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THE TECHNOLOGY OF MARBLE QUARRYING

BY

OLIVER BOWLES

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PREFACE.

In 1914 an agreement was entered into, between the United States Geological Survey, the United States Bureau of Standards, and the Bureau of Mines, for a cooperative study of the building-stone industry of the country. In general, this agreement provided that the Geological Survey should study the data, compare the classification, extent, and geology of undeveloped and quarried deposits of stone and collect statistical information on production and value of output; that the Bureau of Standards should undertake all the physical and chemical tests required for determining the value of stone for structural purposes, or as aggregate for concrete, and that the Bureau of Mines should investigate all mining and technologic data, with special reference to safety, efficiency of operation, and prevention of waste. The general object of the cooperative agreement was to obtain comprehensive data on the occurrence, quality, and methods of preparation for the market of the various building stones of the United States. By agreement the work was begun with an investigation of the marble-quarrying industry.

The Bureau of Mines was fortunate in procuring for its share of the work the services of Mr. Oliver Bowles who had had experience in examining and describing quarries in Minnesota.

During 1914 Mr. Bowles personally visited 64 active marble quarries. Through the cooperation of quarry owners numerous representative samples of the marbles of the United States were obtained and shipped to the Bureau of Standards for testing. The results of these tests will appear in due time. The description of the investigations of quarry methods and the general technology of marble are published herewith.

The aim of this bulletin is to present to the marble workers of the United States a concise statement of the most efficient and economical methods now in use for producing and preparing marble. Progressive quarrymen realize the value of observing the methods employed by others in similar work, and it is hoped that the summary here presented will prove of use in their operations and will save them the inconvenience and expense of extensive travel to obtain such information for themselves.

The observations outlined refer chiefly to the methods employed in the quarrying of marble and the conditions that affect successful operation; the structure of marble and its relation to quarry processes; waste through rock imperfections and inefficient quarry methods; and means of eliminating such waste or utilizing it if elimination is impossible. No attempt has been made to describe in detail all apparatus and equipment used in quarry operations, but special apparatus and any improvements or special designs tending toward increased efficiency are dealt with particularly.

Mr. Bowles has pointed out especially the great need of better systems of cost keeping as a means of keeping check on all unnecessary expense and as a means of testing the efficiency of methods and machines used in quarry operations. The importance of this feature can not be unduly magnified.

There is also pointed out a method for relieving earth pressure in certain quarries particularly subject to natural strains. This method promises to eliminate many of the fractures that constitute a prolific source of waste in quarry operations.

Operators of structural limestone quarries will find that many of their problems are discussed in this bulletin, as the methods and machinery they employ are similar to those used in quarrying marble. A more extended investigation of the particular problems of structural limestone and all other phases of limestone quarrying is contemplated.

Acknowledgment is made of many helpful suggestions received during the preparation of this bulletin. Too much emphasis can not be placed upon the valuable assistance rendered by Maj. J. S. Sewell, general manager of the Alabama Marble Co. His technical training, combined with practical experience, fitted him peculiarly for supplying just such information as the bureau desired and this information he imparted freely.

Others to whom acknowledgment is due are George R. Taylor, Marble, Colo.; J. P. McCluskey, Gantts Quarry, Ala.; A. W. Edson, Proctor, Vt.; John Kern and B. L. Pease, Knoxville, Tenn.; Prof. C. H. Gordon, University of Tennessee; Prof. F. J. Alway, University Farm, St. Paul, Minn.

The bureau desires to express its appreciation of the cordial treatment extended by quarrymen to its representative and the spirit of cooperation almost universally in evidence.

CHARLES L. PARSONS,
Chief, Division of Mineral Technology.

THE TECHNOLOGY OF MARBLE QUARRYING.

By Oliver Bowles.

MARBLE IN GENERAL.

DEFINITION OF MARBLE.

In its geologic sense the term marble is applied to rocks consisting of crystallized grains of calcite or dolomite or a mixture of the two. Although limestone has the same chemical composition as marble it differs in that the component particles of calcium or magnesium carbonates are granular and noncrystalline. In marble the crystals may be intimately intergrown, whereas limestone is an aggregation of unrelated particles cemented together into a solid mass.

In its commercial sense the term marble has a much wider application. As susceptibility to polish is one of its chief commercial assets, all calcareous rocks capable of polish are classed as marbles. Limestones that show little crystalline structure may, if they take a good polish, be classed as marbles. Furthermore, serpentine rocks, even if they contain little calcium or magnesium carbonate, are classed as marbles, as they are commercial substitutes of true marbles.

COMPOSITION OF MARBLE.

Aside from serpentine and other extraordinary varieties, marble is made up almost entirely of calcium or magnesium carbonates. A calcite marble may consist of 96 to 99 per cent calcium carbonate. A dolomite marble, if impurities are disregarded, contains approximately 54 per cent calcium carbonate and 46 per cent magnesium carbonate. Marbles consisting of mixtures of calcite and dolomite may have compositions anywhere between these two extremes. The extremes may be illustrated by examples mentioned by Dale.[a] Marble quarried near Proctor, Vt., contained 98.37 per cent calcium carbonate, and a dolomite marble from Lee, Mass., contained 54.05 per cent calcium carbonate and 45.93 per cent magnesium carbonate. An intermediate type is represented by the crystalline magnesium limestone of Tuckahoe, N. Y., which contained 70.1 per cent calcium carbonate and 25.40 per cent magnesium carbonate.[b]

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[a] Dale, T. N., The commercial marbles of western Vermont; U. S. Geol. Survey Bull. 521, 1912, p. 13.

[b] Kemp, J. F., A handbook of rocks, 1906, p. 138.

A varying percentage of chemical impurities is present in practically all marbles. The more common of these are silica (SiO_2), iron oxides (FeO and F_2O_3), manganese oxide (MnO), alumina (Al_2O_3), and sulphur; less common are minute quantities of the oxides of titanium, potash, sodium, lithium, and phosphorus. Organic matter is commonly present.

The impurities of marble are present in the form of grains of definite minerals. In some specimens the individual grains may be too minute to be recognizable with the naked eye, and in others they may attain considerable size. The more common mineral impurities are quartz (or some other form of silica, such as chert or flint), hematite, limonite, graphite, mica, chlorite, tremolite, wollastonite, diopside, hornblende, tourmaline, pyrite, or marcasite. In the marbles of southern Ontario, Parks [a] notes the occurrence of 37 minerals that have been formed by metamorphic processes acting on the impurities of the original limestone. The more common are quartz or some other form of silicon dioxide, pyrite, marcasite, mica, or chlorite.

Most marbles of commercial value contain small percentages of impurities.

ORIGIN OF MARBLE.

FORMATION OF THE ORIGINAL LIMESTONE.

Marble is derived from beds of limestone. The latter are formed in the sea, mainly as accumulations of calcareous remains of marine organisms, such as corals, rhizopods, and algæ. Water containing carbon dioxide is capable of dissolving calcium carbonate from the rocks through or over which it flows, and in consequence the water of rivers is charged with lime carbonate as it enters the ocean. Thus a supply of dissolved calcium carbonate is always at hand from which the organisms may manufacture their shells. Countless generations live and die and as a consequence the calcareous accumulation may be of vast extent. In places, the chemical precipitation of calcium carbonate may add to this accumulation.

There is abundant evidence that many limestones are of organic origin, as some of them are merely aggregates of fairly well preserved shells. In most specimens, however, a few fragmentary shells only remain in recognizable form, all others, through the beating of the waves or other activities, having been broken into minute fragments.

By pressure of superincumbent material and by deposition of some form of cement in the intergranular spaces the mass is later consolidated as a firm and coherent rock which is termed "limestone." Beds hundreds and even thousands of feet in thickness have been formed by such processes.

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[a] Parks, W. A., Report on the building and ornamental stones of Canada, vol. 1, 1912, p. 307.

METAMORPHISM OF LIMESTONE.

Marble is regarded as being the product of the metamorphism of limestone beds. That granular noncrystalline limestone can be changed into crystalline limestone or marble has been proven in the laboratory, as shown by Clarke.[a] From the results of various experiments he concludes that pressure alone, heat alone, or both together may result in the recrystallization. It is probable that the presence of water assists the process. Marble may therefore result from great pressure exerted on the strata by folding, or by heat produced from an igneous intrusion, or both agencies may work in conjunction. Recrystallization as a result of igneous intrusion has been observed by several authors.[b]

ORIGIN OF ONYX MARBLES.

Onyx marbles have a history rather distinct from that of the true marbles. Although consisting essentially of calcium carbonate, they are purely chemical deposits and have not resulted from the metamorphism of preexisting limestone beds. As pointed out by Merrill,[c] who gives a lengthy discussion of their origin and occurrence, they are of two types. One is a product of precipitation from hot springs, a travertine; the other is a deposit from cold-water solutions in limestone caves. Most deposits of onyx are formed in successive layers. Impurities such as iron and manganese oxides may be present in varying amounts in successive layers, and thus a beautiful banding may result. From the nature of their formation onyx deposits are necessarily limited in extent as compared with deposits of true marbles.

ORIGIN OF VERD ANTIQUE.

Verd antique or serpentine marble is in no respect comparable with true marble either in composition or in origin. Serpentine is in general derived from the alteration of basic igneous rocks such as the peridotites, which are rich in olivine and pyroxenes, or from magnesium silicate rocks formed by the metamorphism of limestone. The process is accompanied by hydration, with an addition of 13 to 14 per cent of water. The movement occasioned by the swelling that results probably accounts for most of the unsoundness common to verd antique.

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[a] Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 491, 1911, pp. 531-532.

[b] Renwick, W. G., Marble and marble working, 1909, p. 4; Conybeare, W., Descriptive notes on the northeast coast of Ireland. Trans. Geol. Soc. London, vol. 3, 1816, p. 210.

[c] Merrill, G. P., Stones for building and decoration, 1903, pp. 242-296.

PHYSICAL PROPERTIES OF MARBLE.

HARDNESS.

Hardness may be defined as the resistance that the surface of a substance offers to abrasion. The hardness of calcite is given as 3 in Moh's scale, and that of dolomite as 3.5 to 4, whereas that of glass is about 5. The hardness of a marble as a whole may be different from that of the individual grains that compose it. The hardness is influenced by the degree of cohesion between the grains. Most fine-grained, compact marbles are harder than coarse-grained varieties. Some marbles are remarkably hard even if no silica or other excessively hard impurities are present. Hardness of the mass as a whole is an indication of "workability," and is an important property, as the cost of quarrying marbles that are worked slowly by tools is much higher than the cost of quarrying those easily worked. Although the cost of quarrying hard marble may be high, the hardness is a valuable property if the material is to be exposed to abrasion.

High resistance to abrasion is desirable in marbles that are to be used for sills, steps, or floor tile, all of which are exposed to the friction of the feet of pedestrians. Marble employed for such uses should be hard, and uniformity in hardness is desirable; otherwise the surface will soon become uneven. In constructing floor patterns of different marbles, it is important that the several varieties should be equally resistant to abrasion, as otherwise the floor will eventually become uneven. This condition may be observed in the floor of the Union Station at Washington, D. C., where the white tiles of Vermont marble, after eight years' use, are in places worn down nearly half an inch lower than the small squares of harder material from Swanton, Vt.

A second agent of abrasion is wind. Wind polish of a pronounced character has been observed on rocks much harder than marble. The Sioux quartzite of southwestern Minnesota, a rock that is probably harder than any other in the United States used for building purposes, has been so wind worn that corners have been rounded and the exposed surfaces have been given a glassy polish. Dust and sand carried by the wind on city streets tend slowly to wear away surfaces, mainly by removing insecure grains and thus exposing fresh surfaces to the agencies of weathering. The effects are most pronounced on corners and in narrow spaces between buildings where the force of the wind is concentrated. Egleston [a] states that in New York City many tombstones that face the prevailing winds are so worn that inscriptions are almost illegible.

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[a] Egleston, J., The cause and prevention of decay in building stones: Am. Architect, vol. 18, September 5, 1885, p. 113.

SPECIFIC GRAVITY AND WEIGHT PER CUBIC FOOT.

The specific gravity of a substance is its weight compared with the weight of an equal volume of water. The specific gravity of calcite is 2.7 and that of dolomite about 2.9. Consequently, dolomite marbles are heavier than calcite marbles. It is found that the actual weight per cubic foot of a block of marble differs more or less from its theoretical weight calculated from the specific gravity of the constituent minerals. A porous rock of given volume will be lighter than an equal volume of similar material that is nonporous. In most marbles the pore space is small, and the actual weight does not differ greatly from that calculated from the specific gravity.

The specific gravity of a compact homogeneous substance having no pore space may be determined in a simple manner, as follows: A thoroughly dried specimen is suspended from a balance by a thread and weighed in the air. It is then weighed while immersed in water. On account of the buoying up of the water it will weigh less while immersed. The loss in weight when immersed is the weight of a quantity of water equal in volume to the substance immersed. The specific gravity is, therefore, the weight of the substance in air divided by its loss in weight when immersed in water, as expresed by the formula $\frac{A}{A-B}$, in which A represents the weight of the substance in air, and B represents the weight of the substance when immersed in water.

An accurate determination of the specific gravity of a marble is, however, a less simple matter, on account of the pore space involved. In order to determine specific gravity accurately the pore space must be eliminated. This may be accomplished by the following procedure: Dry the rock specimen at 110° C. until all the moisture has been driven from the pores; then determine the dry weight. Next completely fill the pores with water, as by soaking the blocks in water for several weeks. Buckley,[a] accomplished the desired result by boiling the specimens for 36 hours under the receiver of an air pump that reduced the pressure to one-twelfth of an atmosphere. By such means the removal of air from all the pores may be facilitated. With the pores thus filled with water, weigh the specimen when immersed in water and determine the specific gravity as described above.

A more accurate method if care is exercised is to eliminate the pores by grinding the rock to a fine powder, and to determine the specific gravity of the powder. This may be done by means of a specific gravity bottle, with an accurately ground stopper that projects upward as a hollow tube of small diameter. The bottle is

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[a] Buckley, E. R., Building and ornamental stones of Wisconsin: Wisconsin Geol. and Nat. Hist. Survey Bull. 4, 1898, pp. 65–67.

dried carefully and weighed. It is then filled with distilled water exactly to the top of the capillary tube and weighed again. Ordinarily the next step is to thoroughly dry the bottle, place within it a part of the finely powdered rock, and weigh. The difference between this weight and that of the empty bottle is the weight of rock taken. The rock powder is retained in the bottle, which is then filled with water and weighed again.

Certain mechanical difficulties make desirable a modification of the last two steps. Considerable time is required to thoroughly dry the narrow-necked bottle. After the dry mineral has been weighed and the bottle filled with water, it is difficult to prevent small particles from floating to the surface and flowing away with the superfluous water when the stopper is inserted. This small error may be avoided by reversing the last two steps. When the bottle full of water is weighed, the bulk of the water may be thrown out, the rock powder poured in, and enough water added to completely immerse it. After all bubbles have been removed the bottle may be filled with water to the top of the capillary tube as before and weighed. The loss of any fine particles during the process of filling and inserting the stopper does not affect the result, as the weighing is done subsequently. After the weighing has been completed, if the powder is thoroughly settled, and the water above it clear, most of the water may be carefully drawn off with a pipette. The remainder may be evaporated in a hot air bath, and the drying continued until the weight is constant. Thus the weight of the bottle containing the dry rock powder is the last figure obtained.

EXAMPLE.

If X = weight of dry bottle
Y = weight of bottle full of water
Z = weight of bottle containing powdered rock and filled with water
and A = weight of dry bottle and powdered rock
then $A-X$ = the weight of the rock employed $=W$.

The sum of W and Y gives the total weight of rock, bottle, and water when none of the water is displaced. When the mineral is placed in the bottle and its volume of water is displaced the weight Z results. Therefore the weight of water displaced by the rock is $Y+W-Z=M$. The specific gravity is therefore $\frac{W}{M}$.

Marbles range in actual weight from 165 to 180 pounds per cubic foot. The economic significance of weight is chiefly in connection with the necessary strength of equipment for handling and freight charges for transportation. By knowing the average weight per cubic foot the quarryman may measure a block and calculate its weight with reasonable accuracy. He is thus enabled to judge the risk involved in handling it with any given equipment. Marble is a heavy structural material, and the necessary transportation charges must be carefully considered when bidding on contracts at a distance from the point of production.

SOLUBILITY.

Calcium and magnesium carbonates are practically insoluble in pure water. Certain dissolved gases, notably carbonic acid gas, which are present in surface water in small proportions, render the water capable of dissolving the carbonates to a limited degree. Marbles exposed to the weather are therefore slowly dissolved. Although the process is slow, its effects may be considerable when long periods of time are involved. That marbles are more soluble than rocks consisting of silicate minerals is demonstrated in nature. Most marble deposits in humid regions are found in valleys formed by the more rapid erosion of the marble belts than of the bordering siliceous rocks.

The rate of solution is variable in different marbles. It depends on the chemical composition, texture, and porosity of the marble, the climate of the region, and the nature of the atmosphere. Near large cities various acids from smoke abound in the air and are taken up by rain water, thus increasing its power of solution. If a rock is permeable it dissolves more rapidly than if impervious. Calcite dissolves more rapidly than dolomite under the same given conditions if the texture of each is similar, but the tendency for dolomite to occur with granular texture usually reverses the order of their solubility. The solubility of marble deserves careful consideration if its use for exterior purposes is contemplated.

COLOR.

The color of a marble is one of its most important physical properties. It is governed by the nature of the constituents. Marbles consisting of pure calcite or dolomite are white because these minerals are white. A serpentine marble is green because the prevailing mineral, serpentine, is green. Variations from the white color of a pure marble are due to admixtures of foreign substances. Such impurities may be uniformly distributed and thus give a uniform coloration, or they may be present in bands or streaks, giving clouded or otherwise nonuniform colors. Examples of nonuniform color distribution are the "Pocahontas" marble of Alabama, the variegated marbles of Vermont, and the "crow foot" structure, irregular dark lines, characteristic of the Tennessee deposits.

The causes of some colors in marbles are easily determined. The black and grayish shades are to be attributed to carbon, which is usually present as fine scales of graphite though amorphous in the "crow foot" of Tennessee marble. Red, pink, or reddish-brown shades are due to the presence of manganese oxides (MnO) and (Mn_2O_3) or to hematite (F_2O_3). Yellow-brown, yellow, or cream colors are caused by minute grains of the hydrous oxide of iron, limonite ($2Fe_2O_33H_2O$). Dale[a] attributes the green color of certain Vermont marbles to the presence of sericite (fibrous potash mica), and the purplish tint of one of the dolomites of the Lake Champlain region to a mixture of hematite and magnetite. Referring to some of the less common colors, Dale comments as follows:

> The more uncommon colors of marble are purplish, as in the Pavonazzo and Seravezza breccias imported from Italy, bright yellow, as in the "Giallo Antico" from North Africa, and orange yellow, as in some marbles from Norway. Among the uncommon combinations of colors is that of rose-pink and deep green in the "Leifset Gloire" from Norway.

The same author states [b] that the dolomite of Hancock and Mount Tabor, Vt., owes its buff color to the presence of siderite. Vogt [c] attributes the sky-blue, red, and orange tints of some Norwegian marbles to organic compounds. The "golden vein" of the Colorado-Yule marble is thought to be caused by the permeation of solutions bearing manganese or iron oxides. The green bands in certain parts of the same quarry are, according to Merrill,[d] caused by the presence of chrome-mica. Parks[e] describes green marbles in Ontario in which the color is due to needles of light-green actinolite. The pink color of one marble he attributes to "scattered flakes of brownish glistening mica." He states that brown colors are in many instances due to the presence of mica. He refers also[f] to a marble having gray dots due in part to some crystals being clear and others milky, and in part to the presence of fine graphite. The clear crystals are dolomite, and the milky crystals calcite. Solution emphasizes the dotted effect.

For certain purposes, it is desirable to have a distinct contrast between chiseled and polished surfaces. Such a contrast is especially desirable in headstones on which inscriptions are cut. The contrast is usually more pronounced in the colored, and less marked in the white marbles. A chiseled surface is opaque and somewhat granular, and reflects rather than absorbs the light. Hence it tends to appear white or light colored even if the stone is dark. When a face is polished the reflecting surfaces are removed, permitting the light

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[a] Dale, T. N., The commercial marbles of western Vermont: U. S. Geol. Survey Bull. 521, 1912, p. 20.

[b] Dale, T. N., The calcite marble and dolomite of eastern Vermont: U. S. Geol. Survey Bull. 589, 1915, p. 54.

[c] Vogt, J. H. L., Norsk marmor, Kristiania, 1897, p. 354.

[d] Merrill, G. P., A report on the Colorado-Yule marble properties, 1914, p. 10.

[e] Parks, W. A., Report on the building and ornamental stones of Canada, vol. 1, 1912, pp. 323-324.

[f] Parks, W. A., Op. cit., p. 329.

to enter the crystals and be absorbed, causing the polished surface to appear much darker than the chiseled surface.

TRANSLUCENCE.

Marbles differ greatly in their capacity for transmitting light. The more translucent varieties, if fine grained, are best adapted for novelties or other ornamental purposes. Some marbles are waxy in appearance, and this property seems to be related to translucence. Dale[a] gives the depths to which certain foreign marbles will admit light. They are as follows: Best Pentelicon, 0.59 inch; Parian, 1.37 inches; Carrara statuary, 1.18 to 1.57 inches. The reputation of some marbles depends greatly upon this quality. As far as is known no figures have been obtained for the depth of light penetration into American marbles. Certain beds of Alabama marble are notably translucent. The same quality has been observed in marbles from Massachusetts, Vermont, and Colorado. Certain modes of artificial treatment are known to increase the translucence of marble. Usually the effects of such treatment are far less permanent than the material itself, and consequently are not to be recommended.

TEXTURE.

The grains of calcite and dolomite that make up a marble mass are crystalline and have a definite rhombohedral cleavage. They are mostly twinned. Both the cleavage and the twinning of each grain are independent as relating to other grains. The texture is usually about the same in all directions, though in some marbles an elongation of grains in one direction has been noted. This characteristic is discussed more fully under the heading "Rift." The degree of interlocking of grains, and other features of cohesion have a definite relation to crushing strength, porosity, and workability. In certain dolomitic marbles the grains of dolomite may differ greatly in size and shape from those of calcite. The difference in grain diameter between the larger and smaller grains in some marbles is rather marked, and in others is small. Uniformity of grain is desirable.

The size of grain is commonly described as fine, medium, or coarse. Such terms are indefinite, and may have quite different meanings with different individuals, the interpretation being dependent upon the range of texture experienced by the observer. In order to place texture upon an absolute basis Dale[b] graded the marbles of Ver-

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[a] Dale, T. N., The commercial marbles of western Vermont: U. S. Geol. Survey Bull. 521, 1912, p. 17.

[b] Dale, T. N., Op. cit., p 54.

mont into six classes, based upon the average grain diameter. The classification is shown in the following table:

Classification of Vermont marbles by grades of texture.

Grade.	Grain diameter.			
	Maximum.	Average.	General averages.	
			Millimeters.	Inches.
	Millimeters.	*Millimeters.*		
1, extra fine	0.2	0.05 to 0.10	0.06	0.0023
2, very fine	.5	.07 to .16	.10	.0039
3, fine	.75	.10 to .25	.12	.0047
4, medium	1.0	.12 to .31	.15	.0059
5, coarse	1.5	.20 to .60	.24	.0094
6, extra coarse	2.54	.30 to 1.35	.50	.0196

The texture of marble is influenced by impurities such as graphite, sericite, tremolite, actinolite, and mica; and also by the folding or plication of the beds. The latter may cause elongation of grain or granulation of certain parts of the mass.

RIFT OR GRAIN.

The terms rift and grain are used synonymously for the direction of easiest splitting in marble. The rift is usually parallel with the bedding. It is probably due to elongation of grain caused by pressure. Dale[a], whose microscopic study of marbles has been extensive, states that "in some marbles one or two axes of the grains are much longer than the others, and the longer axes of different grains are parallel, giving the rock a certain schistosity which is usually parallel to the bedding."

The rift may be emphasized by the presence of fibrous or platey minerals such as scales of mica or graphite or needles of actinolite. These usually occupy positions with their long axes parallel to the direction of grain elongation, and thus increase the tendency to split in that direction.

Rift is a property of marble that the quarryman should take into account in planning operations. By taking advantage of this ease of splitting, drill holes for wedging may be spaced much farther apart than if no rift exists.

POROSITY.

Porosity is the volume of pore space expressed as a percentage of the total volume of the rock mass. The pore space of marbles is usually much less than that of limestones and sandstones, and more

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[a] Dale, T. N., Op. cit., p. 18.

than that of granites, though exceptions toward both extremes are known. It varies from 0.0002 to 0.4 per cent.

A method of determining pore space may be quoted from Parks,[a] as follows:

> The specific gravity is determined as already indicated and the test piece, full of water, is weighed. The difference between this weight and the dry weight of the sample gives the weight of the included water. If this latter figure be multiplied by the specific gravity of the stone, we obtain an expression which represents the weight of the stone which would be required to fill the pores. If this amount be now added to the weight of the dry sample, the result is the weight of that sample, provided that there were no pore spaces. This weight divided into the weight of the stone required to fill the pores, and multiplied by 100, gives the percentage of pore space in the stone.

The difficulty of filling all the pores by saturation has already been referred to in considering specific-gravity determinations. A method is here suggested by which this difficulty may be avoided.

Three factors are necessary in order to determine porosity. They are specific gravity, dry weight, and volume of the material employed. The specific gravity may be determined by the pycnometer (specific-gravity bottle) method as already described. The volume and the dry weight may be determined from a smooth-faced cube of about 1-inch edge. Drying the cube at 110° C. until the weight is constant gives the dry weight. The specimen may then be coated with a thin film of paraffin, wax, or other waterproof substance to make it impervious, and its volume may be determined from water displacement in a large specific-gravity bottle. The film must be made as thin as possible, as its presence increases the volume of the block. If the quantity of waterproof substance used in coating the block is determined, a correction may be made by subtracting its volume from the total volume obtained.

Another method is to saturate the block and then determine its volume by water displacement without any coating. If it is even approximately saturated, further absorption during the brief time occupied in determining its water displacement will be negligible.

The method of calculating porosity is as follows:

If X = dry weight of block
G = specific gravity of material composing block
and V = volume of block
Then $V \times G$ = weight of block if all the pores were filled with marble = Y.
$Y - X$ = weight of marble required to fill pores = W

Percentage of pore space $= \frac{W}{Y} \times 100$.

Porosity is commonly expressed as "ratio of absorption," which is the percentage by weight that the absorbed water bears to the dry

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[a] Parks, W. A., Report on the building and ornamental stones of Canada, vol. 1, 1912, p. 61.

weight of the stone. The specimen is dried in a hot-air bath at a temperature of about 110° C. until the weight is constant. The stone is then immersed in water for a period of time varying from two days to several weeks. The process of absorption may be assisted by boiling or by placing the immersed block beneath the receiver of an air pump as already described. The difference in weight between the dry and the saturated specimens is the weight of absorbed water. The ratio of absorption of American marbles as determined by the Bureau of Standards varies from 0.0018 to 0.00007.

Pore spaces in marbles permit infiltration of water, which may dissolve the stone, or may cause disintegration by freezing. The evils associated with porosity are discussed more fully under the heading "Imperfections of Marble."

STRENGTH.

The strength of a stone is the measure of its capacity to resist stresses of various kinds. It depends partly on the rift of the rock and on the cleavage and hardness of the grains, and partly on the state of aggregation, including degree of cohesion, interlocking of grains, and nature of cementing material, if such is present. Although strength alone is not a sure criterion of durability, a knowledge of the capability of any stone to withstand stresses of various kinds is of great value if the material is to be used for purposes involving extraordinary strains.

Many tests have been made of the strength of building stones. It was early learned from these tests that most stones have many times the strength required for ordinary uses. As pointed out by Buckley,[a] ordinary building stones have 2 to 10 times the crushing strength required in any structure for which they may be used. As a consequence of a recognition of this fact, there was a reaction against making tests, which were regarded as superfluous. An increased demand for strength in structural stone and a wider knowledge of the significance of strain resistance has lately led to a renewed interest in strength tests. It is known that stones are less durable when exposed to intense strains, and it seems reasonable to conclude that the rate of disintegration increases with proportional rapidity as the strain to which the rock is subjected approaches more and more nearly to the ultimate load it is capable of bearing. Rock strength may therefore have a decided influence on the rate of disintegration, even when it is evident that the strength is far in excess of the requirements.

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[a] Buckley, E. R., Building and ornamental stones of Wisconsin: Wis. Geol. and Nat. Hist. Survey Bull. 4, 1898, p. 59.

The tests commonly made are for crushing strength, transverse strength, elasticity, and shearing. As tests can be made only with high-priced specially designed equipment, which is available to few people, a description of the methods of testing is omitted, and the discussion confined to a brief consideration of the significance of the various types of stress resistance of which rocks are capable.

CRUSHING STRENGTH.

As already stated, most rocks that, after ordinary superficial inspection, would be chosen for structural purposes have many times the crushing strength required for ordinary uses. For certain purposes, however, such as bridge piers, abutments, columns, and the base blocks of very high structures, crushing strength demands more than ordinary attention. The tendency, more noticeable every year, to increase the height and superincumbent weight of great city structures makes strength tests more and more useful.

Rock structures have a definite influence on strength. As a rule rocks will bear a greater compressive stress across the bedding plane than parallel with the bedding plane. Hence stones should not be laid with the bedding planes vertical.

TRANSVERSE STRENGTH.

Transverse strength may be measured by testing the capability of a bar of stone supported at its ends to bear weight exerted at its center. Such tests indicate the suitability of a marble for door or window caps, or as bridging material that must bear a heavy load. Breakage of such caps, hovever, must not always be attributed to a weakness in the material employed, as unequal settling or improper laying may be the chief causes.

ELASTICITY.

When subjected to crushing strain rocks are capable of being appreciably compressed before rupture takes place. A measure of this compressibility in terms of the load is what is known as the modulus of elasticity. Parks [a] defines it more explicitly as follows: "The decrease in length of a bar of material thus subjected to pressure divided into the original length of the bar, and multiplied by the load in pounds per square inch, gives what is known as Young's modulus or the modulus of elasticity or compressibility." Merrill [b] found that after relief from intense pressure below the point of rupture rocks failed to completely recover their original form. This he termed a permanent "set."

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[a] Parks, W. A., Report on the building and ornamental stones of Canada, vol. 1, 1912, p. 47.

[b] Merrill, G. P., Stones for building and decoration, 1913, p. 478.

Compressibility may be the cause of cracks in the lower courses of certain large structures. It is evident that building stones having a low modulus of elasticity may under heavy superincumbent load be appreciably compressed with a resultant settling of the structure, and if one part of the building is composed of blocks having a different modulus of elasticity from those of an adjoining part, the settling will not be uniform. Such settling can take place only under extremely heavy loads. A knowledge of the elasticity of marble is, as quoted by Buckley,[a] "valuable in determining the effect of combining masonry and metal or of joining new masonry to old; in calculating the effect of loading a masonry arch; in proportioning abutments and piers of railroad bridges subject to shock, etc."

SHEARING.

The tendency to shear—that is, the tendency of one part of a block to slide laterally with respect to another part—is strong in certain structures, such as massive arches and lintels. Certain blocks in large buildings are subjected to strains in different directions, and the tendency to shear may be pronounced. Thus, shearing tests of marble designed for such purposes are of value.

WEATHERING OF MARBLE.

The term "weathering" is applied to the disintegration that results from exposure of rock to the various natural agencies that are active at or near the surface of the earth. In previous paragraphs a discussion is given of solubility, porosity, permeability, chemical composition, hardness, texture, and state of aggregation of marble.

The rate of decomposition by weathering is somewhat dependent on these physical features. For example, a soluble rock weathers more rapidly than one that is relatively insoluble, and an open-grained porous rock decomposes more readily than one that is more solid and impervious. Owing to this direct dependence of the rate of weathering on the physical properties of marbles, tests of the various qualities of a given stone are of great value in estimating its probable rate of weathering.

Climatic and atmospheric conditions greatly influence the rate of weathering. Oxygen and carbon dioxide are the most effective atmospheric agents of decomposition. The rate of weathering depends also on temperature. Little or no weathering takes place while the temperature is below 0° C. As the temperature rises, solution takes place with increasing speed and in tropical regions is active throughout the entire year. Rapid changes in temperature

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[a] Buckley, E. R., Building and ornamental stones of Wisconsin: Wis. Geol. and Nat. Hist. Survey Bull. 4, 1898, pp. 63-64.

cause rapid disintegration, especially in regions where chemical action is supplemented by the effects of frost.

Aside from the effects of frost, changes in temperature produce differential expansion and contraction, which set up shearing stresses, causing flakes to split off. Rupture by expansion and contraction is probably less in the porous than in the nonporous rocks, as in the former case necessary adjustment is made between the grains. As a rule the finer-grained rocks weather less rapidly than do those of coarser grain. Van Hise[a] states that "this is a consequence of the closer interlocking of the mineral particles of the fine-grained rocks, and of the fact that the differential expansion and contraction by change of temperature is less with fine particles than with coarse particles."

Humidity greatly favors decomposition, as chemical action is slow in the absence of water. For example, Cleopatra's Needle, which stood thousands of years in arid Egypt, began to disintegrate so rapidly in Central Park, New York City, that it had to be coated with paraffin to prevent destruction.

The most favorable conditions, therefore, for rapid weathering are coarse and permeable texture of the stone, humidity, warmth, and rapid changes of temperature between points above and below freezing.

Parks[b] conducted a series of interesting experiments designed to test the relative durability of various stones. As carbon dioxide is the most active agent of chemical decomposition, its effect on various stones was taken as an indication of their relative durability. Cubes of stone were immersed in distilled water through which a stream of carbon dioxide was passed, and the corrosive effect was tested by determining the loss in weight by solution in a given time. Those cubes that showed a comparatively small loss by solution were regarded as the most durable.

The change in color of the rock surfaces during the process corresponded closely with the color modification brought about by many years of weathering. Hence such experiments are useful as a means of testing the probable color changes in untried rocks intended for exterior structural work.

Dale[c] investigated the rate of disintegration of marble, especially that used for tombstones. He states that in New England the lettering on tombstones 75 to 100 years old will probably be entirely effaced in 300 years from the date of cutting. He noted a marble slab at Plymouth, Mass., on which the lettering was almost effaced after 87 years of exposure. He mentions also a block of South

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[a] Van Hise, C. R., A treatise on metamorphism: U. S. Geol. Surv. Mon. 47, 1904, p. 533.

[b] Parks, W. A., Op. cit., pp. 70–71.

[c] Dale, T. N., The commercial marbles of western Vermont: U. S. Geol. Survey Bull. 521, 1912, p. 38.

Dorset (Vt.) marble on which the edges of the letters are fairly sharp after 79 years' exposure.

Although tests of the various physical properties of marble are useful as an index of its probable durability, actual observations of old structures, outcrops, or quarry walls give the most dependable information. Observations may be made of the rate and uniformity of weathering and the stains or other changes in color involved.

Weathered outcrops give the marble prospector valuable information. On ledges where successive beds are exposed the most enduring beds will stand out in relief. The condition of soundness can also be easily recognized, as weathering emphasizes all cracks or lines of weakness.

Erosion of marble beds commonly results in the formation of "mud pockets," a name given to cavities worn in the rock and later filled with soil. In some places they are large, attaining depths of 50 or 60 feet, and the removal of the clay contained in them is a matter of considerable expense to the quarry operator. In the Tennessee marble deposits erosion has followed the unsoundness and has left numerous masses of rock projecting upward from the solid beds and surrounded by clay. These constitute the so-called "bowlder quarries."

Most serpentine marbles are veined with calcite or dolomite, and hence weather unevenly. Moreover, most of them are unsound, and consequently permeable to rain water. Such marbles lose their polish, weather rapidly, become stained, and soon lose both attractiveness and strength if exposed to atmospheric agencies.

VARIETIES OF MARBLE.

Marbles may be classed as statuary, decorative, building, and monumental.

Statuary marble is the most valuable variety quarried. It must be pure white in color, uniform and fine-grained in texture, and somewhat translucent, and must possess a marked adaptability for carving. Renwick[a] recommends that "marble for statuary purposes should never be selected in bright weather. Veinings and discolorations are more difficult to discover at this time than at any other. A dull day with a good light is the best time for inspections; if after a shower of rain, so much the better. Provided no rain has fallen, the blocks should be soused with water. Veins and stains can then be more readily perceived. If possible have each block slung and struck with a hammer. If the sound of the blow is dull and heavy, look out for cracks. Should a hard and metallic tone be emitted, the marble will be heavy in working; but if a soft, clear ring is heard, the material is sound and will both work and wear well."

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[a] Renwick, W. G., Marble and marble working, London, 1909, p. 61.

Decorative marble is usually employed in places unexposed to the weather, and hence may be selected for appearance without regard for the effects of weathering. Marble containing large amounts of iron sulphides may therefore be used for interior decoration, and such marbles may give beautiful effects. Brecciated marbles consisting of angular fragments cemented together in nature by calcium carbonate are widely used for columns. Most marbles of this type are imported, only a limited amount having been produced in the United States up to the present. Both pure white and variously colored marbles that possess unusual attractiveness may be used for interior decoration.

Verd antique, or serpentine marble, is in common use. Most of such marble is somewhat unsound and not of sufficient strength to justify its use where it will have to take a heavy load. The marble is commonly used for exterior decoration, but is not to be recommended for this purpose, as it does not weather uniformly and soon loses it polish. For interior decorative purposes it is popular.

Onyx marble possesses a waxlike luster and an attractive banding which make it a popular material for interior decoration.

Numerous statuary and decorative marbles from American quarries are now on the market. No two are alike, and each has its own particular trade name.

Marbles for building and monumental purposes must have attractive and uniform colors, and in addition must possess the ability to withstand weathering and to retain their attractive appearance. For interior decorative marble appearance is the prime factor determining its value, whereas with exterior marble qualities of endurance rank equally in importance with appearance. Building marble should therefore be strong, uniform, close-grained, reasonably nonabsorptive, and free from such impurities as may stain or corrode the surface.

DISTRIBUTION AND PRODUCTION OF MARBLE IN THE UNITED STATES.

As stated in the discussion of the origin of marble, the recrystallization of the original limestone is promoted chiefly by heat and pressure. As a consequence most marble beds are confined to areas of extreme folding or igneous intrusions, and hence are to be found chiefly in mountainous regions. In some beds recrystallization takes place without igneous intrusion or movement of the beds, as at Kasota, Minn., but such conditions are rare. The important marble belts of the United States are found in the Appalachian region of the Eastern States and in the Rocky Mountain and the Coast Ranges of the West.

According to figures compiled by Burchard,[a] the States producing marble in 1913, arranged according to value of output, are as follows: Vermont, Tennessee, Georgia, Colorado, Alabama, Massachusetts, New York, Pennsylvania, Alaska, California, Maryland, North Carolina, Utah, Arkansas, New Mexico, Washington, Virginia, and Oregon. Deposits of onyx marbles occur in Arizona, Colorado, Utah, New Mexico, California, Kentucky, and Virginia. Deposits of serpentine marble, or verd antique, occur in Vermont, Pennsylvania, Georgia, Maryland, California, Massachusetts, Connecticut, Delaware, Maine, New York, New Jersey, New Mexico, and northern Michigan.

The value of marble produced in the United States in 1913 was $7,870,890, and of this amount the three States, Vermont, Tennessee, and Georgia, produced over 76 per cent. The average price per cubic foot was $2.11.

THE IMPERFECTIONS OF MARBLE.

UNSOUNDNESS.

MEANING OF UNSOUNDNESS.

When intersected by joints or fissures marble blocks are said to be unsound. The term "unsoundness" refers to all cracks or lines of weakness, other than bedding planes, that cause the marble to break before or during the process of manufacture. The various types of unsoundness are known locally as "joints," "headers," "cutters," "hair lines," "slicks," "seams," "slick seams," "dry seams," or "dries," and "cracks." The term "reed" is applied to a weakness parallel with the bedding.

IMPORTANCE OF JOINTS IN MARBLE DEPOSITS.

The presence of joints in marble deposits presents a most serious problem. They may be so close and irregular that the quarrying of profitable material is impossible. Joints should have a marked influence on the mode of quarrying a marble, in order that the waste due to their presence may be reduced to a minimum. The manner in which joints occur and their probable continuance at depth are matters of supreme importance.

NATURE OF JOINTS.

Most joints as they appear in marble deposits are straight and uniform though some may be curved or irregular. Some are open and conspicuous and others so obscure that they can be recognized only by those skilled in their detection by long and constant practice.

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[a] Burchard, E. F., Stone: Mineral resources U. S. for 1913, U. S. Geol. Survey, 1914, p. 1313.

Becker[a] has pointed out that surface tension of water in joints tends to keep them closed. With a space of 0.01 inch the surface tension exerts a force of 13.5 pounds per square foot tending to draw the surfaces together, and if the opening is only 0.001 inch wide the force will be 135 pounds per square foot.

The most striking characteristic of joints is their tendency to occur in parallel systems. The occurrence of two systems approximately at right angles to each other is common. Occasionally a third or fourth system may appear. In exceptional cases joints may present such extreme irregularity that no well-defined system can be recognized.

The spacing of joints is variable. They have a tendency to occur in groups of closely spaced fractures separated by masses in which joints are few in number. In certain Vermont quarries such closely spaced groups are termed "fish-backs." In some deposits joints may be 10 to 30 feet apart, and in others they may be separated by a few inches only. Needless to say, a wide spacing adds greatly to the commercial value of a deposit.

ORIGIN OF JOINTS.

In order that one may even approximately understand the distribution, direction, spacing, and persistence at depth of the joints that intersect marble deposits a knowledge of their origin is necessary. Authors generally agree that joints are caused by strains in the rock masses. It is thought that few joints are due to tensile stresses, as joints so caused would show no slickensided surfaces, and be irregular in form, whereas most joints are straight and even planes and are somewhat slickensided. It is now generally accepted that practically all joints are faulted surfaces although the displacement may be small.[b] Daubrée was so firmly convinced of the correctness of this theory that he rejected the term "joint" as failing to imply the existence of relative motion, and introduced the terms "diaclase" and "paraclase." Joints are probably caused by pressure, and pressures in rocks may be highly complex. Curved joints indicate that the direction of effective pressure varies, or varied, from point to point.

The famous experiments of Daubrée[c] indicate that joints may be produced by simple pressure, the joint planes forming at angles of 45° with the line of pressure. His experiments also show that torsion may cause joints. Torsional strain in glass produced two sets of fractures approximately at right angles to one another and usually at angles of about 45° to the axis of torsion. Becker[d] gives

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[a] Becker, G. F., The torsional theory of joints: Trans. Am. Inst. Min. Eng., vol. 24, 1894, p. 131.

[b] See Becker, G. F., Loc. cit.

[c] Daubrée, A., Étude synthétiques de géologic expérimentale, Paris, 1878, pp. 300-374.

[d] Becker, G. F., Op. cit., p. 136.

a reason for this arrangement. He shows that torsion of a bar causes diagonal lines to be elongated or contracted, the directions of maximum extension and compression being 45° to the axis of torsion and perpendicular to each other. Cracks in fan-shaped groups may also result from torsion.

Crosby [a] claimed that earthquakes were important factors in the production of joints, each system being parallel with the earth waves producing it. Various systems must therefore have resulted from successive shocks. A second system will usually be nearly at right angles to the first, as an oblique shock would have found relief along the fractures of the first system. The presence of an oblique system presumes a shock of such high velocity that time was not allowed for the strain to find relief along previous fractures. The same author in a later publication [b] shows convincingly how shock and torsion may act in conjunction and produce results according with the phenomena as they occur in nature. His theory, in brief, is as follows:

The torsional theory assumes a very slow, and the earthquake theory a rapid process of joint development. As fractures formed by slow processes are apt to be irregular, following all places of weakness, torsional joints should be irregular. Most joints, however, are fairly regular and are even known to pass directly through the hard pebbles of a conglomerate. Thus, a discrepancy appears in the torsional theory. A single system of regular joints may therefore be ascribed to shock. A subsequent shock in a transverse direction would tend to break up the sheets formed by the joints, the fractures being of a less continuous nature than those produced by the first shock, being terminated abruptly in many places by the first system of joints and continuing in a different though parallel plane. Thus two systems of an unlike character are best explained by the earthquake theory. However, two systems of like character may be referred to the torsional theory except when they exhibit the regularity indicative of instantaneous stresses.

Crosby refers to the idea, upheld by many geologists, of an almost universal condition of strain in the earth's crust, and states that if, while under torsional or folding stresses, the rock is traversed by an earthquake wave, fractures may be precipitated. Experiments with sheets of glass showed that a sudden shock while the torsional strain was distinctly below the breaking point would precipitate the fractures, but that the direction of the fractures was governed by the direction of the axis of torsion. It seems reasonable, therefore, that the result of an earthquake wave traversing rocks under strain would

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[a] Crosby, W. O., On the classification and origin of joint structures: Proc. Boston Soc. Nat. Hist., vol. 22, 1882-83, pp. 72-85.

[b] Crosby, W. O., The origin of parallel and intersecting joints: Am. Geol., vol. 12, 1893, pp. 368-375.

be the sudden development of joints, governed in direction by the torsional or folding stresses present.

Becker[a] presents some instructive figures showing the manner in which joints are developed by a compressive force in one direction. In figure 1, A, the force is supposed to act in a direction at right angles to the upper and lower surfaces. Face x and its opposite face are supported to prevent rupture. The force produces fractures in planes perpendicular to x and inclined in opposite directions at angles of 45° from the line of force. The face x is intersected by two systems of joints at right angles to each other. On the other four faces perpendicular to x they appear as parallel lines but may dip in either of two directions. If considerable deformation takes place before rupture, the joints will make angles of more than 45° with the line of force.

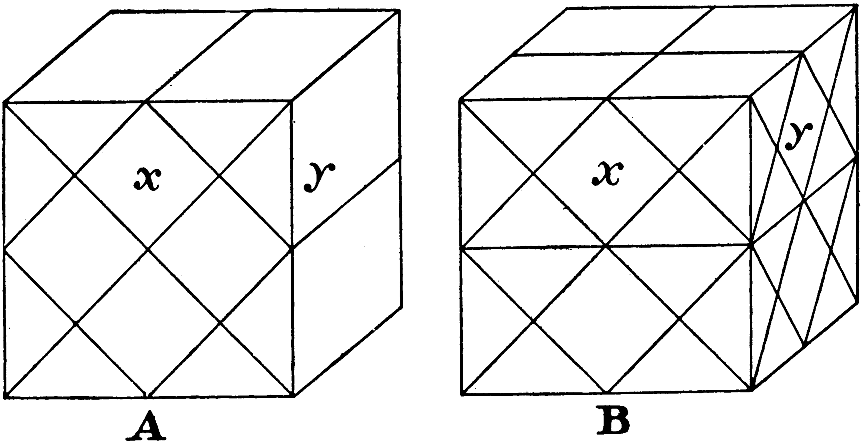

FIGURE 1.—Diagrams illustrating the manner in which a single force may produce several systems of joints—A, joints of two systems, B, joints of four systems.

If the support on x or y is the same, or, in other words, if the resistance perpendicular to the line of force is uniform, two systems will form simultaneously, as shown in figure 1, B, and horizontal and diagonal cracks will appear on both x and y. Thus four systems of joints parallel with octahedral faces will be produced, and the resulting blocks will be octahedral or tetrahedral in form. Other figures given by the author indicate how such systems may be shown to appear on a random plane.

It has been shown in the preceding paragraphs that torsional forces, compressive forces with uniform or nonuniform relief in a transverse direction, or earthquake shocks alone or in conjunction with other forces may produce definite systems of joints. The forces may be

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[a] Becker, G. F., Simultaneous joints: Proc. Wash. Acad. Sci., vol. 7, 1905, pp. 267-275.

multiplied and complex, and the resulting joint systems may present a corresponding complexity, but definite systems are generally developed.

The nature of joint surfaces and some inferences therefrom have been discussed by Woodworth.[a]

PRACTICAL ILLUSTRATIONS OF JOINT SYSTEMS.

The occurrence of joints as observed in many quarries clearly supports the conclusion deduced by theory in so far as systematic arrangement is concerned. A few examples selected from many may be offered in support of this conclusion.

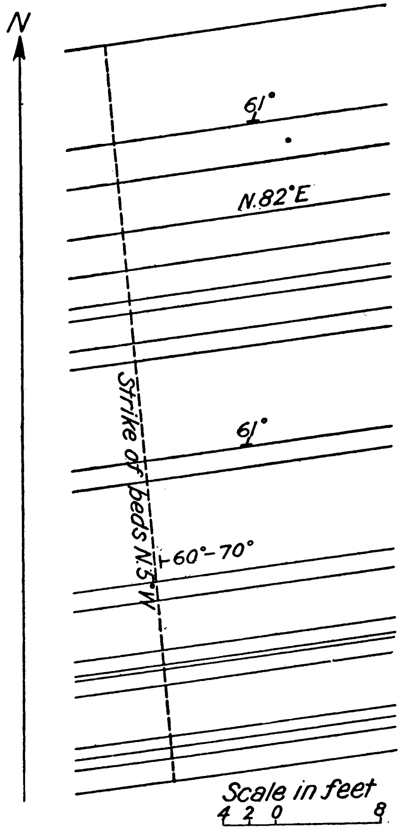

FIGURE 2.—A remarkable system of 21 parallel joints, as found in one outcrop.

In many quarries jointing systems are clear and definite. The direction and spacing of joints as observed at the surface may persist with remarkable uniformity at depths of 100 feet or more. Figure 2 illustrates a system of 21 parallel joints drawn to scale as they appear in an outcrop at a quarry in West Rutland, Vt. They strike N. 82° E. and dip 61° N. 8° W. At a depth of 145 feet they have the same strike, dip, and spacing as at the surface. Four of them are shown in Plate I, *A*.

Figure 3 shows open joints as they appear in a quarry wall. The horizontal lines represent the various floors cut out by channeling machines. The bedding dips about 40° and is marked by one prominent and several less conspicuous open seams. Although some irregularities are to be noted, a definite jointing system may be recognized.

Plate I, *B*, illustrates a system of parallel joints in a Tennessee marble deposit. Erosion has followed the joint planes and thereby given them exceptional prominence. Attention is directed to figure 11 (p. 67) which shows the joint systems in the floor of a marble quarry in Alabama.

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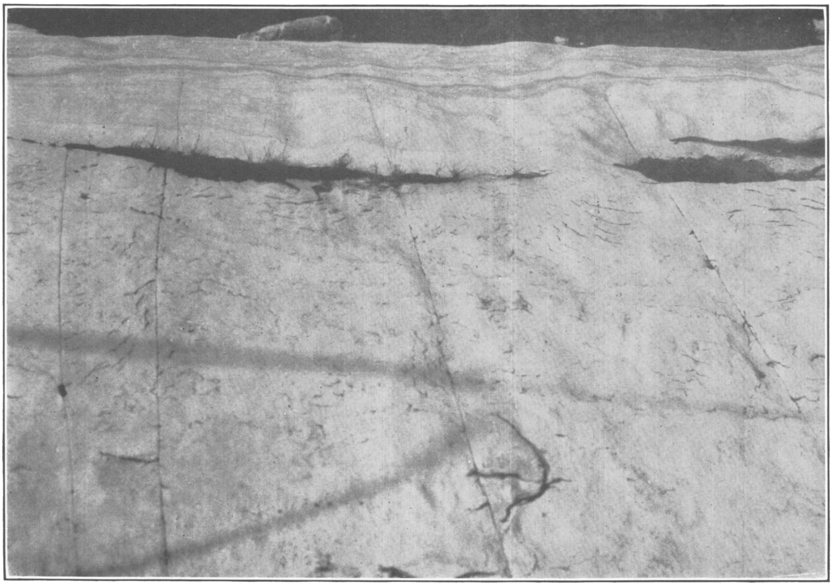
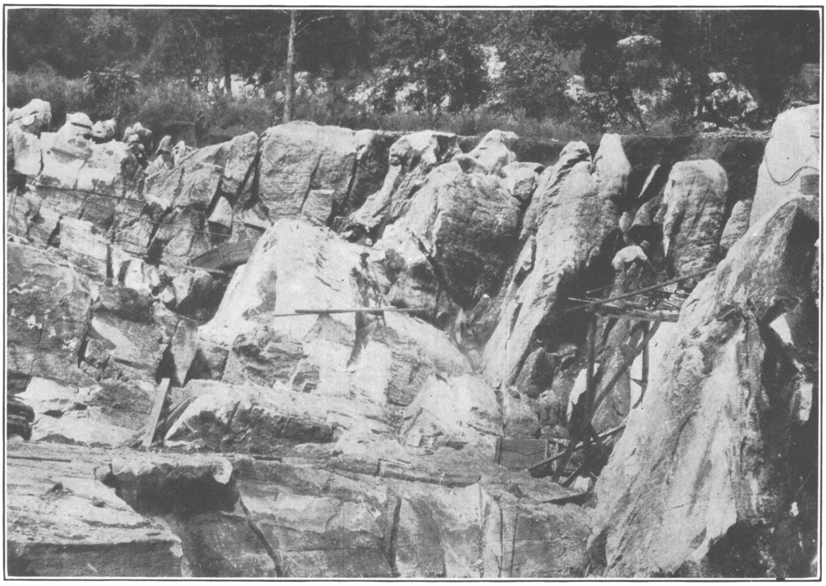
[a] Woodworth, J. B., On the fracture system of joints, with remarks on certain great fractures. Proc. Bos. Soc. Nat. Hist., vol. 27, 1896, pp. 165–183.



A. THE ABRUPT TERMINATION OF JOINTS IN A PLASTIC LAYER IN WHICH DEFORMATION BY FLOWAGE TAKES THE PLACE OF FRACTURES.



B. A SYSTEM OF PARALLEL JOINTS EMPHASIZED BY EROSION.

Hundreds of examples might be given of joint systems, and many quarrymen could supplement them with illustrations from their own experience. On the other hand, in some quarries joint systems may be difficult to recognize. They may be obscure and seemingly rather irregular. However, careful mapping of many of them will reveal definite systems. A practical illustration may be of value.

The operators of a certain quarry declared that the joints in their quarry occurred without any definite system. In order to test the validity of this view the positions of the visible joints were determined as completely as circumstances would permit, with compass, clinometer, and tape measure. A plan, as represented in figure 4, was made showing the arrangement of the joints on the quarry floor. Although some irregularities may be noted, it is evident that only a limited number of joints vary more than a few degrees from a direction N. 45° W. While variations in dip are rather pronounced, a majority of the fractures are within limits of 10° from the vertical.

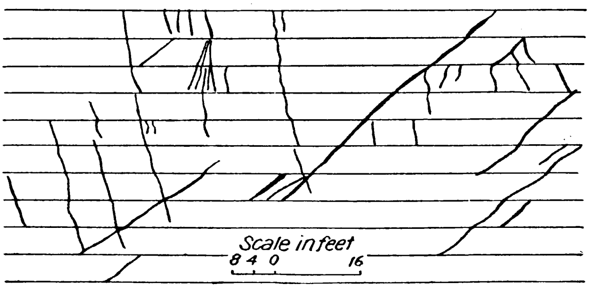


FIGURE 3.—Open joints in a quarry wall.

It is evident, therefore, that with few exceptions definite systems of joints may be recognized in marble quarries. The economic importance of joints is discussed in detail in a subsequent section devoted to a consideration of channeling in relation to unsoundness.

PERSISTENCE OF JOINTS AT DEPTH.

The disappearance or continuance of joints with depth is a matter of profound importance to quarrymen. The belief is common that joints are less numerous at depth. Some persons who hold this opinion can support it by observations in quarries, whereas with others the idea is the expression of an unverified optimism. The origin of joints and the phenomena accompanying their development have a direct bearing on their persistence at depth.

Becker[a] has shown that a mass of rock must occupy a greater space after jointing than before, as cracks and open corners are pro-

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[a] Becker, G. F., Op. cit., pp. 274, 275.

duced. Thus as joints demand increased volume in the mass of rock affected, and as surface rocks have freedom of upward motion, whereas deep-seated rocks are more or less restrained in all directions, there is a stronger tendency for joints to form near the surface than at depth. As pointed out by the same author, the pressure on rocks at depth does not obviate the tendency for fractures to form, but may prevent actual ruptures. Deformation without rupture results, as is clearly shown in Plate I, *A*. The sudden termination of the joints in a plastic layer of soft green marble, as shown near the top of the plate, illustrates the manner in which plasticity permits the necessary adjustment by flowage rather than by fracture.

It is evident, however, that a condition of flowage demands an immense superincumbent load, and takes place, therefore, at depths far beyond the reach of quarry excavations. If deformation without rupture takes place within the limited depth of a quarry pit, it must be by some other phenomenon than that commonly called flowage.

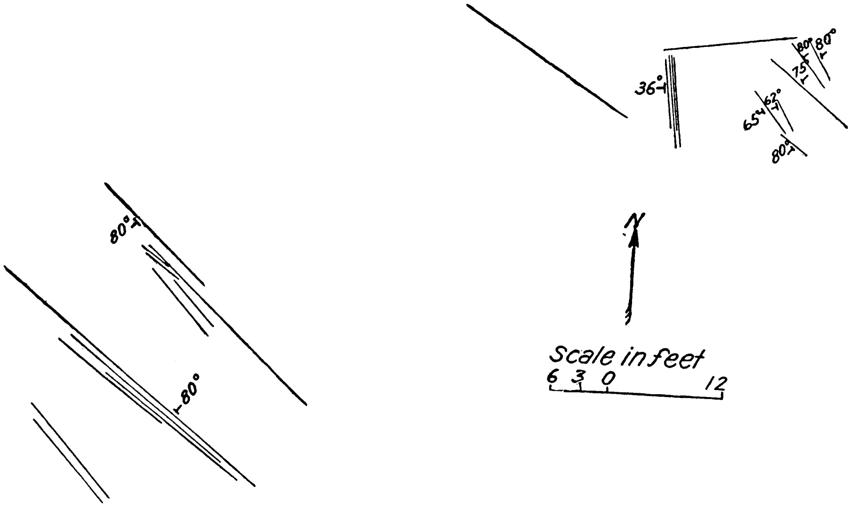

FIGURE 4.—Surface plan of joints that appeared to lack systematic arrangement.

Deformation may take place at moderate depth by the formation of crushed structures which may be masked by recrystallization. Furthermore, deformation without rupture may take place by twinning, or the development of gliding planes in the calcite crystals. As gliding planes have been produced in the laboratory, it is evident that they may occur in nature under pressures of no greater magnitude than those brought about by a superincumbent load of rock within the vertical range of a quarry pit. Deformation may take place by one of these means at moderate depths.

In theory, therefore, joints are characteristically surface phenomena, and should decrease in number with increasing depth. This theory is generally substantiated by the conditions disclosed in quarrying. The decrease may not be constant or uniform. Certain beds are more liable to be intersected with joints than other beds, and in consequence one bed may have more joints than those above it. In general it has been found, however, both in quarrying and in projecting core holes, that if any one steeply inclined bed is followed downward the unsoundness constantly decreases.

Certain fractures, known locally as "slicks" or "hair lines," are, as a rule, evenly spaced, vertical, and at right angles to the strike of steeply inclined beds. They usually disappear at depths of 50 to 100 feet. They are regarded as originating from the expansion and contraction of rocks owing to variations in solar heat.

UNSOUNDNESS IN VERD ANTIQUE.

Unsoundness in quarries of serpentine marble, or what is commonly called "verd antique," is usually rather pronounced and extremely irregular. It is probably caused chiefly by expansion or swelling, owing to the process of hydration as the serpentine is formed. As a consequence, no definite systems of cracks are to be expected. The formation of lens-shaped masses is common. It is frequently difficult to obtain blocks of any considerable size sufficiently coherent to be of commercial value. Occasionally the cracks are recemented by crystalline calcite, producing an attractive white veining on a green background. The so-called brecciated marbles are extremely unsound masses composed of many irregular and usually angular fragments that have been cemented by chemical precipitation of calcium carbonate.

"GLASS SEAMS."

In certain quarries joints that have been recemented in the manner described above are termed "glass seams." They may be sufficiently strong to permit sawing even into thin stock, but most of such seams are planes of weakness. The filling is most commonly of calcite. Occasionally it is of silica, either as quartz, flint, or chert. The silicious filling is least to be desired, as its extreme hardness makes sawing and polishing difficult, and it presents a nonuniform surface. In any case a glass seam usually appears as a conspicuous line which can be regarded only as a blemish when present in otherwise uniform marble.

IRON SULPHIDES.

THE COMMON IRON SULPHIDES.

The sulphides of iron which occur commonly in nature are pyrrhotite, pyrite, and marcasite. Pyrrhotite is a mineral of variable composition ranging from Fe_5S_6 to $Fe_{16}S_{17}$. It appears to be a solid solution of FeS and sulphur. Pyrite and marcasite are identical in chemical composition, which is expressed by the formula FeS_2, but crystallize differently, pyrite being isometric, usually as cubes, octahedrons, or pyritehedrons, and marcasite orthorhombic, with prominent domes and pinacoids. In other respects the two minerals are closely similar and it is difficult to distinguish them.

Pyrrhotite is rare in marble. Pyrite and marcasite are accessory minerals in many marble deposits, the pyrite being the more common. They may appear as scattered crystals of variable size, or may form bands and masses of considerable prominence. The conditions under which pyrite, marcasite, or mixtures of the two may form in nature are discussed by Allen, Crenshaw, and Johnston.[a]

MANNER AND EFFECT OF SULPHIDE DECOMPOSITION.

By weathering, pyrite may combine with oxygen to form iron oxide, iron sulphate, or free sulphuric acid. The oxide may stain, and the acid may corrode the rock. When alumina is present whitish crusts of aluminum sulphate and alum may form. As pointed out by Merrill,[b] if magnesia is present the sulphuric acid may produce a soluble efflorescent salt, which forms white patches on the surface.

The process of weathering may, on the other hand, be less detrimental. The pyrite may gradually change color, become coated with a brown crust, and eventually alter entirely into hydrated iron oxide, which retains the original shape of the pyrite and thus forms a pseudomorph.

Marcasite decomposes in much the same manner, though usually more rapidly than pyrite, and more rarely in the pseudomorphic form.

SULPHIDES NOT ALWAYS INJURIOUS.

Most authors who have discussed impurities in building stone have stated unreservedly that pyrite is injurious when the stone in which it is contained is used for exterior work. This statement is not always true, however.

Many recorded examples and personal observations show that the rate of decomposition of iron sulphides is different in different deposits. In some marbles the sulphides decompose and form undesirable discolorations in a few months or a few years. Marble from other deposits may contain iron sulphide that will withstand many years of weathering, and show no appreciable change. Examples are known of American marbles containing pyrite that have stood

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[a] Allen, E. T., Crenshaw, J. L., and Johnston, John, The mineral sulphides of iron: Amer. Jour. Sci., ser. 4, vol. 33, 1912, pp. 169-217.

[b] Merrill, G. P., Stones for building and decoration, 1903, p. 31.

exposed to the weather for more than 100 years without noticeable staining.

The researches of Julien and Stokes throw considerable light on the conditions governing the rate of decomposition of iron sulphides, and consequently are of great value to quarrymen and architects.

RESEARCHES OF JULIEN.

Julien[a] gives a description of pyrrhotite, marcasite, and pyrite with notes thereon that suggest that the process of metamorphism tends to alter pyrrhotite and marcasite into pyrite, and that, of the iron sulphides, pyrite predominates to a greater extent in marble than in the rocks that have undergone less metamorphism.

He points out that pyrite even in the form of crystals is rarely pure, but contains varying quantities of marcasite more or less intimately mixed with it. The author emphasizes the point that the rate of decomposition depends upon the purity of the mineral; mixtures of pyrite and marcasite weathering readily, whereas pure pyrite is stable.

The relation of specific gravity to rate of decomposition is of interest. The specific gravity of marcasite is given as 4.80, and of pyrite as 5.01. As pyrite is the heavier, any admixture of marcasite with it will lower the specific gravity. Consequently specific gravity may be taken as a criterion of purity, and therfore of resistance to weathering.

In judging the probable resistance to weathering of any iron sulphide present in a rock the author reçommends careful examination of form, color, fracture, and density with supplementary tests for determining whether the mineral is pure pyrite or whether it contains marcasite mixed with it. If mixtures of the two sulphides are found, rapid alteration is to be expected. If possible, pure material, preferably crystals, should be obtained. The observations to be made and their interpretation are as follows:[b]

1. Crystal form; if isometric the material is probably resistant, though such crystals may contain marcasite.
2. Color; if brass yellow the mineral is probably nearly pure pyrite; if pale yellow or tin white marcasite predominates.
3. Fracture; if conchoidal it is probably pyrite; if uneven or granular, marcasite is abundant or the mineral is otherwise impure.
4. Hardness; the hardness of pyrite is 7 and of marcasite 6.5.
5. Odor and streak; a sulphurous odor and greenish streak indicate the presence of much marcasite.
6. Specific gravity; fairly pure pyrite can be expected only when the specimen has a specific gravity greater than 4.97.

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[a] Julien, A. A., On the variation of decomposition in the iron pyrites; its cause and its relation to density: Ann. New York Acad. Sci., vol. 3, 1883-1885, pp. 365-404; vol. 4, 1887-1889, pp. 123-223.

[b] Julien, A. A., Op. cit., pp. 221-223.

7. Observations of weathering effects in quarries or outcrops are recommended as of great practical value.

8. Tests may be made of the comparative rapidity of tarnish when the sulphides are exposed to the fumes of bromine or fuming nitric acid.

RESEARCHES OF STOKES.

Stokes[a] verifies Julien in some respects and differs from him in others. He asserts that in general marcasite oxidizes more readily than pyrite, though finely divided or porous specimens of either decompose rapidly. Mixtures of marcasite and pyrite decompose readily, probably owing partly to porosity and partly to electrochemical action between the two.

Attention is directed to the fact that the presence of various impurities, such as quartz or silicates, may lower the specific gravity of pyrite. Density alone therefore is not a sure method of detecting the presence of marcasite in pyrite unless the absence of all other impurities is known.

The author also casts some doubt on Julien's claim that most isometric crystals contain appreciable amounts of marcasite. Although exceptional specimens may contain marcasite, most isometric crystals are pure pyrite, and orthorhombic crystals pure marcasite.

METHODS OF DETERMINING STABILITY OF SULPHIDES.

Whether a low density is to be attributed to the presence of marcasite or to some other impurities is of little consequence to the stone man. The important point supported by both authors is that specimens of low density are prone to decomposition. Granular or porous specimens are likewise easily oxidized.

It would seem that by making observations and tests as suggested by Julien a fair conception could be gained of the probable stability of the sulphides present, and therefore of the adaptability of the marble for exterior structural purposes. A microscopic examination is of value as indicating whether the sulphides are present as crystals or in porous or granular form. Crystal form and specific gravity are the physical properties that seemingly give the most definite information. The most reliable information may be obtained from observing structures made of sulphide-bearing marble that have stood for many years exposed to weathering. If such observations can not be made, chemical tests may be substituted. The condition of sulphides in the quarry wall or ledge may give less reliable information. Repeated attacks of circulating ground water contain-

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[a] Stokes, H. N., On pyrite and marcasite: U. S. Geol. Surv. Bull. 186, 1901, 50 pp.

ing active solvents may decompose the sulphides, although in the dry wall, or exposed only to the action of rain water, they may last indefinitely without sign of decomposition.

THE USES OF SULPHIDE-BEARING MARBLES.

Although it is true that iron sulphide is not necessarily injurious in marble, it should be carefully avoided in the selection of stone for exterior uses unless good evidence has been obtained that stains will not result. For interior structural or ornamental purposes, however, sulphide-bearing marbles may be used. In some structures the yellow bands and patches of pyrite have produced beautiful effects in polished surfaces.

SILICA.

ORIGIN OF SILICA IN MARBLE DEPOSITS.

Silica may be an original constituent of the marble mass. Marble is formed chiefly from an accumulation of calcareous remains, which have been crushed, folded, and recrystallized to a greater or less degree. It is well known that certain marine organisms, such as diatoms and some varieties of sponges, have silicious skeletons. An accumulation of such shells would form masses of silica. The occurrence of flint balls in chalk cliffs is ascribed to this cause. The silica may appear in straight or lenticular bands or knots.

Van Hise[a] claims that as most of the organic silica is in soluble form it is dissolved and later reprecipitated as chert. He emphasizes the strong tendency in minerals to segregate during the process of deposition from solution, and ascribes to this cause the occurrence of the chert in knots and lenses. The larger and more persistent bands may consist of silicious matter in its original form. The occurrence in concentrated masses may be due to the tendency of marine organisms to live in colonies.

Conditions favoring the propagation of silicious-shelled organisms probably prevailed over a wide area at the same time. If therefore silicious lenses are found in a certain bed in a marble quarry, in all probability they are characteristic of that bed over a wide area.

Silica may also be introduced into marble beds at a later stage in the history of the deposit. Water that percolates through fissures in the mass may contain small quantities of silica in solution, and this material may be precipitated in cracks and cavities. Silica in this form will tend to follow the unsoundness, and may even effectually seal up the fractures.

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[a] Van Hise, C. R., A treatise on metamorphism: U. S. Geol. Surv. Mon. 47, 1904, p. 817.

DETRIMENTAL EFFECTS OF SILICA IN MARBLE.

Silica is at least twice as hard as ordinary marble, and in consequence its presence greatly retards channeling, drilling, or sawing and is injurious to tools, especially wire saws. A flint ball may divert the saw cut to one side or may impede or entirely prevent cutting. Moreover, the unequal hardness presented by the surface of a flinty marble makes it difficult to obtain uniformity of finish under the buffer.

The presence of silica usually detracts from the appearance of marble. The flinty or cherty mass as a rule differs from the marble in color or texture and thus constitutes a blemish comparable with that produced by the presence of a knot in an otherwise uniform stick of timber.

SILICATED MARBLES.

Silicated marbles are those that contain silicates such as pyroxenes, amphiboles, mica, or chlorite. Such silicates may result from the combination of silica with the calcium or magnesium of the marble, with the escape of carbon dioxide. Marbles containing interbedded silicates may also be included under silicated marbles, although none of the silicates may have been derived from the marble.

Interbedded silicates may originate from clay beds in the original limestone. Clay brought down by rivers may be interbedded in limestone deposits formed near the shore. The process of metamorphism that changes the limestone into marble has a pronounced effect on the interbedded clay. Ordinarily it is altered into mica and chlorite. The resulting marbles will therefore contain bands of these minerals. In marbles that have undergone a limited amount of folding and deformation the mica and chlorite bands will remain conformable with the original bedding. Such bands may constitute definite bedding planes separating beds of pure marble. In such form they are not serious imperfections and may even assist the process of quarrying. If deformation has been more intense the mica and chlorite may be scattered throughout the marble mass as a dark banding. Although serviceable for certain purposes, in general a clouding or banding detracts considerably from the market value of the stone.

The formation of silicates by combination of silica with the calcium and magnesium of the marble has usually been accomplished by intense metamorphism. Dolomitic marbles may contain crystals of tremolite, a silicate of calcium and magnesium. Most of the crystals are white with a silky luster, have a characteristic diamond-shaped cross section, and are much harder than marble. They may be microscopic in size or may attain a length of 2 inches. They break out easily and consequently are serious imperfections when of large size. White mica is a common silicate in marble. Its presence tends to make the rock more easily cleavable, as the plates are usually parallel with the grain. Wollastonite, diopside, olivine, and tourmaline are other common silicates occurring in marbles.

DOLOMITE IN MARBLE.

A marble that consists of pure dolomite is harder and more resistant to weathering than one consisting of pure calcite. Thus a marble consisting of dolomite may be no less valuable than one consisting of calcite. As there is a marked difference in solubility and hardness between the two minerals, a marble composed of alternating masses of calcite and dolomite is undesirable. If dolomite is present in lenses or bands, unequal weathering will result and produce a nonuniform surface. There is also the probability of differences in texture, color, or susceptibility to polish between the two minerals. Although pure dolomite, or intimate mixtures of dolomite and calcite, are not to be regarded as inferior types of marble, heterogeneous mixtures in the form of lenses, knots, or bands are, for the above reasons, undesirable.

UNDESIRABLE COLORS.

Marbles may have various colors or combinations of colors, many of which are attractive for decorative purposes. The colors may be permanent or they may change after exposure to sunlight or weather. The fading of an attractive color is undesirable. Vogt[a] states that certain Norwegian blue marbles fade after five years' exposure to the light. Marbles from various other localities are known to fade perceptibly after exposure to sunlight for a number of years. As marble is usually chosen for its inherent attractiveness, color is one of its chief assets, and if the color changes the rock may no longer be of value. Occasionally exposure to the weather improves the color of a marble, but as a rule permanence of original color is to be desired.

The origin of some undesirable shades of color may be easily determined. Black and gray shades are usually due to the presence of carbon. Red and brown shades may be due to manganese oxide (MnO) or to hematite (Fe_2O_3). Cream and yellow colors are caused by the presence of fine particles of hydrous iron oxide, limonite ($2Fe_2O_3.3H_2O$). If pyrite is present in a marble its appearance may be attractive when the marble is first quarried, but may give rise to stains from subsequent oxidation. Green colors may be due to sericite, chlorite, epidote, actinolite, chrome mica, diopside, or serpentine.

Certain other shades of color are of obscure origin. Some variations in color, though slight, may detract immensely from the market value

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[a] Vogt, J. H. L., Norsk marmor, Kristiania, 1897, p. 354.

of the rock. A white marble commonly shades off into a lifeless gray. This may be due to imperfect recrystallization of the gray rock, which may therefore be classed as a limestone rather than a marble. In other deposits an attractive white may fade into an inferior bluish white. Lenses and bands of the bluish material may pass irregularly through the white, and thus occasion excessive waste, or necessitate classifying the marble in a lower grade. The reason for this bluish coloration is unknown; some impurity in minute quantities or some peculiarity of crystallization may be the cause.

During the process of limestone formation there is a tendency for similar conditions to prevail over a wide area at the same time. As a consequence colors due to substances that are original constituents of the marble tend to exhibit a minimum variation in different parts of the same bed and a maximum variation in passing from one bed to another. It is usually found that certain beds in a marble deposit give more attractive colors than other beds, and that each bed exhibits more or less constancy of color. The variation from white to bluish white in different beds may be pronounced, though less marked variations have been noted in different parts of the same bed. If marble of a particularly pleasing color appears in a certain bed, there is much greater probability of finding more of the same material by following the original bed than by seeking for it in other strata.

FISSILITY.

In certain marble deposits numerous parallel cleavage planes have been developed. They may be so closely spaced that little serviceable marble can be obtained. According to Becker,[a] cleavage in rocks is due to a weakened cohesion along planes of maximum tangential strain (or maximum slide). The process of folding, which is so common in marble beds, undoubtedly causes intense strains, which may develop a cleavage or fissility in the marble. Marbles that are fissile have probably been subjected to profound metamorphism. The same author[b] points out that crystals tend to grow in the direction of least resistance, and hence mica plates, so common in easily cleavable marble, tend to grow parallel with the planes of schistosity. Thus the mica may further facilitate the cleavage. The presence of much muscovite (white mica) parallel with the cleavage planes in several fissile marbles has been noted.

Marble with a certain degree of fissility may be used if cut in slabs parallel with the cleavage. There is a probability of great waste, however, and as a rule such deposits should be avoided.

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[a] Becker, G. F., Experiments on schistosity and slaty cleavage: U. S. Geol. Survey Bull. 241, 1904, p. 11.

[b] Becker, G. F., Op. cit., p. 22.

DEFECTS IN TEXTURE AND STATE OF AGGREGATION.

Uniformity of texture is an important requisite of a marble. A noticeable variation in the size of grain from point to point detracts greatly from its appearance. Moreover, different textures decompose at different rates, and therefore nonuniform marble will tend to weather and decay in an unequal manner, and to produce a pitted and uneven surface.

Marbles vary greatly in size of grain. Most of the fine-grained marbles are more durable than the coarse grained. As pòinted out by Dale,[a] acid water travels more rapidly between coarse than between fine grains. For all exterior structural purposes, therefore, fine-grained marble is to be preferred.

Aside from its durability, the fine-grained marble offers other advantages. It usually takes a better polish than coarse-grained material. Moreover it is as a rule better adapted for intricate cutting or carving, though some of the coarse-grained marbles of Georgia carve well.

The percentage of pore space is variable in marbles from different localities. In no marbles are the crystals so firmly cemented together that no pore space exists, though in some specimens it is small. Pores permit the infiltration of water, which affects the marble in two ways. Rain water may contain carbon dioxide or other solvents that hasten the decay of the rock. Water in the pores may freeze in cold climates and thus cause disintegration. Hence, low porosity is desirable in marbles for exterior uses.

However, a marble should not be condemned simply on the basis of percentage of pore space. A rock of low porosity may under certain conditions decompose more readily than one of much higher porosity but having a different type of pores, as explained in the following paragraph:

The rate of solution of marble by circulating water depends on the nature of the solution and the rate of circulation. The nature of the solution depends on environment, and not on any inherent peculiarities of the marble itself, except in so far as the solution is modified by substances dissolved during its passage through the rock. The rate of circulation, however, depends largely on the nature of the pores. If the pores are isolated from each other by walls of rock, circulation must be slow. If, on the other hand, they are connected by open channels, free and rapid circulation is possible. The rate of circulation depends, therefore, rather on permeability than on percentage of porosity. The permeability of marble may be tested by investigating the rate of flow of water forced through it under pres-

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[a] Dale, T. N., The commercial marbles of western Vermont: U. S. Geol. Surv. Bull. 521, 1912, p. 37.

sure as described by Parks,[a] or it may be tested by the distance to which colored analine dyes will pass into the rock in a given time. Naturally those marbles of high permeability are undesirable for exterior work.

In cold climates the effect of frost on exposed marble may materially increase the rate of decay. Although low porosity undoubtedly tends to diminish the danger of deterioration through frost action, the effects of frost are not proportional to the percentage of pore space. As shown by Buckley,[b] the effect of frost on a stone depends on the rapidity with which the stone gives up its included water. Parks[c] in commenting on this statement brings out the following facts: The injury is caused by the expansion resulting when water changes into ice. If the pores are full of water, expansion must cause disintegration of the rock, but if the pores are only partly full, expansion may take place without rupture of the pore walls. Capillarity may keep many of the finer pores full of water, whereas air in the larger cavities prevents complete filling. It is evident, therefore, that a stone having a large proportion of fine pores is in greater danger from frost than one in which the proportion of fine pores is lower. In cold climates, therefore, numerous fine pores are undesirable in marble that is to be exposed to the weather.

Porous stones readily collect dust particles and therefore become dirty much more rapidly than compact varieties. Porous stone should therefore never be used if it is to be exposed to excessive smoke or dust.

In sawing porous marbles sand must be used as abrasive. Although crushed steel cuts more rapidly, it may enter the pores, and later scratch the slab during the process of polishing, or may by rusting cause serious stains.

The strength of a marble depends in part on the state of aggregation of its constituent particles. Marbles in which the particles adhere to one another with great tenacity are stronger and more durable under pressure than those in which the grains are loosely coherent. A remarkable interlocking of crystals has been noted in some marbles, and it is thought that such a condition increases their crushing strength.

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[a] Parks, W. A., Report on the building and ornamental stones of Canada: Can. Dept. Mines, vol. 1, 1912, p. 61.

[b] Buckley, E. R., Building and ornamental stones of Wisconsin: Wis. Surv. Bull., 4, 1898, p. 22.

[c] Parks, W. A., Op. cit., pp. 63, 64.

PROSPECTING AND DEVELOPING MARBLE DEPOSITS.

PROSPECTING.

VALUE OF GEOLOGIC MAPS.

Most marble beds outcrop in long and narrow bands, which may extend for many miles. These bands represent truncated edges of folds in the rock and may be curved or straight, depending upon the topography and on the nature of the fold. Much of the rock surface may be covered with gravel, sand, or clay to a considerable depth. The geologist may, by a careful study of outcrops exposed here and there, obtain a knowledge of the chief structural features, and may thus determine the position, thickness, and attitude of the marble beds with a fair degree of accuracy, even if they are entirely hidden by surface débris. If geologic maps of marble belts are carefully made they are of inestimable value to the marble prospector. By accurately locating himself in the field and carefully consulting a geologic map the prospector may determine the position of marble belts beneath the soil and know something of their extent and attitude although they are unseen. It is important, therefore, that all available geologic maps of the region be consulted freely.

NEED OF DETAILED PROSPECTING.

Knowledge of the suitability of any particular site can be gained only by detailed prospecting including a determination of the depth of overburden and of surface alteration of the rock and of the extent, quality, impurities, and soundness of the deposit. It is extremely unwise to proceed with development work without a reasonable assurance that an available mass of sound and attractive marble is sufficiently uniform in quality and abundant in supply for profitable exploitation.

DETERMINATION OF OVERBURDEN.

The depth of stripping necessary may be determined at small cost by putting down drill holes. The need of such preliminary tests should be recognized. In certain instances stripping has been attempted without any previous investigation of the depth of soil to be removed. The great loss that may result from thus working blindly may be illustrated by one particular instance. A pit opened by a certain quarry company and later abandoned is 60 by 80 feet in extent and 20 feet deep. To make such a pit required the removal of approximately 3,550 cubic yards of soil, which, at an average cost of 25 cents per cubic yard, would have cost $887. The only purpose this pit actually served was to show the owners that the stripping was too deep to make quarrying at this point profitable. The same information could have been obtained by projecting two drill holes each 25 feet deep. At the ordinary cost of rock drilling, $2 per foot, the cost would have been only $100, a saving of $787.

In estimating the necessary cost of stripping for a new quarry the attitude of the marble beds must be taken into account. If the beds are flat a greater area of rock must be uncovered than if they are steeply inclined or vertical.

Naturally conditions relating to disposal of stripping are of great importance. In certain places it is a matter of some difficulty to find a suitable place in which to deposit the soil that must be removed; in other places the soil may be carried to neighboring valleys or low-lying areas.

SURFACE STUDY INSUFFICIENT.

Surface observations are of great value, especially as regards jointing. The process of weathering tends to emphasize all unsoundness and thus facilitates the study of joint systems. Exposed surfaces may also permit a determination of dip and strike and the thickness of the beds.

In determining the quality of a marble deposit a study of uncovered knobs or ledges should not, however, be deemed sufficient. On account of surface weathering the top rock may differ materially from the deeper parts of the deposit. Moreover, the number and spacing of joints at the surface may be no indication of the prevailing conditions at depth. Before the prospective quarry operator installs expensive derricks and hoisting machinery and purchases channeling machines and drills he should have a fair idea of the quality and soundness of the marble and the supply available. In order to obtain this knowledge drill cores should be taken at several points.

DIAMOND-DRILL PROSPECTING.

The ordinary diamond drill will give the necessary information regarding color, uniformity, and general appearance of the stone, and also the extent of the formation. It will not, however, give definite information concerning the dip and the strike or the unsoundness of the marble. If drill cores come out in long, unbroken sections which show no indication of cracks, it may be assumed that the rock is fairly sound. If, on the other hand, the core is in short sections, the rotation of the drill will in most cases have so worn and rounded the broken ends that it will be impossible to determine whether the breaks are due to natural planes of weakness in the rock or to the process of drilling itself.

MECHANISM OF THE DOUBLE CORE-BARREL DRILL.

A method of prospect drilling that has been employed by at least one operator involves the use of the double core-barrel drill that was designed primarily for drilling bituminous coal, and operates in such a manner as to bring out a core from a delicate material with a minimum of breaking or other damage. The drill, shown in Plate II, consists of an outer and an inner tube. The outer is attached to the drill rod by means of the core-barrel plug, and is rotated the same as the cutting tools. The inner tube is suspended by a ball-bearing plug at the top and centered by a ball bearing near the bottom. Thus, while the outer tube revolves, the inner tube which carries the core ring or lifter at its lower end remains stationary. The core passes up through the bit into the inner barrel, where it is protected from friction from the rotating parts, and from the washing action of the water. An ample water supply is provided between the two tubes. The purpose of the inner tube is to hold the core as immovable as possible, and thus to prevent the wearing or rubbing of the broken ends. Although the core does not revolve after it passes through the core lifter into the inner tube, the principle of cutting and the action of the bit on the core until after it passes into the inner tube are just the same as with the single-barrel drill. Therefore, if a natural parting is encountered in the rock, or if for any reason the core is broken off, it is liable to be rotated somewhat before it gets into the inner tube. If the core breaks obliquely the danger of rotation is minimized. Cores should be at least 2½ inches in diameter.

VALUE OF DOUBLE CORE-BARREL DRILL TO PROSPECTOR.

The use of a drill like that described enables the prospector to judge the unsoundness of the marble at points beneath the surface. If one examines carefully the ends of the sections of drill core one can, almost without exception, interpret the breaks, and state whether they are due to natural joint planes in the rock or to the process of drilling. If the cores are properly oriented, the proximity and direction of all natural cracks in the rock in the immediate vicinity of the drill holes may thus be ascertained.

If the marble deposit is well exposed, the dip and the strike may be determined from examination of the outcrops. If, however, it is completely buried, these features may be determined from the drill cores if they are carefully oriented.

DRILLING THE HOLES.

NUMEROUS HOLES UNDESIRABLE.

Information should be obtained with a minimum number of drill holes. In this respect prospecting for marble differs materially from prospecting for metalliferous ores. As regards metalliferous ore, the soundness of the ore is not important, whereas with the marble every crack or cavity increases the proportion of waste in the quarried product. A drill hole in a quarry is quite as objectionable as a crack. If the deposit lies flat or nearly so, a single well-placed core driven entirely through the deposit will give information as to the character of the marble, and show whether it is one homogeneous mass, or is divided by streaks of color or open beds into different layers, and whether the layers differ in character one from the other.

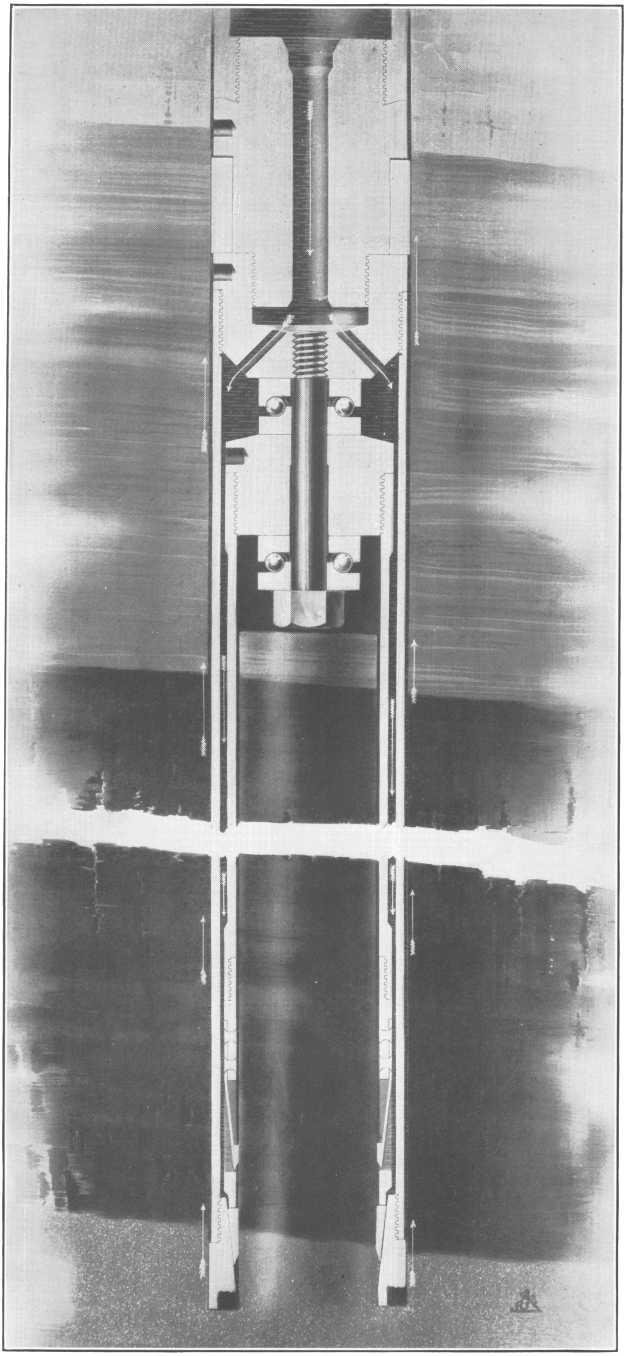
PROSPECTING THICK BEDS DIPPING AT A MODERATE ANGLE.

If the deposit dips at a moderate angle and is comparatively thick, the best way to determine its thickness and the character of its beds is to lay out a line of drill holes at right angles to the strike. The first drill hole that penetrates the upper beds should begin in the hanging wall, a name given to the bed immediately overlying the marble band. The holes should be of such depth and spacing that the bottom of a hole in the upper beds will penetrate the same layer as the top of the neighboring hole on the side toward the footwall. The core nearest the footwall should reach and penetrate this wall. By this method a series of core holes of moderate depth will supply samples from all the beds, and the relatively high cost of drilling deep holes will be avoided. The same information could be obtained by drilling one hole, starting at the hanging wall and penetrating the entire deposit to the footwall, but the cost would probably be much higher.

DETERMINATION OF DIP AND STRIKE FROM DRILL CORES.

If the marble has at any time been subjected to severe stresses, and has been sufficiently plastic to flow freely under the pressure, the original distribution of color may be so disturbed that it no longer bears any well-defined relation to the bedding. Ordinarily, however, the direction of veining or clouding is approximately parallel with the bedding. A vertical core may therefore enable the prospector to determine the average angle of dip of the marble if he measures the angle at which the streaks of color or the grain of the rock traverses the core itself.

If access to the surface of the marble can be obtained before the core is started, the direction of strike may also be determined from a single vertical core by orienting the upper part of the core as it was



DOUBLE CORE-BARREL DRILL.

before drilling, and then by carefully matching the successive pieces. If the surface is inaccessible three cores distributed on the corners of a triangle may serve to determine both dip and strike, provided there are well-defined beds that may be matched in the different cores. If a sufficient area of the marble is stripped the strike and dip can be determined by direct observation, but even then the indications of the core may be of value, because the strike and the dip may vary considerably even within short distances.

ARRANGEMENT OF HOLES TO TEST VARIATION IN QUALITY.

It may seem desirable to test the uniformity in quality of marble in the same bed at different points along the strike. To get a fair idea of any variation in quality it is well to lay out, across the strike, two parallel lines of holes, 300 to 1,000 feet apart, depending on conditions. Every effort should be made to locate the two lines of holes so that each core in the second line will come from the same part of the deposit as the corresponding core of the first line. Thus, fair conclusions can be drawn as to the variation in quality of any layer of the deposit as a whole from point to point. All drill cores should be polished on one side in order to facilitate determination of color, uniformity, and degree of polish that may be obtained.

As core drilling is rather costly, it is well to supplement the evidence of the cores by stripping the marble along each line of holes. It is wise also to dig an occasional trench at right angles to each line of core holes so as to expose the marble to some extent along the strike.

ARRANGEMENT OF HOLES TO DETERMINE UNSOUNDNESS.

A marble deposit in which the color, texture, or other qualities are highly satisfactory may nevertheless not warrant commercial development because of joints. Most joints occur in two systems, the cracks in each system being approximately parallel with each other, and the two systems more or less at right angles. Occasionally more than two systems are present. The spacing of the cracks is subject to wide variation in different deposits and even in different parts of the same deposit. Near the surface the cracks are usually more numerous and more irregular than at depth. Nearly always at least two systems of cracks will persist with more or less prominence to almost any depth to which quarrying operations may be economically carried. It is important to determine as early as possible which of the cracks that appear at the surface are likely to persist and also their nature and spacing in the deeper parts of the deposit.

Most of the cracks are nearly vertical and also nearly at right angles to the bedding of the marble, few cracks deviating from a right angle more than 30°. Hence, a vertical core taken out of marble that is rather unsound may reveal the presence of few of the cracks. Therefore, a vertical hole is not reliable as a means of estimating the unsoundness to be encountered.

Having determined by any means available the systems of cracks that will probably persist at depth, the general compass bearing of each system should be determined. A series of core holes approximately parallel with the bedding should be laid out, the compass bearing of the core hole being such that it will intersect both systems of cracks at approximately the same angle. A core projected in such a direction will give a fair estimate of the unsoundness present. It also results in an oblique break in the core wherever it crosses a crack of either system, and thus makes less likely any grinding of the ends of the core sections. The origin of a fracture may be determined with reasonable certainty, because a freshly broken surface made in sound marble differs materially in its appearance from the surface of a break due to a joint.

It is important to take cores from near the top, from near the middle, and from near the bottom of the deposit, because the unsoundness often varies in different beds as well as in different parts of the same bed.

If the marble deposit stands at a high angle, one set of core holes driven in an inclined direction and penetrating from the hanging wall to the footwall, or the reverse, can be laid out so as to give the information required as to the quality of the stone and also the unsoundness.

It is practically impossible to take out good cores that are representative of the deposit from horizontal drill holes. The core from a horizontal hole invariably breaks into short pieces, which grind on each other, in spite of the use of the double-core barrel. The core hole has to be slightly larger than the outer diameter of the core barrel in order to permit the passage of water and slush and also to prevent binding of the drill in the hole. As a result the progress of the drill brings a considerable weight on the unbroken end of the core, and as soon as the core is a few inches long it breaks off. The break occurrs seemingly at the bottom of the hole, the result being that the spring clips on the inner core barrel, which are supposed to hold the unbroken end of the core and thereby prevent rotation of the inner core barrel, have nothing on which to hold. During the time that the drill is cutting a little farther in and the clips are getting a fresh hold, the inner core barrel rotates to a greater or less extent, so that the core ends grind on each other. Therefore, if the marble beds lie flat or nearly so, unsoundness must be prospected for by inclined core holes; otherwise the cores will not yield the information desired.

ARRANGEMENT OF THE CORES OBTAINED.

In order to get the fullest information from an inclined core hole the core parts should be matched up from one end to the other, and placed, a part at a time, on an inclined rack that will hold the core in a position parallel with the hole from which it was taken. While the core is in this position the compass bearing of the cracks and also the angle that they make with the core can easily be determined. From this information a plan may be made from which the probable percentage of marble unaffected by unsoundness may be computed with reasonable accuracy.

Before an inclined core is started, the first piece should be marked so that it can be laid top side up after it has been removed. The dip of the core hole should be slightly different from the dip of the beds so that a streak of color, the grain of the marble, or any other feature parallel with the bedding will traverse the core at a slightly oblique angle. With such a method of drilling, if clean right-angled breaks occur, one piece of core may easily be matched to the preceding piece, and the prospector may be sure that he has the entire core properly matched from one end to the other.

VALUE OF THE INFORMATION GAINED FROM CORES.

From a careful study of cores taken out as described above, valuable information can be obtained in reference to the unsoundness existing at some depth in the deposit. It will often happen that, although the marble appears so broken at the surface that profitable operation seems impossible, investigation with a drill in the manner above described will reveal the fact that the cracks close and disappear to such an extent that profitable operation may be possible after the top rock has been removed.

A later section discusses the advantages of quarrying in accordance with unsoundness, and shows that a knowledge of the extent, direction, and character of the unsoundness is important in laying out the preliminary opening in order to avoid unnecessary expense.

COST OF MARBLE PROSPECTING.

Prospecting as described above is rather costly. The average cost of double core-barrel drilling by contract is about $3 per lineal foot. If a marble company has sufficient work to justify owning its own drills the cost can be considerably reduced. In any case the information desired can not be obtained for less than $5,000 to $20,000. Many marble deposits, however, can not be profitably worked except on a large scale, so that a considerable outlay made to determine whether conditions are favorable is money well expended.

PRESERVATION OF CORES.

As a rule, drill cores are not preserved with sufficient care by quarrymen. They are often carelessly stored, lost, or given away as samples. It is important that every part of every drill core be carefully marked and stored for future reference. It must not be assumed that the value of drill cores disappears after their first investigation. They are invaluable records which should be available at all times.

STRIPPING.

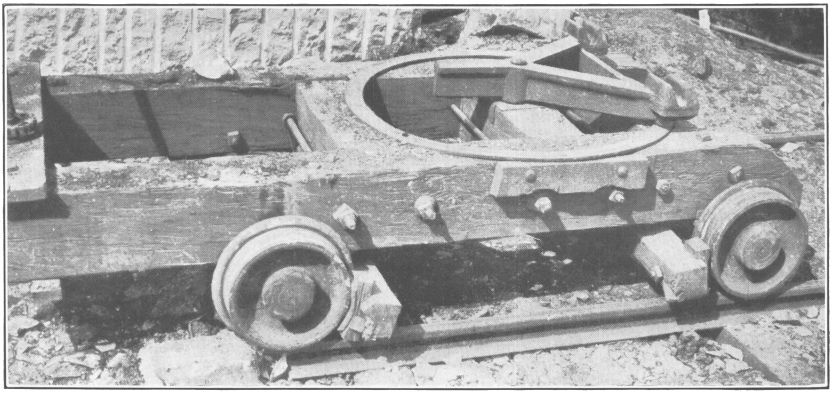
ORDINARY METHODS OF STRIPPING.

Most marble quarried is of a high grade, and the bulk of rock removed is small in comparison with the quantity handled in many quarries where rock is obtained for cement or road construction. As a consequence the area stripped is usually not great enough to justify the use of steam shovels.

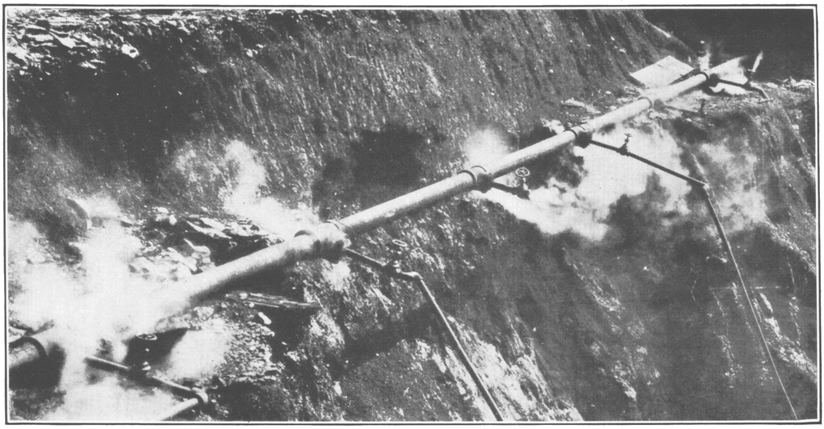
When the surface of a deposit is fairly level, teams and scrapers may be used to advantage. Usually, however, the overburden of soil is so placed that it must be removed by means of large pans which are loaded by hand, and handled with a derrick hoist. In order to remove the soil to a sufficient distance from the excavation, cars and tracks may be necessary. A serviceable car for this purpose is shown in Plate III, *A*. The loaded pan is placed on the car by means of the quarry derrick. Horizontal iron bars on the undersurface of the pan are placed in the iron sockets of the car. These trunnions are so placed that a little more than half the weight of the load is toward the rear end of the car. When the car reaches its destination, the back of the pan is raised, thus overbalancing the load, and dumping it from the front of the car. Where soil must be removed to a great distance, the loaded pan may be dumped into railroad or cable cars.

INSUFFICIENT REMOVAL OF STRIPPING.

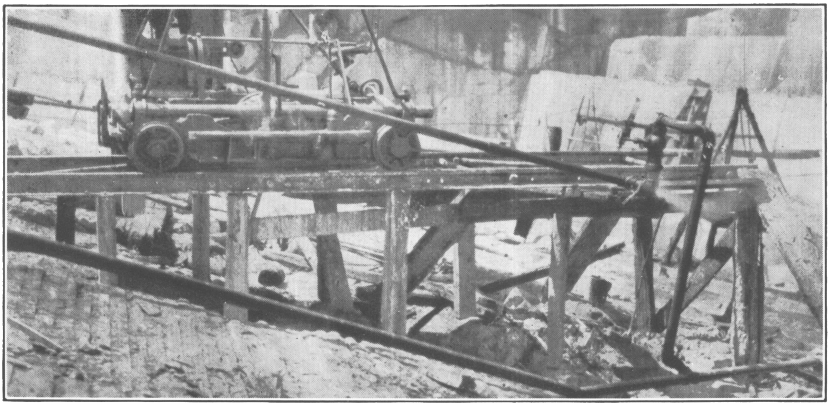
A common mistake in the process of stripping is to remove the soil and waste to an insufficient distance from the excavation. The desire to attain quick results at small expense, and lack of foresight regarding the probable extent of future operations are the chief causes of insufficient removal. As a consequence, quarrymen may find after a few years' operation that they must handle material a second time, thus adding greatly to the expense of quarrying. The extensive marble workings of Italy, in the neighborhood of Carrara, Massa, and Seravezza, are greatly hampered by accumulations of rubbish which have buried vast quantities of good marble. The market price is too low to allow the removal of this débris.



A. SERVICEABLE CAR FOR REMOVAL OF WASTE AND STRIPPING.



B. TYPICAL EXAMPLE OF STEAM LEAKAGE IN A QUARRY TRANSMISSION LINE.



C. TRACK SUPPORTED IN LEVEL POSITION FOR "SAW-TOOTH" FLOOR CHANNELING.

Lack of foresight is also shown at some quarries where quarrymen dump their waste material into abandoned excavations. This procedure may be justifiable if there is no probability that the pit may ever be reopened. The practice has been observed, however, in places where it seemed that greater success would have been attained by going deeper in the old pits than by making new ones.

WASTE HEAPS IMPEDING FUTURE DEVELOPMENT.

Another mistake in the disposition of waste material is due to the inability of the operator to foresee the direction in which future operations will extend his quarry. As regards steeply tilted beds, it is obvious that if excessive depth is to be avoided development can take place only in the direction of strike. Nevertheless, at certain quarries of this type observed, stripping has been deposited directly in line with the strike of the beds, and thus an extension of the quarry excavation must soon overtake a great heap of accumulated débris.

USE OF OVERHEAD CABLEWAY HOISTS.

For the removal of both soil and waste rock to a sufficient distance to avoid interference with future operations an overhead cableway hoist may be desirable. At one quarry at which such a cableway is used the hoist engine is mounted on a truck that travels on a curved track. It can thus be shifted to strip in different places. Where difficulties are in the way of removal of stripping by derrick or car, the advisability of adopting a cableway system may be considered.

HYDRAULIC STRIPPING.

Hydraulic stripping is employed with success in several marble quarries. There are certain conditions, however, that must be met in order that hydraulic stripping may be successful or even possible. Two important conditions are an adequate water supply and easy drainage. If the water supply is obtained from drilled wells or small streams that may go dry, the process will probably fail.

The soil removed by hydraulic stripping may be disposed of in several ways. It may be carried away in a stream valley and deposited naturally at various points along the course of the stream. In some places, however, the deposition of the soil along the stream valley would be detrimental to agriculture or to other interests. In that event, a dam may be built forming a settling basin. In certain operations, surface soil is conveyed to abandoned quarry pits. With such disposal surface drainage is also necessary in order to get rid of accumulated water. Also one must be sure that there will be no future desirability of reopening the pit, as reopening would not be feasible after the pit was once filled with soil.

In certain quarries in Georgia, the good marble is underlaid by a hornblende rock. When in the process of quarrying the hornblende rock is reached, the pit is abandoned, and can then be used as a settling basin in the process of hydraulic stripping.

Those who have had experience in hydraulic stripping estimate that the cost of soil removal by that method may be as low as 2 cents per cubic yard.

GENERAL PLAN OF QUARRYING.

PRODUCTION OF UNIFORM GRADES OF MARBLE DESIRABLE.

Success in marble quarrying necessitates an adequate supply of uniform material. The inherent qualities of certain marbles win immediate popularity. With other types it has been found that by profusely scattering samples and following them with structures in various localities, public taste may be educated to demand a certain type of marble. It is most discouraging for a quarryman who has won popular favor to find that he can no longer match his samples because of failure of the deposit. The desirable bed may have pinched out, or insufficient production may be due to the operator's inability to foresee the general plan of quarry development that ought to have been followed. If the desirable bed lies flat and near the surface, extensive stripping is necessary. If the bed is inclined and the overlying beds are too unsound to permit tunneling, quarrying must follow along the strike of the beds, also demanding extensive stripping. If in either instance the cost of stripping is excessive, the quarrying of the bed must be abandoned.

FACTORS GOVERNING PLAN OF DEVELOPMENT.

The most successful mode of operation can not always be foreseen. Certain geologic factors, however, may give information pointing to the most logical method of developing the deposit. Three chief factors are the attitude of the beds, the depth of overburden, and the uniformity of the product in a given bed and in successive beds, and these three factors are intimately related. Before operations are begun the intelligent prospector will determine, in a general way at least, the necessary depth of stripping, the dip, and the strike of the beds, and the uniformity of the marble, so that he may plan a logical quarry development. The influence of the various factors on the plan of operation is discussed in the following paragraphs.

EFFECT OF ATTITUDE OF BEDS ON PLAN OF QUARRYING.

Most marble beds are situated in regions of extreme folding, and most of the beds, although originally flat, are tilted, though a few are level or nearly so. The attitude of the beds is of great importance to the quarryman, especially if the various beds differ from each other in texture or color. If beds are inclined at a moderate angle, either long shallow quarries or tunnels must be made in order to keep up the supply of stone from a particular bed. If the beds are steeply inclined or vertical, either long, shallow quarries involving a great area of stripping, or deep quarries with their associated dangers and expense are necessary. If the strata are flat and the desirable bed is near the surface, a wide, shallow quarry results.

It is clear that if beds lack in uniformity, their attitude has a direct bearing on the most desirable plan of quarrying. If, however, the bedding is indistinct and a number of contiguous beds are uniform in color and texture, as in certain quarries in the Knoxville region of Tennessee, the attitude of the beds has a minor influence on the type of quarrying to be employed.

EFFECT OF OVERBURDEN ON PLAN OF QUARRYING.

If the marble lies in approximately horizontal beds of limited thickness, the production of large quantities will necessitate the stripping of a wide area. If the overburden of soil or superficial waste rock is great, the cost of stripping may absorb all profit. If a sufficiently strong roof is available, extensive stripping may be avoided by employing tunnel methods.

As regards flat-lying, uniform beds of great thickness, a heavy overburden will tend to promote deep quarrying, whereas a light overburden will encourage the development of wider and shallower pits.

If the beds are vertical or steeply inclined, a heavy overburden will result in deep quarrying or tunneling, whereas if only light stripping is necessary a greater lateral development in the direction of the strike is possible.

EFFECT OF UNIFORMITY OF PRODUCT ON PLAN OF QUARRYING.

In a few deposits thick beds are uniform throughout. However, in many marble regions a certain bed supplies stone of better quality than the beds above or below it. Obviously it is desirable to develop the quarry in such a manner as to obtain a maximum supply of the high-grade material. The shape of the opening, whether it shall be deep or shallow, open pit or tunnel, depends chiefly on the attitude of the beds and the depth of stripping required. Thus one may see how intimately the three factors of attitude, overburden, and uniformity are related, and how necessary it is that they be understood before development is attempted.

QUARRY OPERATIONS AND EQUIPMENT.

POWER PLANTS.

TYPES EMPLOYED.

For a discussion of various power plants and their relative advantages and economies the reader is referred to the work of Brunton and Davis.[a] On account of the special types of machinery employed in marble quarrying, some additional notes bearing particularly on this subject are given herein.

The following types of power plants have been observed in marble quarries in the United States: (1) Steam only; (2) steam for channelers and tripod drills, with auxiliary air compressor for hand drills; (3) compressed air generated by steam and conducted to the quarry by pipe line; (4) electricity developed by steam; (5) compressed air developed by purchased electric power and transmitted to the quarry by pipe line; (6) purchased electricity transmitted directly to the quarry; (7) hydroelectric power plants owned and operated by the quarry company, the electricity being transmitted directly to quarry machinery.

ADVANTAGES OF ELECTRICITY.

The superiority of electricity over any other form of power for quarry operation has lately been demonstrated. This superiority is due chiefly to the recent development of electrically operated machinery. The electric air channeler which is now in common use consumes on an average only 10 horsepower for the machine itself, although a 15-horsepower motor is required to drive it. A steam or air channeler requires a steam capacity in the boiler that, if applied to an economical generating unit, would develop at least 50 to 60 horsepower. The difference in power consumption between the electrical and other machines is due partly to differences in transmission or transformation losses, and partly to the higher efficiency of electrical machinery generally. The electric air channeler is, therefore, much more economical of power for the same results than the other types.

If the nature of the rock is such that "jackhamers" [b] are used in lieu of other types for quarry drilling, an air compressor is necessary. Should a direct-acting electric drill be produced that can do the work of a jackhammer, compressed-air transmission lines might be eliminated from the quarry. Such a drill has not as yet been developed, at least not in a practicable form.

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[a] Brunton, D. W., and Davis, J. A., Safety and efficiency in mine tunneling: Bull. 57, Bureau of Mines, 1914, 271 pp., 6 pls., 45 figs.

[b] Term applied by the manufacturer to a nonreciprocating rock drill, worked without a tripod, and provided with an automatic rotating device. The word is also spelled "jackhammer" in mining literature. It uses hollow steel through which the exhaust air passes and blows the cuttings from the drill hole.

Wire is a more convenient means of transmitting power than pipes or hose. Steam requires pipes with flexible joints for operating channeling machines. Steam pipes are often in the way and there is considerable loss of time in adjusting them in proper position. Compressed air may be transmitted through flexible hose, which is more easily adjusted than steam pipes, but transmission by wire is more convenient than either. If quarry operations are carried on in tunnels, electricity is especially desirable. A network of pipes is always a great hindrance to quarry operations.

Moreover, with electrical operation the percentage of loss in transmission can be determined and kept within small limits. With either steam or air there is a continual struggle with leaks, and radiation and transmission losses are usually excessive.

SOURCE OF ELECTRIC POWER.

If quarry operations are extensive and sufficient water power is within easy distance, it is probable that a hydroelectric plant owned and operated by the company is best, although the first cost may be high, especially if large dams must be built.

Uniformity of water supply is an important factor. If, during certain seasons, the water supply diminishes and it thus becomes necessary to construct auxiliary steam plants or to shut down operations for a part of the season, a hydroelectric plant is of doubtful advantage. Moderate variation in supply may be overcome by constructing a large reservoir.

In central Vermont three hydroelectric power plants supply most of the power required. Auxiliary steam plants supply additional power in times of low water. Transmission lines pass along the great marble valley for a distance of 62 miles. Power from various supply stations is turned into these lines and is drawn off at the quarries and mills scattered up and down its length. The power line is comparable with a great reservoir, into which water is pumped, and from which it is drawn off by pipe lines to supply various needs.

A Colorado marble company operates a hydroelectric plant with a 380-foot head of water. Pipes are laid up the mountain side and intercept streams at a high level. Consequently only small dams are required. Under such conditions a power plant can be established with a relatively small outlay of capital.

If electrical power can be obtained from a power company operating large central stations at a cost not exceeding 1½ cents per kilowatt-hour, it is probably better to purchase power than to erect a power plant at the quarry. If there are no available power lines, or if electrical power costs on the average more than 1½ cents per kilowatt-hour, and if the power required is 300 horsepower or more, it will probably be more economical to erect a steam-driven generating plant at the quarry, provided the engine is of the condensing type. With coal at not more than $3 per ton such a plant can be run economically.

At one quarry where the installation is of 500-kilowatt capacity with an average maximum load of 400 kilowatts, diminishing at night to 200, the total cost of power delivered on the main bus bars of the generating station is less than 1 cent per kilowatt-hour. Coal at this point costs a little over $2 a ton.

The important point is that new quarries should adopt electrical operation from the outset if its adoption will be feasible at any stage of development. Current should be obtained in the most economical manner possible. Determination of the proper source of power often requires the advice of a consulting electrical and mechanical engineer.

COMPRESSED-AIR AND STEAM EQUIPMENT.

If for any reason electrical operation is inadvisable, operation by compressed air is unquestionably more economical than by steam, and vastly more convenient.

Direct steam power is undesirable on account of the transmission losses and the obstruction occasioned by the necessary network of pipes along the quarry floor. If steam must be adopted, care should be taken to reduce to a minimum the losses due to leakage and radiation.

As steam pipes are subject to varying temperatures and pressures, constant attention is necessary to avoid leakage. Plate III, *B*, shows a typical example of waste by leakage in a quarry transmission line. Many quarrymen fail to realize that money is pouring out of these leak holes at an incredibly rapid rate. A good pipe fitter should be on hand to remedy such conditions immediately.

Serious losses are also caused by radiation of heat from the steam pipes and by energy used to overcome the friction of the steam against the inner surface of the pipe. Such waste of energy may be minimized by properly covering the pipes with heat-insulating material. A few quarrymen have insulated their transmission pipes, but by far the greater majority have, as yet, made no attempt to do so. An additional means of reducing loss by condensation is the use of a superheater. Steam will not condense until it has lost its superheat, and consequently condensation of steam in pipes will not occur as long as any of the superheat remains. One degree of superheat is commonly conceded to carry steam 10 feet, but of course the net result depends on the diameter of the pipe and the condition of the insulation. If the factor mentioned be assumed, it may be concluded that if steam is to be conveyed 1,000 feet 100 degrees should be added to its temperature in order that no condensation shall take place. In order to avoid as much as possible of this loss by condensation, the power plant should be situated close to the excavation.

If quarrymen could see the combined loss by leakage and radiation for a given period converted into a pile of coal they would realize that the loss assumes alarming proportions. One southern quarry company, using a battery of four 300-horsepower boilers, found by practical test that on a day of average temperature the full energy developed by one boiler was required to maintain the necessary steam pressure when no work was being done.

In old installations now operating with steam or compressed air any changes or additions ought to be determined with a view to the ultimate electrification of the entire plant. Neglect of this precaution may finally bring the operating company to a position where it can not compete with other companies that have electrified their plants.

CHANNELING.

CHANNELING MACHINES.

Sullivan, Ingersoll-Rand, and Wardwell channeling machines are all used, and each type has its special advocates. For steam operation the Sullivan machine seems to be the favorite, whereas the Ingersoll electric air type is the favorite in quarries having direct electric connection.

The most suitable Sullivan machine for marble quarrying is probably the double-swivel channeler which can be used for straight vertical cuts, for undercutting, or for cutting out corners. A few quarries, in which operations are scattered over a wide area and in which electricity is not used, employ Sullivan machines with portable boilers attached. One Georgia company operates Sullivan "duplex" channelers, consisting of two machines on a single truck working in the same channel, as illustrated in Plate IV. For long cuts such channelers are undoubtedly advantageous, as one operator can manage two machines. For small quarries where the cuts are short and many corners must be cut one machine would probably be idle so great a share of the time that the advantage would be doubtful. These machines are commonly termed "double headers" to distinguish them from the Wardwell "duplex" channelers.

The electric air channeler is self-contained, all the mechanism being on the channeler truck. The air is compressed by a motor-driven "pulsator." The air is never exhausted into the open but is simply driven back and forth under pressure in a closed circuit. The machine may be used for vertical, inclined, or horizontal channeling. The roll guides between which the channel bits run are effective for horizontal or inclined cuts. It is better balanced than most machines for cutting along the lower side of an inclined track.

It is claimed by some quarrymen that the electric air channeler will cut at least 10 per cent more than steam or air machines if all are equally well handled. This superiority is not due to the fact that the electric air channeler cuts faster while it is cutting, but there are fewer and shorter interruptions for adjustment, setting up, etc., so that a higher time efficiency is obtainable. Cables and wires are more quickly adjusted, are less in the way, and are more easily handled than steam pipes or hose. Also, many quarrymen think the electric air channeler is the most economical in power consumption of any machine yet devised.

The Wardwell "duplex" channeler cuts two parallel channels at the same time. On a level floor and with sound stock it gives good service. As pointed out later, in quarrying unsound stock it is sometimes desirable to vary the spacing of the channel cuts in order to make them coincide with joints. With the Wardwell machine such variation would not be possible, and in consequence it is not well suited for working in unsound marble. One company has successfully adapted this machine to electric operation.

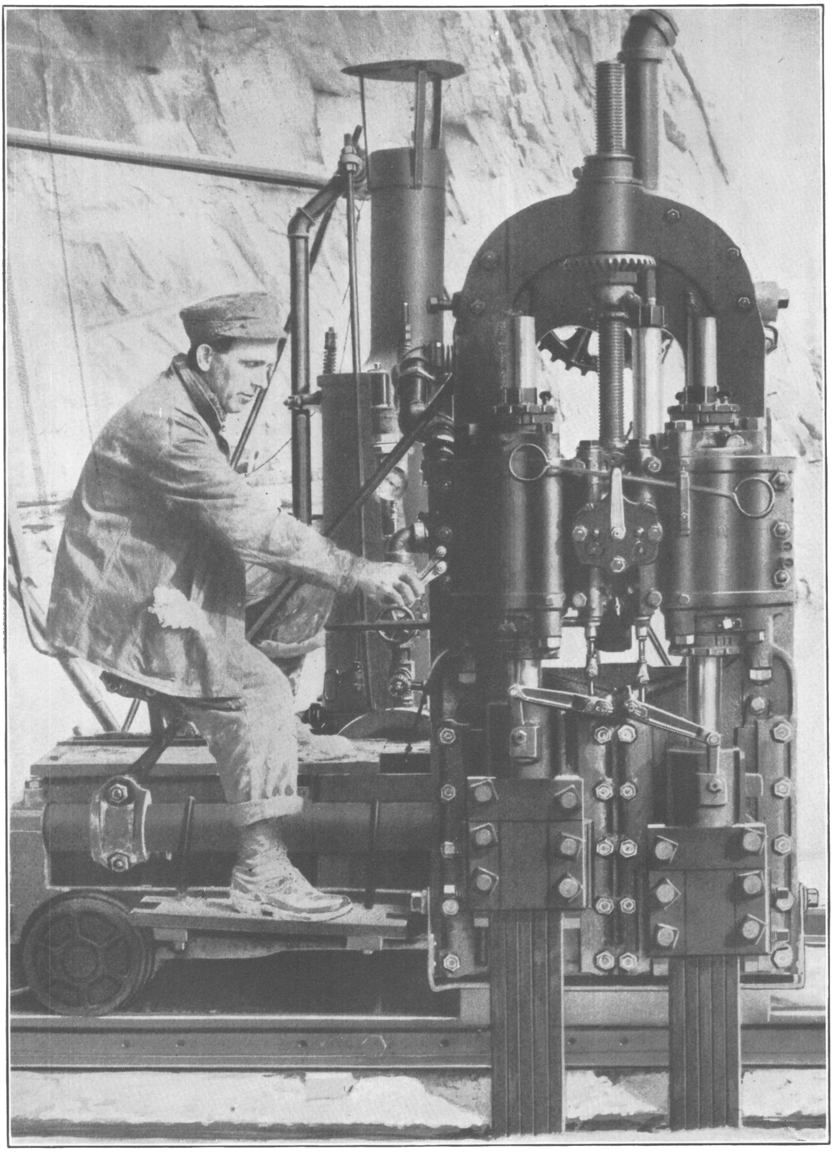
Experiments in one company's quarries in North Carolina indicate that in channeling hard marble, light and rapid blows are more effective than slower and heavier ones. The change from heavy to light blows can be made in most machines by changing the stroke.

CHANNELING IN RELATION TO BEDDING.

INFLUENCE OF ATTITUDE OF MARBLE BEDS ON CHANNELING.

Most marble deposits occur in regions where great folding and contortion of the rock has taken place as a result of tremendous geologic forces. The original flat-lying beds may be tilted at all angles. This condition greatly complicates the process of quarrying. In numerous instances the beds are separated by open fissures which demand a process of cutting in conformity with them. In other quarries the beds may exhibit no planes of separation. A distribution of color or impurities parallel with the bedding may, however, constitute factors of equal importance in their influence upon the plan of rock removal.

If conditions are at all favorable, it is desirable to maintain a level quarry floor. Conditions may be such, however, that efficiency in quarry operation or reduction in the proportion of waste may demand that quarrying be conducted on an inclined floor. No absolute rules can be given, for, as pointed out later, the nature of the product and the uses for which it is to be employed have a direct influence on the most feasible quarry method.



SULLIVAN "DUPLEX" CHANNELER.

LEVEL-FLOOR CHANNELING.

Figure 5, A, shows uniform rock with no open bedding planes and no decided rift. The beds may be horizontal, vertical, or inclined. This condition prevails in some of the Tennessee quarries. The bedding is so indistinct that it can be recognized only by the characteristic "crow feet," as otherwise the rock is uniform throughout. Under such favorable conditions, channeling may be carried on with a level floor, whatever the attitude of the beds may be.

Figure 5, B, shows marble with open bedding planes, the beds being either horizontal or vertical. In either case a level quarry floor may be maintained.

SAW-TOOTH FLOOR CHANNELING.

Figure 5, C, illustrates open marble beds, inclined at an angle less than 45°, such as are worked in a number of Tennessee, Alabama, and Vermont quarries. It is customary in some of the quarries to excavate right-angled blocks and to remove a row of blocks from each successive bed, resulting in the formation of a saw-tooth quarry floor as illustrated in figure 6.

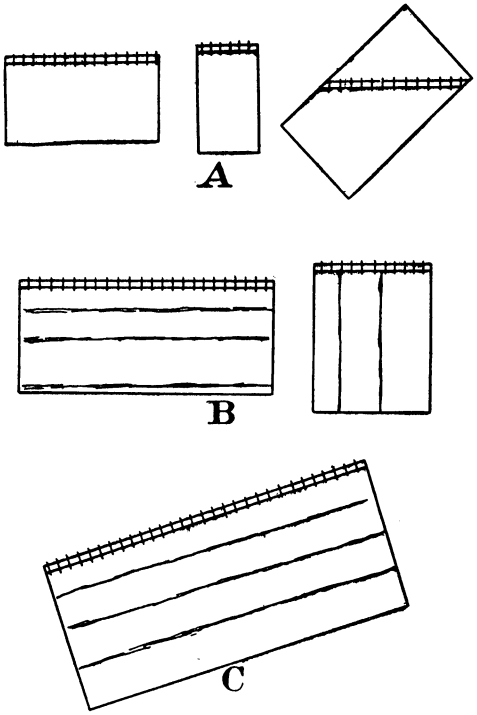


FIGURE 5.—Proper positions of channeling machine tracks for beds of different inclinations. A, horizontal, vertical, or inclined beds that have no open bedding planes or decided rift; B, horizontal or vertical beds separated by open bedding planes; C, open beds inclined at an angle less than 45°.

In quarrying a saw-tooth floor the channeling-machine track is supported by timbers as shown in Plate III, *C*. The disadvantages of such a method are well known to many quarrymen, but are accepted as inevitable because no better method has appealed to them. The disadvantages may be enumerated, as follows: (1) The construction of supports to hold a track in a horizontal position, perhaps 6 or 8 feet above a slanting rock surface, requires considerable timber and many hours of labor, part of which is done by skilled men. (2) There is a great loss of time in starting and straightening channel cuts. The machine is so high above most of the rock surface that the channel bits, no matter how tightly they are clamped, swing to one side or spring when they strike the rock, so that starting or maintaining a straight cut is difficult. In practice the helper generally takes a hand tool and hammer and starts the cut. After a little progress with the machine further delay may be necessary to straighten the cut. Altogether much time may be lost before the machine may be worked continuously. (3) If the rock has a steep dip a short length of track only may be set up, usually resulting in loss of efficiency. In general, operations on a small scale are less economical than those on a large scale. A short channel cut is more expensive per square foot than a long one under similar conditions. (4) On account of the rapidly increasing height of the track above the rock surface as the machine travels in the direction of dip, one length of steel can be used over a small part of the course only, and hence short cuts with frequent changes of steel are necessary.

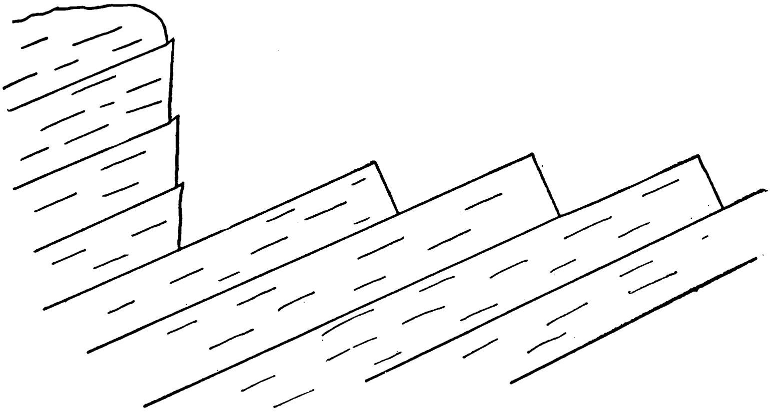


FIGURE 6.—A "saw-tooth" quarry floor.

(5) The necessity of cutting out numerous corners may increase the proportion of lost time.

INCLINED-TRACK CHANNELING.

An improved method of quarrying on an inclined floor is to place the channeling-machine track on the inclined rock surface in the direction of the dip. If the floor is of the saw-tooth type, the upper beds should be worked down successively until a large area of rock surface is obtained parallel with the open beds, as illustrated in figure 7. The force of gravity, which would cause the channeling machine to run too rapidly down the grade and probably entirely prevent its ascent is overcome by the use of a balance car or balance weight. The balance car may be placed on a parallel inclined track and loaded with enough stone or iron bars to exactly counterbalance the weight of the channeling machine, to which it is attached by means of a cable running over a sheave. The sheave is attached to the upper end of the track. This method is employed with success in several Vermont quarries.

A second method is to place the balance-car track on a slanting unused part of the quarry. Though requiring a long cable attachment the plan works well, and is used successfully in Alabama. There is a considerable saving of time and expense in having a permanent balance-car track.

A third device, which must be arranged with special care in order to avoid the danger of accident, is a counterbalance weight attached to a cable that passes over a sheave in the tunnel ceiling.

For light grades a hill-climbing device observed on some machines gives satisfaction. It consists of a cable that passes over a sheave at the upper extremity of the track and winds on drums on the truck axles. The device prevents the machine from slipping, but does not equalize the load like the balance car.

HIGH EFFICIENCY OF INCLINED-TRACK CHANNELING.

Quarrymen who have not had the experience may doubt the success of inclined channeling. However, many who have tried it have met with unqualified success. One Alabama company claims that channeling on a floor parallel with bedding that dips about 33° has resulted in a 50 per cent increase in efficiency over the saw-tooth method of operation.

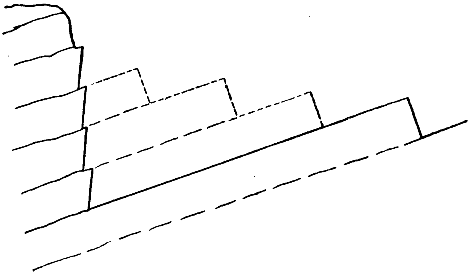


FIGURE 7.—Manner in which an inclined floor may be developed from a "saw-tooth" floor.

In this connection the following quarry report of a company operating in Quebec, Canada, is of interest:

Monthly channeling report covering work of day gang in a Quebec quarry.

Machine No.	Marble excavated.	Time in operation.	Time moving.	Time under repair.	Time shut down.
	Square feet.	*Hours.*	*Hours.*	*Hours.*	*Hours.*
3	529.6	139.5	44.5	34	31
5	613.0	157	31	31	32
7	695.5	208.5	26.5	....	29
8	712.5	187	23.5	18.5	24
9	1,355.1	178	44	8	23

The good showing of machine 9 is the notable feature of this report. Machines 3, 5, 7, and 8 were operated on level elevated tracks on a saw-tooth floor. Machine 9 ran on an inclined track with a balance car. The average month's cutting per machine by the saw-tooth method was 637.6 square feet, whereas the one machine with the balance car cut more than double that amount. Such figures offer convincing proof of the efficiency of inclined channeling.

With many quarrymen the physical difficulties of moving and operating machinery on inclined floors constitute sufficient cause for rejecting the method. However, it has been found that when men become accustomed to the new methods they work with the same facility as on level floors, and may even prefer the changed conditions. Methods of employing cables, snatch blocks, and hoists for handling heavy machinery are quickly devised by intelligent foremen. In one Vermont quarry inclined channeling is conducted successfully on a floor slanting 45°. The cost of channeling is approximately 14 per cent greater than on a level floor, and the cost of other operations shows a small increase.

When channeling machines are being operated on inclined tracks, no scaffolding is required. The tracks are placed flat on the rock surface with little more expense than when placed on a level floor. Much time is saved in the process of starting and straightening cuts, the field of operations need not be limited by short tracks, and the work is not interrupted by frequent changes of steel.

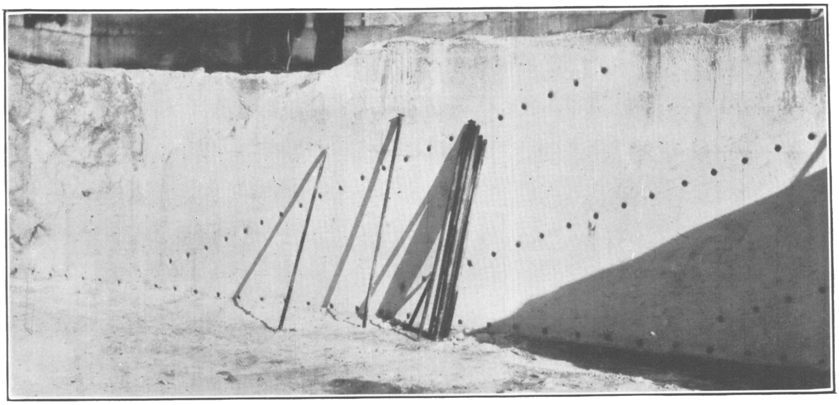
Plate V, *A*, shows a marble quarry with open beds dipping 24° to 28°. The present method is to channel in short cuts with the channeling machines working on tracks supported in level position. The inclined floor shown in the plate has an area of about 4,000 square feet which is sufficient to warrant the use of the inclined track and the balance car.

Even if conditions seem unfavorable the inclined-track method may prove to be the more economical. In one quarry observed the structure is a low anticline or arch, and the open bedding planes dip westward in the western part of the quarry, maintain an approximately horizontal position near the center, and dip eastward in the eastern part. The rock is now quarried on a level floor with the production of a large number of angular blocks. It is probable that the maintenance of a quarry floor parallel with the bedding, even though it involved varying angles of inclination in different parts of the quarry, would give better results.

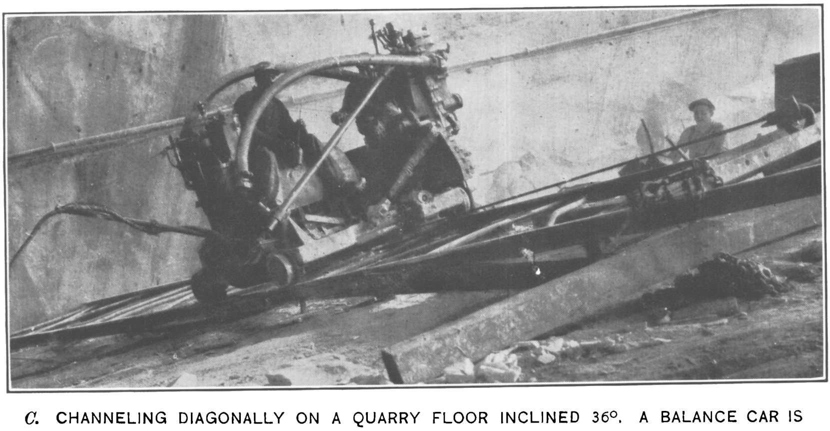
INCLINED-TRACK CHANNELING ACROSS BEDS.

Figure 8, A, illustrates open marble beds dipping at an angle greater than 45°. In order that right-angled blocks may be obtained without a saw-tooth floor, the obvious method of channeling is to make the floor perpendicular to the beds as indicated in the figure. Such a method has not been observed in any American quarry, though it should be successful.

A. A QUARRY FLOOR SUITABLE FOR INCLINED-TRACK CHANNELING.



B. METHOD OF QUARRYING ACUTE-ANGLED BLOCKS.



C. CHANNELING DIAGONALLY ON A QUARRY FLOOR INCLINED 36°. A BALANCE CAR IS USED TO COUNTERACT THE EFFECT OF GRAVITY. QUARRY AT GANTTS QUARRY, ALA.

INFLUENCE OF RIFT OR COLOR BANDS ON CHANNELING.

Figure 8, B, illustrates marble beds dipping at an angle of less than 45° but with no open bedding planes. They are assumed to have, however, parallel with the bedding, a series of color bands or streaks of impurities or a decided rift, or the successive beds are of varying quality. The most desirable development of such beds is more complicated.

If, for artistic effect, it may seem desirable to have the color bands pass diagonally through the blocks, it may be advisable to excavate right-angled blocks on a level floor. Ordinarily, however, a proper classification of material would demand that the marble be split parallel with the bed, also if the material is uniform in quality, and possesses a decided rift, it can be worked more easily parallel with the bedding.

Figure 8, C, illustrates beds having rift, impurities, or color bands as represented in the beds shown in figure 8, B, but with the beds dipping at an angle greater than 45°. In developing such beds, if it seems advisable to use inclined channeling, the floor should be at right angles to the beds rather than parallel with them.

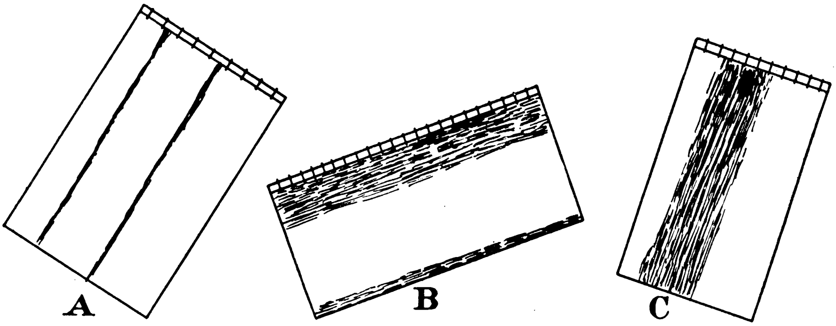


FIGURE 8.—Proper positions of channeling machine tracks for beds of different inclinations. A, open beds inclining at an angle greater than 45°; B, nonuniform beds inclining at an angle less than 45°; C, nonuniform beds inclining at an angle greater than 45°.

WASTE DUE TO ACUTE-ANGLED BLOCKS.

If steeply inclined marble beds are channeled on a level floor, and the cross breaks or cross channel cuts are made parallel with the bedding, acute-angled blocks will result, as is illustrated in Plate V, *B*. A complete discussion of the conditions under which such blocks may or may not be quarried economically is given in a later section dealing with the problem of waste. As pointed out in that section, if thin stock is desired, the waste resulting from acute-angled blocks may not be excessive. Saw gangs require longer blades however, and when longer blades are used the tendency toward unevenness in the cuts is increased. If much cubic stock is desired undoubtedly it is more economical to quarry on a slanting floor parallel with the beds.

EXAMPLE OF INCLINED CHANNELING.

A large tunneled quarry operated in Vermont furnishes a good illustration of quarrying in conformity with bedding, and a detailed description of the various processes may be instructive.

Near the top of the quarry the beds dip about 70° east. At a depth of 50 or 60 feet, they curve back and dip west, and lower down again dip to the east, the angle of dip decreasing to about 30° near the bottom of the quarry. There are few open bedding planes. The excavation is about 300 feet deep, and long tunnels are driven in the direction of the strike.

Gray or variously colored bands occur at intervals, marking off distinct beds. The beds vary greatly in quality, some being almost pure white, and others gray, wavy, or banded. The various beds are named, and the characteristics and qualities are well known to the foremen.

In the upper part of the quarry, where the dip of the beds is steep, a level quarry floor is maintained. According to the rules given above, the quarry floor in this part of the quarry should be inclined to cut across the beds at right angles and thus avoid the production of acute-angled blocks. In this particular place, however, a level floor is preferable. As mentioned above, the beds near the top of the quarry dip to the east, at a lower level are vertical, and at still greater depth dip west. If the floor were to be maintained at right angles to the bedding the condition described would necessitate a constantly changing floor level, resulting in the production of many angular blocks.

Except for wall cuts, channels are made in one direction only—at right angles to the strike. The long masses of rock thus obtained are divided into small blocks by wedging in drill holes, projected in rows parallel with the bedding, as shown in Plate V, *B*. Effort is made to so place the holes that each block is of uniform quality.

Near the bottom of the quarry, where the dip of the beds is 45° or less, the quarry floor is maintained parallel with the bedding. A balance car on a parallel track is employed to overcome the effect of gravity, and thus permit the channeling machine to operate with the same motive power as on a level track.

The depth of the channel is governed by the position of those natural lines of separation that mark out a definite change in the quality of the rock. The channel cut may pass through one or two of these lines of division, but is always terminated by one of them.

If no open bedding planes appear, each of the bands of uniform material may, for convenience, be designated as a bed. The method of determining when the bottom of a bed is reached is of interest. The channeling machine, when running in its ordinary vertical manner, continually loses space at the end of its run, leaving a slanting end. Water is poured down this inclined end in order to wash it clean, and an incandescent light with a specially flattened bulb is let down. By this means, one who is thoroughly familiar with the rock may identify at a depth of 10 to 12 feet the bands that separate the various beds.

When drilling or channeling is done at right angles to the quarry floor, right-angled blocks are obtained. By working thus on an inclined floor, blocks of economical form are produced, and an exact classification of the product is made possible.

INFLUENCE OF DIP AND STRIKE ON DIRECTION OF CHANNEL CUTS.

The influence of bedding on the attitude of the quarry floor has been discussed in detail. The influence of dip and strike on the direction of the channel cuts is also of great importance. If vertical channel cuts make oblique angles with the strike of a marble deposit in which separation of blocks must be made along the planes of steeply dipping beds, it is obvious that blocks having too much of an acute angle will result. It is generally more convenient and more economical to make channel cuts parallel with the strike. Exception may be made if pronounced joint systems meet the strike of the rock at oblique angles. Under such circumstances channeling parallel with the joints rather than with the strike is justifiable. However, an inclined floor should be maintained, and the cuts should be at right angles to the floor in order that rectangular blocks may be produced.

CHANNELING IN RELATION TO UNSOUNDNESS.

CHANNELING PARALLEL WITH JOINT SYSTEMS.

In a previous section (pp. 22–29) a discussion is given of the causes of unsoundness and of the various forms in which it appears. The most important feature of joints in relation to channeling is their occurrence in more or less definite systems. The importance of recognizing such systems and quarrying in accordance with them can scarcely be overestimated. In quarries in which joints are prominent the quarrymen should endeavor to make their channel cuts parallel with the chief joint systems. Blocks that are intersected by oblique joints are almost useless. If, on the other hand, the joints parallel one pair of faces, the waste is greatly reduced.

CHANNELING COINCIDENT WITH JOINTS.

Paralleling the joint system is only one step in economical channeling. If it be assumed that the joints intersecting the blocks are parallel with one pair of faces, considerable waste may still result. If saw cuts are made parallel with the joints, two or three slabs only may be wasted. Usually, however, joints cut across the grain and slabs are cut parallel with the grain. A single joint, therefore, will intersect every slab. Consequently, economy demands that channel cuts not only run parallel to joints, but that they be spaced in such a manner as to reduce to a minimum the number of joints contained within the blocks. In other words, whenever possible the channel cuts should coincide with joints. If joints are spaced at irregular intervals, channel cuts should be spaced in the same way. It is unreasonable to maintain that the production of blocks varying in size is undesirable. The presence of irregularly spaced joints will not permit the quarrying of uniform sound blocks, and it is clear that in the shaping of any structural design sound blocks of various sizes will cut to better advantage than unsound blocks of uniform size.

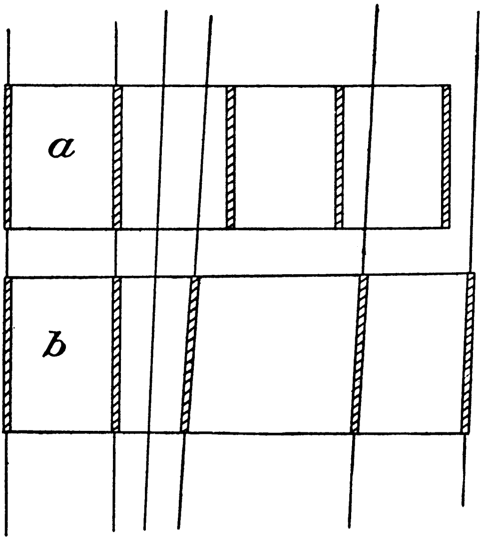


Figure 9.—The right and the wrong way of channeling unsound marble: *a*, Channel cuts equally spaced, involving waste; *b*, channel cuts made coincident with joints, avoiding waste.

The advantage of eliminating joints by channeling coincident with them is illustrated in figure 9. Six unequally spaced joints are shown in an approximately parallel system. In the figure *a* represents equal spacing of channel cuts without regard to unsoundness. Of the four blocks that result, one is intersected by one joint and another by two joints, and two blocks are sound. At *b* is shown spacing varied in such a manner as to make the channel cuts fall on the joints. As a consequence one small block is intersected by a joint, and three blocks, one of which is exceptionally large, are sound. A judicious spacing of channel cuts may thus tend to produce a large proportion of sound stock.

ECONOMY OF CHANNELING IN ACCORDANCE WITH UNSOUNDNESS.

Figure 10 shows the economy of channeling in accordance with unsoundness. Two right-angled systems of unequally spaced joints are shown. They are identical in both parts of the figure. As shown in figure 10, A, the channel cuts make oblique angles with the joint systems. The channel cuts are spaced regularly in both directions without regard to unsoundness. As a consequence, every block quarried is intersected by one or more joints.

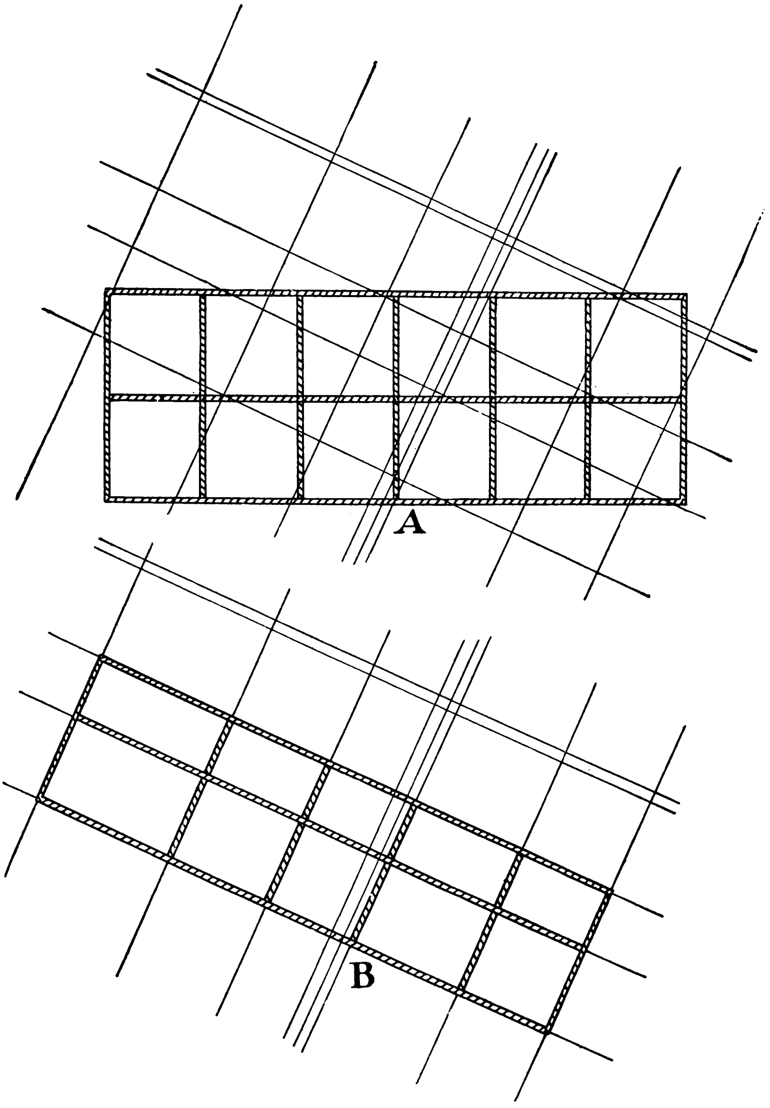


FIGURE 10.—The economy of channeling in accordance with joint systems: A, Plan of channeling without reference to direction or spacing of the joints, involving great waste of marble blocks; B, plan of channeling in which channel cuts are made parallel with, and as far as possible coincident with, joints, avoiding waste of blocks.

Figure 10, B, illustrates the remarkable improvement that results from changing the direction of channel cuts to parallel the joints, and from varying the spacing of the cuts so that they fall exactly on the joints. Of the 10 blocks that will be produced 8 will be sound and 2 will have two parallel joints close to one side. The advantage of cutting out blocks in accordance with unsoundness is so apparent that it is remarkable how few quarrymen have made practical application of the principle.

UTILIZATION OF JOINTS FOR MAKING CROSS BREAKS.

Channeling may be done in one direction only, the cross breaks being made by some other means, or the rock may be channeled in two directions. In many marble deposits, one system of joints is pronounced, and cross joints are few in number. Under such conditions, it is wise to channel in one direction only, at right angles to the chief joint system. Advantage may thus be taken of the joints in making cross breaks. A long mass of marble can be channeled at the back and ends, and wedged up at the floor until it is free. The wedges near one end may then be driven hard and the others left untouched, producing a bending strain which may be sufficient to cause the mass to break at one of the joints, which is a plane of weakness. Heavy wedging at both ends, the middle wedges being left untouched, may be even more effective.

AN ILLUSTRATION OF CHANNELING IN ACCORDANCE WITH UNSOUNDNESS.

An excellent illustration of a modification of channeling directions to parallel strike, dip, and unsoundness is to be found in a certain quarry in Vermont. One channel cut parallels the strike, which is N. 5° W. The beds dip about 70° to the east, and, on account of a green banding parallel with the bedding, the proper classification of the material and the production of attractive patterns in the banding demands that the channel cuts be inclined to parallel the beds. A remarkable system of parallel open joints (see fig. 2, p. 26) intersects a limited part of the quarry. The joints run N. 82° E. and dip 61° N. The second channel cut is made parallel with these joints. Thus the channel cuts meet at an angle of 87°, and are both inclined from the vertical. The maintenance of a level quarry floor is justified by the fact that such conditions prevail over part of the quarry only. By thus quarrying in accordance with rock structures, sound blocks with a desirable color distribution are obtained.

A short distance north of this quarry is another, which is now about 50 feet deep. The system of joints referred to above does not appear as yet in the excavation. As the joints dip 61° N., it is an easy matter to determine the point at which, with continued excavation, they may be expected to appear. The present plan of quarrying is to channel vertically at right angles to the strike, and to make the cross breaks by wedging in drill holes parallel with the bedding. When the zone of parallel joints is reached, a modification of the method will be justified.

A PROPOSED IMPROVEMENT IN QUARRY METHODS.

As another illustration of quarrying in conformity with unsoundness, reference may be made to a certain marble quarry in which a change of plan is contemplated. The prevailing joints run north and south, and a second series of joints filled with crystalline calcite, known locally as "glass seams," run east and west.

The walls of the present excavation run approximately northeast and northwest. Thus a majority of the joints intersect blocks diagonally. When the present excavation is extended it is proposed to make the cuts in north-south and east-west directions, and thus parallel the chief rock structures.

INDISTINCT JOINTS AND JOINT SYSTEMS.

In the preceding paragraphs reference has been made only to those joints or joint systems that are easily recognizable. In quarries in which joint systems are obscure, the problem of economic channeling is more difficult.

The difficulty of recognizing joint systems is due to two main causes. The joints may be rather easily seen, but so irregular and intersecting at so many angles that system seems to be absent, or they may be so indistinct that only skilled men with long practice can recognize them in the quarry. When joints are both indistinct and irregular the problem is complex.

HOW TO DEAL WITH COMPLEX JOINTING.

A desirable method of approaching such a complex problem can be best appreciated by consideration of a concrete example. The operations of an Alabama marble company offer one of the best illustrations obtainable of the means that may be employed to discover systems of unsoundness and of how quarry methods may be modified later in accordance with these systems.

The quarry operations are greatly hampered by the presence of cracks that are locally termed "headers," many of which are almost unrecognizable in the quarry. However, when the blocks are sawn they cause the resulting thin slabs to break into small and angular pieces, many of which can not be used. So serious was this difficulty that profitable operation seemed impossible.

The marble was first quarried on a saw-tooth floor parallel with and at right angles to the strike. The beds dip about 33°. Blocks were intersected by joints and also by mica bands which run parallel to the bedding, and the waste was excessive. The proportion of sound stock was increased to some extent by quarrying on an inclined floor parallel with the bedding. Even with this improvement the presence of many "headers" intersecting the blocks obliquely resulted in great waste.

In an attempt to further overcome the difficulty the quarry floor was laid out in sections, and the marble blocks as they were quarried were all so numbered and oriented that the section to which they belonged and their exact position in the section could be determined. The visible "headers" were located accurately, and diagrams were made showing their position. The "headers" that could not be located in the quarry were found in the slabs after the blocks had been sawed. As every block had been oriented and as the original position of the slab was known, reference of the slab to its original position in the quarry indicated the point at which the joint must cut the quarry wall. As it was known that the joints must be present at certain points, diligent search was made to find evidences of them on the quarry walls. Only persons skilled in such observations through long practice can recognize obscure joints. In the quarry under discussion one efficient quarryman is detailed for the express purpose of finding and marking them on the quarry walls and floors.

The information thus obtained was supplemented by study of a drill core obtained by projecting a hole down the dip with a double core-barrel drill. A diagram of all the "headers" thus discovered on one of the most unsound floors is shown in figure 11. As may be seen from this figure, the joints in general follow two distinct systems. These two sets of joints have for convenience been designated *x* cracks and *y* cracks. The general direction of the *x* cracks is S. 80° E. They are distinctly visible, regular, and sufficiently far apart to allow the production of fair-sized blocks. They are all normal faults, having a slip of less than 1 inch. The *y* cracks are those mentioned above as being very indistinct. Their direction is N. 24° E. They are closely spaced, branching, and fade out and reappear irregularly. They are not faulted, or at least there is no apparent slip. They occur in zones about 50 feet wide, and these are followed by zones 60 feet or more in width in which the *y* cracks are absent or few in number.

In addition to the *x* and *y* cracks there is a series termed "slick seams," which run in the direction of the dip. They are probably caused by expansion and contraction from solar heat. They disappear at a depth of about 75 feet. A few joints are noted in the direction N. 82° E. The strike of the rock is N. 46° E:, and the dip averages about 33° SE.

As indicated in figure 11, the two main systems—the *x* and the *y* cracks—are 76° apart, and the *x* cracks make an angle of about 54° with the strike.

With this arrangement of headers, four plans of channeling were possible, as follows:

(1) Channels parallel with and at right angles to the strike.

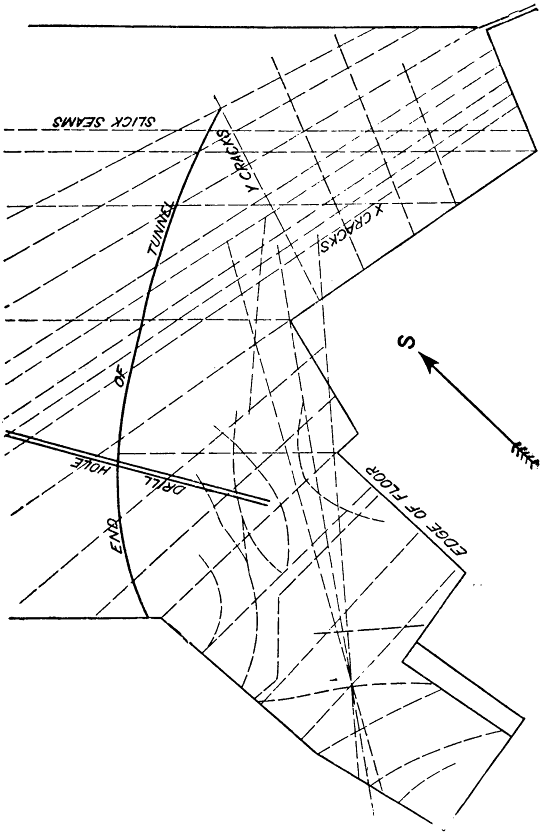


FIGURE 11.—Diagram of joint systems in one bed of an Alabama marble quarry.

(2) Channels parallel with and at right angles to the *y* cracks.

(3) Channels parallel with and at right angles to the *x* cracks.

(4) Channels parallel to the *x* and *y* cracks.

Worked out mathematically, plan 4 is the best, but only slightly better than plan 3. Where quarrying is now carried on, the *y* cracks are not abundant, and plan 3 is now followed. If the *y* cracks become more numerous with further development, plan 4 may be adopted.

The conditions prevailing on this floor were exceptionally bad. With the most economical methods only 15 per cent of the marble quarried was in sound blocks. On the next floor below 30 per cent was sound, and on the third floor 35 per cent. Quarrying parallel with and at right angles to the strike on the floor mapped would give no sound blocks, and probably few would result from a similar method on the lower floors.

It is established beyond question, therefore, that the most economical method of quarrying in this deposit is to channel diagonally on a slanting floor. To quarrymen who would hesitate at quarrying on an inclined floor under favorable conditions such a method must seem impractical. However, its success in this particular quarry is assured. Although the difficulty of operation is undoubtedly great, the advantages more than offset the increased cost per square foot of channeling. Plate V, *C*, illustrates a channeling machine operating on a track placed diagonally on an inclined floor.

The conditions in the quarry mentioned above are about the most complicated that can occur, as the joints are not only seemingly irregular, but many of them are indistinct. If the most complicated conditions can thus be handled satisfactorily simpler problems should be comparatively easy of solution.

CUTTING WITH UNSOUNDNESS IN TENNESSEE QUARRIES.

In some of the Tennessee quarries there are distinct joints known as "cutters," and other cracks which are indistinct, appearing as fine white lines. The latter are known as hair lines. Though the hair lines are difficult to recognize in blocks or in the quarry, thin slabs break readily along these planes.

In some quarries the distinct cutters show a prevailing system and the hair lines a second system nearly at right angles to the former. Under such conditions the rock may be quarried to advantage if the cracks are not too close together.

An excellent example of quarrying in accordance with rock structure and unsoundness is to be found in a quarry near Knoxville, Tenn. Open bedding planes dip 15° to 20° N., "cutters" occur in a predominating east-and-west system, and indistinct hair lines run generally north and south. The rock is channeled north and south, drilled east and west, and quarried on a slanting floor, thus paralleling the three prominent rock structures.

POSSIBLE OBJECTIONS DISCUSSED.

Some quarrymen would condemn a new method immediately if it were found that a decrease in the rate of channeling resulted. Such action would indicate faulty reasoning. Quarrymen must realize fully that their purpose is not to produce channel cuts and drill holes, but blocks of sound marble. If by a new method a greatly increased proportion of sound stock is obtained at a nominal increase in cost of production, the method is successful even though the rate of channeling is greatly reduced.

To properly search out and map unsoundness requires considerable time and energy. However, the far-seeing quarryman realizes that such labor, although temporarily unproductive, prepares the way for more economical and efficient operations. It is important that quarrymen should recognize the undoubted desirability of such preliminary investigation and the modification of methods to suit the conditions.

METHODS OF SEARCHING FOR INDISTINCT JOINTS.

If joints are very indistinct, a method of search devised by a Tennessee marble company is noteworthy. As all quarrymen know, only distinct joints can be recognized on a channeled surface. They are much more easily recognized on a fractured surface. Hence, before making cross breaks on a long channeled mass the quarryman takes a hand tool and a hammer and "points" a strip about 6 inches wide in a horizontal direction across the channeled surface. The effect is to produce a band having a fractured surface on which the natural joints are easily detected. The cross breaks are then made where the joints appear, and much of the unsoundness is in consequence eliminated from the finished blocks.

The same method is followed on the quarry floor. "Pointed" bands are made in two directions at right angles and 10 to 12 feet apart. The joints are thus located and the channel cuts can then be made to best advantage.

In a certain Alabama quarry small pieces are broken off the corner along the working edge of a quarry floor, thus exposing fractured surfaces. When water is thrown on the surfaces the indistinct joints appear as fine white lines. Channel cuts are then spaced to coincide with the joint lines wherever possible.

THE BOWLDER QUARRIES OF TENNESSEE.

Unsoundness in certain Tennessee marble quarries is greatly emphasized by erosion. Running water has entered the minute fractures and so worn them that large cavities have been formed between which the rock stands up as pinnacles and spires. The cavities are now filled with clay. Such a condition constituted what is known in Tennessee as a bowlder quarry. As the erosion began in planes of weakness it is probable that the masses of rock that now remain are comparatively sound. In such quarries little if any channeling is necessary.

STUDY OF UNSOUNDNESS IMPORTANT.

The suggestion in the section devoted to prospecting and developing marble deposits that a careful preliminary study of unsoundness should be made before operations are commenced on any prospect will be more fully appreciated when quarrymen have studied the preceding paragraphs and noted the vast influence unsoundness exerts on the proportion of waste produced. It is probable that greater losses result from quarrying without regard for unsoundness than from any other single cause. Present operators may in many instances greatly increase the proportion of sound stock quarried by making careful study and detailed diagrams of all visible unsoundness and then seeking methods of excavation that are best in accord with the conditions. Sufficient examples have been cited to convince the most doubting of the economy of such methods.

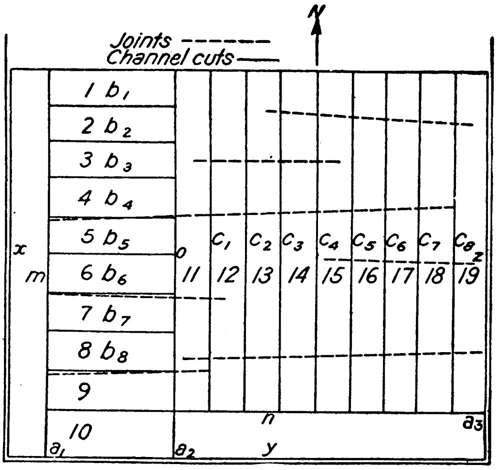


FIGURE 12.—Method of channeling a quarry floor employed by a Georgia marble company.

THE QUARRY OPERATOR'S PRIME OBJECT.

In concluding the discussion of channeling in accordance with bedding and unsoundness the author desires to emphasize the fact that the prime object in marble quarrying is not to establish high records in rate of channeling, or in gross production per man per month, irrespective of the form or quality of the product, but rather to produce rectangular blocks of sound marble. This object should be kept prominently in view, and should govern the choice of machinery and the method of rock removal in every instance.

REDUCTION IN NUMBER OF CORNER CUTS.

All operators of channeling machines are familiar with the loss of time resulting from the necessity of cutting out corners when wall cuts are met by subsequent channel cuts. Methods of channeling should be devised that tend to reduce to a minimum the number of corner cuts required. The plan followed by a Georgia marble company may well be cited. Figure 12 shows the position of channel cuts on a bench that is open to the north. The first step is to make the wall cuts, x, y, and z. Next, the two cuts, m and n, are made. Their purpose is to remove the necessity of cutting out numerous corners. By making these cuts only three corners, a_1, a_2, and a_3, must be cut out. After the cut o has been made, the short cuts b_1 to b_8 follow, and finally the cuts c_1 to c_8. The key blocks *1* to *10* are broken free successively by gadding and wedging, beginning at the open edge of the bench. When these blocks have been removed, blocks 11 to 19 are successively raised and removed. It will be noted that the prevailing joints run approximately east and west. Blocks 11 to 19, when wedged up from beneath, break along joints. This plan has the double advantage of making cross drill holes unnecessary and at the same time of reducing to a minimum the number of joints that intersect blocks. Blocks of considerable length free of joints may be used for columns.

CHANNELING IN RELATION TO RIFT.

In certain marble deposits there is a tendency for the rock to split with greater ease in one particular vertical plane. Ordinarily, under such conditions, channel cuts should be made at right angles to the direction of the rift in order that advantage may be taken of this ease of splitting, thus facilitating the making of cross breaks. If no rift exists, the difficulty of obtaining a straight and even break may be so great as to justify channeling in both directions.

USE OF WIRE SAW IN QUARRIES.

MECHANISM OF THE WIRE SAW.

The wire saw consists of an endless wire rope about one-fourth inch in diameter and composed of three strands. The wire passes around a driving wheel and is carried on pulleys to that part of the quarry where cutting is to be done. A sliding carriage is placed at a convenient point in the circuit to give the necessary tension to the wire. Renwick[a] states that in France and Belgium holes 2 to 3 feet in diameter are cut by means of cylindrical core drills. The cores are removed and standards erected in the holes. Pulleys over which the wire runs are attached to these standards.

THE PENETRATING PULLEY.

In early days much difficulty was experienced in guiding the wire in a slanting direction, but this difficulty was overcome in 1898 by the invention of the "penetrating pulley." This device is thus described by Renwick:[b]

> The pulley consists of three parts—(1) the pulley: This is a steel disk 19.6 inches in diameter and 0.27 to 0.31 inch thick, grooved on its edge to receive the wire. On

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[a] Renwick, W. G., Marble and marble working, London, 1909, p. 34.

[b] Renwick, W. G., Op. cit., p. 38.

the central part of the disk and projecting on each side is a boss supporting a steel axle 0.97 inch long. (2) The fork: This takes the shape of a hollow steel bar 2.4 inches in diameter, grooved at the lower end to receive the pulley, and which can be lengthened by a series of tubes of similar diameter. The bottom of the fork acts as a bearing, on which the pulley runs. (3) The carriage: This consists of a standard which can be placed in position by three screws or guys. The standard carries a screw and drum attachment, by which an automatic progressive motion is given to the fork from the rotation of an exterior pulley, on which the helicoidal wire runs.

The operation of extracting stone is as follows: Two holes are first sunk to receive the fork on which the pulley runs. The standards carrying the wire having been placed in position and the wire set in motion, the penetrating pulley is brought close to the rock. The thickness of the pulley being slightly less than the diameter of the wire, the latter projecting from the edge of the pulley wears into and bites the rock, forming a groove into which the pulley enters. Sand and water are fed to the descending wire, and, the fork supporting the pulley following the hole made to receive it, the wire is carried through the rock from one standard to the other, making a cut in the direction required. Crosscuts are obtained by altering the position of the standards. Cuts can be made along a length of 10.9 to 16.3 yards, and for an equal depth, the progress of the cut being 1.56 to 5 inches per hour, this depending on the nature of the material and the length of the cut.

INSTANCE OF USE OF WIRE SAW IN QUARRY.

Although the wire saw is used extensively by marble-finishing plants, its use in American quarries has, during recent years, at least, been confined to certain Colorado quarries. In these quarries it has been found that the most useful application of the wire saw in quarry work is in the cutting out of masses of rock situated between two shafts. In the early days of these quarries three shafts 60 to 80 feet apart were opened in the mountain side. After they had been carried down to a considerable depth it was found advantageous to remove the intervening masses and to develop a single large opening. By means of a core drill a hole was projected from one excavation to the next at a point close to the ceiling. The wire was passed through this hole, fitted around the necessary pulleys, and spliced to form a continuous belt. Steel shot and water were used as abrasive.

A mass 4 feet wide and 5 feet high and extending from one opening to the other was first removed to give a working space. Both wall and ceiling cuts were made with the wire saw. The ceiling cuts, were somewhat slower and more difficult to make than the wall cuts, as the abrasive would not feed readily to the saw. A second horizontal cut was made about 18 inches below the ceiling cut. The intervening mass was broken up and removed as waste in order to gain sufficient room for the removal of blocks without jamming. On account of the narrowness of the saw cuts, great difficulty is often encountered in removing this material. It may be noted, however, that a great saving of marble is thus effected, as in ordinary tunneling the preliminary opening is 6 or 7 feet high. Additional vertical cuts were spaced in the same manner as those made with a channeling machine, whereas the cross and the floor breaks were made by drilling and wedging.

It has been found that the cutting is just as effective if the abrasive is fed to the saw at one point only, the point where it enters the rock, as when fed at several points along its course through the rock.

DESIRABILITY OF USING LONG WIRE.

It is important that a long wire be employed. The wire is abraded during the process of sawing and continually becomes smaller until at some point it becomes too weak to withstand the strain and breaks in consequence. It is obvious that by increasing the length of the wire the rate of wear on any given part is correspondingly diminished. One company uses a wire nearly a mile long. Formerly the superfluous wire was passed around a drum in numerous turns. It has been found more satisfactory, however, to run the wire in a simple turn over a pulley situated at a distance from the quarry.

METHOD OF REPLACING AN OLD WIRE BY A NEW ONE.

In the early days of wire-saw operation much time was lost when a wire was worn out before a cut had been completed, as the opening cut by a wire gradually becomes narrower as the wire is reduced in size by abrasion. When the wire was replaced by a new one much of the cutting had to be repeated, as the opening was too narrow for the new wire.

Recently a method has been employed that obviates this difficulty. When the wire has been worn small and appears nearly ready to be discarded, the force that crowds it against the bottom of the cut is relaxed, and it is allowed to run freely for some time. It thus wears an opening larger than its diameter. The new wire can be drawn through this opening, and the cut continued with little loss of time.

DISADVANTAGES IN USE OF WIRE SAW.

When working normally the wire saw cuts much more rapidly than a channeling machine and requires less attention.

The presence of flint balls in marble is, however, a serious obstacle to the successful operation of the wire saw. On account of its extreme hardness the flint will greatly diminish the speed of cutting or may entirely suspend progress. Moreover, the wire is likely to pass around the mass of flint, and in doing so, may be offset 3 or 4 inches from its regular course, resulting in an uneven surface.

Another disadvantage in the use of the wire saw is the obstruction of other operations by the wires that pass through the quarry.

They interfere more particularly with the pulling and the hoisting of blocks. Seemingly, the wire saw is best adapted for cutting out masses of rock that intervene between two shafts. Its advantage over the channeling machine in the ordinary process of quarrying has not yet been demonstrated in any American quarry.

DRILLING.

MACHINERY.

Ordinarily in quarry drilling vertical holes are made with a tripod drill or bar, holes in the face in horizontal rows with a quarry bar, and in vertical or inclined rows with a gadder. A bar is better than a tripod drill for projecting rows of holes in a straight line, as it saves much time in moving.

Recently the jackhammer has replaced both bars and tripod drills in several quarries. It has a mechanical rotating device and may be run as a one-man drill. It uses hollow steel. It is run dry, and part of the exhaust passes down inside the drill and blows out the rock dust. On this account it is best operated by air, as steam condenses and forms a mud which is removed with some difficulty. When operated with steam it ceases to be a one-man drill, as a helper is required to pour water down the hole.

The jackhammer is operated as a hand drill, and is a great time-saver, as a few seconds only are required to change steel or to move to a new hole.

In one Alabama quarry jackhammers have now replaced all bar and tripod drills. In 1913 and 1914 tripod and bar drills were used, and in 1915 jackhammers took their places. The increased efficiency that results is shown in the following table:

Drilling record of a quarry in which jackhammers superseded tripod and bar drills.

Period.	Linear feet of drill hole cut per month.	Cost per linear foot.	Cutting rate in 10-hour day.	Cutting rate in 10 hours of actual cutting.	Time efficiency.		
					Proportion of time drilling.	Proportion of time lost in repairing.	Proportion of time lost in moving.
			Linear feet.	*Linear feet.*	*Per cent.*	*Per cent.*	*Per cent.*
1913	[a] 11,981	$0.0780	99.7	132.6	78.63	0.70	20.43
1914	[a] 8,699	.0682	106.0	135.0	79.00	1.09	19.91
1915.							
January	6,022	.0404	90.0	106.2	88.74	0.91	10.35
February	7,203	.0332	105.4	111.0	95.02	0.58	4.39
March	7,760	0392	113.0	117.0	96.50	0.43	3.06

[a] Average of 12-month period.

The cost per linear foot in March, 1915, was just half as much as the average for 1913, and 40 per cent less than the average for 1914. This reduction in cost was due partly to the employment of one instead of two men for each drill, and partly to the increased time efficiency indicated. In 1913 and 1914 the drills were operating on an average only 79 per cent of the time, whereas about 20 per cent was required for moving. In March, 1915, the jackhammers were actually at work 96.5 per cent of the time, and only 3 per cent was required for moving.

Other hollow-steel drills of similar type are now on the market, but are not in as general use as the jackhammer, and no figures concerning their efficiency were obtained.

A highly efficient bar drill employed by a Georgia marble company is used for both vertical and horizontal rows of holes in the quarry face. The bar is more than 12 feet long, and two drills are attached to it. In making a horizontal line of holes, each driller completes 6 feet of holes, and then the whole outfit is moved 12 feet, and the process is repeated. In drilling the face, two vertical rows of holes are projected simultaneously, one drill operating on each row. At the completion of each pair of holes the bar is moved up to the proper position for the next pair. Much time is thus saved as it takes no longer to adjust the bar for two drills than for one.

With the exception of the jackhammer, most drills work successfully with either steam or compressed air. If electric power is available, drills of special design may each be operated by a portable motor-driven pulsator. This method is especially advantageous if drilling operations are carried on at a considerable distance from the power plant, as power can be transmitted with greater ease by wire than by pipe lines or hose, and with less loss of power through leakage, friction, or heat radiation.

DRILLING IN RELATION TO CHANNELING.

The separation of rock masses is ordinarily less expensive per square foot by drilling and wedging than by channeling. The former method can be employed, however, only where a channel cut allows freedom of motion of the block in the direction in which the wedges tend to force it. Thus a certain amount of channeling is unavoidable. If there is a decided rift in the marble, drill holes may be placed much farther apart when splitting is being carried in the direction of the rift than when the splitting is carried across the rift. On this account when the wall cuts are made, if the direction of channeling is not influenced by bedding or unsoundness, one set of channel cuts should be made in a direction at right angles to the rift, and the cross breaks made by drilling and wedging. Advantage is thus taken of the rift direction to reduce the number of drill holes. As regards "liver rock," a term applied to a marble that has no rift, the necessity for placing drill holes close together and the difficulty of obtaining a uniform break if the plug-and-feather method is employed, may render it advisable to channel in both vertical directions and to wedge only on the floor.

ARRANGEMENT AND SPACING OF HOLES FOR CROSS BREAKS.

If the rock is uniform and sound drill holes may be spaced regularly in vertical holes. The spacing of drill holes varies from 4 inches to 2 feet, depending on the ease of splitting the marble. When the marble is unsound or lacks uniformity in color or texture, it may be necessary to make slanting cross breaks in order to avoid waste and to properly grade the product. Such breaks are shown in Plate V, *B*, p. 58.

DRILL HOLES FOR FLOOR BREAKS.

When channeling is done in one direction only, except for wall cuts, the long masses of marble are broken loose from the floor before cross breaks are made. Occasionally a floor cut is made with a channeling machine, but almost invariably they are made by drilling and wedging. As with holes for cross breaks, the spacing of the holes is governed by the ease with which the marble splits. A common practice is to make alternate holes shallow and the intervening holes the full depth of the break desired. The depth of each hole is marked on the rock surface for the guidance of the worker in selecting wedges. The holes may be parallel with each other or may radiate in fanlike form.

PROPER SIZE FOR DRILL HOLES.

Drill holes should be as small size as possible without detracting from wedging efficiency. Most drill holes are made 1½ to 1¾ inches in diameter. It has lately been demonstrated that the diameter of drill holes can be greatly reduced without interfering with the successful operation of wedges. J. P. McCluskey, quarry superintendent of the Alabama Marble Co., found that on an average 4½ minutes was required to drill a 1⅜-inch hole 2 feet deep. The time required to drill a 1⅛-inch hole 2 feet deep was only 2½ minutes. All drill holes in the quarry of the company mentioned are now made 1⅛ inches in diameter. The change from 1⅜ to 1⅛ inches has resulted in a reduction of 44 per cent in the time consumed per linear foot of drilling.

In order to wedge successfully in holes of such small diameter, wedges of special design are used. They are described subsequently under the title "Wedging."

ADVANTAGE OF REAMING DRILL HOLES.

Acting on a suggestion made by the writer, a certain marble company tried the experiment of using a reamer to cut grooves on the opposite sides of drill holes, thereby assisting the splitting so materially that fewer drill holes were required. The reamer was made in the form of a drill with wings at the sides sufficient to cut grooves about one-fourth of an inch deep on opposite sides of the drill hole. It could be used only in a reciprocating drill. When the hole was completed the drill bar was removed and the reamer put in its place. The rotating device was thrown out of gear, and by means of a bar through which the square shank of the reamer passed, the latter was held in proper position to cut the grooves exactly in line with the desired direction of splitting.

It was found that a straight break could be made with drill holes at least twice as far apart as when no reamer was employed. However, no reamers could be found that would bear the work required of them. The projections invariably broke off after short service. Until this mechanical difficulty has been overcome, the method is not considered to be practical.

SHARPENING AND TEMPERING OF DRILLS.

Economy in drilling depends to a great extent on the ability of the blacksmith to properly sharpen and temper drills. If the drills are too hard they will chip easily, and if too soft they dull rapidly. Uniformity in the size of drills is also important. Much annoyance and loss of time will probably result from an endeavor to continue a drill hole with a drill slightly larger than the one employed to drill the first part of the hole.

WEDGING.

TYPES OF WEDGES EMPLOYED.

In some quarries wedges that reach only a short distance into the drill holes are employed. As the entire strain is near the rock surface heavy sledging is necessary, and uneven fractures may result. The method is not effective.

The long wedges commonly used represent a marked improvement. Iron plates or feathers are attached to their extremities with wire in order to hold them in proper position while being inserted into the drill holes. When the wedges are driven the strain is thus exerted at points near the bottoms of the drill holes. If alternate holes are made half depth the strain is more evenly distributed.

It has been mentioned in a previous paragraph that one quarry company reduced the size of drill holes to 1⅛ inches. Ordinary wedges reduced to fit such holes were not strong enough to withstand the heavy sledging required. Consequently a wedge was designed that gave effective service with lighter blows.

The type that has proven highly successful is shown in figure 13 The feathers are 3 feet long and the plug 3 feet 9 inches, the additional

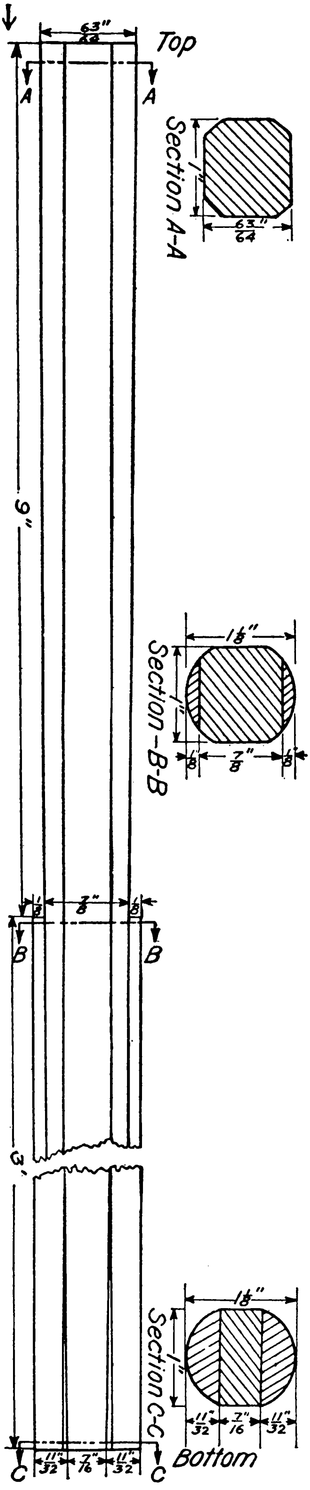


FIGURE 13.—Details of wedge that is effective in a small drill hole.

9 inches being required for driving. The plug tapers gradually from $\frac{63}{64}$ inch in diameter at the top to $\frac{7}{16}$ inch at the bottom. The feathers are curved on one surface to fit the drill hole, and the flat surface is perfectly straight and gives a uniform taper from one end to the other. They are made true to form in a swage. The important feature of the design is that the diameter B–B at the top of the feathers is exactly the same as the diameter C–C at the bottom, $1\frac{1}{8}$ inches. As a consequence when the plug and the feathers are inserted into the drill hole in the position shown in the figure, one side of each feather is in contact with the plug, and the other side with the wall of the drill hole throughout its entire length. When the plug is driven the feathers are forced apart a uniform distance at every point, and as a result the pressure exerted is uniformly distributed over their full length. Straight and even fractures result, and are obtained with much lighter sledging than by any other method yet devised.

UNIFORM STRAIN DESIRED.

It is important that in driving wedges there should be equal strain on all of them. If wedges near one end of a long mass of marble are driven much harder than those near the other end, an irregular cross break may result. In other words an artificial strain break may be produced, especially in long breaks in marble that has no rift. Wedging such marble should never be unduly hastened. A more uniform break will result by giving the rock time to fracture gradually than by forcing it. Uniformity of strain and moderation in the rate of fracturing may both be best accomplished by employing one man only on a single floor break. Different men strike blows with different degrees of force, and thus although one man may drive a wedge with the same number of blows as another, one may exert a much greater strain than the other. Also when two or more men are employed, there is a tendency to force the break at a too rapid rate.

If short breaks are made, or if the marble has a decided rift parallel with the direction in which fracture is desired, more latitude may be allowed. In some quarries several men work together in driving wedges, a leader giving the word so that all strike at once. A gang may, with practice, work together in this manner and produce a uniform strain. If the rapid splitting has no ill effect the method is justified.

EFFECT OF RIFT ON DRILLING AND WEDGING.

It has already been stated that the process of splitting is greatly facilitated by rift. If there is an exceptionally pronounced rift in a horizontal direction, it may be possible to make a floor break double the width of an ordinary marble block. This method is employed by a Maryland company. After the wall cuts have been completed, channel cuts are made 12 feet apart and in one direction only. A floor break is made the full 12 feet wide, and then the mass of marble is split lengthwise by drilling and wedging. Thus, in one direction, the rock is intersected by alternate channel cuts and rows of drill holes, and all the cross breaks are made by wedging. As the cost of drilling and wedging is less than that of channeling per square foot of surface produced, a considerable saving is effected.

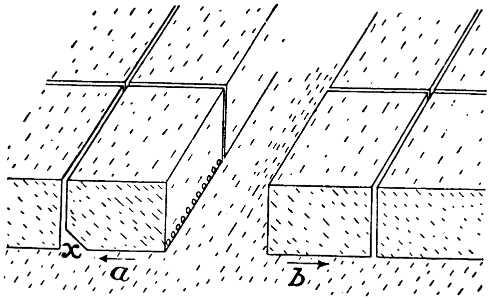


FIGURE 14.—Influence of rift on bottom breaks. Holes drilled in direction *a*, if too shallow, will result in break at *x* and injure blocks; holes drilled in direction *b* will result in a straighter break.

In most marble there is a decided rift parallel with the bedding. Therefore, if the bedding dips at a steep angle, the rift may be inclined in like manner. If the rift is inclined and the quarry floor level, the direction in which drill holes are projected for floor breaks is a matter of considerable importance. In a Colorado quarry in which the floor is level and the rift steeply inclined the channel cuts are made parallel with the strike of the rock. The allowance that should be made for the influence of rift on the process of wedging under such conditions is shown in figure 14. When the row of key blocks has been removed holes may be drilled in the direction shown by the arrow *a* in the figure. When the holes are wedged there is a tendency for the break to leave the plane of the drill holes and slant upward on the rift, thus removing a corner of the block, as at *x*. When the holes are drilled in the opposite direction, shown by the arrow *b*, if the channel cut is not continued lower than the plane of the drill holes, the break will be straight, as it will not run down below the bottom of the channel cut. As a consequence, when the holes are drilled in the direction *a* they must be made deeper than when drilled in the opposite direction. It is apparent that, to avoid waste by broken corners and to reduce the expense of drilling, the row of key blocks should be taken out as near as possible to the left side of the quarry as viewed in the figure in order that most of the drilling may be done in the direction *b*.

In cutting out masses of marble with the wire saw in this quarry it was difficult to maintain a uniform quarry floor. The saw cuts were projected downward 18 or 20 feet. In making the floor breaks in the direction *a* (fig. 14) there was a tendency for the break to pass upward and remove a corner of the block, and in making the floor break in the opposite direction the break would slant downward on the rift and remove a corner of a block on the floor beneath.

REMOVAL OF KEY BLOCKS.

Various methods are employed for removal of key blocks. As in many other quarry operations, the method is controlled to some extent by the conditions and to some extent by the skill and experience of the foreman. The key block may be removed in fragments as waste, it may be divided into a number of small blocks, or it may be removed in its entirety.

REMOVAL OF KEY BLOCKS AS WASTE.

If a band or mass of poorer material traverses the quarry, the key blocks may be located in it. The mass may be blasted into fragments and removed as waste. This method is employed by a North Carolina company. A narrow band of flinty inferior material passes through the middle of the quarry. The key blocks, consisting of this flinty material, are removed by blasting, and no unnecessary loss ensues.

However, some quarry experts think that even inferior rock can be removed more cheaply in large masses with the derrick than by breaking it and removing it in small fragments. In areas beyond the reach of the derrick the latter method is to be preferred.

Even if no such inferior bands or masses occur, some quarrymen blast and remove the first key block as waste, believing this method to be the most rapid and convenient. Unless the marble thus quarried is of low grade, such economy of time will not justify the waste of material.

MAKING THE FLOOR BREAK.

When the key block is to be preserved, the first step after channeling has been completed is to make the floor break for the first block. A common method is to insert a slanting iron plate in the bottom of the channel cut and to place the point of a wedge between it and the the key block. When the wedge is driven, the entire strain is exerted at the bottom of the block. A series of such wedges may be placed close together. If the floor is intersected by other parallel channel cuts, it is necessary to place wedges in those immediately behind the point where wedging is done, to insure that the fracture will take place where desired.

A method now rarely used is to charge an iron tube with blasting powder, tamping it hard above the charge and plugging it lightly below. The end of the pipe containing the charge is placed in the bottom of the channel cut and a strain put on the block by driving wedges. When the charge is fired, a clean break is said to result from the shock. A small charge placed in a hole drilled in the center of the block the exact depth of the channel cuts will act in much the same manner. Such a hole may, however, constitute a serious defect in the block.

After the first block has been removed, horizontal holes may be drilled and the next block broken loose by wedging in the ordinary manner. When the working space is too confined for a bar drill, a jackhammer may be used. When the bench has an open side, the first block may be drilled by placing a drill bar in a waste box and suspending it in proper position with the derrick.

A special method is employed in a Vermont quarry, where operations are conducted on a floor slanting about 45°. If key blocks were drilled and wedged in the ordinary manner, there would be great danger of the blocks sliding down upon the men the moment they were broken loose. To overcome this danger, a single drill hole is projected at the center of the floor line, and a light powder charge is exploded in it. The charge is so small that it makes the floor break without otherwise shattering the block.

HOISTING OUT KEY BLOCKS.

A method that is too wasteful to be recommended is to quarter the first key block with the channeling machine and remove it in sections. Removal in four pieces is undoubtedly easier than in one. There are two serious objections, however—first, the additional expense of making the two extra channel cuts, and, second, the decreased value of the material in small blocks. It is probable that the marble in four pieces is worth less than half as much as the intact block.

There are now in common use three methods of removing the first key block in its entirety. The first of these is by the use of the Lewis pin, which is adapted only to strong rock. A hole several inches deep is drilled into the middle of the block. A bar with an eye in the top is placed in the hole with a wedge at each side of it, as shown in figure 15. The bar is thicker at the bottom than at the top, so that when pulled upward it tends to tighten on the wedges, when the block may be lifted out with the derrick hoist.

A second method which may also be employed in strong rock is the use of grabhooks. Small pieces may have to be broken from the corners of adjoining blocks in order that the holes may be drilled properly and that there may be room for the hooks.

A third method is employed if the beds are weak. Chain loops or cables are thrown over the block from opposite sides. They are placed near the bottom of the block and are drawn tight and the block is lifted out with the derrick hoist.

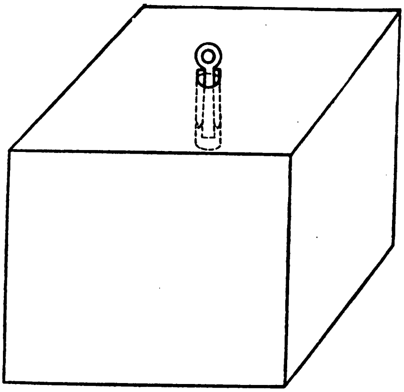


FIGURE 15.—Lewis pin used in hoisting key blocks.

HOISTING.

TURNING DOWN BLOCKS.

Blocks are usually turned down with a quarry bar before the hoist cable is attached. When monoclinic blocks are excavated it is difficult to turn them down. In a Vermont quarry the tip of the block is raised with a bar and a cable sling placed beneath it. The block is then raised several inches with the derrick and blocked up ready for final cable attachment.

The employment of the derrick to assist the bar gang in turning down blocks may result in serious risks to those employed. After the first fracture has been made a block is by no means free. The interlocking of irregularities on the surface may require considerable strain before the block will move. When the derrick is employed there is grave danger of breaking a boom or cable with consequent danger of serious accident.

CABLE ATTACHMENT.

The hoist cable may be attached to blocks by grabhooks or chain or cable slings. Grabhooks are employed only with rock that is hard and coherent. The two holes for the hooks are made on opposite sides of the block a few inches from the top. A mistake is sometimes made in drilling the grabhook holes too deep. The chief strain then comes, not at the tips of the hooks, but on the curved parts that are in contact with the upper edge of the block. As a consequence a corner of the block may chip off and allow the whole mass to fall. The holes should be sufficiently deep to allow a firm grip of the rock but the chief pressure should fall on the tip of the hook in the bottom of the hole. Moreover, great care must be taken in hoisting by this method. The rock should be carefully balanced, as a partial rotation may cause the hooks to slip. Under no conditions whatever should a quarry workman occupy a position beneath a block that is being lifted with grabhooks.

A safer method of attachment is to pass chains under the block and completely around it. Blocks are held much more securely by this method and there is little danger of a mass of rock falling on account of a weak bedding plane or fracture. A chain is, however, rather uncertain in its strength, and detection of weak links is somewhat difficult. When a chain does break the accident is usually quite unexpected. A wide margin of safety and frequent examination are necessary.

The best method of cable attachment is by means of cable slings (Pl. VI, *A*). Such slings are quickly handled and the use of two slings renders balancing of the block comparatively easy. Defects in steel cables are easily recognized. A realization that slings are both safe and convenient has led to their adoption in many quarries.

EFFICIENT HANDLING OF MATERIAL.

All unnecessary handling of material should be avoided. Blocks should be hoisted from the quarry and loaded on cars at a single operation if possible. If circumstances will not permit this, they should be placed in a convenient position for future loading. At most quarries hoisting and loading are done in a fairly efficient manner.

However, more efficient methods of handling waste material should be devised. In many quarries there is great loss of time and power in rehandling waste blocks. At one quarry waste blocks were hoisted from a point near the surface at one side of an excavation, thrown to the bottom of a 50-foot pit, picked up with a second derrick, and deposited on cars. Cars were situated within easy reach of the first derrick, but the placing of the blocks on them necessitated swinging the blocks over channeling machines. Usually such conflict of operations may be avoided by careful and judicious plans for quarry development. Every additional operation in handling waste adds to the cost per cubic foot, and every increase in such cost cuts down the margin of profit on the finished product.

TUNNELING.

DEFINITION OF TUNNEL.

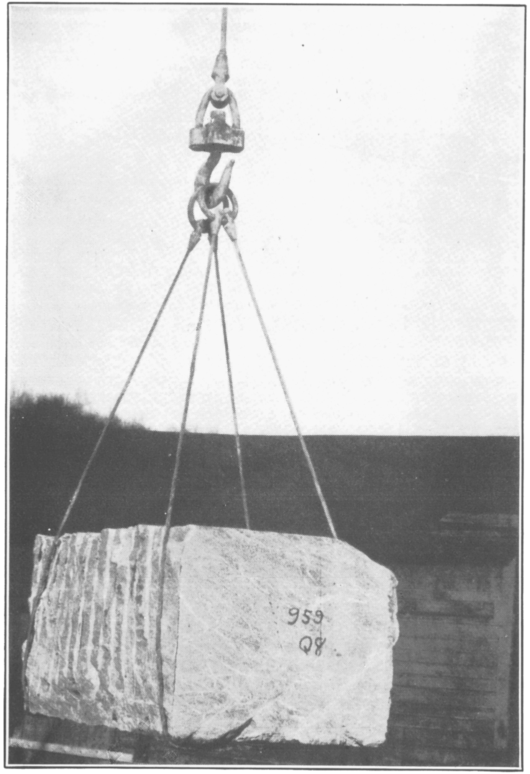
In quarrying the term "tunnel" is applied to a subterranean working, level or inclined, having a roof of undisturbed rock. The term is used in contrast with the "open-pit" quarry in which the opening is the full size of the excavation, and with the "undercut" quarry, the walls of which slant so as to make the floor space wider with increasing depth.

GENERAL CONSIDERATIONS.

Although open-pit quarrying is the more common type, there are conditions under which tunnel methods are to be preferred. A tunnel affords a means of quarrying out desirable beds without the removal of heavy stripping. However, there are certain difficulties and dangers that must be carefully considered. Among them may be mentioned the danger of roof falls, the expense of artificial light and ventilation, and the necessity of additional handling of quarry material. A necessary condition for successful tunneling is the presence of a strong roof. In regions where faulting or jointing are pronounced the danger from roof falls may be so great that tunnel methods are impracticable.

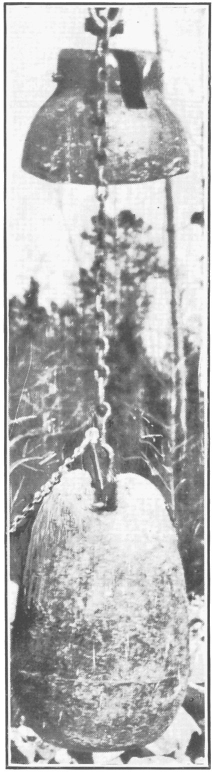
OPENING TUNNELS ACROSS BEDS.

Procedure to be followed in tunneling a deposit in which there are no open bedding planes or when the tunnel roof is to cross the beds may be illustrated by describing the method used in a Vermont quarry. A preliminary opening 6 to 7 feet high is made by channeling and blasting. As the rock thus removed is waste, the opening is, if possible, made in inferior material. Determination is made that the thickness of sound rock above the tunnel is such that there is no danger of roof collapse. After the proper position for the ceiling has been chosen a channeling machine is used to cut a channel about 7 feet deep, starting about 3 feet from the floor and slanting downward to meet the floor line. A row of horizontal drill holes is then made at the roof and another row is made parallel with the floor of this preliminary tunnel. In addition vertical rows of holes are driven at intervals of about 7 feet. The relative positions of channel cuts and drill holes are shown in figure 16. The lower wedge-shaped mass of rock x in the figure is dislodged by blasting in the drill holes below the channel cut. The upper overhanging ledge y is then broken down by discharging blasts in the holes above the channel cut. Black blasting powder is used and all charges are exploded by fuse. Such blasting is probably less effective than a simultaneous discharge of



A. CABLE SLING FOR HOISTING BLOCKS OF STONE.

B. UNDERCUTTING PARALLEL WITH STEEPLY INCLINED BEDS IN QUARRY AT WEST STOCKBRIDGE, MASS.



C. A BALL BREAKER USED IN QUARRY AT GANTTS QUARRY, ALA.

blasts by means of electric detonators. However, if the tunnel is driven in tight beds or if it crosses the beds the simultaneous discharge of a number of blasts would undoubtedly shatter and thus destroy marble adjacent to the tunnel.

When, by repeated blasting, the mass of rock 6 or 7 feet in depth has been shattered across the entire width of the tunnel, the next step is to remove the waste material. Large pans holding 2 to 6 tons each of rock are used. Each pan is shaped like a sugar scoop and is handled by means of a cable fastened to the back of the pan, passing to a second attachment at the front, and then over a sheave in the tunnel roof near the edge of the excavation. Rock fragments are loaded in by hand and the pan is hauled to the edge of the shelf. The cable is then released from the front of the pan, and further hauling causes the back of the pan to be raised, allowing the contents to slide out. If the tunnel floor slants downward from front to back, the empty pan is returned on rollers, whereas if the floor is level or inclined upward the pan is hauled back by means of a cable attached to the back and passed around a sheave at the extremity of the tunnel. The rock fragments are again loaded into pans at the base of the shelf, hauled by trolley or cable cars to the main hoist, elevated to the surface, and loaded directly on railroad cars with the derrick.

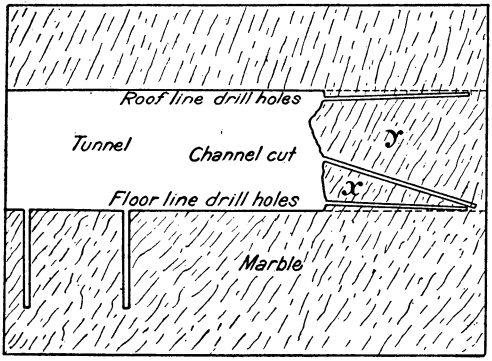


FIGURE 16.—Method of driving a tunnel in marble.

The process of channeling, drilling, blasting, and removal of fragments is repeated over and over until the preliminary tunnel has been projected far enough to give sufficient floor space for economical operations. Plate VII, *A*, shows the appearance of a tunnel in one of the Vermont quarries.

METHOD OF OPENING TUNNELS PARALLEL WITH OPEN BEDS.

In an Alabama quarry tunnels are driven parallel with the beds, which dip about 33°. The tunnel floor is made coincident with a band of soft mica schist which occupies a position between two marble beds. The soft band is thus utilized to take the place of the channel cut as described in the preceding method. One expensive operation is thus saved. Drill holes are projected in a row parallel with the roof, and vertical rows of holes pass from the roof to the floor at intervals. Black blasting powder shots are discharged in simultaneous groups by an electric firing machine. The presence of the band of mica schist at the floor acts as a cushion and prevents the shock from shattering the good marble below. On this account, the more effective simultaneous blasting may be employed.

In removing the material, loaded buckets holding 4 cubic yards are hauled to the edge of the excavation but are not dumped. By means of a derrick at the mouth of the tunnel they are transferred to a position from which they may be hoisted with the main derrick and dumped into railroad cars.

METHOD OF QUARRYING ON TUNNEL FLOOR.

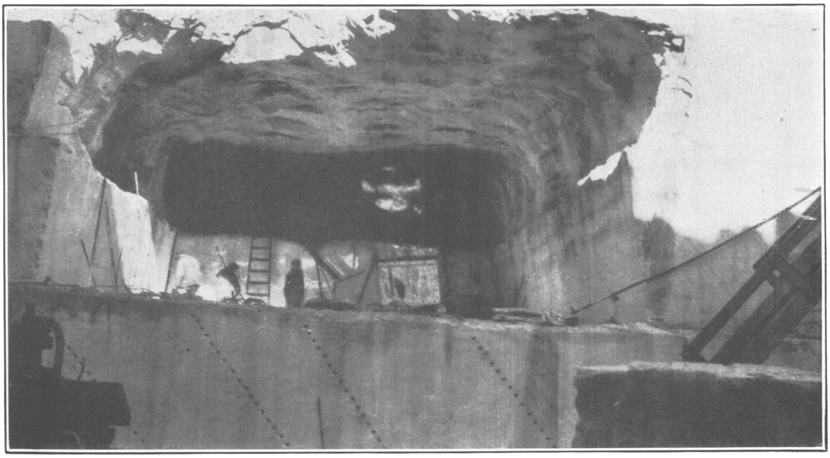
When a preliminary tunnel of sufficient size has been completed, channeling machines may be set up on the floor and operated as in an open quarry. Electricity is the most convenient power for use in tunnels. Air-driven machines are better than steam-driven, as the space for operation is usually confined. The channelers may work on a level or an inclined floor. At West Rutland, Vt., the upper levels are quarried on a horizontal floor and the lower ones on an inclined floor. In an Alabama quarry the channel floor is inclined and the channel cuts intersect the slanting floor diagonally.

ROOF SUPPORTS.

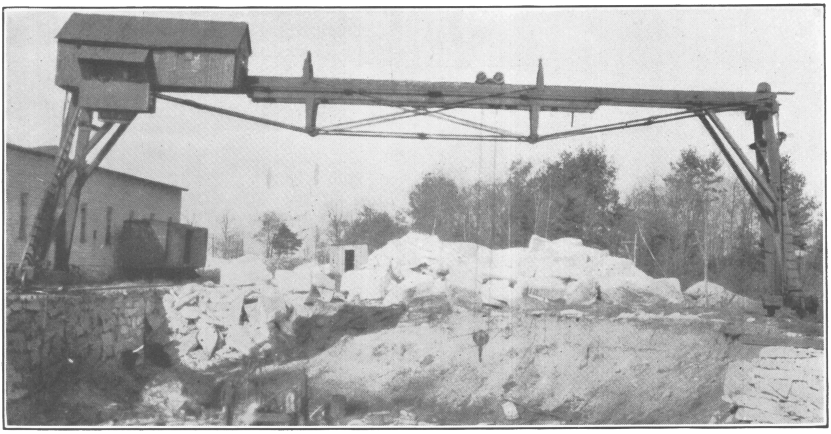
In a West Rutland, Vt., quarry the tunnel roofs are supported by pillars of marble each 20 feet square left at various intervals. The spacing of the pillars is governed by the evident security of the roof. If the beds are heavy and seams absent, the spacing may attain a maximum of 100 feet. In sections where the beds are seemingly less secure the pillars are spaced at intervals of 60 to 80 feet. In early days if the roof slanted the pillars were inclined to form right angles with the roof. Inclined pillars, however, occupy more space, and they form more serious obstacles to the operation of derricks than vertical pillars. Of late years all the pillars are made vertical though the roof may be inclined.

In an Alabama quarry a wall running in the direction of the dip is left, rather than a series of pillars. This plan was adopted after due consideration of the possibility of pillars slipping on a soft, inclined, interbedded mica schist.

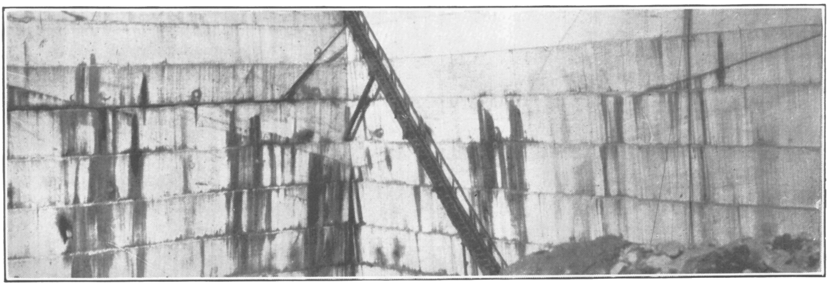
Figure 17 illustrates the present and proposed future arrangement of pillars in a Colorado quarry. The tendency to stagger alternate rows is noteworthy.



A. A TUNNEL IN A VERMONT MARBLE QUARRY.



B. GANTRY CRANE EMPLOYED AT QUARRY AT ASHLEY FALLS, MASS.



C. MANNER IN WHICH OPEN SEAMS PITCH INTO THE CORNER OF A QUARRY WHERE THE QUARRY WALL MEETS THE STRIKE OBLIQUELY.

TRANSPORTATION OF MATERIAL IN TUNNELS.

Blocks of marble or boxes of waste material may be hauled out of tunnels by means of cables. Quarry cars operating on tracks are more efficient. One company operates both cable cars and an electric trolley. If an efficient means of transportation is not provided, great loss of time will result.

LIGHTING AND VENTILATION OF TUNNELS.

In order to promote safety and efficiency in tunnels, adequate lighting is necessary. Either arc or powerful incandescent lights are suitable. If blasting is employed, the harmful gases should be removed. In the ventilation of a Vermont quarry large wooden conduits through which the impure air is drawn by powerful fans are used.

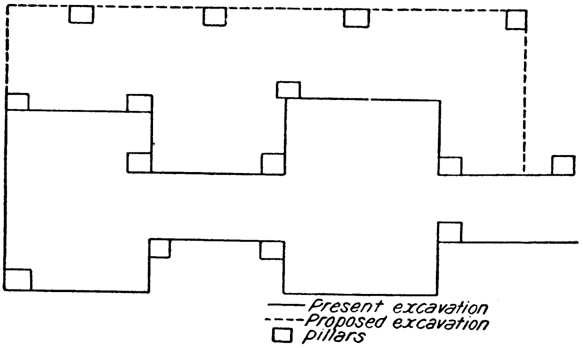


FIGURE 17.—Present and proposed arrangement of pillars in a Colorado quarry.

UNDERCUTTING.

A modification of the tunnel method consists in enlarging the quarry floor by an outward inclination of the wall cuts. The process is simple, requiring no additional equipment and no expensive preliminary operation. A wide floor space is obtained with a minimum of stripping, and with moderate extension no supporting pillars are present to obstruct quarry operations. There are, however, certain disadvantages. In tunneling, the projection of a preliminary opening is costly and produces only waste rock, but when once completed the subsequent operations of channeling and drilling are carried on with almost the same facility as in an open quarry. In undercutting, however, every wall cut is slanting. Channeling at an angle is slow and relatively expensive. Also the blocks of the outer row are angular in shape, resulting in waste.

In extensive undercutting, the danger from overhanging rock may be averted by leaving wing supports of marble at intervals. Undercutting is employed successfully in many of the Georgia marble quarries. It is to be recommended if the rock is sound, and if tunnel methods are too expensive or for other reasons seem impracticable.

In a Massachusetts quarry the walls are undercut parallel with the steeply inclined beds as illustrated in Plate VI, *B*. By this means the desirable beds are followed and the floor space gradually increased. The blocks of the first row are removed as keys and subsequent channels are cut at right angles to the strike.

COMBINED TUNNEL AND UNDERCUT.

If a band of marble is vertical in attitude or inclined at a steep angle and not exceeding 150 or 200 feet in thickness, a safe and economical method of extraction is to project a narrow tunnel and gradually widen it by undercutting. If through weathering the marble has been altered to a considerable depth, it may be possible to project the preliminary tunnel in inferior rock. Undercutting will gradually widen the floor, and the steep walls thus formed are less liable to scale than a flat roof. Undercutting is not to be recommended, except when the lateral walls are to be permanent, for as a rule, it is not practicable to further extend undercut walls. When the lateral limits of the desirable material have been reached, the angle of inclination of the wall cuts may be modified to conform with the dip of the marble beds.

DRAINAGE.

There is great variation in the quantity of water encountered in quarries. In some quarries heavy springs are encountered which require constant pumping; in others surface drainage only must be removed. Steam or motor driven reciprocating pumps are most commonly employed, though motor-driven centrifugal pumps have been used successfully, and are highly recommended by a number of quarry operators.

GENERAL CONSIDERATIONS IN QUARRYING.

Whenever possible, it is wise to conduct quarry operations on a wide floor space. In general, operations on a large scale are more economical than those on a small scale. A large floor space also allows greater choice of material. The encountering of local unsoundness may temporarily suspend production in a small quarry, whereas in a larger one the unsound rock may be avoided for the time being and removed during a dull season.

Greater efficiency in quarry operations may be attained by employing night shifts. By this means the output can be almost doubled without any increase in the power plant or quarry equipment over that required for the day shift only. The work should be so arranged that the night shift is relieved of those operations that on account of poor light, or for other reasons, are not performed to advantage in the night. Machine work is the most satisfactory of all operations for night shifts, and consequently, the day shift should endeavor to leave the machines in the best possible condition for continuous operation.

All quarries should be provided with safe and efficient stairs or ladders.[a] Much time is lost when men are obliged to pick their way over steep and rough rock surfaces or climb down hastily improvised steps or ladders.

Removal of mud and rock fragments from the quarry floor is an operation that should not be neglected. An accumulation of débris impedes quarry operations. The presence of a large heap of rubbish in one part of a quarry may discourage the proper performance of a task and lead to the substitution of a less-efficient method. All rubbish should be cleaned up systematically and frequently, and the entire floor space kept in a condition favoring a free and intelligent performance of all subsequent tasks.

SAFETY FIRST.

"Safety first" should be the motto in planning and erecting all quarry equipment and in the conduct of all operations[b] Many operators fail to realize that safety devices contribute to efficiency. They consider that much of the money spent in safeguarding machinery and the time employed in making examination for possible dangers is entirely lost. The matter of safety should be viewed in a different light. Men become greater producers if they feel that all reasonable means are employed to safeguard their lives and health. Much time is lost if men feel that they must constantly be on the lookout for some overhead dangers. Moreover, accidents deprive the quarry of the services of skilled men and frequently burden the proprietor with a load of expense.

HOISTING EQUIPMENT.

TYPES OF DERRICKS.

Various types of derricks are employed in marble quarries. Both the mast and the boom may be of wood, the mast may be of wood and the boom of steel, or both may be of steel. Spliced wooden derricks having mast and boom each in four pieces are used in some regions. They are strongly supported with iron bars and turnbuckles. They are easy to transport and set up. Those in common use

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[a] See Bowles, Oliver, Safety in stone quarrying: Tech. Paper 111, Bureau of Mines, 1915, pp. 15-16.

[b] See Bowles, Oliver, Op. cit., pp. 12-36.

have a lifting capacity of 15 to 18 tons. All derricks should be painted to protect them from the weather.

USE OF GANTRY CRANES.

A Massachusetts marble company uses a traveling gantry crane in place of a derrick, as illustrated in Plate VII, *B*. It has an 80-foot span and a lifting capacity of 25 tons. The entire crane travels back and forth on tracks placed at each side of the excavation. It is readily accessible to all parts of the quarry, and blocks once lifted are transported directly to the stock pile without further handling. One disadvantage is that the use of the gantry crane limits the width of the quarry. Furthermore, it is not to be recommended for quarries in the development of which considerable hoisting will be required, as it necessitates that all lifting be done with one hoist. If derricks are employed several may be placed in convenient locations and operated simultaneously.

DERRICK GUYS.

All derricks should be strongly supported. For 20-ton derricks eight iron guys of 1¼-inch diameter are necessary. For derricks with 90 to 100 foot masts and with a maximum lifting capacity of 35 tons the guys should be 1¼-inch steel. For locking guys, Crosby, Roebling, or Leschen clips are regarded as more reliable than splices.

A new arrangement of guys is now employed in some quarries in Vermont. Instead of 12 guys being spaced regularly, they are arranged in four sets of three each, the groups radiating at successive angles of 90° from the mast. An advantage lies in the fact that four large secure concrete piers may be constructed at a smaller cost than 12 small and possibly unsafe ones. Where several derricks are situated close together, it is often a problem to properly place guys and at the same time evenly distribute the strain. The arrangement mentioned overcomes this difficulty in a most satisfactory manner.

Where several derricks are situated near together, the top of one mast is occasionally anchored to the top of another. There is considerable risk in this method, as strains on different derricks may occur in the same direction simultaneously and thus multiply the strain on a single guy.

GUY ANCHORS.

Guy anchors are of various sorts. Where bedrock outcrops at the surface the safest method is to drill holes in the rock, insert a bar with a ring in the top, and fill up the hole with melted sulphur. Where considerable depth of soil surrounds the derrick, guys may be anchored to buried timbers. The trunks of large trees, preferably growing trees, are sure supports. It is advisable, however, to place a secondary anchor to support the tree.

A post supported by a pile of stones, as shown in Plate VIII, *A*, is used by some Tennessee quarrymen. The post should be nearly vertical. It should not be slanted backwards, as in that position it forms a lever tending to raise the soil or rock in front of it, and thus is not in the best position to withstand strain. Such posts should also be supplied with secondary anchors.

A concrete pier in which is embedded an angle-steel bar is a highly efficient support. An eyebolt may be passed through the bar and the slack of the guy taken up with a nut, as shown in Plate VIII, *B*.

HOISTS.

Steam hoists are the type most commonly employed in marble quarries, although compressed-air and electric hoists are used in several places. The type of hoist to be employed depends on the nature of the work. Deep quarries demand a higher cable velocity than shallow ones. In any case a very slow motion is not desirable. Much time is lost in quarries where men must wait while blocks are slowly raised to the surface, especially if rock excavation is being carried on near the point of elevation, as safety demands that men must move from their working places while the block is overhead. The power required for hoisting increases rapidly as the speed is increased, and a proper balance must therefore be maintained between the speed of hoisting and the power consumed for the operation.

In many quarries crude methods of sluing are still employed. Sluing is sometimes done by means of a rope attached to the block or by a mechanical sluing device operated by a handwheel. The sluing device that forms a part of all modern hoists is much more efficient, as it gives a more rapid motion than hand-operated devices and is controlled by the hoist engineer.

The spinning of blocks while suspended endangers the lives of employees and makes difficult the guidance of their course during ascent. Spinning may be avoided by using a nonspinning hoisting cable. The central strands of such a cable are twisted to the left and the outer strands are twisted to the right.

LOCATION AND SIZE OF DERRICKS.

The quarryman should have a clear and definite plan of quarry development before placing his derrick. The extension of a quarry excavation in a direction away from the derrick may soon bring it beyond the range of the boom. Thus the erection of a new derrick, and possibly a second handling of material, may be necessary. In several quarries blocks are hauled long distances by cables before they reach a position from which they may be hoisted to the surface. Such preliminary haulage is injurious to cables, involves great loss of time, seriously interferes with other quarry operations, and is surrounded by many dangers. It may be advisable to install a car-haulage system or to replace or supplement a derrick by a new and larger one. The size of the derrick must also be governed by the extent and direction of quarry operations. A small derrick may give satisfactory service for a few months, after which it may have to be replaced by a larger one. It is usually more economical to erect a large and permanent derrick at first, provided the operator is reasonably certain that quarrying within its range is to be extensive.

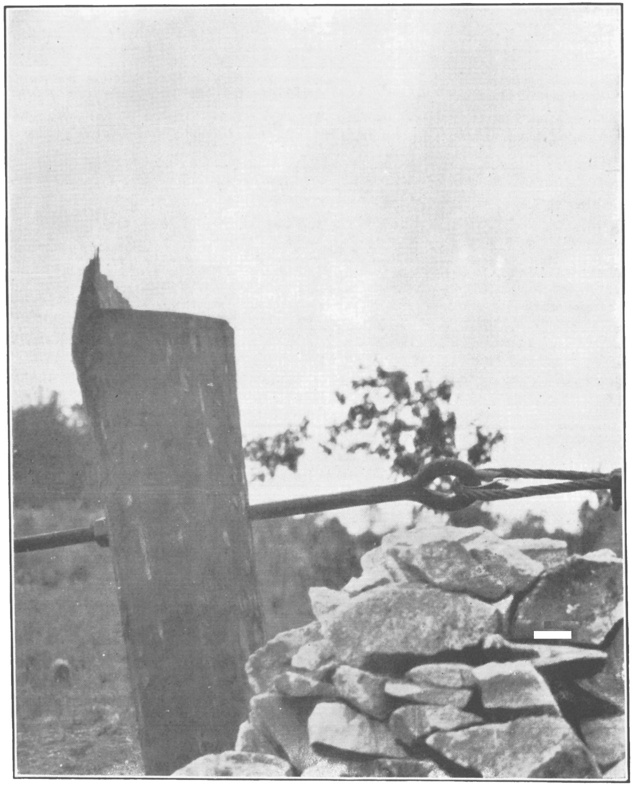
HOIST SIGNALING.

In shallow quarries or in yard operations signaling by hand motion is almost universal. If the hoist engineer can not see the bottom of the quarry, hand-motion signals are sometimes relayed to a man in an intermediate position. Such a method is not to be recommended, as the repetition of signals involves increased danger of misunderstanding and also requires an additional man.

Types of mechanical signal apparatus in common use are electric bells, telephones, and bell pulls. Dry-cell electric bells are not considered reliable; they may fail to act at critical times. Electric bells operated by wet-cell batteries are more reliable if inspected at regular intervals. Telephone connections require inconvenient ear attachments. If noisy operations are conducted, words given by telephone may be easily misunderstood. The bell pull is considered to be the most convenient and reliable method. Both the apparatus and its operation are simple and there is little danger of misunderstanding signals.

SCABBLING.

Where the mill is situated close to the quarry, the process of scabbling may be omitted. If situated at a distance, or if the marble is to be sold in block form, the blocks should be scabbled to avoid transportation of waste material. The most common method of scabbling marble blocks is by manual labor with the scabbling pick. The wire saw is used successfully in some places. Hammer drills and wedges are used occasionally for the removal of the more prominent surface irregularities.



A. A GUY ANCHOR POST USED IN TENNESSEE.

B. AN ANGLE STEEL AND CONCRETE GUY ANCHOR USED IN A QUARRY AT GANTTS QUARRY, ALA.

TRANSPORTATION OF QUARRIED ROCK TO THE MILL.

VARIOUS METHODS OF HAULAGE EMPLOYED.

In some quarry regions mills are so favorably situated that short haulage only is required. In several eastern localities blocks are loaded directly upon the transfer cars by means of the quarry derrick. A number of companies use railroad cars and locomotives. Electric trolley lines are used successfully even on heavy grades. On such grades efficient and dependable brakes must be used. Steam tractors may be employed if roads are graded and firm. It is a matter of considerable expense to grade and keep in proper repair roads suitable for the heavy traffic incident to the use of tractors.

TEAMS AND WAGONS.

Teams and wagons are used in many places. Where quarries are situated on mountain sides and rock must be hauled down steep roads, the chain or shoe attached to the wheel to prevent too rapid descent is destructive to roads. Haulage by horse-drawn vehicles entails a slow rate of haulage, small loads, much repairing of roads, and heavy cost for maintaining horses. Hence, in many places, some form of cable-car transportation would seem to be more suitable than by teams and wagons. Where light grades are encountered, mules or horses may be employed to haul cars.

CONNECTING QUARRIES WITH RAILROAD TRACKS.

Many marble quarries are situated at short distances from railroads, and some form of conveyance is necessary to connect the quarry with the railroad track. Where the grade is light, a railroad siding is to be preferred. Where small quarry cable cars are used, it becomes necessary to erect a derrick at the junction point and rehandle all marble going out and all coal coming in. Where a siding is built, transportation may be conducted by means of standard railroad cars with no transshipping. Where a heavy grade is encountered, cable cars are necessary and transshipping may be unavoidable.

CABLE CARS.

Cable cars are used successfully in a number of regions. The conditions vary so greatly that no one particular form can be recommended. The system must be modified to suit the conditions.

One of the most complete cable-car systems in use in any American marble quarry is that in a Vermont quarry. Two cars are used, the empty car ascending while the loaded car descends. The hoist is operated by a 75-horsepower electric motor. A 1½-inch steel cable passes from one car to the hoist where it makes six turns on a 12-foot drum, then passes out and is attached to the second car. The cable is guided by rollers. The track is three-fourths of a mile long. Over part of its course the grade is light, but at two points it is very steep. The cars pass at the center. Above this point a three-rail track is provided to prevent interference of the ascending and descending parts of the cable. Below the center the cable is always single, and in consequence a single track only is necessary. The maximum load is 40 tons, and 20 minutes is required for each trip. By means of an automatic needle indicator, which travels back and forth on a board, the hoist engineer can accurately follow the course of the loaded car. The rock is transferred from the cable cars to standard railroad cars for transportation to the various mills.

FACTORS CONTROLLING THE METHOD OF TRANSPORTATION.

Before a system of transportation for any particular quarry is adopted the conditions must be studied carefully. The most important considerations are probable output, size of material, number of times it must be handled, rate of haulage, distance, surface conformity of the country to be traversed, first cost of the system, cost of maintenance of equipment and roadway, and capital available for transportation purposes.

EQUIPMENT AND OPERATIONS IN MILLS AND SHOPS.

At least one-half the marble quarries of the United States have more or less completely equipped plants for sawing, polishing, carving, or otherwise preparing marble for structural uses. The operation and equipment in many such mills and shops were noted in connection with quarry observations. Marble mills and finishing plants belong to the manufacturing rather than to the producing phase of the marble industry, and consequently may not strictly be included in a discussion of the technology of marble quarrying. The brief discussion of marble-manufacturing plants presented in this section is justified by the direct interest that many quarrymen have in the manufacturing phase of the industry. Although certain facts relating to method and equipment are presented, for whatever immediate benefits they may suggest, no attempt is made to deal with the subject exhaustively at this time.

LOCATION OF PLANT.

The location of marble works is influenced greatly by water supply and availability of power. Aside from these considerations, although in many respects it is more convenient to erect the plant near the quarry, conditions may be such that this plan is unwise. If the quarry is situated several miles from towns, in a region where roads are poor, it may be wiser to build the plant at some town, especially if other marble plants are centered there.

There are several arguments in favor of placing stone manufacturing plants at a common center rather than at the quarries. Although such an arrangement requires transportation of rock that is later wasted in saw cuts and coping, buyers can the more readily conduct their business if shops are centralized. Furthermore, it is easier to keep men near towns where schools and other public institutions are more convenient and more efficient than in comparatively unsettled regions. If shops are situated at a considerable distance from railway lines, sidings are often uneven and transportation over them is more destructive to thin-finished material than to uncut blocks.

BUILDINGS.

Fireproof mills and shops are to be preferred. When a fire occurs the loss is great, because the heat is liable to destroy all the machinery. If buildings are not already of fireproof construction, a sprinkler system is to be recommended. One advantage of such a system is that water can do little damage. It may possibly cause swelling of the timbers, thus throwing the machinery out of alignment, but otherwise most of the equipment is of such a nature that water will not affect it.

The plan of shop and mill construction carried out by a Georgia marble company is worthy of remark. The company constructed with brick and concrete an absolutely fireproof section separating two units that were not fireproof. With such an arrangement fire can not paralyze production, because if one unit is destroyed the fireproof section prevents spreading of the fire, and operations may be continued in the remaining unit.

HEATING AND VENTILATION.

In cold climates the necessity of preventing the freezing of water employed in the various processes, and also the need of keeping men comfortable while at work, demands that shops be closed structures. A system of heating and ventilation also becomes necessary. Coal stoves are employed in many mills and shops, but are not satisfactory, especially in large buildings. They require too much attention, increase the fire risk, and provide an unequal distribution of heat. In a Vermont mill the air, impelled by powerful fans, is passed through coils over a furnace, and conducted through overhead pipes, from which it is expelled downward at various points. With adequate renewal of circulating air from outside sources, heating and ventilation may be combined into one system. A Pennsylvania company uses the exhaust steam from its power plant to heat the mill and shop.

POWER.

Direct water power is highly satisfactory. The cost of operation and maintenance of turbines is relatively low. An adequate water supply at all seasons of the year is desirable in order that continuous operation may not be interrupted through lack of power. At one Vermont mill two turbines on vertical shafts supply power to an overhead countershaft by means of bevel gears. The turbines are so arranged that one can be disconnected at night or at such other times as only partial power is required.

Steam is a common source of power for mills and shops. Where fuel is cheap steam is satisfactory.

Electricity, which may be developed by the company or purchased from power lines, is used in many places. Where an abundant supply and a good head of water may be obtained with a small outlay of capital, hydroelectric power may be cheaper than steam even though the cost of coal is low. The convenience in transmission of electricity has induced some companies to develop it by steam in places where there is not a sufficient water supply.

Where electricity is used, one motor may provide power for the entire mill. In other places the mill is divided into separate units driven by independent motors. One Tennessee company has one motor for each set of three saw gangs. One advantage of such an arrangement is that one part of the mill may be shut down for repairs to the motor while the remainder is in operation. Some mill men object to the use of electricity if the power is conveyed over transmission lines. To guard against burning out motors by overcharge due to lightning, a circuit breaker is necessary, and during a thunderstorm the circuit may be broken and all the machinery stopped. When saw gangs stop suddenly, sand packs in around the blades, and may make starting difficult or impossible.

METHOD OF POWER TRANSMISSION.

For transmission from fly wheel to countershaft pulley two types of belts are employed—a broad belt of leather or fabric and a rope belt. The latter has the advantage of low first cost and is easily tightened, the tightening pulley being applied to a single turn only of the rope.

Direct water power is commonly transmitted by gears. Wooden cogs in one of the intermeshing wheels and iron cogs in the other have been found a very satisfactory combination. A skillful carpenter can easily replace defective wooden cogs, and such cogs, if properly made, are durable.

PLAN OF MILL, SHOP, AND YARD.

Stone is heavy and excessive handling adds greatly to the cost of the finished product. Consequently, marble producers should aim to arrange mill, shops, and yard in a manner that permits minimum handling. Where sawing and finishing are both done, it is a common practice to place mill and shop parallel, 30 to 60 feet apart, and to have an overhead traveling crane between them. Where sawing and finishing are conducted on a large scale, the plan of a Vermont mill is efficient. The essentials of the plan are shown in figure 18. One traveling crane is employed to unload blocks from cars on their arrival at the mill and to pile them with the stock or to load them on to the transfer cars. A small locomotive crane is employed to haul the transfer cars through the mill, where a track passes down the center with gangs on either side. Beyond the mill is the finishing

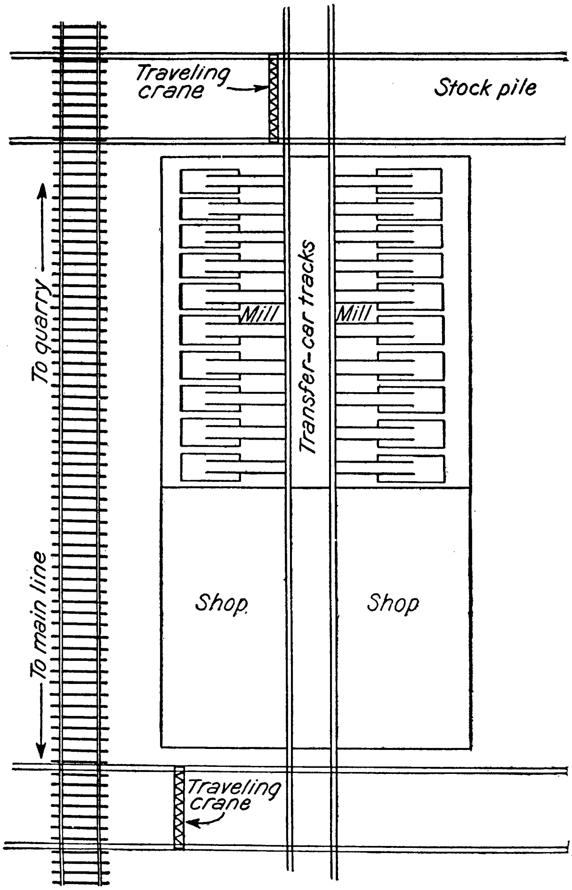


FIGURE 18.—Track arrangement at a Vermont marble mill.

plant and at the end of it another smaller traveling crane for loading the finished stock on railroad cars.

A convenient plan for a small plant having a mill but no shop is that of a Maryland plant, as shown in figure 19. Gang cars are used but no transfer cars. Cars are loaded by either of two derricks situated at opposite sides of the mill. Railway tracks pass at both sides of the mill for bringing marble blocks, sand, or fuel, and for taking away finished stock. Both rough and finished stock are piled within reach of one or other of the derricks.

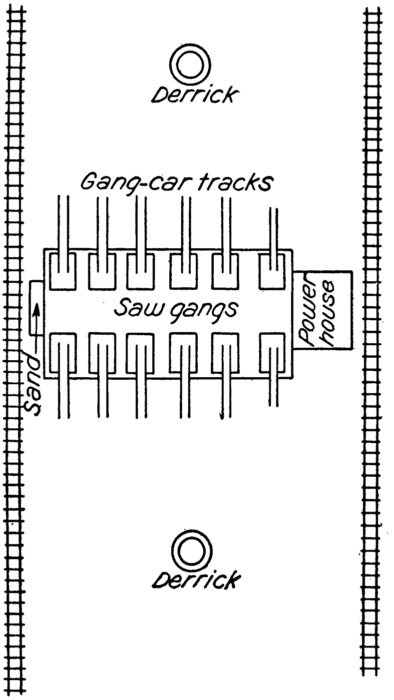


FIGURE 19.—Plan of mill and yard of a Maryland marble company.

MILL.

SAW GANGS.

Saw gangs constructed a number of years ago have wooden frames. Such frames are not to be recommended, as frequent wetting and drying cause them to decay rapidly. Modern gangs have steel frames which are more rigid and durable. An efficient frame devised by a Georgia company consists of iron tubes 8 or 10 inches in diameter, which were set up and filled with concrete. Such frames are constructed cheaply.

All hanger bearings for the gangs should be so capped that they are perfectly sand proof.

ABRASIVES USED IN SAWING.

The most common abrasive used in sawing is clean sharp sand. Many millmen use crushed steel or fine steel shot, either with water alone or with sand and water. The resulting increase in the rate of sawing is variously estimated by different operators at 20 to 50 per cent. As all millmen know, if the saws are fed too fast the blades bend and cut uneven surfaces, which must later be rubbed for a long time to be made uniform. Although it is possible to crowd saws to excess when crushed steel is used as an abrasive, the liability to crowding is less than when sand is used alone.

Certain rules must be followed in the use of crushed steel as an abrasive. It should never be used with rock that contains pores large enough to allow grains of steel to become lodged therein. The same is true of marbles containing soft minerals, as mica. If the grains of steel become lodged in the pores or in the soft minerals, they may later cause scratches when the rock is under the buffer. Also porous marbles, especially those that exhibit a marked permeability, are apt to stain with the iron rust formed from the steel abrasive. A steel abrasive may be used successfully with marbles having small pores and no streaks or bands of relatively soft minerals.

It is well known that the presence of carbon dioxide greatly increases the tendency of iron to rust, and its complete absence renders the process of oxidation (rusting) extremely slow. On this account, many millmen mix lime with the steel abrasive, because lime absorbs carbon dioxide to form lime carbonate according to the chemical reaction $CaO + CO_2 = CaCO_3$. When the carbon dioxide has been thus removed, the tendency for stains to occur in the marble is greatly diminished.

SAND PUMPS.

One good sand pump will supply five gangs. In some of the more improved types of sand pumps a great saving of power is effected by the use of ball bearings.

SAWING WITH UNSOUNDNESS.

If the grain of the marble permits, a great saving of material may be effected by sawing parallel with any joints present in the blocks. This can not be done if joints pass diagonally through blocks, and great waste results. Usually joints strike across the grain, and slabs must be sawed parallel with the grain. Thus joints may intersect a majority of the slabs, and sawing with unsoundness may not be permissible. As a rule unsound blocks can be sawed to better advantage into cubic stock than into thin slabs.

SAWING CORNER BLOCKS.

The ordinary method of sawing a corner block is to saw diagonally, forming triangular blocks. This method wastes material and necessitates a fourth cut. An improved method is illustrated in figure 20. Saw *1* is disconnected when it reaches x and saw *2* is disconnected at y. When cuts are made in a direction at right angles, L-shaped blocks are formed as shown.

LOADING SAW BEDS.

In early days the saw beds consisted of transverse stationary timbers. Roadways passed between the gangs over which marble blocks were hauled by teams or cables to points near the beds.

The blocks were placed in proper position by means of crowbars. Although greatly improved methods are now used, many of the old-fashioned mills are still in active operation, chiefly because the cost of remodeling is deemed to be too great. With the present high cost of labor, and of maintaining horses, the economy of adhering to the old methods is doubtful. Although the first cost of refitting would undoubtedly be high, there would be a subsequent saving of much time and labor. So many modern mills are now in operation that it would be a simple matter for any mill owner to estimate the loss or gain attendant on remodeling his plant.

THE GANG CAR.

The gang car has of late years replaced the stationary bed. The floor of the car constitutes the bed. Blocks may be loaded on the car and the loaded car placed beneath the blades and securely braced. The loading may be done by means of a derrick, a locomotive crane, or an overhead traveling crane. This method permits the loading of blocks and the removal of sawn material with great facility.

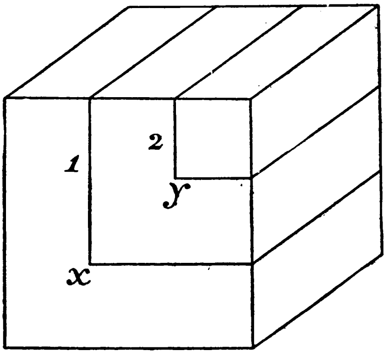


FIGURE 20.—Improved method employed by one marble company for cutting corner blocks.

THE TRANSFER CAR.

The use of a "transfer car" increases the facility of movement, and is a great timesaver especially where a traveling crane is not used. For small mills a convenient arrangement is to place a row of gangs on one side of the transfer-car tracks and a platform on the other. On the transfer car are cross tracks for the gang car. These tracks are level with the gang-car tracks which run beneath the saws on the one side and also level with several similar tracks on the platform at the other side. When a block is sawed, the gang car is hauled out by means of a cable and placed on the transfer car, from which it may be transferred to a position on the platform or taken to the shop. Another gang car with a fresh block may then be placed beneath the saws.

The platform is a great convenience when night shifts are employed. Gang cars loaded and ready are placed on the platform. When the cutting of a block is finished during the night it is removed and a new one placed beneath the saws in a short time. If no such conveniences are provided a gang that reaches the bottom of a block during the night must remain idle until morning.

The transfer car is not used at some plants, especially around mills where an overhead crane is employed. The gang must then remain idle during the time the gang car is being unloaded of slabs and reloaded with a new block. Where a transfer-car system is employed, the car loaded with slabs may be shifted to one side and replaced by another car already loaded and waiting.

The wisdom of using both transfer cars and a crane depends on circumstances. With extremely hard marbles, in which the saws sink only 3 or 4 inches during a shift, the time of loading and unloading is proportionally such a small part of the whole time devoted to the sawing operation that any equipment designed to shorten this time may not be justified. On the other hand, with soft marbles in which the saws advance 1 to 2 inches an hour a slow method of removing sawed material and replacing it with rough blocks may result in a considerable proportion of the saws being idle all the time. Mills have been observed where one-fourth to one-third of the gangs were kept permanently in idleness on account of the time required for unloading and reloading. In another mill equipped with both traveling crane and transfer cars, of the 20 gangs, 19 were in active operation at the time the mill was visited. The transfer car is undoubtedly a timesaver, and is not expensive in first cost, operation, or maintenance.

Some mills are so conveniently situated that the gang cars are loaded directly by the quarry derrick.

AN EXAMPLE OF A WELL-EQUIPPED PLANT.

The mill shown in figure 18 is an example of a mill suitably arranged and equipped for rapid handling of material. This mill has 43 gangs, and hence it is imperative to have ready facility in exchanging gang cars. The depressed transfer-car track passes down the center of the mill between two rows of saw gangs. When a block has been sawed, a small locomotive crane enters the mill from the yard. It pushes ahead of it an empty transfer car and hauls behind it another transfer car supporting a gang car loaded with a new block. When the empty transfer car reaches the proper position, the car with sawed material is hauled from beneath the saws by means of a cable from the crane and placed on the waiting transfer car. The locomotive crane then moves along until the gang car loaded with a fresh block is in proper position, when it in turn is hauled beneath the saws. The crane then passes on through the mill into the shop, where the sawed material is disposed of.

UNLOADING SAW BEDS.

Cubic stock may be removed by derrick or crane by using grab hooks or smooth-faced iron clamps which automatically close upon the block when under tension. Thin stock may be removed in the same way or by cable slings. The removal of thin slabs singly, especially if no transfer-car system is employed, results in great loss of time and keeps saw gangs idle for too great a part of the time. If a pair of steel cable slings is used the whole load of slabs may be removed at a single operation. Some companies use the slings also for cubic stock.

A CONVENIENT DEVICE ON CABLE SLINGS.

The kinking and twisting of steel-cable slings causes annoyance, loss of time, and, occasionally, injury to the operator. A simple device used by one company overcomes this difficulty. A round iron ball weight is attached to the bottom of the sling. This holds the sling under sufficient tension to prevent twisting or kinking. The ball also affords a convenient means of handling the cable. It is less destructive to gloves and less liable to cause injury to hands than the cable itself.

THE WIRE SAW.

A useful adjunct to the mill is a yard equipment for cutting with a wire saw. Four to 12 blocks may be placed in line and sawed simultaneously, sand or crushed steel being employed as abrasives. The operation requires little power or attention and gives satisfactory results in uniform material if slight variation in the thickness of the slabs may be allowed. The wire saw will not give as satisfactory service with marble that contains flint balls or otherwise lacks uniform hardness as with pure and uniform material.

SHOP OR FINISHING PLANT.

LOCATION OF SHOP.

A company which operates both a mill and a shop should logically have the latter so situated that sawed material may be brought to it with the greatest facility. The mill shown in figure 18 illustrates a convenient arrangement, the shop being a continuation of the mill building. A parallel arrangement of mill and shop with a traveling crane between them is convenient, and many companies have their mills and finishing plants arranged in this manner.

COPING.

Although most coping is done by hand, a coping machine is employed in a few places. It consists of a small carborundum or carborundum-faced cutting wheel and a smoothly traveling bed on which the slabs are placed. It cuts rapidly and leaves a smooth surface. It may be used for cutting baseboards and tile. It gives good satisfaction if sound stock is employed. One advantage is that no edge rubbing is necessary after cutting with the machine.

RUBBING.

The two important requisites for a rubbing bed are hardness and uniformity. A good quality of iron has been found most satisfactory. The attempt to make carborundum beds of large size has not as yet been successful, owing to the limited size of carborundum furnaces. Composite carborundum beds could be constructed by joining together a number of segments. However, there would be difficulty in obtaining exactly the same degree of resistance to abrasion in each section. Small carborundum beds are used to some extent for rubbing small pieces.

The common abrasive on rubbing beds is sand. Unless the sand is nearly pure and uniform the use of a simple rotary screen to take out the pebbles is advisable.

The bed surface is kept true by grinding down the high parts with an iron weight. A cubical block of iron resting on the surface of the revolving bed serves this purpose. An improved form of truer consists of cylindrical rotating disks which are adjustable on the frame.

Most rubbing beds are driven from a countershaft and gears above the bed. When driven in this manner the shaft support both above and below the bed keeps the latter in a true horizontal plane. Occasionally, however, beds are geared underneath. It is more difficult to keep the bed running true when driven in this manner, as there is no support above the bed. However, the absence of a shaft above the bed allows great freedom in using a jib crane in handling blocks of marble.

Various methods of rubbing tile are employed to make them true to size and exactly square. Machines for holding them and automatically grinding them true are known to most millmen, and descriptions may be obtained from the various manufacturing companies. One method is to attach 8 to 12 tile together with plaster of Paris and then to rub to size in the same manner that a cubical block is treated.

In order to rub the surfaces of blocks too large to be placed on the rubbing bed, carborundum rubbing heads may be operated in the same way as buffer heads. The carborundum plates may be attached to the head with shellac, melted sulphur, or set screws. A star-shaped head with the water supply entering at the center is a new form that gives good satisfaction.

For curved and irregular surfaces hand rubbing is necessary. A piece of marble with sand and water or a carborundum brick is usually employed.

GRITTING AND BUFFING.

When a polished surface is desired, the marble is placed beneath a buffer to which is attached a head of felt or other soft texture. Emery powder is used for gritting, and the so-called "putty powder" for polishing. The polishing powder is composed of chromium oxide, which makes a green powder, or of tin oxide, forming a white powder, together with oxalic acid. Occasionally these powders are mixed. Different marbles act differently under the buffer. It is only by experience that one can learn the best method of polishing, and the peculiarity of the marble may demand a modification of the polishing machinery. As an illustration, a certain Vermont marble polishes best when nearly dry. The ordinary buffer when nearly dry has a tendency to jump and break thin stock. To overcome this difficulty, "pendulum buffers" have been devised. By means of a crank and pitman large wooden blocks are made to slide back and forth. These blocks are covered with felt pads, by means of which the polishing is done, putty powder almost dry being used.

For hand polishing of curved or irregular surfaces a fine sandstone or hone is employed.

CUBIC STOCK.

Unsound blocks cut to better advantage into cubic than into thin stock. On the other hand acute-angled blocks should be cut into thin stock to avoid waste.

For cutting cubic stock to proper dimensions, a perforated steel circular saw, a diamond circular saw, or a single blade in a straight-cut gang frame may be employed. With the perforated steel circular saw sand or steel shot is employed as abrasive. It cuts fairly well but is now replaced in many places by the more rapidly cutting diamond saw.

Circular diamond saws vary in diameter from 20 to 72 inches. The diamond teeth are replaceable. The first cost is high, though with care the cost of maintenance is not excessive. They occupy little space and saw rapidly. An abundance of water is necessary for successful operation, and care must be exercised to avoid overcrowding. A New York company operates a pair of parallel diamond saws which are adjustable for width.

A single saw blade with crushed steel or sand as abrasive is occasionally used. Its operation is too slow to be satisfactory. A blade set with diamond teeth and placed in a straight-cut gang frame may be employed.

PLANERS.

Planers are used extensively for cutting moldings and cornices. The more improved forms may be applied to either straight or circular work. Of late years a great deal of the work formerly done with planers is performed with carborundum machines.

CARBORUNDUM MACHINES.

Carborundum machines are great time savers. The extensive use of carborundum is one of the most remarkable modifications in the equipment of modern marble-finishing shops. Curved work, moldings, cornices, or balusters are all cut successfully with carborundum wheels.

The method of preparing a carborundum wheel is to set it in a lathe, and by means of a steel tool to cut it into the shape of a negative of the pattern desired. The wheel is then placed on the shaft. The marble block travels on the machine bed beneath the wheel which cuts the molding to the desired shape. A copious stream of water plays on the cutting surface. Plate IX[a] shows the manner in which a molding is cut. Round bases may be carved by rotation of the marble mass, and curved forms may be made by a continuous automatic adjustment of the cutting wheel, as shown in Plate X, *A*. A carborundum wheel in use for making balusters is shown in Plate X, *B*. The piece of marble is roughed out to the general shape desired. The carborundum wheel and the baluster are rotated in opposite directions. Balusters are manufactured much more rapidly by this method than with a lathe, especially if the marble is hard or tough. One company manufacturing balusters from the Roxbury, Vt., verd antique completes in about one hour a baluster 3½ feet long and about 6 inches in diameter at its widest part. The time required to turn a similar baluster on a lathe is about three hours.

Machines are now manufactured for fluting large columns. Rather than cut out all the material with a carborundum wheel, one company finds it advantageous to first use diamond saws to make a series of parallel cuts in the deepest part of the fluting. The intervening marble is broken out with a hammer and the operation completed with the carborundum wheel. By thus using diamond saw and hammer to remove the bulk of the material the time required for fluting is just one-half that required if all the cutting is done with the carborundum wheel.

Another company has introduced a simple machine to save time in cutting circular or other irregular work. A horizontal iron bed about 5 feet in circumference is surrounded by a galvanized-iron pan to catch the drip. Projecting from the center of the bed is a vertical shaft to which a carborundum wheel is attached. The marble block is roughed out and the desired outline carefully marked. In order to facilitate movement of the marble block on the bed, flat iron plates 12 by 1½ inches by ¼ inch are provided with ball bearings inserted in

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[a] Pl. IX and Pl. X, *A* and *B*, were kindly supplied by the Julius Wegner Machine Works, Astoria, Long Island, N. Y.

holes and projecting slightly above the surface. The arrangement of ball bearings is shown in figure 21. The block is placed on these plates and is thus very easily guided. It is held against the rotating carborundum wheel and cut to the line. The claim is made that one man can accomplish as much with this machine as 10 men cutting by hand.

One weakness of the method is the lumpy or uneven surface that inevitably results from hand manipulation. The company contemplates the introduction of an adjustable block support to be attached to a lathe bed running beneath a carborundum wheel. The bed is designed to travel very slowly while the turning of a handwheel raises or lowers the block. Thus the accuracy of machine work will replace the unavoidable inaccuracy of hand labor. Similarly, the introduction into marble-finishing plants of many new and special forms of carborundum machines may be expected.

COLUMN CUTTING.

Various methods are employed for cutting columns of marble. One company cuts small columns by means of a circular steel drum rotating on a vertical axis and fed with sand and water. Other companies employ similar drums having diamond teeth inserted on the lower margin. The cutting is done by the diamonds and no other abrasive is necessary. A stream of water is supplied during the cutting process.

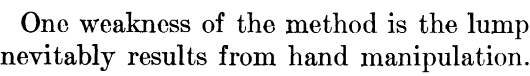


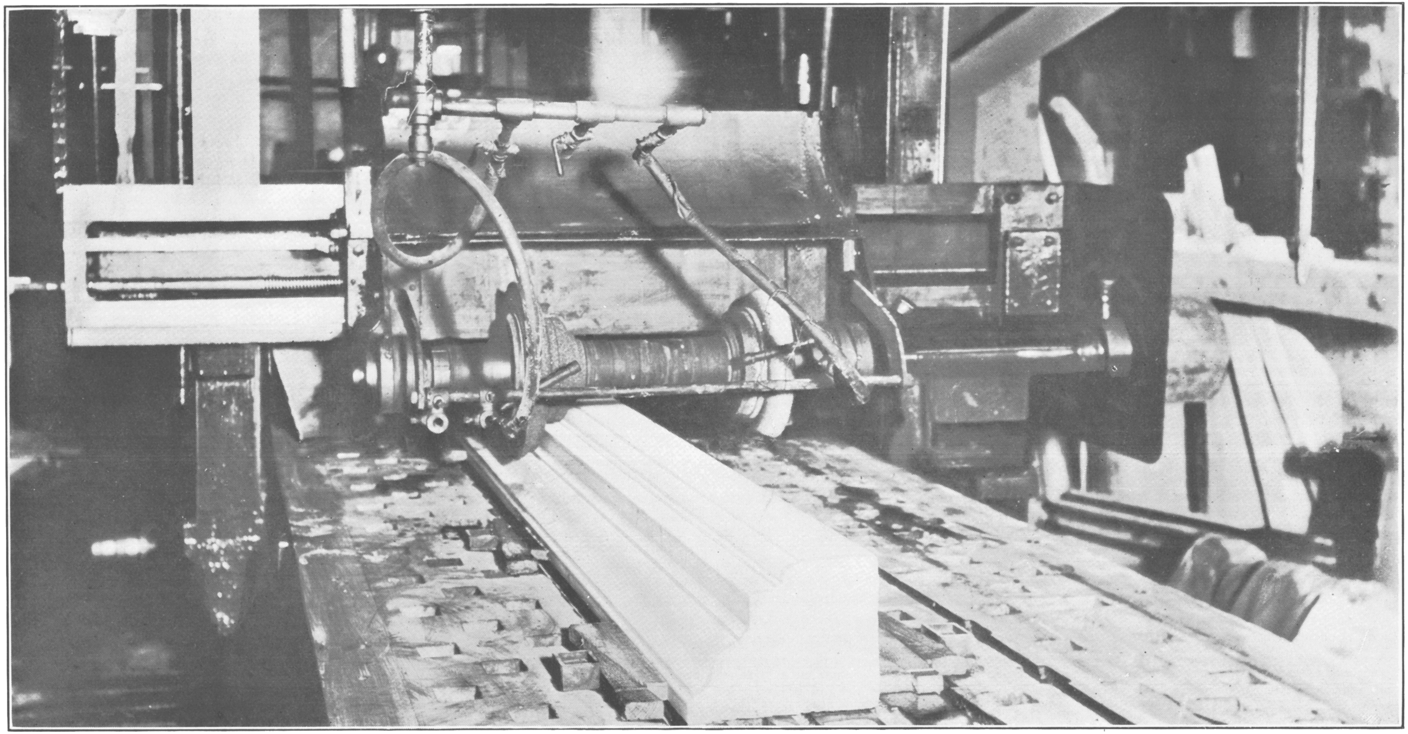
FIGURE 21.—Iron plate with ball bearings used to facilitate movement of marble blocks.

The largest cutting drum of this type yet observed is that employed by a Colorado company in cutting columns for the Lincoln Memorial, now under construction at Washington, D. C. Each section of a column is 7 feet 5 inches in diameter and 58 inches long. The drum has 80 diamond teeth. A period of 4 to 5 hours is required for cutting each section.

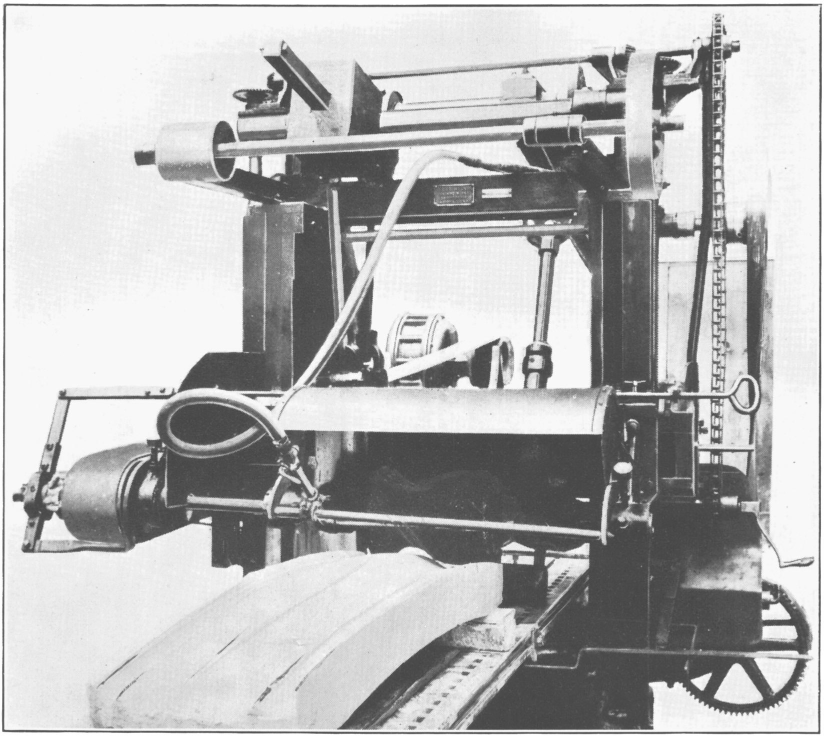
Drum column cutters give good satisfaction for short columns or short sections of columns, as described above. For large monoliths a lathe must be employed. Columns are then roughed out to the approximate form desired before they are placed in the lathe. The cutting tool employed is similar to that used in the ordinary machine lathe for turning metal shafts.

Lathes adapted for fluting as well as turning are now used by some companies.

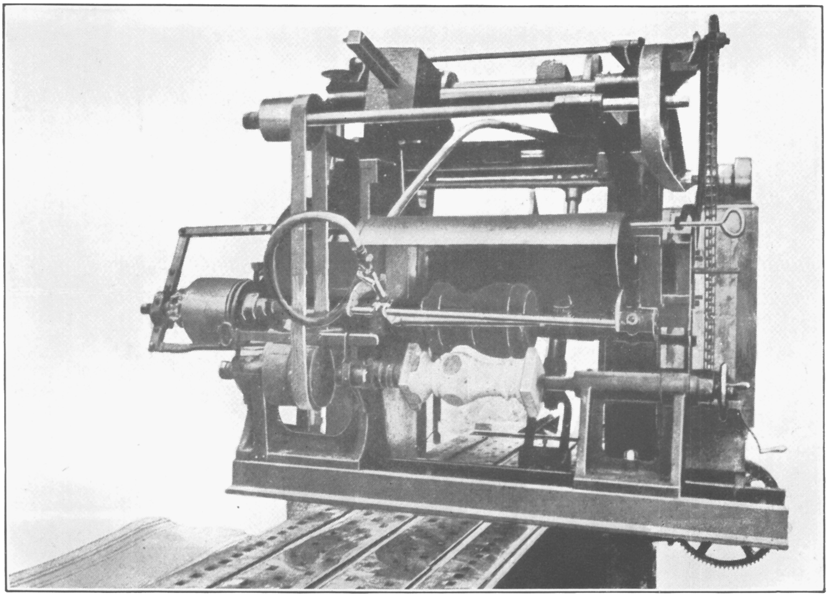
A lathe may also be employed for polishing plain columns, though the rubbing or polishing of fluted columns is done by hand.



CARBORUNDUM MACHINE CUTTING A MOLDING IN MARBLE.



A. A CARBORUNDUM MACHINE ADAPTED FOR CUTTING CURVED MOLDINGS.



B. A CARBORUNDUM MACHINE ADAPTED FOR CUTTING BALUSTERS.

CUTTING AND CARVING.

All complicated patterns, or other irregular designs, must be cut by hand. Much of the cornice and molding work formerly done by hand is now performed successfully with planers or carborundum machines. As mentioned previously, carborundum machines are of especial interest to stonecutters, as they are capable of such varied adaptations. For hand carving, small operators with limited capital employ hand tools and hammers. Pneumatic tools are much better, and should be employed wherever possible.

A method of cutting the letters on headstones by means of a sand blast is employed by at least two companies. A shield with an opening the size and shape of the inscription area is placed over the monument. Steel letters are glued on the rock surface in proper position, and a sand blast directed at high pressure against this surface for a few moments cuts down the entire area except that protected by the steel. A little hand trimming is required to correct irregularities due to varying hardness of the stone. Much time is saved by employing this method, especially when many monuments of the same size and shape are manufactured.

That part of a stone shop that is devoted to cutting and carving should be well lighted and heated.

HANDLING MATERIAL.

An overhead crane is necessary for handling heavy material Electric cranes are efficient, and are so widely known that description of their operation is superfluous. In many shops where small-sized stock is produced the material is handled with great facility by means of small trucks run by hand.

CRATING AND SHIPPING.

Experienced men should be employed for crating and loading finished material upon cars ready for transportation. The material must be packed in such a manner that it will not break by moving about in the car, but, on the other hand, it must not be secured too rigidly, or the straining of the cars on sharp curves may cause breakage. For handling heavy material a derrick, locomotive crane, or overhead traveling crane must be employed. For small stock, trucks are commonly used.

ADEQUATE WATER SUPPLY.

So many operations in the mill and finishing plant require an abundance of water that provision must be made for an adequate supply. Failure of the water supply may make necessary suspension of the operation of part or all of the marble-cutting machinery. If for any reason the supply of water seems liable to diminish and become inadequate, immediate steps should be taken to obtain a larger supply or to build necessary reservoirs for the regulation and conservation of the supply already at hand.

THE PROBLEM OF WASTE.

THE IMPORTANCE OF WASTE.

Conservation of national resources demands economy in quarrying. The stone resources of the United States, although great, are by no means inexhaustible, especially the finer grades of marble. Added to the actual value of the material forming the waste heap is the cost of excavation. The cost of stripping, channeling, drilling, and hoisting waste blocks is often nearly as great as the cost of handling an equal amount of good rock. Aside from the value of the rock and the additional cost of quarrying, the waste material encumbers the ground, impedes lateral development, and interferes with yard operations. The failure of some quarry companies to realize a profit is due to the quarrying of an excessive amount of material that remains unutilized.

The problem of waste is twofold. In the first place it has to do with all types of improved equipment and modern methods of excavation which tend to keep the proportion of waste at a minimum; and in the second place it must deal with the various uses to which waste material may be applied. In other words, it is a problem, first, of waste elimination and, second, of the utilization of whatever waste is unavoidable.

ELIMINATION VASTLY MORE IMPORTANT THAN UTILIZATION.

Waste elimination is much more desirable than waste utilization. A quarryman should by no means countenance methods that result in excessive waste merely because he has found an outlet for his waste material in the form of by-products. As a rule the cash return from by-products is only a fraction of the production cost of the waste material from which they are supplied. As an illustration, it may be assumed that a moderate cost of marble excavation is 25 cents per cubic foot, or $3 per ton. A fair price for riprap is 50 cents a ton, one-sixth of the cost of excavation. The quarryman seeks a market for riprap, not because the production of riprap is profitable, but for the reason that he prefers to obtain one-sixth of the cost of his waste material rather than to receive nothing at all. By eliminating a ton of waste he saves $3, whereas by marketing it he saves only 50 cents.

WASTE ELIMINATION.

UNAVOIDABLE LOSSES.

The loss of a part of the good stone is unavoidable. Channeling, drilling, scabbling, sawing, and coping are all necessary operations which use up an appreciable share of the stone. In addition to losses due to the processes of manufacture, more or less stone must be thrown away on account of imperfections.

AVOIDABLE LOSSES.

It is, however, the throwing away of masses containing many cubic feet of good stone, or the handling of an excessive amount of inferior material, which constitutes the serious and, for the most part, avoidable losses. Causes of these greater losses and methods of quarrying that will eliminate them are discussed below.

CHIEF CAUSES OF WASTE.

The natural imperfections in marble that constitute the source of the greater losses are unsoundness, strain breaks, impurities, and lack of uniformity either in color or texture. On account of the particular method followed in marble quarrying, irregular masses or acute-angled blocks may result and lead to further waste.

SYSTEMATIC PROSPECTING.

Unsoundness, texture, and distribution of color or impurities vary from point to point in the same deposit. The prospective quarry operator must not too hastily open a field of operations. Systematic prospecting is a first step toward waste elimination. Outcrops or stripped surfaces should be carefully examined for unsoundness, bad color, flint balls, etc. Naturally, investigation should follow the direction in which any improvement appears in the rock.

The most suitable location as indicated by surface conditions having been chosen, the next step is to ascertain the qualities of the marble at various depths. Drill holes should be projected at points distributed systematically over the area under investigation. Double core-barrel drills are the best for this purpose, as they give information concerning unsoundness in addition to indicating color, uniformity, and supply. Any change in quality with depth is important as showing whether development should best extend laterally or vertically.

DIRECTION OF QUARRY WALLS.

Before operations are started the outcrop or stripped surface should be mapped carefully to show the direction of strike and dip, and the directions of the chief joint systems. Naturally the quarry walls should parallel those rock structures that are most pronounced. If the beds are tilted and if inferior beds alternate with those of good quality, it may seem advisable to make the quarry walls parallel the strike and dip. If the rock is of uniform quality but intersected by prominent joint systems, the quarry walls should be parallel and at right angles to the chief joints, or possibly the contiguous walls should parallel the two chief systems of joints if these should meet at oblique angles. The quarryman must use keen judgment and give careful study to this question. Careful mathematical calculations may be necessary before he can determine definitely which plan will give him the minimum of waste.

The author knows of instances where a mistake in the original plan of quarrying has led to an excessive proportion of waste. In a certain quarry the marble beds strike N. 35° W., and dip 30°. The sides of the excavation are N. 60° W. and N. 30° E., respectively. Hence, one wall of the excavation makes an angle of 25° with the strike. As a consequence the beds pitch into one corner of the quarry, as shown in Plate VII, *C.* The nature of the rock requires that it be split on the bed, and as a consequence "oblique" blocks result and the waste is excessive.

Of course when such a mistake has been made in the original plan of quarrying, it is possible to change the plan and quarry parallel with the chief rock structures. By such a change, however, corners are left and the original floor space greatly reduced.

TUNNELING TO AVOID UPPER INFERIOR BEDS.

The depth of inferior rock due to surface alteration is an important consideration. Although the actual value of the untouched material may be negligible, the cost of handling great quantities of waste material adds greatly to the expense of quarrying. The removal of such material may, under certain conditions, be avoided by employing tunnel methods.

WASTE IN TUNNELING.

In projecting a tunnel, head room is obtained by blasting out a space 6 to 7 feet in height. If the tunnel is driven in good marble a large quantity of good material is thus destroyed. If practicable, the quarryman should choose an inferior bed in which to drive the preliminary opening. If a tunnel is to be projected with a view to avoiding handling surface-stained material, it should be driven in the band immediately above the good rock, provided a sound roof of sufficient thickness remains.

The blasting required in tunnel work demands care to avoid shattering the good marble. When tunneling is done on the bed, a band of mica schist or even an open bedding plane at the floor of the preliminary tunnel may serve as a cushion and prevent the shock from affecting the good marble beneath. If no such cushion exists, as a safety precaution, only light charges are used, and holes are fired singly as the simultaneous discharge of a series of shots creates too severe a shock. The making of a horizontal floor cut with a channeling machine prevents the effects of blasting from reaching the good marble, but the difficulties and inconveniences of the method make it of doubtful value.

WASTE DUE TO UNSOUNDNESS.

Channeling regardless of unsoundness probably accounts for the loss of a greater quantity of good marble than any other single cause. Unsoundness is the most prolific source of waste, and the one that is receiving least attention in the majority of American marble quarries. Too great emphasis, therefore, can not be placed on this phase of the waste problem.

Waste results whenever joints pass through blocks, and the waste becomes excessive when they pass in diagonal directions. A reduction to a minimum of this form of waste involves first a modification of channeling and drilling directions in order that they may conform with the directions of the chief joint systems, and second a variation in the spacing of cuts to make them coincide with joints and thus eliminate the joints from the blocks. Attention is directed to figure 10 (p. 63) which illustrates the manner in which waste may be eliminated by a judicious arrangement of channel cuts.

WASTE DUE TO LACK OF UNIFORMITY.

If there is a variation in the texture or color or the marble, care should be taken to quarry in such a manner as will tend to produce material that may be closely classified. Thus, channel cuts and drill holes should follow as closely as possible the boundaries between different grades of material. If a block of stone contains 75 per cent of inferior and 25 per cent of good material it will probably be thrown in the waste heap, along with blocks that are 100 per cent inferior. If, however, it is so quarried that even part of the 25 per cent of good material is retained on a good block, a saving has been effected. This feature is discussed on page 60. By making all the cross breaks along lines that mark separations between material of different grades a close classification may be made.

WASTE DUE TO IRREGULAR BLOCKS.

Imperfect quarry methods, such as making too few drill holes or wedging so forcibly as to produce artificial strain breaks, may result in the production of irregular blocks. Channeling or otherwise separating blocks along lines making acute angles with open seams or beds may result in the production of irregular or angular fragments, most of which are thrown in the waste heap. When irregular blocks are placed on the saw bed the removal of thick surface slabs and of irregular or angular ends leaves a relatively small proportion of good stone.

THE VARIOUS REGULAR FORMS OF QUARRIED BLOCKS.

Usually marble is quarried in regular blocks bounded by three pairs of parallel faces. Such regular blocks may be in various forms. The relative waste involved in each form, and the conditions that justify or condemn excavation in such a way as to produce each form are of supreme importance.

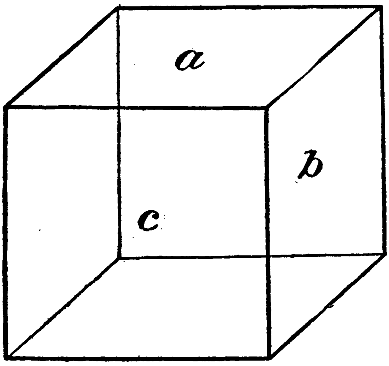


FIGURE 22.—Right-angled block.

Of regular blocks bounded by three pairs of opposite and parallel faces, four different forms are quarried. These are represented in figures 22, 23, 24, and 25. The block represented by figure 22 is bounded by three pairs of parallel faces, all adjacent faces meeting at right angles. Hence, this may be termed a "right-angled" block. In figures 23, 24, and 25 a right-angled block is shown in dotted lines, in order to indicate the relationship existing between it and the other forms described.

Figure 23 represents a block that results when the quarry floor is level, when one channel cut crosses the line of strike at right angles, and when the cross break or second channel cut is made parallel with a steep dip. The angles between faces *a* and *b*, and between faces *c* and *b*, are right angles, whereas between faces *a* and *c* the angle is greater than 90°. The face *c* and its parallel and opposite face are inclined at an oblique angle with respect to one other pair of faces, and in consequence the block is termed a "monoclinic" block.

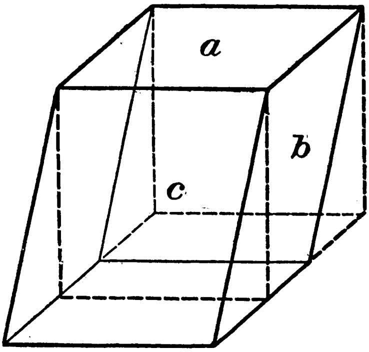


FIGURE 23.—Monoclinic block.

Figure 24 represents the form of block which results when the quarry floor *a* is level, the channel cut forming the face *b* is vertical, and the cross break or channel cut forming the face *c* passes obliquely through the block with respect to both *a* and *b*. Between the faces *a* and *b* the angle is right, whereas the angles between *a* and *c* and between *b* and *c* are both oblique. The line marking the emergence of the plane *c* on the level quarry floor is not perpendicular to the channel cut that forms the face *b*, as with the block shown in figure 23, but passes obliquely across the surface. Hence, this block may be termed "oblique."

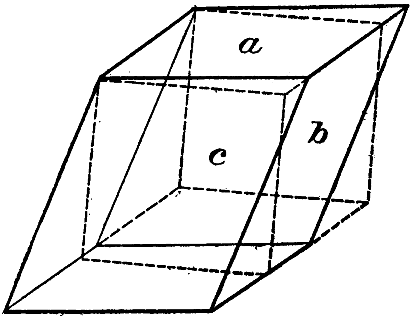


FIGURE 24.—Oblique block.

Figure 25 shows a block in which no right angles exist between the bounding faces. Such a form results when the quarry floor is level and when the channel cuts are neither at right angles to each other nor vertical, being inclined at steep angles. As there are no right angles and as the three pairs of faces are inclined at oblique angles to each other, such a block may be termed "triclinic."

It may be noted that the four forms described represent the varying stages of obliquity that are possible in regular forms bounded by three pairs of parallel faces. Of the angles formed by the meeting of the three faces *a*, *b*, and *c* in figure 22, there are three right angles; in figure 23, two right angles and one oblique angle; in figure 24, one right angle and two oblique angles; and in figure 25, all three are oblique.

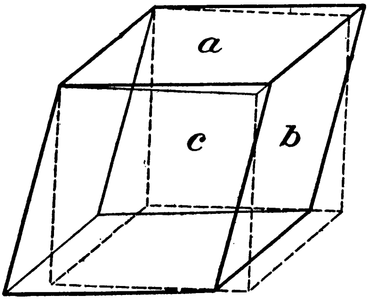


FIGURE 25.—Triclinic block.

CIRCUMSTANCES GOVERNING THE PRODUCTION OF THE VARIOUS FORMS.

For convenience in describing the manner in which blocks are formed, the three cuts by which blocks are separated may be termed the "floor cut," the "strike cut," and the "dip cut." The floor cut or "bottom break," as it is sometimes called, is the break that separates the block from the quarry floor, as shown at *a*, figure 26. The strike cut is parallel with the strike of the rock at shown at *b*, and the dip cut follows a line at right angles to the strike cut, as at *c*.

Right-angled blocks are obtained when the quarry floor is level and when the channel cuts and cross breaks are vertical and at right angles. They may also be produced if the quarry floor slants so as to parallel the dip, if the channel cuts and cross breaks are made in such a manner as to form right angles with each other and with the floor, as shown in figure 26. In some quarries the dip cuts are made with a channeler and the cross breaks by drilling and wedging. If the rift is slight it may be desirable to make channel cuts in both directions. Inclined strike cuts may be made on a slanting floor with Sullivan "Z" or Ingersoll electric air machines. They operate on a level track with the channeling machinery inclined in such a manner as to make the strike cuts perpendicular to the dip as shown in Plate XI.[a]

If beds are inclined at an angle and the quarry floor is maintained on a level it may seem desirable to quarry acute-angled blocks. Inclined marble beds may have a pronounced rift, or a color distribution, or both, in a direction parallel with the bedding. Under such conditions, ease of splitting or a proper grading of material may require the strike cuts to be inclined to parallel the dip as shown in Plate XII, *A*. As a result, with a level quarry floor, and one set of channel cuts perpendicular to the strike, "monoclinic" blocks are produced. Such blocks are also formed if the quarry floor is inclined to parallel the beds and the strike cut is channeled vertically.

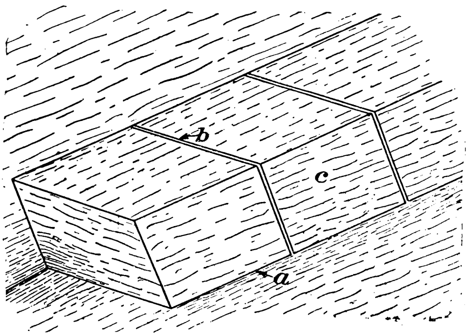


FIGURE 26.—Cuts by which blocks are separated from the solid mass. *a*, Floor cut; *b*, strike cut; *c*, dip cut.

As mentioned previously, a serious mistake is occasionally made by failing to make the quarry walls conform in direction with the strike of the rock. Under such conditions, inclined open beds will pitch into one corner of the quarry, as shown in Plate VII, *C* (p. 86). When a level floor is maintained, a separation parallel with the beds will pass obliquely with respect to the channel cuts, resulting in what have been termed "oblique" blocks, shown in figure 24. Oblique blocks may also result from a modification of the regular vertical and right-angled direction of channel cuts in order to parallel a system of joints.

"Triclinic" blocks are produced only under peculiar conditions. In one quarry previously mentioned the marble is quarried on a level floor, the strike cut, which runs N. 5° W., is inclined 60° from the horizontal to parallel the dip, and the second channel cut is made in the direction N. 82° E., and is inclined 61° from the horizontal to parallel a pronounced system of joints. Thus the three pairs of faces

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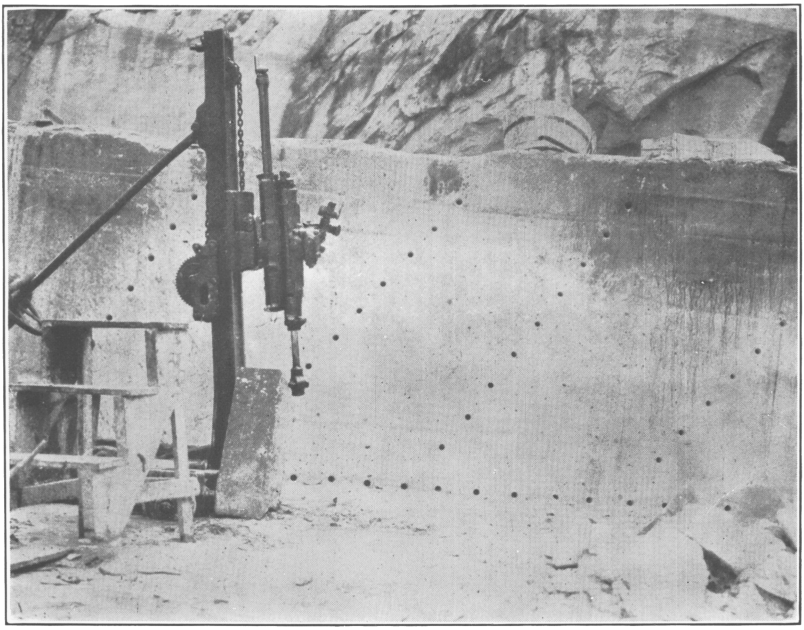
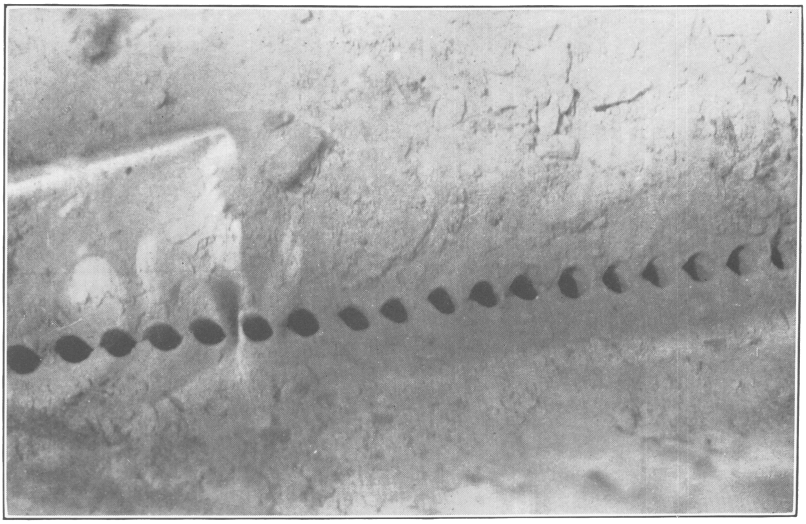
[a] Photograph supplied by the Sullivan Machinery Co.

A METHOD OF CHANNELING RIGHT-ANGLED BLOCKS ON AN INCLINED FLOOR. QUARRY AT AVONDALE, CHESTER COUNTY, PA.



A. METHOD OF QUARRYING MONOCLINIC BLOCKS.



B. VERTICAL DRILL HOLES PARTLY CLOSED BY ROCK EXPANSION.

of the resulting block meet each other at oblique angles to produce a "triclinic" form, as shown in figure 25.

WASTE DUE TO ACUTE-ANGLED BLOCKS.

As by far the greater proportion of all structural material is right-angled in form, right-angled blocks are the most desirable and give a minimum of waste material.

When a monoclinic block is cut into cubic stock, angular corners are cut off and thrown into the waste heap. The excessive waste resulting from such a process is indicated in figure 27. Quarrying on an inclined floor, thus producing right-angled blocks, would greatly diminish the waste.

That a greater proportion of waste must result from oblique blocks than from those of monoclinic form is shown in figure 28. If the oblique form results from a mistake in the original layout of the quarry, and if much cubic stock is desired, it is probable that a change in the direction of channeling to conform with the direction of strike would be justified.

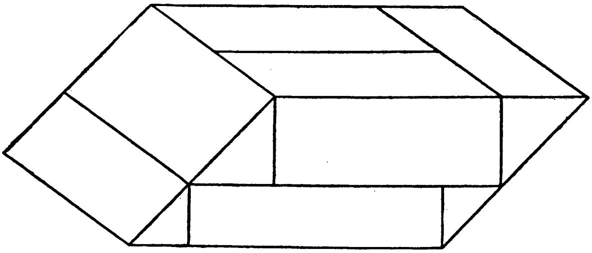


FIGURE 27.—Diagram showing waste resulting from cutting monoclinic blocks into cubic stock.

No diagram is necessary to indicate that the triclinic block is even less economical than the oblique.

The angle of obliquity has a direct bearing on the economy of quarrying. The acute angles may approach 90° or they may be 60°, 45°, or even 30°. It is at once evident that the more acute the angle becomes the greater is the proportion of waste. The increase in waste due to increase in obliquity is especially pronounced when cubic stock is produced.

JUSTIFICATION FOR ACUTE-ANGLED BLOCKS.

It has been shown that with each increase in the number of oblique angles in a block of sound and uniform marble, provided the acute angles are of approximately the same size, there is a corresponding increase in the proportion of waste. The question arises, Is the production of acute-angled blocks ever justified?

The nature of the product has an important bearing on this question. When the quarried material is cut into thin stock exclusively, slabs of uniform size may be produced from monoclinic blocks with little waste, as shown in figure 29. Except for the beveled edges that must be removed in coping, the waste is not abnormal. However, it must be remembered that in sawing monoclinic blocks longer saws are required than for blocks of the same size in rectangular form. Also, if long blades are used, the cuts are liable to be irregular.

Under certain conditions acute-angled blocks are the most economical that can be quarried, especially if the material to be quarried is unsound or nonuniform. It is illogical to state that as acute-angled blocks do not as a rule cut to advantage their production should always be avoided. Usually economy demands that blocks be separated parallel with the prevailing rock structures, and these structures may not be in right-angled arrangement. They may be so arranged that by quarrying in conformity with them, monoclinic, oblique, or even triclinic forms must result. Rock structures are fixed and unavoidable features, and many of them are undesirable in nature, distribution, and direction, so that the quarryman must modify his methods to make the best of them. Although in quarrying sound marble right-angled forms are the most economical, in quarrying unsound or nonuniform material conformity with structure is of greater consequence than right angles.

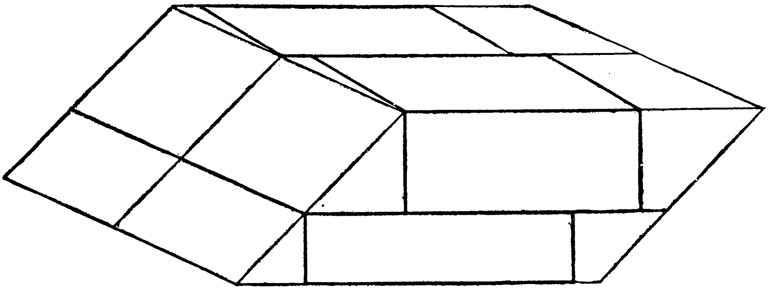


FIGURE 28.—Diagram showing waste resulting from cutting an oblique block into cubic stock.

A concrete example will illustrate this point. In one part of a certain quarry, color bands and joints make oblique angles with each other and with the level quarry floor. Quarrying parallel with these structures results in the formation of triclinic blocks. Inclining the floor to make a right angle with either the color bands or the joints would result in the formation of oblique rather than triclinic blocks with a consequent small saving of material. However, the conditions described prevail over a small part only of the quarry, and as a consequence a change of floor attitude would not be justified.

If in this instance the quarryman had channeled vertically in two directions at right angles, and thus produced right-angled blocks, the undesirable color bands would have passed through the blocks diagonally in one direction, and the joints would have passed diagonally in another direction. Such blocks would probably be worthless. In other words the right-angled block would give the maximum of waste and the triclinic block the minimum. Thus under certain conditions the quarrying of acute-angled blocks represents the highest type of efficiency.

GENERAL RULES GOVERNING SHAPE OF BLOCKS.

Rules for the quarryman's guidance may be summarized as follows:

(1) Effort should be made to produce right-angled blocks, unless there is a valid reason for doing otherwise.

(2) Quarrying on a level floor and splitting diagonally to form monoclinic blocks may be justified where much thin stock is produced. If much cubic stock is desired, the quarryman should consider carefully the advisability of channeling on an inclined floor in order to produce right-angled blocks.

(3) A direction of channeling that results in inclined beds separated by open bedding seams pitching into the corner of a quarry should by all means be avoided. The same is true of inclined beds that are not separated by open seams but have a decided rift or color distribution parallel with the bedding.

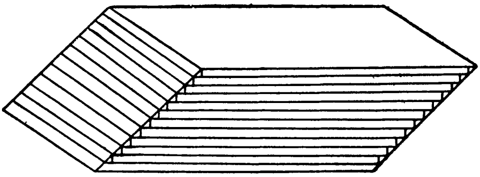


FIGURE 29.—Diagram showing small amount of waste resulting from cutting monoclinic blocks into thin stock.

(4) As regards unsound or nonuniform material, although an effort should be made to avoid oblique angles, conformity of cuts with structure is, as a rule, more economical than right-angled cuts

IMPURITIES THAT CAUSE WASTE.

The more common impurities in marble are: Silica, dolomite, pyrite, or marcasite, and mica.

SILICA.

The presence of flint or some other form of silica in marble beds is a source of waste in many places. Flint balls or lenses of silicious matter that are seemingly conformable with the bedding are probably original constituents of the marble deposit. As mentioned in the section on marble imperfections, such occurrences are probably characteristic of all parts of the beds in which they appear. The presence of flint balls in a marble bed should discourage any attempt at extensive excavation with a view to uncovering other parts of the same bed in the hope that flint may not be present. It is wiser to assume that such a bed is undesirable and to conduct quarry operations in such a manner as to handle as little of it as possible. If silica is a secondary filling in cracks and cavities, it tends to follow the joint system, and consequently if the rules given for economical quarrying in unsound marble are followed the silica may be largely eliminated with the unsoundness.

DOLOMITE.

Bands or lenses of dolomite are present in some marble deposits. Although dolomite is just as desirable a form of marble as calcite, a mixture of the two is undesirable. Dolomite is harder and less soluble than calcite in ordinary atmospheric reagents. On the other hand, owing to the tendency of dolomite to occur in granular form, it frequently dissolves more rapidly than calcite. On exposed surfaces differential weathering is likely to take place, and in time a pitted or otherwise nonuniform surface will result. Quarrying should be conducted in such a manner as to avoid those beds that show a mixture of calcite and dolomite unless the mixture is intimate.

PYRITE AND MARCASITE.

The effect of pyrite and marcasite on the quality of marble may be pronounced or it may be scarcely noticeable. Those forms of either impurity that have a tendency to cause stains by weathering should be avoided in quarrying marble for exterior work.

MICA.

The presence of mica in marble is probably the result of the effects of metamorphism on interbedded clay. As clay bands are formed from stream deposits, they are near-shore phenomena. The marble prospector should have a thorough knowledge of the geologic history of his deposit. It is desirable that he should know the position of the shore line when the original beds that formed the marble were deposited. Other factors being equal, it is desirable to locate quarries at some distance from old shore lines in order to avoid as much as possible of the interbedded mica.

WASTE DUE TO BAD COLOR.

A great saving may be effected by close grading of nonuniform material. Slight changes of color from white to gray or from white to bluish white may seriously detract from the market value of the stone. The reasons for such changes are obscure. They are probably due to the presence of chemical impurities in small amount.

If the impurities are original components of the marble and due to the peculiar conditions of limestone deposition, it follows, as in the case of flint, that the distribution of color will tend to be fairly constant in any one bed, and the greater variations will be found in passing from one bed to another.

WASTE DUE TO STRAIN BREAKS.

A condition of strain within the marble mass has in certain places caused so great a proportion of waste that the workings have been abandoned. The rock is under a severe compressive stress usually in one direction only. The process of quarrying relieves the stress at certain points, and the consequent expansion may cause fracturing. Furthermore the expansion of one mass that is still in rigid connection with the main mass still under compression may cause irregular or oblique fractures to form between the two masses.

In order to avoid the excessive waste due to this cause steps should be taken to bring about relief by uniform expansion of as large a mass as possible at one time. To this end a line of closely spaced deep drill holes should be projected along each side of the quarry parallel with the direction of compression, and a similar line of holes should be projected across the quarry at right angles to the first line. The rock will expand and close the holes in the latter line, and the strain will thereby gain relief. For a more complete discussion of the problem of strain breaks the reader is referred to pages 123–145.

WASTE UTILIZATION.

BY-PRODUCTS.

Although the proportion of waste may be kept at a minimum by the adoption of economical quarry methods and efficient machinery there is always more or less unavoidable waste. The second phase of the problem of rock waste has to do with the various means of utilizing the waste material. Many manufacturers in various lines of industry have found that the manufacture and sale of by-products from otherwise waste materials have placed their industries on a profitable basis. The tremendous heaps of waste material found near many marble quarries testify to the need of greater development along the line of waste utilization as well as waste avoidance.

The difficulties in the way of such development are of various kinds. The need of a market for rock products hinders all activity in some regions. Local conditions may be such that the demand is small, and freight rates may be excessive. Lack of a market in other places may be due to the fact that although certain rock products are useful, the uses are unknown, and the demand is small until a campaign of public education has created an interest in them.

The nonutilization of waste may be due to lack of equipment. Available capital may not be sufficient to build or purchase the necessary tracks, kilns, crushers, or pulverizers for the manufacture or transportation of the various rock products.

RIPRAP.

One important use for waste marble is in riprap for shore protection in rivers and harbors, for filling in piers, or for constructing railroad embankments. The utilization of marble blocks for such purposes depends chiefly on freight rates. The chief item in production is the breaking of massive blocks into fragments of convenient size. This may be done by pop shots for the larger and hand hammers for the smaller blocks.

THE BALL BREAKER.

The cost of breaking may be greatly reduced by adopting a method introduced by an Alabama marble company. A breaker consisting of a steel ball weighing about 2 tons is employed. The bale is set in a cavity to avoid breakage. The ball is hoisted to a considerable height with the derrick, then tripped and allowed to fall on the marble block. The impact is sufficient to break large blocks into fragments of convenient size for handling.

An iron sphere weighing about one ton was first employed. It was not strong enough to withstand the severe treatment, and was later replaced by a steel ball of double the weight.

The spherical form first used was unsatisfactory, because the ball would roll and the bale was frequently at the bottom and difficult to reach. A pear-shaped form with the bale at the small end as shown in Plate VI, *C*, is now used. This form tends to keep the bale always in an available position.

The ball can be handled quickly and is less dangerous and less costly than blasting, as the expense of maintenance is low.

LIME.

Most marble waste makes excellent lime and a number of quarry companies have constructed batteries of kilns for making lime from the waste. The present and the probable future demand and the price must of course be sufficient to justify the expenditure of the necessary capital for such an enterprise.

FLUX.

If smelting works are situated at a convenient distance so that freight rates are not excessive scrap marble may be sold for fluxing purposes.

IMPROVEMENT OF SOILS.

It is doubtful whether either quarrymen or farmers realize how extensive are the areas of agricultural lands that need liming, or how numerous and diverse are the crops that may be benefited by the application of ground limestone or lime.[a] It is a popular error to assume that soils in limestone or marble areas do not need lime. Many soils that have been formed from limestone, are greatly in need of lime. It is beyond the scope of this bulletin to outline the geographic areas in which lime is needed. Such information may be obtained from the various soil survey reports issued by the Department of Agriculture or by State bureaus carrying on experimental work of a like nature. These reports indicate that large areas of farming lands situated in marble regions are giving mediocre returns, although piles of material that would greatly increase the productiveness of the soil lie unused in the near vicinity.

Government reports state that a judicious liming of the soil would increase by a varying percentage the agricultural productiveness of nearly every State. Consequently, those quarrymen who have vast heaps of waste marble in convenient localities for distribution should attempt a campaign of publicity along such lines as will open this market for their waste products and develop an industry mutually beneficial to both quarrymen and farmers.

Marble waste is being used for soil improvement in a few places, but not nearly as extensively as it might be used. Near quarries at Cockeysville, Md., the upper marble beds are decomposed to a fine powder which is sold as fertilizer without grinding or pulverizing. The slush from marble mills is an excellent material for this purpose, and requires no grinding.

Marble for agricultural purposes should be finely pulverized. The general view is that the finer the material the better. It may be, however, that the expense of producing the finer grades may make it more economical to supply a larger amount of coarser material. It may be stated that at least 80 per cent of the ground rock should pass through a sieve having 100 meshes to the linear inch.

Lime derived from burning limestone or marble in kilns is more effective in the soil than the pulverized rock. Also transportation costs less, as marble loses greatly in weight when burned, although no calcium is lost. There is the same amount of calcium in 2,000 pounds of quicklime as in 3,550 pounds of marble. In other words, 2 tons of pulverized limestone have approximately the same effect on the soil as 1 ton of quicklime. Thus it may be seen that by converting limestone to lime half the freight expense could be eliminated and a more efficient product placed in the market. With the develop-

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[a] See Wheeler, H. J., The liming of soils: U. S. Dept. Agr., Farmers' Bull. 77, 1905, 23 pp; the maintenance of fertility; liming the land: Ohio Exp. Sta., Bull. 279, July, 1914, 22 pp.

ment of a wide and active demand for lime fertilizer it may pay to burn the waste marble into lime rather than to pulverize it. Quarrymen who now burn lime from their waste marble should endeavor to develop a market for all waste lime as fertilizer.

TERRAZZO.

For terrazzo flooring the crushed rock fragments should be somewhat cubical in shape and there should be a minimum of material in the form of flat flakes or slivers. Before installing a crusher for producing terrazzo, experiments should be made to determine the type of crusher that will give the maximum proportion of material of the desired form. Fine-grained white marble is in greatest demand for terrazzo, though there is a limited demand for black or other dark colors for making borders or patterns.

CEMENT.

Although marble waste may under favorable conditions be used for the manufacture of cement, its use for this purpose is not usually practicable. The supply is inadequate for the manufacture of cement on a profitable scale. Only where cement plants are situated near marble quarries, and can use the marble waste to supplement their limestone supply, can such a means of utilization be profitably employed.

ROAD MATERIAL.

Crushed marble alone makes a good though not a very durable road. It pulverizes easily and, unless oil or asphaltic material is used, blows away as dust. When mixed with clay it is more durable. It can be used to advantage if more permanent materials are not available.

RUBBLE.

A limited amount of marble is used for foundation stone and retaining walls. Considerable labor is required to reduce the masses to convenient size and shape. The demand is in most places merely local and therefore limited.

MISCELLANEOUS.

Inferior waste material may be used to advantage for local improvement of quarry property. Hollows may be filled and the yard brought to a general level, new roadways may be constructed, or dams built to form water reservoirs.

Certain quarries that use buckwheat coal for fuel, and are situated near large cities, sell their cinders to be used in place of gravel for concrete construction. This is a good illustration of the profitable use of material that many quarrymen would consider to be absolute waste.

STRAIN BREAKS IN QUARRIES.

LOSSES DUE TO STRAIN.

In many quarries in rocks of both sedimentary and igneous origin, at certain stages in the process of rock removal, expansion of the rock will take place, or irregular fractures will suddenly form, occasionally accompanied by subterranean noises. Such minor earth fracturing has been studied by scientists in an effort to obtain new light on earthquake problems. The economic aspects of the phenomena have been almost disregarded, although to quarrymen they are of prime importance. In many quarries a modification of methods may become necessary owing to the interference of strain with the successful operation of certain quarry tools. Of still greater importance is the fact that in a number of marble quarries the formation of the so-called "strain breaks" results in the waste of much valuable material. In recent years it has become necessary to abandon at least three marble quarries in widely separated localities because the marble which otherwise would have been valuable was rendered useless by excessive strain breaks. Such abandonment has occasioned the loss of thousands of dollars, and the excessive waste from the same cause in many other quarries now being worked has resulted in the loss of many thousands more.

STRAIN CAUSES WASTE, NOT IMPAIRED QUALITY.

As reference is subsequently made to particular quarries, one point must be emphasized in order that marble dealers or others may have no misconceptions concerning the effect of "strain" on finished marble. So far as is known, the so-called "condition of strain" in a quarry in no wise detracts from the value of the finished product either in strength or durability. Whatever damage strain breaks cause to the rock is accomplished before the blocks leave the quarry floor and manifests itself in fracturing and rending masses into irregular forms which can not be worked to advantage. The strain causes waste and not impaired quality.

EXTENT AND IMPORTANCE OF STRAIN.

The occurrence of strain breaks is more general than was at first supposed. In view of the heavy losses sustained by several quarry companies, an inquiry into the manifestations and probable origin of strain breaks has been undertaken, and as a result of such investigations new quarry methods are suggested tending toward a reduction in the proportion of waste from this cause. Various instances of strain phenomena recorded in literature are given in brief abstract in chronological order, and to these are added examples from the writer's personal observations.

EXAMPLES OF STRAIN PHENOMENA RECORDED IN LITERATURE.

One of the earliest references to the phenomenon is given in "The Miners Dictionary," by William Hooson, 1747, in which several instances are given of subterranean noises which have greatly alarmed workmen. No attempt at explanation is given. The author states, "Miners say that the knocking is some Being that Inhabits in the Concaves and Hollows of the Earth; and that it is thus kind to some men of suitable tempers, and directs them to the Ore by such its knocking."

In 1854 Johnson [a] described strain in the Portland sandstone quarries near Middletown, Conn. If a uniform channel was cut across the beds in an east-west direction, when the opening reached a point near the bottom of a bed, pressure acting in a north-south direction would suddenly crush into fragments the remaining part. An expansion in the rock mass of three-fourths of an inch is mentioned, but no reference is made to the length of the mass that thus expanded. When a bed was channeled north and south no such compression could be observed. The author states that the rocks are "not perfectly at ease in their ancient bed," but attempts no explanation.

In 1871 Niles [b] described movements and expansions of gneiss as noted in a quarry near Monson, Mass. The strike of the planes of foliation is given as N. 10° E. and the dip as N. 80° W. at an angle of 80°. Cross joints are rare. The rock appears to be under compression in the direction of strike. It was found that fracturing could be prevented by channeling the rock across the strike. A mass of rock 354 feet in length expanded 1½ inches when broken loose. The formation of fractures was accompanied by loud reports, and the projection of dust and rock fragments into the air was noted.

These phenomena are later described by the same author [c] in greater detail. Additional evidence is presented that the rock discussed is clearly under compression and, when freed, expands.

Three years later Niles [d] described a condition of strain in various localities and deduced certain conclusions from these occurrences. The records are briefly summarized in the following paragraphs.

Niles states that in the sandstone quarries of Berea, Ohio, there is evidence of a strong horizontal compressive stress in a north-south direction but none east and west. The process of quarrying requires

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[a] Johnson, John, Notice of some spontaneous movements occasionally observed in the sandstone strata in one of the quarries at Portland, Conn.: Proc. Am. Assn. Adv. Sci., vol. 8, 1854, p. 283.

[b] Niles, W. H., Some interesting phenomena observed in quarrying: Proc. Bos. Soc. Nat. Hist., vol. 14, 1871, p. 80.

[c] Niles, W. H., On some expansions, movements, and fractures of rocks observed at Monson, Mass.: Proc. Am. Assn. Adv. Sci., vol. 22, 1873, pt. 2, p. 156.

[d] Niles, W. H., The geological agency of lateral pressure exhibited by certain movements of rocks: Proc. Bos. Soc. Nat. Hist., vol. 18, 1875-76, p. 272.

channels to be cut at intervals. In quarries with a northerly and southerly working face the channels are cut east and west. When a bed has been channeled nearly through, the stone at the bottom of the channel cut is broken and crushed by the lateral pressure, and the width of the channel is perceptibly decreased by expansion of the adjacent rock. As such crushing renders a portion of the stone worthless for structural purposes, it was found advisable to cut the trenches in short sections in order that the crushing should be confined to limited masses. The expansion and fracturing has been noted at all seasons of the year and hence is seemingly independent of temperature changes. The belief has been general that the pressure was produced by the weight of the adjacent overlying rock. The author points out, however, that the lateral compression observed could not result from vertical pressure on adjacent parts of the beds.

In the Lemont (Ill.) limestone quarries it was noted that in certain places where potholes crossed the boundary between adjacent beds, as a result of the slipping of one bed on the other the upper parts of the holes were offset with respect to the lower parts. An arching of the rock in an anticlinal fold with east-and-west axis was also observed. This again indicated compression in a north-and-south direction. These movements do not perceptibly vary with temperature changes.

In a granite gneiss quarry at Waterford, Conn., where drill holes were made very near each other, the intervening parts of rock were often crushed, and, by expansion of the rock, the drill was so pinched that it could not be operated. The compressive force was in a northeast-and-southwest direction.

Evidences of compression were also noted in quarries at Groton, Conn.

The number and distribution of these occurrences lead the author to conclude that they are due, not to local or external forces nor to peculiarities of composition or metamorphism of the rock mass itself, but to "the continued action of the same geological power which has been the chief agency in the elevation of continents and mountain systems." He likens these fractures and movements to earthquake shocks on a small scale. The tendency toward a north-and-south direction of compressive stress points to a great continental stress in this direction. The gentle undulations that may be noted in the alternate elevation and subsidence of the Atlantic coast from Greenland to Florida are in his opinion the evidence of slight foldings resulting from this compression.

Gilbert [a] discovered several postglacial anticlinal ridges in the horizontal limestones of Jefferson County, N. Y., and in the slates near

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[a] Gilbert, G. K., An account of some new geologic wrinkles: Am. Jour. Sci., 3d ser., vol. 32, 1886, p. 324.

Dunkirk, in western New York. He attributed the expansion that caused such arching to the warming up of the surface rocks as they recovered from the cold of the glacial period.

Strahan[a] describes what he terms "explosive slickensides" in certain lead mines of Derbyshire, England. The walls of the lead veins are rubbed and polished as though moved while in violent contact. When struck or scratched with a pick the wall in many places will break or explode with violence, throwing blocks to a considerable distance. Undercutting of the vein wall has the same effect. His conclusion is as follows: "The explanation which perhaps best satisfies the requirements of the problem appears to be that the spars are in a state of molecular strain, resembling that of the Rupert's drop, or of tempered glass, and that this condition of strain is the result of the earth movements which produced the slickensides."

Hughes[b] refers to similar phenomena in a limestone quarry at Dent Head, and a tunnel at Ribble Head, in Yorkshire, England. He attributes the fracturing to the fact that the limestone rested on shale. When an excavation was made leaving only a thin layer of limestone over the shale, the weight of the overlying limestone on either side was sufficient to cause the shale to flow, after the manner of a viscous fluid, toward the region of reduced pressure. This caused the rock to arch up in the bottom of the quarry. When the brittle rock was thus arched it would break and fly when further excavation was attempted.

Gresley[c] describes explosive fracturing of coal in the mines of South Staffordshire, England. The explosions are termed "bumps," and are said to be of frequent occurrence during the process of excavation, causing many tons of coal to fall down at the working face. Various subterranean rumblings have also been noted. He attributes such phenomena to "the upsetting by the excavation of the equilibrium of the strains or pressure holding everything fast and firm together—the removal of the support, thereby causing the rocks to get relief and to fly off or apparently to explode." He terms such explosions as "miniature earthquakes."

Cramer[d] describes an interesting anticlinal uplift in the bed of the Lower Fox River near Appleton, Wis., which took place immediately beneath a long stone mill, resulting in an arching of the floor and roof with consequent displacement of machinery and cracking of the walls. Two miles distant, at Kaukauna, Wis., the rock between two parallel joints 30 feet apart became arched as a result of compressive stresses. The rock in a zone about 2 feet wide on each side

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[a] Strahan, Aubrey, On explosive slickensides. Geol. Mag., vol. 4, Dec. 3, 1887, p. 400.

[b] Hughes, T. McK., Bursting rock surfaces, Geol. Mag., vol. 4, Dec. 3, 1887, p. 511.

[c] Gresley, W. S., Re "Explosive slickensides:" Geol. Mag., vol. 4, Dec. 3, 1887, p. 522.

[d] Cramer, Frank, On recent rock flexure: Amer. Jour. Sci., ser. 3, vol. 39, 1890, p. 220.

of the joints was splintered by the pressure. No explanation is presented, though the author refers to Gilbert's suggestion that such phenomena may be due to expansion caused by a rise in temperature after the disappearance of ice from glacial regions.

Reade [a] discusses various references to strain. He cites many instances of recent changes of level in the surface of the earth and concludes that from "the prevalence of these vertical movements in recent geologic times it is obvious that the subsidence of a low arch of elevation must tend to put the surface rocks into lateral compression." This state of compression may be influenced by the presence of joints and faults. The fact that conditions of lateral compression are recorded as unusual raises a strong presumption that tangential thrust arising from a shrinkage of the earth's nucleus is not the agent. He concludes therefore that the phenomena are due to the changes of level mentioned above.

A more complete examination of the anticlinal arch at Appleton, Wis., was obtained when the water was removed from part of it and a further description was given by Cramer [b] in 1891. He records several other instances of strain breaks in quarries of that vicinity. The direction of fracturing is highly variable, and seems to be determined rather by the means of relief than by the preponderance of pressure. He concludes that the rock is under compression "in all directions." A set of anticlinal ridges parallel with the strike of the Corniferous limestone beds at Lime Rock in Genesee County, N. Y., are, however, attributed to rock collapse produced by solution and removal of salt and gypsum from the underlying beds.

Gilbert [c] describes anticlinal ridges 6 to 8 feet high in the Devonian shale of Ripley township, in western New York. He notes similar anticlinals in the Devonian shale of northwestern Ohio and in the Trenton limestone in northern New York. He reiterates his former contention that all are to be attributed to expansion due to postglacial rise in temperature.

Matthew [d] describes numerous thrust faults in the slates near St. John, New Brunswick, the most probable cause of which he gives as lateral thrust from the southeast.

Chalmers [e] describes numerous thrust faults in the slates of southeastern Quebec. They all occur near mountains or resisting masses

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[a] Reade, T. M., The cause of active compressive stress in rocks and recent rock flexures: Amer. Jour. Sci., ser. 3, vol. 41, 1891, p. 409.

[b] Cramer, Frank, On the rock fracture at the combined locks mill, Appleton, Wis.: Am. Jour. Sci., ser. 3, vol. 41, 1891, pp. 432-434.

[c] Gilbert, G. K., Postglacial anticlinal ridges near Ripley and Caledonia, N. Y.: Am. Geol., vol. 8, 1891, pp. 230-231.

[d] Matthew, G. F., Movements of the earth's crust at St. John, New Brunswick, in postglacial times: New Brunswick Nat. Hist. Soc. Bull. 12, 1894, pp. 34-42.

[e] Chalmers, R., Report on the surface geology and auriferous deposits of southeastern Quebec: Geol. Survey of Can. Ann. Rep., vol. 10, 1898, pt. J, pp. 9-12.

of rock and are attributed to a pushing of the beds against such masses, to a sinking of the resisting masses by cooling and contraction, or to both.

Campbell [a] has described a fold in sandstone which he attributes to processes of weathering. The increase in volume by weathering causes a forcing apart of joints and cleavage fissures. The process is assisted by thermal expansion and contraction by freezing of water in the joints and by the force of growing roots. The cumulative effect of such forces in many joints produces rupture and arching at a point of weakness.

Beard [b] intimates that gas escapes into coal mines as a result of earth movement, and in this connection shows that many mine explosions are contemporaneous with earthquake shocks.

Woodworth [c] states that thrust faults of recent date occurred near Troy, N. Y. He notes several brick and stone structures resting on the rock, which are fractured and faulted, showing that faulting has occurred since the structures were built. Similar faults were noted in Rensselaer, Defreestville, and Pumpkin Hollow. The whole series is attributed to a mountain-building thrust similar to and in the same direction as that which formed the mountains of the region. Reference is made also to postglacial faults in Quebec, Massachusetts, and New Hampshire.

Dale [d] describes a state of compression in granite quarries of Waldo, Hancock, Kennebec, and Lincoln Counties, Me. He also cites the observations of Gilbert at Lithonia, Ga., and reproduces a photograph of an anticlinal arch formed by compressive stresses in the granite of this region. The same author [e] describes the arching of Vermont granite under compression. Under a later date he describes [f] in detail the compressive stresses in various Vermont granites, and gives the direction of compression of each. At Bethel the direction was east-west, at Barre, chiefly north-south, at Woodbury, northeast-southwest, at Groton, in all directions, at Ryegate, east-west, at Dummerston, N. 10° E. to S. 10° W. The effect of the strain is to close channels and crush cores between drill holes.

Van Horn [g] refers to a series of anticlines in the Chagrin shales of Cleveland, Ohio, which he attributes to the increase in volume that results when iron sulphide contained in the shales alters to iron sulphate and alum-like compounds.

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[a] Campbell, D. F., Rock folds due to weathering: Jour. Geol., vol. 14, 1906, pp. 718-721.

[b] Beard, J. T., Colliery explosions and their causes: Eng. and Min. Jour., vol. 83, 1907, pp. 1051-55.

[c] Woodworth, J. B., Postglacial faults of eastern New York: New York State Museum Bull. 107, 1907, pp. 5-28.

[d] Dale, T. N., The granites of Maine: U. S. Geol. Survey Bull. 313, 1907, pp. 34, 42, 121, 142.

[e] Dale, T. N., Chief commercial granites of Massachusetts: U. S. Geol. Survey Bull. 354, 1908, p. 25, B.

[f] Dale, T. N., The granites of Vermont: U. S. Geol. Survey Bull. 404, 1910, pp. 17-18.

[g] Van Horn, F. R., Local anticlines in the Chagrin shales at Cleveland, Ohio: Geol. Soc. Am. Bull., vol. 21, 1910, pp. 771-773.

Lawson[a] describes a series of postglacial thrust faults in Archean slates near Banning, Ont. He attributes these and similar thrust faults to volume change in the surface rocks brought about by chemical or temperature changes.

EXAMPLES OF STRAIN PHENOMENA OBSERVED IN FIELD WORK.

Other examples of strain phenomena noted by the writer during the field season of 1914 are described below.

In a quarry near Knoxville, Tenn., the strike of the marble beds is N. 55° E., and the dip 35° to 40° SE. Slip joints appear parallel or nearly parallel with the bedding. In certain parts of the quarry zones of parallel joints run N. 40° to 50° W. The rock is subjected to a severe compressive stress approximately parallel with the strike. Great difficulty is experienced in separating the blocks without irregular fractures. Much valuable stone is lost by fracturing into angular pieces during the process of quarrying. A distinct though small earthquake shock is reported by a quarryman to have occurred a few years ago within half a mile of this quarry. This was probably only another manifestation of the condition of strain within the rock. In this instance it exceeded the elastic limit, and sudden fracture and displacement occurred.

A blue-marble quarry situated about a mile and a half north of Florence, Vt., has had some trouble with strain breaks though no details were procurable. Other quarries near the same locality have suffered severely from the same cause. One quarry was abandoned because the strain breaks destroyed so much rock that excavation could not be conducted with profit. The rock is above the average in soundness, masses 35 feet in length having been quarried for columns.

A quarry near Clarendon, Vt., had to be abandoned on account of excessive strain breaks. When the author visited the quarry the pit was full of water. The structure as described by Dale[b] is as follows: The beds strike N. 10° W. and dip 42° W. At least one bed is crossed by a slip cleavage. Joints strike N. 35° W., and dip 45° to 55° W. The rock has a distinct rift parallel with the bedding. When an opening of considerable depth was made near the eastern end of the excavation a violent fracture occurred which shook houses in the vicinity and frightened the workmen so that they could not be induced to reenter the pit for several days. The fractures took place toward the west and thus ran downward on the rift, destroying the rock to such an extent that the pit was abandoned.

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[a] Lawson, A. C., On some postglacial faults near Banning, Ont.; Seism. Soc. Amer. Bull., vol. 1, December, 1911, p. 159.

[b] Dale, T. N., The commercial marbles of western Vermont: U. S. Geol. Survey Bull. 521, 1912, p. 112.

A quarry not far distant was affected by similar, though less extensive, strain breaks. In this quarry the beds strike N. 55° to 60° E., and dip 25° N. 33° W. They are crossed by cleavage dipping 25° E. The direction of strain was not ascertained.

The granite at Vinal Haven, Me., lies in sheets 2 to 5 feet thick. Vertical joints are rare. In quarrying out a floor it has been found that if all material is removed from the upper surface of a sheet 3 feet thick and 50 feet long, the sheet will arch at least three-fourths of an inch in the center. When one end is set free by channeling it will settle back into its original position.

In a quarry near Woodbury Center, Vt., a condition of strain resulted in a minor accident. The projection of a row of horizontal drill holes formed a plane of weakness, and owing to internal strain a mass of rock broke lose and struck a driller's hand with sufficient force to cause a flesh wound.

At Stonington, Me., in certain granite quarries the channel-bar method can not be employed to obtain a heading, as when holes are drilled close together the strain is sufficient to crush the parts of rock between the holes and to jam the drills. To avoid this difficulty a 2-foot channel is made by drilling and blasting. It is stated that when a mass of rock 50 feet long is set free at one end it will stretch three-fourths of an inch.

At Lithonia, Ga., the granite forms anticlinal arches by compression. One of these arches observed by the author was about 30 feet across and was raised so as to leave an open space beneath about 14 inches high.

GENERAL ANALYSIS OF STRAIN BREAKS RECORDED.

An analysis of all the examples noted and the explanations given by various authors points to the conclusion that by far the greater majority of all serious strain breaks in quarries are in reality minor earthquakes and must therefore be attributed to the same causes as earthquakes. The case recorded above of a strain break in a Vermont marble quarry of such intensity that it shook structures in the immediate vicinity is a striking example of the identity of strain breaks with earthquakes.

It seems probable that strain breaks in general are not to be attributed to local causes but to great and far-reaching forces. Most of the explanations given above are in accordance with this hypothesis. Explanations opposed to the hypothesis are as follows:

Both Gilbert and Lawson give as a probable explanation a rise in temperature following the removal of glacial ice. Although this is a possible cause, and may be contributory, its acceptance as the chief cause is discouraged by the fact that in regions in Georgia and

Tennessee that are beyond the limits of glaciation are strain breaks seemingly similar to those in New England.

Hughes's theory of rock flowage in a plastic layer beneath a limestone bed is of local application only, as in most stone quarries no such plastic layer exists.

Cramer's theory of displacement by collapse due to subterranean solution is also of local application only.

The hypotheses of Campbell, of Lawson, and of Van Horn that buckling is due to expansion as a result of the chemical or physical changes which accompany weathering may apply to a few localized superficial strains, but not to a condition of strain at depth.

In addition to the hypotheses mentioned above it seems probable that temperature changes may cause local expansion of rock, as for example the arching of granite, which has been noted at Lithonia, Ga. Merrill[a] refers to the results of tests made at the Watertown Arsenal which indicate that rocks do not completely recover after expansion, but assume a permanent "set." Repeated expansions and contractions by diurnal or seasonal changes in temperature may therefore cause a gradual expansion of surface layers with consequent arching. Changes of temperature are slight at a short distance beneath the surface, and consequently it is unlikely that a state of compression deep within quarries can be attributed to this cause.

All the other explanations offered in the preceding pages have a more or less direct bearing on the theory that the majority of strain breaks are due to the great forces of nature that build mountains and continents, and produce earthquakes.

Dale[b] states that the cause of the strain observed in certain eastern Tennessee marble quarries is the same as that which produced the Appalachian folds, and which operated both parallel and at right angles to the axes of the folds, the former only being operative at present.

RELATION OF EARTHQUAKES TO STRAIN BREAKS.

Milne[c] divides earthquakes into two groups, the macroseismic or great disturbances, and the microseismic or minor shocks. The latter are described as "settlements and adjustments along lines of their (the greater earthquake's) primary fractures," and are confined to areas of a few miles' radius. He estimates the number of the latter as at least 30,000 a year for the entire earth.

Hobbs[d] has pointed out that constant adjustments and changes of level are taking place in the earth's crust, as evidenced by post-

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[a] Merrill, G. P., Stones for building and decoration, 1903, p. 478.

[b] Dale, T. N., The marbles of eastern Tennessee, unpublished manuscript.

[c] Milne, J., Seismological observations and earth physics: Geog. Jour., vol. 21, 1903, p. 1.

[d] Hobbs, W. H., Earthquakes, 1907, pp. 211-223.

glacial faults and known variations in altitude of certain geographic areas, with respect to sea level. Such gradual changes are termed "bradysisms." He refers to the common occurrence of subterranean rumblings, "brontidi," which are not accompanied by sensible earthquake shocks. These are attributed to slow adjustments of the earth's crust, such adjustments taking place as frequently repeated slight displacements rather than as gradual movements.

Chamberlain [a] claims that the earth acts like an elastic, rigid, crystalline body in which strains accumulate until they reach an intensive stage, and then yield either to slow movements of great magnitude, as illustrated by various changes in level, or by sudden, swift, noncontinuous movements of less magnitude, as earthquakes.

Gilbert [b] states that earthquakes are of two types, as follows: (1) The tectonic, those arising from subterranean mountain building forces, and (2) the volcanic, those resulting from the movements of lavas. The former are the more important, especially in the United States. The tectonic process is briefly described by him as follows:

> In the formation of mountains and other great features of the earth the rock masses are forced into new shapes. They are pulled, pushed, twisted, and bent, so that strata, for example, which were originally flat, become inclined and curved. If the changes are sufficiently slow, the component particles of the rock readjust themselves gradually; but if the changes are comparatively rapid, the rocks are broken. Before fracture occurs there is elastic yielding or "strain;" that is, the rock is compressed or stretched or bent somewhat like a spring; and when its strength is at last overcome the dissevered parts recoil. This recoil is instantaneous, violent, and powerful, and is in the nature of a jar.

As a result of observations of earthquakes in Panama, MacDonald [c] concludes that they are manifestations of relief from strain. The noises resembling ice fractures on a cold morning appeared to be "due to the formation of small shears or strain-relieving cracks in the rocks."

ORIGIN OF THE STRESSES.

Deformation of the earth's crust is constantly taking place. Acting under the force of gravity the earth's shell suffers collapse and buckling. According to the isostatic hypothesis it is assumed that the continents with their plateaus and mountains are composed of and deeply underlaid by lighter matter than the sea bottoms and therefore stand higher because they float higher. A variation in load due to erosion and deposition causes an undercurrent or flow of rock material from the area loaded toward the area denuded. Opposed to the isostatic theory is that of high rigidity within the earth's crust,

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[a] Chamberlain, T. C., Diastrophism and the formative processes: Jour. Geol., vol. 21, November-December, 1913, p. 681.

[b] Gilbert, G. K., The cause and nature of earthquakes: Min. Sci. Press, vol. 92, April 28, 1906, p. 272.

[c] MacDonald, D. F., Some earthquake phenomena noted in Panama: Science, new series, vol. 41, May, 1915, p. 783.

a rigidity sufficient to sustain mountains and continents in higher position than sea bottoms merely by lateral thrust.

According to the former hypothesis the flow of rock from one point to another is resisted by rock rigidity, and a condition of internal strain results. Dutton [a] states that one of the probable causes of many earthquakes is the tendency of the earth to recover its isostatic equilibrium when, by denudation, transportation, and deposition of vast masses of material, this condition of equilibrium is destroyed. The theory of high rigidity, on the other hand, assumes that thrust rather than flow causes internal strain. Whatever may be the correct theory the fact remains that changes of level are of constant occurrence, and strains varying in intensity and direction are the result of such adjustments.

ACTION OF ROCKS UNDER STRESSES.

In order to describe the behavior of rocks under stress some principles of earth physics must be emphasized. Hoskins [b] states that "a body is strained when the relative positions of its particles undergo any change." If the limit of elasticity is exceeded, the change will become permanent—that is, the body will not assume its original form when the force is removed. This permanent change of form may find expression in fracture or in flowage, depending upon plasticity. If fracture results, earthquakes of greater or lesser intensity are produced.

When plasticity overcomes elasticity flowage will take place rather than fracture. This condition is illustrated by the somewhat intricate folding in many mountainous regions. Chamberlain [c] has shown that deformation having the aspect of plastic deformation may take place by a process of granulation and progressive recrystallization. Such a process undoubtedly does take place in marble, as evidenced by the extreme recrystallization.

The matter of supreme importance in this discussion is, however, the state and action of the rock under stress within the elastic limit. If the limit of elasticity has not been exceeded the body will recover its natural configuration when the stress is removed. That rocks are both compressible and highly elastic has been clearly shown by the numerous examples of automatic recovery from strain referred to in previous pages, and has been proven in the laboratory by the experiments of Adams and Coker.[d] A condition of strain within the elastic limit is that condition which quarrymen call "strain." The

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[a] Dutton, C. E., Earthquakes, 1904, p. 37.

[b] Hoskins, L. M., Flow and fracture of rocks as related to structure: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 860.

[c] Chamberlain, T. C., Diastrophism and the formative processes: Jour. Geol., vol. 21, 26, p. 678.

[d] Adams, F. D., and Coker, E. G., An investigation into the elastic constants of rocks, more especially with reference to cubic compressibility: Carnegie Inst., Wash., Pub. 46, 1906, p. 16.

latter term includes also all permanent deformations. For the sake of simplicity the term "strain" is subsequently used in the sense of strain within the elastic limit. This is the condition of rock masses that has led to such disastrous losses in many marble quarries.

The exact relation of elasticity to plasticity of rocks under varying conditions has a direct bearing on the permanence of strain. Rudzki [a] states that the elastic force with which a body resists a deforming force diminishes with time. Hobbs [b] in applying this principle to rock folds concludes that the period of time covered by the evolution of a fold may be sufficiently long to permit the resistance within the mass to fall. If this conclusion is correct, we may expect that after a great lapse of time plasticity will overcome elasticity and equilibrium will be attained by folding without fracture. Folding may thus take place within what is usually termed the zone of fracture if the process is sufficiently gradual. If, however, nature's process hastens the operation beyond a certain "speed limit," fracture must result.

Thus it would appear that after a tremendous lapse of time permanent deformation may take the place of strain, and a state of perfect equilibrium be attained. No strain breaks would occur in quarries situated in such masses. It might be concluded that marble deposits that have not visibly suffered mountain-building movements since Cambrian or other early geologic age would have attained such a state of rest, and would therefore be free from strain.

It is possible that strain is more common in regions where intense folding is of comparatively recent age. The examples of destructive strain in marble so far observed are all to be found in the Appalachian belt, which was folded toward the end of the Paleozoic era. No hard and fast rule can be given, however, because, as already pointed out, ever-varying earth movements may cause internal stresses anywhere and at any time.

Rudzki's principle further states that temperature has a decided influence on plasticity, an increase in temperature resulting in a corresponding increase in plasticity. The effect of overburden is to increase the temperature and therefore to increase the plasticity. Denudation lowers the temperature, decreases the plasticity, and therefore increases the tendency to fracturing rather than to deformation by flowage. In surface rocks, consequently, the relaxation time is great, and a condition of strain may exist ages after the initial force has been exerted if the force tending toward deformation has remained constant.

The foregoing discussion indicates that a strain may be inherited from a former geologic era, possibly accounting for a condition of

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[a] Rudzki, M. P., Physik der Erde, Leipzig, 1911, pp. 232-233.

[b] Hobbs, W. H., Mechanics of formation of arcuate mountains: Jour. Geol. vol. 22, 1914, pp. 193-194.

strain in some isolated rock hills to which it seems impossible to some scientists that present forces can transmit their effects. It is conceivable also that rocks now at the surface were formerly deeply buried and subjected to such intense pressure from superincumbent material that they were forced to assume a smaller volume. Processes of denudation gradually brought these masses nearer to the surface, where the residual strain might find expression in shock fracture, or where a means of relief in the form of strain breaks was obtained through quarry operations.

THE LIMITATIONS OF STRAIN.

As these forces are so far-reaching and constant, it might be expected that strains would be almost universal. One explanation that they are not is the limited cubic compressibility of rocks. When strain in a granite is relieved, an expansion of three-fourths of an inch over a length of 50 feet is perhaps a fair illustration of the compression possible without rupture. It is evident, therefore, that little lateral movement is required to bring relief. Most rocks are intersected by joint planes, which permit the necessary movement to give relief from pressure. It is significant that quarries having considerable unsoundness have little or no strain. There is, therefore, some consolation in the fact that these two great evils are not likely to occur in the same quarry.

Strain in one direction only has been noted in a number of localities. In some places the great earth stresses may be in one direction only. In others it seems probable that strain is produced because rocks can find no relief in one direction, but are free in all other directions. It is significant that as regards most rocks having a steep dip, the strain is parallel with the strike and no strain is apparent across the strike.[a] A slipping of the beds one upon another may give the necessary relief in the transverse direction, whereas parallel with the strike the absence of joints or planes of weakness may afford no such slipping. In a Tennessee quarry the strain is approximately parallel with the strike and there is evidence of slipping parallel with the beds, which gives the necessary relief in the transverse direction.

EFFECT OF QUARRYING ON STRAIN.

In quarries in which strain exists the internal strain-stress relations may be complex. Various forces are acting and reacting, and their total result is a condition approximating equilibrium. The fact that a condition of strain exists within the limit of elasticity indicates that true equilibrium has not been attained. According to Rudzki's principle, the elastic resistance of the rock is gradually

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[a] Dale, T. N., The marbles of eastern Tennessee, unpublished manuscript.

diminishing and slow permanent deformation is constantly going on. As a result of excavation the approximate equilibrium is thrown out of balance locally. If we could imagine all stresses except the downward force of gravity ceasing simultaneously, we could conceive of the strained rock recovering its natural configuration without rupture. Even then the realignment of particles in a thick bed could scarcely take place rapidly without fracture. In the stone quarry the conditions are more extreme. The strain-stress relations are disturbed in a limited region only.

Before excavation is begun a stress that tends to deform the rock is balanced by the resistance of the rock plus the weight or lateral pressure of other rock masses. When these masses are removed the resistance of the rock alone is not sufficient to withstand the deforming stress, and fracture results. This is clearly illustrated by the examples previously given of the crushing of rock at the bottom of channels in the Portland and Berea sandstone quarries (pp. 124–125). Such fractures are the result of compression.

Strain may manifest itself in other ways. At some stage in the process of cutting a block of marble free the support that holds it in compression may no longer be sufficient and the block expands. As it is still rigidly connected with the main rock mass, which remains under compression, no considerable expansion can take place without fracturing between the two masses. Such fracturing may be in the nature of shearing, with an even break between the two masses and lateral displacement.

Thus it is established by theory, which unfortunately has been confirmed by practice in many places, that in quarries where strain exists the successive separation of small masses from the main quarry rock generally results in the formation of fractures, producing excessive waste. Some new method of quarrying must be found if this waste is to be reduced.

BASIC PRINCIPLES LOOKING TO REDUCTION OF DAMAGE FROM STRAINS.

The following basic principles looking to a solution of the problem have been established: (1) The causes of strain are not to be found in mere local conditions such as the weight of a near-by hill or the process of surface weathering. Strains are manifestations of the great geologic forces that build mountains and cause earthquakes. (2) In every observed instance of strain the rock has been under compression. (3) The compression is usually in one definite direction. (4) The only way to remove the strain is to bring about expansion of the rock to its normal volume. (5) If the strain on a small mass of rock is relieved, it expands independently of the main mass, with consequent fracturing; therefore relief from strain should be sought for a large mass at one time.

THE REMEDY.

The principles outlined indicate that some means should be found to cause uniform expansion of a large mass of rock at one time in such a manner as to reduce to a minimum the occurrence of irregular fractures between the mass set free and the main quarry rock. When the strain has been relieved the mass can be quarried without fear of fractures. The first step to be made in quarrying rock under strain is to determine the direction of compression. In most instances quarrying will already have been done, as otherwise the condition of strain will not have been revealed. It is usually easy to determine the direction of compression by noting the direction of movement of the loosened blocks with reference to the main mass. The lateral displacement of drill holes or other marks will indicate the direction.

In order to bring about the necessary relief an opening should be made at right angles to the direction of compression. Expansion of the rock will manifest itself by a gradual narrowing of this space, and the rock will thereby find relief from strain. The opening should be of sufficient width to allow complete relief by expansion and of sufficient length and depth to free a large mass of rock at one time.

A channeling machine would probably give poor results, as an open cut gives too ready a means of relief. The pressure would tend to close the cut immediately and to jam the bits, and only a small mass of rock would be freed. Also the opening should in most instances be deeper than a channeling machine can cut. Drilling a row of close holes would probably afford the best means of relief. The compressive force would gradually crush the rock remaining between the drill holes, close up the holes, and thus relieve the strain. The presence of these supporting cores would prevent a too rapid closing, and would thus allow uninterrupted drilling.

If the direction of compression is parallel or approximately parallel with the quarry walls the quarryman is fortunate. Rows of deep vertical holes should be drilled along both quarry walls parallel with this direction. The holes should be deep enough to pass entirely through the bed if the latter is horizontal or nearly so, and if open or weak bedding planes occur. In massive or steeply inclined beds the holes should be at least 12 feet, and preferably 15 or 20 feet deep. Convenient sizes are 1¾ or 2 inches in diameter. The width of rock intervening between the drill holes should average not more than 1 inch.

When the rows have been completed, a row of holes of similar depth and spacing should be projected in a line at right angles. This third row may be placed at either end of the quarry or in some intermediate position. The latter is probably more effective especially if the compression is not exactly at right angles to the line of drill holes, as motion in opposite directions in both masses will afford a more ready means of the cores slipping on each other.

The purpose of the two lines of holes parallel with the direction of compression is to give an easy shear line when expansion takes place. When they are drilled before the cross line of holes, no motion occurs to jam the drills. If, however, they are drilled after the cross line the tendency of the rock to offset by shearing would continually interfere with drilling operations.

The transverse line of holes should be projected rapidly. Several drills should be employed in order to complete the line as nearly as possible before any appreciable closing of the holes takes place.

Care should be taken that no excessively wide cores are left in the corners. The holes should be well cleaned out and covered in some way to keep out débris. Tightly driven hardwood plugs may tend to prevent the desired closing of the holes. Plugs of cotton waste or similar material may be used.

Along the transverse line a crushing of the cores and a closing of the drill holes will indicate expansion of the rock mass. There will probably be some lateral motion, permitting the cores to slip by each other and project into the open holes.

Along the shear lines expansion of the rock will not appreciably close the holes, but will by lateral motion offset one-half of each hole with respect to the other half. The extent of lateral displacement will diminish with distance from the transverse row of holes.

What may occur at the bottom of a mass of rock that is thus permitted to expand is as yet by no means certain. It is possible that fracturing may take place, and fractures so made will tend to occupy diagonal positions, causing much waste. It is for the purpose of reducing such fractures to a minimum that deep holes are recommended.

If irregular bottom fractures cause excessive waste, or if the expense of making deep holes is considered to be too great, an alternate method is proposed, as follows:

A narrow part of a floor along one side of the quarry parallel with the direction of compression may be first removed. The remainder of the floor may then be quarried as shown in figure 30. A row of horizontal holes along the floor at *a* should be closely spaced. A similar line of vertical holes is then projected at *b*. If the direction of compression is parallel or nearly parallel with the face, it is probable that a channel cut may be substituted for this second line of holes. If now a cross line of holes, *c*, is made at either end of the mass or in some intermediate position, expansion will crush the cores and close the holes. Along the planes *a* and *b* the cores will break and shear. Theoretically, at least, no irregular fractures should occur, as an even plane has been provided on every side. It is impossible to foresee what disturbing elements may arise, but the method holds sufficient promise to justify a trial.

If the direction of compression is diagonal to the quarry walls, it may be necessary to change the directions of channeling and drilling in order that they may more nearly conform with the strain line. This change will lead to a reduction in floor space occasioned by leaving masses in the corners. When the angle between the direction of compression and the direction of a quarry wall is not more than 15° or 20°, channeling and drilling in the usual directions will probably be satisfactory.

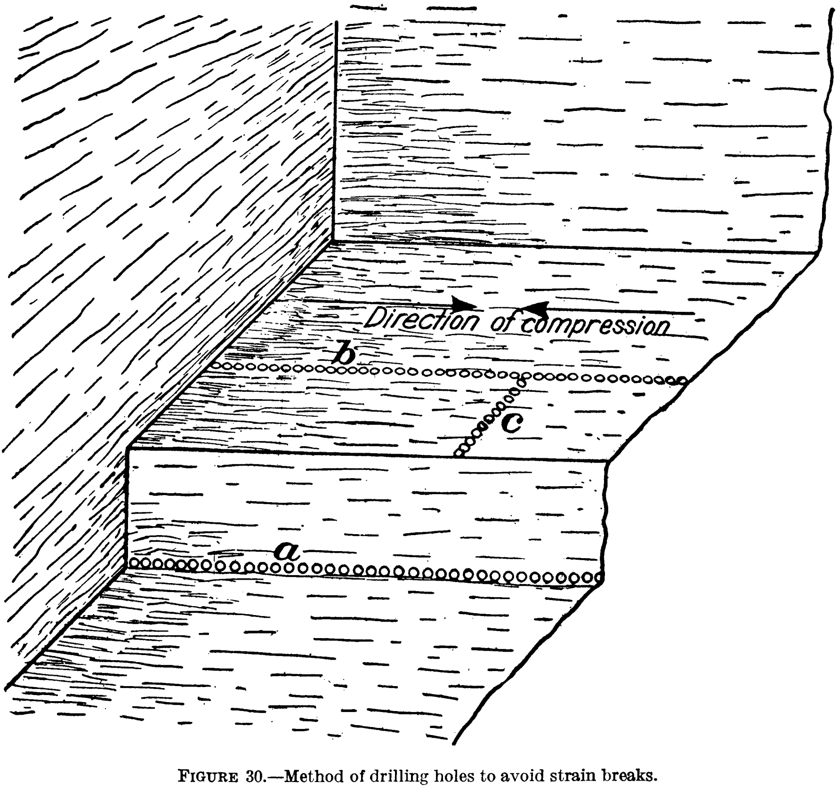

FIGURE 30.—Method of drilling holes to avoid strain breaks.

A SUCCESSFUL EXPERIMENT.

A Tennessee marble company, acting on the advice of Mr. T. Nelson Dale, of the United States Geological Survey, who visited the quarry during the summer of 1914, made an effort to relieve strain by drilling holes in accordance with the first plan outlined above. Although defects were apparent in the preliminary trial, the great increase in the proportion of sound stock produced encouraged a continuation of the method. During April, 1915, the writer observed the progress that had been made up to that time and offered some suggestions toward further improving the method. A complete description of the plan of drilling, effect on the rock, and of suggested changes in method follows.

The mass of rock under observation was 69 feet long, 20 feet wide, and 12 feet thick. It occupied a position along one side of the quarry, the remainder of the floor to the northwest having already been removed. Its position is shown at *A* in figure 31.

A line of holes perpendicular to the supposed direction of compression was first drilled. The holes were $1\frac{3}{4}$ inches in diameter, 12 feet deep, and the average core thickness between drill holes was fifteen-sixteenths of an inch. The direction of the line was N. 40° W. The line was 20 feet long, extending from the corner of the quarry along the northeastern wall and terminating at the excavated part of the floor. Its position is indicated by *a* in figure 31.

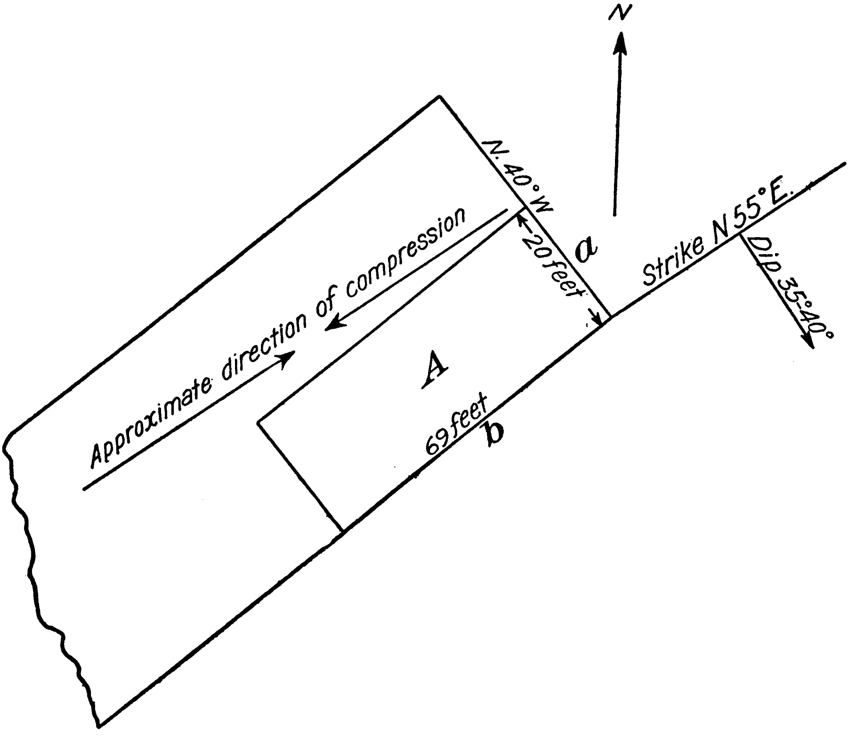

FIGURE 31.—Plan of part of a marble quarry, showing position of a rock mass studied. A, rock mass where observations were made; *a*, position of line of holes driven perpendicular to supposed direction of compression; *b*, position of second line of holes driven to give rock mass freedom to shear on expanding.

A second line of holes of similar depth and spacing was projected along the southeastern wall of the quarry, as shown at *b* in figure 31. The purpose of this line of drill holes was to give the mass of rock freedom to shear when it expanded. On account of the difficulty of placing drills, holes were omitted for a distance of 10 inches from the corner on the northeast wall, and 6 inches from the corner on the southeast wall. As indicated in figure 32, a mass of rock 12 inches wide was left in the corner.

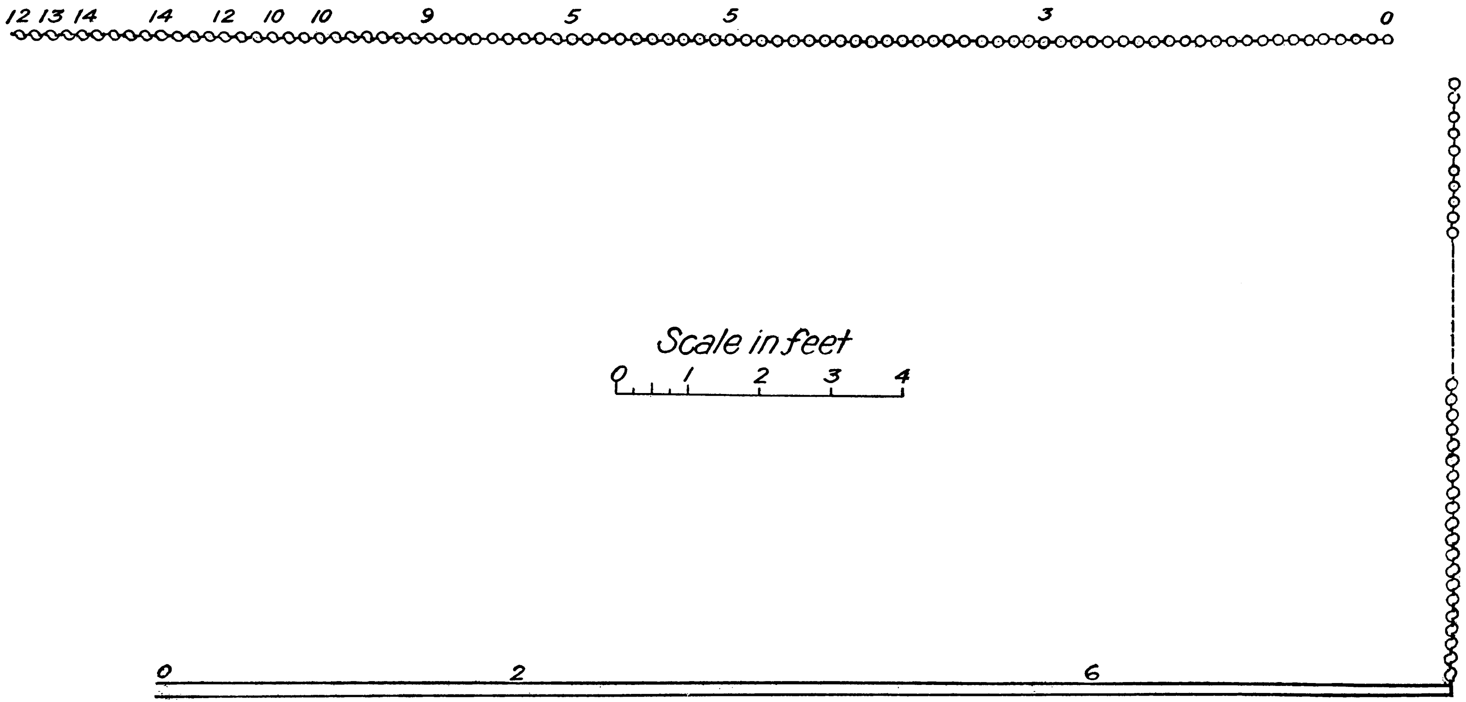

FIGURE 32.—Appearance of drill holes and channel cut after expansion of rock. Size of drill holes and their shape after expansion are drawn accurately to scale. The numbers indicate the degree of closing, in thirty-seconds of an inch, at various points.

Expansion of the marble soon manifested itself by a crushing of the cores and a gradual closing of the drill holes. The closing did not take place uniformly. Near the northwestern end of the line it was greatest, attaining a maximum of seven-sixteenths of an inch, which gradually decreased to zero at the other end of the line. There were 88 drill holes in the 20-foot line. The extent of closing as measured at various points was as follows:

Hole No.	1	3	5	10	14	15	17	20	27	36	64	88
Extent of closing in thirty-seconds of an inch	12	13	14	14	12	11	10	10	9	5	3	0

The appearance of the partly closed holes is shown in Plate XII, *B*. The manner in which expansion took place is shown in figure 32. The cores were broken the entire length of the line, though the movement in the last holes was too slight to be recognizable with the naked eye. Likewise on the perpendicular line every core was broken by shearing. However, the mass in the corner was unbroken, as far as could be seen, and it would therefore appear that this mass of rock, which was 12 inches in width, effectively prevented the major part of the mass to expand so as to gain relief.

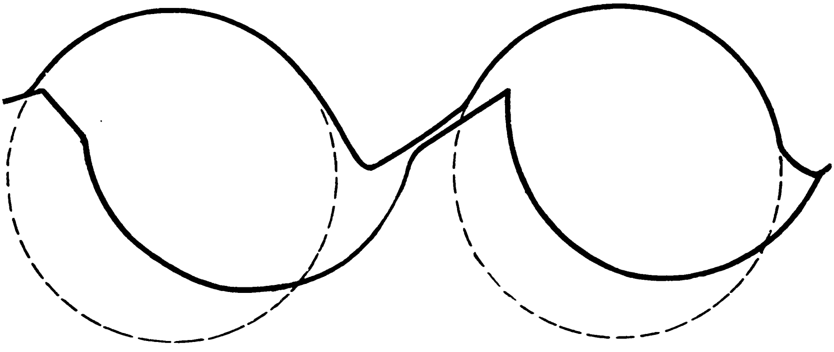

FIGURE 33.—Second and third drill holes from the left end of the line shown in figure 32, illustrating the manner in which the holes were closed by compression. Actual size and shape; dotted lines show original position of drill-hole walls; solid lines show position after rock movement.

Figure 33 illustrates the second and third drill holes in the cross line drawn natural size. In the lower part of the sketch the light line represents the original position of the drill hole walls, and the heavy line the position of the same walls subsequent to the expanding movement. It is evident that motion took place in a diagonal direction, which is undoubtedly due, in part at least, to a lateral slipping of the cores in order that they might gain ready relief by projecting into the open holes. However, the fact that slipping took place toward the corner where a mass of solid rock prevented any movement would seem to indicate that the direction of compression was not exactly perpendicular to the line of drill holes, but inclined at a small angle toward this corner.

At a later time a channel cut was made parallel to the first line of holes and 69 feet distant from it as indicated in figure 32. After the cut had been completed, the fact that complete expansion had not occurred along the first line of drill holes became apparent. That part of the 69-foot mass that had previously been unable to expand eastward on account of the uncut corner began to expand westward and partly closed the channel cut. The shearing accompanying this expansion broke the cores between the drill holes along the entire shear line, and the displacement gradually increased with the distance from the corner.

Measurements were made of the closing of the channel cut. Owing to a shattered condition of the rock, measurements could not be made nearer than 5 feet to the quarry wall. At this point the cut was closed six thirty-seconds of an inch, 13 feet from the wall it was closed two thirty-seconds of an inch, and 18 feet from the wall it was not closed at all.

Thus it is evident that where relief was gained along the original line of drill holes no further relief was necessary, but where in the original line no motion was possible a backward motion took place as soon as a means of relief was provided.

A considerable number of strain breaks are present in this mass of rock. It is reasonable to assume that they were formed in consequence of the nonuniform and imperfect relief obtained, as pointed out above. The part of the mass that had been quarried previous to the time of the author's visit is said to have expanded more uniformly and was remarkably free from strain breaks.

The suggestions following are offered with a view to improving the method of quarrying already outlined.

(1) If it is impossible to complete a line of drill holes in a corner, the corner should be cut across diagonally with a closely spaced row of holes in order that no mass too great to be crushed may remain.

(2) To avoid delay by jamming of the drills, the shear-line holes should be made first, as no appreciable movement of the rock will take place until the cross line of holes is projected.

(3) If drilling costs seem to justify it, holes should be more than 12 feet deep, as the object to be continually kept in view is to gain uniform relief at one time for as large a mass of rock as possible.

COST KEEPING.

BEARING OF COST KEEPING ON SELECTION OF METHODS AND MACHINES.

In the preceding text many different methods and types of machinery have been mentioned. Certain general advantages or disadvantages have been pointed out, but in many instances no absolute rules could be given regarding the desirability of one over another. In no two quarries are conditions alike. Variations in hardness, structure, texture, and rift, in bedding and attitude, or in unsoundness are extreme. The fact that a day's channeling for one machine varies in different quarries from 20 to 150 square feet is a typical illustration. On this account marble quarrying if conducted efficiently must involve considerable experimental investigation. A quarry operator ought to ascertain which of certain methods or machines are best adapted for his peculiar conditions. The results of past experience may enable satisfactory selection, but often experimentation must be adopted. However, no experiments convey definite information unless careful records of relative costs are kept. Therefore, cost keeping is a necessary part of such experiments. It is the yardstick that is used to measure efficiency.

COMMERCIAL RECORDS.

A certain amount of cost keeping is a recognized necessity for every successful business. Accounts that balance general expense, pay roll, fuel and supplies, maintenance and repairs, interest, and depreciation against receipts from sales, and thus furnish a basis for a statement of loss and gain on any transaction are what may be termed commercial records. Practically all quarrymen keep them in some form, though many such systems are inadequate.

TECHNICAL RECORDS.

Another and even more important phase of accounting is that dealing with detailed cost accounts for all operations in and about the quarry—accounts that are kept to supply a definite and accurate record of the relative efficiency of men, methods, and machines. Such may be termed technical records. They may be in the form of production, time-efficiency, or cost records. Cost records of each operation may be connected with commercial books by means of some suitable intermediary accounts, the nature of which should be determined by a skilled accountant.

RELATION OF TECHNICAL RECORDS TO EFFICIENCY.

Webster defines efficiency as the ratio of useful work, or of the effect produced, to the energy expended in producing it. The process of supplying the required energy costs money, and thus from the economist's standpoint efficiency is the measure of accomplishment in terms of the cost. Increased efficiency, then, means decreased cost of production. Many books have been written on efficiency, on the relation of efficiency to organization, system, wages, etc. It is not within the scope of this bulletin to enter into all phases of business efficiency. An attempt is made simply to point out the desirability of keeping accurate and systematic records as a means of promoting efficiency. Some suggestions are offered as to the form in which such records may be kept. For those who desire to enter more fully into a study of commercial efficiency many useful books are now available.[a]

There is a tendency among many quarrymen to overestimate a loss of actual cash and underestimate a loss due to operating inefficiency, as the latter is less tangible. A mistake in bookkeeping by which a workman is paid $2 for overtime that he did not put in is considered a serious matter. If, on the other hand, by channeling a cut instead of drilling and wedging it the same man increases the cost of production of a certain amount of marble by $10, the mistake is overlooked. To the unobservant, heavy losses due to poor methods or machinery are classed as necessary burdens. Even the intelligent and observant operator may place them in the category of necessary working expenses unless a cost system reveals that they are avoidable.

The quarryman's first object should be to keep to a minimum the cost of each operation. It thus becomes his duty to continually improve his present methods, to devise more economical methods, or to maintain a low cost already realized. In order to do this, it has been stated that some efficient means must be employed for testing the various methods and determining accurately the relative value of each. A cost-keeping system supplies this need. It is a tool for cutting down costs.

Thus it may be seen that the highest efficiency demands careful technical records. It has been asserted by one economic writer that nine out of every ten failures in business are the direct result of a lack of proper knowledge of conditions, the deficiency being due to poor bookkeeping methods, or to none at all.

This is an age of competition. Manufacturers are straining every nerve to obtain contracts and to fill them at a profit. Many concerns have an uncomfortable feeling that progress and profits are not as satisfactory as they might be. Such concerns must realize that a cause must be definitely located and that the deficiency must be amended or other concerns will crowd them out. It is obvious that,

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[a] See Church, A. H., The proper distribution of expense burden, 1913, 144 pp.; Church, A. H., Production factors, 1910, 187 pp.; Gantt, H. L., Work, wages, and profits, 1913, 312 pp.; Emerson, Harrington, Efficiency, 1912, 254 pp.; Emerson, Harrington, The twelve principles of efficiency, 1912, 423 pp.; and Carpenter, C. U., Profit-making management, 1908, 146 pp.

other things being equal, the business that is scientifically managed, that can put its finger on every item of excessive cost and immediately direct energy toward a reduction of that cost, is the business that will survive when others fail.

It is thought by many that the only function of a cost system is to ascertain the cost of an article. They completely overlook the fact that a proper analysis of costs furnishes a basis for reducing costs.

QUALIFICATIONS OF SUPERINTENDENTS.

Accounts are a measure of performance but must not be interpreted as performance itself. The establishment of a good system of technical accounting does not assume increased technical efficiency. There must be (1) the ability to interpret accounts and note wherein they reflect inefficiency, and (2) the knowledge and originality necessary to devise new methods and equipment. Such qualifications must be met not only by the general manager, but by the superintendents as well. They are closely in touch with all operations and control to a large extent the methods and equipment employed. The importance of these requisites demands some elaboration.

First, the superintendent must be master of his accounts. This statement does not mean that he must be a skilled accountant. As is shown later, the accounts involved are usually of a simple nature, easily kept and easily understood. Some may feel themselves handicapped by a lack of bookkeeping knowledge. It is a safe assumption, however, that it is much easier for the technical man to attain a sufficient mastery of accounts to interpret them in terms of efficiency than for the accountant to acquire technical knowledge. A premium should therefore be placed on foremen and superintendents who have in addition to their technical training a knowledge of mathematics and bookkeeping or the ability to assimilate the necessary knowledge of these subjects. That some operators employ foremen who can not read or write is almost incredible in this age of ever-increasing commercial efficiency, but it must be accepted as a fact. It is also a fact that some such quarries are not operating at a profit.

Second, the superintendent should have wide knowledge and originality. The ability to analyze and interpret costs is of limited value without a wide knowledge of ways and means of bettering conditions. He must know of methods and equipment used elsewhere or be able on occasion to devise absolutely new ones. The previous discussion of quarry and shop operation is designed to supply necessary information on methods and equipment now in use. Few superintendents can travel widely, but they should supplement their knowledge by visiting other quarries whenever possible.

REAL PURPOSE OF TECHNICAL ACCOUNTS.

The duty of a technical accountant is not to find a convenient means of averaging and spreading costs over various operations on some arbitrary basis, but to separate and localize costs. His purpose is to enable him to follow with his cost book every operation from quarry to finished product and to see at a glance the cost of all the individual items that together constitute the total cost of production. He can then compare these costs with each other, observe which is the heaviest, and determine at what point his chief energies should be directed toward cost reduction. He can also compare the cost of the same operation through different periods of time. He can ascertain whether a new method increases or decreases the cost, and if a new machine is introduced he can determine whether it cuts down the cost of production in its limited field. Such considerations are of supreme importance. When selling prices are fixed by competition an increase in profit can be accomplished only by a decrease in cost of production. A general decrease can be achieved only by bringing about minor reductions here and there. If one is to know at once whether any new machine or method is contributing its share toward such reductions or is maintaining a minimum rate, cost keeping must be localized.

THE COST OF NOT KEEPING ACCOUNTS.

The degree of localization in cost keeping must be governed by common sense. Bookkeeping can be carried to such an extreme that the extra expense of office help will eat up the profit from increased efficiency in other departments. However, reasonably detailed systems may be employed at little extra cost. Many quarrymen are opposed to them on account of the extra office help required. One quarryman remarked, "I can not afford to install a cost system." When reminded of the successful operation of the system in one quarry he replied, ' Their margin of profit is so small that they have to keep close cost accounts." What sort of reasoning is it that leads to the conclusion that the one whose profit is presumably the larger can not afford a cost system, whereas the one whose margin of profit is narrow must burden himself with additional accountants? The two statements are in open conflict, and without doubt the second is correct. With all quarrymen the statement should be, "I can not afford to be without a cost system."

LOCALIZATION OF COSTS.

The need of cost keeping having thus been pointed out, attention may be directed toward the principles governing the localization of control accounts. In order to properly analyze costs it is necessary to divide them into the several factors that are more or less independent of each other. There are certain factors that constitute services toward production and yet are distinct from the actual and direct processes of production. The latter are labor and supplies directly applied to the object under construction, whereas the former are such items as power, rent, interest, supervision, and yard operation. The latter are necessary factors of production, but are less directly connected with the actual processes. The purpose of the technical accountant is to keep the expense figures of these various factors separate from each other so that the efficiency of each may be judged on its own individual merits and quite independent of the influence of any other operation.

Thus, if an operator considers scrapping his steam engine and purchasing electricity at 1½ cents per kilowatt-hour, if he has no records of the present cost of his power per horsepower-hour he has no means of knowing whether the change would be profitable. If, however, he has careful records of the cost of fuel, supplies, repairs, labor, maintenance of buildings, depreciation, interest on capital, etc., for his power plant and thus is able to fix for every month the cost of power per horsepower-hour he is in a position to judge whether a change is justifiable. A special account should be kept for each of the independent factors, which together make up the total cost of production. The total of each of the indirect factors must be apportioned on a fair basis between the different units comprising the entire plant, that is, the production centers.

GENERAL AND SPECIAL ACCOUNTS.

The records kept may be classed as general and special. General accounts are of two types: The first covers operations affecting the whole plant, and the items must on this account be apportioned among the various centers of production, such as quarry, mill, and shop; the second type consists of summarized statements of the total direct and overhead expense confined to each production center independent of all others.

The method of obtaining costs for each production center is shown in the following table, where quarry, mill, and shop are represented as production centers. The total cost for each production center is the actual direct and overhead expense of each, together with the proper proportion of general expense, yard expense, and power expense for each.

Form for keeping costs of various production centers.

Quarry.		Mill.		Shop.	
Item.	Cost.	Item.	Cost.	Item.	Cost.
Direct expense..........	$........	Direct expense........	$........	Direct expense........	$........
Overhead expense.......	....	Overhead expense....	....	Overhead expense....	....
Proportion of general expense allotted to quarry	....	Proportion of general expense allotted to mill.	....	Proportion of general expense allotted to shop.	....
Proportion of yard expense allotted to quarry	....	Proportion of yard expense allotted to mill.		Proportion of yard expense allotted to shop.	....
Proportion of power expense allotted to quarry	....	Proportion of power expense allotted to mill.	....	Proportion of power expense allotted to shop.	....
Total, quarry......	....	Total, mill......	....	Total, shop.....	....

Other general accounts may be kept showing total production and summarized statements of total and unit costs of each operation.

In recording all general accounts it is well for purposes of comparison to place in a parallel column the cost of each item for a preceding period of possibly six months. The average figure for the period would probably be the most useful, as it would show whether an item for any given month was below or above the average cost for the preceding period.

Special accounts are localized to each special operation. Their purpose is to show the working efficiency and the time efficiency of various machines or methods. By means of careful records useful comparisons may be made. In making comparative tests of two or more machines it is wise to employ the same operator on each machine during successive periods, as the efficiency of the operators may vary more than that of the machines. This suggests that special accounts may also be kept to test the relative efficiency of men.

GENERAL ACCOUNTS AFFECTING THE WHOLE PLANT.

The general accounts[a] which must be apportioned among the various production centers are (1) general expense, (2) cost of yard operation, (3) cost of power.

GENERAL EXPENSE.

The general-expense account is made up of all items which can not be directly applied to any single production center, such as quarry, mill, or shop. It consists of the land factor and the organization factor.

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[a] The writer is indebted to Maj. J. S. Sewell for many suggestions relating to quarry accounts.

LAND FACTOR.

When land is acquired for quarrying purposes either a certain amount of capital is tied up by purchase or rent must be paid. The interest or rent, together with taxes, is an annual fixed amount which must be charged against all operations conducted on the property.

ORGANIZATION FACTOR.

Costs due to organization include expenses of administration, office, advertising, and expenses of a general nature which affect the plant as a whole.

The various items of general expense are totaled at the end of each month and apportioned to the various production centers on a fixed basis, as, for example, five-eighths to quarry, one-fourth to mill, and one-eighth to shop, or on whatever other fractional basis may seem justified. A general-expense account may have some such form as the following:

Form of general-expense account.

Item.	June.	
	Month.	Average for 6-month period.
	Dollars.	*Dollars.*
Administration		
Office expense		
Legal expense		
Traveling expense		
Interest and discount expense		
Advertising		
Taxes		
Insurance, fire		
Insurance, liability, etc		
Total		
Charge to quarry		
Charge to mill		
Charge to shop		

YARD-OPERATION FACTOR.

The yard account includes interest on capital expended on yard equipment, wages, costs of supplies, maintenance and depreciation charges, and all other incidental expenses connected with transportation of rock from the quarry to the stock pile and from there to the mill and shop, or directly from the quarry to the mill and shop. It is a very variable account and may be omitted where the rock is loaded directly upon the transfer car with the quarry derrick. The following is a convenient form of account:

Form of account for keeping yard costs.

Item.	June.	
	Month.	Average for 6-month period.
	Dollars.	*Dollars.*
Superintendent		
Engineers and firemen		
Tracks:		
Labor		
Supplies		
Repairs to locomotive or crane:		
Labor		
Supplies		
Fuel		
Cars:		
Labor		
Supplies		
Miscellaneous		
Depreciation		
Total		
Charge to quarry		
Charge to mill		
Charge to shop		

POWER FACTOR.

The simplest case in power charges is where power is purchased at so much per kilowatt-hour or horsepower. The next simplest case is where the transmission and distribution is done by the purchasing company; this will involve charges for interest on capital and for depreciation and maintenance of necessary equipment in addition to the first cost. Where steam power is used, or electricity is developed by steam, there will be the interest on capital expended in boilers, engines, generators, buildings, etc., in addition to charges for maintenance, labor, fuel, and supplies. In the case of hydroelectric plants the price of fuel is usually offset by the capital invested in dams and sluices.

It is important that exact power costs be kept and wherever possible reduced to the unit cost, or rate per kilowatt-hour or horsepower-hour. A large part of the loss connected with stone quarries is in the power factor. A power cost that is excessive as compared with the numerous published statistics of power-development costs indicates that something is radically wrong and that the services of an expert are required to stop the leak. If power from more than one plant is employed a separate account should be kept for each plant in order that the expense be properly localized. The power cost should be apportioned among the various production centers on the basis of the power actually consumed by each.

When power is purchased no account is necessary except for transmission and distribution. Power plants are of various types and the form of account must be varied to suit the conditions; two typical forms are given below.

Form for costs of steam power plant.

Item.	June.	
	Month.	Average for 6-month period.
	Dollars.	*Dollars.*
Firemen and helpers		
Engineers		
Maintenance of buildings:		
Labor		
Supplies		
Maintenance of boilers and engines:		
Labor		
Supplies		
Maintenance of steam lines:		
Labor		
Supplies		
Fuel		
Removing cinders:		
Labor		
Supplies		
Miscellaneous		
Superintendence		
Depreciation		
Total		
Cost per unit		

In the case where steam is conducted directly to the quarry machinery the total cost may be apportioned to the various machines in the special accounts for these machines. Where part of the steam power is used to develop electricity a separate account must be kept for this item.

Cost form for hydroelectric power plant.

Item.	June..	
	Month.	Average for 6-month period.
	Dollars.	*Dollars.*
Attendants		
Maintenance of buildings:		
Labor		
Supplies		
Maintenance of dams and sluices:		
Labor		
Supplies		
Maintenance of power lines:		
Labor		
Supplies		
Maintenance of turbines and generators:		
Labor		
Supplies		
Supplies (oil, waste, etc.)		
Depreciation (amortization)		
Total		
Cost per kilowatt-hour		
Charge to quarry		
Charge to mill		
Charge to shop		

This account gives the proportion of power expense for each department and also indicates the efficiency of the power plant. The cost of developing electric power depends on the amount of capital invested in dams and machinery and on the length of transmission lines and hence is subject to considerable variation. It varies generally from 1½ to 2 cents per kilowatt-hour.

GENERAL QUARRY ACCOUNTS.

The general quarry accounts are (1) direct quarry cost, (2) overhead expense, (3) total cost of operating quarry, (4) quarry-production account, and (5) condensed cost account.

DIRECT QUARRY COST.

The direct quarry cost includes the labor and supplies required for each quarry operation. A form for keeping this account is given below:

Form for keeping direct cost accounts for quarry.

Item.	June.	
	Month.	Average for 6-month period.
Labor:	*Dollars.*	*Dollars.*
Channeling		
Setting up track		
Gadding		
Setting up gadders		
Raising blocks		
Pumping and cleaning up quarry		
Changing channeling machines		
Steel for channelers		
Steel for gadders		
Miscellaneous		
Supplies:		
Channeling		
Setting up track		
Gadding		
Setting up gadders		
Raising blocks		
Pumping and cleaning up		
Changing channeling machines		
Steel for channelers		
Steel for gadders		
Miscellaneous		
Fuel for heating		
Total direct quarry cost		

OVERHEAD EXPENSE.

The distinction between overhead and general expense is clearly defined. The latter is made up of those items which affect the plant as a whole and which must be shared by each production center proportionally. The former is a separate account kept for each production center and includes for each center indirect expenses which pertain to that center only and are independent of all others. The ordinary expenses which fall in this class are maintenance and repairs and supervision—that is, the wages of superintendents and foremen employed in this particular center of production. It seems convenient also to include depreciation charges with overhead expenses. Depreciation is an indirect expense and is an independent item for each production center. It is usually expressed as a percentage of the original cost calculated on a basis of the estimated time which may elapse before the equipment must be replaced. It usually varies within limits of 5 to 10 per cent per annum.

Form for overhead-expense account for quarry.

Item.	June.	
	Month.	Average for 6-month period.
	Dollars.	*Dollars.*
Superintendent and foremen		
Watchman		
Depreciation		
Labor:		
Maintenance of channelers		
Maintenance of gadders		
Maintenance of derricks		
Maintenance of pumps		
Maintenance of buildings		
Miscellaneous		
Supplies:		
Maintenance of channelers		
Maintenance of gadders		
Maintenance of derricks		
Maintenance of pumps		
Maintenance of buildings		
Miscellaneous		
Total overhead expense for quarry		

TOTAL COST OF OPERATING QUARRY.

The total quarry-cost account contains the various items which make up the total cost of operating the quarry. It includes the proportional share of general expense, yard, and power charges, and the total direct and overhead charges for the quarry.

Form for keeping total quarry cost.

Item.	June.	
	Month.	Average for 6-month period.
	Dollars.	*Dollars.*
Apportioned share of general expense		
Apportioned share of yard service		
Apportioned share of power		
Total direct operating cost		
Total quarry overhead cost		
Total cost of operating quarry		

Circumstances may make it advisable to keep other accounts, such as a special development account.

QUARRY PRODUCTION ACCOUNT.

Mere statements of costs are of little value unless accompanied by a statement of production for the same period.

Form for keeping quarry production account.

Item.	June.	
	Month.	Average for 6-month period.
	Cubic feet.	*Cubic feet.*
Gross production		
Scrap blocks		
Net production		
Quantity delivered to mill (or shipped wholesale)		
Quantity delivered to yard		
Quantity delivered from yard to mill (or shipped wholesale)		

CONDENSED COST ACCOUNT.

A summarized account may be kept of the total and unit costs of each operation, including the overhead charge. It is compiled from other accounts, and presents the facts in a convenient form for reference or comparison. A convenient form for keeping such an account is given below:

Form for keeping condensed cost account.

Item.	June.	
	Month.	Average for 6-month period.
	Dollars.	*Dollars.*
Total cost of channeling (includes quarry overhead charge)		
Total number of square feet channeled		
Cost of channeling, per square foot		
Vertical drilling:		
Total cost (including overhead charge)		
Total number of square feet of rock drilled		
Total number of linear feet drilled		
Cost per square foot		
Cost per linear foot		
Bed drilling:[a]		
Total cost (including quarry overhead charge)		
Total number of square feet of rock drilled		
Total number of linear feet drilled		
Cost per square foot		
Cost per linear foot		
Total cost of lifting blocks (including quarry overhead charge)		
Total cost of maintaining quarry		
Total cost of power		
Total cost of quarry plant depreciation		
Total cost of development work		

[a] A term applied to drill holes made for the purpose of freeing the block from the floor.

SPECIAL QUARRY ACCOUNTS.

The accounts just considered cover the total quarry cost, the total production, and the total and unit costs of each operation. More detailed records are necessary, however, both for the purpose of compiling the general records, and to check the efficiency of each separate operation.

In order to test channeling or drilling efficiency no account is taken of the proportion of waste, for it makes no difference whether sound or unsound material is produced, as regards the rate of cutting. Hence all such records are based on gross production. For channeling the following records should be kept:

Form for keeping channeling costs, based on gross production.

Item.	Month.
Square feet channeled	
Channeling cost	
Square feet cut in 10-hour day	
Square feet cut in 10-hours' cutting time	
Channeling cost per square foot	
Square feet channeled per cubic foot	
Channeling cost per cubic foot	

Form for channeling time-efficiency account.

Time.	Month.
Maximum working hours	
Cutting time, per cent	
Time used for repairs, per cent	
Time used in moving and setting track, per cent	

The following gadding accounts should be kept:

Account for keeping gadding costs, based on gross production.

Item.	Month.
Square feet of gadding	
Gadding cost	
Square feet cut in 10-hour day	
Square feet cut in 10 hours' cutting time	
Gadding cost per square foot	
Square feet of gadding per cubic foot	
Gadding cost per cubic foot	
Linear feet cut	
Cost per linear foot	

Account for keeping gadding time efficiency.

Time.	Month.
Maximum working hours	
Cutting time, per cent	
Time used for repairs, per cent	
Time used for moving, per cent	

Separate accounts may be kept for vertical drilling and bed drilling, or they may be united. Both channeling and gadding accounts may for purposes of comparison be localized to machines of the same class or even to individual machines.

Such accounts also afford a means of testing various methods. Suppose a change is made in the direction of a row of drill holes so that advantage is taken of a rift in the rock which permits a wider spacing of the holes. The result would be shown in the decreased gadding cost per cubic foot of rock produced. The exact saving thus effected may be balanced against any increased cost which may be involved in the change of quarry method, and thus the operator will know whether such a plan is justified.

As a further illustration, suppose the rift to be so poorly defined that it may seem advisable to channel in two directions and gad only on the bed. Such a change would lower the gadding cost and increase the channeling cost per cubic foot of rock produced. The sum of the channeling and gadding costs before the change compared with their sum after the change would indicate the loss or gain involved in such a change of method.

The preceding statements indicate that in many cases conclusions must not be drawn from isolated accounts, but from the relation of one account to another. The accounts are often interdependent, and no one can interpret them properly except the man who is familiar with both the quarry operations and the accounts kept.

A very useful account is one which summarizes the unit cost of each item on a basis of gross production followed by the same item on a basis of net production, as follows:

Account for keeping gross and net unit costs.

Item.	June.			
	Month.		Average for 6-month period.	
	Gross.	Net.	Gross.	Net.
	Dollars.	*Dollars.*	*Dollars.*	*Dollars.*
Channeling, per cubic foot	....	....	....	....
Vertical drilling, per cubic foot	....	....	....	....
Bed drilling, per cubic foot	....	....	....	....
Lifting blocks, per cubic foot	....	....	....	....
Maintenance of quarry, per cubic foot produced	....	....	....	....
Power, per cubic foot produced	....	....	....	....
Total cost	....	....	....	....

Such an account indicates clearly how the proportion of waste adds to the cost of production of the finished product.

For a certain month the total cost of production per cubic foot, gross measure, in one marble quarry, was only 35 cents. When calculated on the basis of net production it was, however, $1.31 per cubic foot. This means that if all the marble produced were salable—an ideal condition which is impossible in practice but may be assumed for purposes of illustration—the marble could be sold at 36 cents a cubic foot for a profit, if selling expenses were disregarded. So much rock is thrown away on the waste heap, however, that with no compensating revenue from waste material the good stock must be sold for more than $1.31 in order to realize a profit. If more quarrymen kept records which would clearly indicate the excessive losses that result from quarrying inferior material, it is safe to assume that more active steps would be taken in an attempt to modify quarry methods in such a manner as to reduce the proportion of waste.

Block records are very useful, as they assist the quarry operator in keeping track of his product. A form of record kept by one marble company is as follows:

Block record kept by a North Carolina company.

No. of block.	Date quarried.	Dimensions.	Grade.	Total cubic feet.	To mill.
1243	*July 7, 1914*	*3′ 0″ by 3′ 0″ by 1′ 0″.*	*No. 3*	*9*	*August 4, 1914*

For companies who sell their stock wholesale a block record is still more desirable and requires greater detail. A form used by a Tennessee marble company, which is very complete and enables the operator to trace every block from the quarry pit to its final destination, is given below:

Form of block record kept by wholesale company.

Date listed.	List No.	Grade.	Color.	Official measure.	Cubic feet.	Accepted measure.
May 10	*1234*	*1*	*Pink*	*7′ 0″ by 6′ 0″ by 3′ 0″.*	*126*	
May 10	*1235*	*1*	*do*	*6′ 6″ by 6′ 0″ by 3′ 0″.*	*117*	

Form of block record kept by wholesale company—Continued.

Cubic feet.	Description and condition.	Consignee.	Address.	Charged.	Address.
	Good block, regular shape, fine color.				
	do				

Order No.	Date shipped.	Folio.	Remarks; car No., routing, etc.
18256	*June 14*	*152*	*Southern 1181189, c/o Mobile and Ohio.*
18257	*do*	*152*	*Do.*

The company intends to supplement this report with a sketch of each block showing the position of cutters if the block is unsound, and the position of any irregularities or flaws. Such sketches would be placed on file for reference in case of a dispute with the buyer.

GENERAL MILL ACCOUNTS.

The general mill accounts are (1) direct mill cost, (2) overhead expense, (3) total cost of operating mill, (4) unit cost account, (5) condensed cost account.

DIRECT MILL COST.

The direct mill cost includes charges for labor and supplies for the various processes in the mill. A form for keeping this account is given below.

Form for keeping direct mill costs.

Item.	June.	
	Month.	Average for 6-month period.
	Dollars.	*Dollars.*
Labor:		
Loading and unloading gangs		
Sawing		
Hoisting engineer		
Placing stock		
Sawing with diamond saw		
Removing yard scrap and waste		
Loading sawed stock in cars		
Bracing sawed stock in cars		
Water supply		
Supplies:		
For loading and unloading gangs		
For hoisting engineer		
For placing stock		
For removing yard scrap and waste		
For loading sawed stock in cars		
For bracing sawed stock in cars		
Saw blades		
Sand		
Total direct mill cost		

OVERHEAD EXPENSE.

Overhead expense includes cost of superintendence, maintenance and repairs, and depreciation. A form for keeping an overhead-expense account for the mill is given below.

Form of overhead-expense account for mill.

Item.	June.	
	Month.	Average for 6-month period.
	Dollars.	*Dollars.*
Superintendent		
Foreman		
Depreciation		
Labor:		
Maintenance of gangs and sand pumps		
Maintenance of diamond saws		
Maintenance of crane and runway		
Maintenance of shafting and belting		
Maintenance of drain and settling basin		
Maintenance of buildings		
Maintenance of machine shop and equipment		
Maintenance of heating		
Watchman		
Miscellaneous		
Supplies:		
Maintenance of gangs and sand pumps		
Maintenance of diamond saws		
Maintenance of crane and runway		
Maintenance of shafting and belting		
Maintenance of drain and settling basin		
Maintenance of buildings		
Maintenance of machine shop and equipment		
For heating		
For watchman		
Miscellaneous		
Total overhead		

TOTAL COST OF OPERATING MILL.

A form for keeping a summarized statement of mill costs, similar to that for the quarry, is given below:

Form for keeping total costs of operating mill.

Item.	June.	
	Month.	Average for 6 month period.
	Dollars.	*Dollars.*
Apportioned share of general expense		
Apportioned share of yard service		
Apportioned share of power		
Total direct operating cost		
Total overhead charge for mill		
Total cost of operating mill		

UNIT COST ACCOUNT.

The unit cost account shows the amount of material produced and the unit costs direct and indirect for gangs only. If diamond saws or wire saws are employed, separate accounts should be kept for them.

Form of unit cost account for gangs.

Item.	June.	
	Month.	Average for 6-month period.
	Dollars.	*Dollars.*
Number of gang hours actually made		
Direct cost per gang hour		
Total cost per gang hour		
Square feet of saw cuts		
Direct cost per square foot of saw cut		
Total cost per square foot of saw cut		
Cubic feet of blocks for first cut		
Cubic feet of blocks for second and third cuts		
Cubic feet of blocks for all stock loaded		
Total cubic feet sawed (all between saws)		
Total cubic feet good color obtained		
Total cubic feet good and sound		
Direct cost per cubic foot total sawed		
Total cost per cubic foot total sawed		
Direct cost per cubic foot good color		
Total cost per cubic foot good color		
Direct cost per cubic foot good and sound		
Total cost per cubic foot good and sound		
Average square feet saw cuts per gang hour		
Average square feet sawed per gang hour		
Rate of sawing		
Average number of blades per gang load		
Average length of stock		
Average number of cubic feet per gang load		
Number of gang loads		

This form of account is subject to many modifications. The one given is designed to fit a complex condition, where the marble is marred by both bad color and unsoundness. If either of these is absent the account may be simplified. If the material is graded as No. 1, 2, and 3 as it leaves the saws the account must be modified to suit.

CONDENSED COST ACCOUNT.

The value of material as it enters the mill is the sum of the costs of work already done upon it as indicated by the quarry records. The summarized account gives in condensed form the cost of material through the mill and indicates the additional costs of various operations, both as totals and units.

Form for keeping condensed cost account.

Item.	June.	
	Month.	Average for 6-month period.
	Dollars.	*Dollars.*
Value of blocks to mill from quarry		
Value of blocks to mill from yard		
(*a*) Total value of blocks to mill		
Average value per cubic foot of blocks to mill		
(*b*) Total mill operating cost		
Total value of output of mill (sum of *a* and *b*)		
Thin stock: [a]		
Value of blocks delivered to mill		
Total cost of sawing		
Total value of sawed stock produced		
Average value of sawed stock produced		

[a] Similar accounts may be kept to ascertain the costs per cubic foot of making the first, second, and third cuts, cuts subsequent to the third, and of cutting with the diamond saw.

For convenience in keeping saw-gang records, the accompanying ticket form which is used by one marble company may offer useful suggestions:

SAW TICKET.

Gang No. .... *Dimensions*........ *Block No.* .... *Grade*........

	Date.	Hour.	
When last down			No. saws.....
When started			No. pcs.......
When down			

Total hours under gang...... *Idle for loading*...... *Sizes sawed into*......

HOURS RUN AND INCHES SAWED EACH SHIFT.

Sawyer.	1		3		5		7	
	Hrs.	Ins.	Hrs.	Ins.	Hrs.	Ins.	Hrs.	Ins.
	2		4		6		8	
Totals								

Total hours sawed ...... *Total inches sawed* ...... *Total hours delay* ......

DELAYS.

Date.	Hours.	Cause.

SPECIAL MILL ACCOUNTS.

The special mill accounts show the amounts produced by the various operations and the total and unit costs of each operation, with certain other useful figures such as rate of sawing, number of blades, etc. A summarized statement of total quantities produced and cost of the same may be given as follows:

Form for keeping cost account of total quantities produced.

Total quantities produced by gang.	June.	
	Month.	Average for 6-month period.
Gang hours actually made		
Direct cost per gang hour		
Total cost per gang hour		
Square feet of saw cuts		
Direct cost per square foot of saw cut		
Total cost per square foot of saw cut		
Gross measure blocks for first cut		
Gross measure blocks for second and third cuts		
Gross measure all stock loaded		
Total [a] cubic feet sawed (all between saws)		
Direct cost per cubic foot (total sawed)		
Total cost per cubic foot (total sawed)		
Average number of square feet sawed per gang hour		
Average number of cubic feet sawed per gang hour		
Rate of sawing		
Average number of blades per gang load		
Average length of stock		
Average number of cubic feet per gang load		
Number of gang loads		

[a] Similar items showing the cost of producing the different grades may be given if desired.

A thin-stock account may be kept in more or less detail. The form given here may be modified at the operator's discretion.

Form for keeping thin-stock account.

Thin stock.	June.	
	Month.	Average for 6-month period.
Gross measure, cubic feet		
Total [a] cubic feet sawed (all between saws)		
Total number of square feet of saw cuts		
Total gang hours		
Direct operating cost		
Total operating cost		
Direct cost per cubic foot of total quantity sawed		
Total [a] cost per cubic foot of total quantity sawed		
Direct cost per square foot of saw cut		
Total cost per square foot of saw cut		
Average number of square feet sawed per gang hour		
Average number of cubic feet cut per gang hour		
Average rate of sawing		
Average number of blades per gang load		
Average length of stock		
Average number of cubic feet per gang load		
Total number of gang loads		

[a] Items similar to this one for the different grades might be inserted here.

Similar accounts may be kept for cubic stock, showing the cost of making the first cut, second cut, third cut, and cuts subsequent to the third cut, and for diamond saws. Cuts subsequent to the third cut are usually diagonal or some such direction for the purpose of decreasing mill labor, and as a consequence are charged to the mill.

Time-efficiency reports are of great value. The various causes of delay may be enumerated and calculated to percentages of the maximum sawing hours, as in the form following:

Form for time-efficiency record of gang.

Item.	June.			
	Month.		Average for 6-month period.	
	Hours.	per cent.	Hours.	per cent.
Maximum sawing time				
Actual sawing time				
Time consumed by delays:				
Loading and unloading				
Coming down at night				
Without water				
Without power				
Repairs to gangs				
Repairs to belting and shafting				
Repairs to pumps				
Repairs to lead pipes				
Without blocks				

Suppose that in addition to a traveling crane a transfer-car system is installed. In the next monthly report the advantage of this additional equipment would be reflected in the time-efficiency record as a material reduction in the time consumed in loading and unloading.

SHOP OR FINISHING PLANT ACCOUNTS.

In considering the various operations in the shop a new condition presents itself. Although the whole shop has been termed a production center it is in reality a group of smaller independent production centers comprising coping, rubbing plain stock, gritting plain stock, buffing plain stock, cutting, matching, drilling holes for anchors, boxing, and loading. Keeping in mind the principle that technical accounts should be localized if costs are to be properly isolated, for each of these smaller production centers, a separate account must be kept, each bearing its proper share of general expense, yard service and power, and its total direct and overhead charge. The apportioning of general expense and other indirect costs requires careful adjustment. Some departments require more supervision or more yard service than others, and each should be burdened with no more than its fair share. Power cost is apportioned on the basis of the actual amount of power used by each department.

Two general shop accounts are necessary, one being a summary of shop costs and the other a summary of shop production.

Cost account for shop or finishing plant.

Item.	June.	
	Month.	Average for 6-month period.
General expense:	*Dollars.*	*Dollars.*
Percentage of main general expense account		
Draftsmen (percentage of total)		
Drafting supplies (percentage of total)		
Total general expenses		
Yard operation (percentage of total)		
Power (amount actually used)		
Direct shop costs:		
Labor		
Supplies		
Total direct shop costs		
Overhead expense for shop:		
Draftsmen (percentage of total)		
Drafting supplies (percentage of total)		
Superintendence		
Shop depreciation		
Maintenance of shop machinery—		
Labor		
Supplies		
Total overhead expense for shop		
Summary:		
General expenses		
Yard operation		
Power		
Direct shop costs		
Overhead expense for shop		
Total cost of operating shop		
Total number of productive hours of shop labor		
General expense per productive hour		
Yard expense per productive hour		
Power expense per productive hour		
Direct expense per productive hour		
Overhead expense per productive hour		

A plain-stock production account summarizes the number of cubic feet of stock handled and the work done on it at each operation.

Form for keeping records of plain-stock production.

Plain-stock production.	June.	
	Month.	Average for 6-month period.
Square feet of stock coped (excluding tile)		
Cubic feet of stock coped (excluding tile)		
Square feet of tile coped		
Cubic feet of tile coped		
Square feet of stock rubbed (excluding tile)		
Square feet of second surface rubbed (excluding tile)		
Total square feet rubbed		
Cubic feet of stock rubbed		
Square feet of tile rubbed		
Cubic feet of tile rubbed		
Square feet of stock gritted		
Square feet of second surface gritted		
Total square feet gritted		
Cubic feet of stock gritted		
Square feet of stock buffed		
Square feet of second surface buffed		
Total square feet buffed		
Cubic feet of stock buffed		

The account for each of the production centers within the shop may have somewhat the following form:

Form for keeping costs of individual operations.

Coping.	June.	
	Month.	Average for 6-month period.
Total number of productive hours		
Square feet of stock coped		
Cubic feet of stock coped		
General expense		
Yard service		
Power		
Overhead shop expense		
Direct expense:		
Copers		
Helpers		
Foremen		
Removing scrap		
Supplies		
Total cost of coping per cubic foot (*a*)		
Cost of stock per cubic foot before coping (*b*)		
Value of coped stock per cubic foot (sum of *a* and *b*)		

In this account the value of the stock is the sum total of the costs of all previous operations. After it has been coped the stock will have increased in value by the amount of the coping costs. The same process is followed during all subsequent operations, and the final boxing and loading account will show as the value of the stock the total cost of all operations through quarry, mill, and shop. The accounts for rubbing plain stock, gritting plain stock, buffing plain stock, cutting, matching, and other necessary processes are kept in the same form as the coping account, though certain modifications must be made in the direct expense of each. Tile stock or refinishing may require additional accounts.

Accounts should be kept for all by-products, such as terrazzo, road material, fertilizer, riprap, lime, etc.

JOB ACCOUNTS.

In shops where novelties are manufactured it may seem desirable to determine the total cost of an article which has passed through the hands of a number of operators. Such a record when placed on file affords a ready means of making future estimates on similar articles. If a block of cubic stock is taken, its first cost may easily be ascertained from the total cost of third-cut cubic stock in the condensed cost account of the mill records. The final cost will be this amount plus the cost of all subsequent work done upon it. For keeping such records the following forms of cost tickets are suggested. When the job is completed, the information contained in ticket 1 is transferred in condensed form to ticket 2. The latter may be of cardboard, of convenient size and shape for filing.

Suggested forms for cost tickets.

COST TICKET NO. 1.

Order No. .... Design..............................

Kind of marble......................... Size ....

Article..................................

Class of workman.	Name of workman.	Time started.	Time stopped.	Total time.	Rate.	Cost.	Remarks.
Cutter...............	*L. Smith..*	*7.30 a. m.* *6/27/14*	*11 a. m.* *6/27/14*	*3½ hrs.*	*50¢*	*$1.75*	
Cutter...............							
Cutter...............							
Polisher.............							
Polisher.............							
Tracer...............							
Turner...............							
Lathe polisher........							

COST TICKET NO. 2.

Design............ Order No. .... For............ Price............

Sizes.	Cubic feet.	Cost of—					Total cost.
		Cutting.	Polishing.	Tracing.	Turning.	Lettering.	

PUBLICATIONS ON MINERAL TECHNOLOGY.

A limited supply of the following publications of the Bureau of Mines is temporarily available for free distribution. Requests for all publications can not be granted, and to insure equitable distribution applicants are requested to limit their selection to publications that may be of especial interest to them. Requests for publications should be addressed to the Director, Bureau of Mines.

BULLETIN 16.—The uses of peat for fuel and other purposes, by C. A. Davis. 1911. 214 pp., 1 pl., 1 fig.

BULLETIN 42.—The sampling and examination of mine gases and natural gas, by G. A. Burrell and F. M. Seibert. 1913. 116 pp., 2 pls., 23 figs.

BULLETIN 45.—Sand available for filling mine workings in the Northern Anthracite Coal Basin of Pennsylvania, by N. H. Darton. 1913. 33 pp., 8 pls., 5 figs.

BULLETIN 47.—Notes on mineral wastes, by C. L. Parsons. 1912. 44 pp.

BULLETIN 53.—Mining and treatment of feldspar and kaolin in the southern Appalachian region, by A. S. Watts. 1913. 170 pp., 16 pls., 12 figs.

BULLETIN 64.—The titaniferous iron ores of the United States, their composition and economic value, by J. T. Singewald, jr. 1913. 145 pp., 16 pls., 3 figs.

BULLETIN 81.—The smelting of copper ores in the electric furnace, by D. A. Lyon and R. M. Keeney. 1915. 80 pp., 6 figs.

BULLETIN 84.—Metallurgical smoke, by C. H. Fulton. 1915. 94 pp., 6 pls., 15 figs.

TECHNICAL PAPER 3.—Specifications for the purchase of fuel oil for the Government, with directions for sampling oil and natural gas, by I. C. Allen. 1911. 13 pp.

TECHNICAL PAPER 8.—Methods of analyzing coal and coke, by F. M. Stanton and A. C. Fieldner. 1913. 42 pp., 12 figs.

TECHNICAL PAPER 14.—Apparatus for gas-analysis laboratories at coal mines, by G. A. Burrell and F. M. Seibert. 1913. 24 pp., 7 figs.

TECHNICAL PAPER 32.—The cementing process of excluding water from oil wells, as practised in California, by Ralph Arnold and V. R. Garfias. 1912. 12 pp., 1 fig.

TECHNICAL PAPER 38.—Wastes in the production and utilization of natural gas, and means for their prevention, by Ralph Arnold and F. G. Clapp. 1913. 29 pp.

TECHNICAL PAPER 39.—The inflammable gases in mine air, by G. A. Burrell and F. M. Seibert. 24 pp., 2 figs.

TECHNICAL PAPER 41.—Mining and treatment of lead and zinc ores in the Joplin district, Missouri, a preliminary report, by C. A. Wright. 1913. 43 pp., 5 figs.

TECHNICAL PAPER 43.—The influence of inert gases on inflammable gaseous mixtures, by J. K. Clement. 1913. 24 pp., 1 pl., 8 figs.

TECHNICAL PAPER 50.—Metallurgical coke, by A. W. Belden. 1913. 48 pp., 1 pl., 23 figs.

TECHNICAL PAPER 66.—Mud-laden fluid applied to well drilling, by J. A. Pollard and A. G. Heggem. 1914. 21 pp., 12 figs.

TECHNICAL PAPER 68.—Drilling wells in Oklahoma by the mud-laden fluid method, by A. G. Heggem and J. A. Pollard. 1914. 27 pp., 5 figs.

TECHNICAL PAPER 70.—Methods of oil recovery in California, by Ralph Arnold and V. R. Garfias. 1914. 57 pp., 7 figs.

TECHNICAL PAPER 76.—Notes on the sampling and analysis of coal, by A. C. Fieldner. 1914. 59 pp., 6 figs.

TECHNICAL PAPER 88.—The radium-uranium ratio in carnotites, by S. C. Lind and C. F. Whittemore. 1915. 29 pp., 1 pl., 4 figs.

TECHNICAL PAPER 95.—Mining and milling of lead and zinc ores in the Wisconsin district, Wisconsin, by C. A. Wright. 1915. 39 pp., 2 pls., 5 figs.

TECHNICAL PAPER 110.—Monazite, thorium, and mesothorium, by Karl L. Kithil. 1915. 32 pp., 1 fig.

TECHNICAL PAPER 111.—Safety in stone quarrying, by Oliver Bowles. 1915. 48 pp., 5 pls., 4 figs.

TECHNICAL PAPER 126.—The casting of clay wares, by T. G. McDougall. 1916. 12 pp., 2 figs.

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