and Ordovician age. The following formations crop out:

Pleistocene: Drift.
Ordovician:
- Platteville limestone.
- St. Peter sandstone.
- Shakopee dolomite.
- Oneota dolomite.

Cambrian:
- Jordan sandstone.
- St. Lawrence formation (sandstone, limestone, and shale).

Quarry rock is obtained only from the Shakopee and Platteville formations. The sandy dolomitic limestone of probable Shakopee age was once quarried extensively in the bluffs of St. Croix River, near Stillwater, and is still utilized.

BEAN AND McGEE QUARRIES.

In 1854 a quarry was opened in the bluff between Stillwater and South Stillwater, near the corner of Fourth Avenue and Burlington Street, and a great quantity of rock was removed from an excavation about one-fourth of a mile long. The quarry face is about 30 feet high and has been worked back into the bluff as a shelf quarry for about 100 yards. Two quarries, the Bean and the McGee (fig. 25), are separated only by a roadway and are similar. No rock was quarried in 1913.

The 6-foot bed at the bottom of the quarries is much the best, the upper beds being porous. It is fine grained, dense, uniform in color,

and very attractive in appearance, being pale yellow to white. The proportion of magnesium carbonate present, as shown by chemical analysis of a sample from the lower 6-foot bed, is almost high enough to constitute a dolomite. The rock consists of 50 per cent calcium carbonate, 40.21 per cent magnesium carbonate, and 9.26 per cent insoluble in hydrochloric acid.

Prominent north-south and east-west jointing systems were noted, the planes being 2 to 6 feet apart. Transportation is by wagon.

Although of excellent quality the 6-foot ledge of good building stone is so placed that it could not be worked profitably alone. However, if crushing were carried on and the porous rock thus removed, much fine building stone could be obtained as a by-product. St. Michael's Catholic Church in Stillwater, a notable structure built from this stone in 1873, shows no evidence of deterioration either in appearance or durability after 40 years of weathering. The Lincoln and Central schools, also built of Stillwater stone, are very attractive. The Eichter block, at the corner of North Main and East Myrtle streets, is of local stone, as are many basements, steps, and retaining walls.

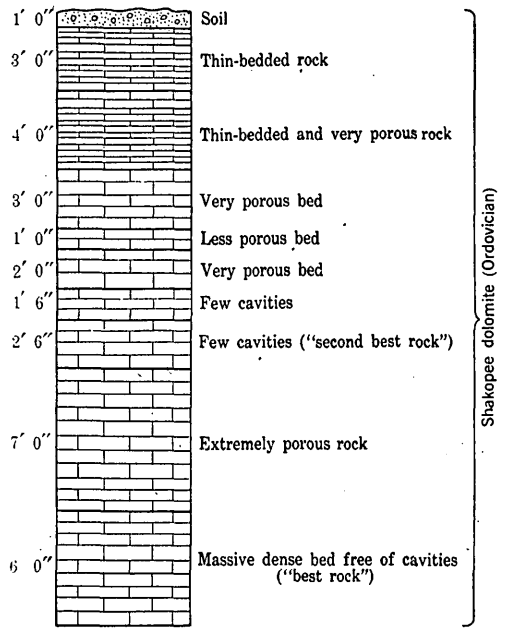


FIGURE 25.—Vertical section of the McGee limestone quarry, Stillwater, Minn.

Nearer the river a lower ledge of very porous rock, best adapted for crushing for macadam or concrete, has been worked to a depth of about 12 feet.

STILLWATER CITY QUARRY.

In North Stillwater, near Wilkin Street, close to the St. Croix River bluff is a quarry which was purchased in 1913 by the city of Stillwater from C. H. Carli. It is one of the oldest in the State, excavation having first been made in 1847.[1] A large crusher is employed to furnish material for street construction. The quarry is admirably situated for loading the crushed stone either on wagons or trains, both a roadway and the Northern Pacific tracks lying at the foot of the nearly vertical bluff.

[1] Winchell, N. H., op. cit., p. 159.

The rock is very porous, cavities of one-fourth to one-half or even 1 inch in diameter being abundant. Some holes are open and some filled with sand. It does not seem probable that the rock will ever be used for building to any extent.

MINOR QUARRIES.

The Platteville limestone outcrops in many places in the higher land in the central and western parts of Washington County. Small quarries were worked many years ago in Grant, Oak Dale, Lakeland, Afton, Newport, and Cottage Grove townships. Except as quarried occasionally for local purposes, they are now idle.

WINONA COUNTY.

GENERAL FEATURES.

Limestone quarrying is an important industry in Winona County. The Lower Ordovician Oneota dolomite outcrops in many places along the bluffs of Mississippi River and tributary streams, and away from the river the Platteville limestone of Middle Ordovician age caps the hills. Both formations supply stone of fair quality and each is quarried in several places. In 1912 nine active quarries, employing about 140 men, were producing (in descending order of importance) crushed stone, riprap, cut stone, and rubble. The rocks, all of Cambrian and Ordovician age, outcrop as follows:

Pleistocene: Drift and loess.
Ordovician:
- Platteville limestone.
- St. Peter sandstone.
- Shakopee limestone (including sandstone).
- Oneota dolomite.

Cambrian:
- Jordan sandstone.
- St. Lawrence formation (limestone, sandstone, and shale).
- Franconia sandstone.
- Dresbach sandstone.

The Cambrian rocks, except the Dresbach sandstone (see p. 209), are extremely loose and crumbling and are consequently unfit for structural purposes.

QUARRIES IN THE ONEOTA DOLOMITE.

GENERAL FEATURES OF THE ROCK.

The Oneota dolomite is quarried in many places, chiefly along the Mississippi River bluffs, but as the underlying Cambrian rocks form cliffs over 400 feet high, the Oneota quarries are perched at difficultly accessible points along the summit of the bluff. The rock is at all points nearly uniform.

The thickness of the rock quarried ranges from 18 to 60 feet in the vicinity of Winona city, and reaches 100 feet at Minneiska and Lamoille. It lies in beds 1 to 6 feet thick. The dip is low, not more than 1° to 3°, and is variable in direction, though generally south or east. Joints are in general at right angles and are 3 to 20 feet apart; but they are variable, both in direction and spacing, the maximum variation occurring in individual quarries. The color of the rock is gray or white. Near the top of the quarries a bed 2 to 12 feet thick, locally known as freestone, is a soft dolomite which quarries in large pieces, trims easily, and is used for cut stone. The post office, the Methodist Church, and many other buildings in Winona are made from this ledge. A partial analysis showed 45.83 per cent calcium carbonate, 39.42 per cent magnesium carbonate, and 11.93 per cent insoluble in hydrochloric acid. The white limestone is of better grade than the gray but forms only a small proportion of the whole. Some layers are flinty, and all the stone is somewhat porous and contains many "sand pits." The lower beds are sandy. Rock is quarried as cut stone, rubble, riprap, crushed stone, and flagging. All quarries are of the shelf type.

HAUN QUARRY.

Three miles northwest of Winona, near Gilmour Valley, a quarry owned by John Schultz and operated by George Haun is reached by a winding and precipitous road which mounts about 450 feet above the river flats. Transportation is by wagon. The quarry shows the following section:

Section in George Haun quarry, near Winona, Minn.

	Feet.
Soil and broken stone, stripping	6
Dolomite, "freestone"	4
Limestone, sandy, valueless	6
Limestone, gray, for building purposes	10
Limestone, white, of good quality, for cut stone or rubble	2
Limestone, gray, building stone	10
Limestone, for crushing	20

Joints are in four systems, north, east, N. 30° W., and N. 60° E. The joints are far apart, 40 feet in places, which adds to the difficulty of quarrying. Bedding planes are closed seams but split with ease at intervals of 6 inches to 3 feet. The rock is very porous with small cavities, many of which contain white friable sand and are known as "sand pits." Stone from this quarry was employed in the foundation of the new capitol at St. Paul, and the Central Methodist Church, Baptist Church, and county jail at Winona. The rock is well adapted for dressed stone with bush-hammered surface. Window sills or steps may be obtained 8 inches thick and 10 or 12 feet long.

The rock was tested at St. Paul when the capitol was built, and its employment in this structure should recommend it as a satisfactory material.

BIESANZ STONE CO. QUARRY.

The Biesanz Stone Co. operates a quarry at Minnesota City, 6 miles northeast of Winona, where work began about 1903. A section of the quarry shows the following beds:

Section of Biesanz Stone Co.'s quarry at Minnesota City, Minn.

	Feet.
Broken rock and soil	6–8
Best rock, used for rubble, cut stone, and ground for fertilizer	10
Inferior rock, used only for riprap	8

The rock, like that in the Haun quarry, splits easily along horizontal planes. It is carried by cable cars on an inclined track to a crusher at the foot of the bluff. A siding from the Chicago Great Western Railroad facilitates transportation. Cut stone, rubble, riprap, and crushed stone are produced. A new enterprise, that of placing on the market finely ground stone for fertilizer, was begun in 1909, and in 1911 supplied 400 tons, valued at $1,000, to a constantly increasing demand. The demand for building stone, on the other hand, is decreasing.

ABELL QUARRY.

West of Winona, in sec. 34, T. 107 N., R. 7 W., is a quarry owned by Otis Abell. Transportation is by team and wagon, but its situation close beside a main highway leading to Winona, 1½ miles distant, is advantageous. The rock is similar to that in the Biesanz Stone Co. quarry. The quarry has not operated since 1907.

One-fourth of a mile beyond, a quarry owned by the city of Winona to provide crushed stone for street construction, has been idle since 1910.

UNITED STATES GOVERNMENT QUARRY.

Near Lamoille, in sec. 12, T. 106 N., R. 6 W., the United States Government operates a large quarry for riprap for dams and shore protection along the Mississippi between Dresbach and Winona. Rock was first quarried in 1899 and has been removed in large quantities, the cliff face having been cut away to a depth of about 100 feet, from 510 to the present floor level at 412 feet above low water. The back wall of the quarry is now about 70 feet high. (See fig. 26.) The beds dip 1° to 2° S.—that is, away from the river. This is somewhat unfavorable to drainage but is overcome by projecting holes from the quarry floor to the porous sandstone beneath.

The rock is shattered by heavy blasting in holes projected by three steam drills and is then broken by hand tools into pieces convenient

for handling. Tracks laid on the quarry floor bear cars on which skips (large metal pans) are placed. The skips are loaded with rock fragments by hand and are hauled by horsepower to a heavy steel cable 1,200 feet in length, which extends from the quarry to the river, passing over the Chicago, Milwaukee & St. Paul Railway tracks. A carriage on this cable attached to the skip by three powerful hooks, hoists it free of the car, and lowers it swiftly to a barge on the river, which carries the rock to the point desired. Each skip holds 6 tons of rock and one skip is lowered every six minutes. About 65 men are employed.

The output of this quarry from August 1, 1910, to July 31, 1911, was 20,241.9 cubic yards, considerably below the annual average, which in an average full season (six months) is about 38,000 cubic yards. The cost of production from August 1, 1910, to July 31, 1911, including stripping, drilling, blasting, subsistence, quarrying, and loading barges, was 59.7 cents per cubic yard. The total cost of quarrying, including deterioration of plant, rental of quarry, and repairs, is about 70 cents per cubic yard. For small quarries, operating with fewer labor-saving devices, the cost would of course be higher.

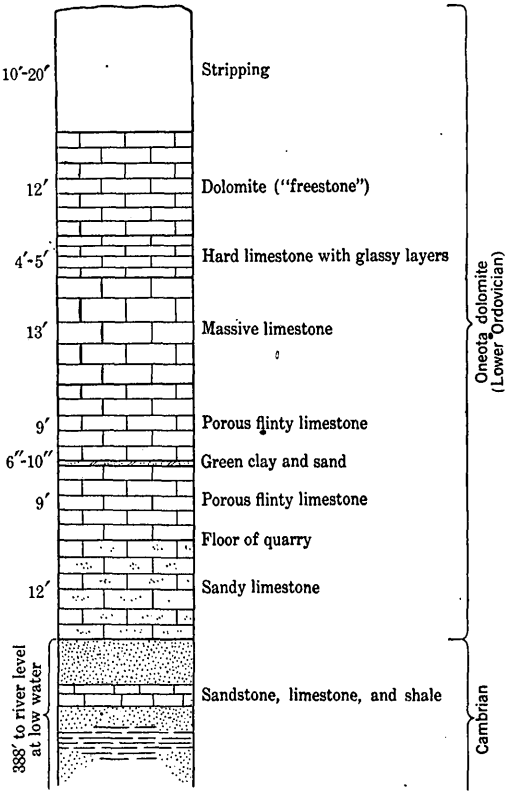


FIGURE 26.—Vertical section of the United States Government quarry, Lamoille, Minn.

GENTZKOW & MOGREEN QUARRY.

About 2 miles southeast of Minneiska station, in the northeastern corner of Winona County, a quarry similar to the Government quarry is owned by Gentzkow & Mogreen. It was operated many years ago by John Gage, the present ownership dating from 1908. The quarry floor is 283 feet above the river, and is very close to the top of the Cambrian. (See fig. 27.)

The production is entirely riprap, supplied to the United States Government under contract for river protection. Transportation is by cable cars on a double track 1,000 feet long from quarry to river, passing beneath the Chicago, Milwaukee & St. Paul tracks. The loaded car going down brings up the empty one. Further transportation is by barges on the river. About 45 men are employed. The contract in 1912 called for 18,000 cubic yards.

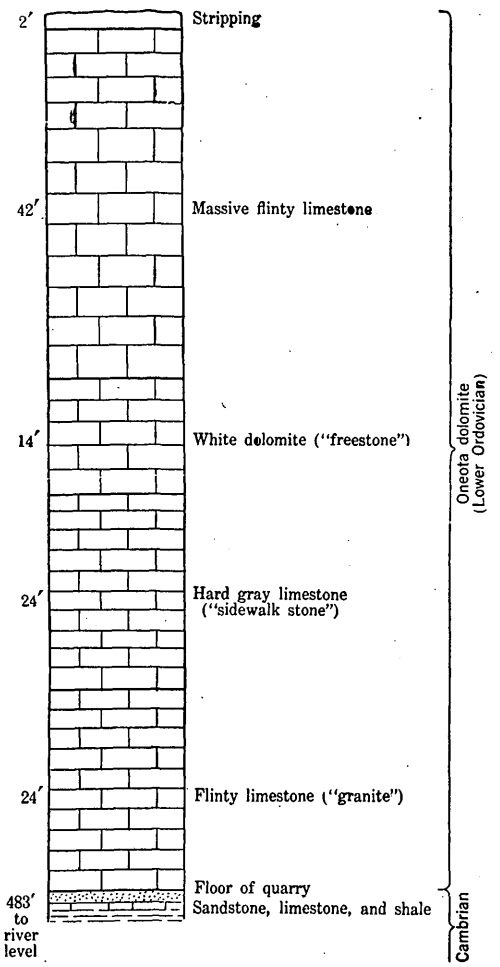


FIGURE 27.—Vertical section of the Gentzkow & Mogreen quarry, Minneiska, Minn.

DRESBACH QUARRY.

A quarry at Dresbach supplied riprap in past years but is not operating at present. The conditions are less favorable than at the two quarries just described, for the rock must be transported a mile by team and wagon.

CHICAGO & NORTHWESTERN RAILWAY QUARRY.

An important quarry in the Oneota dolomite is that owned by the Chicago & Northwestern Railway, midway between Stockton and Lewiston. It has been operated by the Widell Co. of Mankato since 1907. On account of the steep grade in the railway from Winona to this point, the quarry floor is level with the tracks. The rock is gray to white, and is similar to the stone at Winona.

Beds may be obtained up to 3 feet in thickness. Major joints strike N. 25° E. and secondary joints N. 75° W. They are vertical and are 4 to 5 feet apart. Blocks of large size are available, but none are now quarried, the entire product for the last 8 or 10 years having been used for crushed stone for railway ballast and concrete.

Previous to that time the rock was used for bridge construction along the railway line near the quarry. The present annual output is about 50,000 cubic yards, valued at $35,000.

MINOR QUARRIES NEAR LEWISTON.

Two small quarries near Lewiston, owned by Charles and Alvin Hossfeld, have been worked at intervals for many years to supply foundation stone in Lewiston. They were idle during 1912 and 1913, the stone used in Lewiston being shipped from Winona.

A small quarry operated by Nick Myers near Rolling Stone is worked only at intervals to supply stone for local demand.

The remaining quarries in the Oneota formation are in the northwestern part of the county, where a steep and precipitous valley has been excavated by Whitewater River and its tributaries. The valley is narrow and the roads which traverse it drop abruptly from the rolling, open prairie to a narrow, wooded valley, walled in by craggy cliffs, rising in places as sheer walls 150 to 200 feet in height.

KRAMER QUARRY.

Several quarries have been operated in the vicinity of Elba in past years, but the only one at present active is that owned by Mr. Zastrel and operated by John Kramer. It is in a ravine on the east side of the river in sec. 11, T. 107 N., R. 10 W. The rock is buff in color, somewhat porous, and contains sand pits and some iron stain. It closely resembles the rock near Winona. Jointing planes are vertical and 3 to 10 feet apart. Three systems were observed, N. 20° W., N. 45° W., and S. 45° W. The chief output is range rock for a new church at Elba. The wall of John Kramer's barn is of even-course stone from this quarry, and is of very attractive appearance. The quarry floor is approximately 100 feet below the prairie level and 150 or 200 feet above the stream bed. The quarried stone is rolled about 30 feet down the hill to the wagon road and some is broken in transit.

LEATHERMAN QUARRY.

In the northwest corner of the county, in the northwest quarter of Elba Township (T. 107 N., R. 10 W.) a quarry bought by Abe Leatherman, of Plainview, in 1900, has been operated for many years. The rock is gray to yellow, the best bed being cream-colored. Beds are 3 inches to 2 feet thick, and dip southward at a low angle. Jointing is irregular, and no definite systems were observable. In the following section the figures are approximate:

Section in Abe Leatherman quarry, Elba Township, Minn.

	Feet.
Limestone, from prairie level to top of quarry	150–200
Limestone, thin bedded, white, shaly	2
Limestone, yellow to white	10
Limestone, cream-colored, best quality	3
Limestone, porous, gray	6
Limestone, porous, quarry floor to river bed	30

The 3-foot cream-colored ledge is the best rock observed in Winona County. It is free of sand pockets and iron stain, and is of a rich and pleasing color. Under the microscope its even texture and purity are at once apparent, a few scattered grains of quartz constituting the only foreign matter present. A partial analysis of the rock shows calcium carbonate, 54.50 per cent; magnesium carbonate, 37.75 per cent; insoluble, 2.92 per cent. Its true specific gravity is 2.885, its pore space 9.96 per cent, and its weight per cubic foot 162.3 pounds when dry.

Transportation is difficult, the road being rough and hilly until the prairie is reached. The nearest town is Plainview, about 6 miles distant.

QUARRIES IN THE PLATTEVILLE LIMESTONE.

From Winona to St. Charles the Chicago & Northwestern Railway track ascends at a steep grade until it passes above the Oneota horizon. Bluffs of the St. Peter sandstone, capped by Platteville limestone, appear near St. Charles, where several small quarries are situated.

THOMPSON QUARRY.

About a mile east of St. Charles a small quarry, owned by Mrs. Kate Conway and operated by John Thompson, has been worked about 18 years. A portable crusher was used from 1909 to 1912 and was then removed. The rock is blue but weathers yellow near seams and joints. This character may be observed in the same formation at Minneapolis and St. Paul (p. 170). Beds are 3 to 14 inches thick, the thinner beds being near the surface. Major joints strike N. 30° E. and secondary joints N. 60° W. They are open seams in places, dissolved out into open spaces 6 or 8 inches wide. Minor joints strike north and south and are closed seams. The present output is rubble for foundations and bridges. The most serious imperfections are the thinness of the upper beds and the presence of some flinty layers. The stone has been used for foundations of many buildings in St. Charles. It is attractive in appearance and durable.

WOLTER QUARRY.

Half a mile northeast of St. Charles station a quarry owned by Fred Wolter is remarkable for its open joints, which are 6 to 8 inches wide and are partly filled with clay. Three joint systems trend

east, N. 10° E., and N. 60° E. With the microscope the rock appears as a fine-grained aggregate of calcite or dolomite grains. The yellow ferruginous stain is not uniformly distributed. A typical specimen of the limestone has a true specific gravity of 2.608, a pore space of 8.29 per cent, and a weight of 149.5 pounds per cubic foot when dry. The thickness of the rock down to the St. Peter sandstone is about 15 feet, and the lower 7 or 8 feet is of good quality. No rock is shipped away by rail, but steam tractors convey it to the country for use in farm buildings.

PALMER QUARRY.

In southwestern St. Charles a quarry owned by Mrs. Hart Palmer was first worked in 1876. The rock contains many characteristic Platteville fossils and a few cavities lined with pyrite crystals. No rock was excavated in 1912.

ST. CHARLES CITY QUARRY.

One-fourth of a mile south of St. Charles station a quarry owned by the city of St. Charles has supplied paving stones and crushed rock for city use but has not been operated since 1901. The quality of the rock is well shown in the pavements, which have been in use for 11 to 13 years and are still in excellent condition. The total output was about 3,000 cords.

MCGRATH QUARRY.

Near the city quarry and similar to it in every respect is a quarry owned by M. G. McGrath and operated by Peter Kramer. It was opened in 1908 and was not operated in 1912. Its total output is about 135 cords.

SANDSTONES AND QUARTZITES.

DISTRIBUTION AND CHARACTER.

The available sandstones and quartzites of Minnesota are of Huronian, Keweenawan, Cambrian, and Ordovician age. Huronian quartzites outcrop in the southwestern counties and in St. Louis County north of the Mesabi Range, and Keweenawan sandstones along Kettle River and near Fond du Lac. Cambrian sandstones are for the most part friable and have been quarried in a few places only, notably at Taylors Falls, in Chisago County; Dresbach, in Winona County; and Jordan, in Scott County. Ordovician sandstones are even more friable. The St. Peter sandstone has been quarried for structural blocks at one point only, on a small island near the confluence of Minnesota and Mississippi rivers. The Keweenawan sandstones and Huronian quartzites, however, are abundant, attractive, durable, and of great economic value.

HURONIAN QUARTZITES.

NICOLLET COUNTY.

DISTRIBUTION AND CHARACTER.

Intermediate between New Ulm and Courtland, extending from the railroad bridge over Minnesota River for 1½ miles to the east, is an outcrop of the Sioux quartzite, of Huronian age. It is a northeastward extension of the massive ridges of similar quartzite in Pipestone and Rock counties. (See pp. 203–205.)

The rock is in beds 6 to 18 inches thick, which dip from horizontal to 45° generally to the north or northeast. In past years the rock was known as the "Redstone quartzite." It was originally a sandstone but is so firmly cemented by silica that the individual grains have for the most part lost their identity, the whole mass appearing as a dense reddish quartz. It is so extremely hard that it is unprofitable to use it extensively for structural purposes.

NEW ULM STONE CO. AND MINNESOTA FLINT ROCK CO. QUARRIES.

The New Ulm Stone Co. and the Minnesota Flint Rock Co. quarry extensively near Courtland and have large crushing plants. Each company ships about 800 carloads of crushed rock per annum. A small amount of building stone is obtained as a by-product, pieces of convenient shape and size being put aside and trimmed in the winter for building blocks. Irregular "one-man stones," weighing 40 to 80 pounds, are set aside for riprap. All the remaining rock quarried is crushed for concrete and road construction. Though extremely hard, the rock is brittle and therefore not exceptionally hard to crush.

The Bureau of Chemistry, of the United States Department of Agriculture, investigated the qualities of the stone and reported the following mineral composition:

Mineral composition of the "Redstone quartzite," Courtland, Minn.

Quartz (SiO_2)	96.3
Orthoclase ($KAlSi_3O_8$)	1.4
Zircon ($ZrSiO_4$)	.1
Hematite (Fe_2O_3)	2.2

It was found to be the hardest quartzite ever tested by the bureau. Its toughness also is above the average, but its cementing value, like that of all quartzites, is low. In road construction it should be rolled wet. It is best adapted for heavy traffic.

About a mile nearer New Ulm, in the W. ½ sec. 27, Courtland Township, a jasper conglomerate, some of which has been quarried, outcrops in a ridge about 1,000 feet long with strike N. 20° E. and dip 18° S. 60° E. The pebbles, which are of all sizes up to a foot in

diameter, are well rounded by water action, and are cemented firmly together with a quartz cement, forming a firm, indurated rock. Both pebbles and cement being largely of silica, the rock is more uniform in hardness than most conglomerates. It is possible that decorative rock of good quality could be obtained from this ridge.

PIPESTONE COUNTY.

DISTRIBUTION AND CHARACTER.

The only bedrock known in Pipestone County is a red quartzite, of Huronian age, which extends into northwestern Iowa, where it is known as the Sioux quartzite.

This rock must not be confused with the "pipestone" noted in Indian tradition. The latter is a dense, red, claylike, much softer rock, which is found in a bed 18 inches thick within the massive quartzite.

The quartzite is quarried near Pipestone and Jasper. North of Pipestone the rock outcrops extensively as two distinct types, an attractive deep-red stone in beds rarely more than 8 inches thick and a pale grayish red of poorer quality. Under the microscope the deep-red stone is seen to consist mainly of angular quartz grains, set in an aggregate of muscovite, feldspar, and hematite. Originally the rock was evidently an arkose. There is no evidence of secondary growth of quartz grains, and the rock should therefore be much easier to work than that at Jasper. (See p. 204.)

The rock is very strong. Under crushing stress the first crack came at 10,429 pounds per square inch and final collapse at 20,277 pounds. Under transverse breaking stress the modulus of rupture proved to be 6,583 pounds per square inch.

Both on account of its attractive appearance and its strength the rock is to be highly recommended for ornamental trimming. It is one of the most beautiful and durable stones in the State.

The rock is thin bedded, 8 or 10 inches being its maximum thickness. The beds dip about 10° E., and the joints are uneven and irregular. The rock bleaches gray along joints but evidently does so very slowly.

NASON CO. QUARRY.

The only working quarry near Pipestone is that owned by Leo Moore and operated under lease by the O. P. Nason Co., about half a mile north of the city. During 1912 part of the output was shipped to Sioux Falls, to be employed in the construction of a school for the deaf and dumb. The major part of the rock quarried is crushed to the size of coarse sand and is shipped to Chicago for roofing. About six men are employed, producing 2 to 4 carloads a week of the crushed stone.

JASPER COOPERATIVE STONE CO. QUARRY.

A large quarry, opened half a mile from Jasper in 1890, is owned by the Jasper Cooperative Stone Co. and is worked under lease by Andrew Roy. The rock is a highly indurated pale-pink quartzite, which in thin section is seen to be made up almost entirely of quartz with very little iron stain and calcite cement. The most notable feature is the secondary enlargement of quartz grains—that is, the cementation of the original sand grains by the deposition of quartz in the intergranular spaces. Such cementation results in the formation of a very hard rock, and microscopic examination indicates that the "Jasper" stone is more difficult to cut than the deep-red rock from Pipestone, in which secondary enlargement of the quartz is not apparent and iron oxide forms much of the cementing material.

Bedding planes are 6 inches to 2 feet apart and dip generally less than 5° approximately southeast. Major joints strike about N. 20° W. but curve and become irregular in places. Some are open and some filled with clay. Secondary joints at right angles to the major joints are not so prominent. They are spaced several feet apart. Quarry conditions are good, the overburden being 1 to 4 feet of soil and the quarry of bench type.

Paving stones, building blocks, rubble, and, of late years, some crushed stone, are produced. The Sioux Falls post office was made of stone from this quarry. The quarry is equipped with steam drills and horsepower hoist and is connected by a spur line with the Chicago, Rock Island & Pacific tracks.

STAPLES QUARRY.

About 2 miles south of Jasper a quarry was opened by H. W. Staples in 1907 in rock of the same type as that just described. The entire output is paving stones, of which one-half to three-quarters of a million are produced annually. A railway siding from Jasper simplifies transportation.

JASPER STONE CRUSHING CO.

The Jasper Stone Crushing Co. operates no quarry but crushes rock from the waste heaps of the Staples quarry. The rock is transported by cars on an inclined track to a crusher capable of handling 160 cubic yards of stone a day, and the crushed stone is passed directly into cars on the siding.

ABANDONED QUARRIES.

A short distance from the Staples quarry the Jasper Stone Co. quarry (office, Watertown, S. Dak.) operated extensively until about 1902. Several other quarries are now idle. In past years, when labor was less expensive, rock was shipped from Jasper to Minneapolis and St. Paul and used in the construction of several beautiful dwellings.

COTTONWOOD AND WATONWAN COUNTIES.

In Cottonwood County the Sioux quartzite is exposed as an extensive ridge running east and west through Storden, Amboy, and Selma townships, and extending into Adrian Township, in Watonwan County. It is of the same type as the rock at Jasper and is as yet undeveloped.

ROCK COUNTY.

The only bedrock known in Rock County is an extension of the Sioux quartzite, which runs south to a point about 2 miles north of Luverne and ends abruptly in a prominent ridge known as "The Mound." The rock is of the same general type as the "Jasper" stone but is badly broken by numerous irregular joints. Good rock may be obtained in pockets of uncertain size, which, about 30 years ago, were excavated extensively and used in many structures in Luverne. The Fowler Methodist Church in Minneapolis was made from the quartzite near Luverne. At present it is quarried on a small scale at irregular intervals for local purposes. The best blocks have been used for monument bases but are inferior for such uses. Orm Carter, J. B. Hinkley, and others own land on which rock outcrops. The high elevation of the Mound, allowing perfect drainage and easy transportation, favors the establishment of crushing plants.

ST. LOUIS COUNTY.

The Pokegama quartzite, which outcrops north of the Iron Range, in St. Louis County, is similar to that quarried near Courtland, in Nicollet County, and at Jasper, in Pipestone County. It is of Upper Huronian age and rests unconformably upon the southern flank of the Giants Range granite. It dips southward and forms the floor of the iron-bearing Biwabik formation. Some of this quartzite has been quarried and crushed about 2 miles north of Hibbing, where the entire output is used for street construction. It is a hard, glassy, fine-grained, pale-pink rock but is not well adapted for building stone, as the joints, both horizontal and vertical, are closely spaced and very irregular. Spaces of more than a foot between seams are rare. In places the rock is interbedded with a green shale.

KEWEENAWAN SANDSTONES.

GEOLOGIC RELATIONS.

A yellow to reddish sandstone that outcrops abundantly along Kettle River in Pine County is of somewhat doubtful geologic age. Both Hall[1] and Winchell[2] concluded that it was conformable with the overlying Cambrian sandstones and hence of Cambrian age, but

[1] Hall, C. W., The red sandstone series of southeastern Minnesota: Science, vol. 27, p. 722, 1908.
[2] Winchell, N. H., Geology of Minnesota: Minnesota Geol. Survey, vol. 1, pp. 422-424, 537, 1884.

in a recent report Thwaites [1] maintains that the sandstones of adjacent areas in Wisconsin are of Keweenawan age. Though there is no visible connection between the sandstones in Wisconsin and those of Sandstone, Minn., it seems probable that the latter represent an extension of the Bayfield group into Minnesota and are consequently of upper Keweenawan age.

A brown sandstone which outcrops extensively near Lake Superior in Wisconsin and extends over the boundary into Minnesota at Fond du Lac is also of doubtful age. Winchell [2] and Hall [3] reported it as Potsdam (Cambrian) and Buckley [4] accepted this classification. Thwaites,[5] however, places it in the Orienta sandstone, of the Bayfield group, which is of upper Keweenawan age.

PINE COUNTY.

KETTLE RIVER QUARRIES CO. QUARRY.

Sandstone is quarried very extensively by the Kettle River Quarries Co. on the bluffs of the Kettle River at the town of Sandstone, about 87 miles northeast of Minneapolis on the Great Northern Railway.

The quarry was first worked by Col. W. H. Grant in 1885, and the rock was hauled by teams to Hinckley. Later it was operated by Ring & Tobin, and with direct railroad connection stone was shipped to Minneapolis, Omaha, Duluth, and other points for curbing, bridge work, and buildings. In 1893 and 1894 the Wing Dam at St. Anthony Falls was built of it. In 1894 the disastrous Hinckley fire destroyed the entire equipment. The Minnesota Sandstone Co. was organized in 1895, the name being later changed to the Kettle River Quarries Co. Of late years the equipment has been greatly improved and extended. Kettle River furnishes power for air compressors, shops, crushers, and dynamos. The quarries are now equipped with 25 large derricks, 2 locomotives, several miles of standard track, and a large locomotive crane. About 500 men are employed.

The rock forms high precipitous bluffs along Kettle River, and as the quarry floor is higher than water level drainage is perfect and rock removal easy. The face of the largest quarry is about 100 feet high and over 2,000 feet long. (See Pl. XIX, *B*.) Most of the rock is a light pink, but near the top of the quarry and in places near the bottom, it is of a darker yellow, with a distinctly red cast.

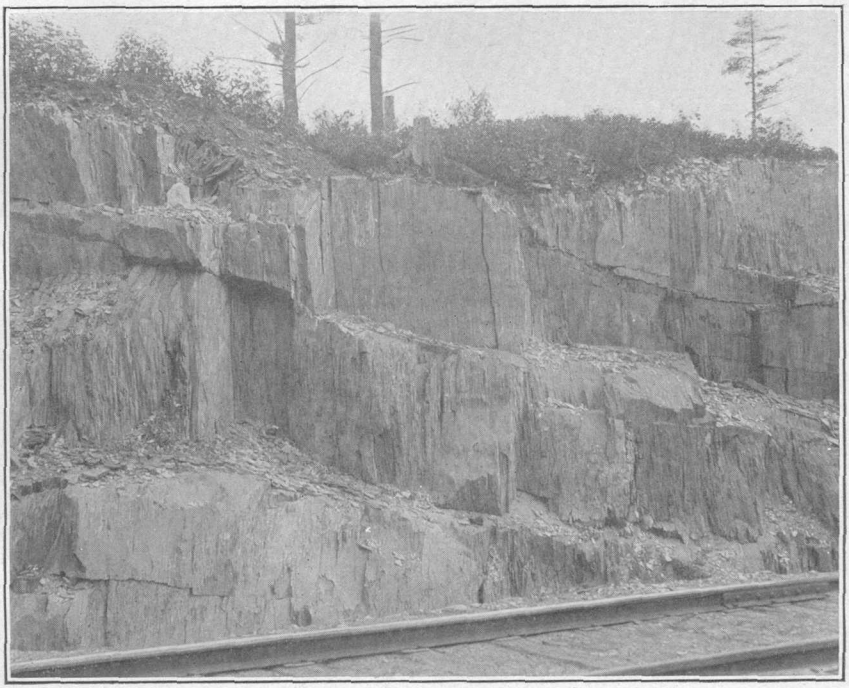
[1] Thwaites, F. T., Sandstones of the Wisconsin coast of Lake Superior: Wisconsin Geol. and Nat. Hist. Survey Bull. 25, pp. 102-103, 1912.

[2] Winchell, N. H., op. cit., vol. 4, p. 571.

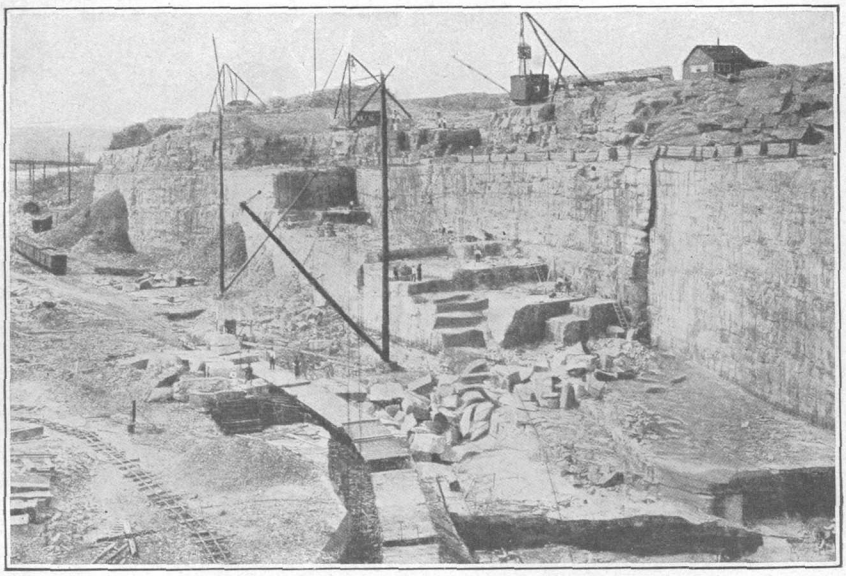
[3] Hall, W. C., Geol. Soc. America Bull., vol. 12, p. 319, 1901.

[4] Buckley, E. R., Building and ornamental stones of Wisconsin: Wisconsin Geol. Survey Bull. 4, p. 167, 1898.

[5] Thwaites, F. T., op. cit., pp. 41-47, 73.



A. SLATE OUTCROPS AT THOMSON, CARLTON COUNTY, MINN.



B. KETTLE RIVER QUARRY AT SANDSTONE, MINN.

Most of the cementing material is silica, and the rock grains are sufficiently adherent to form a strong and durable structural stone. The rock is granular in appearance, many of the grains showing a bright reflection due to the addition of secondary quartz which has developed crystal faces. The grains are of uniform size, the majority of them passing through a 40-mesh sieve. About one-fourth of the rock is suitable for high-grade structural purposes, and the remainder chiefly for paving blocks. Beds are 1 to 6 feet thick and dip 2° to 4° S. or SE. Three thin shale beds appear at intervals of 15 to 20 feet, but otherwise the rock is a uniform sandstone. Open joints are vertical and are 40 to 300 feet apart. Their wide spacing makes quarrying difficult, as the rock is too hard for economical channeling.

The method employed in quarrying is to drill rows of holes nearly the full depth of the heavy beds in such a manner as to mark off a mass of rock 30 or 40 feet square. The Knox system (see p. 65) is employed, and a simultaneous discharge of blasting powder in the drill holes breaks loose a mass the thickness of which is governed by the position of the shale beds. Further division of the rock into blocks of convenient size is by plug and feather methods. The difficulties of quarrying rock of this type are discussed in greater detail by Bowles.[1]

Large blocks to be made into paving stones are transported on flat cars to the river flats, where cutters reduce them to proper size and shape. In this operation the directions of natural splitting in the rock are of prime importance. The rift is parallel with the stratification, the run (or second direction of splitting) is east and west, and the head grain north and south.

The chief output of the quarry is paving stones, though considerable building stone and cut stone for structural purposes are also produced. Footings, rubble, crushed rock, and sand, the latter a by-product of the crusher, are of minor importance. Stone is also cut to order in a well-equipped shed. The rock is well adapted for cornice or other carved work. The shops and quarry are directly connected with the Great Northern Railway.

According to tests made at the United States arsenal, Watertown, Mass., the rock will bear a very high compressive strain, the ultimate crushing strength in two tests being 12,295 and 12,799 pounds per square inch. An analysis made by the United States arsenal shows silica (SiO_2), 97.10 per cent; alumina (Al_2O_3), 2.20 per cent; lime (CaO), 0.60 per cent; magnesia (MgO), 0.10 per cent.

Among the many structures made from this stone may be mentioned the library building of the University of Illinois, at Urbana, Ill., the Spokane Club building at Spokane, Wash., Des Moines

[1] Bowles, Oliver, Sandstone quarrying in the United States: Bur. of Mines Bull. 124, pp. 35-37, 1917.

Public Library, courthouses at Elk Point, S. Dak., Crookston, Grand Rapids, and Benson, Minn., the Duluth and Minneapolis reservoirs, bridges over Missouri River at Sioux City, Iowa, and Omaha, Nebr., the large Duluth-Superior bridge, and the Government bridge at Rock Island, Ill.

The new Great Northern station in Minneapolis, which contains 40,000 cubic feet of cut stone, was completed in 1913. (See Pl. XX.) Pillsbury Hall of the University of Minnesota (Pl. XXI) is made partly of this rock and partly of "Fond du Lac" brown sandstone.

BARBER ASPHALT PAVING CO. QUARRY.

Rock of the same type as that at Sandstone has been quarried for many years at Banning, Minn., by the Barber Asphalt Paving Co., of Philadelphia. The quarries are at present inactive.

ST. LOUIS COUNTY.

"Lake Superior brownstone," as it is commonly called, has been quarried extensively in Wisconsin and at Fond du Lac, near Duluth, in Minnesota.

KRAUSE QUARRY.

A quarry owned by C. A. Krause was opened in 1882 at Fond du Lac, in sec. 5, T. 48 N., R. 15 W., and was worked actively during the years when brownstone was popular.

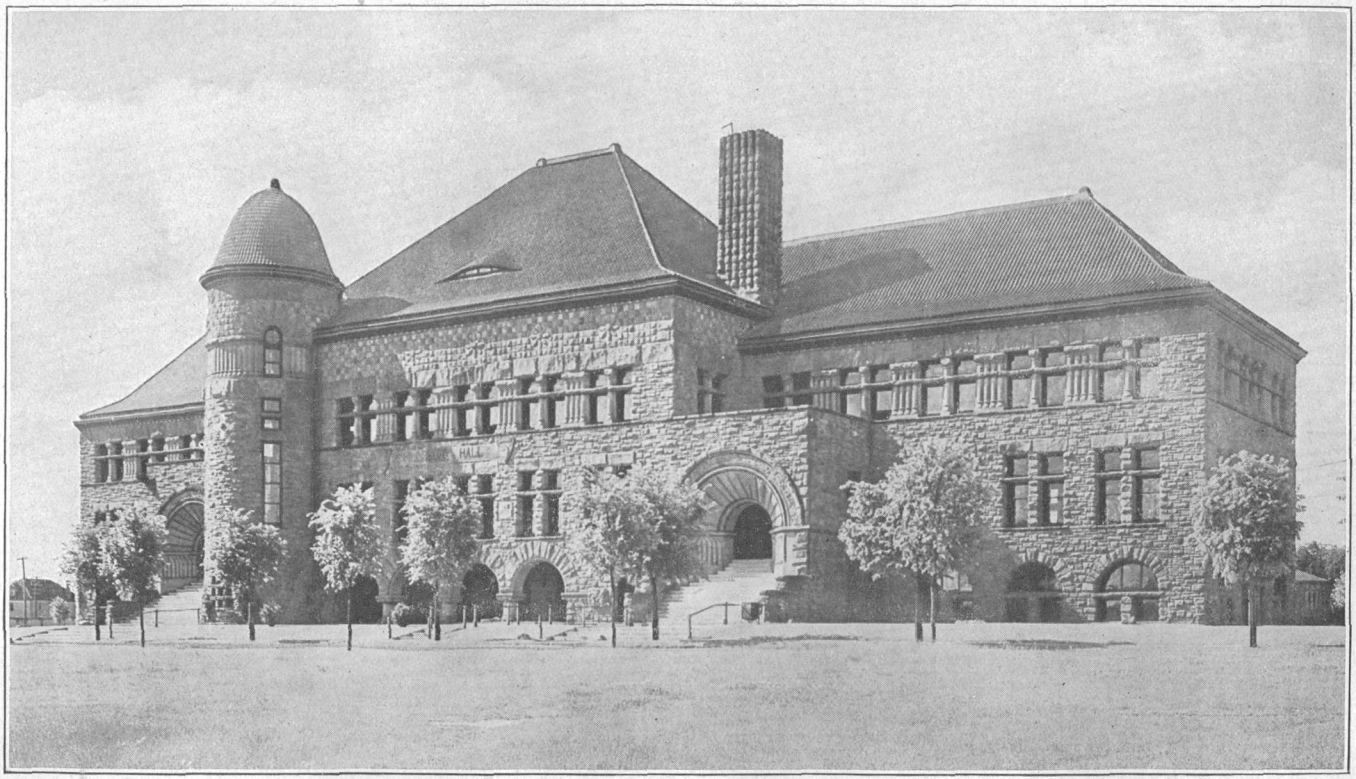
The rock is light to dark purple-maroon in color, much of it having light spots one-eighth to one-fourth of an inch across. It is fairly even-grained in texture and is interbedded with shale. Under the microscope it proves to be a feldspathic sandstone or arkose. The quartz grains forming the main mass are somewhat angular in form; with them are many grains of orthoclase, plagioclase, and microcline. Flakes of biotite and grains of hornblende and magnetite are present. Decay of the ferromagnesian minerals has resulted in the separation of iron oxides which give the rock its characteristic color.

Major joints strike north and south and secondary joints east and west, are 1 to 10 feet apart, and nearly vertical. Bedding planes are very distinct and are 1 to 5 feet apart. The dip is about 15° SE. and the strike northeast. Distinct cross-bedded planes are in places only a few inches apart.

The demand for brownstone has of late years been very small. This is due mainly to the fact that when stone of this type was popular much rock of good color but poor quality was placed on the market. Also much of it was set with the bedding vertical, and after a few years' exposure the ill effects of weathering turned popular opinion against all brownstone, and lighter-colored stone became

GREAT NORTHERN RAILWAY STATION, MINNEAPOLIS, MINN.

Constructed of sandstone from the Kettle River quarries.



PILLSBURY HALL, UNIVERSITY OF MINNESOTA, MINNEAPOLIS, MINN.

Constructed partly of "Kettle River" sandstone and partly of "Fond du Lac" brownstone.

more in demand. In this particular quarry, present inactivity has resulted both from decreased demand for the stone and increased expense of operation. Further excavation requires the removal of a much greater overburden of soil than heretofore. Better stone, however, would probably be obtained at greater depth.

Just over the State line in Wisconsin a quarry operated by the Duluth Brownstone Co. produces rubble of the same type as the best rock obtained from the Krause quarry at Fond du Lac, Minn. The rock exhibits the same characteristics, white spots, cross-bedding, and shale bands. Stone from this quarry was employed in the construction of the American Exchange Bank, Duluth; the Irving School, in West Duluth; and the Adams School, on Seventeenth Avenue, Duluth.

The rock in the two States is similar and the tests made by the Wisconsin Survey give fair indications of the character of the Minnesota stone. The average crushing stress of sandstone from the South Shore area (in Wisconsin) is given by Buckley[1] as 5,272 pounds per square inch and the transverse breaking stress as 444.9 pounds. All samples tested indicated sufficient strength and durability for structural work of any kind. Samples from the Duluth Brownstone Co. quarry gave the highest strength tests and the lowest porosity of any of the samples tested. Consequently the more massive beds of Minnesota stone in the near vicinity are probably as durable and efficient as any sandstone in the region. The stone as tested by Winchell[2] broke under a crushing stress on the bed of 3,625 pounds and on edge of 5,750 pounds per square inch.

Many large and beautiful structures have been built of the "Fond du Lac" stone, among them being the Metropolitan Life Building and the Lumber Exchange in Minneapolis. Careful examination of these buildings shows no important deterioration.

CAMBRIAN SANDSTONES.

The Cambrian sandstones of Minnesota are for the most part too friable to be used successfully for structural purposes.

WINONA COUNTY.

The Dresbach sandstone was quarried many years ago near the base of the Mississippi bluffs at the towns of Dresbach and Dakota, in the southeastern extremity of Winona County. Its geologic relations are shown in connection with the limestones of Winona County (p. 194). It is white and somewhat friable and resembles the Berea sandstone of Ohio. It has not been quarried recently. The Rolling Stone Catholic Church was made of Dresbach stone.

[1] Buckley, E. R., op. cit., p. 197.

[2] Winchell, N. H., op. cit., vol. 1, p. 200.

CHISAGO COUNTY.

Cambrian sandstone crops out along the St. Croix bluffs in the northeastern part of the county and south of Taylors Falls to the Washington County line. It was quarried many years ago near Taylors Falls and was used in the construction of several business blocks of that town and of a mill at Franconia. It is white, coarse grained, and rather friable when quarried but is said to become much harder with age.

SCOTT COUNTY.

At Jordan the Jordan sandstone, of Cambrian age, has been quarried for many years. This formation lies immediately above the St. Lawrence limestone and outcrops in the bluffs near the old mill pond. The quarries were opened about 50 years ago and were operated intermittently until 1911. The beds are horizontal and are 1 to 2 feet in thickness. Joints are at right angles, vertical, and 2 to 6 feet apart. There is an overburden of 8 to 10 feet of drift. The color is white to reddish. Near the top of the quarry the rock is blotched with oblong, rounded, or irregular white patches half an inch to 2 inches in diameter and shows a few ferruginous bands. Near the bottom of the quarry its color is more nearly uniform. The rock is medium grained and somewhat friable, the lower beds being of better quality than the upper beds, but poor drainage discourages deep quarrying. The output of the quarries averaged from 250 to 400 cords annually, most of which was used locally. As observed in the public school, the Catholic school, and the old and new breweries, the rock is attractive in appearance and fairly durable.

LE SUEUR COUNTY.

Except in small patches seen at Ottawa, which are cemented almost as hard as quartzite, the Jordan sandstone is much more friable in Le Sueur County than at Jordan, in Scott County. The incoherent material is used by the Minneapolis Steel & Construction Co. as a molding sand and for making cores. It is also used at Kasota as an abrasive in sawing marble slabs. Several loads are shipped annually from Ottawa to Minneapolis, St. Paul, and even to California to supply steel works and foundries.

ORDOVICIAN SANDSTONES.

The only sandstone of Ordovician age which has been quarried in Minnesota is on a small island in Mississippi River, in the SW. ¼ sec. 33, Mendota Township, in the St. Peter formation. It is exceptional that the St. Peter is sufficiently coherent to be utilized for structural work. The rock is in thick beds, dipping slightly south-

ward. It weathers to a rusty yellow of almost exactly the same shade as the weathered Platteville limestone at Mendota. It was used for two walls of the old Faribault House at Mendota and for the piers of the Fort Snelling Bridge but has not been quarried for many years.

SLATES.

Slates and schists of upper Huronian age outcrop along St. Louis River between Carlton and Cloquet and in the southern part of Carlton County in the vicinity of Barnum and Moose Lake. The slates are dark and fine grained and dip steeply. An attempt has been made to use them in roofing, but most of them are too brittle and schistose. A small slate quarry supplies stone for local use at Barnum. From a small excavation at Cloquet a little roofing slate and crushed rock are obtained.

The most prominent outcrops are near the big dam at Thomson, where slate and graywacke are interbedded and form massive arched folds with nearly vertical slaty cleavage. (See Pl. XIX, *A*.) Many areas of slate 30 feet or more in thickness are quite free of graywacke. The slate was at one time extensively quarried near Thomson, and was used partly for roofing and partly in the manufacture of brick. The quarries now belong to the Great Northern Power Co. and have been inactive for at least 20 years.

The development of a slate industry in the region is a future possibility. The massive hogback ridges indicate an almost unlimited supply; large areas have no overburden, and railways are convenient.

STRUCTURES IN WHICH MINNESOTA STONE WAS USED.

The structures named in the following list were built in whole or in part from Minnesota stone. The list includes only the names of structures that were brought to the writer's notice in the course of visiting the quarries throughout the State and therefore is not complete.

Structures in which Minnesota stone was used.

Granite and gneiss.

Structure.	Date.	Stone.
U. S. customhouse and post office, St. Paul, Minn.; corners, steps, and trimming.	1868	"East St. Cloud" granite.
State Capitol, St. Paul, Minn.; 4 columns	About 1900	"Ortonville" granite.
Hennepin County courthouse, Minneapolis, Minn	1888	Do.
Yellow Medicine County couthouse, Granite Falls, Minn.; basement.	.....	"Granite Falls" biotite gneiss.
Redwood Falls Public Library	.....	"North Redwood" granite.
Redwood Falls High School	.....	Do.
Redwood Falls Granite Block	.....	Do.
North Redwood Bank	.....	Do.
Hans Nelson Hauge Monument, Moorhead, Minn	1912	"Morton" gneiss, Anderson Granite Co.
Part of Catholic Church, Waconia, Minn	.....	Do.
St. Paul Cathedral, St. Paul, Minn	1914	"Rockville" granite, Clark & McCormack.
St. Cloud, Minn., post office	1902	"St. Cloud red" granite, J. B. Robinson.
Lower part of old Minneapolis post office	1884–1886	Do.
2 columns of Zapp State Bank, St. Cloud, Minn	1913	Red granite, Pioneer Granite Co.
Basement and approaches of State Capitol, St. Paul, Minn.	About 1900	Do.
Steps of Gateway Park Building, Minneapolis, Minn	1913	Do.
Trimming of Ford Motor Works, Minneapolis, Minn	1914	Do.
Basement of post office, Menominee, Wis	1914	Do.
Olympia Building, Winnipeg, Minn	1914	Do.
Chicago, Milwaukee & St. Paul Railway bridge over Mississippi River between St. Paul and Minneapolis, Minn.	1879	Red granite, Old Rock Island quarry, near East St. Cloud.
Northern Pacific Railway bridge over Missouri River at Bismarck, N. Dak.	1881	Red granite, Old Rock Island quarry near East St. Cloud; granite from sec. 35, Watab Township, Benton County.
Wall around State Reformatory grounds, East St. Cloud, Minn.	1902–1914	Gray granite, State Reformatory quarry.
Water tower of State Reformatory, East St. Cloud, Minn	1912	Do.
Main building of State Reformatory, East St. Cloud, Minn	About 1900	Do.
Great Northern Railway stone-arch bridge, Minneapolis, Minn.	1882–83	See p. 171.
Friedland German Church, St. Cloud, Minn. (in part)	1908	Granite, J. O. McConnell quarry, East St. Cloud.
Gordon & Ferguson glove factory, St. Cloud (in part); Davidson Opera House (in part); St. Cloud Cathedral (in part).	1911	Red granite, Fischer Co. quarry, East St. Cloud.
Courthouse, Grand Forks, N. Dak	1913	Gray granite, Coates quarry Sauk Rapids.

Limestone and marble.

State Capitol, St. Paul, Minn.; some interior panel work	1896–1903	"Kasota" marble; marble from the McClure and the Widell Co. quarries near Mankato; limestone from Geo. Haun quarry, Winona.
State prison, Stillwater, Minn	Begun 1852	Exterior, limestone from near Stillwater. Some interior finish from Kasota quarries and from McClure and Widell quarries near Mankato.
Bridge at Boone, Iowa	1900–1901	Limestone, J. McClure and the Widell Co. quarries near Mankato.
Bridge at Cedar Rapids, Iowa	About 1898	Do.
Cedar River Bridge, Menominee Junction, Wis	1912	Limestone, T. R. Coughlan Co. quarry, Mankato.
Mother House and Academy, Mankato (in part)	1911	Do.
Le Sueur Center jail and sheriff's house (in part)	1912	Limestone, Mankato Limestone & Fuel Co. quarries, Mankato.
Mankato post office, basement	1894–1896	Do.
Old Fort Snelling, near St. Paul, Minn	1820	Limestone, Mendota.
Gen. Sibley's house, Mendota, Minn	1835	Do.
Faribault House, Mendota, Minn	Between 1835 and 1840	Limestone from Mendota and St. Peter sandstone from island in Mississippi near Mendota.

Structures in which Minnesota stone was used—Continued.

Limestone and marble—Continued.

Structure.	Date.	Stone.
Farmhouse, sec. 24, Lakeville Township, near Farmington, Dakota County, Minn.	1866	Limestone quarried near the house.
Masonic Temple, Rushford, Minn	1912	Limestone, Akre & Dahl quarry, Rushford.
Lutheran Church, Rushford, Minn	1906	Do.
Lutheran Church, Red Wing, Minn	1895	Limestone, Red Wing.
Do	1905	Do.
Methodist Church, Red Wing, Minn	1908	Do.
Lake City High School, Lake City, Minn	1894	Limestone, Frontenac.
City Hall, Lake City, Minn	1899	Do.
Girls' college, State Training School, Red Wing, Minn	1891	Do.
Cathedral of St. John the Divine, New York City; interior decoration (in part).	1913	Do.
St. John's Catholic Church, Caledonia, Minn	1899	Limestone, Hoscheit quarry, Caledonia.
St. Peter's Catholic Church, Caledonia, Minn	1873 or 1874	Do.
Houston County courthouse, Caledonia, Minn	1883	Limestone, Caledonia.
Houston County jail, Caledonia, Minn	1875	Do.
Gateway Park Building, Minneapolis, Minn. (in part)	1913	"Kasota" marble.
Minnesota School for the Deaf, Faribault, Minn., a group of 8 or 10 buildings.	Period 1866 to 1913	Limestone, Eberhart Kaul, Cromer, and other quarries, Faribault, Minn.
Main building, Minnesota School for Feeble Minded, Faribault, Minn.	1881	Limestone, Liebquarry, Faribault.
Willis Hall of Carlton College, Northfield, Minn	1872	Limestone, Dundas.
St. Michaels Catholic Church, Stillwater, Minn	1873	Limestone, Stillwater.
Lincoln School, Stillwater, Minn	1872–73	Do.
Central School, Stillwater, Minn	1869	Do.
Eichter Co. Block, Stillwater, Minn	.....	Do.
Central Methodist Church, Winona, Minn	1895	Limestone, Haun quarry, Winona.
Winona County jail, Winona, Minn	1871	Do.
Baptist Church, Winona, Minn	1888	Do.
Como Avenue Bridge, St. Paul, Minn	About 1897	Limestone, Widell Co. quarry, near Mankato.
South St. Paul Belt Line bridge, South St. Paul, Minn	1898	Do.
St. Paul Public Library; interior	1915	Marble, Widell Co. quarry, near Mankato.
Aberdeen, S. Dak., post office	1900	"Kasota" marble.
Aurora, Ill., post office	1902	Do.
Cedar Rapids, Iowa, post office	1899	Do.
Davenport, Iowa, post office	1906	Do.
Faribault, Minn., post office	1910	Do.
Mankato, Minn., post office	1904	Do.
St. Paul, Minn., courthouse	1890	Do.
St. Paul, Minn., county jail	1900	Do.
Kasota Block, Minneapolis, Minn	1888	Do.
Administrative building, State School for the Blind, Faribault, Minn.	1912	Do.
Library building, Carlton College, Northfield, Minn	1892	Do.
St. Paul Hotel, St. Paul, Minn	1910	Do.
State Capitol, Madison, Wis	1914	Do.
Union Depot, Kansas City, Mo	1915	Do.
Woodward Building, Washington, D. C	1913	Do.
St. Mark's Episcopal Church, Minneapolis, Minn	1912	Do.

Sandstone and quartzite.

Fowler Methodist Church, Minneapolis, Minn	1907	Quartzite, Luverne.
Wingdam, St. Anthony Falls, Minneapolis, Minn	1893–94	"Kettle River" sandstone.
Library building, University of Illinois, Urbana, Ill	1896	Do.
Spokane Club building, Spokane, Wash	.....	Do.
Public Library, Des Moines, Iowa	1900	Do.
Elk Point, S. Dak., courthouse	1898	Do.
Crookston, Minn., courthouse; trimming only	1900	Do.
Grand Rapids, Minn., courthouse; foundation and trimming	1895	Do.
Benson, Minn., courthouse; foundation and trimming	1897	Do.
Bridge over Missouri River at Sioux City, Iowa	.....	Do.
Duluth-Superior Bridge, Minn	.....	Do.
Great Northern Railway station, Minneapolis, Minn	1913	Do.
Pillsbury Hall, University of Minnesota, Minneapolis, Minn	1889	"Kettle River" sandstone; "Fond du Lac" brownstone.
Catholic Church, Jordan, Minn	1890	Jordan sandstone.
Public school, Jordan, Minn	1897	Do.
Basement of St. John's Parochial School, Jordan, Minn	1910	Do.
Old brewery, Jordan, Minn	1860	Do.
Metropolitan Life Building, Minneapolis, Minn	1890	"Fond du Lac" brownstone.
Lumber Exchange Building, Minneapolis, Minn	1885	Do.

QUARRY OPERATORS.

In the following directory a star is placed before the names of operators whose quarries are not described in the foregoing text:

Granite operators:	County location of quarry.
Aberdeen Granite Co., Ortonville	Lac qui Parle.
*Amalgamated Granite Co., St. Cloud	Stearns.
Anderson Granite Co., Morton	Renville.
Atwood, C. L., St. Cloud	Stearns.
*Benton Co. Granite Co., Sauk Rapids	Benton.
*Bigstone Granite Works, Bigstone, S. Dak	Lac qui Parle.
Black Diamond Granite Co., St. Cloud	Stearns.
Clark & McCormack, 138 East Sixth Street, St. Paul	Do.
Consolidated Granite Co., Ortonville	Lac qui Parle.
Davidson & Davidson, Little Falls	Morrison.
Doerner, John, St. Cloud	Stearns.
East St. Cloud Granite Co., Box 275, St. Cloud	Sherburne.
Empire Quarry Co., St. Cloud	Stearns.
Erickson, August, East St. Cloud	Sherburne.
Fischer Co., East St. Cloud	Do.
Flaherty Bros., St. Cloud	Stearns.
Frick & Borwick Granite Co., Box 202, St. Cloud	Do.
*Graham & Fister, R. D. 4, St. Cloud	Benton and Stearns.
Graham, Robert, St. Cloud	Stearns.
Granite City Granite Co., St. Cloud	Do.
Hilder Granite Co., St. Cloud, R. D. 6	Sherburne.
Holes Bros., St. Cloud	Stearns.
Jones, S. A., St. Cloud	Do.
Kellas, John, 704 Sixth Avenue Southeast, St. Cloud	Sherburne.
Keystone Granite Co., R. D. 4, St. Cloud	Stearns.
*Lintgen Bros. Granite Co., R. D. 4, St. Cloud	Do.
Melrose Granite Co., St. Cloud	Do.
*Miller, Fred C., Sauk Rapids	Benton.
Minnesota State Reformatory, Box B, St. Cloud	Sherburne.
Monarch Granite Co., St. Cloud	Stearns.
Murray & Metzroth, St. Cloud	Do.
National Quarry Co., St. Cloud	Do.
Noreen, L. E., R. D. 4, St. Cloud	Do.
North Redwood Granite Works, North Redwood	Redwood.
Northwestern Granite Co., R. D. 3, St. Cloud	Stearns.
Old Rock Island Quarry, East St. Cloud	Sherburne.
Pike Horning Granite Co., 612 Pillsbury Building, Minneapolis	Kanabec.
Pioneer Granite Co., St. Cloud	Stearns.
Reynolds Granite Co., Warman	Kanabec.
*Roan, James, St. Paul	Morrison.
Robinson, J. B., St. Cloud	Stearns.
Rockville Granite Co., Rockville	Do.
St. Cloud Granite Works, St. Cloud	Do.
Sauk Rapids Granite Co., Sauk Rapids	Benton.
Schwab, C. D., St. Cloud	Stearns.
Simmers & Campbell, St. Cloud	Do.

	County location of quarry.
Granite operators—Continued.	
Streitz Bros., R. D. 4, St. Cloud	Stearns.
Swanson & Hagstedt, Sauk Rapids	Benton.
United Granite Co., St. Cloud	Stearns.
Warman Creek Granite Co., Warman	Kanabec.
Williams, M. M., Little Falls	Morrison.
Gabbro or trap-rock operators:	
Duluth City Quarry, Board of Public Works, Duluth	St. Louis.
Duluth Crushed Stone Co., 1505 Alworth Building, Duluth	Do.
*Lake County Quarry, Two Harbors	Lake.
*Trap Rock Co., 605 Lumber Exchange, Minneapolis	Chisago.
Two Harbors Municipal Rock Crushing Plant, Two Harbors	Lake.
Sandstone and quartzite operators:	
*Betcher, Fred, Mazeppa	Wabasha.
Hinkly, R. B., Luverne	Rock.
Jasper Cooperative Stone Co., Jasper	Pipestone.
*Jasper Granite Co., 1150 Plymouth Building, Minneapolis	Do.
*Jasper Granite Co., New Ulm	Nicollet.
Jasper Stone Crushing Co., Sioux City, Iowa	Pipestone.
Krause, C. A., Fond du Lac	St. Louis.
Kettle River Co., 1111 Plymouth Building, Minneapolis	Pine.
Larson, Otto, Peterson	Fillmore.
*Lieder, Robert, R. D. 6, New Ulm	Nicollet.
*McDermott, Fred A., Luverne	Rock.
Minnesota Flint Rock Co., New Ulm	Nicollet.
New Ulm Stone Co., New Ulm	Do.
Nason, O. P., Co., Pipestone	Pipestone.
Staples, H. W., Jasper	Do.
Limestone and marble operators:	
Abell, Otis, Winona	Winona.
Akre & Dahl, Rushford	Fillmore.
Anderson, A. P., Minneapolis	Hennepin.
Babcock & Willcox, Kasota	Le Sueur.
*Bailey, H. D., R. D. 1, Altura	Winona.
Baldwin, Charles, Caledonia	Houston.
Bean, W. H., Stillwater	Washington.
Beaver, John, Wabasha	Wabasha.
*Benson, Albert, Pine Island	Goodhue.
Bielenberg, C., St. Paul	Ramsey.
Biesanz Stone Co., Winona	Winona.
Bjork, A., Red Wing	Goodhue.
Blomstrand & Olson, Nininger	Dakota.
Blue Limestone Co., Minneapolis	Hennepin.
Bly, T. M., Spring Valley	Fillmore.
*Boldman, Charles, Hokah	Houston.
Bradley, G. R., Mankato	Blue Earth.
*Bratland, John, Rushford	Fillmore.
Breen Stone Co., Kasota	Le Sueur.
Bremer, Claus, Wabasha	Wabasha.
*Brudinsick, R. F., Mazeppa	Do.
*Bullene, C. E., Elba	Winona.
Burkhardt, Alfred, Wabasha	Wabasha.

Limestone and marble operators—Continued.	County location of quarry.
Carey, W. H. (also lime), Spring Valley	Fillmore.
Carli, C. H., Stillwater	Washington.
Carlson, O., Hastings	Dakota.
Carney's Bricklayer Cement Co., Mankato	Blue Earth.
Chicago & North Western Railway Co., Chicago, Ill	Blue Earth and Winona.
Clayton, E. L., Chatfield	Olmsted.
Coughlan, T. R., Co. (also lime), Mankato	Blue Earth.
Cromer, Philip, Faribault	Rice.
Dahl, A. M., Red Wing	Goodhue.
*Deedrick, George, Altura	Winona.
Donahue Bros., Rochester	Olmsted.
Duffy, James, Caledonia	Houston.
Dutcher, D. L., Pine Island	Goodhue.
*Eagon, Thomas, La Crosse, Wis	Winona.
*Fieback, William, Elba	Do.
*Fiedler, H. C., St. Peter	Nicollet.
First National Bank, Wabasha	Wabasha.
Fischer, John, St. Paul	Ramsey.
Fowler & Pay (also lime), Mankato	Blue Earth and Mower.
Frontenac Stone Co., Frontenac	Goodhue.
Gengler, J. P., Caledonia	Houston.
Gentzkow & Mogren, Nininger and Minneiska	Winona and Dakota.
Haglund, Andrew, Red Wing	Goodhue.
Hange, L. E., Caledonia	Houston.
*Hanson, Andrew, Kenyon	Goodhue.
Haun, George, Winona	Winona.
*Henretty, Pat, R. D. 5, Mankato	Nicollet.
Hix, Charles, Ottawa	Le Sueur.
*Hodapp, Wendel, Mankato	Nicollet.
*Holt, Charles S., Rochester	Olmsted.
*Holtzhammer, George, La Crosse, Wis	Houston and Winona.
Hortenbeck, R., Minneapolis	Hennepin.
Hoscheit, J. A., Caledonia	Houston.
Hossfeld, Alvin, Lewiston	Winona.
Hugunin Estate Co., Kasota	Le Sueur.
Jefferson, A., & Son (also lime), Mankato	Blue Earth.
Jewell Nursery, Wabasha	Wabasha.
Johnson, Bert, Cannon Falls	Goodhue.
Johnson, Johannes, Red Wing	Do.
*Johnson, J. T., Le Roy	Mower.
Johnson, L. P., Minneapolis	Hennepin.
Johnson, M. C., Stone & Concrete Co., North Mankato	Nicollet.
Johnson, P. G., Cannon Falls	Goodhue.
Kaul, Eberhart, Faribault	Rice.
*Keller, Adolph, St. Charles	Winona.
*Keller, Nic., St. Charles	Do.
Kramer, John, Elba	Do.
*Kroning, H. G., St. Charles	Do.
Leatherman, Abe, Plainview	Do.

Limestone and marble operators—Continued.	County location of quarry.
Lieb, F., Faribault	Rice.
Lillyblad, Gust (also lime), Red Wing	Goodhue.
*McCloud Stone Co., Minneapolis	Hennepin.
McClure, James, 61 East Sixth Street, St. Paul	Blue Earth.
McGee, Ed., Stillwater	Washington.
McGrath, M. G., St. Charles	Winona.
Mankato Limestone & Fuel Co., Mankato	Blue Earth.
*Mantorville Stone Co., Mantorville	Dodge.
*Maunder, John, Ottawa	Le Sueur.
*Meyers, Nicholas, Rolling Stone	Winona.
Minneapolis Park Board, Minneapolis	Hennepin.
Minneapolis Stone Co., Minneapolis	Do.
Minnesota Crushed Stone Co., Minneapolis	Do.
Nelson, Martin, Rushford	Fillmore.
North Mankato Stone Quarry Co., North Mankato	Nicollet.
Palmer, Hart, St. Charles	Winona.
*Palmer, P. W., Brownsville	Houston.
*Reiss, O. W., Rochester	Olmsted.
Rengens, Andrew, Minneapolis	Hennepin.
Robbins, J. B., St. Paul	Ramsey.
Rochester State Hospital, Rochester	Olmsted.
St. Charles City quarry, St. Charles	Winona.
*St. Paul Crushed Stone Co., St. Paul	Ramsey.
Schroeder Brick & Lime Manufacturing Co. (also lime), Shakopee	Scott.
*Sparrow, W. A., Mantorville	Dodge.
*Snyder, C. E., Preston	Fillmore.
Stillwater City quarries, Stillwater	Washington.
*Tesco, F. L., Chatfield	Fillmore.
*Trayer, George, Brownsville	Houston.
United States Government quarry, 304 Custom House, St. Paul	Hennepin.
United States Government quarry, Room 11, Government Building, La Crosse, Wis.	Winona.
*Volz, F. J., Rochester	Olmsted.
Walde, Robert, Rochester	Do.
*Weimer, A. M., R. D. 6, North Mankato	Le Sueur.
Widell Co., Mankato	Blue Earth.
*Wing, Martin, Red Wing	Goodhue.
Wolter, Fred, St. Charles	Winona.

STONE-FINISHING PLANTS.

The following list includes stone-finishing plants operated by quarry companies and by wholesale manufacturers:

Granite finishers:
- Anderson Granite Co., Morton.
- Benzie & Campbell, St. Cloud.
- Black Diamond Granite Co., St. Cloud.
- Clark & McCormack, Rockville.
- Frick & Borwick Granite Co., St. Cloud.
- Graham, Robert, St. Cloud (near).
- Granite Sample Works, St. Cloud.
- Hilder Granite Co., East St. Cloud.
- Holes Bros., St. Cloud.
- Jones, M. E., St. Cloud.
- Jones, S. A., East St. Cloud.
- Keystone Granite Co., St. Cloud (near).
- Melrose Granite Co., St. Cloud.
- Milne, Robert, East St. Cloud.
- Monarch Granite Co., St. Cloud.
- Morgan Flaherty & Son, St. Cloud.

Granite finishers—Continued.
- National Granite Co., St. Cloud.
- North Redwood Granite Co., North Redwood.
- Pioneer Granite Co., St. Cloud.
- Rockville Granite Co., Rockville.
- St. Cloud Granite Works, St. Cloud.
- Saleski, John, St. Cloud.
- Sauk Rapids Granite Co., Sauk Rapids.
- Simmers & Campbell, St. Cloud.
- United Granite Co., St. Cloud.
- Yaeger & Son Granite Works, East St. Cloud.

Sandstone finishers:
- Kettle River Co., Sandstone.

Limestone and marble finishers:
- Babcock & Willcox, Kasota.
- Breen Stone Co., Kasota.
- Fowler & Pay, Mankato.

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