To F. A. Wilder.
With compliments of
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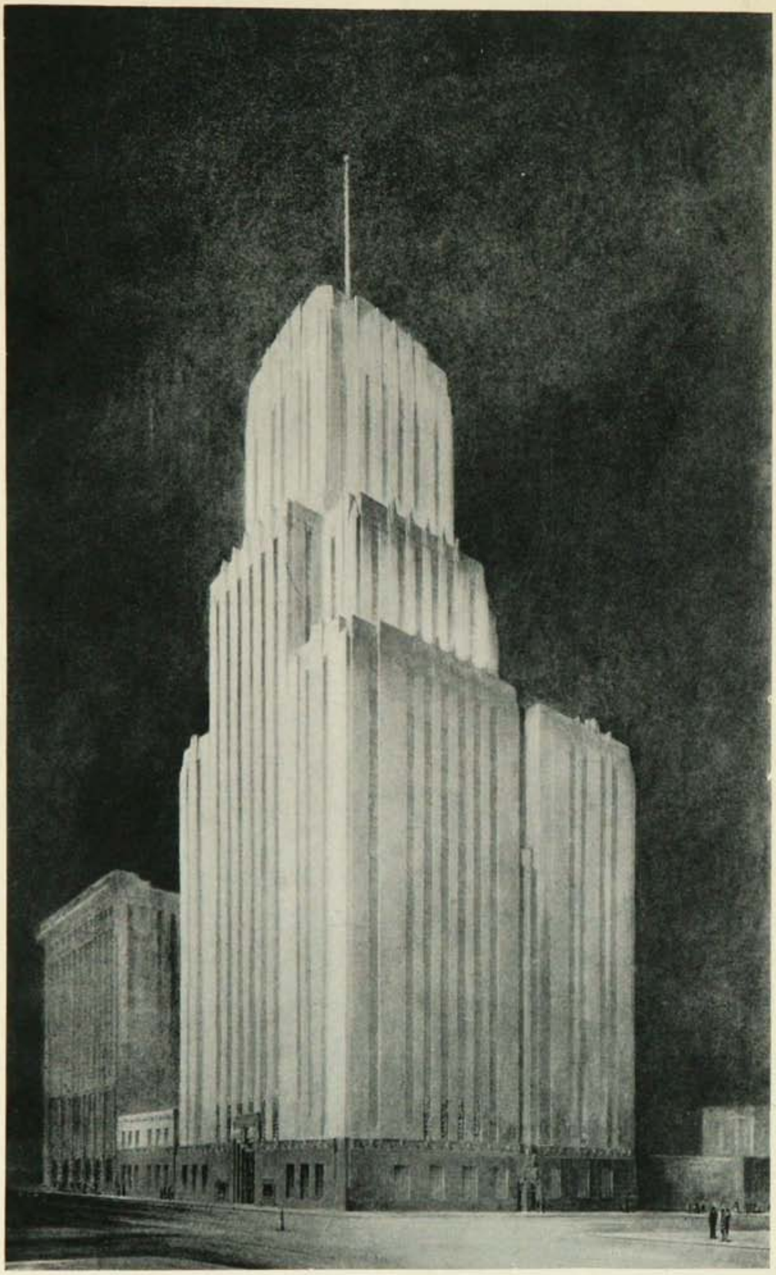
1935



THE NORTHWESTERN BELL TELEPHONE COMPANY BUILDING
MINNEAPOLIS, MINNESOTA

The base course is of Morton gneiss and the superstructure of Mankato-Kasota dolomite.

UNIVERSITY OF MINNESOTA

MINNESOTA GEOLOGICAL SURVEY • BULLETIN 25

WILLIAM H. EMMONS, DIRECTOR

THE ARCHITECTURAL, STRUCTURAL, AND MONUMENTAL STONES OF MINNESOTA

BY

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MINNEAPOLIS • 1935

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FOREWORD

The stone industry in Minnesota began more than a century ago when limestone was quarried to build part of Fort Snelling. From this small beginning in the early history of the territory, the industry has progressed, with periods of fluctuations and retardation, until today it has become the second in value in the mineral production of the state. The stone industry now gives employment to hundreds of persons, from trained administrators and salesmen to quarrymen and skilled stonecutters and carvers. Early geological surveys demonstrated that the state was endowed with an unlimited supply and a great variety of building material. The results of these surveys were published in earlier reports by the Minnesota Geological Survey * and by the United States Geological Survey.†

Since the publication of these reports new varieties of stone have been located and quarried for commercial purposes, and numerous new properties have been developed in widely separated regions within the state. Furthermore, great strides have been made in the methods of quarrying and fabricating stone. Modern machinery has eliminated much of the tedious manual labor, and wastage has been greatly reduced by the utilization of by-products.

In this report an attempt is made to acquaint architects, building contractors, and real estate firms with the merits of the various structural and ornamental stones quarried and fabricated in Minnesota. Until recent years our stone products were used more extensively in distant states than within our own communities. Minnesota stones enjoyed a national reputation for beauty and adaptability before their merits were recognized by our local builders. Even today many architects and structural contractors do not realize that more than fifty distinct varieties of architectural stone are quarried and fabricated in this state.

Geological reports cannot be distributed to every architect or builder who may be interested in his state's resources. The quarry operators and cut-stone dealers must bear the responsibility for distributing information as to their products and the facilities of their plants to supply the type of stone specified for a given structure. This report is designed, however, to help disseminate information regarding the nature and characteristics of the stone available for architectural and monumental uses. The inadequate conception that most people have of the importance of the stone

* N. H. Winchell and others, *The Geology of Minnesota* (Final Report of the Minnesota Geological and Natural History Survey, vols. 1–4, St. Paul, 1884–99).

† Oliver Bowles, *The Structural and Ornamental Stones of Minnesota* (United States Geological Survey Bulletin 663, 1918).

industry in Minnesota was evident to the writers from the surprise shown by many persons the first time they saw polished samples of the many beautiful varieties of granites, limestones, dolomites, and sandstones that were collected during the preparation of this report.

Since earlier reports have described the general geological structures and the geologic history of the state in detail, these subjects are treated briefly here. The main body of the report is devoted to descriptions of the various types of stone and the quarries where they are produced. The methods of fabrication are outlined and the various types of finishes described. An attempt has been made to show the color and texture of the more important granites and dolomites by means of colored plates. These should prove valuable to architects and builders in selecting stone for building and monumental purposes. Half-tone illustrations of a few prominent buildings and monuments constructed with Minnesota stone are also included. In view of the fact that many of the quarries described by Mr. Oliver Bowles in Bulletin 663 of the United States Geological Survey are now inactive, such quarries are simply listed and reference given to descriptions in that bulletin.

The authors desire to express their appreciation of the kindness of the following firms, who have given assistance with illustrations: the Cold Spring Granite Company, the North Star Granite Company, the T. R. Coughlan Company, the Breen Stone and Marble Company, the Babcock and Wilcox Company, the Fowler and Pay Company, the Biesanz Stone Company, and the Northwestern Bell Telephone Company. Thanks are due also to Mr. John Smith, who supplied much valuable data from his files on the building stone industry of the state, and to Mr. D. W. Kessler and Mr. W. H. Sligh of the United States Bureau of Standards for furnishing the results of tests on the properties of Minnesota limestones. The United States Geological Survey kindly furnished much statistical data. Most of the maps, sketches, and diagrams were made by Mr. Leonard Snell and Mr. Leroy Hassenstab, students at the University of Minnesota. The writers also take this opportunity to acknowledge their obligation to Mr. Oliver Bowles for his assistance in obtaining plates from the publishers of Bulletin 663 of the United States Geological Survey and for the use of much of the data he compiled for that bulletin. The work of N. H. Winchell on the building stones of the state has also been referred to frequently in the bulletin.

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THE USES OF STONE

During the last half century there has been an increasing demand for durable material for constructional purposes. When the concrete industry was first established, keen competition arose between the advocates of stone for structural purposes and the advocates of concrete. Prior to the manufacture of cement and its use in concrete, most of the stone quarried in Minnesota was used for building bridges, culverts, churches, public institutions, and foundations for large buildings. As the demand for concrete increased, it was accompanied by a demand for crushed stone, and many of the quarries that were producing building blocks began to install stone-crushing plants. This was especially true in the areas where the poorer grades of structural stone were being quarried. Today concrete has replaced stone to a considerable extent in the building of bridges, roads, culverts, curbing, pavements, sidewalks, retaining walls, etc. However, natural stone is being used for many of the public structures and large industrial office buildings.

Because of the low cost of production, manufacturers of artificial stone products are able to undersell the dealer in natural stone. At the present time a number of "cast stone" companies are profitably engaged in the manufacture of "trim stone" and other types of artificial stone for the facing and decorating of almost any kind of building. Some of the products are denser and heavier than natural stone. But in spite of all the encroachments of artificial products, there is today a greater demand than ever for the natural beauty and durability of real stone.

A building may be constructed almost entirely of stone. The walls, both exterior (see Figures 1 and 2) and interior (Figure 3), the foundation, sills, steps, terraces (Figures 4 and 5), roof, floors, and ornamentation may all be of stone. For each of the uses listed above the stone requires a somewhat different type of fabrication and finish. Because of the cost of high-grade finished stone, the walls of many large buildings are no longer constructed of huge blocks with a "finished" exterior face. Such walls are now commonly made of steel and concrete, and a thin veneer of "finished" stone is used as a facing. Granite and other crystalline rocks are now sawed by means of diamond and carborundum saws that cut the rock into slabs for facings that range from half an inch to any thickness desired. (See page 53 for methods of fabrication.) Such stone is commonly used in decorative construction for such purposes as frontages, base courses of large buildings and monuments, and various types of ashlar. For base courses and frontage structures the stones most commonly used are granites and other crystalline rocks, including the more massive

FIGURE 1. — The Minnesota State Office Building in St. Paul, built of pink St. Cloud granite.

Courtesy T. R. Coughlan Co.

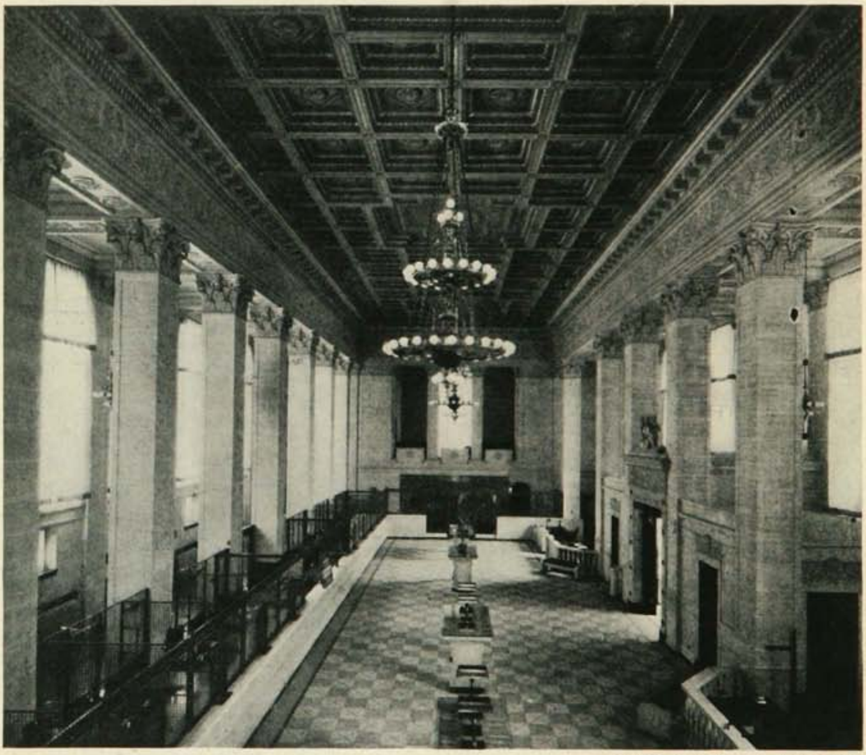
FIGURE 2. — The Art Museum in Philadelphia. The entire exterior is constructed of Mankato and Kasota stone.

marbles. For interior and ornamental work, marbles and limestones are more adaptable and can be fabricated at a lower cost. During the past fifteen years stone has been used very extensively in the construction of homes, especially medium-priced to high-priced homes, many of which are of stone exterior. On construction contracts awarded in thirty-seven states from 1925 to 1929, nearly three billion dollars were spent each year on residential structures.* Thus residential construction is becoming an outlet for the by-products of the higher grades of dimension stone. Every quarry operator who produces ornamental or building stone has a large stock of material that is odd-sized or off-grade. Much of this stone can be disposed of by developing a residential stone market.

* P. Hatmaker, *Markets for Residential Stone* (United States Bureau of Mines, Information Circular 6749, 1933).

In modern residential construction natural stone is usually employed as a veneer. Such a veneer is applied as a facing over some form of backing, which may be frame construction, hollow tile, concrete, common brick, or lightweight aggregates such as cinder blocks. Of this group a veneer over frame construction is the least costly type of stone-faced wall.

The sizes of stock offered for residential construction vary somewhat according to the physical condition of the stone in the quarry — that is, the kind and frequency of bedding planes and the kind and number of joint planes. Natural seams are utilized where circumstances permit. A quarrier of granite has rubble available for ashlar work, and a producer of limestone has random strips of stone three or four inches thick and from two to six feet long. These strips can be broken to desired lengths by the masonry contractor. Some limestone producers place upon the market limestone that has been sawed on four sides. This stone used in combination with seam face produces a pleasing textural contrast. (See Figure



Courtesy Biesanz Stone Co.

FIGURE 3. — Interior of the Cass Bank and Trust Building in St. Louis. The interior stone is Winona Travertine.

71.) Sandstone may be used in a similar manner. Some sandstone producers prepare brick strips for residential structures. These strips are $2\frac{1}{4}$ inches in height, $3\frac{3}{4}$ inches in width, and 6 to 36 inches in length. They are easily broken into the lengths required.

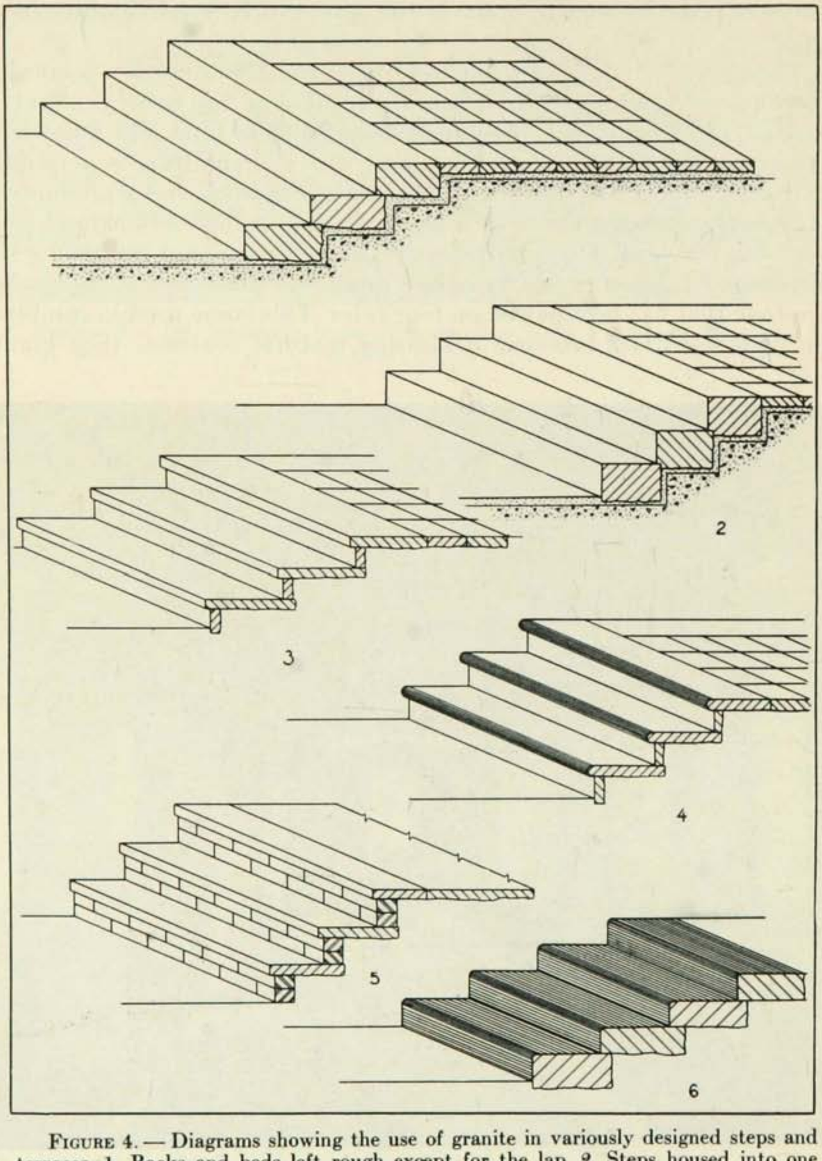


FIGURE 4. — Diagrams showing the use of granite in variously designed steps and terraces. 1. Backs and beds left rough except for the lap. 2. Steps housed into one another. 3 and 4. Treads and risers of thin granite slabs. 5. Granite tread with face brick for risers. 6. Heavy-duty step with rounded nosing. Redrawn after design of the Cold Spring Granite Company.

The producers and the architects must cooperate in order to develop the market for residential stone. A cordial relationship between contractors, producers, and architects is mutually beneficial. It has been shown that architects encourage the use of good building stones because an attractive, well-built, and well-designed stone residence is an advertisement for the architect as well as for the stone itself.

Stone is used extensively in the manufacture of monuments. (See Figure 6.) The monumental granites used in the United States in 1930 were valued at approximately ten million dollars. The extent to which a certain type of stone is used for monuments is influenced very largely by the reputation it establishes. In Minnesota the red and gray granites of the St. Cloud and Ortonville districts have long been favorites. During recent years the variegated granite from the Morton region has also become progressively more popular. Other stones in the state, however, are equally attractive. In spite of the excellent monumental stone that is quarried in Minnesota, many monuments are shipped to Minnesota and neighboring states from the quarries in New England and from Scotland, Scandinavia, and other European countries. There are various reasons for the importation of monuments from outside Minnesota, but undoubtedly one is the desire of the friends and relatives of a person who has immigrated from another country to place a monument of stone from his native land as a marker for his resting place in the country of

STATES LEADING IN THE PRODUCTION OF STONE PRODUCTS, SHOWING THE POSITION OF MINNESOTA IN 1929

Stone	Value
Building stone for exterior use	
Granite, total for United States	$11,695,667
Massachusetts	1,911,893
New York	1,808,411
Minnesota	1,695,667
Building stone for interior use	
Marble, total for United States	$35,307,244
New York	8,967,839
Tennessee	5,388,943
California	3,142,318
Missouri	1,999,271
Illinois	1,634,710
Massachusetts	1,063,960
Pennsylvania	986,946
Minnesota	938,210
Limestone, total for United States	$854,954
Minnesota	286,509
Monumental stones	
Granite, total for United States	$49,634,342
Vermont	14,222,581
New York	6,075,957
Massachusetts	4,072,656
Minnesota	3,454,380

his adoption. Another reason is the established reputation of such New England products as those from Quincy, Massachusetts, and Barre, Vermont. Increased publicity measures on the part of stone dealers in the granite districts of the state would tend to offset the extravagant claims made by some dealers concerning foreign stone. No more beautiful gran-

THE QUARRYING INDUSTRY IN MINNESOTA, 1919–29 *

	1919	1925	1927	1929
Number of establishments	109	56	52	76
Number of salaried officers	173	176	194	230
Number of wage earners	1,021	1,181	1,340	1,781
Salaries	$281,713	$441,595	$528,680	$654,189
Wages	1,282,349	1,735,923	2,194,621	2,645,673
Cost of materials	1,779,686	1,897,786	1,721,784	1,903,213
Cost of fuel and energy	122,123	123,743	261,103	326,746
Value of products	4,721,138	5,706,283	6,352,415	7,703,151
Value added by manufacture	2,819,329	3,808,497	4,369,528	5,473,192

* General statistics compiled from *United States Census: Manufactures.*

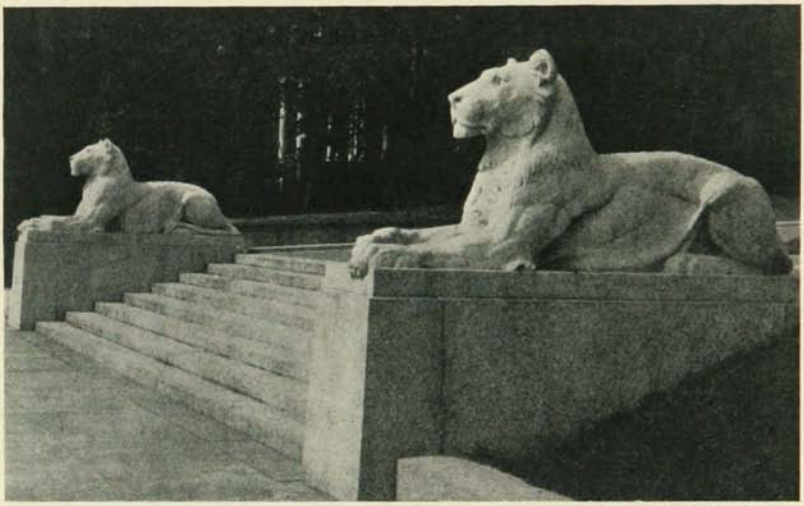
AMOUNT AND VALUE OF STONE PRODUCED IN MINNESOTA IN 1930*

Stone and Use	Amount	Value
Limestone		
Rough architectural	91,490 cu. ft.	$98,047
Finished architectural	139,360 cu. ft.	411,262
Rubble	6,360 tons	13,269
Riprap	30,580 tons	20,280
Concrete and road material	221,110 tons	242,534
Agricultural	15,450 tons	13,909
Other	7,710 tons	40,151
Granite		
Architectural stone (rough and dressed)	316,420 cu. ft.	$1,177,154
Monumental stone		
Rough	99,520 cu. ft.	238,188
Dressed	136,500 cu. ft.	1,233,567
Basalt (mainly crushed stone)	155,130 tons	$302,155
Sandstone (all uses)	55,850 tons	$112,278
Total crushed stone (all uses)	391,490 tons	$460,983

* Data from *Mineral Resources, 1930* (United States Geological Survey).

ite for monumental purposes can be found anywhere in Europe or in New England than that which is being produced in Minnesota. The pink and red granites, whether brilliant or subdued in color, cannot be surpassed in beauty by any imported products, and the dark gray granites (diorites and monzonites) are as good in every respect as those quarried elsewhere.

Immense quantities of crushed stone are used in making concrete for road construction. The relative value of screened gravel and crushed stone for this purpose has not been definitely determined, but tests * indicate that crushed stone makes a better wearing surface than gravels. This advantage is due to the better bond produced by the angular fragments of crushed stone. Rounded gravel pebbles tend to "kick out" of the concrete of a road surface, producing pockets which soon develop into holes. Large crushed stone fragments of hard, tough, crystalline rocks have the disadvantage of being more resistant to wear than the cement bond. The bonding mortar wears away and allows the rock fragments to protrude, making an uneven and bumpy surface. Once the surface



Courtesy Cold Spring Granite Co.

FIGURE 5. — Terrace, steps, and carved figures at the entrance to the Kansas City Insurance Building. The entire approach is made of pink granite from the St. Cloud district.

is roughened, the hammering action produced by heavy truck traffic over the protruding stones greatly increases the rapidity of wear on the road surface. Crushed sandstone that wears down with approximately the same rapidity as the bonding mortar produces a smooth, even surface as the road is subjected to wear. At present, crushed stone and gravel are used mainly for the concrete of the base course of the pavements. The upper surface or "wearing coat" is commonly made of graded sand and cement.

Large fragments of rough stone, commonly called riprap, are used extensively in the construction of piers, breakwaters, and cribs along the shore of Lake Superior at Duluth and Two Harbors. Some of the quarries at Duluth were formerly worked exclusively for this type of product. Along the Mississippi Valley from St. Paul to the Minnesota-Iowa state line, numerous jetties have been constructed in the channel of the river.

* Charles F. Shoop, *An Investigation of the Concrete Road-Making Properties of Minnesota Stone and Gravel* (University of Minnesota Studies in Engineering, No. 2, 1915).

These are built entirely of stone quarried from the limestone strata that crop out along the valley. Crushed stone is used also as a railroad ballast. In Minnesota, however, glacial gravels are readily available over large areas and consequently washed gravel is more commonly used as ballast.

Limestone and dolomite are quarried also for the manufacture of lime and cement. A bulletin published recently gives the location and analyses of Minnesota rocks most suited for that purpose.* There are three

Courtesy Cold Spring Granite Co.

FIGURE 6. — Finishing a monument of Morton granite gneiss.

types of stone which on being burned yield three types of lime: (1) pure limestone yields *high calcium limes;* (2) magnesian limestone yields *magnesian limes;* (3) argillaceous and siliceous limestones, *hydraulic limes.*

Considerable quantities of stone are used as abrasives for grinding and polishing. The Sioux quartzite, quarried in southwestern Minnesota, is used both as grinding pebbles and lining blocks (see Figure 7) in tube

* C. R. Stauffer and G. A. Thiel, *The Limestones and Marls of Minnesota* (Minnesota Geological Survey Bulletin 23, University of Minnesota Press, Minneapolis, 1933).

mills. Grindstones for sharpening tools and shaping metal work are made from well-cemented, fine-grained sandstone. The Hinckley sandstone has supplied crude blocks of stone for the manufacture of various types of grindstones. Sand derived from the Jordan sandstone is used as an abrasive in sawing and dressing architectural and monumental stone. It is also used in the sandblast for cleaning stone and brick structures and for cutting patterns and inscriptions on stone.

Finely crushed and sized fragments of stone are used for roofing pebbles, or granules. Archean greenstone is being quarried and crushed near Ely, and red jaspery beds in the Sioux quartzite in Rock County are used for the same purpose.

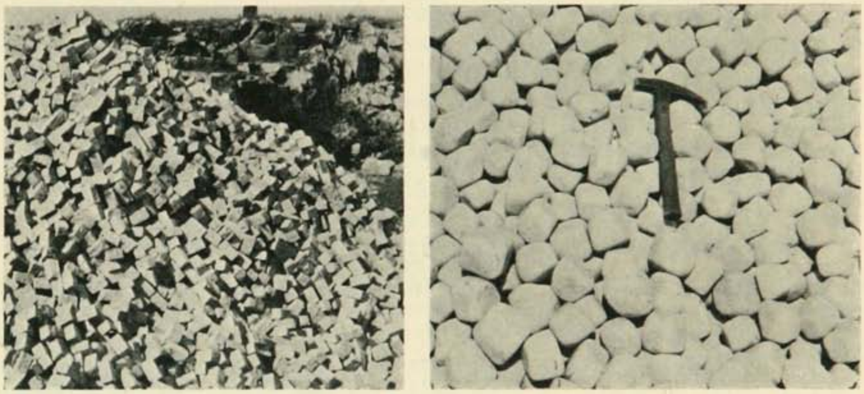


FIGURE 7. — *Left:* Quartzite blocks for lining grinding mills. *Right:* Quartzite pebbles for grinding mills.

There are many other minor uses of stone, some of which were more important formerly than they are now. The cutting of paving blocks and curbstones was once a major phase of the stone industry in this state. Reports of the United States Geological Survey show that the paving block industry has decreased steadily throughout the country during the last ten years. The decrease has been general for all varieties of stone sold for this purpose. The widespread use of concrete is responsible for the change. Some limestone has been quarried for fluxing stone, but this industry is no longer active in the state.

Dimension stone is a general term covering stone sold in the form of blocks which, with certain exceptions, are cut to definite shapes and often to specified sizes.* The production of dimension stone in the United States in 1931 and 1932 is summarized in the table on page 10.

* Dimension stone includes cut, carved, and also rough-hewn blocks of building stone, monumental stone, paving blocks, curbing and flagging, roofing slabs, and many special products such as tubs, sinks, blackboards, furnace blocks, steps, baseboard, and floor tile. Such products are contrasted with crushed and broken stone, which consists of irregular fragments that are sized chiefly by mechanical screening or air separation.

The Production of Dimension Stone in the United States in 1931 and 1932 *

Stone	1931	1932
Building stone †	14,816,030 cu. ft	11,200,000 cu. ft.
	$27,049,886	$17,177,900
Monumental stone	2,869,150 cu. ft.	1,967,600 cu. ft.
	$9,634,168	$6,083,700
Paving blocks	22,440,590 blocks	7,627,000 blocks
	$1,938,158	$660,000
Other stone ‡	$4,124,967	$2,287,300
Slate	138,440 tons	68,400 tons
	$4,185,819	$1,863,000
Miscellaneous building stone	935,780 cu. ft.	756,000 cu. ft.§
	$216,559	$635,000 §
Total value	$47,149,557	$28,706,900
Total tonnage	2,894,920	1,942,000

* Estimated. † Cut stone.
‡ Rough construction stone, rubble, curbing, and flagging.
§ Includes soapstone.

Amount and Value of Different Kinds of Stone Imported for Consumption in the United States, 1930 *

Stone	Quantity	Value
Marble, breccia, and onyx		
In blocks, rough, etc.	717,436 cu. ft.	$1,578,856
Sawed	797	2,983
Slabs or paving tiles	591,616 superficial feet	254,179
All other manufactures	....	329,279
Mosaic cubes of marble or onyx		
Loose	....	9,383
Attached to paper	....	2,774
		2,177,454
Granite		
Dressed	....	226,318
Rough	138,831 cu. ft.	202,037
		428,355
Quartzite	102,032 short tons †	174,334 †
Travertine stone (unmanufactured)	74,163 cu. ft.†	64,997 †
Other stone		
Dressed	....	23,396
Rough (monumental or building stone)	214,424 cu. ft.	203,417
Rough (other)	....	73,908
		300,721
Grand total	....	$3,145,861

* From *Mineral Resources, 1930* (United States Geological Survey).
† Figures cover June 18 to December 31; not separately classified prior to change in tariff.

CHAPTER I

THE COMPOSITION, CLASSIFICATION, AND HISTORY OF ROCKS

ROCK MINERALS

For general purposes the term "rock" is used to designate the solid portion of the earth or a fragment of that portion. Not all rocks are alike. Most variations are due to differences in the composition, arrangement, and size of the particles which compose the rocks. These particles are crystallized bodies known as minerals. Although it is not proposed to give a detailed account of minerals here, some general statements concerning their physical properties will make possible an easier and more complete understanding of building stones.

The most obvious property of a mineral is its color. The color is fairly constant in most minerals but not in all. It is generally due to pigments or impurities in the mineral. Quartz is commonly colorless, but it may be blue, purple, rose, or pink because of impurities in the mineral grains.

Another property closely associated with color is the streak, which is the color of the powder of the mineral. This color may not be the same as that of the mineral from which the powder came. The streak is usually obtained by rubbing the mineral across a plate of unglazed porcelain, on which the fine powder will be retained.

Many minerals break along one or more relatively plane surfaces, and such a feature is known as cleavage. Regardless of external form or arrangement of the minerals, the cleavage surfaces intersect to form constant and characteristic angles, such as a diamond-shaped pattern with angles of 124° and 56°, or a square pattern with all angles of 90°.

The hardness of a mineral is its resistance to abrasion, and is usually measured in relation to other minerals. A scale of increasing hardness, based upon comparison with familiar objects and expressed numerically, is as follows:

1. Scratched easily with finger nail; example, talc
2. Scratched with difficulty with finger nail; example, gypsum
3. Scratched easily with knife blade; example, calcite
4. Scratched with difficulty with knife blade; example, fluorite
5. Scratched with great difficulty with knife blade; example, apatite
6. Scratched by file and will not scratch glass; example, orthoclase
7. Not scratched by file and will scratch glass; example, quartz
8. Example, topaz
9. Example, corundum
10. Hardness equal to that of diamond

Minerals with a hardness greater than 7 are not commonly found in building stones.

Inasmuch as it is desirable to have some classification of the minerals commonly present in building stones, we shall group them according to the substances of which they are composed. Because of the characteristic substance present in all the minerals of each group, the groups are called silicates, carbonates, oxides, and sulphides.

SILICATES

The silicate group is so named because of the presence of silica, which makes up ordinary glass or glassy sand grains.

Feldspar.—A whole family of minerals is designated by the name feldspar, but the principal types are orthoclase (silicate of aluminum and potassium), microcline (silicate of aluminum and potassium with a different arrangement of molecules), and plagioclase (silicates of sodium and calcium). The last are further subdivided into varieties, but these need not be considered here.

The feldspars are abundant and important in those rocks commonly referred to as "granites." The red, white, and gray colors in rock patterns are usually due to the presence of these minerals.

Orthoclase has a hardness of 6 and two cleavages, intersecting at 90°, which may be readily recognized by the bright reflection of light as a specimen is turned in various positions. The usual color of this mineral is pink, but white and gray varieties are common also.

Microcline, a mineral not easily distinguished from orthoclase without microscopic examination, occurs abundantly in some Minnesota granites.

The plagioclase varieties are similar to orthoclase in hardness and cleavage but are characteristically light or dark gray in color. If the crystals are large enough to be easily examined, plagioclase may be distinguished by the presence of striated or lined surfaces. Plagioclase feldspars are predominant in the light and dark gray granites and in the "black granites," or gabbros.

Mica.—The two types of this mineral are usually known as isinglass. The white or colorless mica is muscovite (hydrous silicate of potassium and aluminum) and the black is biotite (hydrous silicate of potassium, aluminum, iron, and magnesium). Both types are characterized by one perfect cleavage which permits a specimen to be split into very thin sheets. Mica is one of the soft minerals in building stones, its hardness varying from 2 to 3. Because of its more contrasting colors and greater abundance, biotite is readily recognized, and with hornblende it usually forms the dark grains present in granites.

Hornblende.—This mineral (complex silicate of calcium, magnesium, aluminum, and iron) is the common variety of a group called amphiboles. It is very dark green or black in color and for that reason might be confused with biotite. It is much harder, however, and it will not split into thin sheets. If the crystals are of medium or large size, they may be observed to have a characteristically elongated prismatic shape and cleavages which intersect at angles of 124° and 56°.

Augite.—Another group, known as the pyroxenes, contains augite (similar to hornblende but with different molecular arrangement) as its most common variety. The similarity of composition results in similarity of color and hardness, and the two minerals may therefore be easily confused. The difference in molecular arrangement results in less brilliant augite cleavage surfaces and an angle of intersection of 87°, i. e., almost a right angle. Augite is present in dark colored rock and is usually associated with plagioclase feldspar.

Chlorite. — Chlorite (hydrous silicate of aluminum, iron, and magnesium) is related to mica by its similar but more poorly developed cleavage and its hardness of about 2. Its color is dark green. Chlorite is usually present in crystalline building stone, where it is formed by the decomposition of hornblende, augite, or biotite.

Epidote. — Like chlorite, epidote (hydrous silicate of calcium, aluminum, and iron) results from the alteration of dark minerals in dark colored crystalline rocks. It may be abundant and give the entire rock a yellow-green color, but more often it is localized and results in "green lines," or stains within the rock.

Olivine. — The mineral olivine (silicate of iron and magnesium) has an olive-green color and a hardness of from 6.5 to 7. It is associated with minerals that are present in the darker colored varieties of "granites," or gabbros.

Talc. — The decomposition of hornblende, augite, or olivine may yield talc (hydrous silicate of magnesium). It is number 1 in the scale of hardness and possesses a characteristic soapy or greasy feeling that accounts for its being called "soapstone" or "soap rock."

Carbonates

The carbonate group is so named because of the combination of carbon and oxygen with other elements which are found in each mineral.

Calcite. — Calcite (carbonate of calcium) is the chief constituent of limestones. It represents number 3 in the scale of hardness; and although colorless or white to yellow varieties are most common, red, blue, and green colors also occur. Calcite has a rhombic cleavage in which three perfect cleavages meet at angles of approximately 75°. It is not commonly present in crystalline rocks other than marble, but it does occur abundantly in such rocks as sandstones, shales, and limestones.

Dolomite. — This mineral (carbonate of calcium and magnesium) differs so little from calcite that its recognition depends largely upon microscopic or chemical determinations. Chemical determination simply requires placing a drop of cold dilute "muriatic" acid upon the specimen in question. If it is calcite, gas bubbles will form in the drop; if dolomite, no bubbles will form. The occurrences of dolomite are similar to those of calcite.

Oxides

All the minerals in this group are characterized by being compounds of oxygen and such substances as silicon, iron, or aluminum.

Quartz. — The mineral quartz is composed of silicon dioxide. Next to feldspar it is the most abundant material in the earth's crust. It commonly occurs as six-sided or hexagonal crystals. When pure, these are colorless, but many are pink, violet-purple, blue, or brown in color. Quartz has no cleavage and hence it rarely presents flat surfaces when broken. In granites in which the light colored minerals are quartz and feldspar, the quartz may be distinguished from the feldspar by turning the rock so as to get a reflection of light from the cleavage planes of the feldspar. The broken quartz grains appear glassy. They are usually rounded or irregular in outline.

Magnetite.—Magnetite (oxide of iron) is so named because of the attraction a magnet exerts upon it. The mineral is black and has a black streak. It generally occurs as small grains in the rocks commercially known as "black granites." The hardness of magnetite is from 5.5 to 6.5. It therefore takes a good polish which appears white with a pitted surface when light is reflected from it.

Hematite.—This mineral (also an oxide of iron) is an excellent example of the difference between color (red to black) and streak (red to brown). Hematite is largely responsible for the red colors in rocks. It may predominate, as in the iron ores of Minnesota, or it may be sparsely included as in pink varieties of orthoclase and microcline. Hematite may occur as a hard metallic mineral or as an aggregate of soft earthy particles.

Limonite.—Common iron rust is a well-known form of this mineral (an iron oxide like hematite but combined with water). Rust is the soft yellow form of the mineral, but limonite occurs also in a hard, dark brown or black form. Both varieties have a yellow-brown streak. Limonite results from the decomposition of iron-bearing minerals such as hornblende, augite, biotite, or pyrite.

Sulphides

The presence of sulphur in combination with an element such as iron, copper, etc., accounts for the name applied to this group of minerals.

Pyrite.—Pyrite (sulphide of iron) has a pale yellow appearance, and although it generally occurs in rocks as small grains, it may be readily recognized by its characteristic color. Its hardness is from 6 to 6.5, and it therefore takes a good polish.

Marcasite.—This mineral is like pyrite except for the arrangement of its molecules. It can be distinguished from pyrite only with difficulty.

Miscellaneous

Other minerals that are present in building stone but that are commonly too small to be identified except by the use of the microscope are as follows: sphene or titanite (silicate of calcium and titanium); zircon (silicate of zirconium); garnet (silicate of iron and aluminum), a mineral that occurs in included rock masses within some granites; and apatite (compound of phosphorus, oxygen, and calcium).

CLASSIFICATION OF ROCKS

A classification of rocks based on their origin results in three major groups, namely (1) igneous, (2) sedimentary, and (3) metamorphic.

Igneous Rocks

Igneous rocks are those resulting from the cooling and solidification of a mass of molten material. The chambers of molten material, called magma, are deep-seated within the earth (see Figure 8), and the liquid rock moves from such depths toward the outside of the earth. If the material is poured out on the surface, the outlet is called a volcano and the rock is called lava. Under such conditions, cooling is rapid and the resulting rock is fine grained or glassy. Other igneous rocks are the product of magma that did not reach the outside of the earth but was forced into

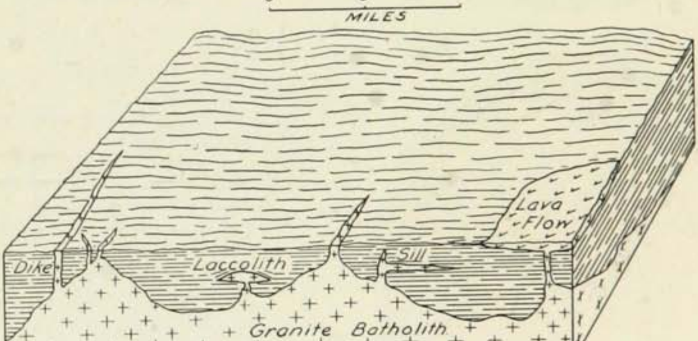
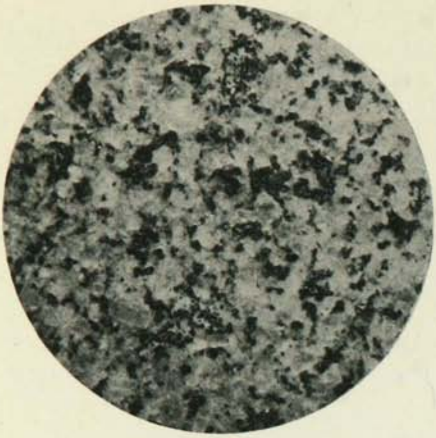
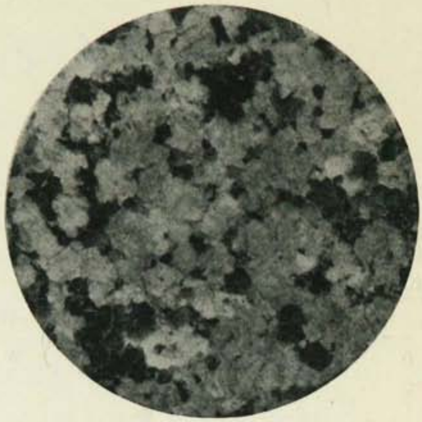


FIGURE 8. — Diagrammatic sketch showing cross-section of a granite batholith and associated rock masses intruded into sedimentary rocks.

openings and melted a passage for itself in the rocks with which it came in contact. Since these rocks were not at the surface, solidification of the lava was slow, and consequently the mineral crystals were large and the rocks coarse grained. Just as the differences in textures of igneous rocks result from different conditions of solidification, so the difference in color is the result of different minerals or different proportions of minerals in the rock.

Igneous rocks are of many types, but only a few varieties are important as building stone from Minnesota quarries.

Granite. — The term "granite" is used in the stone industry to designate all crystalline rocks other than marble. Geologically, however, granite is a rock composed of orthoclase and quartz as essential minerals, with mica, hornblende, magnetite, etc., as accessory constituents. The minerals are all of sufficient size to be easily recognized. The grains, which may be of different sizes in different rocks, are designated as fine, medium (about a quarter of an inch in length), and coarse grained. (See Figure 9.)



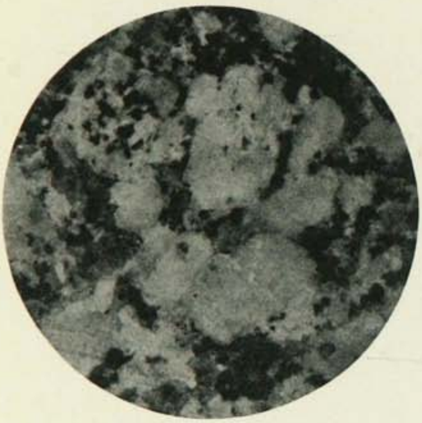


FIGURE 9. — Polished granites showing variations in texture. *Top left:* Fine-grained granite from Sauk Rapids. *Top right:* Medium-grained granite from St. Cloud. *Lower:* coarse-grained granite from Rockville. Approximately natural size.

The color of granite is usually determined by the color — pink, gray, or white — of the feldspars. In some granites, biotite or hornblende is abundant and is scattered as small black grains throughout the rock. The "black granite" of the stone industry is not a granite; it is described below under the term "gabbro."

Gabbro. — This igneous rock differs from granite in having feldspar of the plagioclase variety, usually associated with augite and such accessory minerals as hornblende, biotite, olivine, and magnetite. Because of this difference in the mineral composition, gabbros are green, dark gray, or black in color, and are commercially referred to as "green granite" or "black granite."

Basalt. — This is a fine-grained igneous rock with the same composition as a gabbro.

Diabase. — This rock is a variety of gabbro. It contains prominent lath-like crystals of plagioclase.

Sedimentary Rocks

Sedimentary rocks are composed of mineral or rock particles that have been transported by gravity or by wind, water, or ice. Some minerals are dissolved by water and carried in solution. Minerals or earthy materials are often transported by air and water — as is evident when air carries them as dust and water as mud or sand. The material that is being transported was formerly a portion of the earth's surface. As a result of the destructive power of wind, frost, water, ice, etc., solid rock is continually being made into particles of soil or earth, which are then subject to the carrying power of these natural forces. When the carrying power is lessened, a portion of the load is dropped and a layer of sediment results. As this process is repeated, beds of material accumulate in lakes

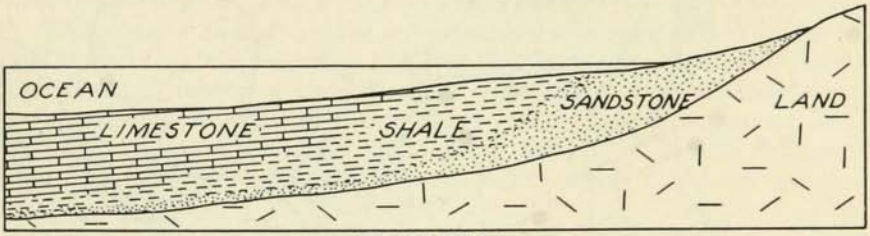


Figure 10. — Diagram showing the submergence of a land area. Muds that form shale are deposited on sand, and fine calcareous oozes that form limestone are deposited upon the earlier deposits of mud.

and stream valleys, on ocean shores, and underneath and at the end of glaciers. The gravels, sands, and clays are more or less intermixed as they are transported by water, but when they are deposited, grains of a particular size ordinarily predominate in a given environment. (See Figure 10.) These minerals and rock grains are then more or less firmly cemented together by the deposition, in the spaces between the grains, of minerals from water solutions which percolate through and saturate the sediment so as to form the solid rocks known as conglomerate, sandstone, or shale. Those that are highly calcareous are called limestones. All sedimentary rocks most commonly occur as interbedded layers or strata.

Conglomerates and shales are not commonly used as building stones, but sandstone was formerly quarried extensively along the upper St. Croix River and is still quarried along the Kettle River at Sandstone, Minnesota.

At the present time in Minnesota most of the sedimentary rocks quarried for building purposes are limestones and dolomites. Some varieties of the rocks are also called "marble" and "travertine." These rocks are made up of mineral particles that were dissolved and carried by water. Under certain conditions, such as evaporation or agitation, but principally as a result of physiological processes of some plants and animals, part of such dissolved material may assume a solid form, such as

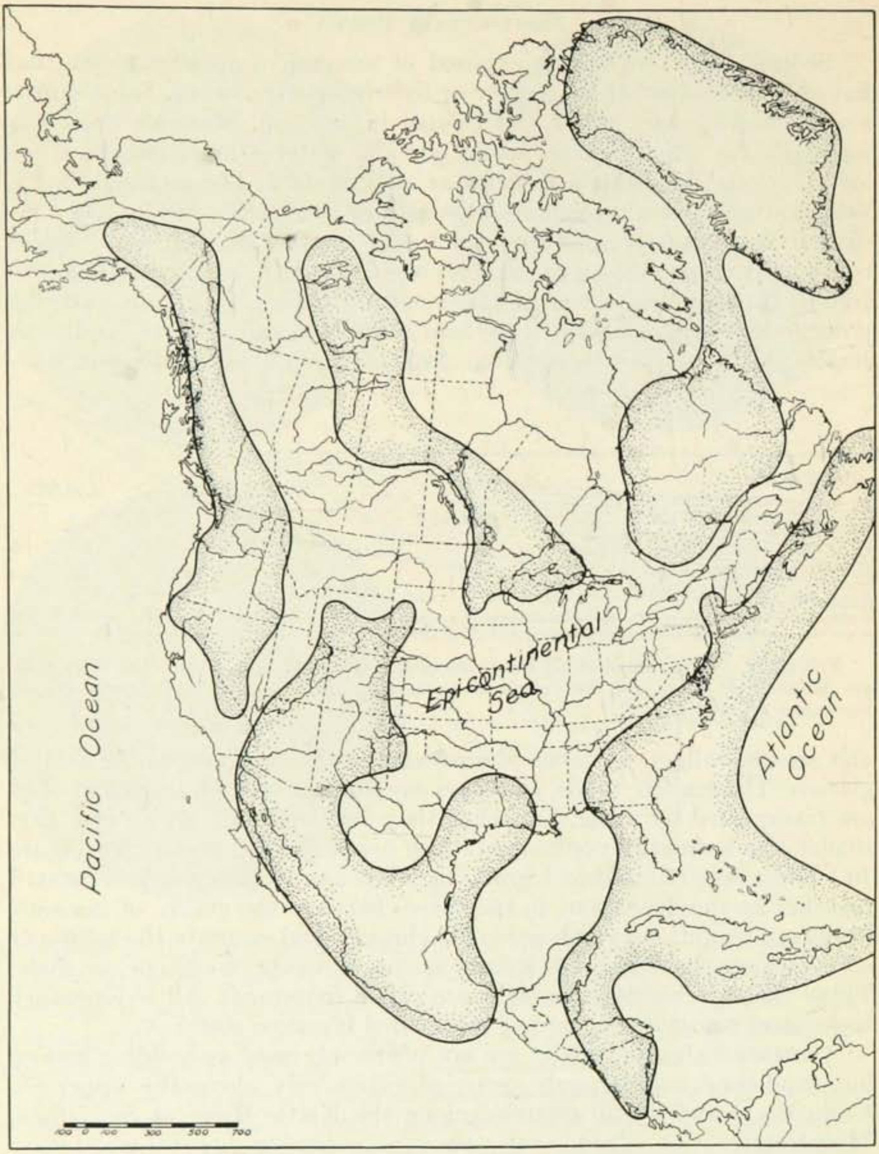


FIGURE 11. — Map of North America showing the distribution of land and sea during Middle Ordovician time. The stippled areas are land.

the mineral calcite (calcium carbonate), the predominant mineral in limestone. The principal areas in which limestones are forming are the bottoms of seas along continents or in shallow epicontinental seas. (See Figure 11.) In these areas are found innumerable forms of animals, such as clams and corals, of which the shells or skeletons are made of calcium carbonate extracted from the sea water. The hard skeletal parts of these animals are often preserved in the limestones and are known as fossils. Most limestones are made up of entire or broken shells, firmly cemented by a "mud" of finely crushed shells and precipitated calcium carbonate. Limestone is usually light or dark gray, but it may be blue, red, buff, etc. The coloring is due to impurities of iron or to organic material.

Dolomite.—The manner in which dolomite is formed is not definitely known, but it is generally accepted that it is formed when limestone has been acted upon by solutions containing some magnesium salt. Under such conditions some of the calcium of the limestone (calcium carbonate) has been replaced by magnesium, and the result is dolomite (calcium-magnesium carbonate). Although the double carbonate may have been deposited as such, it is more probable that a process of replacement acted upon the partially consolidated limestone and converted it into dolomite.

Sandstone.—Sandstones are sedimentary rocks composed of grains of sand bound together by mineral matter that serves as a natural cement. The grains of sand are chiefly quartz, but many other minerals may occur with the quartz, such as feldspar, mica, garnet, magnetite, etc. The Hinckley and Fond du Lac sandstones contain much feldspar, whereas the Jordan and St. Peter sandstones are 90 to 99 per cent quartz.

Metamorphic Rocks

Metamorphic rocks are the result of great changes in igneous or sedimentary rocks, produced by pressure, heat, or chemical action. Pressure may cause elongated mineral grains to turn so that all grains are aligned in one direction. Heat and pressure may cause the rock to become less rigid and may permit complex structures to form. Chemical action may cause some minerals to dissolve and others to change by additions from the dissolved material. The final result is generally a rock in which the kind, size, and interrelation of minerals are very different from those in the original unaltered mass.

Gneisses.—When the rocks of the earth are thrown into folds to form mountain ranges or when masses of molten rock force their way toward the surface, terrific pressures are developed within the earth's crust. The pressure causes the rocks to become so plastic that new minerals are formed. These are rudely parallel in arrangement, so that the deformed rocks have a banded appearance. Such rocks are called gneisses. They may form from either igneous or sedimentary rocks. The parallel arrangement of mineral grains may result in straight bands, but more commonly they are greatly contorted and more or less broken. Most gneisses have the same minerals and therefore the same color as granites but they are not of uniform texture. This textural variation adds to their value for certain types of architectural stone.

Quartzite.—This rock is formed from sandstone by processes of cementation which make the cement as strong as the mineral grains. The cementing material is silica (of which quartz is a common crystalline va-

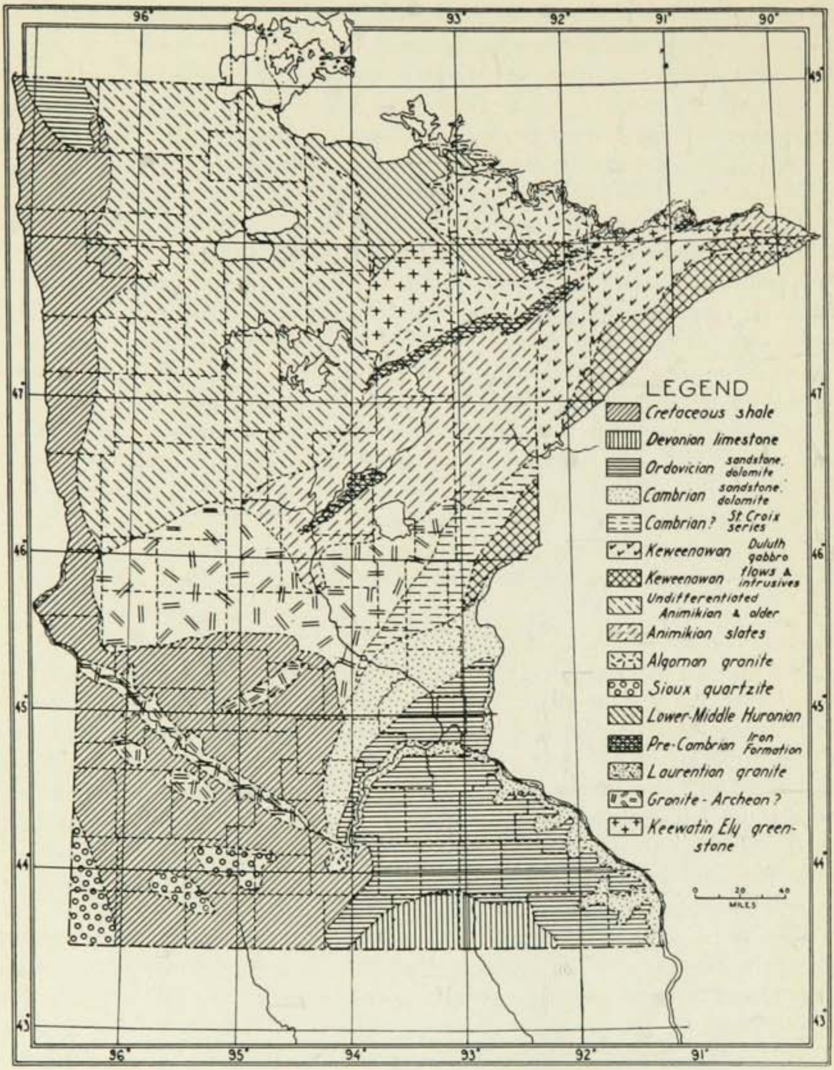


FIGURE 12. — Geologic map of Minnesota.

riety) carried and then deposited either by downward percolating cold water or by hot water moving away from regions of igneous intrusion and mountain-making. The color may be white, pink, or red, depending upon the amount of iron minerals present. The texture is generally so fine as to be visible to the unaided eye only upon very close examination. Quartzite is probably the most enduring of all building stone, but its hardness makes it so difficult to cut and trim that it is not widely used.

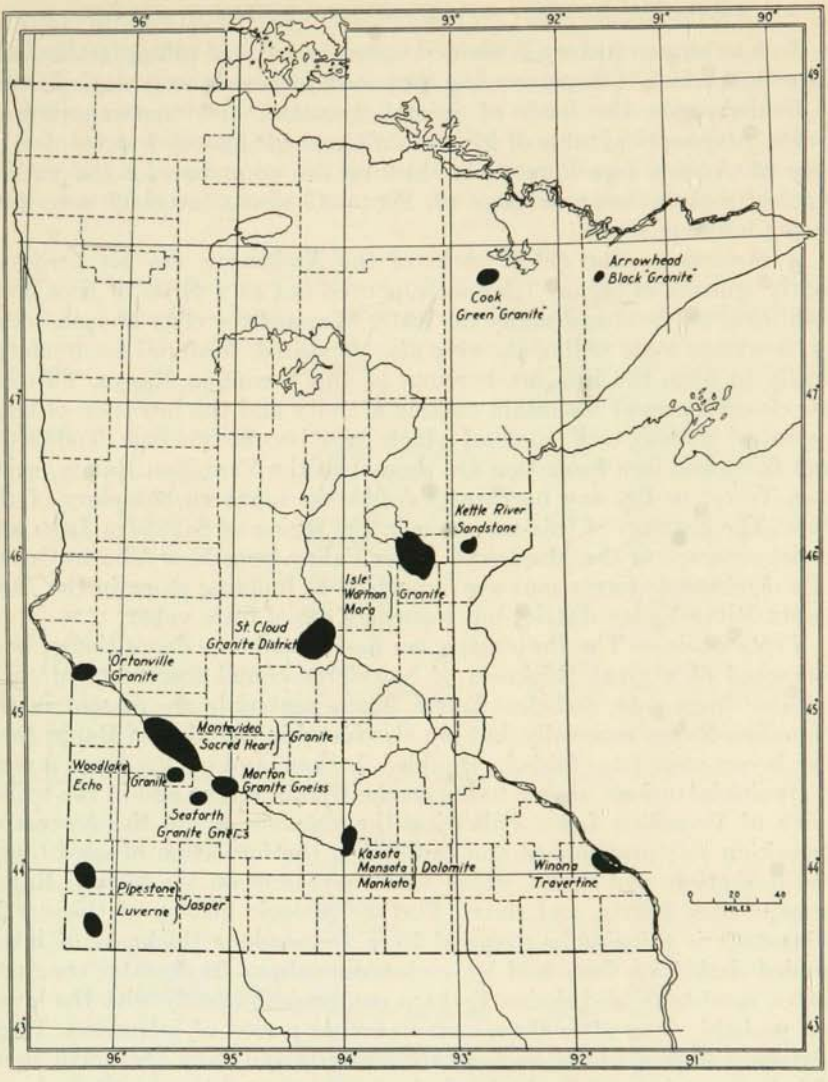


FIGURE 13. — Map of Minnesota showing the location of the most active stone-producing regions.

Marble. — Marble is a metamorphosed limestone. The change in the rock brings on a whiter color and a decided crystalline character. Sometimes a similar crystalline character forms apparently without the intense heat and pressure usually associated with metamorphism. Such limestones are often designated "marbles." Some of them are quarried in Minnesota.

GEOLOGIC HISTORY OF MINNESOTA BUILDING STONES

Just as human history is divided upon the basis of ruling families and the events which took place while they were in power, so geologic history is divided upon the basis of animal dynasties and contemporaneous events. A synoptical table of Minnesota's geologic history is presented on page 23. A map (see Figure 12) showing the occurrence of the various types of rock is shown on page 20. Figure 13 shows the chief areas producing building stone.

Archeozoic.—The oldest rocks of the Archeozoic era are predominantly igneous in origin. They were poured out as a series of lava flows both upon the land and under the water. Toward the close of such activity, however, some sediments were also deposited. Material accumulated locally to form the iron ore horizons of the Vermilion Range. This era was closed by great mountain-making activity and the intrusion of large masses of igneous rock, some of which have become gneissic. Today the lava flows and iron formation are present in the Vermilion Range region from Tower to Ely and northeastward to the northern boundary of the state. The granites of this era occur in the region of Saganaga Lake and in the outcrops of the Minnesota River Valley from New Ulm to Ortonville. Archeozoic formations are important as building stone in the Minnesota River Valley district but elsewhere are of little value.

Proterozoic.—The Proterozoic era first records the deposition of beds composed of a great thickness of bowlders—small fragments of rock, volcanic fragments, and dust layers. These materials are present in the Vermilion Range especially, but are also found in the Mesabi Range area. The layers were later folded, crumbled, broken, and cut by large masses of granite intrusions, shown today on the Giants Range and in the region north of Vermilion Lake. Following the volcanic action the process of deposition was pronounced and resulted in the formation of sandstones, iron formation, and shales, which are now present on the Mesabi Range as quartzites, cherts, and slates. Further geologic history of this era in Minnesota is principally recorded by a tremendous thickness of interbedded dark lava flows and by such sediments as fresh-water conglomerates, sandstone, and shales. Perhaps contemporaneously with the lavas, but probably long after them, came another period of intrusions. These intrusions were gabbros, such as are found inland from the north shore of Lake Superior and in the Cook-Angora area, and the granites of central Minnesota (the St. Cloud area). These rocks furnish important building stones in the state.

Paleozoic.—The formations of the Paleozoic era are all sedimentary in character and are found in east-central and southeastern Minnesota. (See Figure 12.) These rocks indicate the former presence of great floods, which came up the area of the Mississippi Valley and covered those portions of the state. The submergence of the land beneath the seas probably was more extensive than the area now covered by the Paleozoic beds, and the shores of those seas were composed of rock belonging to the Proterozoic or Archeozoic eras. The streams on these ancient rock areas carried material into the Paleozoic seas in the same way as streams do today. If the shores were high, the streams flowed swiftly and carried many bowlders, much sand and mud, and only small amounts of dissolved material. Upon entering the seas the streams dropped their loads and the waves began to act upon the sediment. As a result of these processes the underwater shore areas had zones of deposition characterized by decreas-

GEOLOGICAL COLUMN OF MINNESOTA

Era	System and Series	Formation	Approximate Thickness	Character of Rocks
Cenozoic	Recent	Recent	0–300	Sands, silts, clays, muds
	Pleistocene	Glacial	0–600	Loess, gravel, sand, loams, clays
Mesozoic	Cretaceous	Benton shale	0–550	Clays and shales
		Dakota formation	0–200	Sands and clays
Paleozoic	Devonian	Cedar Valley limestone	100	Sandstones and limestones
	Ordovician	Maquoketa	100	Shale and limestones
		Galena		Limestone
		Decorah	230	Shale
		Platteville		Limestone
		St. Peter	80–200	Sandstone
		Shakopee	100	Dolomite
		Oneota	75–200	Dolomite
	Cambrian	Jordan	75–200	Sandstone
		St. Lawrence	100–200	Dolomite and shale
		Franconia	50–100	Sandstone
		Dresbach	300–450	Sandstone, shale, limestone
Proterozoic	Keweenawan	Red Clastic series in southern Minnesota, sandstone in northern Minnesota	2,250 maximum	Sandstones and shales
		Conglomerate and sandstone	500	Conglomerate and sandstone
		Eruptives	Unknown	Igneous rock
	Huronian			
	Upper Huronian (Animikie group)	Intrusives	Unknown	Acid and basic igneous rocks
		Virginia and other slates	3,000	Slates
		Biwabik and Gunflint	600	Taconite, iron ore, chert
		Pokegama	100	Quartzite, Sioux quartzite (southwest)
	Lower Middle Huronian	Giants Range	Unknown	Granite, dolomite, porphyries
Archeozoic		Slates	5,000	Slate, graywacke, conglomerates
	Laurentian	Igneous rocks	Unknown	Granites, schists, porphyries
	Keewatin	Soudan	Unknown	Banded cherts and jaspers, iron ore
		Ely and other formations	Unknown	Greenstone, schists, porphyries

ing size of particles with increasing depth of water. Where the lands were low, the streams carried little material in suspension, and only dissolved material was carried to the sea. The resulting deposits were predominantly limestone or dolomite.

The Paleozoic formations of Minnesota are sandstones, shales, limestones, and dolomites. These layers are found today in interbedded and almost horizontal positions. The first relationship is interpreted as being due either to variation in the height of the land that was being eroded or to variation in the depth of water where materials were deposited. As a flood became more extensive and the shore line moved inward upon the continent, the depth of water increased and finally a zone of sandstone deposits changed to one of shale. Similarly, the zone of shale was succeeded by one of limestone deposition. The reverse order is, of course, possible also, and as a result of the two possibilities, the layers may vary gradually in a horizontal direction but usually change more sharply in a vertical direction.

The second relationship, in which the layers are in horizontal position, means that the layers have not been deformed since they were deposited. Their present location far from any seacoast is due to a gradual elevation of the North American continent and a corresponding retreat of the shore line from its ancient positions across the upper Mississippi Valley and the Great Lakes areas.

The table on page 23 shows the vertical sequence, the thickness, and the general character of the Paleozoic beds. The only formation that is important as a building stone at the present time is the Oneota dolomite which is quarried in the Mankato-Kasota area and at Winona.

Mesozoic.—Formations of Mesozoic age are present over large areas of western and southwestern Minnesota, though they are found only in small quantities elsewhere. The sediments are poorly cemented clays and sands that are not suitable for building stones.

Cenozoic.—The last part of the Cenozoic era is known as the Ice Age. As a result of the transporting power of glaciers, the northern and northeastern parts of the state were scraped and scoured until large areas of bed rock were exposed. In the other portions of the state, except the southeastern corner, glacial débris or glacial-lake sediments accumulated until little bed rock was left exposed. A large stream, draining a lake whose waters were of glacial origin, cut the course now occupied by the Minnesota River and uncovered the bed rock of that valley.

RELATION OF ROCK STRUCTURES TO QUARRYING

The aim of quarrying is to obtain blocks of rock of specified sizes and shapes. In order that operations may be efficient, the general practice is to excavate large blocks and then subdivide or reduce them to the desired dimensions. The sizes and shapes of the large blocks are often dependent upon natural openings or directions of weakness in the rock. Such structures should be recognized and considered in quarrying.

Joints.—Joints are natural open seams which are vertical or nearly vertical in position. Ordinarily the rock contains two prominent systems of parallel joints which intersect at approximately 90°. This arrangement of joint systems permits the removal of blocks more or less "squared up." In some cases, unfortunately, there is also a third or even a fourth system of joints. The intersection of these systems divides the rock into blocks of irregular shape and necessitates much waste in trimming.

The distances between individual joints of a system are as important as the angles of intersection. Inasmuch as large blocks are usually desirable, the joints should not be too closely spaced. If, however, they are too widely spaced, the removal and hoisting becomes difficult and expensive. The mode of operation, equipment, and use of the stone will usually determine the effect of joint spacing in individual quarries.

Dry seam.—The name "dry seam" is applied to a closed joint which though invisible or marked only by fine lines will open readily when the rock is shaken by a blast.

Sheeting planes.—Sheeting planes are natural open seams in a more or less horizontal position in igneous or metamorphic rocks. Ordinarily they are roughly parallel to the form of the outcropping surface. Sheeting planes determine the third dimension of the blocks outlined by joint planes and are generally used as benches or steps in quarry operations. It is desirable that sheeting planes, like joints, be neither too closely nor too widely spaced. When the spacing is too wide or when sheeting planes are absent, benches are maintained by blasting in a row of horizontal "lift" holes.

Bedding planes.—In sedimentary rocks, contacts of different layers or natural open seams parallel to the contacts are known as "bedding planes." They are horizontal in undisturbed formations and inclined where folding has occurred. Spacing requirements and quarry methods are the same as those discussed under the heading of sheeting planes.

Rift and run.—Quarrymen recognize planes or directions along which an igneous or metamorphic rock will split easily. The "rift" is the plane of easiest splitting, and the "run" or "grain" is a plane at right angles to the rift which is present in some quarries. The plane at right angles to both the rift and the run, in which the rock will not split except with difficulty, is known as the "hardway" or "head grain." The rift and the run can usually be recognized only by skilled stonecutters and quarrymen, who use mineral orientations which are shown by dark minerals or by smooth surfaces as a result of abundant feldspar cleavage planes.

The bedding planes of sedimentary rocks correspond to the rift of igneous rocks. The direction of easiest splitting in sedimentary beds is parallel to the bedding planes. Such weakness may have been caused by a change in the character of the sediment deposited or by a short period of non-deposition which allowed a smooth upper surface to form before another layer was deposited.

Extent of deposit.—Because most of the igneous rocks quarried are portions of large intrusions that came from deep within the earth, little consideration need be given to the possibility that the rock will play out at depth. If the quarry is located near the contact of the intruding and the intruded rock, it is possible that some lateral variation will be present in the rock as the quarry is extended toward or away from the contact.

Most sedimentary rocks that are quarried are of marine origin, and it is to be expected that the rock layers will change as the quarry is deepened, but little change is likely to be found if the quarry is merely increased in area.

FIGURE 14. — Weathered and fractured granite near the surface, grading into massive, fresh granite suitable for building stone at depth. Quarry of the Pyramid Granite Company at St. Cloud.

QUARRY METHODS

Stripping. — Although many quarries in Minnesota are begun on outcrop surfaces, the area of operation usually becomes sufficiently large to necessitate removing the mantle cover above the bed rock. This mantle cover, or overburden, is usually gravel, sand, or clay of the glacial drift. At one quarry in the Morton area, however, and at one in the St. Cloud area (see Figure 14), the overburden is decayed bed rock. At Odessa the granite is immediately overlaid by strata of Cretaceous age.

The removal of such valueless material from the bed rock is known as "stripping." The operation is usually performed by teams and scrapers, but in some places by hand loading into large iron trays, which are lifted from the pit by means of a hoisting derrick. In the Kasota-Mankato region, steam shovels are used for stripping operations. The overburden should be moved far enough from the quarry not to interfere with probable future expansion.

Plan of operation. — If sufficient rock is exposed, careful consideration should be given to joints, sheets, and rock imperfections before the quarry site is opened. For most efficient operation there should be only two joint systems, intersecting at approximately 90°. Such a relation yields blocks that require a minimum amount of trimming. Blocks are most easily removed if the sheeting planes are inclined toward the hoisting derrick, so that the pulling force is aided by the force of gravity. Imperfections such as knots, hair lines, dikes, and decayed rock are responsible for a large percentage of the waste material in most quarries. It is

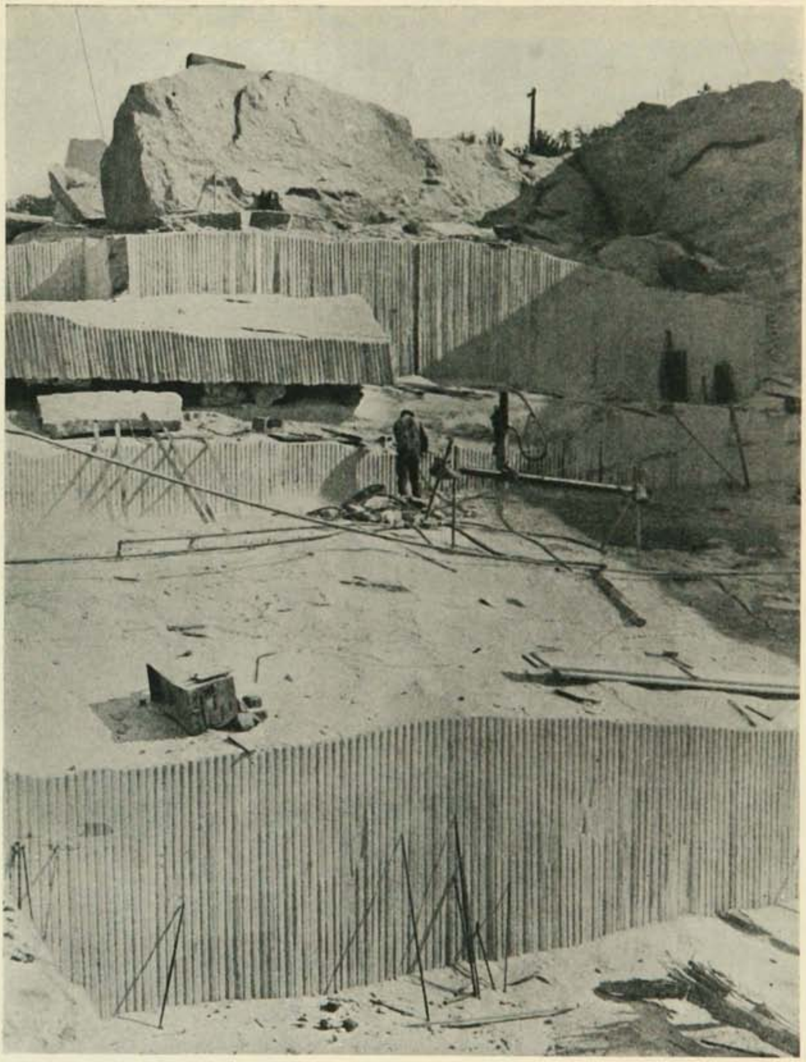


FIGURE 15. — Making ledges with "drifters." Quarry of the Cold Spring Granite Company at Morton.

necessary therefore that quarry operations be so planned as to avoid or minimize the detrimental effects of these features.

Drilling. — Various types of hammer drills operated by compressed air are now used almost exclusively in quarrying operations. In some quarries, particularly those operated by the Cold Spring Granite Company, a method known as broaching or "channeling" is used. This method consists of drilling straight parallel rows of holes (see Figure 15) by a "drifter" drill mounted on a quarry bar. The holes are from 1⅝ to 2

FIGURE 16. — Removing blocks from a quarry ledge by drilling and wedging. Quarry of the Breen Stone and Marble Company north of Mankato.

inches in diameter and are so spaced as to leave approximately ¾ of an inch of rock between the holes. This rock between the holes, known as the "web," is then cut out by means of channel bars. Quarry blocks of the desired length and width are outlined by such a method. The thickness is determined by the depth of the holes, which is usually sufficient to maintain ledge levels. These levels are produced by blasting a few horizontal holes which undercut the outlined block. This method produces blocks that are sent as "saw blocks" to the finishing plants.

In some quarries, rows of holes for blasting are drilled by the hand-held "jackhammer" drills. The distances between holes and the depths of the holes are determined by the character of the rock and the size of the stock desired.

Blasting. — After holes have been drilled along the desired line of fracture in the bed rock, the block is broken loose by firing charges of blasting powder that have been put in the holes. Because of the lifting and heaving effect, black powder is more generally used than dynamite. Simultaneous discharge in a line of holes may be effected by the use of an electric blasting machine.

Wedging. — After the quarry block has been broken loose by ordinary blasting methods, it is divided into smaller blocks by "plugs and feathers." This method consists of using jackhammer drills to make rows of shallow holes (see Figure 16), the spacing of which is determined by the ease with which the rock splits. Two half-round steel "feathers" with an iron "plug" (wedge) between them are placed in each of the holes. (See Figure 17.) A fracture is formed by driving in the wedges at a uniform rate. Further trimming at the quarry is accomplished by means of hammers with prism-shaped heads.

An unusual wedging technique is used in one quarry in the St. Cloud area. Three length of plugs and feathers are employed. (See Figure 18.) These lengths are ½, 1½, and 3 feet. The sizes are arranged as follows, spaced 6 inches apart horizontally from left to right: one 3-foot length, four ½-foot lengths, one 1½-foot, four ½-foot, one 3-foot, etc. By this arrangement, straight and even breaks are made through ledges 12 to 14 feet thick and much waste of rock from irregular breaks is avoided.

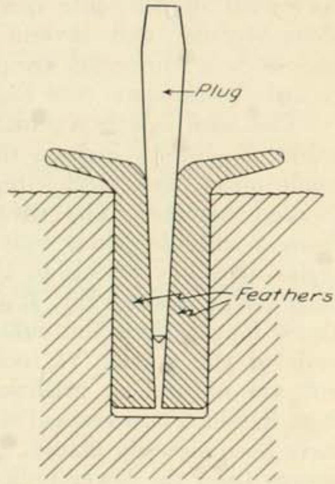


FIGURE 17. — Diagram showing plug and feathers in a drill hole. The rock is wedged apart by driving the plug between the feathers.

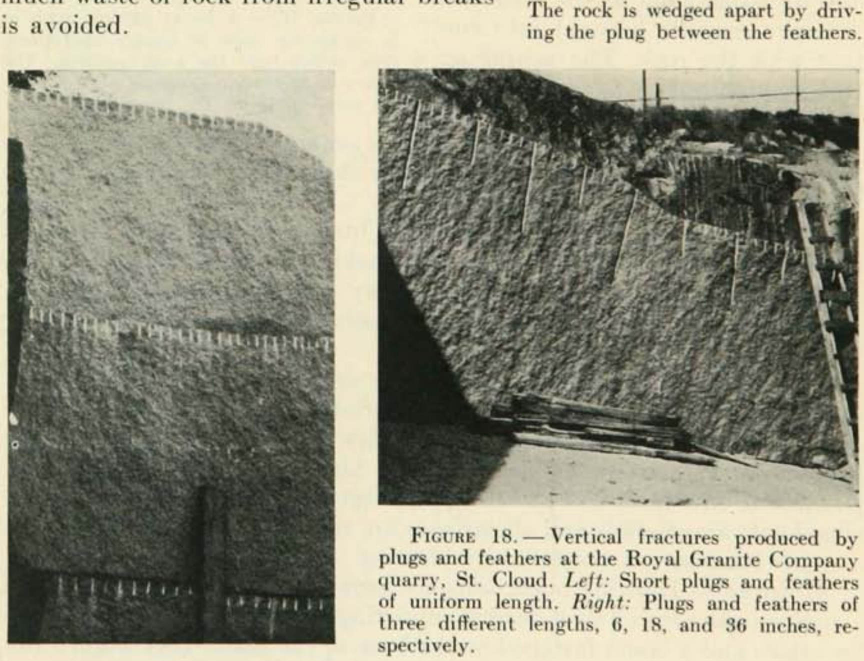
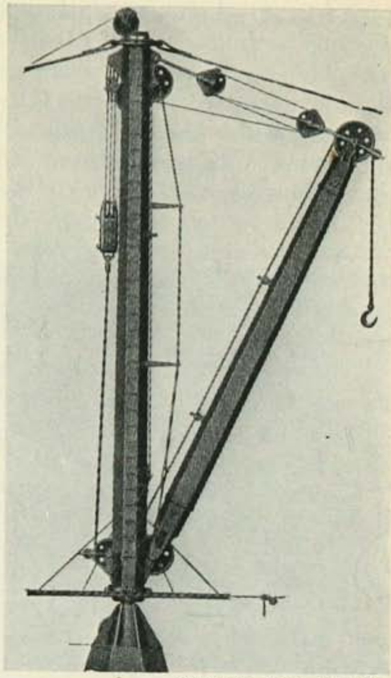


FIGURE 18. — Vertical fractures produced by plugs and feathers at the Royal Granite Company quarry, St. Cloud. *Left:* Short plugs and feathers of uniform length. *Right:* Plugs and feathers of three different lengths, 6, 18, and 36 inches, respectively.

Wire sawing. — Wire sawing is a quarry method which originated in the marble quarries of Belgium. In the United States the method is not common as yet, but it has proved successful in the slate quarries of Pennsylvania, and several quarry operators in Minnesota are planning to install wire saws. (See Figure 20.)

The wire saw is a taut endless cable, $^3/_{16}$ or $^1/_4$ inch in diameter, made up of three steel wire strands twisted together. The wire moves from a suitable power unit over a series of pulley wheels to the location of the desired cut. It is many times longer than the cut. At the ends of the portion of rock to be cut are natural or artificial openings, in which two vertical standards have been securely placed. The wire moves from the lower pulley wheel of one standard to that of the other, and by adjustment of the standards the wire may be brought into contact with the rock. The sawing action is produced by feeding a water-sand mixture to the wire as it enters the cut. The sand used for this purpose is generally very angular, and as it is drawn along by the twisted wire, the sharp edges of the sand grains cut the rock.



Courtesy Lane Mfg. Co.

FIGURE 19. — A boom derrick, such as is commonly used in quarry operations. Guy cables hold the mast vertical. The heavy base casting contains a steel conical step, on which the mast turns.

When necessary, an opening is made for the standards by means of blasting, or by use of a drill capable of making a 36-inch core, or by use of a smaller core and a penetrating pulley in which the groove is only one-half the diameter of the wire and so permits cutting as it passes over the pulley.

This method of quarrying offers some very great advantages: (1) it reduces the great amount of waste produced by common blasting methods; (2) the cost of equipment is very low as compared to channeling machines; (3) continuous operation and high speed of cutting make it possible to saw from 250 to 350 square feet of slate in 9 hours; (4) inclined cuts are possible and all surfaces are smooth; and (5) quarry walls are safe because not shattered by blasting.

Hoisting. — Hoisting operations are generally carried on by means of a common wooden or steel derrick consisting of a vertical mast stabilized by cables and a boom fastened at the base of the mast. (See Figure 19.)

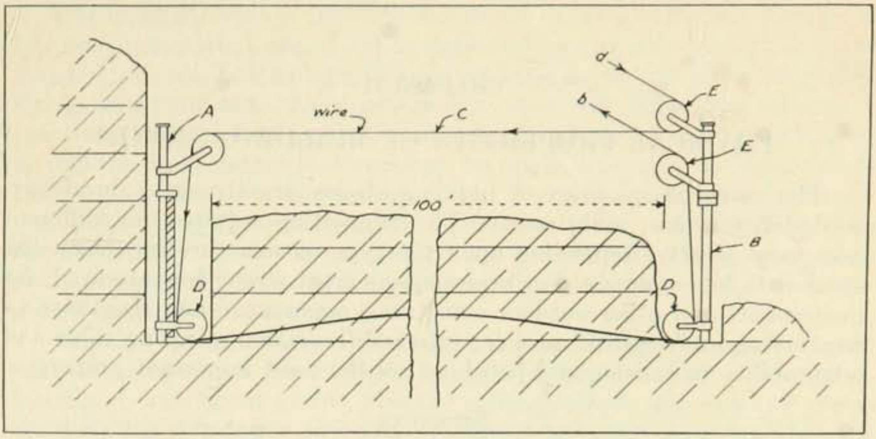


FIGURE 20. — Diagrammatic sketch showing the use of a wire saw in quarrying. A and B. Tension posts. C. A three-strand wire. D. Adjustable sheaves. E. Guide sheaves. b and d. Leads of the wire to and from the source of power. After R. G. Skerrett.

CHAPTER II

PHYSICAL PROPERTIES OF BUILDING STONES

The essential qualities of building stones are strength, durability, workability, color, and beauty. The properties required for different uses vary greatly, depending upon the type of structure for which the stone is to be employed. For bridge spans great strength is essential; for monuments and other outdoor structures, appearance and resistance to weathering are required; and for interior decoration, pleasing color and adaptability to carving and polishing are the most important properties.

Strength

The strength of a stone is measured by its ability to withstand stresses. A stone in a wall is subjected to strains of various kinds. Of these the most important are the crushing, the tensile, the transverse, and the shearing stresses. Most building stones when unweathered are sufficiently strong for all ordinary structural uses. In some large buildings a single column or block may be required to carry a very heavy load, but even then the load rarely approaches the limit of strength of the stone. Few stones when tested show a strength of less than 5,000 pounds per square inch, and many, especially igneous rocks, sustain pressures of 20,000 to 43,000 pounds to the square inch. Merrill * has shown that the stone at the base of the Washington Monument supports a maximum pressure of only 314.6 pounds per square inch. Even at the base of the tallest buildings the pressure is not more than a few hundred pounds per square inch.

The strength of a stone and the permanency of its strength under stresses are determined by a number of factors, such as the composition of the stone, its texture, structure, and mode of aggregation.

Composition. — Most rocks consist of more than one mineral, and each mineral is composed of chemical elements combined in definite proportions. Different minerals have different coefficients of expansion under changes of temperature. The stresses resulting from differential expansion and contraction are more important in a rock composed of several minerals than in a rock such as sandstone or marble which is composed mainly of one mineral. Furthermore, different minerals vary widely in hardness (see page 11) and in resistance to crushing forces. Quartz is harder and has a higher crushing strength than hornblende. Also, some minerals, such as calcite and feldspar, have a prominent cleavage, whereas others, such as quartz and magnetite, have little or none. Because of cleavage planes some minerals are weaker in certain directions than in others.

* F. J. Merrill, *Stones for Building and Decoration* (New York, 1910).

Chemical analyses of building stones are of little value, for they yield few conclusions that are of aid in determining the strength of the rock. The analysis of a particular granite gives little indication of its adaptability to structural uses. An analysis may show the difference between a limestone and a dolomite; or it may indicate whether a sandstone is pure or impure. Such determinations may be made, however, by simple tests that require less time and are much less expensive than chemical analyses. The use of the petrographic microscope is far more effective than chemical study. With the microscope one can identify the minerals that compose the rock and determine their relative abundance and their freshness, impurities, and texture.

Texture. — Other things being equal, coarse-textured rocks are weaker than those having a fine texture. In a coarse texture there is less interlocking of component grains, and the contact planes between the grains are distributed in fewer directions. It should be noted, however, that the terms "fine grained" and "coarse grained" as applied to building stones are entirely relative, and depend largely on the kind of rock that is being considered. A granite, for example, with mineral constituents that averaged a quarter of an inch in diameter would be a rather fine-grained granite. On the other hand, a sandstone with sand grains of that size would be a very coarse-grained rock; and in a limestone such large grains would rarely be found.

Structure. — The chief structural feature that influences the strength of a building stone is its lamination. In sedimentary rocks these laminae are stratification planes or bedding planes produced by a slight change in the character of the sediments that were being deposited. All planes of stratification are planes of weakness. Strength tests of sandstones, limestone, and marbles are, therefore, always made both parallel to the bedding planes and perpendicular to them. (See Figure 21.) Such lamination is comparable to the rift of igneous rocks, although the planes of fracture are of different origin. Quarrymen commonly refer to such planes as "capping." In igneous rocks, such as granite, lamination is due to a number of factors. In certain granites the component minerals are arranged with their broader faces parallel. In others there may be a segregation of the component minerals in parallel bands, and in still others a structural lamination is produced by pressure and shearing that results in the development of incipient fractures along which the rock cleaves.

Type of aggregation. — The mode of aggregation of the grains in a building stone has a direct bearing on the strength of the rock. Three types of aggregation are commonly recognized: (1) Chemical aggregates as exemplified in a compact, non-granular limestone or in a non-crystalline igneous rock, such as volcanic glass. The material is amorphous or homogeneous and consequently there are no directions of unequal strength. (2) Crystalline aggregates such as are found in a granite. In such coarse-grained crystalline rocks the various mineral grains are intimately interlocked as the minerals crystallize from the

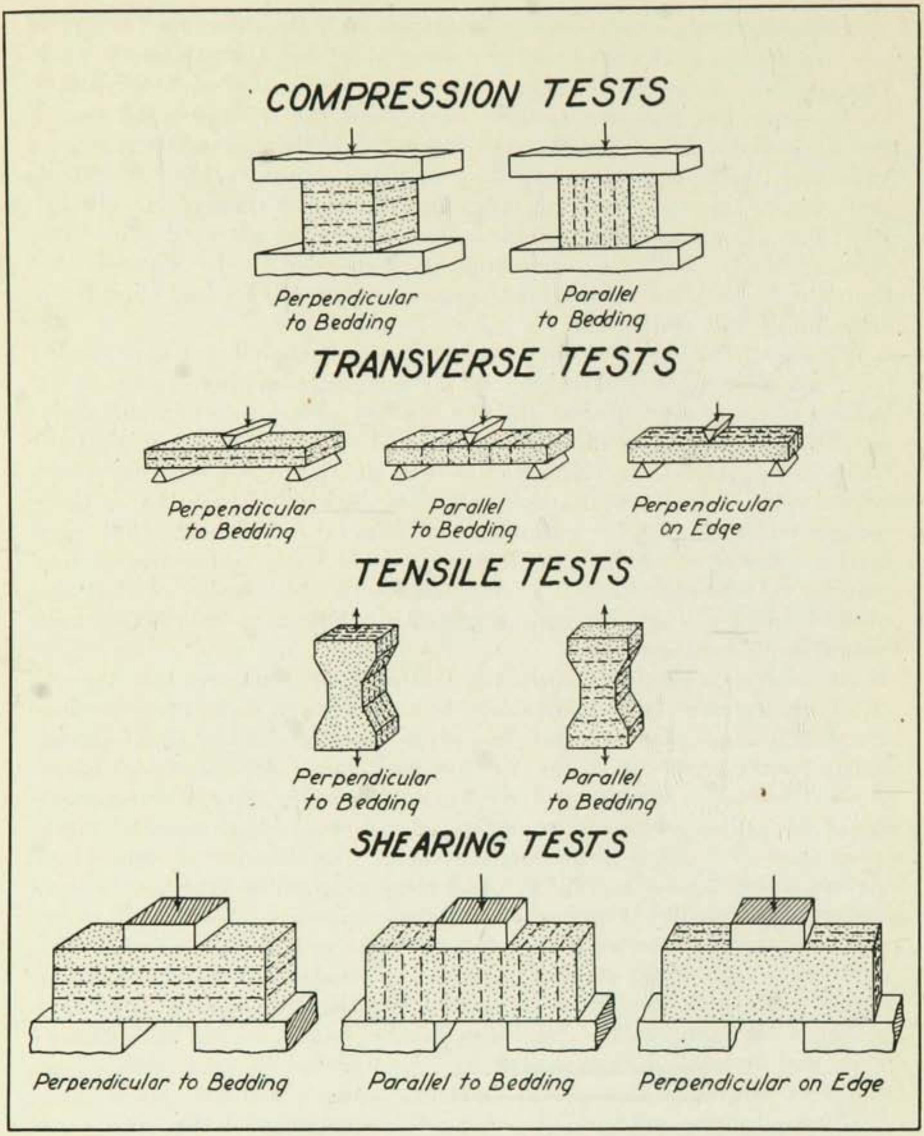


FIGURE 21. — Diagrams showing the relation of the applied stresses to the structure of the rock in making physical test determinations. After Kessler and Sligh, United States Bureau of Standards.

molten magmas to which they owe their origin, and consequently the bond is a strong one. (3) Cemented aggregates as seen in a sandstone or quartzite. The grains in a sandstone are held together either by a cementing material or by a simple pressure cementation. The commoner cementing materials are silica, calcite, clayey material, and iron oxides.

Of these silica is the strongest and most desirable because it is insoluble and free from cleavage and has the same coefficient of expansion as the sand grains that it binds together. Calcite is soluble, has very pronounced cleavage, and has a different coefficient of expansion from that of the sand grains.

Durability

One of the chief considerations in selecting stone for exterior work is durability. All stone structures exposed to the atmosphere should be able to resist the attacks of weathering agents. The weathering of any rock depends primarily upon its mineral composition, texture, and structure, and to some extent upon the conditions under which it is used.

Composition.—Some minerals are very stable under all ordinary conditions of use; others are very unstable, and the presence of even a small percentage of them may be sufficient to affect seriously the durability of the rock in which they occur. Certain minerals are injurious under all circumstances, while others are to be avoided only when they occur abundantly in certain types of rocks.

1. *Mica* is an objectionable impurity in limestones and marbles. It may occur in scattered grains, isolated blotches, or bands. When it is present in appreciable amounts its interferes with the continuity of the polish, and it may yield to the attacks of weathering agents and lead to the development of pits or spalled spots on the polished surface. Mica is not harmful in crystalline rocks such as granite and gabbro unless it is segregated into bunches or knots that make the stone unattractive. Large tablet-like crystals of mica an eighth of an inch or more in diameter in certain granites of inferior quality have been known to swell during prolonged exposure and finally to "pop" out, leaving a pitted surface. In gneissic rocks mica is seldom injurious unless it becomes so abundant that a schistose structure is developed, rendering the rock susceptible to weathering along the planes of schistosity.

2. *Pyrite* and other sulphides of iron such as marcasite and pyrrhotite are to be avoided. These minerals on exposure to the weather are oxidized and hydrated to yellow or brown iron oxide, which may wash down over the surface of the rock and produce an unsightly stain. Furthermore, in the oxidation of pyrite some sulphuric acid is generated, and this attacks and dissolves any carbonate minerals that may be present in the rock. Under certain conditions iron sulphate is formed from pyrite. This salt is very soluble and is brought to the surface as evaporation takes place. If sufficient salt is present, a whitish scum is deposited on the surface of the stone.

3. *Flint* or *chert* nodules occur as objectionable features in limestones and marbles. The flint is much harder than the rock that encases it, and it therefore interferes with cutting and polishing. If the nodules or concretions are distributed along bedding planes, the rock is likely to split along the concretions. Or it may happen that as the rock weathers the

flint nodules, being more resistant than the rest of the rock, in time will stand out as irregular knots on the surface of the stone.

4. *Tremolite* is a pale green or colorless magnesium and calcium silicate that is found in some crystalline limestones and marbles. When weathered it tends to decompose into a greenish-yellow clay. In time the clay is washed out and a pitted surface remains. The limestones of Minnesota have not been subjected to sufficient metamorphism to produce tremolite in objectionable quantities.

5. Minerals of the clay group, if present in abundance, decrease the desirability of a rock. Recent studies * of this group have shown that it consists of a complex series of minerals, of which certain members are harmless from the standpoint of weathering, whereas others are very unstable because of their capacity to absorb moisture and swell to a remarkable degree. These unstable clay minerals are formed by the attack of acid and sulphate waters on silicate minerals that contain aluminum. Products of hot-water alteration such as sericite and chlorite are especially subject to attack. These minerals may be detected by a careful microscopic examination. Some granites that tend to "blister" or scale along finely bush-hammered surfaces have been softened by the effects of alteration of the aluminum-bearing silicates.

Texture and porosity.—A stone may be either coarse or fine grained and it may also be dense or porous. The coarse-grained rocks are not so durable as the fine grained, and porous rocks disintegrate more rapidly than dense rocks. Dense rocks are quite impervious; hence weathering agents cannot penetrate them. Porous rocks permit the infiltration of water, which may contain solvents or which may freeze in the pores. It was formerly believed that danger of damage from frost is directly proportional to the percentage of pore space in the rock. It has been pointed out,† however, that the important factor is the ease with which the stone gives up water. Since rocks with small pores give it up less readily, they suffer more seriously from the action of frost. The permeability of many rocks has been determined, ‡ and has been found to have no relation to percentage of porosity or the effect of frost. It is to be expected, however, that the solvent effect of water will be greater in rocks of greater permeability. The amount of water absorbed is not the same under all conditions, nor is it the same for stone in different positions in the same building.

Granites hold water in microscopic spaces both within and between their constituent mineral grains. It has been shown that granite generally contains about 0.8 per cent of water and is capable of absorbing about 0.2 per cent more. In other words, a cubic yard of granite weighing two

* G. F. Loughlin, "Notes on the Weathering of Natural Building Stones," Proceedings of the American Society for Testing Materials, Vol. 31, Part 2 (1931), p. 47.

† E. R. Buckley, *The Building and Ornamental Stones of Wisconsin* (Wisconsin Geological Survey Bulletin 4, 1898), p. 22.

‡ W. A. Parks, *Report on the Building and Ornamental Stones of Canada* (Canada Department of Mines, Geological Survey, 1912–17), 1:62.

tons contains about $3\frac{1}{2}$ gallons and can absorb nearly a gallon more if submerged in water for a considerable length of time.

Specific gravity and weight per cubic foot. — The specific gravity of a rock is its weight as compared to that of an equal volume of distilled water. The specific gravity of granite ranges from 2.59 to 2.73. It weighs, therefore, about 2 long tons to the cubic yard. The average weight per cubic foot of eight Minnesota granites is 167.8 pounds. The average specific gravity of the limestones and dolomites is similar — nearly 2.7.

Workability

The workability of stone is determined by its hardness and texture and by the character of its rift and run. The ease with which a stone can be sawed, tooled, or polished depends mainly on its hardness and texture, whereas the ease with which it can be split or trimmed into blocks with even surfaces depends upon natural lamination planes within the rock. The ability of a stone to take a polish depends on the character of the mineral constituents. A rock composed of the grains of one mineral or even of different minerals of approximately the same hardness will take a better polish than a combination of minerals of varying hardness. Such minerals as quartz, feldspar, and calcite take a good polish, while hornblende and augite are less easily polished. The micas are polished with difficulty. The jointing of the rock is one of the principal features to be noted in determining its workability, for it determines the size and shape of the largest blocks that can be quarried. (See the section on Quarry Methods, page 26.)

Color and Beauty

Very often the success of an architect is determined to a considerable extent by his ability to select stone of a color that will be most effective and harmonious in the finished building. The colors in most rocks are of a composite character, produced by a blending of the colors of the individual minerals. Where uniformity of color exists, it is due either to uniform distribution of mineral grains or to the fact that the rock is composed entirely of one mineral. In selecting a colored building stone the points to be considered are its tint, its permanence, and its regularity. The color of a freshly broken piece of the stone should be compared with that of a weathered surface in order to determine the permanence or change of the tint. The chief coloring matter in rocks is iron, which exists either in chemical combination with other elements, as in mica or hornblende, or as free oxides or sulphides disseminated in minute grains throughout the rock. The oxides of iron give the rock a brownish-red hue, whereas the carbonates or sulphides impart a grayish color. A light or nearly white color denotes the absence of iron in any of its forms. Among building stones as a whole a great variety of colors may be noted, including brown, buff, yellow, red, pink, green, gray, and black. In granites, shades of red and gray are dependent on the proportion of red and white feldspar. Some "black granites" with plagioclase feldspar have a distinctly iridescent color, others are uniformly black on a polished surface, and still others are greenish gray. Sedimentary rock may show a variation in color within the same quarry or even within short distances in the same stratum or ledge.

Permanence of color, particularly in sedimentary rocks such as sandstone and limestone, is rarely to be expected if the stone is quarried from below the water level. If, however, all the stone in a structure changes uniformly, the resulting color may be as attractive as the original. As a rule the buff, yellow, brown, and red colors are most stable, since they represent the iron-bearing constituents in an oxidized form. 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 whitish efflorescent coatings. Impurities such as crystals of pyrite, marcasite, or siderite will oxidize and produce rusty stains that form streaks on the rock wall.

An important property of a stone is the contrast in color between its hammered and its polished surface. This difference must be taken into account if the stone is to be used for monumental or inscriptional work. The contrast is most prominent in stones containing a high percentage of transparent feldspar and dark colored minerals.

Individual tastes in colors differ greatly; nevertheless, fashions and fads are a potent factor in the selection of building stones. Years ago brownstone was very popular and was used in almost unlimited quantities. At the present time warm, bright colors are used extensively. "Black granite" is becoming increasingly popular, especially for base courses of large structures with lighter colors for the upper part of the buildings.

Tests of Physical Properties of Building Stone

Samples of building stone are tested with the object of determining the strength, workability, and durability of the material. The stones from some quarries have long been in use, and the best test of their durability is the way in which they have withstood the action of the weather in different parts of the country where they have been used for structural purposes. When new types of stone are placed on the market, however, tests are of value in helping to determine the comparative quality of the product. Methods of testing the properties have grown in precision, but there is still much difference of opinion as to how the various tests should be conducted and what interpretation should be placed on the results. Slight modifications in test precision and in the method of procedure often produce radically different results. Furthermore, the stone from different levels in the quarry may show a variation in properties. To arrive at a trustworthy average for any deposit, therefore, duplicate tests should be made on the rock at various horizons within the formation.

The various tests are grouped according to the kind of information they give regarding the specimen that is being tested.

I. Tests to determine strength	Compression Transverse Tensile Shear Elasticity Flexibility Hardness Impact
II. Tests to determine durability	Absorption Freezing Heat Efflorescence Resistance to acids
III. Tests to determine density	Specific gravity Weight Porosity
IV. Tests to determine composition and structure	Chemical analysis Microscopic study

Compressive strength.—The compressive strength per square inch as shown by any given stone in a crushing machine is known to vary with the shape of the test piece, its size, and the character of the bearing surface. In sedimentary rocks the strengths perpendicular to the bedding and parallel to the bedding are determined. (See Figure 21.) In igneous rocks the directions of rift and run must also be considered. The tests are made on both wet and dry specimens. The dry samples are first placed in an oven at 110° C. for a period of twenty-four hours. The samples for the wet test are placed in the machine after having been soaked in water for two weeks. The usual practice in determining compressive strength is to load small cubes until failure occurs. Cylindrical specimens from one to two inches in diameter are also commonly used.

The strength of different types of rock varies greatly. The table below gives a range of values, in pounds per square inch, as determined by the United States Bureau of Standards:

Basalt	28,000–67,000
Quartzite	16,000–45,000
Granite	10,000–40,000
Diorite	16,000–35,000
Syenite	14,000–28,000
Marble	8,000–27,000
Limestone	2,500–28,400
Sandstone	5,000–20,000

Transverse strength.—This test determines the strength of a material when submitted to bending stresses, such as those involved in a loaded beam or lintel. The test is commonly made on a bar one inch square resting on supports an inch apart, the load being applied in the middle. The strength is expressed in terms of the *modulus of rupture*, which is computed from the breaking load and dimensions of the test pieces, according to the formula

$$R = \frac{3wl}{2bd^2},$$

in which R is modulus of rupture, w is weight required to break the stone, l is distance between supports, b is width of stone, and d is thickness of stone.

The value of this test is now generally recognized. Formerly, however, it was rarely applied. In old stone buildings many window caps or even sills have cracked under the transverse strain because the modulus of rupture of the stone slab was too low.

The United States Bureau of Standards has designed charts with curves of maximum loads on stone beams of various spans. These charts are available for distribution, and may be found useful in proportioning lintels.

Tensile strength.—Building stone is seldom required to take direct tensile stresses that are due to structural relations. It may, however, be subjected to such stresses by frost action. Freshly quarried blocks of dimensional stone may be disrupted during the winter months because the stone lacks the tensile strength to resist the expansive force of ice forming in the pores. Tensile strength determinations also reveal the weakest directions with respect to bedding and other planes of weakness in the rocks. The tests are generally made on specimens similar in form to those used in testing clay or cement briquettes.

The following ranges in tensile strength, in pounds per square inch, have been reported by the United States Bureau of Standards:

Slate	3,000–4,300
Marble	400–2,300
Granite	600–1,000
Limestone and dolomite	280–1,000
Sandstone	280– 500

Shearing tests.—The data available on shearing tests are very incomplete, and the methods used have been so dissimilar that the results are of little comparative value. One of the methods employed a machine in which the shearing edges were displaced half an inch from the supporting plates. The results indicate that the breaks are due to bending stresses rather than to the true shearing breaks. Other devices have been designed to eliminate bending stresses. One employs a double-shear and another a single-shear surface. The latter is a punching shear apparatus which punches a two-inch disk from a slab of stone.

The following ranges of values have been recorded by the United States Bureau of Standards. The unit is pounds per square inch.

Marble	1,300–6,500
Granite	2,000–4,300
Slate	2,000–3,600
Limestone	1,200–3,000
Sandstone	300–3,000

Elasticity.—The modulus of elasticity of stone is of value in determining the effect of combining masonry and metal, or of joining different kinds of masonry, or of joining new masonry to old. It is also used in calculating the effect of loading a masonry arch and in proportioning abutments and piers of bridges subject to shock. Modulus of elasticity may be defined as the weight required to stretch a rod of one square inch section to double its length. A method of determining elasticity value is to measure the amount of compression shown by a specimen of known dimensions with each increment of 500 to 1,000 pounds' load, up to the limit of its elasticity.

The following elasticity values, in millions of pounds per square inch, have been compiled by the United States Bureau of Standards:

Slate	9–15
Marble	7–14
Granite	5– 8
Limestone	3– 6
Sandstone	2– 7

Flexibility.—Although rock is composed primarily of brittle material and although the interlocking of its mineral grains gives it great cohesion and rigidity, in thin sheets it is flexible. Carefully controlled tests made by the Bureau of Standards have led to the conclusion that the flexural elasticity estimations are not comparable with the compression elasticity.

Hardness.—The hardness of a stone determines its resistance to mechanical wear. Hardness is rarely an important consideration where the stone is used strictly as a building material. Steps, sills, flooring, flagging, and tunnel lining are subjected to wear, however, and abrasion tests are therefore of value. Some stones wear very unevenly because of their irregularity in hardness. Such stones may be less desirable than others which are uniformly soft.

RESULTS OF ABRASION TESTS ON VARIOUS ROCKS *

Rock	On Rubbing Table			With Sand Blast at Right Angles to Bedding	
	Surface (sq. cm.)	Average Loss (c.c.)	Abrasion (sq. cm.)	Abrasion (c. c. per sq. cm.)	Average Loss (c. c.)
Basalt	50	5.4	0.11	0.06	1.8
Basalt lava	49	9.6	0.20	0.21	7.06
Granite	49	5.1	0.10	0.09	3.78
Gneiss	48	9.6	0.20	0.14	3.26
Porphyry	49	8.5	0.17	0.12	2.58
Graywacke	50	10.8	0.22	0.15	4.16
Sandstone	50	18.4	0.37	0.39	8.42
Schist	50	29.7	0.59	0.28	5.90

* Gary, *Baumaterialkunde*, Bd. X (1905), p. 133.

A common method of making this test is to lay the stone on a rubbing table, weight it down, and apply an abrasive at a given rate while the table revolves at a uniform velocity. Another method consists in noting the rate of penetration of a drill of a given diameter, or measuring the distance a drill will penetrate without being sharpened. Still another method involves the use of a sand blast. The sand is forced through a six-centimeter opening under a dry-steam pressure of three atmospheres for two minutes. The loss of weight of the specimen is then determined. The results of abrasive tests are shown in the table on page 41.

Impact tests.—Impact tests are made to determine the toughness of a rock. Such determinations are of special value for road materials, curbstones, and other structures that are subjected to repeated blows or shocks. The sample to be tested is generally a one-inch cylinder an inch in length. It is held on an anvil by means of a small clamp. A two-kilo weight is dropped on a plunger which makes contact with the end of the test specimen. The weight is first dropped from a height of one centimeter and then increased by one centimenter for each succeeding drop until the specimen breaks. The height of the highest drop is recorded as the toughness value of the stone. The following impact values have been compiled by the United States Bureau of Standards:

Slate	10–56
Sandstone	3–47
Rhyolite	6–42
Diorite	12–36
Schist	6–34
Granite	7–31
Quartzite	14–30
Limestone	3–21
Serpentine	6–17

Absorption tests.—Absorption is a measure of the capacity of a stone to absorb moisture. The mineral grains of which a stone is composed are practically nonabsorbent, but ordinarily there is a small amount of space between the grains. Under ordinary conditions a stone never absorbs as

Comparative Absorption, Porosity, and Permeability of Several Rocks
(Determined by the United States Bureau of Standards)

Serial Number of Rock	Percentage of Absorption by Volume	Percentage of Porosity	Permeability *
2	11.0	13.2	16.2
7	6.5	7.6	0.95
48	9.0	14.0	1,500.0
113	12.2	17.0	16.0
114	8.3	9.5	109.0
115	12.2	13.5	8.6

* Permeability is here referred to as the number of cubic inches of water per hour that will flow through 1 square foot of stone ½ inch thick under a pressure of 100 pounds per square inch.

much as its theoretical maximum. Ratios of absorption are determined, therefore, for various periods of time and degrees of pressure. Furthermore, since stones of different mineral composition are not of equal bulk density, a distinction must be made between absorption by weight and absorption by volume. It is more logical to compute the percentage of absorption on a volume basis, for such results are comparable for all types of stone. This computation is made by dividing the volume of water absorbed by the volume of the specimen that is being tested.

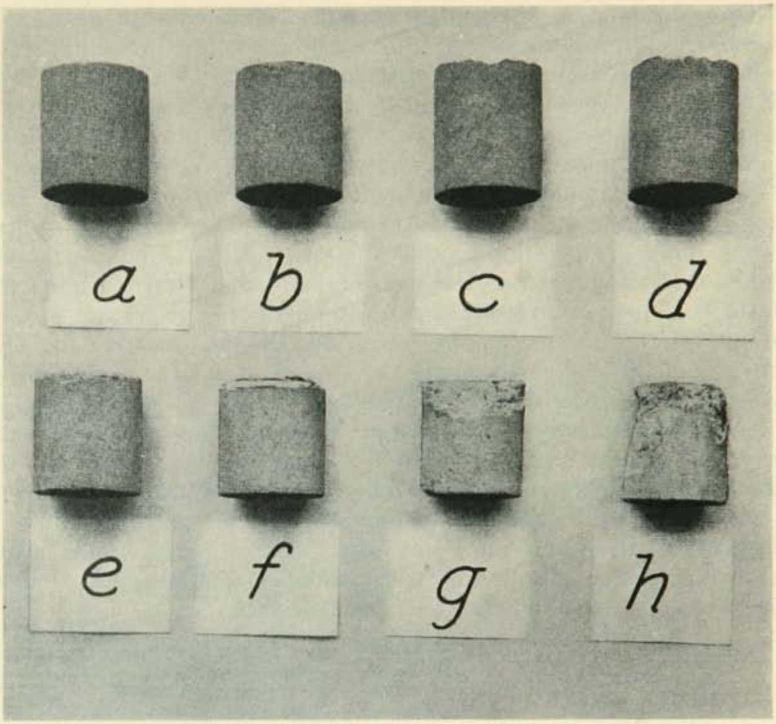


FIGURE 22. — Specimens from freezing test illustrating various stages of decay, which are designated a, b, c, etc. (See pages 44–45.) After Kessler and Sligh, United States Bureau of Standards.

The following percentages of absorption by volume have been computed by the United States Bureau of Standards:

Sandstone	6 –18
Limestone	6 –15
Slate	0.2– 0.3
Granite	0.2– 0.4
Marble	0.1– 0.4

Permeability. — Permeability tests are made to determine at what rate water will soak into a given stone. Sedimentary rocks such as limestones and sandstones are tested with water soaking both across the grain of the stone and parallel to the grain. In most stone structures the penetration of water results from the combined pressure due to gravity and to capillary action. In some instances hydrostatic pressure also aids the penetration.

Permeability measurements indicate characteristics of the pores which are not determined by absorption or porosity tests. For instance, two stones of nearly equal porosity values may differ in permeability by several hundred per cent. The examples on page 42 will serve to illustrate this point.

Freezing tests.—A stone which becomes saturated with water and is then subjected to repeated freezings may be weakened to such an extent that its crushing strength is lowered considerably. One might expect a stone of high absorption to be weakened and broken by frost more easily than one of low absorption. This is not always true, however, for a rock of high porosity may have such large pores that the water drains out readily or is forced out as freezing begins. The finer the pores, the longer the rock retains the water; and water retained in the rock may, on freezing, exert sufficient pressure to split the stone. Most stone in a building is soaked under atmosphere pressure only, and this is rarely sufficient to saturate the stone completely. Probably the worst places are found in buildings where snow lies on the coping and cornice, thawing slightly in the middle of the day and keeping the stone wet until freezing temperatures are reached toward evening. The lower courses of a stone wall also are kept damp, as a result of moisture brought from below the surface by capillarity. Here also freezing and thawing tend to disrupt the rock.

The difference between partial and complete saturation is shown in the tabulation below. The first column shows the number of times the stone stood freezing without injury after soaking under normal atmosphere pressure; the second shows the number of times the stone was frozen after soaking in a partial vacuum.

Limestone	31 times	5 times, broken in two
Marble	25 times	3 times, cracked
Sandstone	25 times	7 times, spalled off
Tuff	25 times	14 times, many cracks
Coarse granite	....	8 times, mica scales detached

In making freezing tests on limestones at the United States Bureau of Standards the samples were but partly saturated. They were then frozen and thawed until disintegration occurred. The number of freezings re-

CONDITIONS OF VARIOUS STONES AFTER WEATHERING TESTS *

Rock	Observed Condition of Specimens after Number of Freezings Indicated †								Remarks
	a	b	c	d	e	f	g	h	
Mantorville Blue	225	...	...	...	...	450	650	880	
	225	450	...	...	...	...	...	880	
	90	...	...	...	...	...	225	450	
	225	450	650	...	...	...	...	880	
	90	...	...	225	...	...	...	450	
Kasota Pink Fleuri ..	825	...	...	...	...	...	...	990	
	225	...	450	...	...	...	...	990	
	225	450	...	...	...	...	...	990	
	225	450	990	...	...	...	...	...	Still in "c" condition after 1,800 freezings.
	90	...	...	...	...	225	...	450	

* Performed by the United States Bureau of Standards.

† The "a" condition means that the stone is unaffected; the "h" condition that it is badly disintegrated; the other letters indicate intervening stages.

Rock	Observed Condition of Specimens after Number of Freezings Indicated								Remarks
	a	b	c	d	e	f	g	h	
Kasota Yellow Fleuri	225	...	...	...	...	...	...	450	
	...	...	...	...	...	...	...	90	
	225	...	...	...	...	...	...	450	
	...	...	...	...	...	...	...	90	
	...	...	...	...	...	...	...	90	
	...	...	...	...	...	...	90	450	
	625	...	...	...	...	...	...	680	
	850	...	...	...	...	1,015	...	1,115	
	...	...	...	...	...	...	...	225	
	625	...	...	...	...	...	...	680	
	225	...	...	...	...	...	...	425	
	...	...	...	...	...	...	...	225	
Mankato Cream.....	650	...	...	...	...	...	...	850	
	650	...	...	...	...	...	...	850	
	450	...	...	...	...	...	...	650	
	1,015	...	...	...	...	...	...	1,115	
	850	...	...	...	...	...	...	1,015	
	450	...	...	...	...	650	...	850	
Mankato Gray......	...	90	225	...	...	...	...	650	
	225	450	650	...	...	...	...	850	
	90	225	...	850	1,115	...	...	1,193	
	...	90	850	...	...	...	...	1,193	
	...	90	450	...	...	650	850	1,632	
	...	90	450	...	650	850	...	1,632	
Kato...............	...	...	...	...	...	...	...	1,880	
	650	...	850	...	...	...	...	1,632	
	450	...	650	...	...	...	...	850	
	450	650	...	...	...	...	...	...	Still in "b" condition after 1,949 freezings.
	450	650	...	...	...	...	...	850	
	450	...	...	...	...	...	...	650	
Winona Cream......	450	...	650	1,627	1,898	...	...	...	
	650	...	...	850	...	...	...	1,015	
	450	650	1,898	...	...	...	...	...	
	450	650	...	...	...	1,115	1,627	...	Still in "g" condition after 1,898 freezings.
	450	650	...	...	1,627	...	...	1,898	
	450	650	1,627	...	1,782	...	...	...	Still in "e" condition after 1,898 freezings
Winona Gray.......	...	...	...	...	...	...	...	...	Still in "a" condition after 1,948 freezings.
	...	...	...	...	...	...	...	...	
	...	...	...	...	...	...	...	...	
	...	...	...	...	...	...	...	...	
	...	...	...	...	...	...	...	...	
	...	...	...	...	...	...	...	...	
Winona Buff........	1,453	...	...	...	...	1,677	...	1,832	
	695	...	...	...	...	...	...	895	
	1,832	1,948	...	...	...	...	...	...	
	1,677	1,832	...	...	...	...	...	...	Still in "b" condition after 1,948 freezings.
	1,832	1,948	...	...	...	...	...	...	
	1,677	1,832	1,948	...	...	...	...	...	

quired to produce a certain state of decay was used as an index of durability. The samples were graded on an arbitrary scale showing eight stages of disintegration, from the "a" condition, in which no effects of frost action were found, to the "h" condition, in which the specimen was badly disintegrated. (See Figure 22.)

The 65 samples of limestone included in the freezing tests were chosen to represent the dolomite-producing areas as well as possible. Usually three specimens of each sample were tested, but sometimes a larger number were used. It frequently happened that specimens from the same sample showed a large difference in resistance to frost action; or in some cases one part of a specimen would disintegrate readily and the rest hold out in a sound condition for several hundred freezings. In computing the summary of results given on page 44, the average number of freezings required to disintegrate all the specimens of a certain sample to the "h" condition was taken as the "resistance number" of that sample.

The effect of frost can be produced artificially by immersing the test sample in a saturated solution of sodium sulphate. The growth of the sulphate crystals in the pores of the rock as the water evaporates exerts a pressure comparable to that of ice crystals. The test is more severe than ordinary freezing tests, and tabulated data show that direct comparison of results is not justified.

Heat resistance.—Since rock is a poor conductor of heat, building stones are low in fire resistance, especially if cooled rapidly by a strong stream of cold water from a hose. The disintegration due to fire or heat is caused by unequal stresses set up within the stone when the outer part of a slab or block becomes highly heated before the interior has had time to reach the same temperature. Also, if after heating the rock is quickly cooled, contraction of the outer shell takes place. The differential stresses produced rupture the rock and the outer shell spalls off.

Different building stones show a considerable difference in their capacity to withstand high temperatures. McCourt * made a series of tests on three-inch cubes. The following statements are taken from the summary of his findings:

At 550° C. (1022°F.) most of the stones stood up very well. The temperature does not seem to have been high enough to cause much rupturing of the samples, either upon slow or fast cooling. The sandstones, limestones, marble, and gneiss were slightly injured, while the granites seem to have suffered least.

The temperature of a severe conflagration would probably be higher than 550° C. but there would be buildings outside of the direct action of the fire which might not be subjected to this degree of heat and in this zone the stones would suffer little injury. The sandstones might crack somewhat; but, as the cracking seems to be almost entirely along the bed, the stability of the structure would not be endangered, provided the stone had been properly set.

The gneiss would fail badly, especially if it were coarse grained and much banded. The coarse-grained granites might suffer to some extent. These, though cracked to a less extent than the sandstones, would suffer more damage and possibly disintegrate if the heat were long-continued because the irregular cracks, intensified by the crushing and shearing

* W. E. McCourt, *Fire Tests on Building Stone* (New York State Museum Bulletin 100, 1906).

on the stone incident to its position in the structure, would tend to break it down. The limestones and marble would be little injured.

The temperature of 850° C. (1562° F.) represents the probable degree of heat reached in a conflagration, though undoubtedly it exceeds that in some cases. At this temperature we find that the stones behave somewhat differently than at the lower temperature. All the cubes tested were injured to some degree, but among themselves they vary widely in the extent of the damage.

All the igneous rocks and the gneiss at 850° C. suffered injury in varying degrees and in various ways. The coarse-grained granites were damaged the most by cracking very irregularly around the individual mineral constituents. Naturally, such cracking of the stone in a building might cause the walls to crumble. The cracking is due, possibly, to the coarseness of texture and the differences in coefficiency of expansion of the various mineral constituents. Some minerals expand more than others and the strains occasioned thereby will tend to rupture the stones more than if the mineral composition is simpler. The rupturing will be greater, too, if the rock be coarser in texture. For example, a granite containing much plagioclase would be more apt to break into pieces than one with little plagioclase for the reason that this mineral expands in one direction and contracts in another, and this would set up stresses of greater proportion than would be occasioned in a stone containing little of this mineral. In the gneisses the injury seems to be controlled by the same factors as in the granites, but there comes in here the added factor of banding. Those which are made up of many bands would be damaged more severely than those in which the banding is slight.

All the sandstones which were tested are fine grained and rather compact. All suffered some injury, though, in most cases, the cracking was along the lamination planes. In some cubes, however, transverse cracks were also developed.

Efflorescence.—Efflorescence is the unsightly white streaking which disfigures many masonry walls. It is due to the exudation of soluble salts contained either in the masonry material itself or in the mortar materials employed in laying the stone. Instead of being a sign of age, this defacement is rather a by-product of leaks in the wall. Water soaking into the interior dissolves mineral salts. Later the water evaporates and leaves the salts to incrust the surface. The penetration of moisture capable of causing this effect may be from various sources, such as (1) direct penetration from rains and melting snow, (2) absorption by capillary action from soils surrounding the base of the structure, and (3) leaching of acid solutions from soot on flat surfaces and ledges.

Any salt that is soluble in water or weak acids may be finally dissolved and leached to the surface under continued damp conditions. Samples of efflorescence salts collected from limestone masonry accompanied by disintegration gave the composition shown in the tabulation below. The composition of these salts seems to be mainly water-soluble sulphates and carbonates.

	Sample 1	Sample 2
SiO_2	0.28	2.20
Fe_2O_3 and Al_2O_3	0.10	3.00
CaO	31.30	46.90
MgO	1.33	trace
SO_3	42.32	5.40
SO_2	....	3.25
Ignition loss	25.03	34.60

In general it may be said that under damp conditions any soluble salt that is present in the masonry may cause efflorescence. The more common salts found in masonry and their solubilities, expressed as the number of grams that can be dissolved in a liter of water at 20° C., are as follows:

Sodium sulphate (Na_2SO_4, $10H_2O$)	194
Magnesium sulphate ($MgSO_4$, $7H_2O$)	356
Calcium sulphate ($CaSO_4$)	2

Other salts that are more rarely present in the masonry or that find admittance from external sources are:

Sodium carbonate (Na_2CO_3)	214
Potassium sulphate (K_2SO_4)	111
Sodium chloride ($NaCl$)	358
Potassium chloride (KCl)	343
Calcium chloride ($CaCl_2$)	745

Efflorescence of a wall can be checked by stopping the leaks. This may be accomplished by inserting strips of impervious material between the source of the leak and the wall proper. Open joints in projecting ledges, windows, lintels, and copings on parapet walls are particularly subject to such leaks.

Acid resistance.—Appreciable quantities of sulphuric acid and carbonic acid gases are present in the atmosphere in the vicinities of smelters and of certain railroad shops and factories. Through a long series of years these acids may exert sufficient solvent action on limestones, dolomites, and sandstones with calcareous cement to produce a roughening of the surface or even a scaling off of the surface layers of the stone. The resistance of a building stone to such acids is determined by subjecting small cubes of the stone to gaseous fumes for a given period of time and then noting their loss in weight.

Method of Sampling Building Stones

Numerous methods of sampling building stones have been recommended, but none are standardized. In an attempt to encourage a uniform procedure, the American Society for Testing Materials has published a pamphlet describing and illustrating a suggested sampling method. The following outline is taken from their publication.

A Tentative Method of Sampling Natural Building Stone and Sample for Testing *

1. Whenever a sample of stone from any quarry ledge is to be submitted to a testing laboratory for physical tests in order to determine its compressive strength and other physical properties, regardless of whether

* From American Society for Testing Materials, *A Tentative Method of Sampling Natural Building Stone and Sample for Testing*, New York, 1932.

In view of the fact that the value of physical tests on any material is dependent upon the tests showing a true average for the particular product, it is a great mistake for a producer to select for purposes of tests the so-called best material that the particular quarry or ledge produces, as such material may give test values which are not truly representative of the particular product and by establishing such values for the particular stone, place the test values and specification requirements for that stone on a basis which cannot be met in commercial practice, resulting later as a hardship to the producer.

weathering tests or the full range of physical tests are to be conducted, a sample of standard size and shape shall be furnished.

2. Samples shall be selected so as to represent a fair true average of the particular type, kind, and grade of material on which the tests are desired. In order that perfectly sound samples may be obtained, regardless of whether mechanical or explosive quarrying processes are employed, the sample blocks shall not be taken from a slab or from the face of a quarry block that occurs adjacent to a channel-cut where mechanical quarrying is employed, or adjacent to the split face of the rock adjoining the fracture made by an explosive charge.

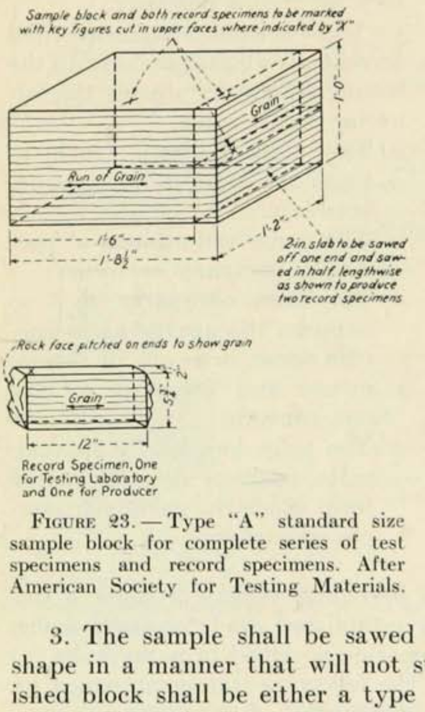


FIGURE 23. — Type "A" standard size sample block for complete series of test specimens and record specimens. After American Society for Testing Materials.

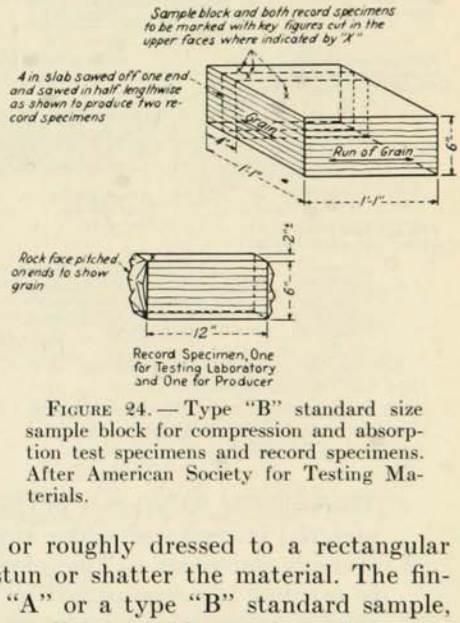


FIGURE 24. — Type "B" standard size sample block for compression and absorption test specimens and record specimens. After American Society for Testing Materials.

3. The sample shall be sawed or roughly dressed to a rectangular shape in a manner that will not stun or shatter the material. The finished block shall be either a type "A" or a type "B" standard sample, as shown in [Figures 23 and 24], depending upon the number of tests required, or the sample shall be a roughly squared block of a size not smaller than either type "A" or type "B" sample. Type "A" sample is required where a full range of physical tests is desired and type "B" sample, where only compressive strength and absorption tests are desired.

4. The direction of the grain (bedding planes or rift) shall be carefully marked on each sample.

5. From the standard sample, two record specimens shall be sawed from one end as shown in [Figures 23 and 24], leaving a sample block for testing of the size indicated. The ends of the record specimens shall be pitched off so as to produce slabs with projecting rockface ends, ap-

proximately 6 by 12 inches in size and about 2 inches in thickness as shown in [Figures 23 and 24]. One of these record specimens shall be retained by the quarry producer and the other shall be sent to the testing laboratory along with the sample block for testing.

6. The sample block for testing and both record specimens shall be marked, where indicated by "X" in [Figures 23 and 24], with a suitable number, letter, or key-diagram cut into the upper sides of the stone with a chisel as a permanent means of identification. This lettering or key-diagram shall conform with the key that may be assigned to the particular quarry by the testing laboratory for record purposes.

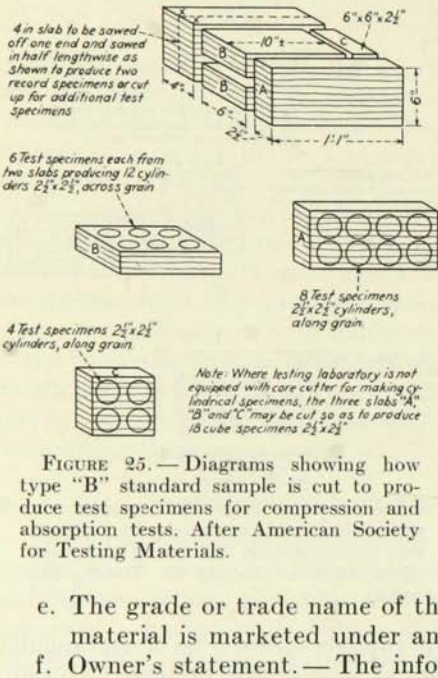


FIGURE 25. — Diagrams showing how type "B" standard sample is cut to produce test specimens for compression and absorption tests. After American Society for Testing Materials.

7. A written statement shall accompany all samples sent to the testing laboratory stating the following information.

a. The kind of stone (such as limestone, sandstone, granite, marble);
b. The name and address of producing company or owner;
c. The name of quarry, if it so happens the quarry has a specific name, or is one of several owned and operated by the one concern;
d. The ledge location or approximate position in said quarry from which the particular sample was taken;
e. The grade or trade name of the particular variety of stone, if this material is marketed under any established grade or trade name;
f. Owner's statement. — The information specified in paragraphs (a) to (e) shall be accompanied by the following statement signed by the producer, or by an authorized executive of the producing company, transmitting the sample:

This is to certify that the sample of stone and the accompanying record specimen sent to you for testing and designated by key number —— is, in our opinion, a true average sample of the grade and kind of stone as above described. This stone was quarried in the month of ———, 19—.

Signed————

(Company)

By————

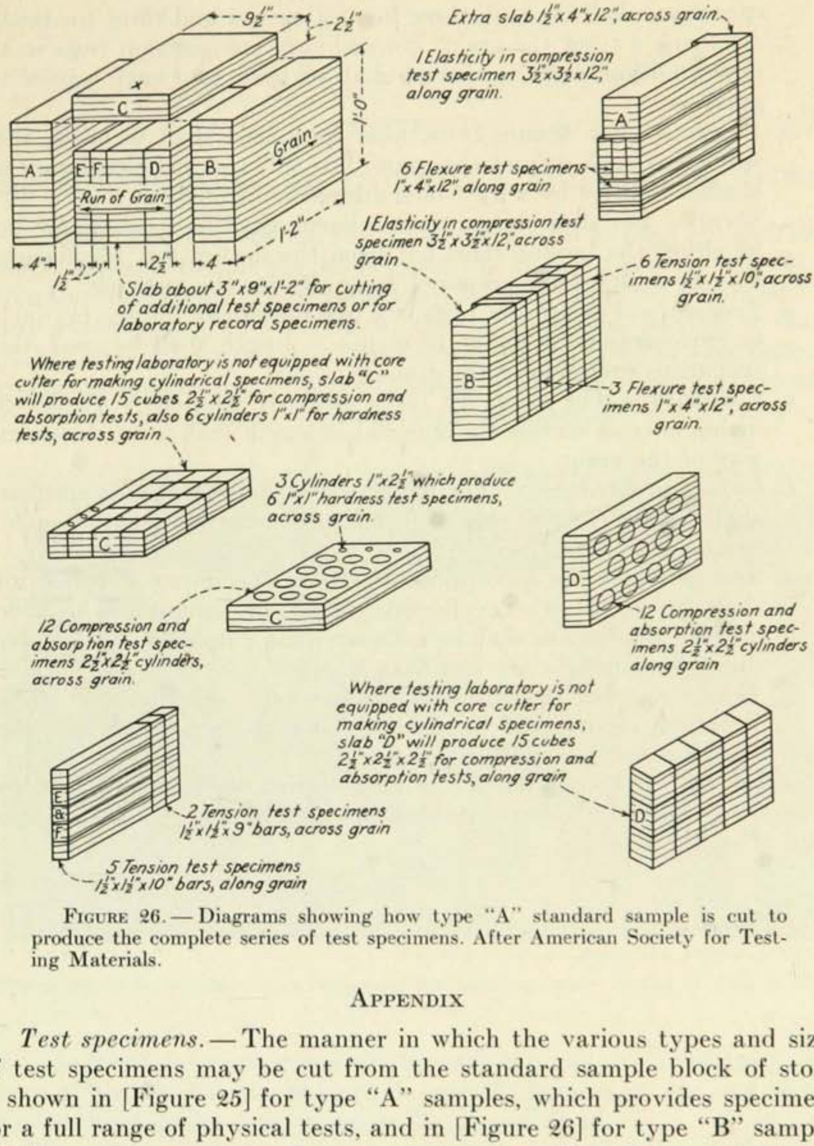


FIGURE 26. — Diagrams showing how type "A" standard sample is cut to produce the complete series of test specimens. After American Society for Testing Materials.

APPENDIX

Test specimens. — The manner in which the various types and sizes of test specimens may be cut from the standard sample block of stone is shown in [Figure 25] for type "A" samples, which provides specimens for a full range of physical tests, and in [Figure 26] for type "B" sample, which provides specimens for compressive strength and absorption tests. The test specimens shall conform to the requirement of the methods of test relating to natural building stone of the American Society for Testing Materials.

Number of test specimens. — The following minimum number of test specimens is recommended:

a. *Compression.* — For a complete series of compression tests, twelve specimens shall be used, three for testing wet and three for testing dry, each way of the grain. For ordinary compression tests in the dry condition, eight specimens shall be used, four each way of the grain.

b. *Flexure.*—For flexure tests, nine specimens shall be used, three specimens each way of the grain. For this test slab specimens not smaller than 12 by 4 by 1 inch are recommended.

c. *Shear.*—For shear tests, six specimens shall be used. These may be either the broken slabs left from the flexure test specimens or may be 1 inch slabs prepared especially for this purpose.

d. *Tension.*—For tension tests, six bar specimens 1½ by 1½ inches in cross-section by about 10 inches in length shall be used, three specimens each way of the grain.

e. *Elasticity.*—For elasticity tests, two bar specimens 3½ by 3½ inches in cross-section by 12 inches in length shall be used, one each way of the grain.

f. *Impact or hardness.*—For impact or hardness tests, six specimens shall be used, consisting of 1 inch diameter cylinders 1 inch in height.

g. *Absorption.*—For absorption tests, three specimens of regular form shall be used, either cylinders, cubes, or square prisms whose greatest dimensions shall be not more than 2 inches and whose least dimension shall be not less than 2 inches.

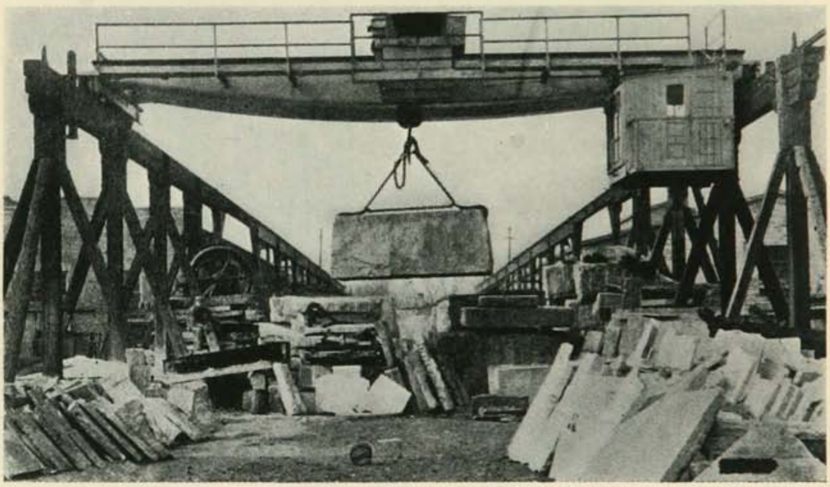
h. *Freezing.*—For freezing tests, six specimens shall be used consisting of 2½ inch diameter cylinders about 2½ inches in height, three specimens each way of the grain.

Marking test specimens.—The load-bearing surfaces and the direction of the bedding planes or rift shall be carefully marked on each specimen after finishing.

CHAPTER III

THE PREPARATION OF STONE FOR BUILDING PURPOSES

Certain types of stone are ready for use as soon as they are quarried; others, however, require special preparation. Building stone is dressed or given the required form and surface by machines that cut stone with as great precision as that with which other machines cut lumber or shape iron and steel. The mallets and hard chisels are still used in very delicate carving operations, but all other chiseling work is done with pneumatic tools. In a modern stone-dressing plant the machines are so arranged



Courtesy Whiting Corporation, Harvey, Illinois

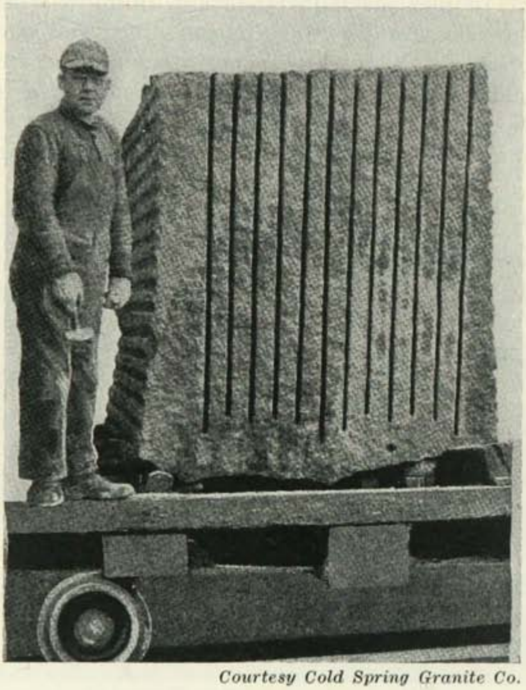
FIGURE 27. — An overhead traveling crane for handling heavy blocks of rock in the yard or shop.

that the stone passes progressively through the mill, from the gang saws that cut the blocks into slabs of desired thicknesses at one end of the shop to the shipping department at the opposite end.

The machines are driven by electric power, and most of them are operated by push-button controls. Such machines include traveling cranes (Figure 27), gang saws, rotary saws, planers, lathes, and complicated mechanisms for cutting twisted and curved handrails for stairways. The operators are guided in their work by patterns prepared by draughtsmen, directly from the architects' plans. Carvers use plaster casts of the design which they are preparing.

Stone-Cutting Machines

Gang saw. — A gang saw is a series of bands or strips of steel from 3 to 5 inches wide and from 6 to 20 feet long, suspended at adjustable distances from a steel frame by suspension rods. The saws are so mounted that they can be moved in a short to-and-fro motion of from 8 inches to 16 inches at a rate of about 175 strokes per minute. The actual cutting is done by abrasives such as chilled steel shot, sharp "crystal" sand, and

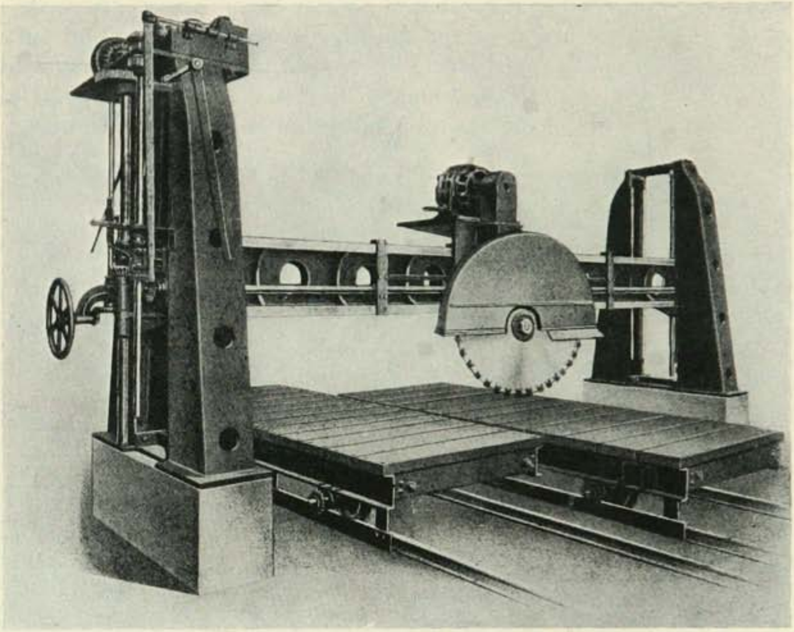


Courtesy Cold Spring Granite Co.

Figure 28. — A large quarried block of Morton granite cut into slabs by a gang saw that made twelve cuts at one operation.

carborundum. These are supplied to the blades through automatic feeds. A water spray or a small stream is also delivered to the cutting edge to prevent overheating. The saws are under constant pressure, and they descend vertically as they make their cut. In this way huge blocks of rock are cut into slabs of the desired thickness. (See Figure 28.)

Rotary saws. — The rotary saw is the fastest cutting machine in the stone industry. (See Figure 29.) It consists of a thin disk of steel from 24 to 98 inches in diameter, around the circumference of which are inserted teeth for cutting. The teeth may be crowned with carborundum, or diamonds may be set in the outer margins. (See Figure 30.) Diamond saws are commonly used for cutting marble and limestone, but they are not suited to the cutting of harder rocks such as granites and sandstones. The larger diameter saws are commonly called ripsaws, while those of smaller diameter are called jointers. (See Figure 31.) The saws are



Courtesy Pollard Machinery Co., Inc.

FIGURE 29. — A rotary saw such as is commonly used for heavy checking, jointing, or ripping. The saw blades are from 3 to 6 feet in diameter and are equipped with either diamond or carborundum teeth.

mounted so that the stone is either fed to the saw or the saw to the stone. The speed of feeding is varied according to the thickness or hardness of the rock, the variation being accomplished by means of gears or of variable speed motors.

Cylindrical saws. — A cylindrical saw is used for converting rough blocks into cylinders. (See Figure 32.) It has the advantage of operating more rapidly than the old method of lining by hand, plug drilling, and bullsetting or lathe turning. The method is very similar to gang saw or rotary saw cutting in that a steel blade $1/4$ inch thick carrying attached teeth $3/8$ inch thick is revolved against the stone while a stream of water and chilled steel shot is fed under its rim. The saw is suspended from a circular carriage to which are attached saws of different sizes, according to the capacity of the machine. A 6-foot machine can be made to saw any diameter between 3 and 6 feet by simply changing blades. The operation consists of placing the block of stone upon a car which is rolled under the saw. The saw is then lowered to meet its face and is revolved. The blade, surrounded by shot and water, cuts downward into the stone. The sash to which the saw blade is attached is hollow, so that long columns can be sawed by simply removing the waste rock outside of the blade whenever the saw has penetrated so deep that the waste corners reach the sash.

Lathes. — Lathes are used for finishing stone columns. The cutting tools of lathes are high-speed steel chisels held in fixed positions on both sides or above the column of stone, or they may be circular disks with beveled edges, revolving on spindles on either side of the columns.

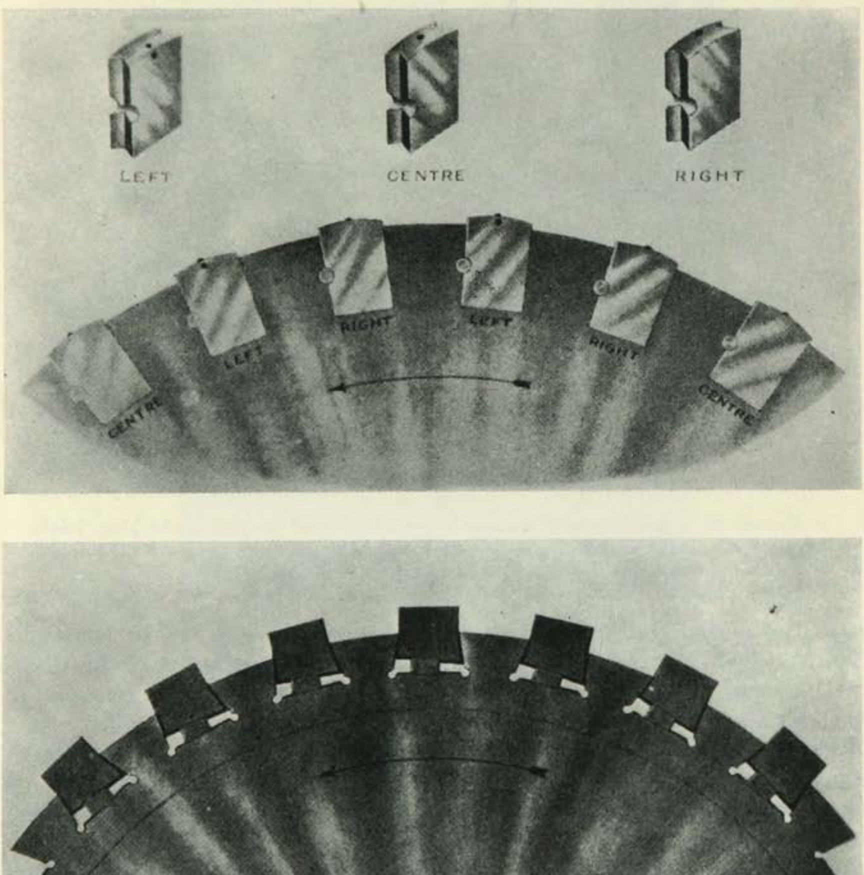
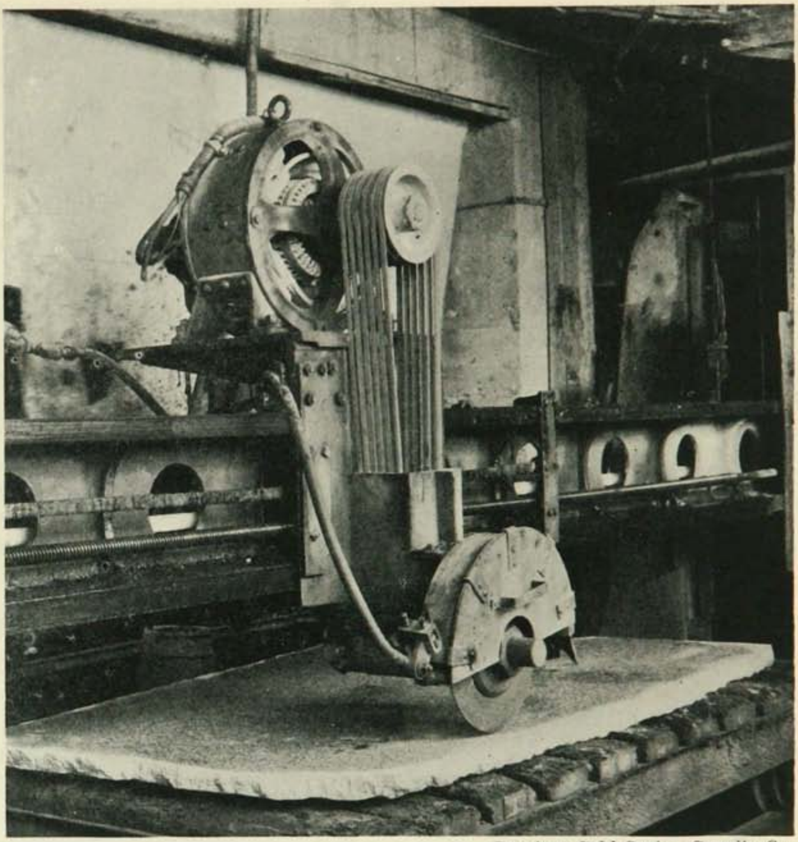


FIGURE 30. — Diagrams showing different types of teeth used in rotary saws. *Above:* Diamonds in removable teeth. *Below:* Carborundum teeth inserted in saw blade. After M. F. Goudge.



Courtesy Cold Spring Granite Co.

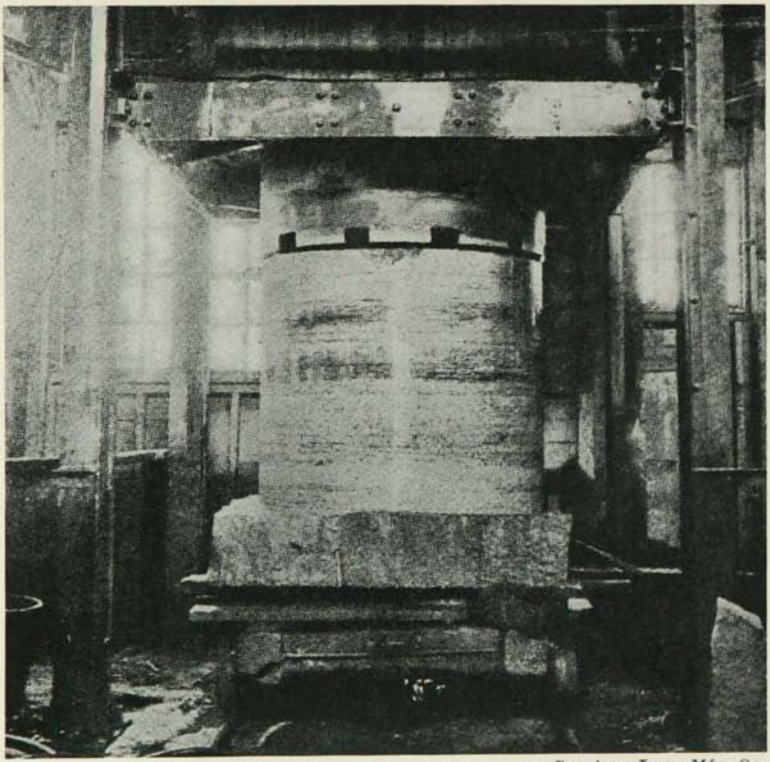
FIGURE 31. — Small rotary carborundum saw for trimming and edging.

A block of stone that is to be cut into a column is first roughly hewn to a cylindrical shape. Then the center of each end of the block is determined and a steel bearing-plate is attached in line with the axis of the block. The stone is held in the lathe by the spindles of the head- and tail-stocks of the machine. The stone is swung and rotated horizontally between these spindles. The cutting tools are carried along the column. For the turning of tapered columns, adjustments are made so that the cutting tools travel in a curved path. Attachments are provided so that a column may be fluted with carborundum wheels without removing it from the lathe. Small lathes for the turning of balusters are of similar design. Many of these are fitted with grinding wheels made of artificial abrasives.

Planers. — The function of the planer is to smoothe the surface of the stone and to cut grooves, moldings, cornices, etc. The machine consists of a heavy framework to which cutting tools are attached and a sliding table or platen on which the stone is fastened. The table is driven back and forth and the cutting tools are spaced and adjusted so that the required pattern is cut as the stone is carried toward them.

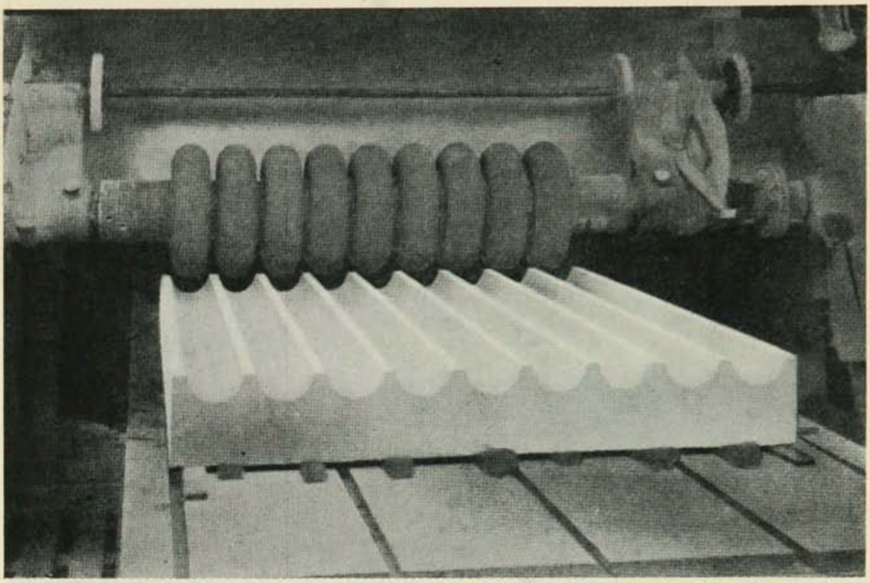
Carborundum wheels. — Carborundum is the trade name for silicon carbide. It is nearly as hard as diamond and therefore is an effective agent in cutting stone. Some rotary saws have carborundum rims on the steel-centered blades; others use steel blades fitted with inserted teeth of carborundum. Smaller wheels of a great variety of shapes are now available, and can be mounted to do the work of planers and other surfacing machines. (See Figure 33.) Some machines have both a horizontal and a vertical arbor, each of which is adjustable to any angle. The stone is fed toward the cutting wheels on a rigid table in the same manner as in the planer. With the use of carefully outlined patterns, very complicated designs may be cut.

Finishing machines. — Formerly in the surfacing, ironing, emerying, and buffing of stone a different machine was used for each operation. (See



Courtesy Lane Mfg. Co.

FIGURE 32. — A cylindrical saw for cutting columns and cylinders.



Courtesy Carborundum Co., Niagara Falls

FIGURE 33. — A fluting machine for limestone or marble pilasters. The flutes are five inches wide and two and one-half inches deep.

Figures 34 and 35.) At present, however, much of this work is done successfully and more rapidly by automatic surfacing and polishing machines that are operated and controlled by electric power. The stone is set in polishing beds (see Figure 34) as formerly, but the beds instead of being stationary are mounted on large cars which travel forward and back under the polishing wheels. The polishing wheels, some of which weigh several thousand pounds, can be shifted to any position across the car or bed by push-button controls. Very large surfaces may be finished in one operation, for if the stone is larger than the capacity of one car, it may be loaded on two cars coupled together so that they will operate as one unit when the machine is set in motion.

The processes of ironing, emerying, and buffing a granite may be completed at the rate of from 10 to 15 square feet per hour. At the present time, by the use of automatic machines with surfacing wheels, from four to six times as much stone may be surfaced in a day as was surfaced by former methods.

Rubbing beds. — A rubbing bed consists of a horizontal revolving iron table from 6 to 14 feet in diameter. Blocks of stone are placed on the table and held stationary by radial arms. Abrasives are supplied continuously to the surface of the center of the table, and the stone is abraded as the table revolves. In many marble plants the stone is first surfaced on such a rubbing bed before it is honed and polished.

Surface Finishes

Different types of finish produce differences in texture and color in the natural surface of a stone. Finishes may be adjusted to various types of architectural specifications. Those commonly used are outlined below.

Seam face. — A seam-face finish is the natural surface produced by splitting sedimentary rock along the bedding planes.

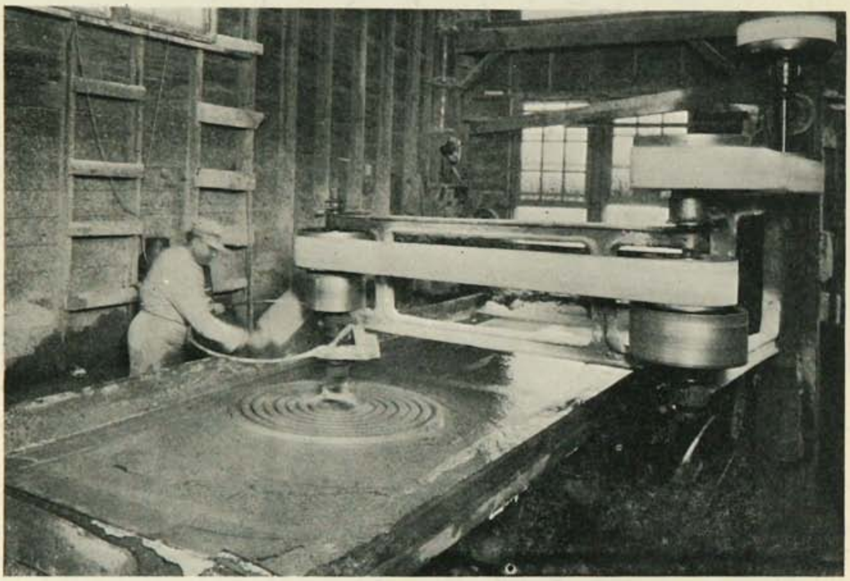


FIGURE 34. — A stationary polishing bed and belt-driven polishing machine in the plant of the Universal Granite Company at St. Cloud.

Rock face. — The natural rough broken surface is a rock-face finish. This surface is most popular for large houses, churches, and schools.

Picked finish. — The picked finish surface is produced by smoothing the rough rock face to an approximate plane by means of picks.

Bush-hammered finish. — The bush-hammered finish is produced by pneumatic hammers that pound sharp pyramidal points into the smooth surface of stone. The surface is covered with many tiny dots. This process may have an undesirable effect on the durability of the stone, for the entire surface is covered with bruises that become centers of weathering and decay.

Sand-sawed finish. — A sand-sawed surface is one that has been sawed by gang saws that use sand as an abrasive. At a short distance the finish appears similar to that produced by bush-hammering. If coarse sand is used, the surface is somewhat scored.

Shot-sawed finish. — A shot-sawed rock shows deep, rough, parallel scoring produced by the use of chilled-steel shot as a cutting medium for straight-cut gang saws. It is a rough-textured finish that is desirable in combination with other finishes.

Diamond-saw finish. — A diamond-saw finish is distinguished from a shot-saw surface by the pattern of its scoring. Diamond teeth are most commonly used in rotary saws. A diamond saw therefore leaves shallow arc-like grooves.

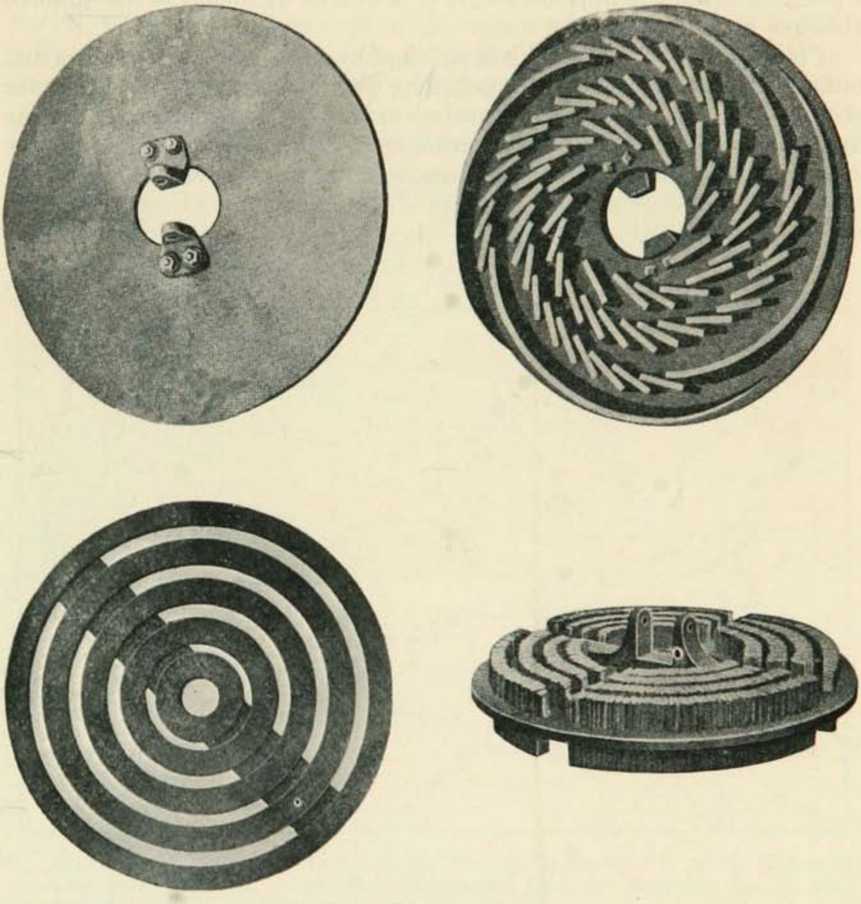


FIGURE 35. — Polishing wheels for machines such as that shown in Figure 34. *Top left:* Iron disk for use with sand or shot as an abrasive. *Top right:* Scroll wheel. *Lower left:* Emery rings. *Lower right:* Felt buffer.

Planer finish. — The planer produces a smooth unpolished surface such as is used for a great variety of purposes in stone structures.

Sand-rubbed finish. — A sand-rubbed finish is produced by placing the stone on a rubbing bed, where it is subjected to sand grinding until it is smooth. It is generally smoother than a planer finish.

Carborundum finish.—A carborundum wheel produces a semi-polished surface. Such a surface approaches the color of the polished rock. It is usually darker than the finish produced by sawing, since only a very small amount of pulverized stone is left in the irregularities on the surface.

Honed finish.—A honed stone becomes very smooth and approaches a polished surface in appearance. It is produced by means of fine-grained abrasive powders.

Polished finish.—The rock is polished by using abrasive powders and buffers. The abrasives used for polishing differ according to the character of the stone. Tin oxide (putty powder) or rouge is commonly used for the final stages of polishing. In the earlier stages of polishing, emery, tripoli, diatomite, pumice, alumina, alundum, and other abrasives are also used.

CHAPTER IV

GRANITES AND RELATED IGNEOUS ROCKS OF MINNESOTA

The term "granite" as used in this report includes granites, gneisses, diorites, gabbros, and other igneous rocks. The granites of greatest economic value are found in three widely separated regions in Minnesota: (1) central Minnesota, particularly in the region of the city of St. Cloud; (2) the upper Minnesota River Valley from New Ulm to Ortonville; and (3) the Arrowhead region, which includes the area north of Duluth in St. Louis, Cook, and Lake counties. Stone quarried in these regions has been used extensively and has enjoyed a wide distribution for architectural use. (See Figure 36.)

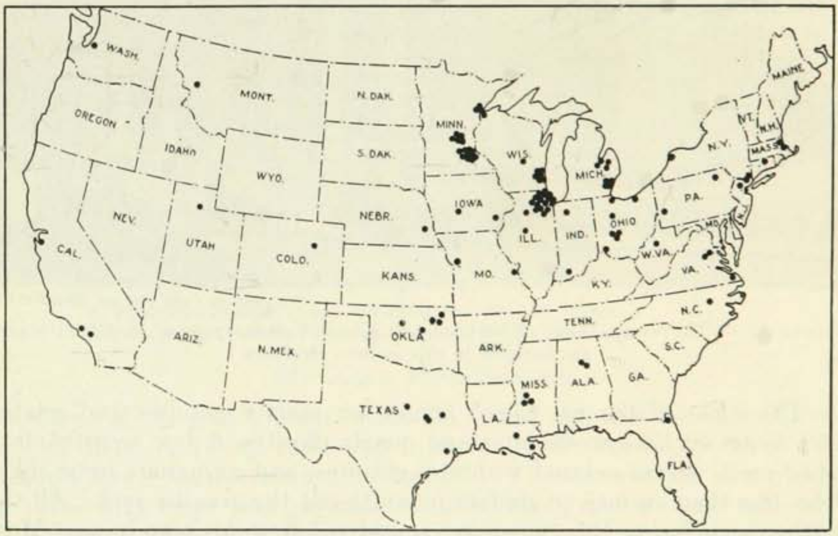


FIGURE 36. — Map of the United States showing the localities in which Minnesota granites have been used for architectural purposes. Each dot represents one or more prominent buildings in which the granite was installed.

GRANITES OF THE ST. CLOUD REGION

The granite industry of the Northwest began in the St. Cloud area as early as 1867. The first quarry was opened in the village of Sauk Rapids. In 1868 Breen and Young opened a quarry in East St. Cloud which supplied stone for the United States Custom House and Post Office in St. Paul. By the year 1870 both red and gray granites were being developed in the region. From 1900 to the present time the growth of the granite industry has been steady, and over thirty establishments, great and small, have grown up in the area. St. Cloud has earned the title of the "Granite City" of the Northwest. The region has long been famous for both monumental and building granite. (See Figure 37.)

Courtesy Cold Spring Granite Co.

FIGURE 37. — The Stearns County Courthouse, St. Cloud. Various types of St. Cloud granite are installed in this modern structure.

The rocks of the St. Cloud region are mainly granites and related rock types such as monzonites and quartz diorites. A few areas of dark basic rocks are associated with the granites, and numerous basic dikes from less than an inch to six feet in width cut the granitic rocks. All the intrusive masses in this region are considered post-Archean in age. Most of the granites are tentatively correlated with the Keweenawan intrusives that occur in the region southeast of Mille Lacs.

The rocks crop out most extensively in eastern Stearns County, northwestern Sherburne County, and southwestern Benton County. (See the outcrop map, Figure 38.) They constitute the most valuable mineral resource of central Minnesota.

The stone of the St. Cloud region may be grouped into three major types, namely, pink granite, red granite, and gray granite. Their occurrence is shown in Figure 39 on pages 68 and 69. Below are listed the producers of rough stone and building stone.

Granite Producers of the St. Cloud, Minnesota, District

Quarries *

Empire Quarrying Company, 905 6th Ave. So., St. Cloud (office)
Robert Graham Company, 1602 St. Germain St., St. Cloud (office)
Minnesota Quarrying Company, 22 16th Ave. No., St. Cloud (office)
John Kellas Company, 423 4th Ave. So., St. Cloud (office)
Plachecki Brothers Granite Company, 230 19½ Ave. No., St. Cloud (office)

Producers of Building Stone and Memorials †

North Star Granite Corporation, St. Cloud
Cold Spring Granite Company, Cold Spring
John Clark Company, Rockville
Sauk Rapids Granite Company, Sauk Rapids
Melrose Granite Company, West St. Germain St., St. Cloud
Monumental Sales and Manufacturing Company, 537 22nd Ave. No., St. Cloud
Jones Monumental Works, 1812 8th Street So., St. Cloud
Royal Granite Company, Osseo Ave. No., St. Cloud
Granite City Granite Company, Osseo Ave. No., St. Cloud
A. M. Simmers and Sons, Osseo Ave. No., St. Cloud
Pyramid Granite Company, West St. Germain St., St. Cloud
St. Cloud Granite Company, West St. Germain St., St. Cloud
United Granite Company, 505 17th Ave. No., St. Cloud
Universal Granite Company, 211 Cooper Ave. No., St. Cloud
Gopher Granite Company, Lincoln Ave. N. E., St. Cloud
Rex Granite Company, Lincoln Ave. N. E., St. Cloud
Lincoln Granite Company, Lincoln Ave. N. E., St. Cloud
Memorial Art Company, Lincoln Ave. N. E., St. Cloud
Central Minnesota Granite Company, 25 Wilson Ave. N. E., St. Cloud
Grewe Granite Company, 3d St. N. E., St. Cloud
Ideal Granite Company, 830 Metzroth Place So., St. Cloud
Kollmann Monumental Works, 1915 Division St., St. Cloud
Frank Mehelich Company, 1811 3d Street No., St. Cloud
John Salaski Company, 318 15th Ave. No., St. Cloud
Liberty Granite Company, R. F. D., St. Cloud
Quarry Center Manufacturing Company, Sauk Rapids

Producers of Samples and Fancy Forms ‡

N. Finneman Sample Shop, 749 18th Ave. So., St. Cloud
William Smith Sample Shop, 41 1st Ave. N. E., St. Cloud

St. Cloud Pink Granite

Most of the pink granite of the St. Cloud region is found southwest of St. Cloud in a zone extending from Sec. 2, T. 124 N., R. 29 W. (St. Joseph Twp.) southwestward to Rockville. The stone is best described as a stone with large pink crystals set in a finer grained black and white background. The minerals of the matrix occur in remarkably uniform sizes and the pink crystals are sufficiently uniform in distribution to give the stone a very attractive appearance.

The finished stone is marketed under the trade names "Rockville Pink," "Cold Spring Pearl Pink," "Original Minnesota Pink," and "Sauk Rapids Pink" granites.

Rockville Pink granite.—The John Clark Company now operates the Clark and McCormack Quarry at Rockville, which was opened in

* Rough stone producers.
† Cut or polished. Many firms operate their own quarries.
‡ Polished.

1907. Since 1912 it has been one of the large producers of architectural stone in the state.

At the quarry the rock rises in a great dome which is exposed over at least an acre. 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 importance. Sheeting planes also are few. Where quarrying is now carried on, none are present, and blocks have to be forced by "lift holes." Blocks of immense size, much larger than can be handled by derrick, are obtainable. Formerly, large blocks were broken loose by blasting and were subdivided by plug and feather. Now drifters, or channeling machines, are used in removing the stone from the quarry. A noteworthy feature of the quarry and the adjoining finishing plant is the small waste heap. Nearly all the stone is fit for use.

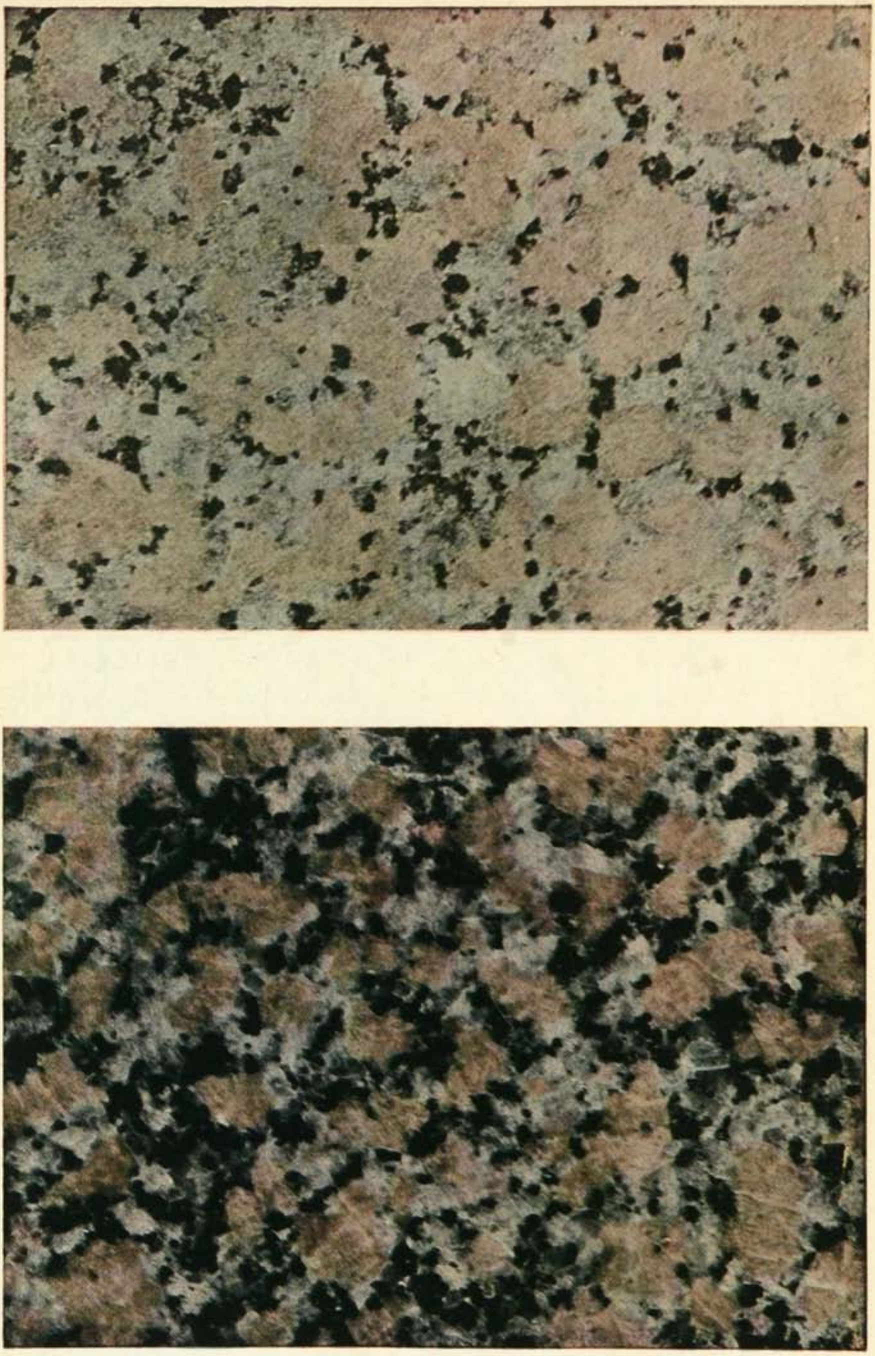
The Rockville stone is uniform and exceptionally coarse grained, the angular feldspar crystals being ½ to ¾ of an inch long. The granite consists of pale pink feldspar, quartz, and black mica (see Plate 2), the combined effect of which on a hammered surface is pinkish gray. No pyrite or other minerals that 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. The accompanying table is an analysis by F. F. Grout of typical Rockville Pink granite.

SiO_2	69.63	K_2O	4.33
Al_2O_3	13.85	H_2O (above 100° C.)	0.23
Fe_2O_3	0.54	H_2O (below 100° C.)	0.10
FeO	4.01	TiO_2	0.33
MgO	0.83	P_2O_5	0.28
CaO	2.58	Total	99.03
Na_2O	2.32		

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 the final collapse at 17,294 pounds per square inch. The modulus of rupture was 2,048 pounds per square inch.

The finished stone has a tone and individuality that have been recognized by leading architects in all parts of the United States. One of the first prominent buildings for which this stone was chosen was the Cathedral in St. Paul. The remarkable adaptability of the stone for carving was demonstrated in this building. Many magnificent pieces of sculpturing are included.

Rockville Pink has recently been selected for the new federal courthouse in New York City. A feature of the building as designed by Cass Gilbert, New York architect, will be a tower of thirty-eight stories rising



Courtesy Cold Spring Granite Co.

PLATE 1. — ST. CLOUD PINK GRANITE

Above. — Rubbed finish. *Below.* — Polished finish.

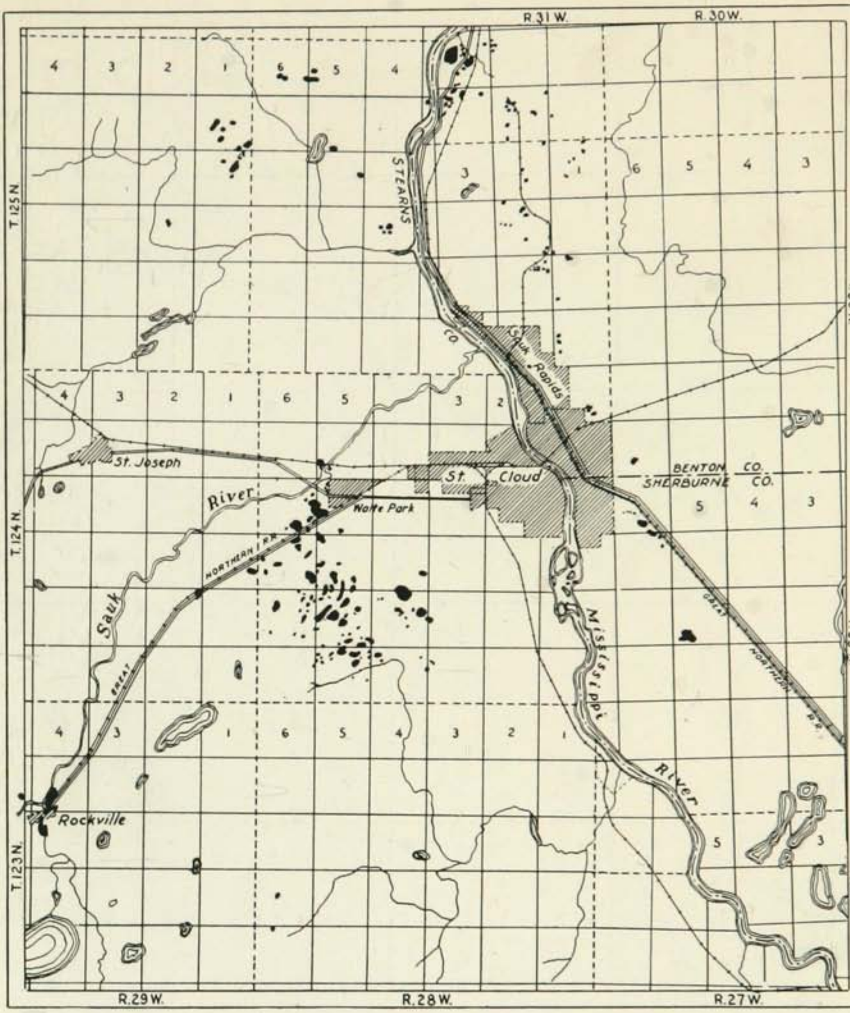


FIGURE 38. — Map of the St. Cloud region showing the occurrence of rock outcrops.

from a square-columned base structure. The entire building will have a granite exterior. It has been estimated that eleven hundred carloads of finished stone will be required for the structure.

Other prominent buildings in which Rockville granite has been used are listed below:

Tribune Tower, Chicago
Pioneer Trust and Savings Bank, Chicago
Belden Hotel, Chicago
Reese Hospital, Chicago
Bankers Building, Chicago
Fullerton State Bank, Chicago
Metropolitan National Bank, Minneapolis
Hennepin Theater, Minneapolis
Cathedral, St. Paul
East First National Bank, St. Paul
Paramount Theater, St. Paul
St. Cloud Hospital, St. Cloud, Minnesota

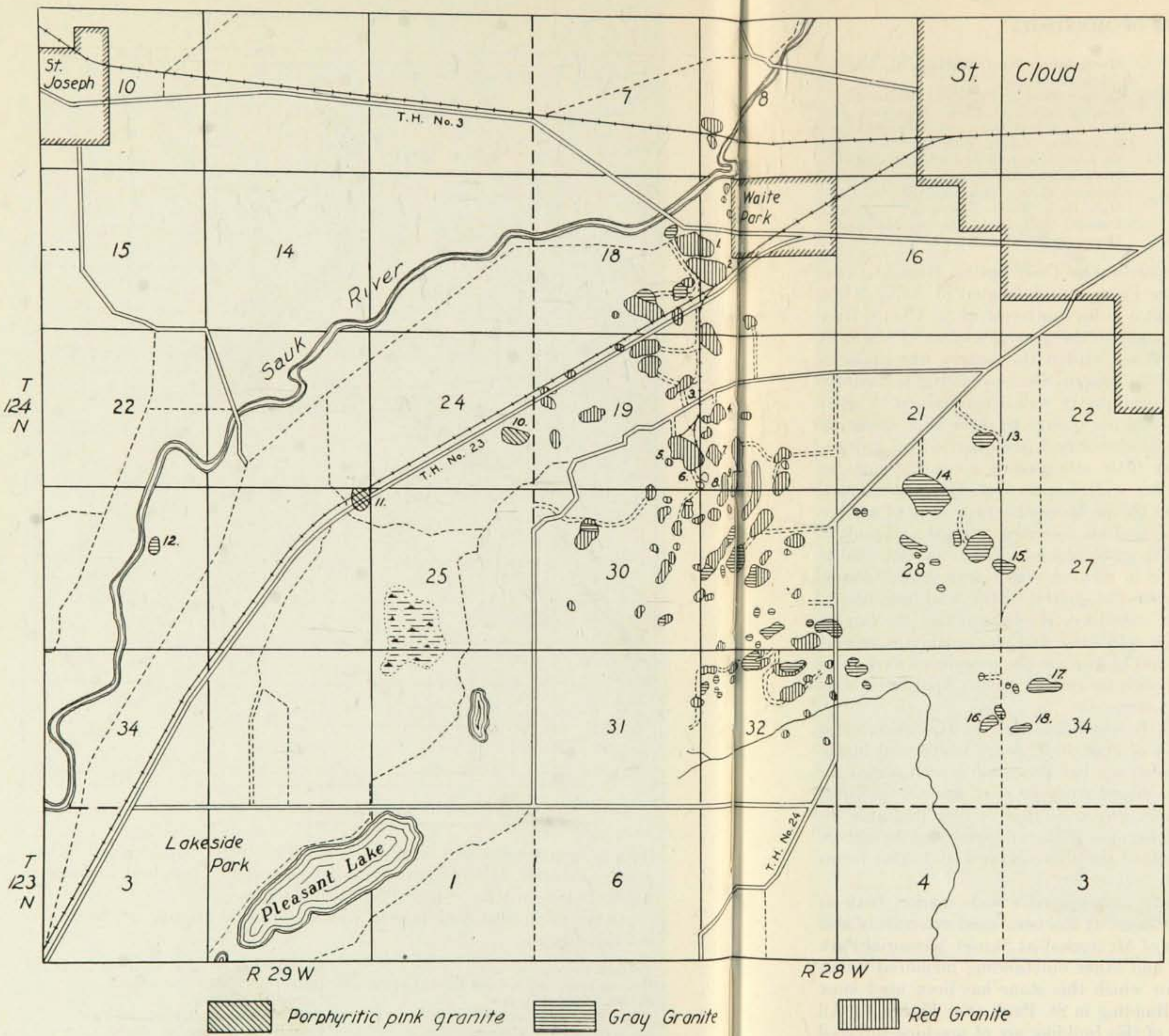


FIGURE 39. — Map of the region southwest of St. Cloud, showing outcrops and quarries.

1. Granite City Granite Company
2. North Star Granite Company
3. North Star Granite Company
4. A. M. Simmers and Sons
5. Empire Quarrying Company
6. Empire Quarrying Company
7. Melrose Granite Company
8. Pyramid Granite Company
9. Universal Granite Company
10. North Star Granite Company
11. Cold Spring Granite Company
12. Pyramid Granite Company
13. Robert Graham Company
14. Plachecki Brothers Quarry Company
15. Granite City Granite Company
16. North Star Granite Company
17. Melrose Granite Company
18. Royal Granite Company

American Fore Office Building, Chicago
American Furniture Mart, Chicago
Fisher Body Company Building, Detroit
Detroit Stock Exchange, Detroit
Washington Boulevard Building, Detroit
Book-Cadillac Hotel, Detroit
Post Office, Milwaukee
Straus Building, Milwaukee
Journal Building, Milwaukee
Gradens Theater, Milwaukee
Federal Reserve Bank, Minneapolis
Pro-Cathedral, Minneapolis
Montgomery Ward Building, St. Cloud, Minnesota
Lardner Building, St. Cloud, Minnesota
Garfield School, St. Cloud, Minnesota
Jefferson School, St. Cloud, Minnesota
Post Office, Duluth, Minnesota
St. Louis County Jail, Duluth, Minnesota
Western United Building, Aurora, Illinois
National Bank, Valparaiso, Indiana
State Bank, Beloit, Wisconsin
Dansard State Bank, Monroe, Michigan
Democrat Building, Davenport, Iowa

Cold Spring Pearl Pink granite.—The Cold Spring Granite Company's quarry in pink granite (see Figure 40) is located in NE¼ NE¼ Sec. 26, T. 124 N., R. 29 W., about 5 miles southwest of St. Cloud. Here a rock outcrop rises about 20 feet above the general surface of the drift over an area of about an acre. When visited the quarry was approximately 300 by 200 by 90 feet in dimensions. Because of the uniformity of the rock a remarkably symmetrical quarry wall is maintained. A pillar of rock has been left in the center of the quarry to serve as a mounting for a gigantic boom derrick. The blocks of rock are quarried by drifters, or channeling methods, and very little attention is given therefore to natural seams and joints, which are widely spaced, as Figure 40 shows.

The rock is somewhat similar to the Rockville type, but of a finer texture and more even color. It is medium to coarse grained and 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 present in smaller amounts. Hornblende and biotite are the prominent dark minerals, the latter being associated with magnetite grains. Apatite crystals are common and are of unusually large size.

When polished (see Plate 1) the stone has rich and pleasing color tones consisting of a combination of pink, buff, pearl, white, and black. These colors are artistically blended so that the stone is well suited for any architectural treatment. Machined surfaces that are not polished (see Plate 1) show a warm pinkish-gray tone that is very desirable for certain exterior and interior uses. Because of the uniformity of its texture and size of grain, the stone lends itself readily to carving and other forms of fine ornamentation.

Cold Spring Pearl Pink granite has enjoyed a wide market both as architectural and as monumental stone. It has been used extensively also for such structures as the "Tower of Memories" at Sunset Memorial Park in Minneapolis (see Figure 41) and other outstanding memorial buildings. The prominent structure for which this stone has been used most recently is the new State Office Building in St. Paul. (See Figure 1.) All the exterior walls and the pillars of this building are of machine-surfaced

FIGURE 40. — Quarry of the Cold Spring Granite Company southwest of St. Cloud.

pink granite. Other prominent buildings for which Cold Spring Pearl Pink has been used are listed below:

City Hall, Duluth, Minnesota
Oklahoma Gas and Electric Company Building, Oklahoma City
Ford Museum buildings, Dearborn, Michigan
Merchandise Mart, Chicago
Board of Trade Building, Chicago
Jefferson County Courthouse, Birmingham, Alabama
Criminal Courts Building, New Orleans
Cadillac Building, Boston
New York Central Station, Buffalo, New York
Gallinger Hospital, Washington, D. C.
Koppers Building, Pittsburgh
City Hall, Columbus, Ohio
Chamber of Commerce Building, Jacksonville, Florida
Bell Telephone Company Building, Dallas, Texas
First National Bank, San Jose, California
Home Telegraph and Telephone Company Building, Pasadena
Youngs Market Building, Los Angeles
New Bismarck Hotel, Chicago
Schroeder Hotel, Milwaukee
Post Office and Courthouse, Des Moines
Post Office, Missoula, Montana

Original Minnesota Pink granite.—The North Star Granite Corporation obtains its pink granite from a quarry in NE¼ SE¼ Sec. 24, T. 124 N., R. 29 W. (St. Joseph Twp.). The old Baxter Quarry and the Pioneer Granite Company formerly operated in this region. The rock approaches Pearl Pink granite in texture, but is deeper pink in color than either the Rockville or Pearl Pink type. It is, however, paler than the typical St. Cloud Red. This stone is marketed under the trade name "Original Minnesota Pink."

The jointing planes in the rock are widely spaced and permit the

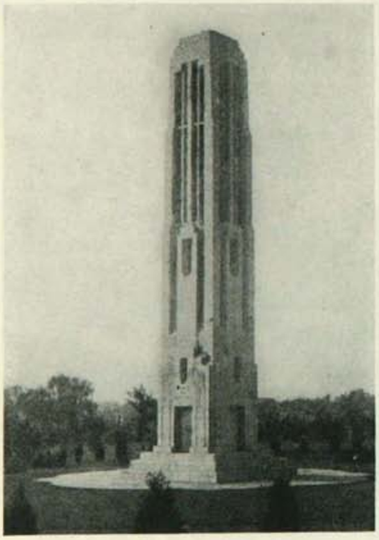


FIGURE 41.—The "Tower of Memories" in Sunset Memorial Park, Minneapolis. The tower is constructed of pink St. Cloud granite.

Courtesy North Star Granite Co.

FIGURE 42.—The Kinnaman Memorial Fountain, Ashland, Ohio, built of steeled-finish pink granite from the St. Cloud district.

quarrying of large blocks. The joints that are present form three systems: N. 5° E., N. 60° E., and N. 60° W. Minor joints cross in other directions. A number of dark hair lines cut the rock, but they are not so numerous as to interfere with quarrying operations.

When studied in detail the rock is found to consist of grains of microcline, orthoclase, plagioclase, quartz, hornblende, and biotite. Of this group of minerals, microcline is the most abundant, and it gives the rock its characteristic pink color. The hornblende and biotite are present as large grains and flakes, many of which contain large inclusions of quartz and feldspar. Locally the dark colored minerals are segregated into knots, but these are easily avoided in the fabrication of quarry blocks at the finishing plant.

The rock is suitable for the manufacture of excellent architectural stone. It is attractive in color, very strong and durable. One of the early uses of this stone was for the approaches to the State Capitol in St. Paul. Since 1913 the products from this quarry have been used for every type of structure for which stone is adaptable. (See Figure 42.) The following list includes some of the prominent buildings in which Original Minnesota Pink has been used:

Fisher Building, Detroit
Detroit Times Building, Detroit
Theater and office building, Detroit
Eaton Tower, Detroit
Kresge Administration Building, Detroit
Bell Telephone Building, Cleveland
Dollar Savings Bank, Pittsburgh
Mincks Hotel, Tulsa, Oklahoma
Fountain Theater, Cincinnati
Office Building, Fort Worth, Texas
Muskegon Chronicle Building, Muskegon, Michigan
Huron County Bank, Norwalk, Ohio
Talcott Building, Rockford, Illinois
Lib-ral Arts Building, University of North Dakota, Grand Forks

Sauk Rapids Pink granite.—A number of different types of pink granite were formerly quarried in the region of Sauk Rapids in Benton County. At the present time all the quarries are inactive and the finishing plants at Sauk Rapids are engaged in fabricating stock from other quarries. The Sauk Rapids Granite Company, operated by R. V. Storer, is the best equipped and most active producer of finished stone in the Sauk Rapids area.

The pink granites near Sauk Rapids are rather different in appearance from either the Rockville or Cold Spring types. The Sauk Rapids types are similar in texture and mineral constituents to St. Cloud Red. The feldspar grains, however, are pale pink in color and consequently the rock is pinkish gray rather than red. A very large supply of high-grade rock for structural and monumental stock is still available in the area, and when the demand for such colors and textures is revived, the quarrying industry will again become active.

Rocket Granite Company quarry.—A new quarry has been opened in a pink granite in Sec. 13, T. 36 N., R. 31 W., northeast of Sauk Rapids. A gray granite and a red granite crop out in an exposure that is approximately 200 feet long and 150 feet wide. The rock that is being marketed is a pink phase of red granite, similar to St. Cloud Red. It shows a gradation from dark red to light red and pink in the quarry walls. Gray granite is present on the east side of the quarry, but it is not being quarried because of numerous seams, intrusions, and inclusions in the rock. In the pink rock the joint systems trend N. 65° E. and N. 10° W. The joints are widely spaced, occurring at intervals of about 15 feet. Sheeting is moderately well developed. A few ledges, however, must be maintained by lifts.

Another area of pink granite occurs in NE¼ Sec. 14, T. 36 N., R. 31 W. (Sauk Rapids Twp.). A small pit known as the Arnold Quarry was opened in this area as early as 1884.* In 1906 it was sold to the Western Granite Company of Sauk Rapids, which operated it until 1911, after which time it was idle until 1914, when it was purchased by the Sauk Rapids Granite Company.

Prominent outcrops occur over an area of about 30 acres, the rock rising at places 35 feet above the adjacent swamps. A quarry is situated at the contact of red and gray granite. The red granite is hornblende and paler than the typical St. Cloud Red. Near the contact with the gray granite the color is a paler pink and the texture is 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 is uncertain.

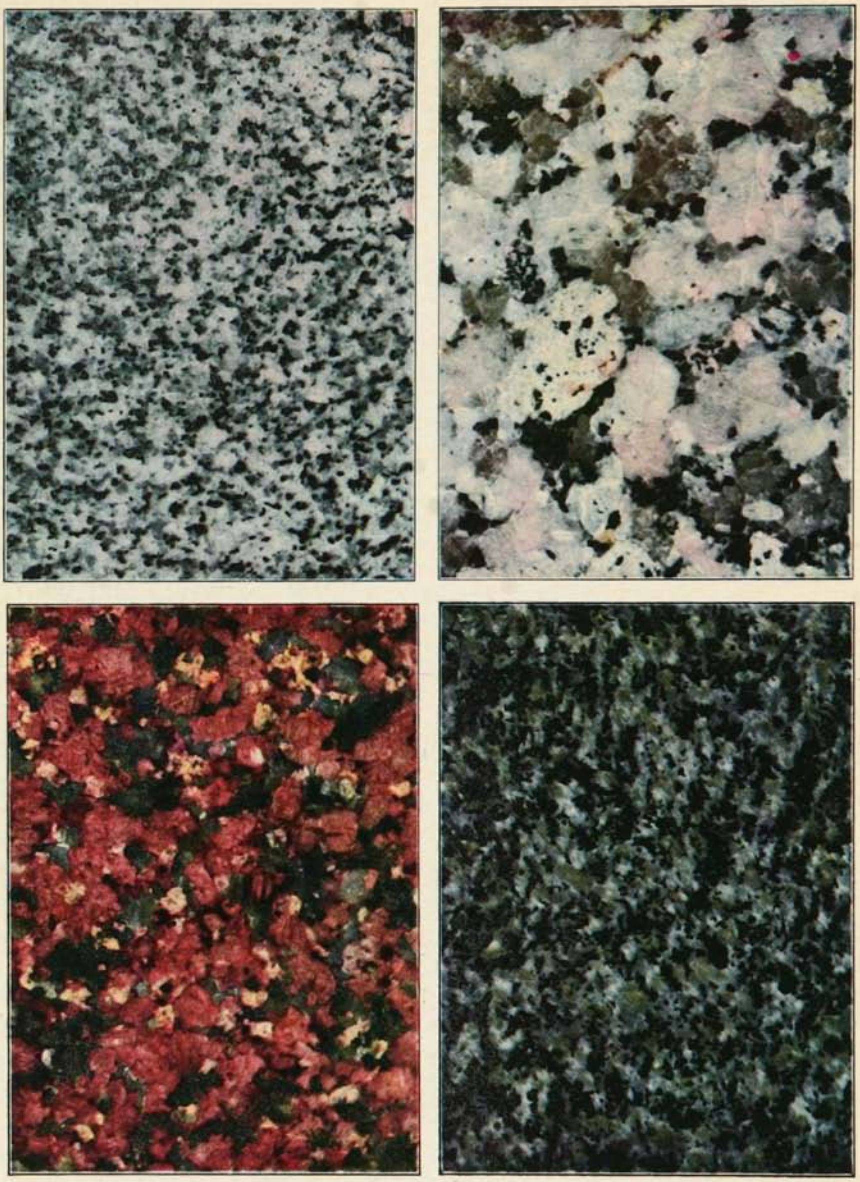
The gray rock is a hornblende granite, somewhat finer grained than the red granite and containing less quartz. Major joints strike N. 20° E. and dip about 80° west. Several minor joints intersect them at various angles.

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 likewise results in considerable waste.

Pink granite has also been quarried in NW¼ NE¼ Sec. 1, T. 136 N., R. 31 W. Swanson and Haystedt began quarrying there about 1896 and continued till 1909. Bowles † describes the rock as a very pale pink or almost gray hornblende granite with the texture of the St. Cloud Red. It has a uniform texture. 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 from 2 to 6 feet apart — much closer and more distinct than in most of the quarries of the region. Consequently, slabs of large size may easily be obtained. One block lying in the quarry was 10 feet 8 inches long, 6 feet 6 inches wide, and 14 inches thick.

* Bowles, *op. cit.*, p. 126.
† *Ibid.*, p. 129.



Courtesy United States Geological Survey

PLATE 2. — MINNESOTA GRANITES

Upper left. — Warman Creek Gray. *Upper right.* — Rockville. *Lower left.* — St. Cloud Red. *Lower right.* — Morrison County Gray.

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. These are easily eliminated at the fabrication plant.

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 it is well adapted for paving stone, building blocks, flagging, door sills, and steps.

The following is a list of some of the buildings in which Sauk Rapids granite has been used:

Civic Opera Building, Chicago
Lake State Bank, Chicago
Bell Building, Chicago
Home Bank and Trust Company Building, Chicago
Madison Square Bank Building, Chicago
West Irving State Bank Building, Chicago
Southmoor Hotel, Chicago
Security Bank Building, Chicago
Adams and Franklin Building, Chicago
Mutual National Bank Building, Chicago
St. Philip Neri Church, Chicago
Maywood State Bank, Maywood, Illinois
First National Bank, Waukegan, Illinois
Springfield Marine Bank, Springfield, Illinois
Third National Bank, Mt. Vernon, Illinois
Barlum Tower, Detroit
Barlum Hotel, Detroit
Film Exchange, Detroit
McGregor Library, Detroit
Metropolitan Building, Detroit
Edmund Clark Building, Detroit
Fort Wayne Hotel, Detroit
Bank of Saginaw, Saginaw, Michigan
Consumers Power Company Building, Saginaw, Michigan
Literary Building, University of Michigan, Ann Arbor
Genesee County Courthouse, Flint, Michigan
Dayton Biltmore Hotel, Dayton, Ohio
Ohio Bell Telephone Company, Cleveland
Commercial Savings Bank, Berea, Ohio
Peoples Banking and Trust Company, Marietta, Ohio
Home Savings and Loan Bank, Reading, Ohio
Elks Club, Hammond, Indiana
Odd Fellows Temple, Hammond, Indiana
Peru Trust Company, Peru, Indiana
Terre Haute Hotel, Terre Haute, Indiana
First National Bank, Elkhart, Indiana
Loew Theater, Pittsburgh
Kentucky Loan and Savings Bank, Newport, Kentucky
Breslin Building, Louisville, Kentucky
Wisconsin Theater, Milwaukee
National Exchange Bank, Milwaukee
Tripoli Mosque, Milwaukee
Milwaukee General Hospital, Wauwatosa, Wisconsin
Memorial Union, Ames, Iowa
Iowa Memorial Union, Iowa City
Hawkeye Building, Waterloo, Iowa
Central Lutheran Church, Minneapolis
University Hospital, Minneapolis
Hotel Duluth, Duluth, Minnesota
Webber High School, Salt Lake City
Technical High School, Omaha
Peabody Hotel, Memphis, Tennessee

Undeveloped outcrops of pink granite.—Since the pink granite of the St. Cloud region is such an attractive and durable stone and is adaptable for the best and most artistic architectural and monumental purposes, its fabrication will undoubtedly continue to increase. There are a number of outcrops of the same general type of rock that have not been prospected.

Near the center of Sec. 19, T. 123 N., R. 28 W. (St. Augusta Twp.) a prominent outcrop covers an area about 250 long and 100 feet wide. The rock extends westward under a very thin cover of glacial drift. To the east it slopes abruptly to the margin of a marsh. The rock is a coarse-grained porphyritic granite of the Rockville type. At the south end of the outcrop the joints are from 4 to 10 feet apart. They strike N. 22° W. and N. 60° E. At the north end of the outcrop the rock is cut into angular masses by three systems of joints that strike N. 70° W., N. 50° W., and N. 85° W. These are spaced sufficiently far apart so that dimensional blocks could be quarried. The rock is a coarse-grained hornblende biotite granite. Pale pink feldspar crystals half an inch to an inch across make up three-fourths of the rock. Quartz is abundant in the form of small glassy grains. The dark colored constituents are scattered grains of hornblende, biotite, and magnetite.

Another outcrop of pink granite occurs in NE¼ NW¼ Sec. 30, T. 123 N., R. 28 W. (St. Augusta Twp.). This outcrop is close to the road, where it rises about three feet above the surface over an area 135 feet long and 100 feet wide. The rock is a coarse-grained biotite granite of the Rockville type. Surface joints are spaced from 8 to 12 feet apart and strike N. 78° E. and N. 25° W. Four narrow dikes cut the eastern part of the outcrop. They are composed of large quartz crystals and grains of feldspar that interlock with the walls of the dike so that their borders are indistinct. One diabase dike of unusual composition crosses the outcrop with an N. 65° E. trend. It is a quartz diabase porphyry, containing many large crystals of quartz and feldspar.

The rock at this outcrop is less promising for high-grade building and monumental stone than that in Section 19 of the same township.

Several undeveloped exposures of excellent pink granite are located to the south of the John Clark Company's quarry at Rockville. These areas have been leased and will be developed when the demand for more stone of the Rockville type warrants further expansion of the industry in that region.

St. Cloud Red Granite

The red granite outcrops are most abundant throughout western St. Cloud Twp.—T. 124 N., R. 28 W. In Sections 8, 17, 18, 19, and 20 the exposures are almost entirely of red granite, and in Sections 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 the Mississippi River, the largest exposure being in Section 17, Haven Twp., Sherburne County. Other outcrops, some of considerable size, appear in western Benton County.

The red granite of the St. Cloud region is a medium- to coarse-grained rock (see Plate 2), the feldspar grains averaging about a quarter of an inch in diameter. The chief minerals are feldspar and quartz, with minor amounts of black hornblende and biotite. Red or pink feldspars constitute about 75 per cent of the rock and give it its characteristic red color. The quartz occurs as coarse glassy grains.

An average of the analyses of three typical St. Cloud Red granites made by G. H. Hammond, W. W. Willard, and F. F. Grout is given below: *

* Bowles, *op. cit.*, p. 126.

SiO_2	71.17	K_2O	4.33
Al_2O_3	13.30	H_2O	0.64
Fe_2O_3	3.52	CO_2	0.21
MgO	0.30	TiO_2	0.23
CaO	1.56	P_2O_5	0.23
Na_2O	3.85		

Physical tests of St. Cloud Red granite show the following results:

Crushing strength *	
First crack	9,733 pounds per square inch
Final collapse	19,101 pounds per square inch
Modulus of rupture *	2,291 pounds per square inch
True specific gravity *	2,643
Pore space †	0.32 per cent
Weight †	164.6 pounds per cubic foot

The granite is marketed under a variety of different trade names, such as "Indian Red," "Rose Red," "Melrose Red," "North Star Red," "Ruby Red," "Mahogany Red," "Standard Red," etc. Most of the rock is used for monumental purposes, but some architectural stone is also fabricated.

Many of the quarries that were once prominent are now inactive. Only those that are now in operation and a few of the more prominent inactive quarries are described in this report.

Empire Quarrying Company quarries.‡—The Empire Quarrying Company produces Rose Red granite. Its properties are located in NE¼ SE¼ Sec. 19, T. 124 N., R. 28 W. (St. Cloud Twp.). Some of the land extends eastward into Section 20. On this property the rock crops out as 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. 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.

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 ¼ of an inch across consists of clear quartz and black mica with no feldspar.

On the same rock dome, about 60 rods southeast of this quarry, another excavation has been opened. 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, some grains being clear and others smoky. Joints, which are rather uneven, strike N. 5° W. and N. 87° E., 2 to 12 feet apart. Sheeting planes are

* Tests at quarry of the Melrose Granite Company.
† Tests at the J. B. Robinson Quarry.
‡ Abstracted from Bowles, *op. cit.*, p. 89.

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 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.

Some imperfections in the form of inclusions and "green hair lines" occur in the rock. These, however, are confined to limited areas and can be avoided in the quarry operations.

Transportation facilities are ideal. A spur of the Great Northern Railway passes so near the pit that the quarry derricks can load directly on to the cars. Most of the rock is quarried in blocks of the size suitable for monuments.

Granite City Granite Company quarry.—The Granite City Granite Company operates a quarry in red granite west of Waite Park in Sec. 18, T. 124 N., R. 23 W. Although the color of this rock is normal for its type, the texture is slightly coarser than typical St. Cloud Red. Variations in the color and texture of the rock cause much waste, and huge piles of riprap have accumulated.

Both the outcrops and the quarry show an unusual number of fine-grained black dikes, most of which are vertical. The dikes range in width from 2 to 18 inches. Some of the dikes show chilled contacts. Pegmatite stringers occur both in the granite and in the larger basalt dikes.

Two joint systems are prominent. One system strikes N. 80° W. with joints spaced about 4 to 6 feet apart. The basalt dikes run more or less parallel to this joint system. The other system trends N. 5° W., and the joints vary considerably in their spacing. The quarry faces show blocks approximately 4 feet wide along the latter joint system.

At the time the quarry was examined, a ridge of closely jointed rock cut by dikes extended through the center of the excavation. The east pit was about 40 feet below the ground surface and the west pit was about 60 feet deep. The entire quarry was 250 feet long in an east-west direction and about 200 feet wide. An overburden of glacial drift ranged up to 8 feet in depth, although in some places the rock was free of overburden.

The Melrose Granite Company quarries.—The Melrose Granite Company (see Figure 43) formerly operated a number of quarries in red granite in Secs. 17, 18, 19, and 20, T. 124 N., R. 28 W. The more recent developments are in NW¼ SW¼ Sec. 20 and in NW¼ NE¼ Sec. 19. The rock in Section 20 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. Clear transparent quartz is prominent, and hornblende is present in small amounts. The feldspars in the rock show considerable alteration.

Jointing is somewhat irregular. The open joints trend 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 some places are close together. They permit water percolation with consequent reddish stains. Sheeting planes are uneven.

The quarry in NW¼ NE¼ Sec. 19 is in a granite of excellent quality. The rock is a medium-grained red hornblende granite. Feldspars are

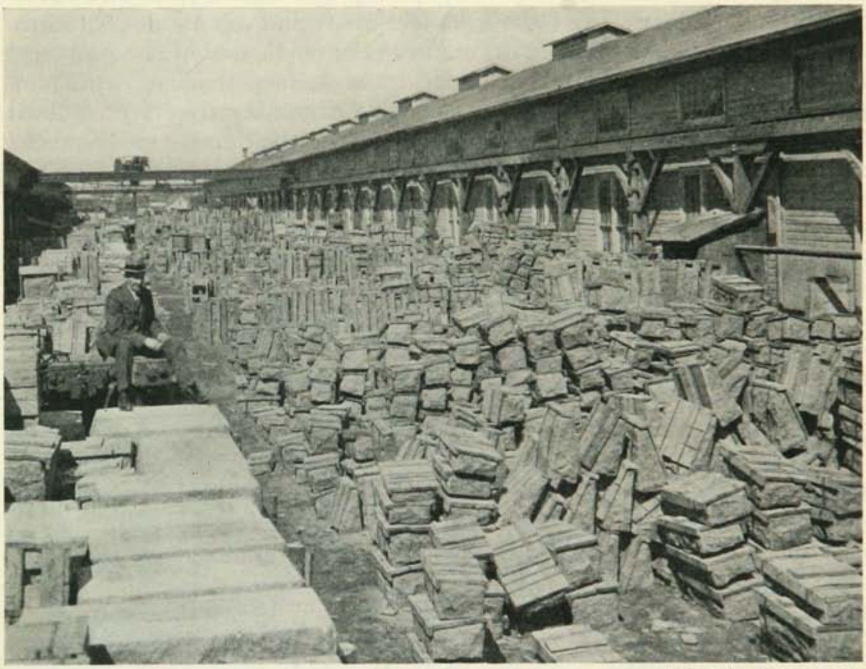


Photo by Guy's Studio

FIGURE 43. — The shipping yard of the Melrose Granite Company at St. Cloud.

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 dip about 10° northwest. This northwestward dip of the sheeting planes is toward the front of the excavation, and thus aids greatly in the removal of blocks. With the exception of one small diabase dike trending N. 51° E., no defects were observed.

North Star Granite Company quarries. — The red granite quarries of the North Star Granite Company are located in Secs. 17 and 19, T. 124

N., R. 28 W. (St. Cloud Twp.). The quarries in Section 17 were opened by Simmers and Campbell, pioneer granite workers of the St. Cloud area. Some of the old excavations now abandoned and partly full of water are nearly 100 feet deep. The rock crops out in a glaciated dome about 50 feet above the general level of the region. It is a hornblende-biotite granite, predominantly orthoclase.

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

Transportation is facilitated by a siding of the Great Northern Railway.

The property in SE¼ Sec. 19, T. 124 N., R. 28 W. was opened by the Minnesota Granite Company. In 1906 it was acquired by the Frich and Borwick Granite Company. The North Star Granite Company now operates in this area and markets its product under the trade name "Indian Red."

The rock is a red hornblende granite of uniform texture and attractive appearance. It is deeper red in color toward 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 of orthoclase (present in abundance), quartz, microcline, biotite, magnetite, and apatite. Quartz is more plentiful than in the St. Cloud Gray granite, though in other respects the two rocks are markedly similar. Several smaller inclusions of the same types of gray rock may be seen in the quarry walls.

Pyramid Granite Company quarry.—The quarry of the Pyramid Granite Company is in Sec. 20, T. 124 N., R. 28 W. Although most of the rock is red granite, abundant gray granite is present along the west side of the quarry. Because of the presence of both red and gray granites, much of the rock contains hair lines and color streaks. The rock with these imperfections is quarried only in order to give access to marketable stock.

There are two joint systems, trending north-south and east-west, and rectangular blocks are therefore available. This relation is used to advantage along the east side of the quarry, where by the aid of sheeting, ledge levels are maintained for operation. Stock blocks are broken from the blasted ledge by plugs and feathers. Elsewhere in the quarry, blasting yields blocks of irregular shape which are then trimmed for dimensional stock.

Simmers and Sons quarry. — The Simmers and Sons quarry is located in Sec. 20, T. 124 N., R. 28 W. It is quarried mainly for monumental stock, and as in other quarries in which this rock is produced there is much waste due to variation in color.

Prominent joints trend N. 60–75° W. and show no uniformity of spacing, although usually they are widely separated (approximately 8 feet). Secondary joints, very irregularly spaced, are present in a north-south direction. Sheeting is present at the west end of the present excavation and yields ledges 3 to 5 feet thick. There are a few prominent basalt dikes, all of which are steeply inclined to the south.

FIGURE 44. — Quarry of the Universal Granite Company in red granite at St. Cloud. The left wall is a basalt dike.

At one place along the north wall quarrying operations have exposed a mass of gray granite. The contact of the granites is sharp and straight and shows no offshoots that would indicate the age relationships of the two rocks. Both the red and the gray granite, however, are cut by a dike of basalt. Glacial drift 2 to 20 feet thick is present as an overburden.

Universal Granite Company quarry.—The quarry of the Universal Granite Company is located in Sec. 20, T. 124 N., R. 28 W. It is unusual in shape, having four walls that are straight and nearly vertical. (See Figure 44.) Quarry operations have extended downward rather than laterally, and consequently the quarry is approximately 100 feet deep. The rock is a red granite, moderately uniform in color and in texture.

Prominent joints with an average spacing of 4 to 5 feet trend N. 75°–85° E. Other joints are N. 10° E. to N. 10° W. These are spaced about 5 feet apart on the average, although distances of from 2 to 18 inches are not uncommon. A well-developed rift and grain are present, and account for the smooth, straight quarry faces. On the south side operations had been discontinued at the time of observation along a basalt dike about 10 inches thick.

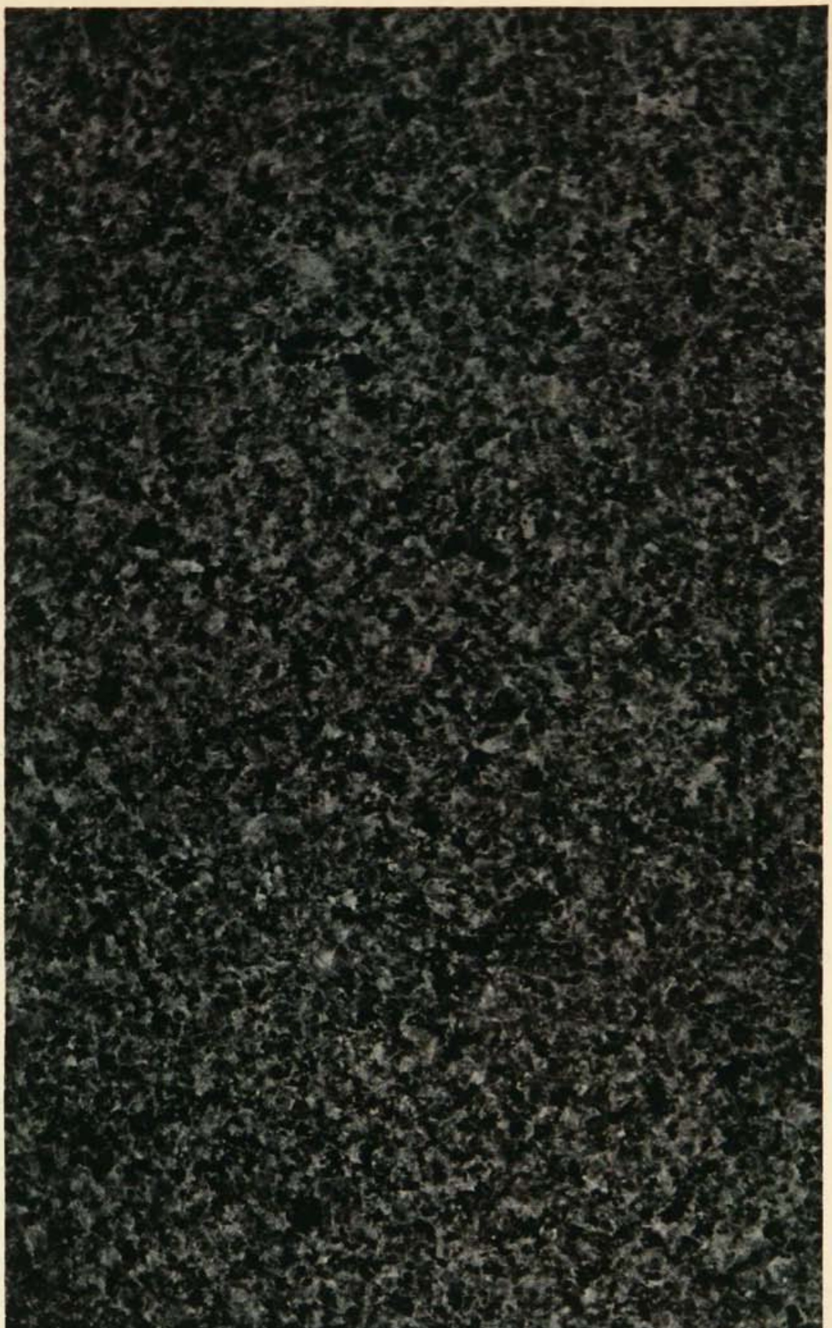
The east end of the quarry is in an outcrop surface, but the glacial drift overburden increases in thickness toward the west to approximately 20 feet.

St. Cloud Gray Granite

The most extensive outcrops of gray granite are in Secs. 21 and 28, T. 124 N., R. 28 W. (St. Cloud Twp., Stearns County). There are a great number of smaller exposures in Sections 29, 30, 32, and 33 of the same township, but these are all more or less intimately associated with red granite. East of St. Cloud in Sherburne County numerous outcrops occur in Secs. 6 and 7, T. 35 N., R. 30 W. (Haven Twp.), and isolated outcrops appear in western Benton County from Sauk Rapids to Watab.

The gray granite of the St. Cloud district is marketed under a variety of trade names, such as "Reformatory Gray," "Pioneer Dark Gray," "Minnesota Dark Gray," "St. Cloud Gray," "Crystal Gray," etc. (See Plate 3.) It is finer grained than the red. The feldspars average about one-eighth to three-sixteenths of an inch long. The minerals that may be recognized in the hand specimen are gray feldspars, black hornblende or mica, and colorless quartz. In some regions quartz is more abundant than hornblende, but it is never very prominent. The rock owes its color to the gray feldspars and associated black minerals. In some localities part of the feldspar is pale pink. Under the microscope both orthoclase and plagioclase feldspar are seen to be present. The rock is a monzonite, therefore, rather than a granite.

An analysis by F. F. Grout of gray granite from NE¼ Sec. 28, T. 124 N., R. 28 W., shows the following chemical composition:



Courtesy Security Printing Co., St. Cloud

PLATE 3.—DARK GRAY ST. CLOUD GRANITE

SiO_2	64.40	H_2O (below 100° C.)	0.07
Al_2O_3	14.93	CO_2	0.18
Fe_2O_3	1.63	TiO_2	0.57
FeO	3.13	ZrO_2	0.07
MgO	3.05	P_2O_5	0.57
CaO	4.18	S	0.12
Na_2O	3.31	MnO	0.09
K_2O	3.95	BaO	0.05
H_2O (above 100° C.)	0.15	Total	99.45

Physical tests on a sample from NE¼ SE¼ Sec. 21 show that under crushing strain the first crack came at 15,080 pounds per square inch and final collapse at 21,000 pounds per square inch. Under transverse breaking stress the modulus of rupture is 2,979 pounds per square inch. The specific gravity is 2.761, pore space 0.37 per cent, and weight per cubic foot, dry, 171.9 pounds. A sample of gray granite from East St. Cloud had a crushing strength of 16,996 pounds per square inch.

Scores of quarries that were formerly active in the areas of gray granite have been abandoned entirely or are temporarily inactive. Recent developments have opened a number of new quarries about a mile south of the region where much of the St. Cloud Gray was formerly quarried. The new operations are in Secs. 33 and 34, T. 124 N., R. 28 W. The quarries are close together and the geological conditions are similar.

Melrose Granite Company quarry.—The new quarry in gray granite of the Melrose Granite Company is located in NW¼ Sec. 34, T. 124 N., R. 28 W. When visited in 1932 the dimensions of the quarry were 500 by 300 by 70 feet. The major joints in the rocks strike north-south. They extend to varying depths and their spacing is therefore very irregular. Some sheeting occurs to a depth of 25 feet, but below that depth blasting is required to loosen the blocks of rock. The rock is moderately uniform in color and texture. Some hair lines are present, and locally the rock is discolored by alteration along joints. These imperfections result in considerable waste.

Building stone and monumental stock is removed by the plug and feather method. The quarried blocks are hauled by truck to the company's finishing plant in St. Cloud.

The Melrose Granite Company also operates a quarry in gray granite in the E½ SE¼ Sec. 21, St. Cloud Twp. This quarry was opened in 1910 and much rock has been removed. It is hornblende granite, consisting chiefly of gray feldspar, prominent hornblende, and blue quartz in scattered grains. A few grains of pyrite are visible, confined mainly to the walls of seams. A microscopic study of a typical specimen shows the minerals present, in order of abundance, to be orthoclase, microcline, quartz, hornblende, mica, magnetite, and sphene. The rock is uniform, medium grained, and of attractive color.

At the south end of the quarry the rock outcrops at the surface, and at the north end the removal of from 6 to 10 feet of soil is necessary. Where it is exposed at the surface the rock is stained and partly decayed or shattered to a depth of from 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 from 4 to 6 feet apart. A few minor joints cross the major joints at acute angles. The rock splits easily and is suitable 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.

FIGURE 45. — The west quarry face of the quarry of the Royal Granite Company near St. Cloud. Two joint systems cut the rock at approximately right angles.

North Star Granite Company quarry. — The gray granite quarry of the North Star Granite Company is located in NE¼ Sec. 33, T. 124 N., R. 28 W. Here the north-south jointing system is well developed, but the joints are spaced sufficiently far apart to permit the removal of large blocks of stone. Sheeting planes were observed in the upper 20 feet of the quarry wall. From the top downward they were spaced the following number of feet apart: 5, 1, 1½, 7, 3.

A quarry bar has been installed and some of the rock has been cut with drifters. Most of the excavations, however, are done by ordinary blasting methods. The rock is hauled by truck to the company's finishing plant in St. Cloud.

Royal Granite Company quarry. — The new quarry of the Royal Granite Company in gray granite (see Figure 45) is located in SW¼ NW¼ Sec. 34, T. 124 N., R. 28 W. When visited in 1932, the quarry was 200 feet long, 190 feet wide, and 35 feet deep. Two joint systems cut the rock at approximately right angles. One trends N. 80° E. and the other nearly north-south. The latter system is poorly developed. Sheeting was observed in the upper part of the quarry wall and yielded ledges from 1½ to 2 feet in thickness.

The rock is very uniform in color and texture. Scattered imperfections such as segregations, inclusions, stringers, and a few red granite dikes were noted, but they appear only in a small percentage of the rock. Some building stone blocks were being hammered and cut at the quarry but most of the stock is hauled to St. Cloud for fabrication.

Pyramid Granite Company's "Crystal Gray" quarry.—The Pyramid Granite Company has opened a quarry on an outcrop near the Sauk River in Sec. 27, T. 214 N., R. 29 W., about 8 miles southwest of St. Cloud. The rock is coarse grained and porphyritic in texture, similar to Rockville Pink. It differs from Rockville granite, however, in that its color is dominantly gray. Both phenocrysts and matrix are of the same pinkish-gray color. Some have a greenish-gray tint. A few large blue quartz grains are present also. Because of the large feldspar phenocrysts the stone is sold under the trade name "Crystal Gray." Both rough and finished surfaces have a pleasing appearance.

This quarry, when examined in 1932, was a pit 150 feet long, 125 feet wide, and 40 feet deep. The north face of the quarry showed severe decomposition to a depth of about 20 feet, and elsewhere in the quarry, stains were present along all the joints and sheets. The stains were observed even though the joints and seams are not actually open. Joints are too widely spaced to control operations, although sheets are spaced from 3 to 5 feet apart and may be of considerable aid. Imperfections observed were green stringers and hair lines, coarse feldspar masses, and black and green schist inclusions. These are not abundant, however, and by careful selection good blocks of considerable size may be obtained.

The stone is a new type for the St. Cloud district. Because of its coarse texture it should find a ready market in designs in which variations in texture are desired.

Robert Graham Company quarry.—The quarry of the Graham Company is located in NE¼ SE¼ Sec. 21, T. 124 N., R. 28 W. The rock is an even-grained quartz diorite in which the feldspars are dominantly gray with some grains showing a pale pink color. Quartz is not abundant, but a few relatively large grains are present. Some of the grains are blue. Hornblende is the dominant dark mineral. The other dark colored constituents are biotite and magnetite. All the dark minerals are fine grained and evenly distributed, giving the rock a very uniform texture.

The major joints trend north and east, and are 6 to 20 feet apart. Sheeting planes are poorly developed. In the quarry wall the rock is exceptionally uniform and free of imperfections. A pronounced rift and run facilitates cutting for paving blocks and small blocks for other structural purposes.

Granite City Granite Company quarry.—The gray granite quarry of the Granite City Granite Company is located in Sec. 27, T. 124 N., R.

28 W. The granite is cut by two vertical joint systems which trend N. 80° E. and N. 10° W., respectively. Sheeting is conspicuously developed and is spaced at 2- to 10-foot intervals. The joints and sheets aid in the quarrying of large symmetrical blocks. Because of the well-developed joints the quarry faces are moderately smooth and regular. The granite is cut by two basalt dikes 4 and 12 inches wide which dip steeply toward the south. These dikes as well as numerous red streaks, hair lines, and color variations are culled out in quarrying.

Plachecki Brothers' Quarry.—The Plachecki Brothers operate a gray granite quarry in SW¼ SE¼ Sec. 21, T. 124 N., R. 28 W. The rock is made up chiefly of gray feldspar crystals, some of which show distinct striations, but it contains a few reddish feldspars, which give it a faint red tinge when observed closely. Scattered grains of blue quartz are a rather unusual feature of the rock. Hornblende and biotite constitute the darker portion.

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.

Minnesota State Reformatory quarries.—The land owned by the State Reformatory is in NE¼ Sec. 7 and SE¼ Sec. 6, T. 35 N., R. 30 W. (Haven Twp., Sherburne County). Quarrying operations by the inmates began in 1889 and an number of large pits have been excavated.

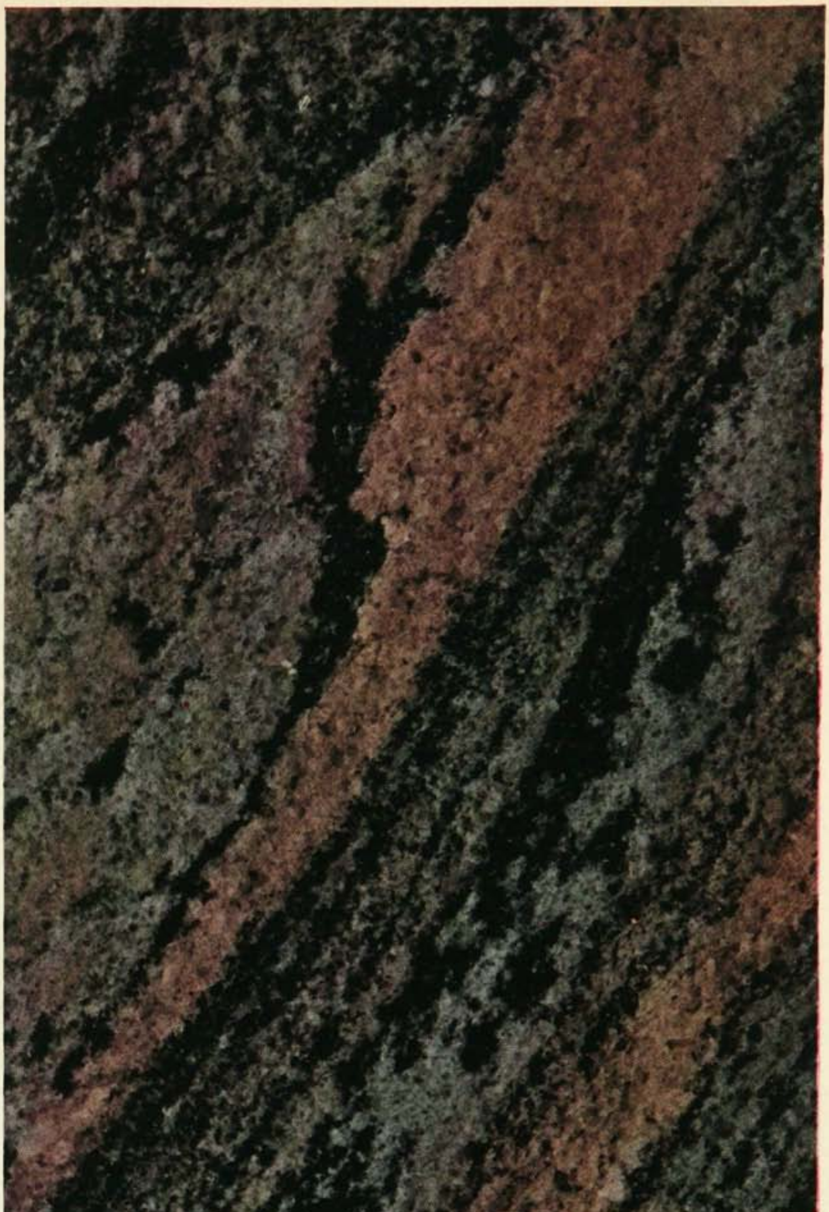
The rock, commonly known as "Reformatory Gray" granite, is a medium-grained quartz monzonite consisting of gray and slightly pink feldspars, black hornblende, biotite, and a small amount of quartz. The rock is uniform in color and texture and shows but slight alteration when subjected to weathering.

At the south quarry within the walls the major joints strike N. 88° E. and N. 22° E. They are 3 to 14 feet apart. At the pits farther north the major joints trend N. 88° W. and a system of secondary joints strikes N. 5° E. Sheeting is poorly developed. A few segregations and inclusions of black minerals are encountered, and white and red aplite dikes from less than an inch to 2 inches in thickness are also present.

The chief output is building blocks and crushed stone. Formerly several hundred carloads of building blocks were marketed annually. At the present time, however, all the stone is being used for the construction of buildings within the Reformatory wall.

Much stone was used in constructing the Reformatory buildings and wall. The wall is 4 feet thick at the base, 2½ feet thick at the top, 22½ feet high, and more than a mile long. A huge water tower 30 feet across at the base and 115 feet high is built of the same stone.

Inactive and abandoned quarries.—In addition to the quarries described above, there are a number in this region that are no longer operated. A list of such quarries is given on page 87.



Courtesy Security Printing Co., St. Cloud

PLATE 4. — VARIEGATED MORTON GRANITE GNEISS

INACTIVE AND ABANDONED QUARRIES IN THE ST. CLOUD REGION

STEARNS COUNTY

T. 126 N., R. 35 W., SW¼ NW¼ Sec. 17, epidote granite. Bowles,* p. 75.
T. 125 N., R. 28 W., Sec. 17, near middle of east side, red granite. Bowles, p. 75.
T. 125 N., R. 28 W., SE¼ NW¼ Sec. 21, porphyritic granite. Bowles, p. 76.
T. 125 N., R. 29 W., SE¼ Sec. 12, gabbro. Bowles, p. 116.
T. 125 N., R. 29 W., NE¼ Sec. 13, gabbro. Bowles, p. 116.
T. 124 N., R. 28 W., W½ SW¼ Sec. 8, red and gray granite. Bowles, p. 85.
T. 124 N., R. 28 W., NE¼ SE¼ Sec. 18, red granite. Bowles, p. 92.
T. 124 N., R. 28 W., SE¼ NE¼, Sec. 19, red granite. Bowles, p. 93.
T. 124 N., R. 28 W., W½ SE¼ Sec. 20, red granite. Bowles, p. 108.
T. 124 N., R. 28 W., SW¼ SE¼ Sec. 21, gray granite. Bowles, p. 101.
T. 124 N., R. 28 W., SE¼ SW¼ Sec. 21, gray granite. Bowles, p. 105.
T. 124 N., R. 28 W., SE¼ SE¼ Sec. 27, gray granite. Bowles, p. 87.
T. 124 N., R. 28 W., SW¼ SW¼ Sec. 28, gray granite. Bowles, p. 92.
T. 124 N., R. 28 W., NW¼ NE¼ Sec. 28, gray granite. Bowles, p. 98.
T. 124 N., R. 28 W., NE¼ NW¼ Sec. 28, gray granite. Winchell,† 2:456.
T. 124 N., R. 28 W., NE¼ Sec. 29, red granite. Winchell, 2:456.
T. 124 N., R. 28 W., NE¼ NE¼ Sec. 30, red granite. Bowles, p. 92.
T. 124 N., R. 28 W., SW¼ NE¼ Sec. 32, red granite. Bowles, p. 101.
T. 124 N., R. 28 W., NW¼ NW¼ Sec. 33, gray granite. Bowles, p. 88.
T. 124 N., R. 28 W., NW¼ NW¼ Sec. 33, diorite. Bowles, p. 90.
T. 123 N., R. 30 W., SE¼ Sec. 19, coarse granite. Winchell, 2:454.
T. 123 N., R. 30 W., NE¼ Sec. 22, red granite. Winchell, 2:454.

BENTON COUNTY

T. 37 N., R. 31 W., Sec. 35, light gray granite. Bowles, p. 135.
T. 37 N., R. 31 W., NW¼ Sec. 35, gray granite. Winchell, 2:434.
T. 36 N., R. 30 W., E½ SW¼ Sec. 31, red granite. Bowles, p. 125.
T. 36 N., R. 31 W., SE¼ SE¼ Sec. 11, red granite. Bowles, p. 126.
T. 36 N., R. 31 W., NE¼ NW¼ Sec. 11, red granite. Winchell, 2:434.
T. 36 N., R. 31 W., N½ NE¼ Sec. 11, red granite. Winchell, 2:434.
T. 36 N., R. 31 W., NE¼ Sec. 14, gray granite. Winchell, 2:434.

SHERBURNE COUNTY

T. 35 N., R. 30 W., SW¼ Sec. 17, gray to pink monzonite. Bowles, p. 119.
T. 35 N., R. 30 W., NE¼ Sec. 7, gray granite. Bowles, p. 121.
T. 35 N., R. 30 W., NE¼ SW¼ Sec. 6, gray granite. Bowles, p. 123.
T. 35 N., R. 30 W., NW¼ SW¼ Sec. 6, gray granite. Bowles, p. 123.

THE MINNESOTA VALLEY REGION

From New Ulm to Ortonville a number of different types of crystalline rocks crop out in or near the Minnesota Valley. Most of the outcrops were exposed by the erosive action of the glacial River Warren, which during the last stages of the glacial period reached such proportions that it almost filled the entire valley. This enormous stream with its immense volume of water derived from the melting ice sheet swept away all decayed and weathered rock débris, leaving fresh rock at the surface on the floor of the valley. The geologic work of the stream had a direct bearing on the availability of rocks for quarrying purposes in the Minnesota River Valley today.

Over this entire area the ancient crystalline rocks were covered by

* *The Structural and Ornamental Stones of Minnesota* (United States Geological Survey Bulletin 663, 1918).

† *The Geology of Minnesota* (Final Report of the Minnesota Geological and Natural History Survey, St. Paul, 1884–1901).

Cretaceous sediments that protected them from the scouring action of the ice sheet. In the Minnesota Valley, however, all the Cretaceous sedimentary beds and the decomposed upper surface of the granite were eroded away, leaving a surface of fresh rock. Figure 46 shows the relations of the rock at the quarries to that on both sides of the valley.

The types of rock include the granites known as "Rainbow," "Oriental," "Iridescent," and "Antique," quarried in the vicinity of Morton; a fine-grained black diabase near Franklin; a variety of pink granite ("Sacred Heart") between the towns of Echo and Belview; "White Oriental" southwest of Seaforth; and "Ortonville Ruby Red" near Odessa.

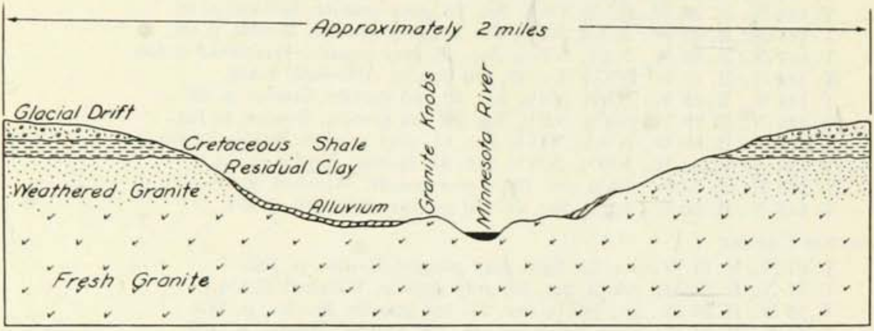


FIGURE 46.— A generalized cross-section of the valley of the Minnesota River at Morton, showing granite hills that have been exposed by stream erosion.

Favorable prospects occur in a red granite south of Wood Lake and a pink gneiss south of Montevideo. All these rock types belong to the Archean group, the complexity of which has prohibited determination of their relations to each other.

Although outcrops are numerous in this region, the quarry operations are somewhat localized. These will be discussed as areas within the region.

MORTON–REDWOOD FALLS AREA

In the Morton area huge mounds or dome-shaped outcrops of granite gneiss are seen in the valley. (See Figure 47.) The tops of these mounds are from 75 to 100 feet above the level of the present Minnesota River. For the most part their upper surfaces are smooth and rounded, but on the top of the highest hill grooves and potholes made by running water still exist. These facts indicate that the highest points in the valley were once under water.

The rock is a pink and black biotite granite gneiss with contorted laminations or bands. Although it is distinctly gneissic, the rock is very firm and does not permit ready percolation of water. In some places it is porphyritic and in others contains pegmatitic dikes and masses that are very coarsely crystalline. A few red dikes are present, but in most cases they do not weaken the rock.

The prominent dome at the margin of the village of Morton has been quarried extensively since 1884. From 1884 to 1887 the Saulpaugh Company employed about three hundred men in its quarries. Subsequently quarrying was carried on by John Anderson until 1908, when the Anderson Granite Company was formed. Stone companies from the St. Cloud

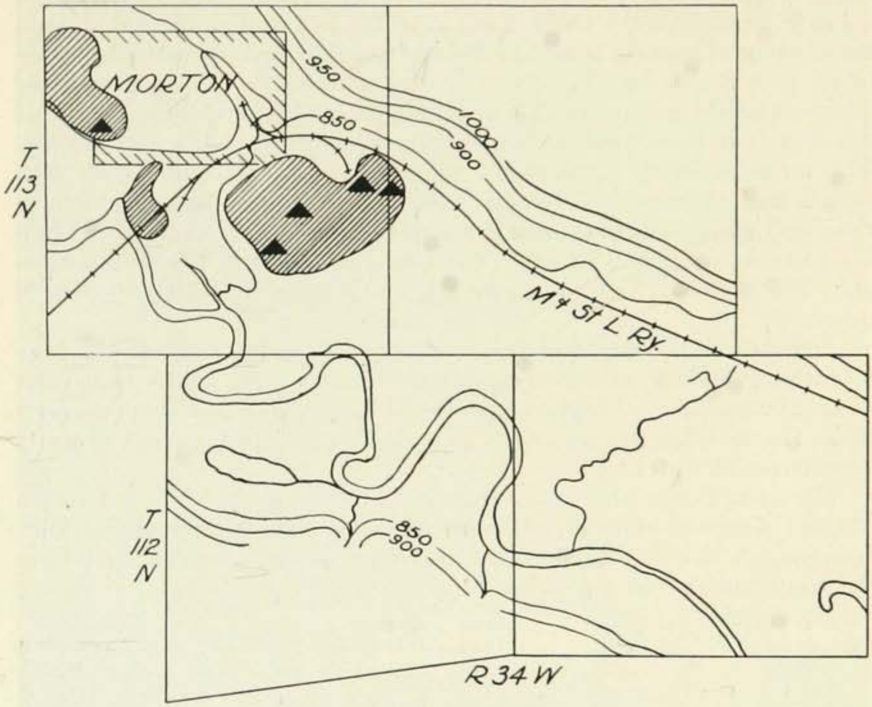


FIGURE 47. — Map showing the occurrence of granite outcrops and the location of quarries in the valley of the Minnesota River near Morton. Redrawn from a survey by United States Army Engineers, 1910.

district later began operations in and near Morton, and most of the rock is at present shipped from the quarries to the stone-cutting plants near St. Cloud for fabrication.

Characteristics of Morton stone. — Morton stone is composed of red feldspars and dark minerals which appear mostly in the form of streaks and bands. The feldspars constitute the larger share of the rock, both orthoclase and plagioclase being abundant. Considerable quartz is also present. The chief dark mineral is biotite, with a small amount of hornblende and a few grains of magnetite.

The rock is distinctive and outstanding. (See Plates 4 and 5 and

Figures 48 and 49.) Because of its attractive color tones and its peculiar wavy veins and swirling figures, the granite has been given a variety of trade names such as "Oriental," "Rainbow," "Tapestry," "Antique," "Imperial," "Variegated," etc. Its variations in color and texture make it especially desirable for facings, columns, and certain types of interior work. It is in demand as a facing for large buildings, for which its variegated coloring is well suited. It has been used as a base course in the Doherty–City Service Building in New York City and the Baker Building in Minneapolis, the Daily News Building in Chicago, the San Juanto Building in Houston, Texas, and many other equally prominent structures. (See Figure 48.) In such base-course finish the stone is commonly quarter-sawed like oak. In this way unique patterns and designs may be developed. It is a "granite" which has the fanciful coloring of marble. This unique coloring lends itself remarkably well to a combination with bronze and copper or with colored terra cotta. Its gradual color transitions and gradations produce attractive patterns where carving or sandblast ornamentation is desired. The stone has recently become fashionable, and because of its great strength and beauty its popularity is well deserved.

Strength.—Physical tests made at the University of Minnesota gave a crushing strength of 20,340 pounds per square inch. Under transverse stress the modulus of rupture was found to be 3,042 pounds per square inch. The rock has low porosity and does not, therefore, permit of ready percolation of water.

Chemical composition.—A chemical analysis made by S. S. Goldich of the University of Minnesota of a composite sample representing fourteen pounds of chip samples taken from quarry walls showed the following constituents:

SiO_2	71.54	K_2O	3.92
Al_2O_3	14.62	H_2O (above 100° C.)	0.30
Fe_2O_3	0.69	H_2O (below 100° C.)	0.02
FeO	1.64	CO_2	0.14
MgO	0.77	TiO_2	0.26
CaO	2.08	P_2O_5	0.10
Na_2O	3.84	MnO	0.04
		Total	99.96

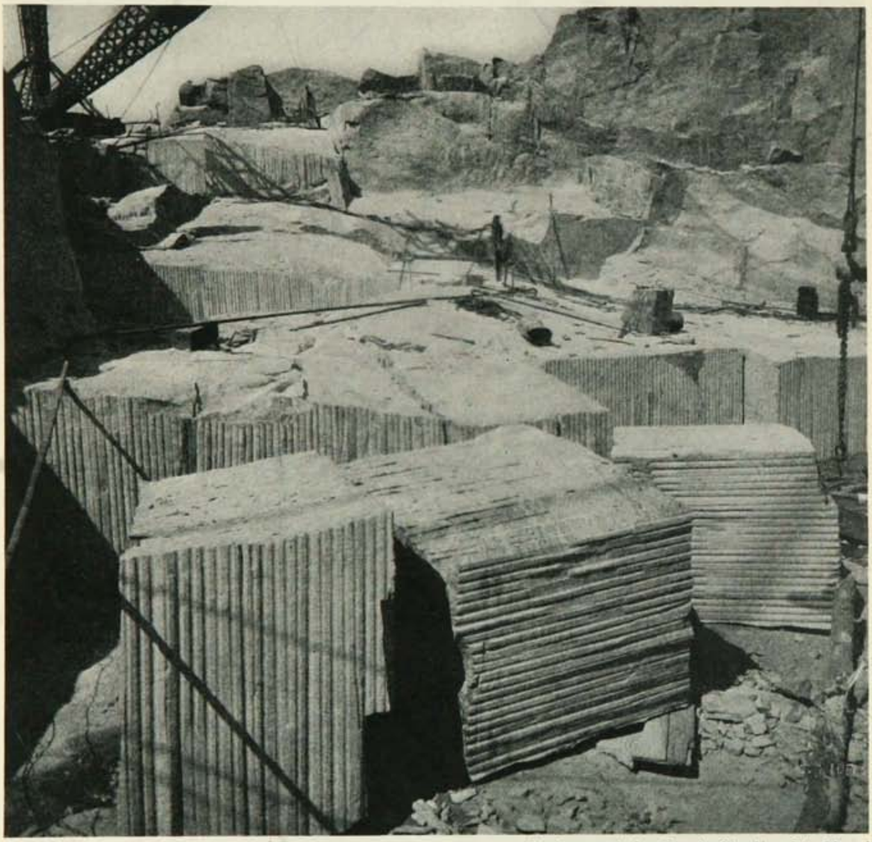
Quarries.—Quarrying conditions are excellent. The bluff is high and for that reason can be worked in shelf quarries. The outward dipping of the sheeting planes not only insures perfect drainage but greatly facilitates the removal of blocks from the quarry. The tracks of the Minneapolis and St. Louis Railroad are only a few rods from the quarries.

Cold Spring Granite Company quarry.—This quarry is probably the most impressive stone operation in the Minnesota Valley area. (See Figure 49.) The general dimensions of the opening are 300 by 125 by 45 feet. The rock is quarried by channeling it into saw blocks 11 feet wide, 9 feet 6 inches high, and long enough to make a carload. Major joints trend north and east, and it is in these directions that the blocks are

Courtesy Cold Spring Granite Co.

FIGURE 48. — Entrance of the David Stott Building, Detroit. Constructed of Morton granite.

channeled. Since sheets are not well developed, ledge surfaces are maintained by horizontal lift holes. The Cold Spring Granite Company has erected the largest boom derrick in the world at this quarry. The mast is 120 feet high, and the swing of the boom describes a circle 200 feet in diameter. It has a hoist that will lift 100 tons with ease, and it is rigged with thirteen $1\frac{1}{2}$-inch cable guys.



Photograph by Guy's Studio, St. Cloud

FIGURE 49. — The quarry of the Cold Spring Granite Company at Morton. Large blocks are removed by means of drifters. Very little blasting is required. The boom derrick, the largest in the world, will lift a hundred tons with ease.

Bohmer and Luckemeyer Company quarry. — This quarry is situated only a short distance to the east of the quarry of the Cold Spring Granite Company, and the two have approximately the same dimensions. The rock is quarried by blasting and then trimmed into stock blocks. In general, the rock is well jointed, although at some places the spacing is too close or too wide. Prominent joints form the north, south, and east faces of the quarry, while operations are continued to the west. Sheeting is moderately well developed and is used as ledge surfaces because the dip is eastward, thereby permitting the blocks to be readily removed.

John Clark Company quarry.—A shelf type of quarry is operated by the John Clark Company of Rockville. It is a shelf on the west side of a rock "knob." The face is approximately 125 feet long and 35 feet high, in an outcrop about 225 feet by 175 feet in area. Because the sheets dip southward, removal of blocks is facilitated by quarrying in a face with a southern exposure. The major joints are north-south and east-west.

Universal Granite Company quarry.—Two openings have been made by the Universal Granite Company in the outcrops northwest of Morton. The older quarry is 100 by 100 by 25 feet and the newer one is 100 by 75 by 25 feet. The locality is somewhat higher above the river flat than the quarries previously mentioned. Outcrops are numerous, indicating a very large area suitable for prospective development. Because of the poorly developed joints and sheets, quarry operations have produced many irregular "shakes," which have caused a rather high percentage of waste rock. Drifters were just starting to work in the older quarry at the time of examination, and these should increase the efficiency of operation. The new quarry is similar to the old in all respects except that the contortion effects of the stone are slightly more pronounced in the new one. The rock in these quarries shows very few schist inclusions or pegmatite veins.

Granite City Company quarry.—Some of the best rock of the Morton district is reported to have come from this quarry. In the summer of 1932 the opening was 75 feet in diameter and contained 18 feet of water. Little observation of actual quarry operation or of stock material was possible. The 30 feet of rock exposed above water level was badly stained along joints and sheets. Sheets were spaced from 2 to 4 feet apart on the average. The rock contained more biotite and hence was generally somewhat darker than that in the quarries previously described.

North Redwood Granite Company quarries.—From two exposures about 100 feet apart in the Minnesota River Valley north of Redwood Falls, the North Redwood Granite Company obtains "greenish-gray granite" and Morton stone. The exposure that yields the Morton stone seems to include the contact of the two types. In the north side of the quarry normal granite is present but toward the south the gneissic appearance becomes more evident until the rock is typically of the Morton phase. Only a few poorly developed north-south joints are present. The "greenish-gray granite" is obtained from residual bowlders in a badly weathered exposure. The rock is altered along joints and sheets, thus allowing easy removal of the masses, which must be subjected to considerable trimming to get satisfactory stock material.

The following tests were recorded by Bowles: true specific gravity, 2.69; pore space, 0.6 per cent; weight per cubic foot, 167.1 pounds; crushing strength, first crack, 12,308 pounds, collapse, 21,236 pounds; modulus of rupture, 4,526 pounds per square inch.

Anderson Company quarry.—South of Franklin in Sec. 9, T. 112 N., R. 33 W., an opening has been made by the Anderson Company in an outcrop of fine-grained diabase (called "black granite"). The outcrop has little relief above the surrounding lowlands, but its general dimensions are 400 by 100 feet. Other outcrops are common near by. The joints and sheets are well developed but spaced much too closely (maximum 2 feet) to permit removal of stone in blocks of marketable size.

The following is a list of some of the prominent buildings in which Morton stone has been installed:

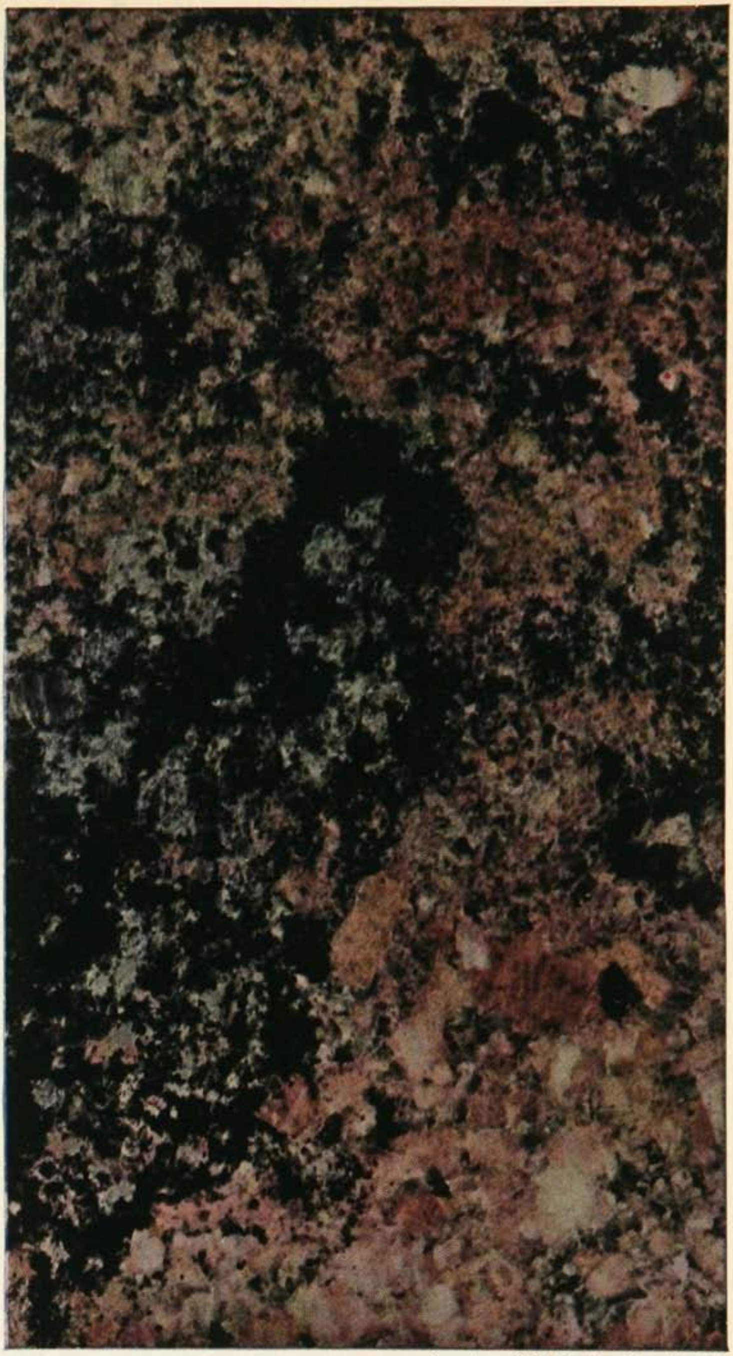
- Cincinnati Telephone Building, Cincinnati
- Dallas National Bank, Dallas, Texas
- Oklahoma Natural Gas Building, Tulsa, Oklahoma
- Dougherty-City Service Building, New York
- Peoples Bank and Trust Company, Passaic, New Jersey
- McGraw-Hill Building, Chicago
- Adler Planetarium, Chicago
- Watts Building, Birmingham, Alabama
- David Stott Building, Detroit
- Baker Building, Minneapolis
- Northwestern Bell Telephone Building, Minneapolis
- Northern States Power Company, St. Paul
- Daily News Building, Chicago
- Mariner Tower, Milwaukee
- San Juanto Building, Houston, Texas
- Hemenway Building, Boston
- Hartford Gas Company, Hartford, Connecticut
- J. E. Simpson Building, Washington, D. C.
- Gas and Light Building, Milwaukee
- Southland Hotel, Norfolk, Virginia
- Pickwick Theater, Park Ridge, Illinois
- Bankers Guarantee Trust Company, Akron, Ohio
- Holy Name Church, Columbus, Ohio
- Saint Mary's Church, Shelby, Ohio
- Saint Basil's Church, Chicago
- Sacred Heart Cathedral, Superior, Wisconsin

THE MONTEVIDEO–SACRED HEART AREA

Southeast of Montevideo in Secs. 19, 20, and 29, T. 117 N., R. 40 W., several rounded knobs and domes of granitic rock occur in the wide valley of the Minnesota River. The outcrop in Section 19, about half a mile south of Montevideo, is a banded red granite gneiss that consists mainly of quartz in clear small grains and of both orthoclase and plagioclase feldspars. The dark mineral is mainly biotite. Several small quarries have been opened in past years, none of which is now being worked. In Sections 20 and 29 the rock is deeply grooved by water channels and potholes. It is a red granite gneiss with distinct gneissic banding.

Seaman Quarry.—A quarry has been opened on the north margin of an outcrop that forms a large hill with an elongation in an east-west direction about 1½ miles southeast of Montevideo in SE¼ Sec. 19, T. 117 N., R. 40 W.

The principal color of the rock is red, but there are black bands of biotite which brings out a gneissic structure. Such structures strike N. 75° E. and dip 85° to the south. There is some tendency toward rifting parallel to the gneissic structure, and the major joints also have the same orientation. Sheeting planes are not well developed, but those that were observed dip northward and are spaced from 2 to 3 feet apart.



Courtesy Cold Spring Granite Co.

PLATE 5. — MORTON GRANITE GNEISS CUT IN THE DIRECTION OF THE GRAIN

Because of black knots of biotite, stains, quartz and aplite veins, pegmatitic areas, and the marked gneissic texture, only a small percentage of the rock is of uniform texture and grade. Some of it is used for monumental purposes. It is also serviceable for foundations and wall rock and for crushed stone.

THE SACRED HEART AREA

About 7 miles south of Sacred Heart quarries are being operated in the granite outcrops of the Minnesota River Valley. (See Figure 50.) The quarries are closely spaced and consequently all produce similar stock, which is used for monumental purposes. Although two granites, a pink and a gray, are present, it is probable that the difference in color simply indicates different phases of the same intrusive, inasmuch as their

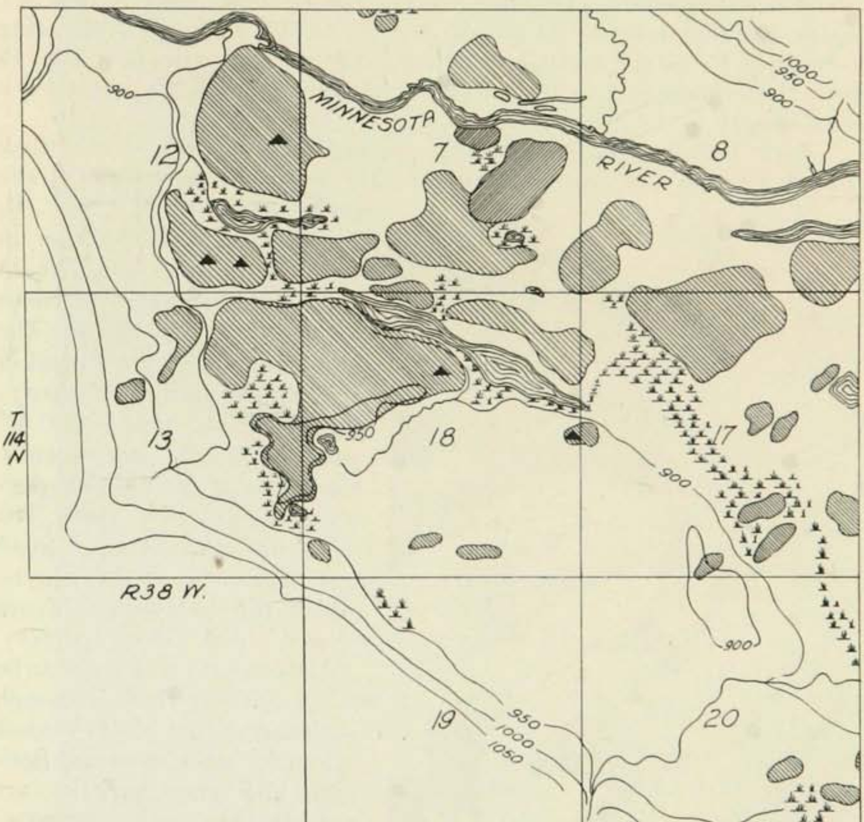


FIGURE 50. — Map showing the occurrence of granite outcrops and the location of quarries in the valley of the Minnesota River south of Sacred Heart. Redrawn from a survey by United States Army Engineers, 1910.

mutual contacts are gradational. Defects of the granite include coarse-grained areas, some pegmatite veins, schist inclusions, dry seams, and, locally, pyrite grains.

Hayquist Quarry.—A quarry in Sec. 18, T. 114 N., R. 37 W., was operated from 1928 to 1930. Jointing and sheeting are well developed, but the joints strike N. 80° W. and N. 45° E., which causes the angle of intersection to be such that much of the rock is wasted in trimming the blocks. The dimensions of the Hayquist quarry are 120 by 120 by 30 feet.

Stam Brothers' Quarry.—Another quarry in Sec. 18, T. 114 N., R. 37 W., was opened in 1929 but inactive in 1931. It was a large contributor to the output of its district, as is shown by its dimensions, 300 by 175 by 50 feet. The pink and gray phases of the granite are present in about equal amounts. The joints are well spaced, being about 6 to 8 feet apart, and they intersect at almost 90° (N. 45° E., N. 50° W.). Sheeting is inclined 15° to the south, and although the spacing varies from 3 to 15 feet, the average is 8 to 10 feet. The topographic relief is suitable for a shelf quarry to the present depth.

Rock Valley Granite Company quarry.—The quarry of the Rock Valley Granite Company (see Figure 51) is the farthest west of the group in Sec. 12, T. 114 N., R. 38 W. It began operation in 1927 and was still active in 1932. The general dimensions are 225 by 100 by 35 feet. The joints and sheets are spaced in a way that facilitates quarrying. The joints trend N. 55° W. and N. 35° E.; consequently the angle of intersection does not cause excessive waste. The joints are spaced from 2 to 10 feet apart, and the sheets, which dip to the south, are spaced about 7 feet apart.

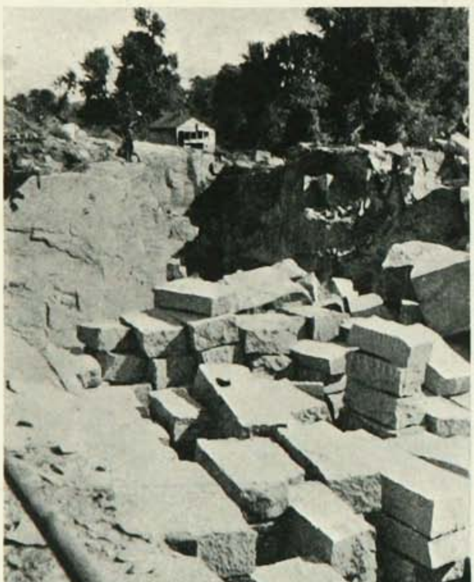


FIGURE 51.—The quarry of the Rock Valley Granite Company south of the village of Sacred Heart in Renville County.

Although the rock seems to be fairly uniform, there is enough variation so that blocks are not sawed for stock material. Both pink and gray varieties are present, but only comparatively small amounts of the gray are used.

Seaforth quarry.—The John Clark Granite Company has a quarry in Sec. 1, T. 111 N., R. 38 W., about three miles southwest of the village of Seaforth. The outcrop is a low, rounded knob. (See Figure 52.) The area exposed measured about 180 by 130 by 12 feet. The joints and sheets are poorly developed but the rock has a tendency to split along the gneissic bands. These bands strike N. 70° E. and are inclined from 30° to 40° to the southeast. In some cases the surfaces along this rift direction are covered with biotite flakes. The proportion of black to white mineral components and the texture of the rock are variable, but such features are not detrimental.

FIGURE 52. — Quarry of the Clark Granite Company near Seaforth. The rock is a light gray biotite granite gneiss.

The rock is a black and white granite gneiss with contorted bands and laminations. (See Figure 53.) Because of its similarity to Morton stone in texture and markings it is sold under the trade name "White Oriental." The tapestry-like pattern is conspicuous on polished surfaces, especially in large panels or on the face of large monuments. It is a very attractive stone and will undoubtedly enjoy a good market for interior and monumental work.

Clark and Anderson Company quarry. — A new development 7 miles south of Wood Lake on the Bode property in Sec. 29, T. 113 N., R. 39 W., has been opened by the Clark and Anderson Company. The rock is a medium-grained red granite, moderately uniform in color and texture. The area exposed, about 200 by 200 feet, shows only one system of major joints. These joints trend N. 60° W. and are exceptionally well spaced, the average being about 6 feet. Development in the northwest portion of the outcrop uncovered a sheet at a depth of 15 feet. The slight rise of the sheet to the southeast will facilitate removal of quarry blocks. Areas of biotite concentration, quartz veins, and coarse-grained feldspars are present as defects but not in sufficient amounts to cause a great deal of trouble.

Echo Granite Company quarry. — A quarry in red granite is operated by the Echo Granite Company about 100 yards east of the Clark and Anderson Quarry. The two quarries have been operating about the same length of time. The Echo quarry is 130 feet long, 65 feet wide, and 25 feet deep. The joint systems trend in the general directions as in the

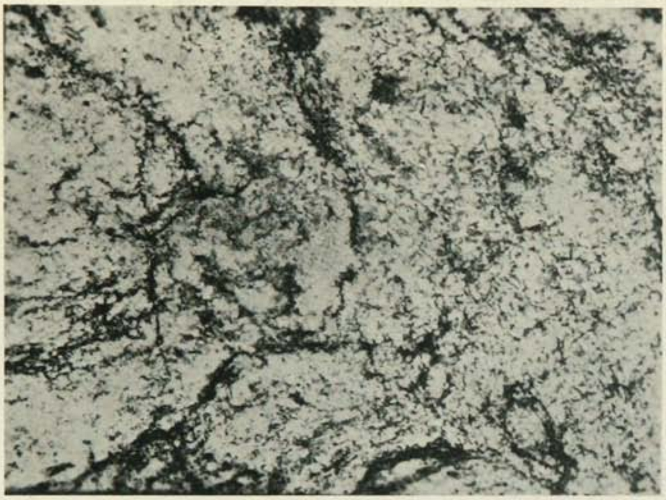


FIGURE 53. — Photograph of a polished surface of Seaforth granite, known as White Oriental granite. Approximately one-fourth natural size.

other quarry but intersect at angles of approximately 80°. Although joints average from 3 to 5 feet apart, some of them are only 6 to 10 inches apart, and consequently increase the percentage of waste. This rock is carefully examined to avoid defects of color, texture, and seams. The sheets are well spaced, being 4 to 6 feet apart, with an inclination to the south. They aid in quarrying operations, which are advancing northward.

View Quarry Company. — The View Quarry Company has a number of openings along a ridge trending northwest-southeast in T. 114, N., R. 38 W. The most recent and only active operation is in a grayish-pink granite in Section 12. Because the lowland to the north furnishes suitable difference of elevation, a shelf quarry may be developed, although sheeting is rather inconspicuous. The major joints strike N. 60° W. and are spaced from 1 to 4 feet apart.

THE GRANITE FALLS AREA

Along the Minnesota River from Granite Falls to about a mile beyond Minnesota Falls, rocks crop out almost continuously 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 but containing biotite and a little quartz. It is very much altered by weathering.

About a quarter of a mile from the station of the Chicago, Milwaukee and St. Paul Railway 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 that was seen in the district around Granite Falls. It is a dark diorite, consisting of hornblende, plagioclase, garnet, small grains of magnetite, and some chlorite. It is less schistose than the rock at Montevideo, and jointing planes are sufficiently spaced to give blocks 3 feet in length. The rock is too dark in color to be attractive for entire structures, but it appears to be substantial for foundation purposes.

Many years ago a small quarry was opened by the Granite Falls Stone Company about half a mile from the Great Northern Railroad where it approaches the 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 the 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 from 1 to 3 feet apart, are commonly so closely spaced that the rock is useless. Firm rock, suitable for ordinary foundation work, may be obtained from the back part of the quarry.

About half a mile south of Granite Falls, in Sec. 4, T. 115 N., R. 39 W., is an area of garnetiferous gabbro. It is not suitable for structural purposes.

Outcrops of granite gneiss are numerous in and about Granite Falls. It was so deeply decomposed that the great glacial river did not completely remove the weathered part as it did at Morton and North Redwood. Post-glacial decomposition has doubtless increased the amount of decay. The chances for finding good rock in this vicinity are not encouraging.

Granite Falls is favorably situated for the production of crushed rock. The Northern States Power Company operates a large power plant at the outskirts of the city, and a smaller plant is owned by the city. The close proximity of rock, power, and railroad transportation is noteworthy.

Ortonville-Odessa Area

From Ortonville southeastward to the neighborhood of Odessa and Correll there are many large areas of granitic rocks (see Figure 54) which rise 30 to 40 feet above the general level of the Minnesota River Valley. The rock is a biotite granite that is somewhat gneissic, but the gneissic texture is not so pronounced as at Montevideo and at Morton. The rock consists of orthoclase, microcline, quartz, and biotite. Microscopic examination shows that the feldspars are intergrown as in microperthite; the

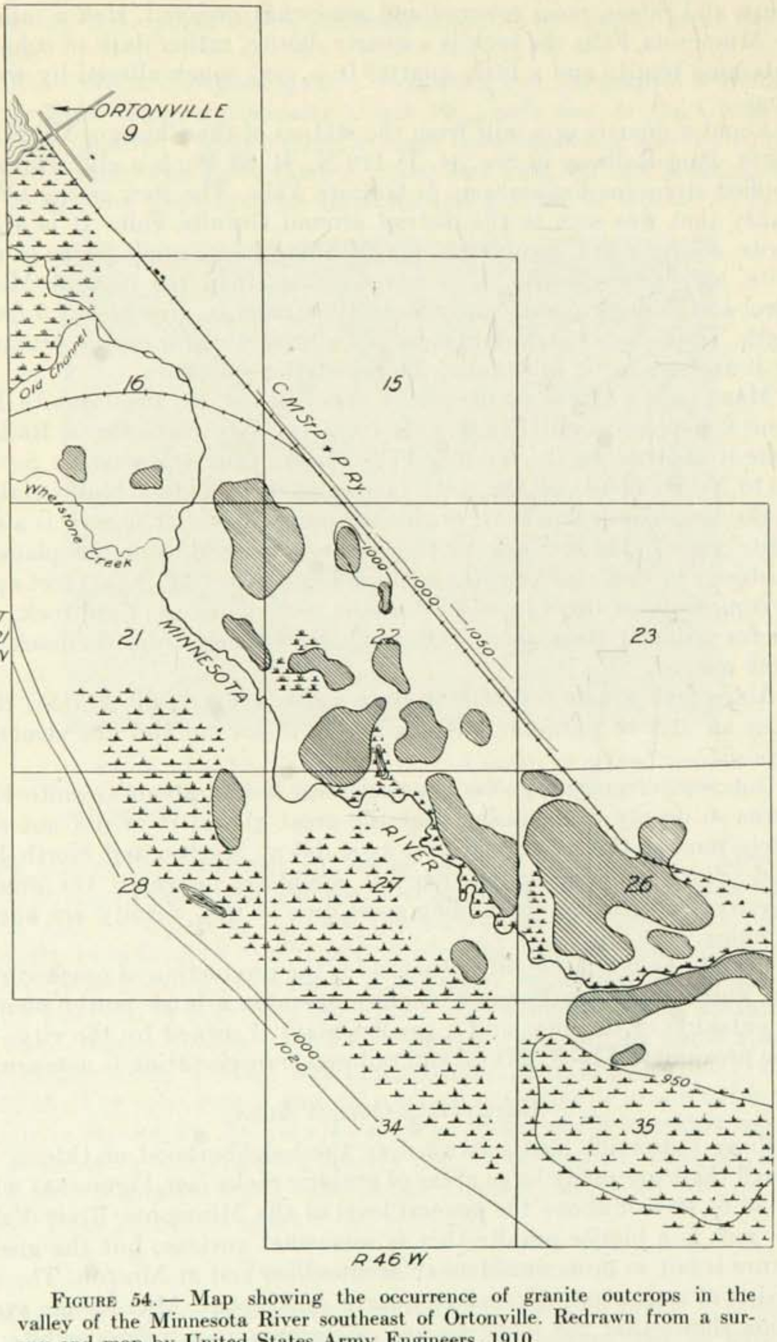


FIGURE 54. — Map showing the occurrence of granite outcrops in the valley of the Minnesota River southeast of Ortonville. Redrawn from a survey and map by United States Army Engineers, 1910.

quartz is abundant and the mica occurs as scattered flakes. The rock is an attractive deep red color, and when polished it is one of the most attractive stones in the state.

Like most others, Ortonville stone has certain defects which must be avoided in the selection of good monumental stone. The chief of these are black mica knots, pegmatite masses, and close jointing. All these defects can be avoided by careful quarry operations.

Several large quarries were formerly operated near Ortonville. The Consolidated Granite Company and the Aberdeen Granite Company were the most active. These companies acquired other smaller quarries, all of which have been abandoned for a number of years. The Johnson and Lindholm Company operates a polishing plant in Ortonville, but most of the stock that is fabricated there is shipped from the quarries near Milbank, South Dakota.

Odessa Quarry.—In 1921 the Johnson and Lindholm Company opened a quarry in red granite about 2 miles south of Odessa in Sec. 32, T. 121 N., R. 45 W. The rock is a mottled red and gray coarse-grained granite in which the feldspar grains average 3/8 to 1/2 an inch in length, although some are 3/4 of an inch long. The usual defects are present in small amounts, but on the whole the rock has good uniformity. The general dimensions of the quarry are 225 by 100 by 45 feet.

In this quarry the blocks are cut by drifters; thus the wide spacing of joints and sheets is used to advantage. Such joints as were observed strike N. 35° W. and N. 80° W. Sheets are steeply inclined 35° north.

By the drifting operation blocks 12 feet wide and 6 feet thick are removed. Proposed uses determine the lengths to which the blocks are cut. Stone from this quarry was used in the Aetna Life Insurance Building in Hartford and in the 21st Street Office Building in New York.

INACTIVE AND ABANDONED QUARRIES IN THE MINNESOTA RIVER VALLEY REGION FROM NEW ULM TO ORTONVILLE

BROWN COUNTY

T. 111 N., R. 32 W., near east line of township, recent calcareous sediment. Winchell,* 1:587.

T. 109 N., R. 35 W., Sec. 25, Cretaceous sandstone. Winchell, 1:587.

REDWOOD COUNTY

Near Redwood Falls in the gorge of the Redwood River, gneiss. Winchell, 1:587.

YELLOW MEDICINE COUNTY

T. 116 N., R. 32 W., Sec. 32, granite gneiss. Bowles,† p. 71.

T. 115 N., R. 39 W., Sec. 4, garnetiferous gabbro. Bowles, p. 71.

CHIPPEWA COUNTY

T. 117 N., R. 40 W., Sec. 19, granite gneiss. Bowles, p. 69.

T. 116 N., R. 39 W., Sec. 34, diorite. Bowles, p. 69.

BIG STONE COUNTY

Seven old quarries in red granite in valley of the Minnesota River near Ortonville. Bowles, p. 68.

* *The Geology of Minnesota* (Final Report of the Minnesota Geological and Natural History Survey, St. Paul, 1884–1901).

† *The Structural and Ornamental Stones of Minnesota* (United States Geological Survey Bulletin 663, 1918).

THE ISLE–WARMAN CREEK REGION

The Isle–Warman Creek region is located in the zone of granite that extends northeastward from St. Cloud across Benton and Mille Lacs counties and includes the northwestern corner of Kanabec County and the southeastern part of Aitkin County. Most of the rock is deeply buried under glacial drift, but locally low dome-shaped masses crop out at the surface. A great variety of different types of granites, syenites, diorites, and hornblendic rocks are found in this zone.

In Mille Lacs County outcrops of red granite occur on the west branch of the Rum River in Secs. 29 and 19, T. 38 N., R. 27 W., about 5 miles west of Milaca.

At the south end of Mille Lacs in NW¼ T. 42 N., R. 26 W., a cut on the Minneapolis, St. Paul and Sault Ste. Marie Railway exposes igneous rocks covered by about 15 feet of drift. Two types, a gray and a black rock, are present. The gray rock appears to be intrusive into the black, though this was not established. The dark rock is a medium-grained mica diorite; the gray appears to be a lighter phase of the same type. It exhibits large flakes of biotite in a finer groundmass of feldspars.

On the upper part of the main branch of the Rum River (East Branch) several outcrops occur in Sec. 18, T. 41 N., R. 26 W.* These include syenite, hornblende rock, gneiss, greenstone, and granite.

In Sec. 29, T. 41 N., R. 26 W., occur outcrops consisting of a medium- to coarse-grained hornblende-biotite granite which is somewhat porphyritic in texture. The rock is cut by fine-grained dikes of red granite. This rock would probably make a good building stone. Exploratory work is recommended.

Cold Spring Granite Company quarry.—A quarry operated by the Cold Spring Granite Company (see Figure 55) is located 5 miles south of Isle in Sec. 2, T. 41 N., R. 25 W. In 1932 the excavation was about 250 feet long, 130 feet wide, and 55 feet deep. Joints and sheets have little influence on the quarry operations, inasmuch as the blocks are cut by drifters. It was observed, however, that there are three prominent sheets in the quarry at its present depth. The sheets dip 10° to 15° westward and are spaced from the top downward at 5 feet, 22 feet, and 27 feet. They are wet seams, and when lift holes are shot near by, the breaks tend to follow them. The major joints trend from due north to 10° west. At some places they are widely spaced (20 ± feet), although they are somewhat closer toward the west end of the quarry. The rift is parallel to this joint system and it is used in determining the length of blocks. The blocks are cut 11 feet wide and 9 feet high; lengths are determined by the desired stock and by the load capacity of equipment. The uniformity of the color and texture is good except for an occasional biotite concentration or a schist inclusion. Many of these can be eliminated during fabrication.

* Winchell and others, *op. cit.*, 2:617.

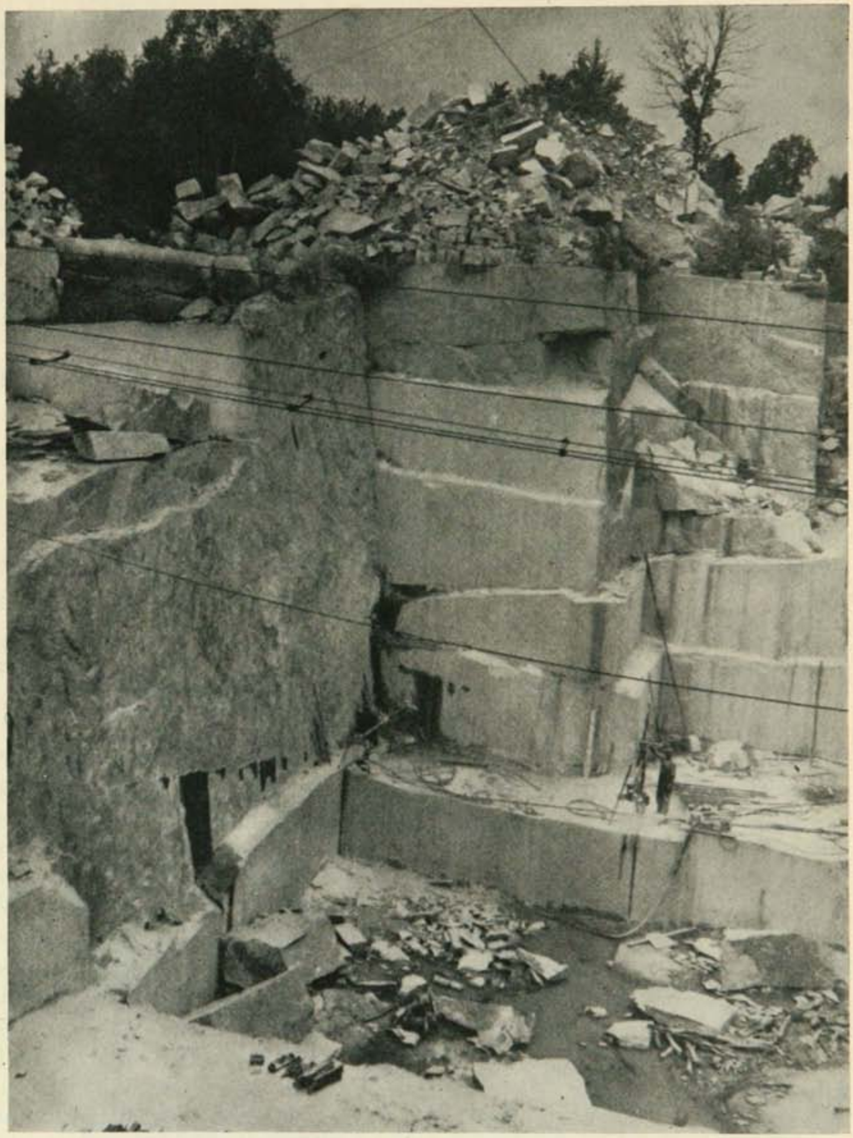


FIGURE 55. — The Isle Quarry of the Cold Spring Granite Company.

The rock is a light gray granite composed of large white feldspar crystals, imbedded in a matrix of colorless quartz, and biotite. The majority of the feldspar grains range from $\frac{1}{4}$ to $\frac{1}{2}$ an inch in length; the quartz grains are about $\frac{1}{16}$ of an inch in diameter; and the biotite occurs as small flakes scattered between the other two minerals. The Isle granite is similar in texture to the Rockville and Cold Spring Pearl Pink granites but differs in the color of the coarse crystals. (See Plates 1, 2, and 6.)

The stone from this quarry is marketed under the trade names "Isle" and "Cold Spring Pearl White" granite. It is adaptable for all types of architectural and memorial purposes. The stone takes an excellent polish. Its porosity is low and consequently it is quite impervious to solutions that produce stains and discolorations. Cut finishes such as sawed, axed, or hammered surfaces leave the stone nearly white. The difference in color between a polished finish and a sawed finish is shown in Plate 6. The stone has been used for building constructions of every kind, including facing, ashlar, trimmings, sills, steps, floor tile, stairways, columns, fountains, and monuments. (See Figure 56.)

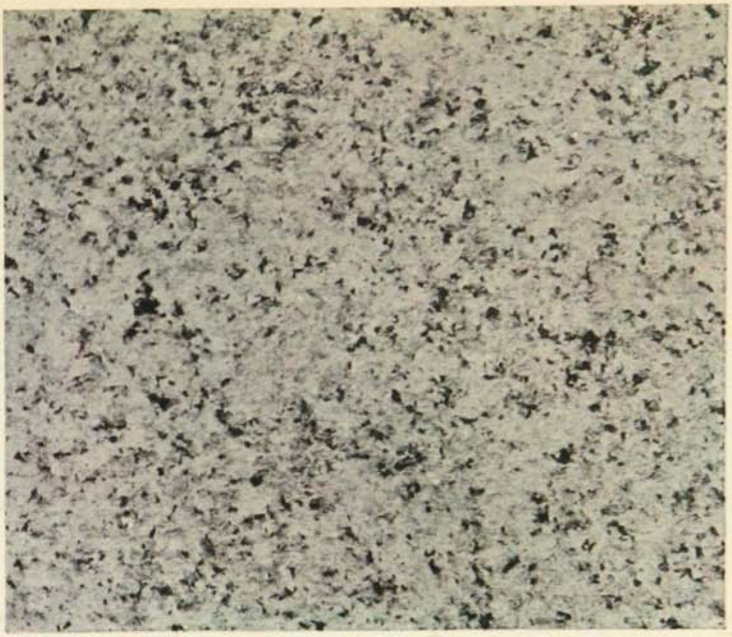
The following is a list of some of the prominent buildings in which Cold Spring Pearl White granite quarried near Isle has been used:

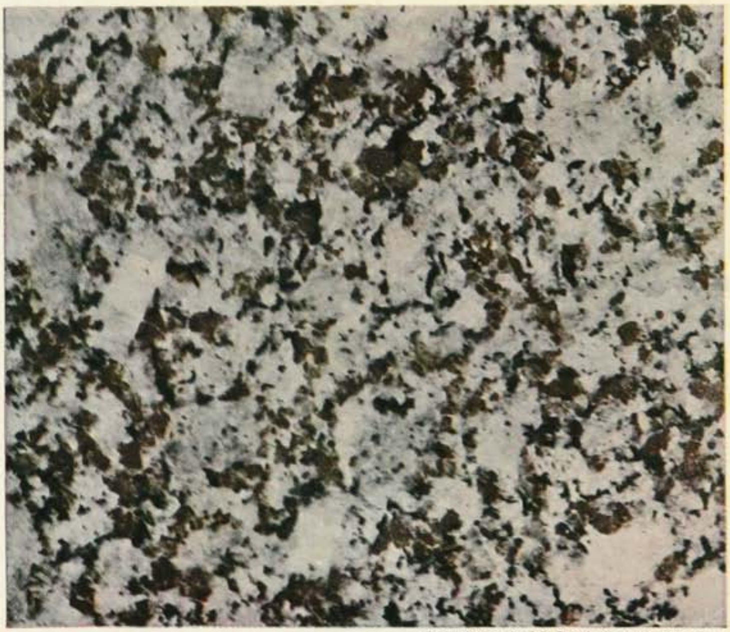
Gateway and office, Lakewood Cemetery, Minneapolis
Louisiana State Capitol, Baton Rouge, Louisiana
Consumers Power Building, Pontiac, Michigan
Bell Telephone Building, Evansville, Indiana
Masonic Temple Building, Shawnee, Oklahoma
Aviation Building, Fort Worth, Texas
Waite Phillips Building, Tulsa, Oklahoma
Plaza Investment Building, Jackson, Mississippi
Price Building, Kansas City, Missouri
Sherman Office Building, Corpus Christi, Texas
Hurds County Courthouse, Jackson, Mississippi
South Side Bank Building, Scranton, Pennsylvania
Capital Club Office Building, Raleigh, North Carolina
Post Office, Bartlesville, Oklahoma
Post Office, Clarksburg, West Virginia

Warman Creek.—In Kanabec County the best granite is that quarried near Warman, where quarries were opened in 1907 by the Warman Creek Granite Company and the Pike-Horning Granite Company. Some years later the Reynolds Granite Company operated the Pike-Horning property under lease, A few years ago the Royal Granite Company of St. Cloud began exploratory work on an area in Sec. 8, T. 41 N., R. 33 W.

The Warman rock is a medium- to fine-grained light gray or mottled black and white granodiorite that in general appearance resembles the granite of Barre, Vermont. It is composed mainly of quartz, white feldspar, and mica. The feldspars are both plagioclase and orthoclase, the latter being somewhat more abundant. The mica is in the form of small flakes of biotite. All the minerals are fairly uniform in size and distribution. A few black knots and inclusions of biotite schist are present. Some of the black areas represent segregations of biotite and others show the characteristics of inclusions. A few coarsely crystalline pegmatite dikes cut the massive granite. The rock tends to be slightly lighter gray near the surface than at the bottom of the quarries.

The chief defect of the rock in the Warman area is the jointing. The joints are closely spaced and they intersect at acute angles. At the quarry of the Reynolds Granite Company there are three systems at small angles. The joints strike N. 33° W., N. 32° E., and N. 78° E. Two sets





Courtesy Cold Spring Granite Co.

PLATE 6.—ISLE GRAY GRANITE

Above —Axed finish. *Below.*—Polished finish.

Courtesy Cold Spring Granite Co.

FIGURE 56. — Entrance to Lakewood Cemetery, Minneapolis. Constructed of Isle granite.

are vertical and the third dips 70° to the west. In addition to these joints there are dry seams that appear as rusty lines parallel to the joint planes. In the Warman Creek Granite Company's quarry the joints are much more regular, but also are closely spaced. Two prominent systems are developed, running N. 30° E. and N. 30° W. These joints are bunched at intervals of 10 or 15 feet. Between such groups they are from 2 to 4 feet apart. At the newly opened quarry of the Royal Granite Company there are likewise three intersecting systems, N. 20° E., N. 65° W., and N. 65° E. The first of these systems dips at an angle of 75° toward the west. The joints are too closely spaced to obtain large stock blocks for monumental work. It seems probable, however, that larger blocks may be obtained at greater depth.

None of the quarries near Warman were being operated at the time the region was visited in 1932. In view of the demand for monumental stone of the Barre type, it is hoped that further exploration work will be done in that area. F. F. Grout made the following chemical analysis of Warman granite from the Reynolds Granite Company's quarry.

SiO_2	69.55	K_2O	2.12
Al_2O_3	15.52	H_2O (above 100° C.)	0.40
Fe_2O_3	0.14	H_2O (below 100° C.)	0.10
FeO	3.29	Ti_2O	0.44
MgO	1.61	ZrO_2	0.02
CaO	3.67	P_2O_5	0.07
Na_2O	3.79	Cr_2O_5	0.01
		Total	100.73

Physical tests of a sample from the quarry of the Warman Creek Granite Company showed a crushing strength of 17,246 pounds per square inch. The transverse breaking strength or modulus of rupture was 3,519 pounds per square inch.

THE ARROWHEAD REGION

Many varieties of volcanic rocks are found in the northeastern part of Minnesota, commonly known as the Arrowhead region. (See Figure 57.) The ancient Archeozoic granites and basic extrusives have been so profoundly metamorphosed and converted into gneissic and schistose rocks that their original structures and textures are obliterated. They are of no value for building stone. The Proterozoic granites crop out promi-

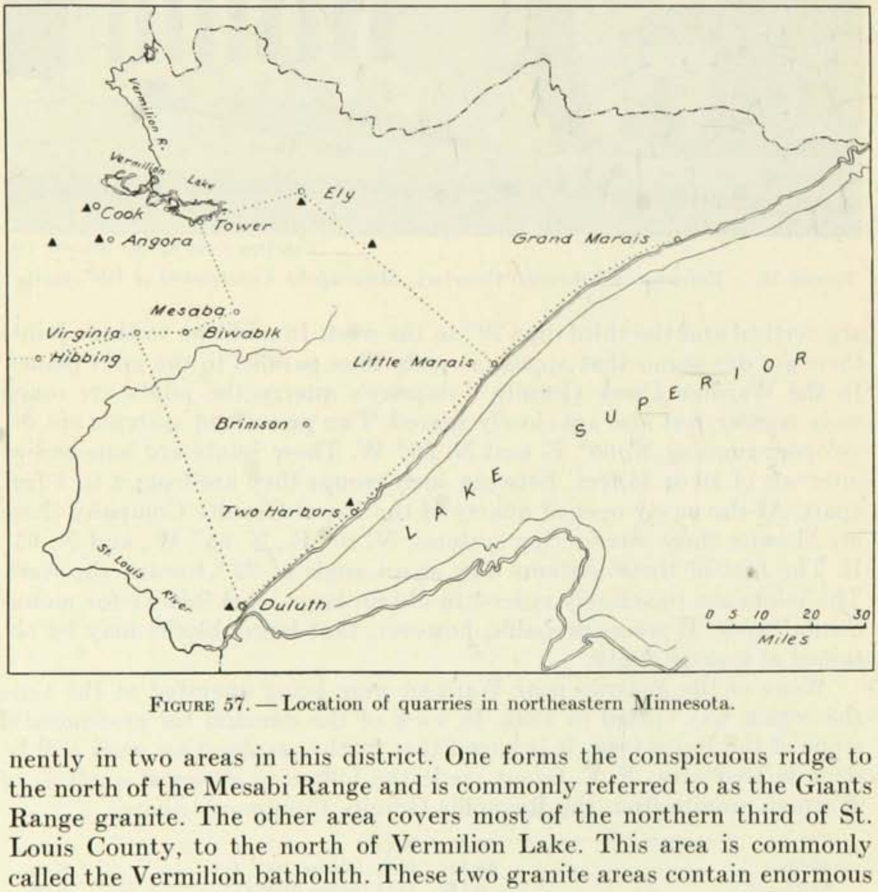


FIGURE 57. — Location of quarries in northeastern Minnesota.

nently in two areas in this district. One forms the conspicuous ridge to the north of the Mesabi Range and is commonly referred to as the Giants Range granite. The other area covers most of the northern third of St. Louis County, to the north of Vermilion Lake. This area is commonly called the Vermilion batholith. These two granite areas contain enormous masses of rock suitable for structural stone, but on account of their geographic locations and of poor transportation facilities they are not being quarried.

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 and Iron Range Railroad. The quarry, which was opened about

* Bowles, *op. cit.*, p. 146.

1891, is about 100 yards from the siding near the top of a bluff that rises some 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 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, pale pink phenocrysts and greenish gray grains, 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, lined up so 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. Apatite inclusions are numerous. On account of the small amount of quartz present the rock should be comparatively easy to dress.

Winchester Quarry.—In 1929 the Melrose Granite Company of St. Cloud opened a quarry in Secs. 14 and 23, T. 61 N., R. 20 W., near Angora, in a medium- to fine-grained light gray granite. In general the rock is similar in color and texture to the "Rock of Ages" granite quarried at Barre, Vermont. After a prospect pit approximately 120 feet in diameter and from 20 to 30 feet deep had been excavated, the property was abandoned. It was found that the rock has many imperfections, such as black schist inclusions, dark, fine-grained stringers and dikes, and extensive discolorations from iron-bearing solutions along joints. The joints are closely spaced and strike N. 75° E. and north-south. The plug and feather method was employed for removing monumental stock blocks.

Black and green "granites."—The Duluth gabbro of Keweenawan age occupies a large area in the Arrowhead district. (See the map on page 106.) This black rock, commercially known as "black granite" and "trap rock," has been quarried for many years in the region of Duluth, where it has been used for crushed rock, riprap, and subordinately for foundations and retaining walls. Most of the crushed rock is used for road construction and concrete work and the riprap for harbor protection. As early as 1896 the rock was quarried in several places along the bluff to supply stone for lining the water reservoir for the city of Duluth. The Duluth Crushed Stone Company began operations in West Duluth in 1903, and in 1913 the Duluth City Quarry was opened near 11th Avenue West and Superior Street. The whole output was employed in improvements upon the Superior breakwater. At the present time the Duluth Crushed Stone Company is operating a plant at Short Line Park. Another quarry at 40th and Pitt Street, northwest of the Northland Country Club, has also produced riprap and crushed stone.

During the past few years there has been a growing demand for polished "black granite" as a structural and ornamental stone. Because of the increased interest in this type of stone a number of new quarries have been opened within the area of the Duluth gabbro. This rock is dark gray or dark greenish gray to black in color. It owes its dark color to the dominance of gray-green feldspar minerals and dark green to black ferro-magnesian minerals such as hornblende and augite. Most of the rock is gabbro, consisting almost entirely of plagioclase crystals ranging from half an inch to nearly an inch in length.

Arrowhead Granite Company quarry.—Eighteen miles southeast of Ely in the Superior National Forest a quarry (see Figure 58) has recently been opened by the Arrowhead Granite Company, which has its main office in Hibbing. The quarry is in an outcrop 900 by 200 by 25 feet in Sec. 7, T. 61 N., R. 10 W. The stone is sold under the commercial names "Arrowhead Black Granite" and "Hibbing Granite." In appearance it is similar to the "Ashland Black Granite" of Wisconsin. The pattern formed by the crystal arrangement, however, is slightly different.

The outcrop in the region of the quarry is sufficiently large to permit extensive operation without the additional cost of stripping. The topography is such that a shelf quarry may be developed. The joint and sheet patterns indicate the possibility of removing large dimensional blocks for sawing and finishing. The joints trending N. 80° W. are spaced at an average distance of about 8 feet, and those trending N. 10° W. are from 5 to 20 feet apart. The rock shows a uniform texture and color. It is slightly discolored along joints, but no more than might be expected in an environment that furnishes a large supply of humic acid to the ground water.

The stone is a coarse-grained gabbro in which the predominant mineral is plagioclase in long striated grains, with augite and some yellowish-green grains of olivine. The normal surface has a gray color with brilliant reflections from the feldspar cleavage faces. When polished the rock has a dark gray color in which the feldspars refract the light, making them appear silvery. The individuality of the olivine and augite is lost in the dark gray background which they form. On the polished surface, which reflects light, the augite and magnetite grains are apparent because of their lesser polish as compared with the plagioclase.

"Green granite."—The rock having this trade name is a gabbro of medium-grained texture, the greenish tint of which is due to the faint color of the plagioclase. On broken surfaces the black and dark gray minerals appear more abundant than the greenish feldspar, but when polished the green color is intensified and so characterizes the rock. The minerals commonly present are, in order of abundance, plagioclase, augite, and magnetite, the last as small scattered metallic grains.

"Green Granite" quarry.—A quarry has recently been opened by the Arrowhead Granite Company on the west upland slope of the Little Rock River, about 2 miles west of the village of Cook. The quarry is in an outcrop of gabbro in which the joint and sheet pattern permits the removal of stone of good dimensions. One set of joints spaced at 3- to

8-foot intervals trends N. 80° E. and another set from 2 to 20 feet apart trends N. 15° W. The dimensions of the quarry when visited were 250 by 125 by 25 feet.

Some of the rock is a mottled green and black. This phase is called "Emerald-Tone." The other grade is a somewhat lighter green and is sold under the trade name "Green Granite." The colors and texture are fairly uniform although some streaks and black knots (inclusions) are encountered. Most of the stone has been cut for monumental stock at the quarry. Some saw blocks, however, have also been removed.

McDonald Quarry. — The McDonald Quarry is being operated in gabbro in Sec. 8, T. 61 N., R. 18 W., 2 miles west of Angora. In 1932 the pit was approximately 150 feet long and of nearly equal width. It was excavated to a depth of about 25 feet. The general environment, type of rock, and joint pattern are similar to those in the Cook region. Although present operations are of the pit quarry type, conditions indicate that a good shelf type quarry could be made by extending operations toward the lowland to the east. This quarry has an advantage in that large saw blocks can be obtained for dimensional stone. Blocks shipped for the Medical Arts Building in Duluth included two carloads

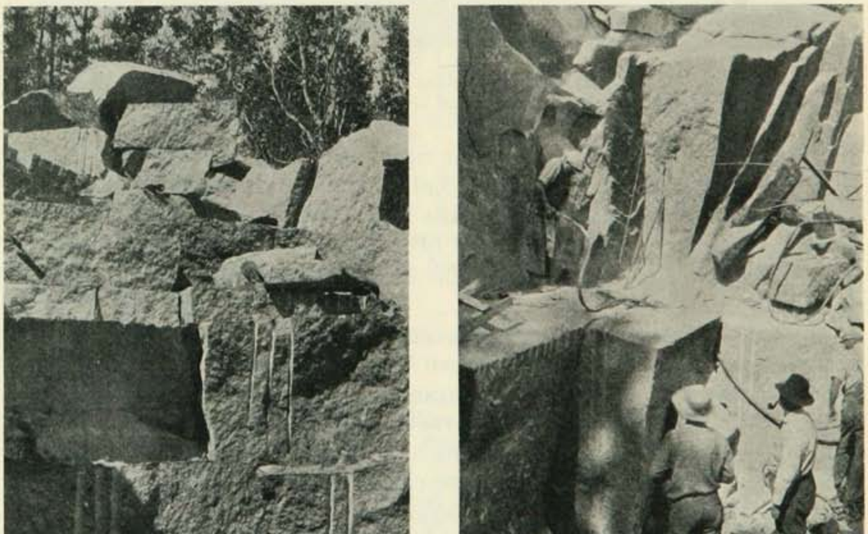


FIGURE 58. — *Left:* "Black granite" quarry of the Arrowhead Granite Company near Ely. *Right:* Removing blocks of "black granite" from a quarry of the Arrowhead Granite Company near Cook.

of blocks 6 by 3 by 4 feet and one carload of blocks 8 by 4½ by 3 feet. The trade name of this rock is "Archean Green."

Other "black granite" areas. — A great number of unexplored outcrops of gabbro and diabase are to be found in the Arrowhead region, some of which may furnish "black granite" for architectural use.

FIGURE 59. — Quarry of the B. F. Nelson Company in Archean greenstone near Ely. The rock is crushed and screened for roofing granules.

1. Along the highway between Split Rock Lighthouse and Beaver Bay there are many exposures of diabase. These rocks show a variation both in color and texture. Some are very dark gray and would yield a black surface when polished. Most of the rock is highly fractured, but a thorough survey of the region might lead to the discovery of a valuable deposit.

2. A coarse-grained anorthosite occurs as a large knob in the topography along the state highway between the Split Rock River and the lighthouse. Very little fresh rock is exposed, but where the rock has been broken by blasting it shows an attractive greenish-gray color. It appears mottled because of the arrangement of the feldspar grains. The rock has a uniform coarse texture. Joints are closely spaced near the surface, but a test pit would be required to determine their spacing at greater depth.

3. Near Brimson at a distance of a quarter of a mile from mile post 49 on the track of the Duluth and Iron Range Railroad is a cut 400 feet long and 20 feet deep. Three types of rock are exposed there. One is a coarse-grained gabbro that may warrant prospecting as a source of "black granite." Heavy blasting during the excavation of the cut has obscured the original jointing. An enormous amount of rock is available. Railroad transportation facilities are ideal and a branch of the Cloquet River is near enough to furnish water for quarry operations.

4. About 1¼ miles south of the village of Mesaba is an outcrop of gabbro in a rock cut 120 feet long and 10 to 12 feet deep. The rock is coarse grained and dark gray to black in color. Joints and sheets are numerous but many are due to the blasting that was done when the cut was excavated. The rock has an attractive color and texture on the fresh surface. Further exploration is recommended.

Archeozoic Greenstone Basalt

Extensive areas of green basalt crop out in the Vermilion Range region. Much of the rock is intensively altered and recrystallized but locally massive varieties may be found. Some of the rock has been quarried for foundation purposes, retaining walls, ballast, etc. It has not been quarried for building stone. Recently, however, it has been found useful as a source of roofing "granules."

B. F. Nelson Company quarry.—The B. F. Nelson Company of Minneapolis has opened a quarry in Archean greenstone (see Figure 59) southwest of Ely in Sec. 31, T. 63 N., R. 12 W. The rock is massive grayish-green basalt. It is blasted from the quarry walls as irregular blocks which are loaded into small tram cars by means of a steam shovel. The cars are drawn by a cable and emptied into a hopper from which the stone is fed into a crushing plant. Fragments approximately a quarter of an inch in diameter are screened from the crushed stone. Because of their uniformity in color and texture the stone fragments are used for coloring rubberoid roofing and shingles. Weathering tests have shown that they do not bleach readily, and they act as a fireproofing on the surface of the roofing. Formerly the B. F. Nelson Company obtained its stone-surfacing material from New England. The site of the quarry in Archean greenstone in Minnesota was chosen by the Geological Survey as a result of a request of the B. F. Nelson Company that suitable stone be located nearer their factory.

Inactive and Abandoned Quarries in the Arrowhead Region

Carlton County

City of Cloquet, Huronian slates. Bowles,* p. 211.
Near the village of Barnum, Huronian slates. Bowles, p. 211.
Near the village of Thomson, Huronian slates. Bowles, p. 211.

St. Louis County

T. 48 N., R. 15 W., Sec. 5, Fond du Lac sandstone. Bowles, p. 208.
Mission Creek, north of Fond du Lac, sandstone. Winchell,† 1:181.
Two miles north of Hibbing, Pokegama quartzite. Bowles, p. 205.

* *The Structural and Ornamental Stones of Minnesota* (United States Geological Survey Bulletin 663, 1918).

† *The Geology of Minnesota* (Final Report of the Minnesota Geological and Natural History Survey, St. Paul, 1884–1901).

CHAPTER V

THE SEDIMENTARY AND METAMORPHIC ROCKS OF MINNESOTA SUITABLE FOR DIMENSIONAL STONE

LIMESTONES AND MARBLES

Certain calcareous beds are found in the regions of Archeozoic and Proterozoic rocks in northeastern Minnesota, but no limestones suitable for building stone are associated with the crystalline rocks of that region. The limestones of Minnesota that are of economic value belong chiefly to the Paleozoic group (see the table on page 23), and are included in the Cambrian, Ordovician, and Devonian systems of rocks. They crop out in the eastern and southeastern counties of the state. A heavy covering of mantle rock, the greater part of which is glacial drift, covers most of this region. Along the Mississippi River and its tributaries, however, numerous ledges crop out along the bluffs. This is true especially along the Minnesota, St. Croix, Cannon, Root, and Cedar rivers.

Nearly all the limestones of Minnesota are more or less dolomitic and many are nearly pure dolomite. (See the analyses on pages 120 to 130.) The lower Ordovician strata are somewhat recrystallized and certain strata are sufficiently crystalline to take a good polish. Limestone suitable for many purposes has been quarried. In some localities quarries were opened to obtain stone for certain specific structures, on the completion of which the quarries were abandoned. Other localities have a large supply of attractive and durable rock, but the value of the rock for building purposes is not known outside the region where it is quarried. Along the Mississippi River Valley riprap is quarried extensively for engineering projects in the valley, and in the driftless and loess-covered areas where gravel is scarce much limestone is quarried and crushed for highway construction work. In several localities limestone is burned for the manufacture of lime and some dolomite is quarried for cement. There is a steady demand for Minnesota limestone for architectural purposes, and with the growing desire for attractive, permanent, and dignified stone buildings, the limestone industry should continue to flourish. The accompanying map (see Figure 60) shows the localities where limestone from Minnesota has been used in the construction of prominent buildings.

THE MANKATO-KASOTA DISTRICT

In the Mankato-Kasota district the Cambrian and Ordovician sedimentary rocks are exposed in the walls of the valleys of the Minnesota, Blue Earth, Watowan, Le Sueur, Maple, and Big Cobb rivers. The rock formations are nearly horizontal, dipping at a low angle toward the north

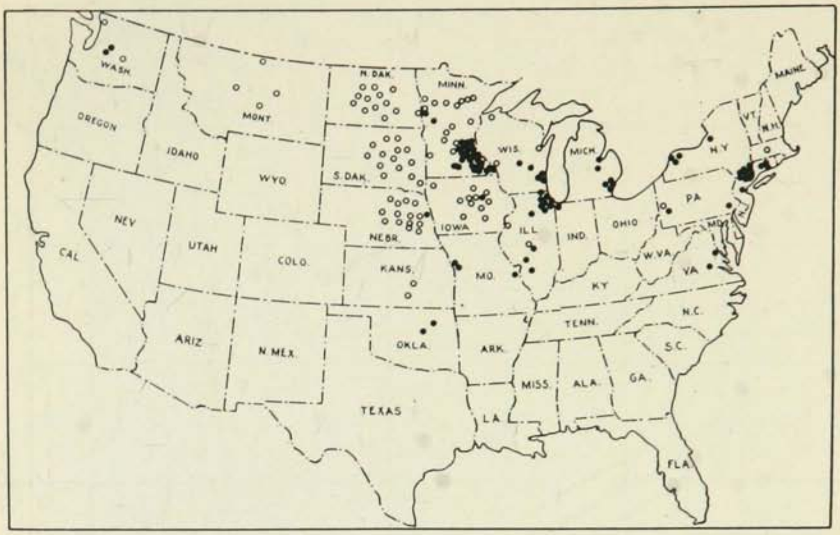


FIGURE 60. — Map of the United States showing the localities in which Minnesota limestones and sandstones have been used for architectural purposes. Each dot and each circle represents one or more prominent buildings in which the stone was installed. Solid dots represent limestone, circles represent sandstone.

and east. The strata are continuous over large areas, but because of the great thickness of the glacial drift they crop out only in the bottomlands and in the lower part of the bluffs of the deep river valleys. The following formations are found at the surface:

Pleistocene	Drift
Cretaceous	Clays and sand
Orodovician.....	Shakopee dolomite
	New Richmond sandstone
	Oneota dolomite
Cambrian	Jordan sandstone
	St. Lawrence dolomite

In the above group of formations the Oneota and the St. Lawrence are the only members from which building stone may be obtained. The Shakopee dolomite is locally less dolomitic and produces some rock for the production of lime, cement, and riprap.

The St. Lawrence dolomite crops out at Judson and at Hebron. It rises 30 to 35 feet above the river and forms the border of a terrace, covered by reworked drift that lies between it and the bluffs. As a building stone it is inferior to the Oneota dolomite, being thinly bedded and closely jointed. Some ledges, however, may be of value for structural stone. Upham describes some of the outcrops as follows:

At Mrs. G. W. Wolf's house (Judson post office), in the SE¼ of section 33, this limestone has been quarried along an extent of about twenty rods, exposing a vertical thickness of four to eight feet, the top being 30 to 35 feet above low water of the river. Another quarry on the same farm, about sixty rods farther southeast, also shows a thickness of eight feet. The section here is at top 5 or 6 feet of very hard durable, flesh-colored or buff

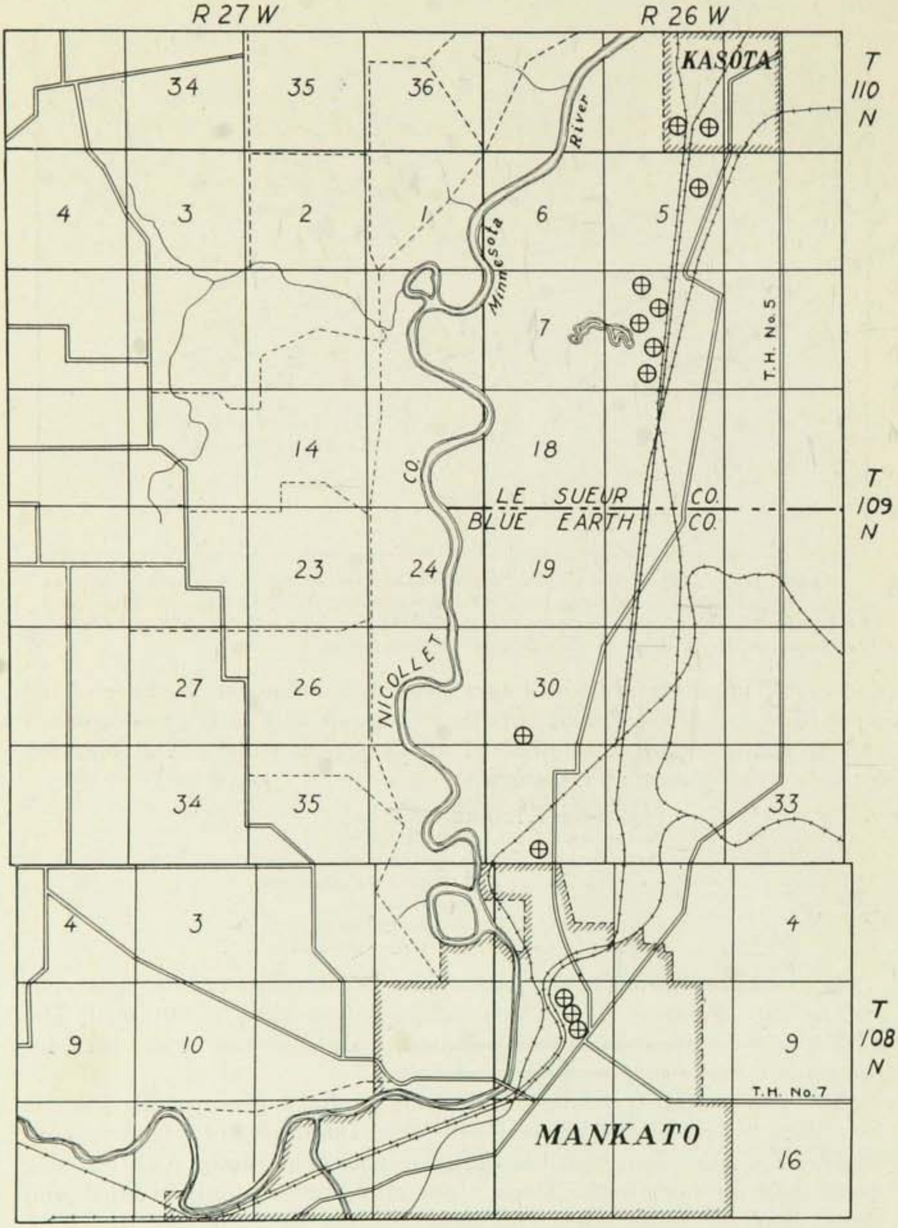
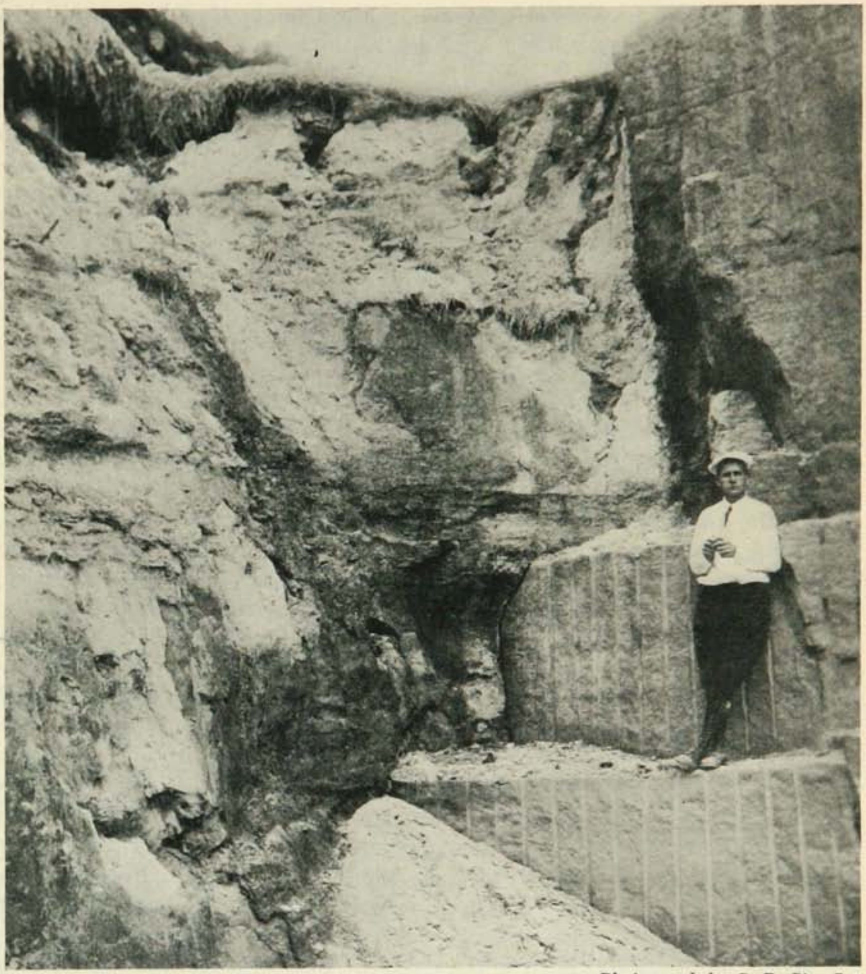


FIGURE 61. — Map of the Mankato-Kasota region showing the location of quarries.



Photograph by C. R. Stauffer

FIGURE 62. — A quarry near Kasota, showing the outline of a solution cavity in the Oneota dolomite filled with clay, sand, and gravel.

magnesian limestone, somewhat striped or mottled with greenish tints, in layers from a few inches to one foot thick, having their planes of bedding and jointage often covered with green films; then a dark greenish sandy shale much of it finely laminated, crumbling under the influence of the weather, 1½ feet; changing below to a yellowish gray calcareous sandstone, about 4 feet thick; underlain by sandy shale, which is blue for its first foot, becoming yellowish gray below, excavated only 2 or 3 feet, but reaching deeper. All these beds, and their other exposures, both in Judson and Nicollet, are nearly level, but appear to have a slight general dip, in some portions amounting to two or three degrees, to the southeast.*

Outcrops of the Oneota dolomite are numerous along the Minnesota River Valley and its tributaries as far as Garden City and Rapidan. The

* "The Geology of Blue Earth County," in *The Geology of Minnesota*, 2:425.

village of Kasota is on a rock terrace of the Oneota that is 1½ miles in width and extends from north of Kasota southward to Mankato, a distance of over 8 miles.

Throughout most of the Mankato-Kasota district large solution cavities are found in the Oneota dolomite near its base, where it rests on transition beds of silt and clay that have been called the Kasota siltstone horizon.* Locally this silt and clay has been squeezed upward into the cavities and chambers by the differential settling of huge blocks of Oneota dolomite. Also sand, gravel, and bowlders from the bed of the stream that once covered the terrace have been dumped into the caves and channels. (See Figure 62.) The cave-like origin of the cavities is shown by their shape and also by the stalactitic deposits on the cavity walls.

The geographic location of the quarries in the Mankato-Kasota region is shown in Figure 61. The quarries of the Kasota and Mansota areas are pits in a terrace of the Minnesota River Valley, but at Mankato they are of the shelf type in the rise from this terrace to the upland.

All the quarries in this district operate in the same geologic formation, but some variation in color or texture gives rise to the various trade types. Likewise the same general quarry technique is used in all quarries, with such modifications as the foreman considers necessary.

The first operation for quarrying is the removal of waste rock above the ledges to be quarried. In the Kasota and Mansota areas this overburden, about 12 feet thick, consists of soil, river deposits, and fractured dolomite (see strata numbers 10 and 11 of Breen Quarry section, Kasota). At the Mankato quarries the overburden is about twice as thick as a result of the presence of layers (numbers 10 to 17 of Coughlan Quarry section) which have been removed in the Kasota and Mansota areas by the erosion of the River Warren, an Ice Age ancestor of the Minnesota River. The overburden is stripped off by steam shovel, scoop scraper, trucks loaded by hand, or iron trays handled by the hoisting derrick.

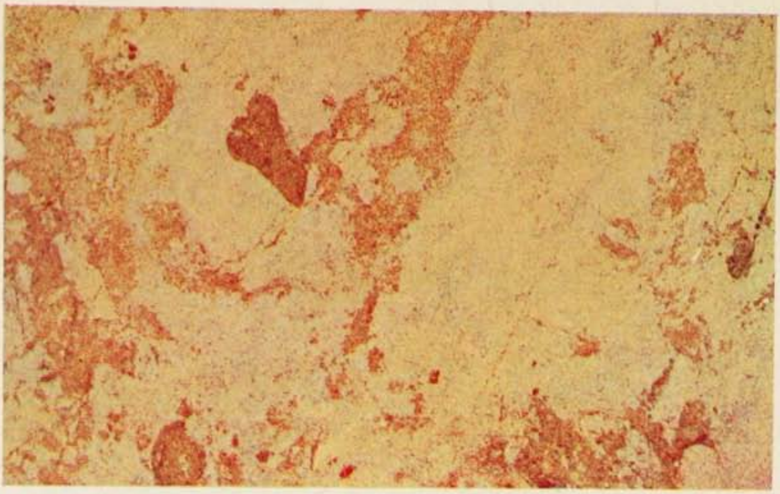
When the ledge has been uncovered, the next operation is the cutting of a "key block" by a channeling machine. (See Figures 63 and 64.) The cut is made by the impact of five steel bars so fastened by clamps and activated by an eccentric drive wheel as to be successively raised and then dropped upon the stone. The bars are ⅞ of an inch thick, 1½ inches wide, and about 12 feet in length. They have wedge-shaped cutting edges at the lower ends, which are not parallel when the machine operates but are set as the lines of the letter "W." The machine also moves back and forth automatically on steel rails by the action of a worm gear on the shaft of the drive wheel. As the machine operates along the tracks, a straight channel about 1½ inches wide is cut to the determined depth.

* Louis H. Powell, unpublished thesis, 1932, on file in the University of Minnesota Library.

Courtesy Breen Stone and Marble Co.

PLATE 7. — MANKATO-KASOTA DOLOMITE

Above. — Light gray. *Below.* — Fine-grained yellow.



Courtesy Breen Stone and Marble Co.

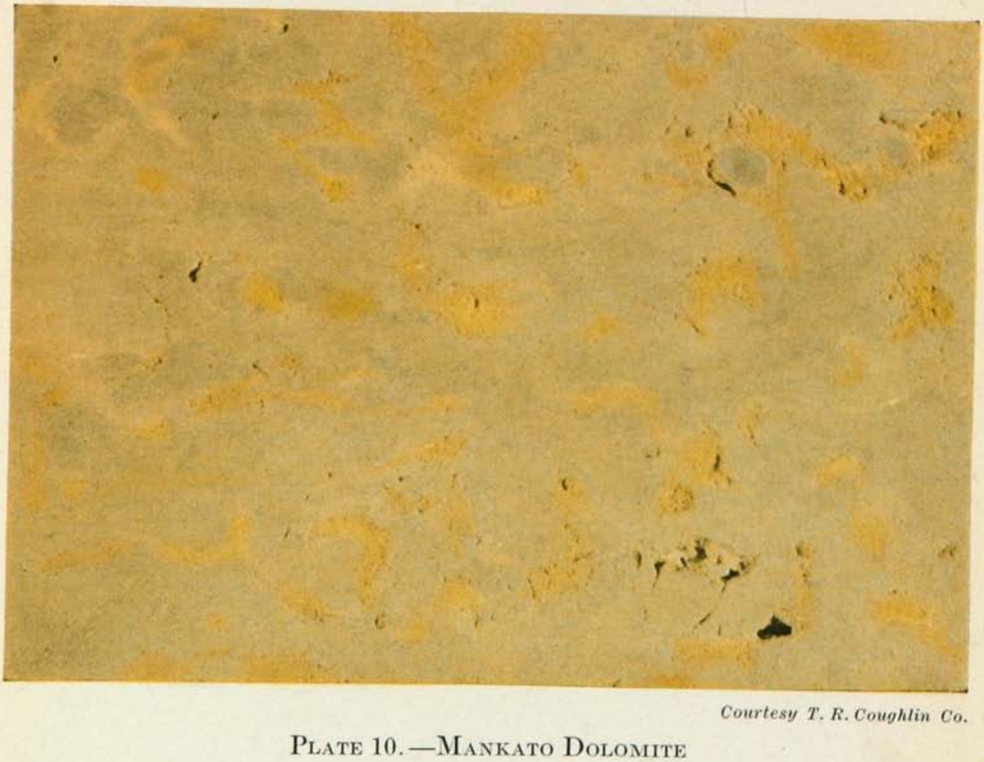
PLATE 8. — MANKATO DOLOMITE

Above. — Coarse yellow. *Below.* — Buff-pink.

Courtesy Breen Stone and Marble Co.

PLATE 9. — KASOTA DOLOMITE

Above. — Pink Veine. *Below.* — Pink Fleuri.



Courtesy T. R. Coughlin Co.

PLATE 10.—MANKATO DOLOMITE

Above.—Fine-grained cream-colored. *Below.*—Coarse yellow.

The channels are cut in order to facilitate quarry operations, such as dividing a ledge into rectangles for further work (see Figure 66), or permitting access to a ledge of road through a key block (see Figure 63), or avoiding undesirable directions of breaks in the rock, such as that shown in Figure 65.

After the ledge has been uncovered and made accessible for operation, it is cut into blocks of sizes suitable for fabrication. This subdivision is accomplished by drilling with jackhammers and wedging with plug and feather. Holes about 8 inches apart are drilled vertically through the ledge along the desired line of fracture. Then "feathers," the lower ends of which are welded together to furnish a grip, are placed on the end of long "plugs" and lowered into the holes. By means of successive and uniform driving of the plugs, the rock will eventually be fractured in vertical directions. The thickness of the ledge, the third dimension, is usually determined by the bedding planes, and along such planes the rock is more or less free. Sometimes, however, horizontal breaks must be made, the method being the same as that used in making vertical breaks, although the holes are drilled less deep.

After the blocks are loose, they are hoisted and carried to the stock pile to await shipment. Figures 67 and 68 show such piles in the quarries of the Fowler and Pay Company and the T. R. Coughlan Stone Company at Mankato.

SECTION OF ST. LAWRENCE FORMATION, JUDSON
(Measured by C. R. Stauffer)

	THICKNESS
5. Soil and river deposits	0 ft. 6 in.
ST. LAWRENCE FORMATION	
4. Dolomitic limestone, thin-bedded, gray to buff or brown, with some glauconite	8 ft. 0 in.
3. Covered interval	4 ft. 0 in.
2. Dolomitic limestone, gray to brown, with much glauconite, often in streaks or along the bedding planes. Fucoids and worm tubes abundant. *Billingsella* occurs near the top; also some cystoid stems	9 ft. 0 in.
1. Covered to the level of Minnesota River	5 ft. 0 in.

SECTION OF QUARRIES OF THE BREEN STONE AND MARBLE COMPANY, KASOTA
(Measured by C. R. Stauffer)

	THICKNESS
11. Soil and river deposits	4 ft. 0 in.
ONEOTA DOLOMITE	
10. Dolomite, dense, brown with some chert. Massive to thin-bedded and shaly where weathered	8 ft. 0 in.
9. Dolomite, pink to buff. These beds are the finest building stone in half a dozen or more layers	7 ft. 2 in.
8. Dolomite, uneven, cavernous, dense, and very massive	7 ft. 0 in.
7. Dolomite, massive to thin-bedded or shaly; purple, and dark red ranging to yellow; middle layer called "Castile Ledge"	2 ft. 6 in.
6. Dolomite, thin-bedded, mottled gray to buff. Includes the "hummocky" layer. Uneven contact at base	6 ft. 0 in.

FIGURE 63. — A key block cut by a "channeler" in a ledge of the quarry of the Babcock and Wilcox Company near Kasota.

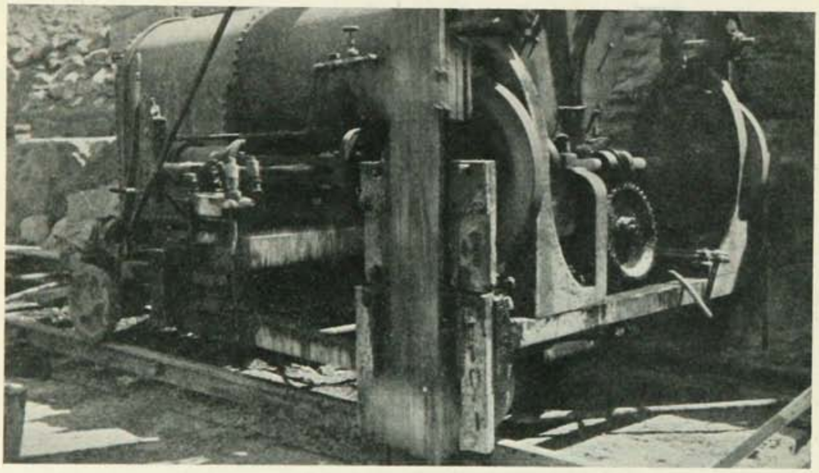


FIGURE 64. — A channeler in operation at the quarry of the Breen Stone and Marble Company at Kasota.

TRANSITION BEDS

5. Clay or clay shale, light gray, variable in thickness....................	0 ft. ±6 in.
4. Sandstone, medium to coarse, white with *Raphistoma* and other fossils. An erosion surface at base..	6 ft. 6 in.

JORDAN SANDSTONE

3. Sandstone, medium to coarse, white with streaks of green.............	6 ft. 0 in.
2. Sandstone, fine-grained, cross-bedded, white with spots or blotches of pink	20 ft. 0 in.
1. Covered to level of Minnesota River.................................	10 ft. 0 in.

Section of Quarry of the T. R. Coughlan Company, Mankato *
(Measured by C. R. Stauffer)

	Thickness
17. Soil covering	0 ft. 6 in.
Shakopee Dolomite	
16. Dolomite, oolitic, with occasional conglomerates, gray to brown. Beds contain some oolitic chert and weathered surfaces may show sand grains	7 ft. 4 in.
15. Covered interval	1 ft. 0 in.
14. Dolomite, sandy, brown, with some flat pebbles. Indefinite contact with beds below	2 ft. 6 in.
New Richmond Sandstone	
13. Sandstone, white to yellowish, with hard masses like quartzite. Some layers ripple-marked	5 ft. 0 in.
12. Shale, saudy green, uneven at base, containing a few fossils, chiefly *Raphistoma*	0 ft. 6 in.
Oneota Dolomite	
11. Dolomite, vesicular, occasionally oolitic, gray to drab, often with a pink tinge. Calcite geodes common	5 ft. 6 in.
10. Dolomite, massive, gray to yellowish, with occasional cherty masses	9 ft. 10 in.
9. Dolomite, massive, gray to brown and pink or reddish brown, usually mottled. Contains small cavities and calcite geodes. Some sand penetrates cracks to this depth and fills cavities	13 ft. 0 in.
8. Dolomite, single layer, fine gray to buff, almost without cavities	4 ft. 0 in.
7. Dolomite, massive, buff, slightly mottled, fine-grained. The best building stone in the quarry. Occurs in two layers with the parting hardly perceptible	7 ft. 6 in.
6. Shale, hard, dense, buff with purple blotches grading into purple. When unweathered this bed may appear massive	2 ft. 6 in.
5. Dolomite, massive, buff, continuing to the quarry floor and to water	3 ft. 6 in.
4. Dolomite, massive, buff to brown (covered)	9 ft. 6 in.
3. Shale, gray (covered)	3 ft. 0 in.
2. Dolomite, massive, uneven-bedded, gray to buff	7 ft. 6 in.
Jordan Sandstone	
1. Sandstone, white, covered to level of Minnesota River	40 ft. 0 in

Section of Quarry of the Carney Cement Company Near Pilgrims Rest Cemetery, Mankato
(Measured by C. R. Stauffer)

	Thickness
11. Drift	2 ft.±0 in.
Oneota Dolomite	
10. Dolomite, weathered, thin-bedded, buff	3 ft. 6 in.
9. Dolomite, massive, buff to brown or pink; often is mottled and has cavities	4 ft. 0 in.
8. Dolomite, massive, pink to buff, vesicular	4 ft. 2 in.
7. Dolomite, massive, buff with blotches of pink	7 ft. 6 in.
6. Shale, purple, grading into ashen gray at top	2 ft. 6 in.
5. Dolomite, massive, buff, continuing to the floor of the quarry and to water	3 ft. 6 in.
4. Dolomite, massive to shaly, gray	4 ft. 0 in.
3. Shale, soft and putty-like, gray	0 ft. 4 in.
Jordan Sandstone	
2. Sandstone, massive, white, poorly cemented but with hard masses	10 ft. 0 in.
1. Covered interval to creek and lake level in old abandoned channel of Minnesota River	15 ft. 0 in.

* See Figure 68 for a photograph of the quarry.

Analyses of Mankato and Kasota Stone *

Sample	Insoluble Silica, etc.	Oxides (Iron, etc.)	Total Insoluble	CaO	$CaCO_3$	MgO	$MgCO_3$
2.	. . .	. .	11.55	. . .	48.49	. . .	39.83
3.	. . .	. .	8.99	. . .	51.02	. . .	40.06
4.	. . .	. .	11.23	. . .	49.95	. . .	39.01
78.	10.4	1.1	11.50	27.4	48.9	18.9	39.5
79.	30.5	1.2	31.70	21.6	38.6	14.2	29.7
80.	26.5	1.8	28.20	22.0	39.3	15.2	31.8
81.	21.8	1.1	22.90	23.5	42.0	16.3	34.1
82.	13.5	1.4	14.90	26.2	46.8	18.0	37.7
83.	12.4	1.3	13.70	26.5	47.3	18.4	38.5
142.	. . .	. .	16.00	. . .	48.72	. . .	33.95
143.	. . .	. .	11.67	. . .	50.97	. . .	33.01
144.	. . .	. .	13.18	. . .	49.54	. . .	32.34
145.	. . .	. .	8.94	. . .	54.58	. . .	30.99
152.	. . .	. .	9.08	. . .	49.70	. . .	41.55

* Compiled from Stauffer and Thiel, *The Limestones and Marls of Minnesota* (Minnesota Geological Survey Bulletin 23, University of Minnesota Press, Minneapolis, 1933).

2. Oneota dolomite (Kasota stone), Kasota, Le Sueur County. Sample of the pink layer sawed and polished by the Breen Stone and Marble Company. This is a marketable horizon. It consists of pink to buff beds of fine dolomite 14 feet thick.
3. Oneota dolomite, White Cliff or White Rock Buff, Ottawa, Le Sueur County, on Charles Schwartz's farm along the Minnesota River. Sample from the 6-foot bed of brown to reddish-brown or pink magnesian limestone with a little chert. Fossils common but poorly preserved.
4. Oneota dolomite from cliff opposite Sibley Park, Mankato, but in Nicollet County.
78. Oneota dolomite, quarry of the Carney Cement Company (Pilgrims Rest Cemetery), Mankato, Blue Earth County. Sample from bed no. 7, which is of massive, buff-colored dolomite with splotches of pink, 2 feet, 10 inches thick.
79. Oneota dolomite, quarry of the Carney Cement Company (Pilgrims Rest Cemetery), Mankato, Blue Earth County. Sample from the upper part of bed no. 6 which is purple, shaly dolomite.
80. Oneota dolomite, quarry of the Carney Cement Company (Pilgrims Rest Cemetery), Mankato, Blue Earth County. Sample from the lower part of bed no. 6 which is ashen, gray dolomite.
81. Oneota dolomite, Pilgrims Rest Cemetery, Mankato, Blue Earth County. Sample from bed no. 10 from the natural outcrop below the bluff of the quarry of the Carney Cement Company. The stone is thin-bedded, weathering to buff, dolomitic layers.
82. Oneota dolomite, quarry of the Carney Cement Company (Pilgrims Rest Cemetery), Mankato, Blue Earth County. Sample from bed no. 5 which is massive, gray dolomite with several poorly developed bedding planes.
83. Oneota dolomite, quarry of the Carney Cement Company (Pilgrims Rest Cemetery), Mankato, Blue Earth County. Sample from bed no. 8, which is a massive layer of pink dolomite weathering to buff and vesicular in places.
142. Oneota dolomite, Coughlan Quarry, Mankato, Blue Earth County. Sample from the upper 15 feet of the formation, or the 15 feet just below the sandstone.
143. Oneota dolomite, Coughlan Quarry, Mankato, Blue Earth County. Sample from the 10 feet immediately below beds from which sample 142 was taken.
144. Oneota dolomite, quarry of the Breen Stone (Babcock and Wilcox) Company, Kasota, Le Sueur County. Sample from the 7 feet, 2 inches of pink to cream colored "polish ledges."
145. Oneota dolomite, quarry of the Breen Stone (Babcock and Wilcox) Company, Kasota, Le Sueur County. Sample from the 10 feet below the "polish ledges."
152. St. Lawrence dolomite from the old quarry near St. Lawrence, Scott County.

BUILDING STONES OF THE DISTRICT

Former uses. — Early settlers in the Minnesota Valley utilized the outcropping stone for foundations and for buildings, many of which are still to be seen. The railroads also found this stone satisfactory and readily accessible for building bridges, culverts, and retaining walls on their roadbeds. Much of the stone was shipped throughout the surrounding states for this use. In fact, the outlet for this purpose was so large that until recent years, when the use of concrete became more general, the Mankato quarries produced almost entirely for this type of construction, to the exclusion of supplying stone for building. Many examples of this stone work are found on the lines of the Minnesota railroads. The stone arch bridge at Minneapolis and the railroad bridge at Blair, Nebraska, are representative examples.

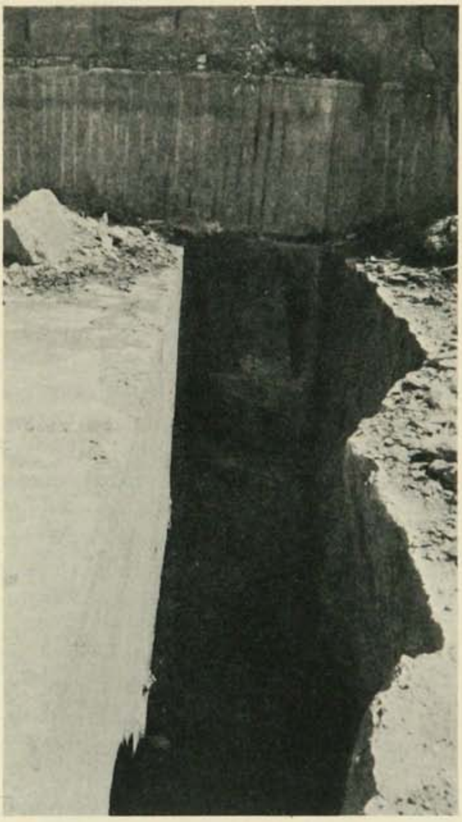


FIGURE 65. — An irregular "natural" fracture on the right and a straight channeled face on the left. Quarry of the Fowler and Pay Stone Company at Mankato.

As more efficient tools and methods of milling stone were invented, the stone was used more for building operations. Installations are now to be found in many parts of the United States. (See the map on page 113.) The stone is enjoying a wide market for exterior work and for interior decorative work, and it is also well adapted for carving, sculpture, and other highly ornate designs.

PROPERTIES OF MANKATO-KASOTA STONE

Color varieties. — The color of the stone from this district has been an important factor in bringing it to the foreground as one of the leading limestones and "marbles" in the United States. Architects are becoming more and more interested in variegated wall surfaces, and are building up a demand for stone that varies both in color and in texture. Several ledges or strata of different color are found in the Mankato-

Kasota district, and when used at random these blend beautifully and give individuality to the structures. Typical installations may be seen in the Northwestern Bell Telephone Building in Minneapolis, in the Administration Building at St. Thomas College, St. Paul, in the Art Museum Building in Philadelphia, and in Loew's State Theater, New York City.

The following trade varieties are based on the color and texture of the stone. (See Plates 7–12 for reproductions in natural color.)

Mankato Cream	Mankato Pink Buff
Mankato Yellow	Mankato Red
Mankato Coarse Yellow	Kasota Yellow
Mankato Gray	Kasota Pink
Mankato Silver Gray	Kasota Interior Pink Veine
Mankato Gray Buff	Kasota Interior Pink Fleuri
Mankato Gray Pink	Mansota Cream
Mankato Pink	Mansota Pink-Buff

Much of the stone is sufficiently hard to take a polish and is therefore sometimes called marble. "Kasota marble" has been quarried since 1868. At the present time a similar stone is quarried also at and near Mankato. It is widely known as "Kasota marble" in many states of the United States and also in Canada and Mexico. Most of the stone is a fine-grained dolomitic limestone, yellow and yellowish pink in color. Certain ledges of yellow stone have large solution cavities that give it a texture similar to that of travertine. When sawed across the bedding planes it is called "Veine," and when cut parallel to the beds its design is called "Fleuri." (See Plate 9.) The yellow is extensively used for decorative details because of its rich color with markings a trifle darker in shade. Such shadings are also characteristic of some of the pink varieties.

The following is a list of stone ledges designated by color as quarried from top to bottom at the T. R. Coughlan Quarry at Mankato.

1. Red ledge. Maximum rise 2 feet 2 inches; suitable for broken ashlar or random ashlar. Impossible to quarry in long lengths. Fine texture with few holes.

2. Pink buff ledge. Maximum rise 1 foot 6 inches. Suitable for broken ashlar and short random lengths. Impracticable to quarry in set lengths or long lengths. A "travertine" stone with many small holes.

3. Cream ledge. Fine texture, close grained, no holes. Maximum rise 3 feet 2 inches, but usually quarried at 2 feet 6 inches rise; color range from plain cream color with fleuri markings to variegated cream with dark brown line markings and a graduation between these extremes. Finished, polished, honed, rubbed, sand sawed, sandblasted, or tooled. Holds its color well in exterior work.

4. Yellow ledge. A rough texture stone with some holes. Maximum rise 5 feet but usually quarried at 3 feet 6 inches and 2 feet rises. Color range grayish buff to full yellow color. Honed, sand rubbed, sand sawed, sandblasted, or tooled. Holds its color in exterior work and stays clean.

Courtesy Fowler & Pay

PLATE 11.—MANKATO DOLOMITE

Above.—Buff. *Below.*—Dark gray.

Courtesy Fowler & Pay

PLATE 12.—MANKATO DOLOMITE SHOWING VARIATIONS IN TEXTURE OF CREAM LEDGE

5. Gray ledge. Rough texture stone with some holes yet different from the yellow ledge. Maximum rise 3 feet 2 inches. Color range is gray to gray buff. Finished, polished, honed, sand rubbed, sand sawed, sandblasted, and tooled. An especially strong, durable stone for exposed places such as steps, coping, carvings, cornice, etc.

In the Kasota area the varieties of rock are quarried from two ledges (number 9 of the Breen Quarry at Kasota). The upper ledge, which is 3 feet 10 inches thick, furnishes the yellow stone, and the lower ledge, 3 feet 6 inches thick, the pink stone. All the material can be cut and polished.

The rock in the ledges of the Mansota * area has a more porous appearance than the Kasota varieties because it is coarser grained and contains more cavities.

A number of new quarries have been opened in the area south of Kasota between Mansota and the village of Kasota. Those on the Hugunin estate (Sec. 5, T. 109 N., R. 26 W.), are operated by the Kasota Stone Quarries Corporation. The ledges are similar to those at Kasota, and excellent quarry stock has been excavated. Most of the stone is shipped to the plants of the William Penn Stone Company in Minneapolis and in Sandstone, Minnesota, for fabrication.

Since the alternation of pink and yellow beds is peculiar, Bowles made a study of the coloring matter in the stone to determine its cause. A chemical and microscopic investigation was made in the laboratory at the University of Minnesota by A. W. Gauger. Iron is the common constituent that gives the pink, buff, or yellow colors to limestone. Careful determinations were made, therefore, of total iron and also of ferrous iron, to discover whether the degree of oxidation affected the color. In determining the ferrous iron the samples were crushed, but not ground, to pass through an 80-mesh sieve, and were then decomposed and dissolved in an atmosphere of CO_2, according to the method of W. F. Hillebrand.† The percentages of total and ferrous iron obtained were as follows:

	Pink	Yellow
Total iron determined as FeO	0.708	0.504
Ferrous iron oxide (FeO)	0.250	0.152

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 all specimens tested, from 0.35 to 0.30 — making it evident that neither the difference

* The term "Mansota" is applied to the region south of Kasota in the valley of the Minnesota River between Mankato and Kasota. It is a coined term, a combination of parts of the names "Mankato" and "Kasota."

† *The Analysis of Silicate and Carbonate Rocks* (United States Geological Survey Bulletin 422, 1910), p. 223.

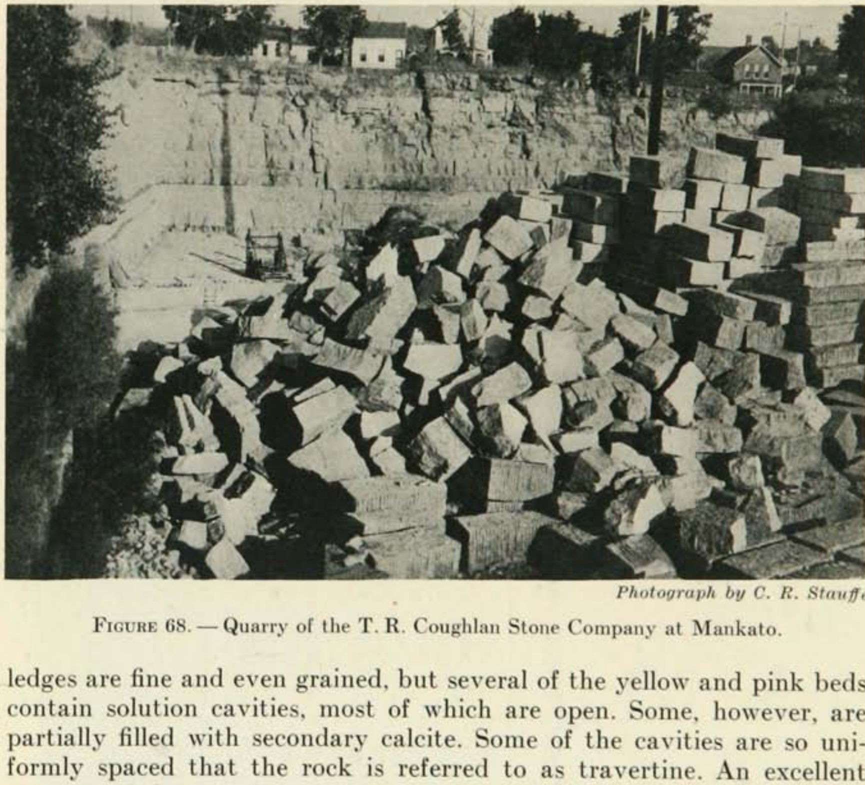
FIGURE 66. — Quarry of the Fowler and Pay Stone Company at Mankato.

FIGURE 67. — Blocks of quarried stock at the quarry of the Fowler and Pay Stone Company at Mankato.

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 every section, when thus magnified, the main mass was gray. In one set there were minute red specks, evidently hematite (Fe_2O_3), and in the other yellow grains, apparently limonite ($2Fe_2O_3 \cdot 3H_2O$). It appears, therefore, that the variation in color is due rather to the degree of hydration than to oxidation in 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.

Textural varieties. — The texture as well as the color of stone is given serious consideration by present-day architects. A good example of this tendency is found in the growing demand for stone that is classed as "Old Gothic." Such marble contains spots of coarse-grained calcite and large or small solution cavities and other markings. The Mankato-Kasota stone exhibits a wide textural range. (See Plates 7–12.) The massive



Photograph by C. R. Stauffer

FIGURE 68. — Quarry of the T. R. Coughlan Stone Company at Mankato.

ledges are fine and even grained, but several of the yellow and pink beds contain solution cavities, most of which are open. Some, however, are partially filled with secondary calcite. Some of the cavities are so uniformly spaced that the rock is referred to as travertine. An excellent example of the use of the coarse-textured yellow variety may be seen in the interior walls of the library of the University of Minnesota.

Recommendations for exterior use. — Any limestone or marble is subject to efflorescence when used on an exterior wall surface. In order to prevent such reactions, the following procedure is recommended:

After the stone is cut and before it is set it should be waterproofed on the back with one coat of paint manufactured for that purpose. After this has set another coat is applied. Then the stone is thoroughly parged with non-staining setting mortar. This prevents stain from coming

PHYSICAL PROPERTIES OF THE LIMESTONES AND DOLOMITES OF MINNESOTA USED FOR BUILDING STONE *

Kind of Rock	Compressive Strength (lbs. per sq. in.)				Shearing Strength (lbs. per sq. in.)		Transverse Modulus of Rupture (lbs. per sq. in.)		Impact Height, Perpendicular (cm.)	Per Cent Absorption		Per Cent Porosity by Volume	Weight (lbs. per cu. ft.)
	Dry		Wet										
	Parallel	Perpendicular	Parallel	Perpendicular	Parallel	Perpendicular	Parallel	Perpendicular		Weight	Volume		
Kasota Pink Fleuri	17,900	21,300	14,800	16,000	2,590	2,940	1,865	1,995	4	3.3	8.3	9.5	158
Kasota Yellow Fleuri	11,300	12,000	8,100	10,500	2,290	2,690	645	1,230	4	5.0	12.2	13.5	152
Kasota Golden Buff	10,000	15,000	7,600	10,800	2,220	3,130	1,370	1,450	4	3.9	9.8	...	157
Kasota Pink Buff	14,300	15,200	10,400	12,000	3,120	3,080	1,710	1,710	3	3.4	8.6	...	158
Mankato Gray	13,300	10,700	7,800	10,400	1,820	2,210	....	1,155	3	3.6	8.8	12.3	155
Mankato Cream	13,000	14,500	9,900	12,900	2,720	3,130	1,590	1,565	4	4.4	10.7	12.9	153
Kato	13,000	14,200	9,700	11,800	2,440	3,140	1,140	1,650	4	3.0	7.5	9.6	159
Mantorville Buff Travertine	12,600	11,700	11,100	10,300	2,590	2,240	1,215	1,080	3	4.7	11.3	14.8	151
Mantorville Blue Travertine	11,200	11,500	8,400	7,600	2,320	2,680	1,290	1,360	4	5.2	12.2	17.0	147
Winona Cream	8,900	17,000	8,800	12,500	2,460	2,240	550	960	4	2.9	7.2	9.8	158
Winona Gray	12,600	11,100	14,100	12,000	1,940	2,350	840	1,240	3	3.2	7.8	14.9	152
Winona Buff	8,700	9,600	9,050	8,800	1,480	1,490	780	705	2	4.5	10.9	13.7	151

* Averages based on cylindrical test specimens. Data derived from D. W. Kessler and W. H. Sligh, *Physical Properties of the Principal Commercial Limestones Used for Building Construction in the United States* (United States Bureau of Standards, Technological Paper 349, 1927). For weathering tests see page 44 of the present bulletin.

through the rock from the cement mortar used in the brick work and stops efflorescence, which causes disintegration.

Mankato and Kasota stone has been used for the exterior cut stone work in the following prominent buildings constructed between 1924 and 1930.*

	Number of Carloads	Number of Cubic Feet	Approximate Value at Time of Construction
Art Museum, Philadelphia	855	350,000	$1,500,000.00
Cathedral, Springfield, Illinois	100	40,000	195,000.00
Ponchartrain Club, Detroit	60	24,000	110,000.00
Savings Bank, Rochester, New York	40	16,000	80,000.00
City Hall, Buffalo, New York	100	42,000	190,000.00
Christian Scientist Church, Detroit	30	12,000	45,000.00
Building at 2 Park Ave., New York	30	12,000	50,000.00
Eagles Club, Milwaukee	30	12,000	45,000.00
Union Trust Building, Detroit	55	22,000	85,000.00
Total	1,300	530,000	$2,300,000.00

The following table shows the sales of limestone at Mankato and Kasota over a ten-year period:

LIMESTONE SOLD BY PRODUCERS AT MANKATO AND KASOTA, 1921–30 *

Year	Rough and Dressed Building Stone		Other		Total	
	Cubic Feet	Value	Short Tons	Value	Short Tons (Approximate)	Value
1921	111,487	$271,230	32,627	$41,409	41,500	$312,639
1922	151,110	261,275	29,910	32,329	42,600	293,604
1923	138,890	312,911	33,980	34,867	44,900	347,778
1924	130,660	495,036	46,610	43,152	65,560	538,188
1925	320,050	586,451	66,060	60,179	91,380	646,630
1926	245,330	638,284	58,050	32,655	77,410	670,939
1927	199,640	414,350	41,990	26,766	57,760	441,116
1928	184,610	339,291	30,900	19,850	45,560	359,141
1929	230,290	495,895	38,410	22,962	56,590	518,857
1930	241,400	451,683	50,170	42,193	68,420	493,876

* From *Mineral Resources, 1930* (United States Geological Survey).

Below is a representative list of buildings in which Mankato-Kasota stone was used.

Northwestern Bell Telephone Building, Minneapolis
Post Office, Minneapolis
Post Office, St. Paul
Northern States Power Company, St. Paul
Administration Building, St. Thomas College, St. Paul
Art Museum, Philadelphia
Department of Commerce Building (interior), Washington, D. C.
Wisconsin State Capitol (interior), Madison, Wisconsin
Cream of Wheat Building, Minneapolis
Daily News Building, Oklahoma City
Young-Quinlan Building, Minneapolis
Hotel Lowry (interior), St. Paul

* Compiled by John Smith of Minneapolis.

Union Trust Building, Detroit
Stock Exchange, Detroit
Manufacturers Trust Building, New York
Cathedral, Springfield, Illinois
Christian Science Church, Detroit
City Hall, Buffalo, New York
Savings Bank, Detroit
Eagles Club, Milwaukee
Women's Club, St. Paul
Ponchartrain Club, Detroit
Smith Building, Buffalo, New York
Art Museum Court, Kansas City, Missouri
Post Office, Bay City, Michigan
Post Office, Flint, Michigan
Basilica of St. Mary (interior), Minneapolis
Library, University of Minnesota (interior), Minneapolis
Cathedral (interior), St. Paul
Milwaukee Journal Building, Milwaukee
Auditorium (interior), St. Paul
Kasota Block, Minneapolis
Minnesota State Capitol (interior), St. Paul
Library, Carleton College, Northfield, Minnesota
Union Depot, Kansas City, Missouri
St. Mark's Episcopal Church, Minneapolis
Post Office, Mankato, Minnesota
Post Office, Faribault, Minnesota
Post Office, Davenport, Iowa
Post Office, Cedar Rapids, Iowa
Post Office, Aurora, Illinois
Auditorium (interior), Minneapolis
University Baptist Church, Minneapolis
Northwestern Bell Telephone Building, Albert Lea, Minnesota
State Hospital, Fergus Falls, Minnesota
Guild Hall, St. Paul

Inactive and Abandoned Quarries in the Mankato-Kasota Region

Blue Earth County

T. 109 N., R. 28 W., SE¼ Sec. 33, near Judson Post Office, St. Lawrence dolomite. Winchell,* 1:446.
T. 109 N., R. 26 W., NW¼ Sec. 20, Oneota dolomite. Bowles,† p. 154.
T. 109 N., R. 26 W., SW¼ Sec. 20, Oneota. Winchell, 1:446.
T. 109 N., R. 26 W., SE¼ Sec. 19, Oneota. Winchell, 1:446.
T. 108 N., R. 28 W., Sec. 3, southeast of Judson post office, St. Lawrence. Winchell, 1:446.
T. 108 N., R. 26 W., SW¼ Sec. 6, Shakopee. Winchell, 1:447.
T. 108 N., R. 26 W., NW¼ Sec. 6, Shakopee. Winchell, 1:447.
T. 107 N., R. 27 W., NE¼ Sec. 11, Shakopee. Winchell, 1:447.
T. 107 N., R. 27 W., NE¼ SW¼ Sec. 12, Shakopee. Winchell, 1:447.
T. 107 N., R. 27 W., SW¼ SW¼ Sec. 12, Shakopee. Winchell, 1:448.
T. 107 N., R. 27 W., SE¼ SW¼ Sec. 12, Shakopee. Winchell, 1:448.
T. 107 N., R. 27 W., NW¼ Sec. 13, Shakopee. Winchell, 1:448.
T. 107 N., R. 26 W., Sec. 18, Shakopee dolomite. Winchell, 1:448.
T. 107 N., R. 26 W., Sec. 19, Shakopee dolomite. Winchell. 1:448.
About 3 miles northeast of Mankato, McClure and Widell Quarry, Oneota dolomite. Bowles, p. 155.
1½ miles northeast of Mankato, Jefferson and Willard quarries, Oneota dolomite. Bowles, p. 156.
Same location as above on opposite side of ravine.
City of Mankato, many old pits along the bluffs.
Southwest of Mankato along Blue Earth River, several pits.
North Mankato, 30 rods west of north end of Front Street, Shakopee dolomite. Winchell, 1:447.

Le Sueur County

T. 111 N., R. 26 W., near Ottawa, Oneota dolomite. Bowles, p. 180.
T. 111 N., R. 26 W., near Ottawa, Jordan sandstone. Bowles, p. 210.
T. 110 N., R. 26 W., Sec. 21, near St. Peter, Oneota dolomite. Bowles, p. 181.

Nicollet County

T. 109 N., R. 29 W., near Courtland, quartzite. Bowles, p. 202.
T. 109 N., R. 29 W., Sec. 27, Jasper conglomerate. Bowles, p. 202.
T. 108 N., R. 27 W., in North Mankato, Oneota dolomite. Bowles, p. 182.

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* *The Geology of Minnesota* (Final Report of the Minnesota Geological and Natural History Survey, St. Paul, 1884–1901).

† *The Structural and Ornamental Stones of Minnesota* (United States Geological Survey Bulletin 663, 1918).

Southwest corner of Faxon Twp., St. Lawrence. Bowles, p. 182.
South boundary of Nicollet Twp. near Hebron. Winchell, 2:176.
In Belgrade, opposite Mankato, Oneota dolomite. Winchell, 2:176.
2 to 3 miles below New Ulm, group of quarries in the quartzite. Winchell, 2:176.
2 miles southwest of St. Peter, near the asylum, Oneota dolomite. Bowles, p. 182.
In city of St. Peter along the valley, group of quarries in Oneota dolomite. Winchell, 2:177.
1½ miles west of Fort Ridgely in bottomland, porphyritic granite. Winchell, 2:176.

The Winona Region

Winona is located in the so-called "driftless area," but a large portion of the high ground is loess-covered, and thus a large part of what would probably be outwash and residual soils is obliterated. In general the bed rock is close to the surface and ranges from the Cambrian sandstones to late Middle Ordovician beds.

The Oneota dolomite caps the bluffs along the Mississippi River throughout the region and forms the prominent walls of the picturesque valleys leading away from the river. It has been quarried in a number of places, especially in the vicinity of Winona, and furnishes a good grade of cut stone and crushed rock.

The following rocks crop out in this area:

Pleistocene —	Drift and loess
Ordovician —	Platteville limestone
	St. Peter sandstone
	Shakopee dolomite
	New Richmond sandstone
	Oneota dolomite
Cambrian —	Jordan sandstone
	St. Lawrence formation (limestone, sandstone, and shale)
	Franconia sandstone
	Dresbach sandstone

The Cambrian rocks, except the Dresbach sandstone, are extremely loose and crumbly and are consequently unfit to be used for structural purposes.

The Oneota dolomite is the most important formation from an economic point of view. The thickness of the rock where it is quarried ranges from 18 to 60 feet in the vicinity of Winona and reaches 100 feet at Minneiska and Lamoille. It lies in beds from 1 to 6 feet thick. The dip is low, not more than one to three degrees, and is variable in direction, though generally south or east. Joints are in general at right angles and are from 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 and buff. 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 light colored limestone is of better grade than the gray, but it 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.

The accompanying table shows partial analyses of typical Oneota dolomite from the Winona region.

Analyses of Oneota Dolomite from the Winona Region *

Sample	Insoluble Silica, etc.	Oxides (Iron, etc.)	Total Insoluble	CaO	$CaCO_3$	MgO	$MgCO_3$
84	73.6	0.2	73.80	14.8	26.4	0.1	0.2
85	15.9	1.2	17.10	28.7	51.3	15.0	31.4
86	3.2	0.6	3.80	30.8	55.0	19.7	41.2
87	10.6	1.2	11.80	27.5	49.1	18.4	38.5

* Compiled from Stauffer and Thiel, *The Limestones and Marls of Minnesota* (Minnesota Geological Survey Bulletin 23, University of Minnesota Press, Minneapolis, 1933).

84. Oneota dolomite, Winona, Winona County. Sample from bed of arenaceous dolomite, gray to brown, in the Sugar Loaf section.
85. Oneota dolomite, Winona, Winona County. Sample from a bed of slightly arenaceous dolomite, with an oolitic texture in part, in the Sugar Loaf section.
86. Oneota dolomite, Winona, Winona County. Sample from a bed of fine-grained, laminated, arenaceous pink dolomite in the Sugar Loaf section.
87. Oneota dolomite, quarry of the Carney Cement Company (Pilgrims Rest Cemetery), Mankato, Blue Earth County. Sample from a bed of massive, buff-colored dolomite with splotches of pink.

Biesanz Stone Company quarries.—The Biesanz Stone Company owns a 900-acre tract 3 miles northwest of Winona on which are a large gravel pit, rock quarries, a screening and crushing plant, and a finishing plant for building stone (see Figure 69). The various plants, quarries, and pits are all connected with a standard gauge railroad track which connects with three railroad systems, affording excellent facilities for shipment to all parts of the country.

Section of the Quarry of the Biesanz Stone Company, 3 Miles Northwest of Winona
(Measured by C. R. Stauffer)

	Thickness
Residual	
5. Mantle rock consisting of sandy clay soil and broken rock	4 ft. 8 in.
Oneota Dolomite	
4. Dolomite, arenaceous, massive, laminated, porous, white to buff and yellow. Contains some flint nodules	11 ft. 6 in.
3. Dolomite, very porous, soft, gray to yellow. Contains flint nodules	3 ft. 11 in.
2. Dolomite, fine grained, crystalline, very porous, hard, tough; the best building stone. Contains flint nodules	3 ft. 8 in.
1. Approximate distance of Mississippi River level below quarry floor	300 ft. 0 in.

Originally the main product of the Biesanz Stone Company was crushed rock, sand, and finely ground limestone for soil fertilizing. Recently, however, the company began to produce a porous dolomite which is sold under the trade name "Winona Travertine." (See Figure 70.) This stone is somewhat similar in texture to the celebrated travertine stone quarried in Italy and shipped to many parts of the world for building purposes. Perhaps the principal difference between the Italian travertine and the product of the Biesanz Stone Company is that when the

Italian stone is first quarried it is quite soft and easily worked, then hardens on exposure. Winona Travertine, on the other hand, is an extremely hard rock when quarried and remains hard, being practically unaffected by climatic extremes. It has been used for interior and exterior construction; is impervious to grease or stain; and in spite of its picturesquely pitted surface, is highly resistant to frost.

FIGURE 69. — Finished architectural stone in the yard of the Biesanz Stone Company at Winona.

A number of different color and textural varieties are fabricated. Cream, buff, and gray are the common colors. The rock is also broken along the natural seams or bedding planes and sold as "seam face" dolomite. (See Figure 71.) The more granular beds are classed as "sandy travertine." All the above varieties are excellent products that should continue to be in demand for architectural purposes.

The following are the results of physical tests made by the United States Bureau of Standards:

1. CREAM COLORED TRAVERTINE

Compressive strength (lbs. per sq. in.)

Specimens dry, perpendicular to bedding, average of 4 tests	17,000
Specimens dry, parallel to bedding, average of 4 tests	8,900
Specimens wet, perpendicular to bedding, average of 4 tests	12,500
Specimens wet, parallel to bedding, average of 5 tests	8,800

Transverse tests (lbs. per sq. in.)	
Modulus of rupture, perpendicular to bedding, average of 2 tests	960
Modulus of rupture, parallel to bedding, average of 2 tests	550
Percentage of absorption by weight, average of 12 tests	2.88
Porosity (percentage by volume)	9.8
Apparent specific gravity, average of 12 tests	2.53
Weight when dry (lbs. per cu. ft.)	158

2. Gray Travertine

Compressive strength (lbs. per sq. in.)	
Specimens dry, perpendicular to bedding, average of 5 tests	11,100
Specimens dry, parallel to bedding, average of 3 tests	12,600
Specimens wet, perpendicular to bedding, average of 4 tests	12,000
Specimens wet, parallel to bedding, average of 4 tests	14,100
Percentage of absorption by weight, average of 12 tests	3.20
Porosity (percentage by volume)	14.9
Apparent specific gravity, average of 12 tests	2.43
Weight when dry (lbs. per cu. ft.)	152

3. Buff Travertine

Compressive strength (lbs. per sq. in.)	
Specimens dry, perpendicular to bedding, average of 4 tests	9,600
Specimens dry, parallel to bedding, average of 3 tests	8,700
Specimens wet, perpendicular to bedding, average of 3 tests	8,800
Specimens wet, parallel to bedding, average of 3 tests	9,000
Transverse tests (lbs. per sq. in.)	
Modulus of rupture, perpendicular to bedding, average of 2 tests	710
Modulus of rupture, parallel to bedding, average of 2 tests	780
Percentage of absorption by weight, average of 12 tests	4.52
Porosity (percentage of volume)	13.7
Apparent specific gravity, average of 12 tests	2.41
Weight when dry (lbs. per cu. ft)	151

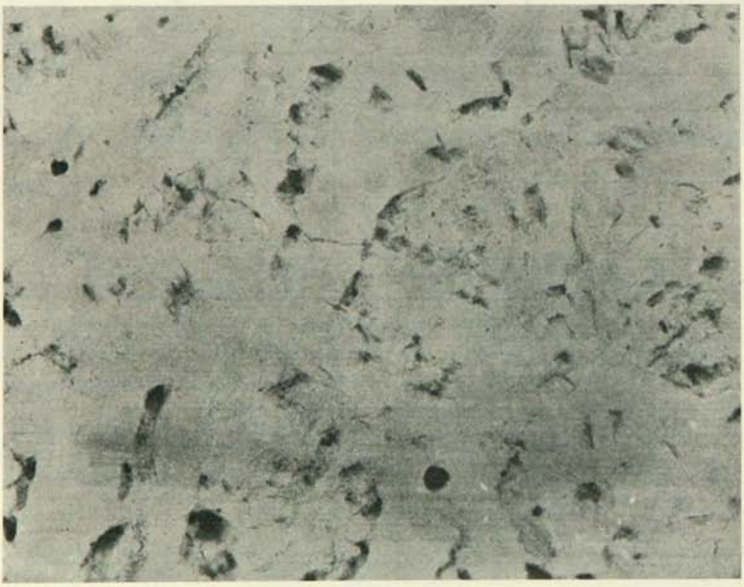
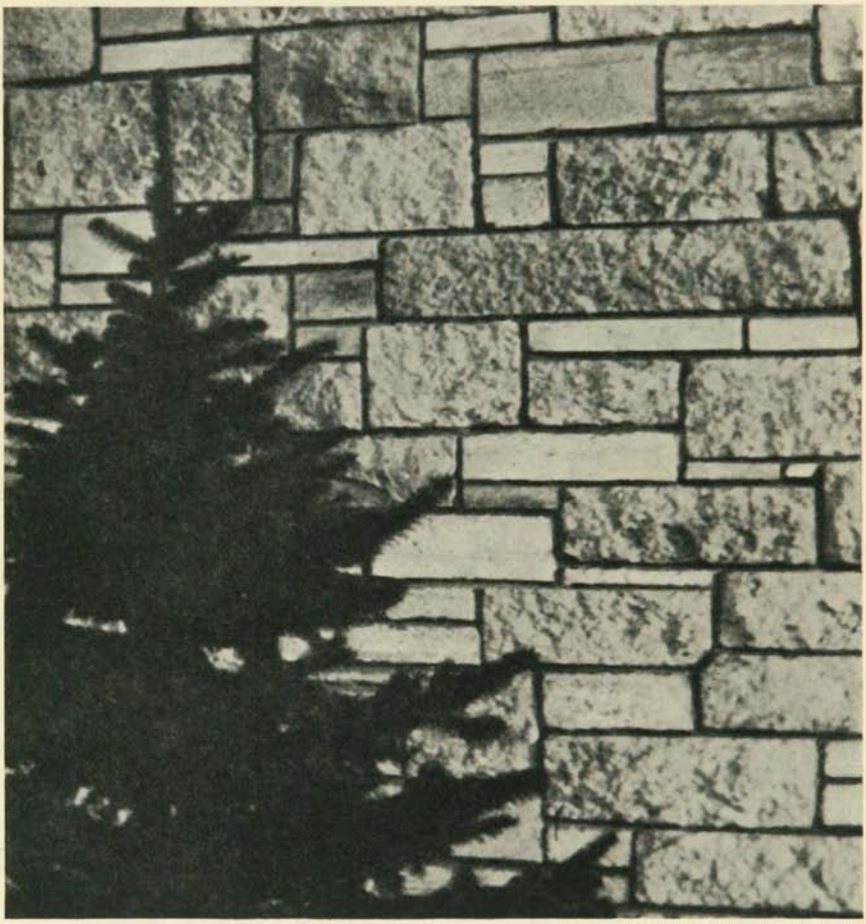


Figure 70. — A sawed surface of Winona Travertine, showing its pitted texture. Approximately natural size.

The Biesanz Stone Company also prepares stone chips for terrazzo work. (See Figure 72.) It is said to be the only company in the United States that produces travertine chips. Similar chips, called "Granedo," are produced by the Italian travertine quarries and marketed in the United States. The Winona stone is peculiarly adaptable to this use.



Courtesy Biesanz Stone Co.

FIGURE 71. — Wall of a building showing the use of both sawed and seam-face Winona stone in the same wall. A pleasing variation in texture is produced.

Small pieces do not chip or splinter, and the fragments may be readily "worked down" in finishing the terrazzo after it has been installed. This product has been sold to many contractors in widely separated areas in the United States. A typical installation may be seen in the Young-Quinlan Building in Minneapolis. It is very desirable also for floors in

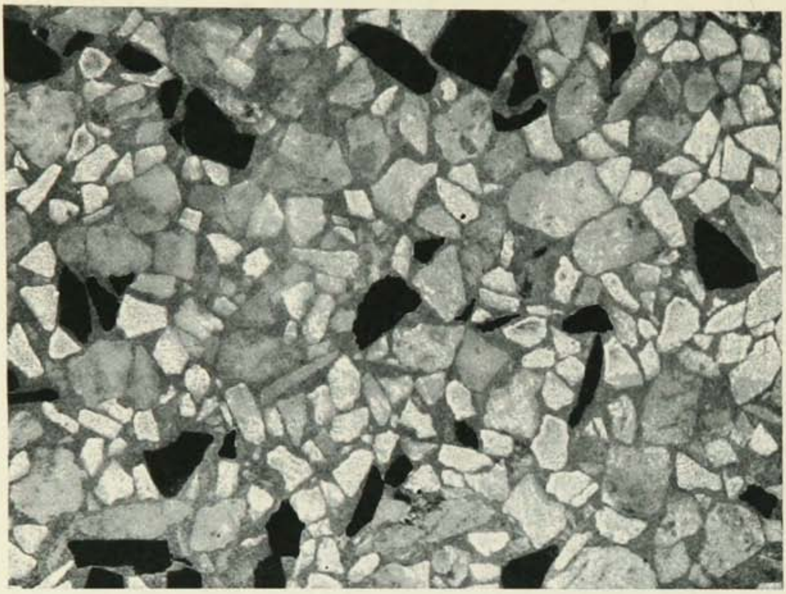


FIGURE 72. — Terrazzo chips prepared by the Biesanz Stone Company at Winona.

hospitals and other institutions. The University Hospital at Iowa City contains 250,000 square feet of terrazzo floors made with chips of Winona Travertine.

The following is a partial list of buildings in which Winona Travertine has been used:

Harkness Memorial, Yale University, New Haven, Connecticut
Peter Stuyvesant Hotel, New York
Federal Reserve Bank Building, Minneapolis
Liggett Building, New York
Garment Center Capitol, New York
Auditorium of Metropolitan Life Insurance Building, New York
Lumber Exchange, Winona, Minnesota
Chicago Trust and Savings Bank, Chicago
Telephone Exchange, Brooklyn, New York
State Teachers College, Winona, Minnesota
Belmont Hotel, Chicago
Agricultural College Library, Ames, Iowa
Dexter-Horton Bank Building, Seattle
Dunwoody Institute, Minneapolis
Michael Dowling School, Minneapolis
Mayflower Hotel, Washington, D. C.
St. Teresa Chapel, Winona, Minnesota
Connecticut Life Insurance Building, Hartford, Connecticut
Memorial Union and Tripp Commons Building, Madison, Wisconsin
Illinois Women's Reformatory, Dwight, Illinois
Women's Club, Wilmette, Illinois
Cook County Courthouse, Chicago
Constance Hall, Peoria, Illinois

INACTIVE AND ABANDONED QUARRIES IN THE WINONA REGION

WINONA COUNTY

T. 107 N., R. 10 W., Sec. 11, Oneota dolomite. Bowles,* p. 199.
T. 107 N., R. 7 W., Sec. 34, Oneota dolomite. Bowles, p. 196.
T. 106 N., R. 6 W., Sec. 12, Oneota dolomite. Bowles, p. 196.

* *The Structural and Ornamental Stones of Minnesota* (United States Geological Survey Bulletin 663, 1918).

T. 105 N., R. 4 W., Sec. 18, Oneota dolomite. Bowles, p. 198.
T. 105 N., R. 4 W., Sec. 18, Dresbach sandstone. Bowles, p. 207.
3 miles northwest of Winona, near Gilman Valley, Oneota dolomite. Bowles, p. 195.
Minnesota City, Oneota dolomite. Bowles, p. 196.
Between Stockton and Lewiston, Oneota dolomite. Bowles, p. 198.
Near Lewiston, two small quarries, Oneota dolomite. Bowles, p. 198.
Near Rolling Stone, Oneota dolomite. Bowles, p. 198.
1 mile east of St. Charles, Platteville limestone. Bowles, p. 200.
½ mile northeast of St. Charles, Platteville limestone. Bowles, p. 200.
¼ mile south of St. Charles, Platteville limestone. Bowles, p. 200.

WABASHA COUNTY

T. 111 N., R. 12 W., Sec. 6, Oneota dolomite. Bowles, p. 192.
2 miles southeast of Minneiska station, Oneota dolomite. Bowles, p. 196.
3 miles south of Plainview, on Whitewater River, Platteville limestone. Bowles p. 190.
Near Mazeppa, Oneota dolomite. Bowles, p. 190.
Near Millville, Oneota dolomite. Bowles, p. 190.
Near Reads Landing, three quarries, Oneota dolomite. Bowles, p. 190.
Near Wabasha, St. Lawrence formation. Bowles, p. 190.
1½ miles from Lake City, Oneota dolomite. Bowles, p. 191.

THE MANTORVILLE REGION

A number of different strata of Ordovician limestone crop out along the tributaries of the Zumbro River in Dodge County. These have been quarried in many localities but most extensively at Mantorville and Wasioja. The following formations crop out in this region:

Pleistocene — Drift and loess
Ordovician — Galena limestone
Decorah shale
Platteville limestone
St. Peter sandstone
Shakopee limestone

In the village of Mantorville a quarry formerly operated by the Pierson Stone Company shows the following ledges:

SECTION OF THE QUARRY OF THE PIERSON STONE COMPANY AT MANTORVILLE
(Measured by C. R. Stauffer)

	THICKNESS
6. Drift	15 ft. 0 in.
GALENA (STEWARTVILLE) DOLOMITE	
5. Dolomite, massive, gray to buff	20 ft. 0 in.
4. Dolomite, thin to medium beds, gray to buff	7 ft. 9 in.
3. Dolomite, thin bedded to shaly, gray to brown	6 ft. 6 in.
2. Dolomite, gray, 6- to 14-inch beds	5 ft. 6 in.
1. Covered interval to level of river	20 ft. 0 in.

The rock is a yellow to buff dolomitic limestone. Where it is not exposed to weathering agencies it is bluish gray in color. Because of the numerous solution pits it has a vesicular texture. For this reason the finished stone is marketed as travertine. Two-color varieties of the Mantorville Stone Company are sold under the trade names "Blue Mantorville Travertine" and "Cream Mantorville Travertine." Both are high-grade building stones.

Both crushed stone and structural stone are produced at the Mantorville Stone Company quarry, which is owned by Frank P. McDonough.

The accompanying tabulation of physical properties gives the results of tests on samples from this quarry, as made at the laboratory of the Minnesota Highway Department. Sample 1 is from the lower 10 feet of the quarry. Sample 2 was taken from the upper 35 feet of the quarry.

Sample	Sp. Gr.	Wt. per Cu. Ft.	Per Cent Absorption	Per Cent Wear	French Coef.	Average Toughness
1.	2.31	144	4.1	11.7	3.42	5.0
2.	2.34	146	5.6	8.8	4.55	6.0

Partial analyses of these samples show the following chemical composition:

Sample	Total Insoluble	$CaCO_3$	$MgCO_3$
1.	18.05	49.38	31.12
2.	11.58	52.93	32.58

The Faribault-Northfield Region

The cities of Faribault and Northfield are located in Rice County. The western half of this county is completely covered by drift, as is the high area forming the southeastern part. But along the Straight River and in the whole northeastern part of the county, bed rock is near the surface.

The Shakopee dolomite has been quarried at Northfield. In fact, some of the basements in the town were quarried out of solid rock. The quarrying industry never attained importance in this region, however, and quarries that were opened have long been abandoned.

The Platteville limestone was formerly quarried near Dundas, and one of the early buildings at Carleton College (Willis Hall) was constructed of stone taken from that region. The Platteville, including the basal layers of the Decorah, has been quarried for many years in and near Faribault.

The following partial analyses of samples from this region were made by W. Cornell:

Sample	Total Insoluble	$CaCO_3$	$MgCO_3$
1.	16.91	67.43	14.87
2.	11.11	63.75	• 19.28

Sample 1 is Platteville limestone from the 10-foot face exposed in the State Quarry at Faribault; sample 2 is Platteville limestone from the 21-foot face exposed in the State Hospital Quarry at Rochester.

The Comer Quarry, located along Fall Creek 2 miles east of Faribault, now owned by Mr. Jaeger, formerly supplied much building stone. This was used in a number of buildings in Faribault, including several of the buildings of Shattuck Military Academy. One or two of the lower limestone layers in the Decorah shale are exceedingly hard and compact. These have been polished and used as marble.

The workable ledge in this quarry is 11 feet thick. Below the stripping of 6 inches to 6 feet of soil, four beds, 12, 8, 10, and 9 inches in thickness, have been used for the manufacture of lime. 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 are from 6 to 10 feet apart. A little iron stain which was observed originates in the bedding planes of the upper strata. This quarry is now abandoned, although it still contains great quantities of available limestone.

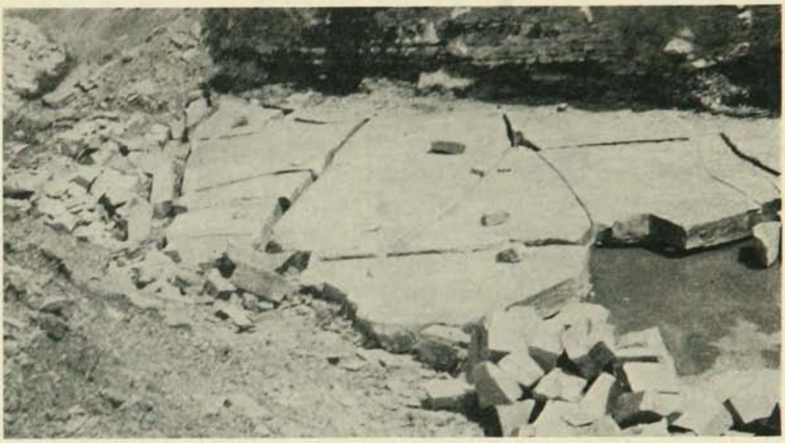


FIGURE 73. — The "marble" ledge at Lieb's Quarry, Faribault. The fracture pattern produces irregular slabs.

A test of a general sample gave the following data: * specific gravity, 2.64; weight per cubic foot, 165; percentage of absorption, 1.5; percentage of wear, 3.3; French coefficient, 12.2; average toughness, 15.25.

Lieb's Quarry, Faribault. — A quarry of the shelf type is being operated by George Lieb in the bluff on the east side of the Straight River in Sec. 3, T. 109 N., R. 20 W., about 3/4 of a mile southeast of Faribault. (See Figure 73.) The geologic formations exposed in this quarry are as follows:

SECTION OF THE GEORGE LIEB QUARRY ON THE STRAIGHT RIVER, 3/4 MILE SOUTH OF FARIBAULT

(Measured by C. R. Stauffer)

	THICKNESS
18. Drift, full of bowlders	50 ft. 0 in.
DECORAH SHALE	
17. Shale, blue, alternating with 4-inch layers of fossiliferous gray limestone	12 ft. 0 in.
16. Limestone, fossiliferous, hard, gray to brown. The "marble" layer	1 ft. 0 in.
15. Shale, brown	0 ft. 1 in.
14. Shale, light gray to green, argillaceous. An altered bentonite	0 ft. 3 in.
13. Limestone, bluish, gray to brown	2 ft. 2 in.

* Stauffer and Thiel, *op. cit.*, p. 38.

12. Shale, brown to bluish, fucoidal at base	0 ft. 7 in.
Platteville Limestone	
11. Limestone, bluish	7 ft. 0 in.
10. Shale, soft, blue, argillaceous	1 ft. 4 in.
9. Limestone, argillaceous, blue	5 ft. 3 in.
Glenwood Beds	
8. Shale, argillaceous, bluish to brown. Some sand grains	2 ft. 0 in.
7. Sandstone, brown, iron-stained	0 ft. 7 in.
6. Shale, soft, argillaceous, blue	1 ft. 0 in.
5. Shale, soft sandy clay, blue to yellow	0 ft. 4 in.
4. Shale, argillaceous, blue to green with some sand grains	1 ft. 4 in.
3. Sandstone, calcareous, blue with much pyrite	0 ft. 8 in.
2. Shale, lumpy, blue	4 ft. 0 in.
St. Peter Sandstone	
1. Sandstone, yellow to white, to level of the Straight River	11 ft. 10 in.

Approximately 60 feet of material (layers 17 and 18) must be removed at this location in order to expose the desired ledges. (See Figure 74.) This thick overburden makes stripping rather expensive. The "marble" layer (number 16) is usually dense, but some discontinuous fossiliferous horizons are present. Small veinlets and spots of pyrite were observed in this layer. Only a few joints are well developed, of which the major ones trend N. 85° E. and the secondary ones N. 10° W. Most of the layer is split along these two directions into large rectangular blocks, and these are then subdivided into desired sizes and shapes.

Rock from this ledge was sawed and used in the Faribault Courthouse. The rock seems to chip easily, as may be observed in the cut stone in the building. Because of the slight thickness of this layer, slabs of large area were sawed parallel to the bedding and were set on edge when placed in the wall. Such a position in exterior work is not favorable for this type of rock. Moreover, some of the rock contains pyrite veinlets, and this will become badly discolored when subjected to weathering.

The bluish-gray limestone which lies below the "marble" layer is quarried also and is used as hammer-finished building blocks. The ledges are not uniform in color but are of light and dark gray varieties. The variation in color makes it unprofitable to attempt separate quarry types, and may therefore limit the use of the stone. The color of the rock along joints has been changed to buff by weathering processes. If it is to be useful for building purposes it is desirable that such stained zones be removed to make the color more nearly uniform. From the lower ledge, blocks suitable for sawing and finishing into banded gray building stone may be obtained. This rock is used in a number of buildings of the Shattuck Military Academy. It is also used in the schools for the blind, the feeble-minded, and the deaf at Faribault.

Twin Cities Region

Most of the region around St. Paul and Minneapolis is heavily drift-covered. Along the valleys of the Mississippi and Minnesota rivers, however, the bed rock is at the surface or so near the surface that it crops out at numerous places along the steep bluffs. The exposed rocks include all the geologic formations from the Oneota dolomite to the Galena (Prosser) limestone. Numerous quarries have been opened in the limestone beds, but only a few are active at the present time. The chief product of those that are active is crushed stone for concrete and ballast. Some of the finely ground tailings are used for liming acid soil and for other agricultural purposes.

Minnesota Crushed Stone Company quarries. — The Minnesota Crushed Stone Company operates a number of quarries at 1500 Johnson Street N. E., Minneapolis. There the entire thickness of the Platteville limestone is exposed in the quarry wall.

FIGURE 74. — Lieb's Quarry at Faribault. An overburden 60 feet thick of glacial drift and decomposed dolomite covers the ledges.

This quarry furnishes some ground rock and some unusually fine building stone. The stone must be carefully selected and laid to produce a pleasing and satisfactory wall. The best building stone comes from the buff beds of the upper 7½ feet of the Platteville formation. The main product of this quarry, however, is crushed rock for con-

PHYSICAL PROPERTIES OF ROCK FROM THE QUARRY OF THE MINNESOTA CRUSHED STONE COMPANY, MINNEAPOLIS *

Sample	Sp. Gr.	Wt. per Cu. Ft.	Per Cent Absorption	Per Cent Wear	French Coef.	Average Toughness
1	2.67	167	0.80	3.08	13.07	11.5
2	2.61	163	2.98	3.10	12.90	12.0
3	2.56	160	3.73	3.70	9.25	12.5
4	2.64	165	1.56	5.00	8.00	9.5
5	2.53	158	4.53	4.50	8.88	14.0

* Compiled from Stauffer and Thiel, *The Limestones and Marls of Minnesota* (Minnesota Geological Survey Bulletin 23, University of Minnesota Press, Minneapolis, 1933), p. 25.

Section of the Minnesota Crushed Stone Company's Quarry
(Johnson Street Quarry, Minneapolis)
(Measured by C. R. Stauffer)

	Thickness
Recent	
7. Soil and river gravel	4 ft. 0 in.
Pleistocene (Early Wisconsin)	
6. Red drift	8 ft. 0 in.
Decorah Shale	
5. Limestone, hard, semicrystalline, gray to brown with calcite and pyrite cavity fillings	1 ft. 4 in.
Platteville Limestone	
4. Limestone, buff to gray, dolomitic, with numerous fossils in "nests" or lenticular streaks. Physical test sample no. 3. Also physical test sample no. 5 taken 7 inches above base	7 ft. 5 in.
3. Limestone, shaly, blue to gray	0 ft. 10 in.
2. Limestone, argillaceous, blue to slate colored. Shows conchoidal fracture. Poor in fossils. Physical test general sample no. 2	5 ft. 4 in.
1. Limestone, hard, irregular thin laminae with shaly partings. Fossils abundant. Physical test general sample no. 1. Also physical test sample no. 4, 5 feet above the floor of the quarry	11 ft. 4 in.

crete and ballast. The table on page 139 shows the physical properties of the rock.

In St. Paul along Stewart and Victoria avenues the St. Paul Crushed Stone Company controls a large acreage and operates on an extensive scale. The quarry is located on a rock terrace one hundred feet above the river, in the lower portion of the Platteville limestone. Although some of this rock has been used as a local building stone, the chief product of the quarry is crushed stone. The accompanying table gives the physical properties of the rock.

Physical Properties of Rock from the Quarry of the St. Paul Crushed Stone Company *

Sample	Sp. Gr.	Wt. per Cu. Ft.	Per Cent Absorption	Per Cent Wear	French Coef.	Average Toughness
1	2.60	162.50	1.20	4.20	9.52	14.00
2	2.63	164.00	1.78	3.10	12.90	11.50
3	2.54	159.00	3.01	5.00	8.00	10.50

* Compiled from Stauffer and Thiel, *The Limestones and Marls of Minnesota* (Minnesota Geological Survey Bulletin 23, University of Minnesota Press, Minneapolis, 1933), p. 28.

Section of Quarry of the St. Paul Crushed Stone Company at Stewart and Victoria Avenues, St. Paul
(Measured by C. R. Stauffer)

	Thickness
7. River gravels, sand and clay	3 ft. 0 in.
Platteville Limestone	
6. Limestone, thin bedded, white mottled with gray streaks. Physical test sample no. 3	3 ft. 0 in.

5. Limestone, light gray mottled with white, compact and abundantly fossiliferous	4 ft. 0 in.
4. Limestone, gray, often mottled with lighter color, fossiliferous. Contains small grains of pyrite and marcasite. Physical test sample no. 1	3 ft. 0 in.
GLENWOOD BEDS	
3. Shale, blue to green, often sandy	4 ft. 0 in.
ST. PETER SANDSTONE	
2. Sandstone, white, exposed in excavations in the city adjacent to the quarry	15 ft. 0 in.
1. Covered interval to the level of the Mississippi River	110 ft. 0 in.

The Twin City Brick Company operates a quarry in the river bluff in West St. Paul. The Decorah shale serves as the source of clay for the manufacture of brick and other clay products. No stone is quarried for structural purposes.

At Hastings both the Oneota and Shakopee dolomites are well exposed and some attempt has been made in recent years to utilize them. The region is faulted and otherwise disturbed so that the Cambrian sandstones are locally exposed. The Hastings Stone Company has taken advantage of the river bluff about 3 miles southeast of town, locating its quarry where a minimum of stripping is necessary and where gravity may be used for transporting the stone to the crusher and to the tracks below.

Northwest of Hastings between Nininger and Spring Lake there is a continuous bluff along the Mississippi River. The bluff ranges in height from 50 to 150 feet, of which the lower 20 to 30 feet are Jordan sandstone and the remainder Oneota dolomite. The rock is a porous, light gray to buff dolomite. In most places the formation has a well-defined bedding that is generally spaced at intervals of from 2 to 5 feet. Some joints are present and are locally so spaced as to make the face undesirable as a dimension-stone prospect.

Although a few large slabs were observed near Nininger, most of the quarried rock was used for riprap in river improvement. Quarry operations in former years removed a width of 10 to 25 feet from the bluff face for over a half mile near Nininger, but later work has been confined to three quarries. These are located in NE¼ NE¼ and SW¼ NW¼ Sec. 13 and in NE¼ NE¼ Sec. 23, T. 115 N., R. 18 W.

Formerly the Oneota dolomite was extensively quarried at Stillwater and at Frontenac, and many local buildings are constructed of the stone. The industry declined, however, and the quarries are now abandoned. Small quarry pits, where local supplies of rock have been obtained, occur in the Oneota, the Shakopee, and the Platteville of the southern part of Washington County, but they are now all abandoned. These three formations are well suited to the ordinary types of construction and concrete work. Abandonment of the quarries is largely due to a falling off in demand and this in turn is due to the substitution of other building materials for this dolomite.

Inactive and Abandoned Quarries in the Twin Cities Area

Anoka County

T. 30 N., R. 23 W., Sec. 3, near Fridley, Platteville limestone. Winchell,* 2:422.

Dakota County

T. 115 N., R. 18 W., ¾ mile northwest of Nininger, Oneota dolomite. Bowles,† p. 158.
T. 115 N., R. 19 W., Sec. 7, Platteville limestone. Winchell, 2:83.
T. 115 N., R. 21 W., NW¼ Sec. 23, Oneota dolomite. G. M. Schwartz.‡
T. 114 N., R. 18 W., Sec. 21, Shakopee dolomite (?). Winchell, 2:74.
T. 114 N., R. 20 W., Sec. 24, Platteville limestone. Bowles, p. 160.
T. 114 N., R. 20 W., Sec. 13, Platteville limestone. Bowles, p. 160.
T. 113 N., R. 19 W., Secs. 13 and 14, on section line, Platteville limestone. Winchell, 2:83.
T. 113 N., R. 19 W., Sec. 22, Platteville limestone. Winchell, 2:83.
T. 113 N., R. 19 W., Sec. 26, Platteville limestone. Winchell, 2:83.
T. 113 N., R. 20 W., Sec. 27, Platteville limestone. Winchell, 2:83.
T. 112 N., R. 19 W., Sec. 24, Platteville limestone. Winchell, 2:74.
T. 28 N., R. 23 W., at Mendota, Platteville limestone. Bowles, p. 14.
T. 28 N., R. 23 W., SW¼ Sec. 33, on island in Minnesota River, St. Peter sandstone. Bowles, p. 210.
T. 27 N., R. 24 W., Sec. 23, Platteville limestone. Winchell, 2:82.

Hennepin County in the City of Minneapolis

Nicollet Island, Platteville limestone. Winchell, 1:175.
West bluff of the Mississippi River opposite the University of Minnesota. Winchell, 1:175.
University of Minnesota campus below Washington Avenue Bridge. Bowles, p. 169.
End of Minneapolis, St. Paul, and Sault Ste. Marie Railroad Bridge. Bowles, p. 169.
At 29th Avenue S., Platteville limestone. Bowles, p. 169.
Foot of St. Anthony Falls, Platteville limestone. Bowles, p. 169.
1131 4th Street N. E., Platteville limestone. Bowles, p. 171.
Corner 3d Street and 13th Avenue N. E., Platteville limestone. Bowles, p. 171.
5th Avenue and 5th Street N. E., Platteville limestone. Bowles, p. 172.
Near Minnehaha Park on bluff of Mississippi River, Platteville limestone. Bowles, p. 173.
T. 28 N., R. 23 W., Sec. 32, Fort Snelling Reservation, Platteville limestone.

Ramsey County in the City of St. Paul

Adrian and Hathaway Streets to Mississippi River, Platteville limestone.
N ar E. George Street, Platteville limestone. Bowles, p. 184.
Near Fort Snelling Bridge, north side of river, Platteville limestone. Bowles, p. 185.
Fort Street, Platteville limestone. Winchell, 1:173.
Dayton's Bluff, Platteville limestone. Winchell, 1:173.
West St. Paul, Platteville limestone. Winchell, 1:173.
Near State Capitol Building, Platteville limestone. Winchell, 1:173.

Washington County

T. 31 N., R. 20 W., NW¼ Sec. 19, Oneota dolomite. G. M. Schwartz.
T. 31 N., R. 20 W., NW¼ Sec. 30, Oneota dolomite. G. M. Schwartz.
T. 31 N., R. 20 W., SW¼ Sec. 32, Oneota dolomite. G. M. Schwartz.
T. 30 N., R. 21 W., SW¼ Sec. 32, shore of Long Lake, Platteville limestone. Winchell, 21:389.
T. 30 N., R. 20 W., NW¼ Sec. 20, Oneota dolomite. G. M. Schwartz.
T. 29 N., R. 20 W., SW¼ Sec. 9, Platteville limestone. Winchell, 2:389.
T. 29 N., R. 20 W., SE¼ Sec. 30, Platteville limestone. G. M. Schwartz.

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* *The Geology of Minnesota* (Final Report of the Minnesota Geological and Natural History Survey, St. Paul, 1884–1901).

† *The Structural and Ornamental Stones of Minnesota* (United States Geological Survey Bulletin 663, 1918).

‡ Personal communication.

T. 29 N., R. 20 W., SW¼ Sec. 22, Platteville limestone. Winchell, 2:389.
T. 29 N., R. 20 W., SW¼ Sec. 3, Oneota dolomite.
T. 28 N., R. 21 W., Sec. 33, Platteville limestone. Winchell, 2:389.
T. 28 N., R. 20 W., NW¼ Sec. 30, Platteville limestone. Winchell, 2:389.
T. 28 N., R. 20 W., NW¼ Sec. 31, Platteville limestone. G. M. Schwartz.
T. 27 N., R. 21 W., SW¼ Sec. 1, Platteville limestone. Winchell, 2:389.
T. 27 N., R. 21 W., SE¼ Sec. 2, Platteville limestone. Winchell, 2:389.
T. 27 N., R. 21 W., NE¼ Sec. 6, Platteville limestone. Winchell, 2:389.
T. 27 N., R. 22 W., NE¼ Sec. 1, Platteville limestone. Winchell, 2:389.
T. 28 N., R. 22 W., Sec. 25, Platteville limestone. Winchell, 2:389.
T. 27 N., R. 22 W., SE¼ Sec. 36, Platteville limestone. Winchell, 2:389.
T. 27 N., R. 21 W., NE¼ Sec. 30, Shakopee dolomite.
Near 4th Avenue and Burlington Street, Stillwater, Shakopee dolomite. Bowles, p. 192.
T. 27 N., R. 22 W., NE¼ Sec. 26, Shakopee dolomite.
Marine Ferry, Franconia sandstone. G. M. Schwartz.
St. Croix Bluff, North Stillwater near Wilkin Street, Shakopee dolomite. Bowles, p. 192.

SANDSTONES AND QUARTZITES

The value of sandstone as a building stone 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 on 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, for some forms of it alter and stain the rock. It also makes a weak cement, less durable even than 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 called a quartzite. (See the section on Metamorphic Rocks, page 19.)

The Sandstone and Kettle River Region

A buff to salmon-colored sandstone has been exposed by the downward-cutting action of the Kettle River in Pine County. At the present time precipitous bluffs more than one hundred feet high form the walls of the valley. The age of this sandstone has not been definitely determined,* but recently discovered fossil evidence indicates that it may be correlated with the Middle Cambrian.

This sandstone which is quarried extensively (see Figure 75) within the city limits of Sandstone is a portion of the Hinckley sandstone, locally known as the Kettle River sandstone. In the region of the quarry

* See C. W. Hall, "The Red Sandstone Series of Southeastern Minnesota," *Science*, 27:722 (1908); F. T. Thwaites, *Sandstones of the Wisconsin Coast of Lake Superior* (Wis-

the rock dips toward the southeast at an angle of approximately 3 degrees.

The quarrying of this rock was begun by Colonel W. H. Grant in 1885. For a number of years the rock was hauled by team up the steep rocky road out of the valley and over ten miles of rough road to Hinckley, where it was loaded onto flat cars for shipment to St. Paul and Minneapolis. The rock was used extensively for paving, curbing, and bridgestone. Later the quarry was operated by Ring and Tobin, and with the advent of direct railroad connection, stone was shipped to

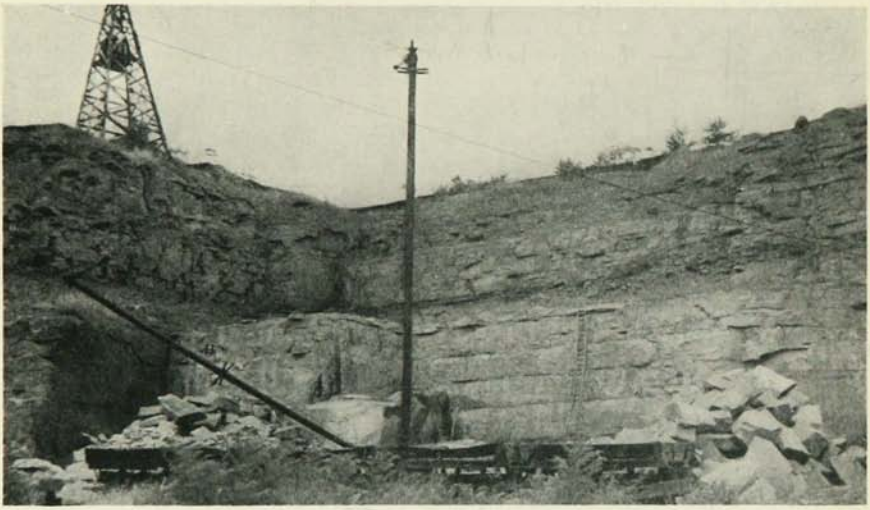

FIGURE 75. — Part of the quarry wall of the Sandstone Quarries Company at Sandstone.

Minneapolis, Omaha, Duluth, and other points. In 1893 and 1894 the Wing Dam at St. Anthony Falls was built of this stone. In 1894 the disastrous Hinckley fire destroyed the quarry equipment. The Minnesota Sandstone Company was organized in 1895, the name being changed later to the Kettle River Quarries Company. Recently the firm was reorganized, and it now operates as the Sandstone Quarries Company. The equipment has been greatly improved and extended. Kettle River furnishes power for air compressors, shops, crushers, and dynamos. Most of the rock is fabricated at the William Penn Stone Company plant near the quarry.

The quarry floor is higher than water level, and drainage is therefore perfect and rock removal easy. The face of the quarry is about 100 feet

consin Geological and Natural History Survey Bulletin 25, 1912), pp. 102–03; C. W. Hall, *Bulletin of the Geological Society of America*, 12:319 (1901); E. R. Buckley, *The Building and Ornamental Stones of Wisconsin* (Wisconsin Geological Survey Bulletin 4, Madison, 1898), p. 167; and C. R. Stauffer, "The Age of the Red Clastic Series," *Bulletin of the Geological Society of America*, 38:469 (1927).

high and over 2,000 feet long. Most of the rock is a light pink, but near the top of the quarry and in places near the bottom has a darker pink shade, with a distinctly red cast.

The Kettle River sandstone is well cemented. The mineral matter forming the cement is mainly secondary quartz that has been deposited on the original quartz grains of the sand. Small amounts of iron oxide in the form of limonite and hematite are also present. Where the limonite predominates it gives the rock a buff to yellow color, whereas hematite produces various reddish tints. The degree of cementation varies in different localities. This variation is due to differences in the textural range of the sand grains and to the position of the bed with relation to the channels of circulating ground water.

The following tests made by the United States Department of Agriculture on the Kettle River sandstone summarize its physical properties: specific gravity, 2.5; weight per cubic foot, 156 pounds; water absorbed per cubic foot, 1.23 pounds; per cent wear, 15.8; French coefficient, 2.9; hardness, 14.8; toughness, 4.0; and crushing strength,* 8,000 to 12,000 pounds per cubic foot.

The following table shows the results of chemical analyses made of sandstones of the Kettle River region.

ANALYSIS OF SANDSTONE OF THE KETTLE RIVER REGION

	1	2	3
SiO_2	97.10	98.69	78.24
Al_2O_3	2.20	1.06	10.88
Fe_2O_3	....	with Al	3.83
MgO	0.10	0.01	1.60
CaO	0.60	0.42	0.95
Na_2O	....	0.17	0.06
K_2O	....	trace	1.67

1. Sandstone from the quarry at Sandstone, Minnesota. Bowles, *The Structural and Ornamental Stones of Minnesota* (United States Geological Survey Bulletin 663, 1918).
2. Hinckley sandstone from Hinckley, Minnesota. N. H. Winchell, *The Geology of Minnesota,* 1:200 (Final Report of the Minnesota Geological and Natural History Survey, St. Paul, 1884–1901).
3. Fond du Lac sandstone. *Ibid.*, 1:202.

The Sandstone Quarries Company produces building stone, sawed slabs, flagstone, curbing, rubble and riprap, paving blocks, crushed stone, and silica sand. The finished building stone is sold under the trade names "Kettle River Standard" and "Kettle River Variegated." These architectural stones are very attractive. Because of their red, pink, and buff tints, beautiful effects may be produced. Typical installations may be seen in the Baker Building of Minneapolis (see Figure 76) and in the interior of the Hill Reference Library in St. Paul. Some of the other

* United States Arsenal test.

buildings in which the stone has been used (see Figure 77) are listed below:

Business Blocks

Gas Company Building, Eau Claire, Wisconsin
J. I. Case Building, Fargo, North Dakota
Harvester Company Building, Fargo, North Dakota
Hubinger Block, Keokuk, Iowa
Opera House, O'Neil, Nebraska
Brinker Block, Pittsburgh
Farwell, Ozmun, and Kirk, St. Paul
Clubhouse, Spokane

Courthouses

Atwood, Kansas
Benson, Minnesota
Bridgeport, Nebraska
Britton, South Dakota
Crookston, Minnesota
Elbow Lake, Minnesota
Elk Point, South Dakota
Grand Rapids, Minnesota
Gettysburg, South Dakota
Hillsboro, North Dakota

Schoolhouses

Aberdeen, South Dakota
Alliance, Nebraska
Armour, South Dakota
Bancroft, South Dakota
Bath, South Dakota
Beardsley, South Dakota
Bemidji, Minnesota
Burlington, North Dakota
Creighton, Nebraska
Dodge, Nebraska
Emerson, Nebraska
Fort Dodge, Iowa
Grinnell, Kansas

Churches

Worcester, Massachusetts
Albion, Nebraska
Alliance, Nebraska
Alta, Iowa
Bowlus, Minnesota
Brookings, South Dakota
Centerville, Iowa
Cokato, Minnesota
Dickinson, North Dakota
Fargo, North Dakota
Rolfe, Iowa
Sioux Center, Iowa
Wimbledon, North Dakota

Banks

Albion, Nebraska
Arlington, North Dakota
Bismarck, North Dakota
Brainerd, Minnesota
Brinsmade, North Dakota
Burlington, North Dakota
Cherokee, Iowa
Culbertson, Montana

Libraries

Urbana, Illinois
Aberdeen, South Dakota
Albion, Nebraska
Des Moines, Iowa
Hibbing, Minnesota
Owatonna, Minnesota
Pawnee City, Nebraska
St. Paul, Minnesota
Tecumseh, Nebraska
Woodbine, North Dakota

Railway Stations

Great Northern Union Depot, Minneapolis
Aberdeen, South Dakota
Billings, Montana
Havre, Montana
Wenatchee, Washington

City Halls

Albion, Nebraska
Rochester, Minnesota
Superior, Wisconsin

The Jasper-Pipestone Area

In Pipestone and Rock counties in southwestern Minnesota there is a red quartzite of Huronian age, known as the Sioux quartzite, which extends into eastern South Dakota and northwestern Iowa. The color of the rock varies from pale pink to deep purplish red. Interbedded with the quartzite layers are strata less indurated and in some places very clayey. One such clayey bed is noted in Indian tradition for the carved clay pipes and a variety of other trinkets made from it. This is the real "pipestone" from which the rock formation gets its name. This "pipestone" is a dense, red, indurated clay or shale, much softer than the quartzite beds above and below it.

North of the city of Pipestone the quartzite crops out extensively as two distinct types. One is an attractive deep red stone that occurs in beds rarely more than 8 inches thick; the other is a pale grayish-red stone of poorer quality. The red stone was originally an arkose. Under the microscope it is seen to consist mainly of angular quartz grains imbedded in a matrix of muscovite, feldspar, and hematite. There is very

FIGURE 76. — The Baker Building in Minneapolis. The base course is Morton granite and the upper exterior is Kettle River sandstone.

little evidence of the secondary enlargement of quartz grains by the deposition of quartz in the intergranular spaces, and for that reason the rock should be fairly easily fabricated.

Uses. — On account of its uneven and irregularly spaced joints the rock is not cut into large dimension blocks for structural purposes. Its attractive appearance, however, and its great strength make it very durable for ornamental trimming. The stone is used extensively for building blocks, roofing chips, ball mill "pebbles," ball mill lining blocks, and crushed stone.

Strength tests. — The rock is very strong. When subjected to crushing stress the first crack came at 10,429 pounds per square inch and the final collapse at 20,277 pounds. The modulus of rupture is 6,583 pounds per square inch.

Scarlet Stone Quarry. — This company makes roofing granules from a poorly cemented quartzite of maroon color that is quarried just north of the town of Pipestone. The quarry is about 400 feet in diameter and from 15 to 40 feet deep. The ledges as quarried are from 6 to 8 inches thick, but where exposed for some time these have again separated into layers averaging 2 inches thick. In general the rock is medium grained, but there are long thin lenses composed of coarse grains. Blocks are quarried with sledge hammers and crowbars, since there are numerous intersecting joints (N. 40° E. and N. 55° W.). Little blasting is necessary. The rock is leached to a buff color along the joints and this portion is trimmed off before loading.

The plant consists of crushers and screens by means of which the rock is broken and then screened to desired sizes. Oversized material is returned to the circuit and undersized is put onto a waste pile.

Jasper Stone Company quarry. — Some building stone has been quarried at Jasper by the Jasper Stone Company, but most of the rock is used for ball mill lining blocks and "pebbles" (see Figure 78) or for crushed stone. The quarry is 500 feet long, 300 feet wide; the height of the face varies from 15 feet on the west side to 35 feet on the east. The rock is a pale bluish-pink quartzite of very uniform texture, but since it is bedded there is some slight variation in color. The chief difference between this rock and that at Pipestone is that the secondary enlargement of the quartz grains has almost completely filled the spaces between the original sand grains, and consequently the rock is very hard and strong. The thickness of beds varies from 6 inches to 3 feet and

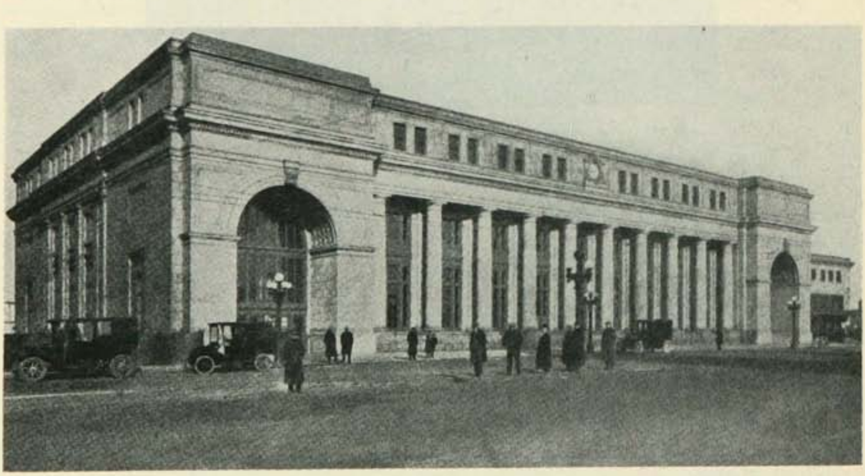

FIGURE 77. — The Great Northern Union Depot, Minneapolis. Constructed of sandstone from the Kettle River quarries. Photograph by Bowles.

FIGURE 78. — Stone products made by Jasper Stone Company. 1. Eight-hour grinding pebble. 2. Eleven-hour grinding pebble. 3. Regular lining block. 4. Wedge-shaped lining block for side of mill. 5. Wedge-shaped lining block for end of mill.

averages about 1½ feet. The joints are N. 80° E. and N. 65° E. but are so irregularly spaced that large blocks are not common. Blocks 3 by 4½ by 1½ inches, others 10 by 1½ by 1 inch, as well as burr stone 6 feet in diameter and 18 inches thick, have been quarried.

Other quarries. — Two small openings in the same type of quartzite are present 2 miles south of Jasper. Most of the rock is made into lining blocks and ball mill "cubes." The Jasper Silica Products Company and the Sandberg Quartzite Company operate the properties. The Minnesota Quartzite Company owns a quarry and crushing plant about a mile east of Jasper. Operations have been suspended since 1928.

Quartzite Quarries, Inc. — The Sioux quartzite extends southward from Pipestone to a point about 2 miles north of Luverne, where it ends abruptly in a prominent ridge known locally as "the Mound." Here the Quartzite Quarries, Inc., operate a quarry for crushed stone. The excavation in the side of the ridge is about 525 by 160 by 100 feet. The rock is variegated along the joints but the original colors vary from gray to red. The formation strikes N. 30° E. and dips 5° north. The parting along bedding planes is spaced about 2½ feet, but the actual stratification as shown by differences in color has a thickness of from ¼ to 6 inches. Some horizons are cross-bedded and ripple-marked. The quarry operations were started on the southeast side of a bluff and were continued to the northwest. Two general joint systems trending north-south and east-west were observed. The rock is of the same general type as the Jasper stone, but it is less favorable for structural purposes because of its many joints. The high elevation of the ridge, allowing good drainage and easy transportation, favors the operation of crushing plants.

APPENDIX

Other Inactive and Abandoned Quarries

The inactive and abandoned quarries listed below are located in areas that do not produce stone at the present time and for that reason are not considered in the present bulletin.

Cass County

T. 134 N., R. 32 W., NW¼ Sec. 28, granite. Bowles,* p. 144.

Chisago County

Near Taylors Falls, trap rock. Bowles, p. 149.
Near Taylors Falls, Cambrian sandstone. Bowles, p. 210.

Cottonwood County

T. 107 N., R. 35 W., SE¼ Sec. 8, Sioux quartzite. Winchell,† 1:500.
T. 106 N., R. 36 W., SW¼ Sec. 6, Sioux quartzite. Winchell, 1:502.

Dodge County

T. 108 N., R. 17 W., Sec. 15, Platteville limestone. Winchell, 1:370.
T. 108 N., R. 17 W., NW¼ Sec. 23, Platteville limestone. Winchell, 1:370.
T. 108 N., R. 17 W., Sec. 13, Galena limestone. Winchell, 1:372.

Fillmore County

T. 104 N., R. 11 W., at Chatfield, Platteville limestone. Winchell, 1:292.
T. 104 N., R. 11 W., ½ mile from Chatfield, Platteville limestone. Bowles, p. 165.
T. 104 N., R. 8 W., near Rushford, St. Lawrence formation. Winchell, 1:323.
T. 104 N., R. 8 W., Sec. 12, Oneota dolomite. Bowles, p. 166.
T. 104 N., R. 13 W., Sec. 36, sandy limestone. Bowles, p. 164.
T. 103 N., R. 12 W., Sec. 10, St. Lawrence formation. Winchell, 1:292.
T. 103 N., R. 12 W., NE¼ Sec. 9, St. Lawrence formation. Winchell, 1:292.
T. 103 N., R. 12 W., near Fillmore, St. Lawrence formation. Bowles, p. 162.
T. 103 N., R. 11 W., Sec. 13, Platteville limestone. Winchell, 1:288.
T. 103 N., R. 11 W., SW¼ Sec. 4, Platteville limestone. Winchell, 1:293.
T. 103 N., R. 11 W., 2 miles south of Fountain, Platteville limestone. Winchell, 1:292.
T. 103 N., R. 10 W., Lanesboro, St. Lawrence formation. Winchell, 1:323.
T. 103 N., R. 10 W., Lanesboro, Oneota dolomite. Bowles, p. 165.
T. 103 N., R. 13 W., Spring Valley, Devonian limestone. Winchell, 1:306.
T. 103 N., R. 13 W., 1 mile east of Spring Valley, Galena limestone. Winchell, 1:299.
T. 103 N., R. 13 W., ¾ mile east of Spring Valley, Devonian limestone. Bowles, p. 162.
T. 103 N., R. 13 W., 4 miles north of Spring Valley, Platteville limestone. Bowles, p. 162.
T. 103 N., R. 13 W., SE¼ Sec. 14, Platteville limestone. Winchell, 1:291.
T. 103 N., R. 13 W., SE¼ Sec. 23, Platteville limestone. Winchell, 1:291.
T. 103 N., R. 13 W., Sec. 25, Platteville limestone. Winchell, 1:291.
T. 103 N., R. 12 W., Sec. 10, Platteville limestone. Winchell, 1:292.
T. 103 N., R. 12 W., NE¼ Sec. 9, Platteville limestone. Winchell, 1:292.
T. 102 N., R. 13 W., Sec. 36, Cedar Valley limestone. Winchell, 1:305.

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* *The Structural and Ornamental Stones of Minnesota* (United States Geological Survey Bulletin 663, 1918).

† *The Geology of Minnesota* (Final Report of the Minnesota Geological and Natural History Survey, St. Paul, 1884–1901).

T. 102 N., R. 13 W., SE¼ Sec. 28, Cedar Valley limestone. Winchell, 1:305.
T. 102 N., R. 13 W., NW¼ Sec. 26, Cedar Valley limestone. Winchell, 1:305.
T. 102 N., R. 13 W., Sec. 25, Cedar Valley limestone. Winchell, 1:305.
T. 102 N., R. 13 W., Sec. 14, Cedar Valley limestone. Winchell, 1:306.
T. 102 N., R. 12 W., Sec. 15, St. Lawrence formation. Winchell, 1:323.
T. 102 N., R. 12 W., Sec. 27, Platteville limestone. Winchell, 1:323.
T. 101 N., R. 10 W., NE¼ Sec. 36, Platteville limestone. Winchell, 1:323.
T. 101 N., R. 11 W., Sec. 36, Galena limestone. Winchell, 1:298.
T. 101 N., R. 11 W., Sec. 3, Platteville limestone. Winchell, 1:323.
Along the bluffs between Whalen and Peterson. Bowles, p. 165.

GOODHUE COUNTY

T. 113 N., R. 14 W., several quarries near Red Wing, Oneota dolomite. Bowles, p. 166.
T. 112 N., R. 18 W., Sec. 19, Platteville limestone. Winchell, 2:43.
T. 112 N., R. 17 W., near Cannon Falls, Platteville limestone. Bowles, p. 169.
T. 112 N., R. 17 W., south of Cannon Falls, Platteville limestone. Bowles, p. 169.
T. 112 N., R. 13 W., 2 miles northeast of Frontenac, Oneota dolomite. Bowles, p. 168.
T. 111 N., R. 17 W., Sec. 9, Galena limestone. Winchell, 2:43.
T. 111 N., R. 17 W., Sec. 20, Galena limestone. Winchell, 2:43.
T. 111 N., R. 17 W., Sec. 22, Galena limestone. Winchell, 2:43.
T. 111 N., R. 17 W., Sec. 23, Galena limestone. Winchell, 2:42.
T. 111 N., R. 18 W., NW¼ Sec. 32, Platteville limestone. Winchell, 2:42.
T. 110 N., R. 17 W., Sec. 8, Galena limestone. Winchell, 2:42.
T. 110 N., R. 17 W., Sec. 33, Galena limestone. Winchell, 2:42.
T. 110 N., R. 16 W., Sec. 14, Platteville limestone. Winchell, 2:43.
T. 110 N., R. 16 W., Sec. 15, Platteville limestone. Winchell, 2:43.
T. 109 N., R. 18 W., SE¼ Sec. 7, Galena limestone. Winchell, 2:42.
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T. 104 N., R. 4 W., Sec. 28, St. Lawrence formation. Winchell, 1:231.
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T. 102 N., R. 5 W., 4 miles east of Caledonia, St. Lawrence formation. Bowles, p. 175.
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T. 41 N., R. 30 W., Sec. 18, dark gray granite. Bowles, p. 139.
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T. 107 N., R. 14 W., 1 mile northwest of Rochester, Platteville limestone. Bowles, p. 184.
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T. 107 N., R. 13 W., Sec. 31, Platteville limestone. Bowles, p. 183.
T. 106 N., R. 14 W., Sec. 18, Platteville limestone. Winchell, 1:341.
T. 105 N., R. 14 W., Sec. 31, Galena limestone. Winchell, 1:341.
T. 105 N., R. 14 W., Sec. 32, Galena limestone. Winchell, 1:341.
T. 105 N., R. 15 W., near Rock Dell, Platteville limestone. Winchell, 1:341.

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T. 43 N., R. 20 W., near Banning, sandstone. Bowles, p. 208.
T. 41 N., R. 21 W., near Hinckley, sandstone. Winchell, 2:639.
T. 39 N., R. 20 W., NE¼ Sec. 36, sandstone. Winchell, 2:640.
T. 43 N., R. 20 W., Sec. 17, sandstone. Winchell, 2:639.
T. 43 N., R. 20 W., Sec. 32, sandstone. Winchell, 2:638.

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T. 111 N., R. 20 W., Sec. 25, Platteville limestone. Winchell, 1:671.
T. 111 N., R. 20 W., NW¼ Sec. 34, Platteville limestone. Winchell, 1:671.
T. 111 N., R. 20 W., east of Dundas, Platteville limestone. Winchell, 1:671.
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T. 110 N., R. 20 W., Sec. 33, Platteville limestone. Bowles, p. 188.
T. 110 N., R. 20 W., Sec. 31, Platteville limestone. Winchell, 1:671.
T. 110 N., R. 19 W., Prairie Creek valley, Platteville limestone. Winchell, 1:671.
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T. 110 N., R. 20 W., 3 miles east of Faribault, Platteville limestone. Winchell, 1:672.
T. 110 N., R. 20 W., 2 miles east of Faribault, Platteville limestone. Winchell, 1:672.
T. 110 N., R. 20 W., at Faribault, Platteville limestone. Winchell, 1:672.
T. 111 N., R. 20 W., near Northfield, Platteville limestone. Winchell, 1:672.

SCOTT COUNTY

T. 115 N., R. 23 W., at Louisville, Shakopee dolomite. Winchell, 2:140.
T. 115 N., R. 23 W., at Shakopee, Shakopee dolomite. Winchell, 2:140.
T. 114 N., R. 23 W., at Jordan, Jordan sandstone. Bowles, p. 210.
T. 114 N., R. 24 W., near St. Lawrence, St. Lawrence formation. Winchell, 2:140.
T. 114 N., R. 24 W., between St. Lawrence and Belle Plaine, St. Lawrence formation. Bowles, p. 189.

STEELE COUNTY

T. 108 N., R. 20 W., Secs. 28 and 33, Galena limestone. Bowles, p. 189.

A List of Cut-Stone Producers in Minnesota

Babcock and Wilcox, Kasota
Biesanz Stone Company, Winona
Breen Stone and Marble Company, Kasota
Central Minnesota Granite Company, St. Cloud
John Clark Company, Rockville
Cold Spring Granite Company, Cold Spring
T. R. Coughlan Company, Mankato
Drake Marble Company, St. Paul
Duluth Cut Stone Company, Duluth
Fowler and Pay, Mankato
Gopher Granite Company, St. Cloud
Granite City Granite Company, St. Cloud
Grewe Granite Company, St. Cloud
Hastings Stone Company, Minneapolis
George Haun Stone Company, Winona
Ideal Granite Company, St. Cloud
Jones and Hartley, Minneapolis
Jones Monumental Works, St. Cloud
Kasota Stone Quarries Corporation, Kasota
Kollman Monumental Works, St. Cloud
Liberty Granite Company, St. Cloud
Lincoln Granite Company, St. Cloud
Mantorville Stone Company, Mantorville
Frank Mehelich, St. Cloud
Melrose Granite Company, St. Cloud
Memorial Art Company, St. Cloud
Monumental Sales and Manufacturing Company, St. Cloud
North Star Granite Corporation, St. Cloud
Northwestern Marble Corporation, Minneapolis
Ortonville Monument Works, Ortonville
William Penn Stone Company, Minneapolis
Pyramid Granite Company, St. Cloud
Quarry Center Manufacturing Company, St. Cloud
Rex Granite Company, St. Cloud
Rich, McFarlane Cut Stone Company, Minneapolis
Royal Granite Company, St. Cloud
St. Cloud Granite Company, St. Cloud
John Salaski, St. Cloud
Sandstone Quarries Company, Sandstone
Sauk Rapids Granite Company, Sauk Rapids
A. M. Simmers and Sons, St. Cloud
Standard Tile and Marble Company, Minneapolis
Swenson Stone Company, St. Paul
Twin City Tile and Marble Company, Minneapolis
William H. Ulmer Stone Company, St. Paul
United Granite Company, St. Cloud
Universal Granite Company, St. Cloud
Wilcox Cut Stone Company, St. Paul
C. H. Young Company, St. Paul

Samples and Fancy Forms (Polished)

N. Finneman Sample Shop, St. Cloud
William Smith Sample Shop, St. Cloud

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