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PHYSICAL AND CHEMICAL TESTS ON THE COMMERCIAL MARBLES OF THE UNITED STATES

BY

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I. INTRODUCTION

In the year 1914 plans were made by the United States Geological Survey, Bureau of Mines, Office of Public Roads, and the Bureau of Standards for a cooperative study of the various deposits of stone in the United States.

The part of this work undertaken by the Bureau of Standards is the determination of the physical and chemical properties of the stone to establish its value for use in masonry structures. So far the work of this Bureau in the investigation has been confined mainly to the laboratory, but it is proposed to later supplement this with an extensive study of structures illustrating the uses of the various types under various conditions and periods of exposure.

This investigation was started with the study of marble, and it was intended to complete this material before taking up another type. The laboratory work, however, has been confined to the developed quarries, owing to the difficulty of securing samples from the undeveloped deposits. It is proposed to supplement this report with subsequent studies of other marble deposits, together with more extensive experiments on the weathering qualities of the types here reported.

Acknowledgment is made to T. Nelson Dale and G. F. Loughlin, geologists of the United States Geological Survey, and Oliver Bowles, quarry technologist, Bureau of Mines, for assistance in securing samples. For assistance rendered by members of the Bureau staff acknowledgment is made to G. J. Hough and H. A. Bright for chemical analyses, H. L. Curtis for volume-resistivity measurements, and L. W. Schad for thermal-expansion determinations.

II. PURPOSE OF STONE TESTING

Stone in actual use is required to bear certain stresses and resist the action of a number of destructive agents. The first requirement is that the stone shall have sufficient strength to safely support the weight of the superimposed masonry and any other loads that may come upon it. The compressive strength of stone is nearly always sufficient for the requirements of ordinary structures. Theoretically a stone with a compressive strength of 6000 pounds per square inch, weighing 170 pounds per cubic foot, could be built into a tower over 5000 feet high before the lower course would fail by crushing. Few stones have a compressive strength less than this, and many test as high as 20 000 pounds per square inch. There are, however, other factors that come into consideration when the stone is placed in the structure: First, in a wall of masonry or a pier the load is probably never uniformly distributed over the individual members of the different courses—that is, some stones support more than their share of the load, while others may receive practically no load at all, due to the manner of bedding—second, the element of fatigue must be considered, as a stone under continuous stress will finally break under a very much lighter load than it will stand for a short time; third, the stresses due to the loads may be greatly augmented (*a*) by expansion and contraction of the stone; (*b*) by the expansion of water in the pores while freezing, and (*c*) by vibrations in some structures, such as bridge piers. Stone is frequently used for beams, as in the case of lintels, where the stone is required to carry a weight of masonry above doors and windows. Here the stone is subjected to bending or transverse stresses. The resistance of stone to this kind of stress is comparatively low, and hence the determination of the transverse strength of the stone previous to use for beams is important.

Stone used in floors, steps, sidewalks, and pavements is subjected to an abrading action and the stone chosen for these purposes, other things being equal, should be the one that shows the greatest endurance under such conditions. Frequently stone is required to resist abrasion in bridge piers, breakwaters, etc., because of the water carrying sand against the surface. In certain localities the walls of stone buildings are worn to a considerable extent on account of strong winds blowing sand against the surface.

Probably the most destructive agent for stone when exposed to the weather is frost. In humid climates having cold, changeable winters this action is most marked, and many varieties of stone show signs of disintegration after a few years of exposure.

A study of the durability of various types of stone in New York City was made by Alexis A. Julien and is included in the Tenth Census of the United States, volume 10, pages 364 to 393. This study is valuable, first, in indicating the relative durability of different stones in the structures of that city; and second, in pointing out architectural defects which cause parts of buildings to disintegrate where other parts do not suffer. The estimate of the "life" of different types of stone was based on observations of buildings and represents the period the stone will endure until disintegration renders it so unsightly in appearance that repair is necessary. This estimate assigns the durability of different types as follows:

Coarse brownstone	5 to 15 years.
Laminated fine brownstone	20 to 50 years.
Compact fine brownstone	100 to 200 years.
Bluestone	Untried, probably centuries.
Nova Scotia stone	Untried, probably 50 to 200 years.
Ohio sandstone (best siliceous variety)	Perhaps from one to many centuries.
Limestone, coarse fossiliferous	20 to 40 years.
Limestone, fine oolitic (French)	30 to 40 years.
Marble, coarse dolomitic	40 years.
Marble, fine dolomitic	60 to 80 years.
Marble, fine	50 to 200 years.
Granite	75 to 200 years.
Gneiss	50 years to many centuries.

The defects in architecture pointed out in this report were mainly those of projecting copings, lintels, sills, brackets, etc., where no means were provided to prevent the water from flowing over these and soaking the masonry below. Where rain falls on the top surface of a projection it runs off over the outer edge and following the lower surface reaches the wall, which becomes soaked for some distance below. Also snow which is allowed to remain on these projections finally melts and causes the same difficulty. By the simple means of "throating"—that is, making a groove in the lower surface of projecting members—this difficulty is overcome, as the water when it reaches this groove drops to the ground. Also the upper surface of projecting masonry, if left horizontal, absorbs much water and causes the adjacent wall to become soaked for some distance up. Such conditions in winter cause excessive disintegration at these places. Hence, much can be accomplished by the architect to lengthen the life of the stone.

The above-mentioned report is apparently the first attempt in this country to establish the relative durability of different types of stone. Although the data given apply strictly to one locality, they may be considered to have a relative value for the greater portion of the country.

A great deal of useful information concerning a stone may be obtained from laboratory tests. The ultimate strength in compression, cross bending, and tension may be definitely obtained, and the results are useful to the architect and engineer when the question of strength comes into consideration. The action of destructive agents may be closely imitated, and by measuring the amount of this over a given period of time an idea can be gained of the durability of the stone under such action. Hence the purpose of laboratory tests is to determine the suitability of the different stones for use under given conditions and to establish as nearly as possible the length of service that may be expected from the various types.

III. SELECTION OF SAMPLES FOR TEST

In most cases the samples herein reported were selected by representatives of the United States Geological Survey or the Bureau of Mines. In a few cases the selection was left to the producers. So far as possible the samples were chosen to represent the average product of the quarries. When these samples were cut into test pieces, slabs 8 by 12 inches were retained for reference and future comparison.

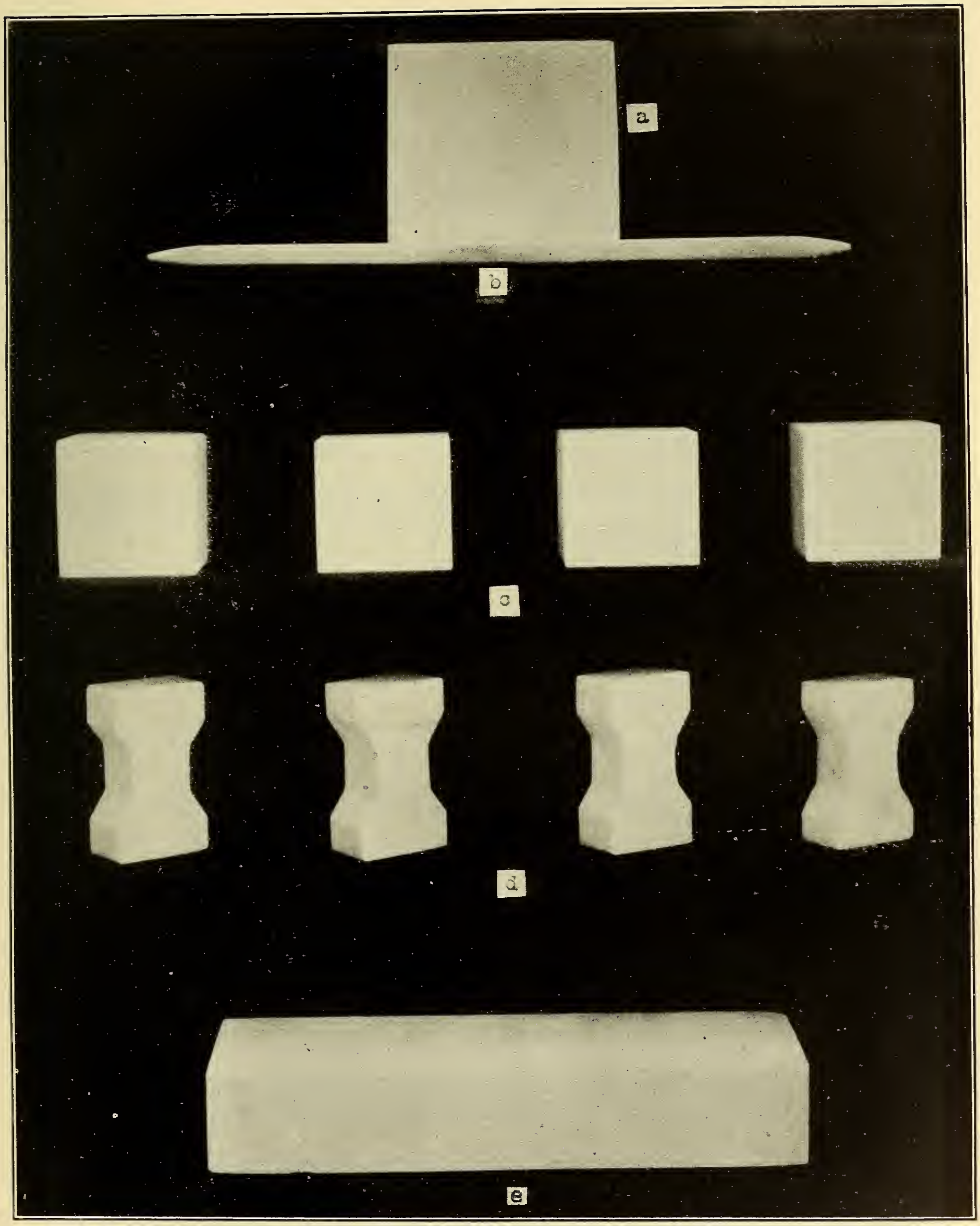

Fig. 1.—*Specimens of marble prepared for tests*

(*a*) Plate for electrical resistivity determination, (*b*) bar for thermal expansion measurement, (*c*) cubes for compression, absorption, apparent specific gravity, and freezing tests, (*d*) briquets for tension tests, (*e*) bar for transverse test

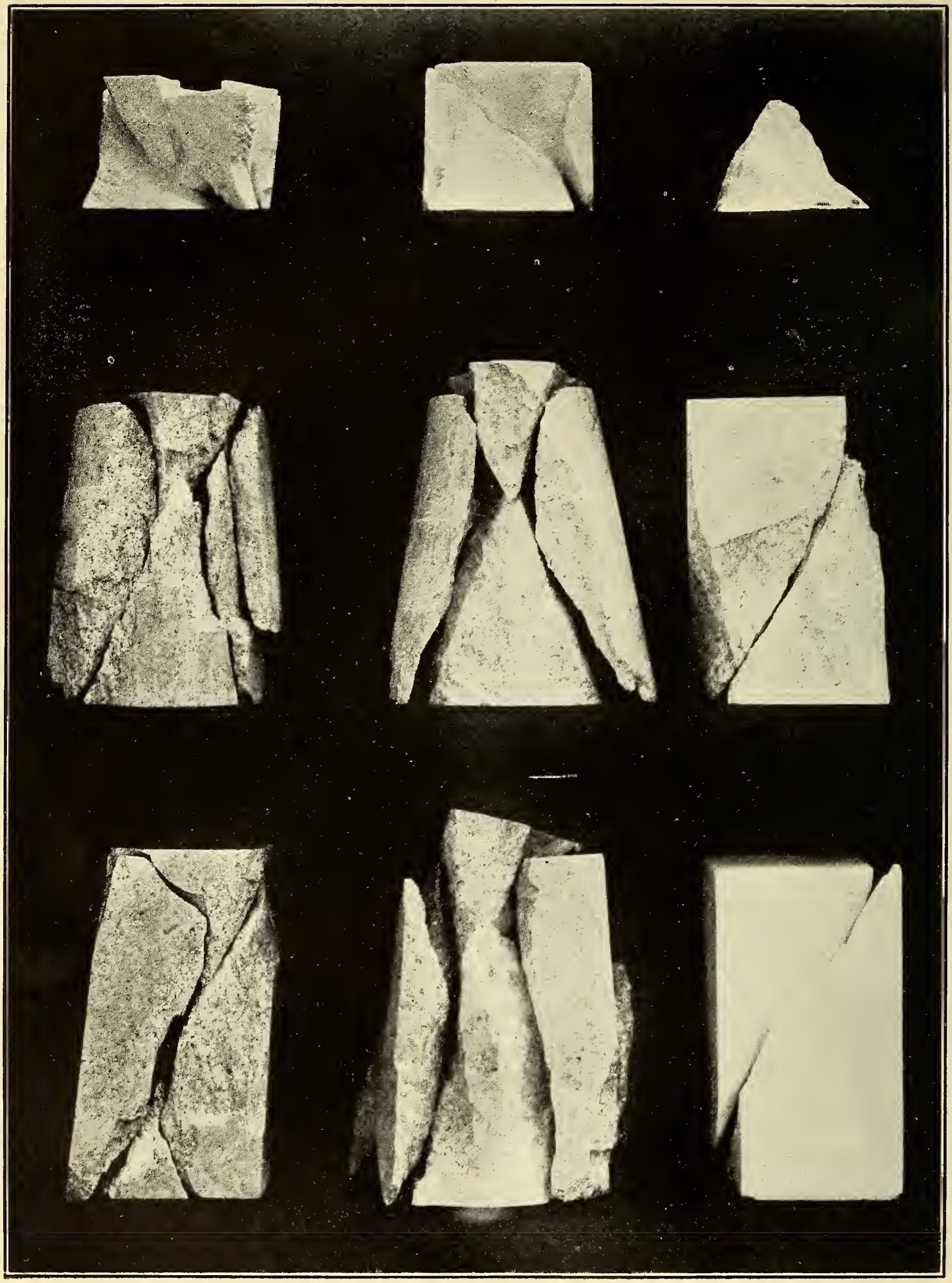

FIG. 2.—*Showing manner of breaking in compression tests on cubes, cylinders, and prisms*

IV. PREPARATION OF TEST SPECIMENS

The samples secured from the quarries for testing in this investigation were approximately 1 by 1 by 2 feet. The test specimens were prepared from these blocks by sawing them, first into slabs with a 48-inch carborundum-tooth wheel and then into cubes, beams, etc., with a 30-inch carborundum-rim wheel. The cubes, which were made for compression, absorption, apparent specific gravity, and freezing tests, were cut approximately 2¼ inches in size and finished by grinding on a fine carborundum grinding lap. The faces of the cubes which were to receive the load in the compression tests were ground as nearly parallel as possible by the following method: One face was first ground to a plane surface, which was determined by testing it on a glass plate until all the edges rested in contact. The opposite face was then ground as nearly parallel to this as could be determined with a pair of outside calipers. The broad faces of the transverse pieces were ground parallel in the same manner. All cubes used for determining the apparent specific gravity, water absorption, and loss due to frost action were rounded slightly on the edges to prevent a loss due to crumbling during the test.

The briquets for tension tests were prepared as far as possible from the pieces used in determining the transverse strength. These pieces were purposely cut to the proper cross section, and after being broken transversely the ends were squared and grooved on the opposite faces with a carborundum fluting wheel. This wheel was 2 inches thick and had the corners beveled at 45°, so that the flute obtained was composed of three plane surfaces, each three-fourths of an inch wide. The grooved pieces were then sawed transversely, giving briquets with a cross section of 1 square inch.

The complete set of specimens prepared from each sample consisted of 12 cubes, one-half finished for compression tests "on bed" and one-half for compression tests "on edge"; 4 pieces for transverse-strength tests; 2 prepared for tests perpendicular to the bedding and 2 for tests parallel to the bedding; 6 briquets for tension tests; 3 perpendicular to the bedding and 3 parallel to the bedding; 1 bar for expansion measurements 1 by 1 by 30 cm; and 1 plate for electrical resistivity 10 by 10 by 1 cm. The prepared specimens are illustrated in Fig. 1 and the tests are described in the following sections.

V. COMPRESSION TESTS

The compressive strength of stone is determined, first, to find what loads it will support in structures; second, in the laboratory to study various treatments which may cause a loss of strength, such as continuous soaking in water, repeated freezing and thawing, repeated heating and cooling, etc.

The compression tests in this report were made on a 200,000-pound, four-screw, universal testing machine. The cubes, after being carefully prepared and measured, were centered on a 6½-inch spherical bearing block on the table of the machine. One thickness of blotting paper was placed below and one above the cube to allow for any slight inequalities in the surface of the cube or the metal bearing plates of the machine. The head of the machine was then brought down, and when almost in contact with the upper face of the cube a slow speed was used. While the head of the machine was coming down to a firm bearing the operator gripped the plate of the spherical block with both hands and, holding the cube in the center with thumbs and forefingers, revolved the plate and cube slightly to right and left to bring the lower plate parallel to the bearing face of the descending head. This was to insure the uniform contact and application of the load over the entire area of the cube faces. Experiments were made to determine the effect of different procedures in making this test with a view of securing more uniform results. Different sizes of spherical blocks were tried, placed above and below the specimen. Also, two spherical blocks were tried at the same time, placing one above and one below the cube. These experiments indicated that the greatest uniformity could be obtained by using the 6½-inch spherical block, and this could be placed above or below the specimen with equal results so long as proper care was exercised in centering and securing uniform application of the load. One point in the use of a spherical block should be carefully noted—i. e., the specimen must be accurately centered over the spherical bearing; otherwise the load will be applied eccentrically and one side of the specimen will receive a much higher load than the other, due to the moment of the load about the center of the block tending to tip the bearing plate.

With all the care that can be exercised in preparing good specimens and testing them, a considerable variation of results may be obtained on the same material. A series of three shapes of specimens was carefully prepared and tested to determine the variation that should be expected under the best conditions and the relation of the results for different shapes of specimens. The manner in which these specimens broke is illustrated in Fig. 2, and the results of the experiments are given as follows:

Series A.—Compression Tests on 11 Cubes of a Uniform-Texture White Marble

Cube No.	Face dimensions	Height	Sectional area	Ultimate load	Unit strength
	Inches	Inches	Inches [a]	Pounds	Lbs./in.[a]
1	2.64 by 2.67	2.62	7.05	66 350	9411
2	2.64 by 2.64	2.62	6.97	62 450	8951
3	2.64 by 2.66	2.64	7.02	62 810	8947
4	2.62 by 2.68	2.62	7.02	64 950	9252
5	2.64 by 2.66	2.62	7.02	64 060	9125
6	2.64 by 2.68	2.63	7.07	66 000	9335
7	2.66 by 2.66	2.63	7.08	63 280	8938
8	2.66 by 2.65	2.61	7.05	64 080	9089
9	2.65 by 2.63	2.62	6.97	61 790	8865
10	2.68 by 2.70	2.50	7.24	69 960	9663
11	2.63 by 2.65	2.63	6.96	65 000	9340
Average					9174

[a] Maximum deviation from the mean equals 489 pounds, equals 5.3 per cent.

Series B.—Compressive Strength on Nine Prisms

[Prepared from same sample as the cubes in Series A]

Prism No.	Sectional dimension	Height	Sectional area	Ultimate load	Unit strength
	Inches	Inches	Inches [a]	Pounds	Lbs./in.[a]
1	2.62 by 2.62	5.68	6.86	55 520	8093
2	2.66 by 2.68	5.50	7.13	52 100	7307
3	2.64 by 2.66	5.62	7.02	54 730	7796
4	2.64 by 2.65	5.65	7.00	53 340	7620
5	2.60 by 2.68	5.66	6.96	54 640	7851
6	2.60 by 2.69	5.62	7.00	55 100	7871
7	2.64 by 2.68	5.70	7.07	54 740	7742
8	2.64 by 2.66	5.65	7.02	54 830	7811
9	2.64 by 2.60	5.65	6.86	55 520	8093
Average					7828

[a] Maximum deviation from mean equals 521 pounds, equals 6.7 per cent.

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Series C.—Compressive Strength on Nine Prisms of a Uniform-Texture Pink Marble

Prism No.	Sectional dimension	Height	Sectional area	Ultimate load	Unit strength
	Inches	Inches	Inches [a]	Pounds	Lbs./in.[a]
1	2.65 by 2.70	5.90	7.16	120 020	16 762
2	2.67 by 2.66	5.90	7.10	124 300	17 509
3	2.67 by 2.68	5.90	7.15	137 130	19 179
4	2.66 by 2.65	5.90	7.05	124 770	17 698
5	2.65 by 2.65	5.90	7.02	118 120	16 826
6	2.70 by 2.63	5.90	7.10	136 940	19 287
7	2.63 by 2.67	5.90	7.02	138 650	19 750
8	2.63 by 2.65	5.67	6.97	139 710	20 044
9	2.70 by 2.66	5.80	7.18	130 030	18 110
Average					18 352

[a] Maximum deviation from mean equals 1692 pounds, equals 9.2 per cent.

Series D.—Compressive Tests on Nine Cylinders of Same Marble as Series C

Cylinder No.	Diameter	Height	Sectional area	Ultimate load	Unit strength
	Inches	Inches	Inches [a]	Pounds	Lbs./in.[a]
1	2.92	5.70	6.70	127 420	19 018
2	2.92	5.70	6.70	130 070	19 404
3	2.92	5.65	6.70	128 500	19 180
4	2.92	5.70	6.70	116 410	17 374
5	2.92	5.70	6.70	122 970	18 354
6	2.92	5.75	6.70	121 420	18 122
7	2.92	5.70	6.70	122 100	18 224
8	2.92	4.15	6.70	135 240	20 185
9	2.92	4.70	6.70	134 160	20 023
Average					18 876

[a] Maximum deviation from mean equals 1502 pounds, equals 8 per cent.

It should be noted that the results recorded in the last two cases were obtained on a different sample from those in the first two.

However, by comparison the following relations between the different shapes may be obtained:

$$(1)\quad \frac{\text{Strength of prism of dimensions } h\times h\times 2\,h}{\text{Strength of cube of dimensions } h\times h\times h}=0.85$$

$$(2)\quad \frac{\text{Strength of prism of dimensions } h\times h\times 2\,h}{\text{Strength of cylinder of diameter}=1.1\,h,\ \text{height}=2\,h}=0.97$$

$$(3)\quad \frac{\text{Strength of cylinder diameter}=1.1\,h,\ \text{height}=2\,h}{\text{Strength of cube of dimensions } h\times h\times h}=0.87$$

In this series of tests practically no difference in strength was indicated between the cylinders and prisms of the same height.

The cubes showed about one-eighth more strength than the cylinders and prisms of twice the height of the cubes. More uniformity was obtained with the cubes, and here the maximum deviation from the mean was 5.3 per cent.

In determining the compressive strength of a sample of stone, three tests are usually made and the average taken as the correct value. Considering the average of the 11 tests on cubes in the first table as the correct value for that sample, then the maximum deviation of the average of any three consecutive tests of this series from this value is 210 pounds, or 2.3 per cent, and the mean deviation of any three consecutive tests from this value is 85 pounds, or 0.9 per cent.

The results of this investigation show a great range in compressive strength for marble. The lowest was 7850 pounds per square inch on a white calcite marble from Vermont, and the highest was 50 205 on a red dolomitic marble from the same state. As a rule, the dolomitic marbles appear to be stronger than the calcite marbles. The two serpentines included in this report gave high compressive strength both "on bed" and "on edge," although considerably less "on edge."

VI. TRANSVERSE STRENGTH TESTS

The transverse tests in this investigation were made on bars of the marble 3 by 1¾ inches in section and 6 to 12 inches in length. The pieces were supported on adjustable knife-edges at the ends placed on the bed of a 20 000-pound, three-screw compression machine and the load applied by means of a third knife-edge at the center of the span. The breaking load was recorded and the unit strength computed from the formula $R=\frac{3\,Wl}{2\,bd^2}$ where R equals modulus of rupture in cross breaking, W equals breaking load, l equals length between the supporting knife-edges, b equals breadth of specimen, and d equals depth of specimen. The quantity R represents the maximum unit strength of the material when used as a beam and may be used to proportion blocks of the material which are to be placed under bending stresses in structures.

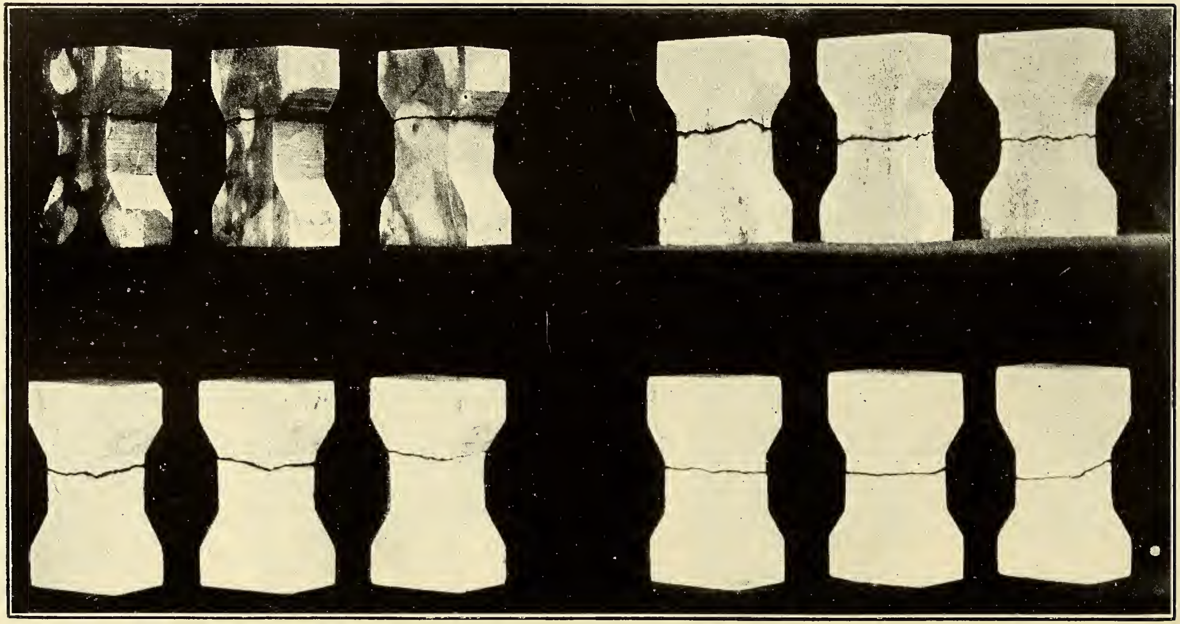
This is a very important test because of the comparatively low transverse strength of stone and its frequent use where it is required to support considerable weight. The frequent failures of lintels indicate the lack of attention on the part of architects to the transverse strength of the stone. The loads should be carefully considered and a large factor of safety allowed in proportioning all members of stone to be used under this condition of stress.

The tests in this investigation were made in both directions of the bedding; i. e., half of the specimens from each sample were cut with the long dimension parallel to the bedding and half with the long dimension perpendicular to the bedding. The transverse strength is usually very low parallel to the bedding. Hence stone should be used under this condition of stress with caution.

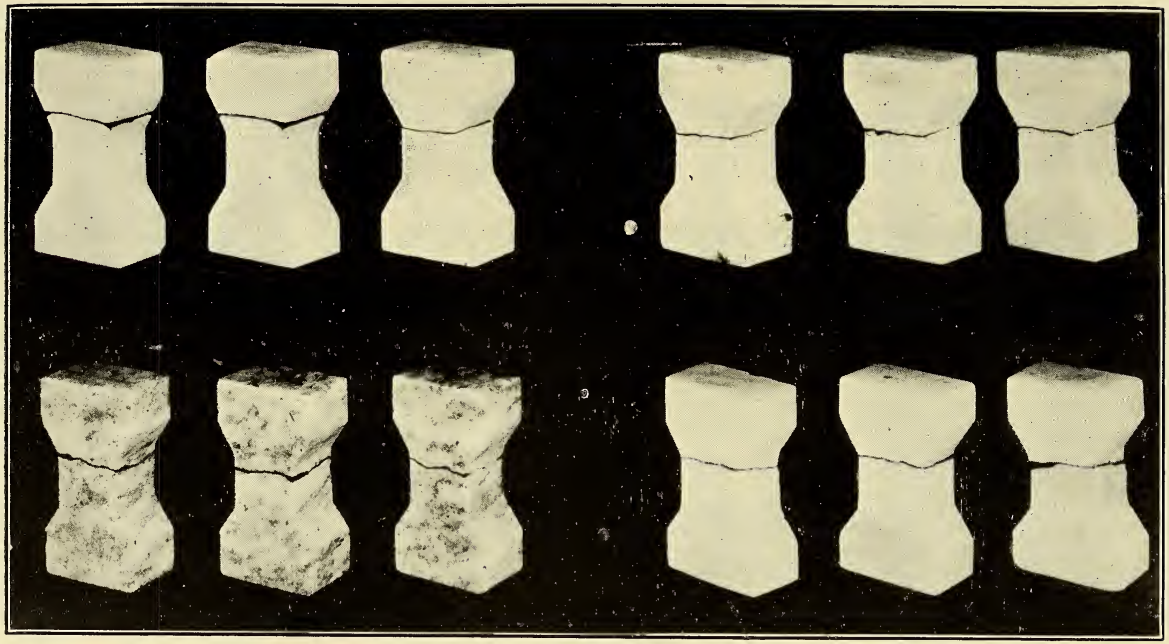
VII. TENSILE TESTS

Tensile tests are seldom made on stone, apparently for the reason that the results have no direct application to actual use. The first determinations of this kind were made by Hirshwald to determine the softening effect of water. He determined this by testing two bars of the stone in tension, one dry and the other after a period of soaking in water. The quotient obtained by dividing the strength of the wet sample by that of the dry sample was termed the coefficient of softening and was regarded by him as an indicator of the durability of the stone.

The tensile tests in this report were made on briquets of the form illustrated by Fig. 1 (*d*) and were made on a 20 000-pound, three-screw testing machine, using the grips employed in cement-testing machines. The results show a range of from 2254 pound per square inch for the oriental marble of Vermont to 154 pound per square inch for West Rutland green marble of the same state. While these values may have no application to stresses in structures, they show the relative cohesive strengths of the marbles, which are useful in showing how well the materials will stand carving. This test might well be applied in the durability test instead of in the compression test; that is, instead of determining the effect of freezing on the compressive strength it is just as rational to determine what the effect would be on the tensile strength. This would facilitate the process considerably in testing marbles and limestones on account of the greater simplicity in preparing the test pieces and the shorter time required in making the test. However, it appears that a greater range in results is obtained from tensile tests than compression tests. This is probably due to the presence of invisible strain lines in the material which affect the tensile strength more than the compressive strength. The presence of these strain lines is



a



b

Fig. 3.—*Briquets from eight samples broken in tension, showing break following certain lines in the different specimens of the same samples*

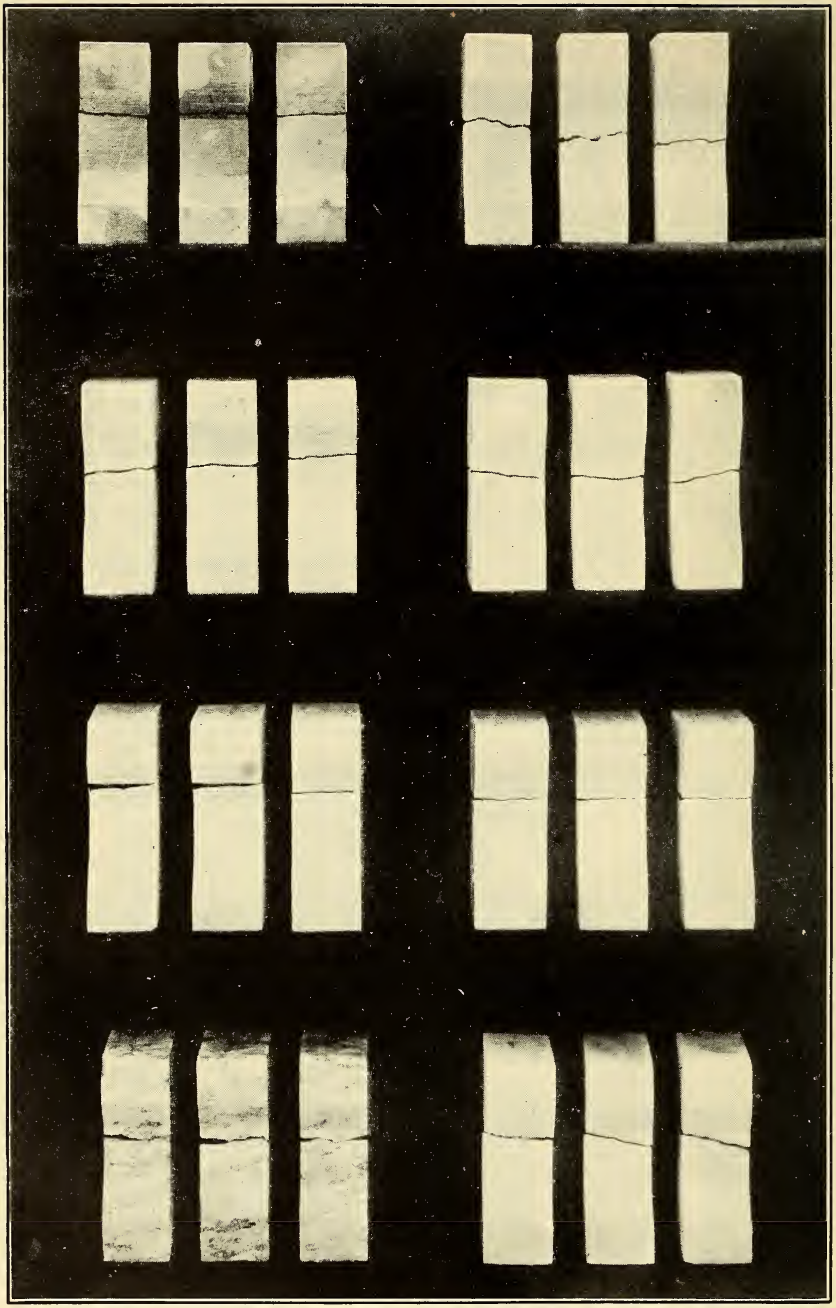


FIG. 4.—*Side views of the samples shown in Fig. 3*

indicated in the illustrations in Figs. 3 and 4, which show the manner in which a set of briquetes broke in tension. The briquets were cut from adjacent portions of the sample and show the rupture following a definite direction. This indicates clearly the lines of weakness, which in most cases could not be discerned otherwise. The cases illustrated were the most marked of all the samples tested, but it may be said that the greater portion showed indications of the presence of these strain lines. These local faults are evidently harmful to the stone, since they furnish a means of more ready access to water as well as causing lines of weakness.

VIII. EFFECT OF FREEZING AND THAWING

The determination of the effect of freezing water in the pores of stone is probably the most important laboratory test that can be made on material which is to be exposed to the weather. This is done by repeated freezings and thawings of cubes of the stones that are kept continually wet throughout the process. The tests for this report were made as follows: The cubes used for the absorption and apparent specific-gravity tests were taken out of the water after 48 hours of immersion and placed in the freezing chamber. When completely frozen, they were taken out and placed in warm water until thawed out; then cold water was turned on until they were cooled again, after which they were returned to the freezing chamber. This operation was repeated 30 times and then the cubes were dried at 110° C to constant weight. The final weight was obtained and compared with the original to determine whether there was any loss in weight. The cubes were carefully examined for signs of disintegration and then tested in compression to determine whether there was any loss in strength. Table 3 gives the results of the compression tests after freezing, and Table 4 gives a comparison of the strength obtained on dry, wet, and frozen cubes; also the change in weight on freezing.

This table shows a loss in weight for practically all the samples and a loss in strength for the greater portion. It has been shown that results of compression tests may vary considerably from the correct value, even under the best conditions. In this series two cubes were tested "on bed" and two "on edge," and the mean was taken for each set of two and compared with the average of the two tested in the original state. Hence an allowance should be made for the probable variation of this mean from the correct value. Referring to the table on page 10, it is found that the maximum variation of any two consecutive tests from the average of the series is 3.5 per cent. It seems proper, then, to disregard all changes in strength equal to or less than 3.5 per cent. There are, however, several samples showing an increase in strength which is much greater than this, and therefore can not be justly accounted for by instrumental variations. This is a feature that very often occurs in the freezing test, and some experimenters account for it by instrumental variations. Dr. Parks, of the Canada Department of Mines, in his report on the "Building and Ornamental Stones of Canada," volume 1, found this to occur on certain limestones and sandstones. He suggests the explanation that there may be a recementation of loosened particles, due to the process of heating and soaking, which may strengthen the stones. To show that such a recementation is possible, he cites an interesting case which occurred at Marmora, Ontario. Here a lithographic quarry was once in operation and the fine dust obtained in working the stone was barreled for use as a polishing material. Several of these barrels were left in the mill, and by the simple process of becoming damp and drying out, protected from both sun and rain, the contents have been converted into a solid mass rivaling the stone itself in hardness.

Another explanation which suggests itself in connection with marble tests is the fact that many samples of marble have numerous strain lines which produce local planes of weakness. Hence if cubes were frozen that happened to be free of these, while those on which the original strength was determined had strain lines, the frozen cubes would probably show a greater strength than the original. On the other hand, many cases which show a great loss of strength in freezing may be explained by the reverse conditions. In cases showing an increase of strength on freezing or a considerable loss the freezing should be repeated, using a large number of cubes for a check. At the best, the results of 30 or 40 freezings, which represent the usual limits of laboratory practice, are not conclusive. Apparently the only sure method of determining the action of freezing is to subject the stone to a great number of freezings; i. e., enough to show plainly a certain amount of disintegration. By the usual method of making this test this would be out of the question on account of the length of time it would require. To overcome this difficulty, an automatic apparatus has been installed at the Bureau of Standards, which consists of a low-temperature chamber and a high-temperature chamber with a shifting mechanism operated by a small electric motor, the periods of which are controlled by a clock. The low temperatures are maintained by a one-half ton refrigerating machine and the high temperatures by a steam coil. It is believed that with this apparatus 48 freezings can be made each 24 hours, and that it will be possible to carry the test far enough to show definite results.

In the freezing tests made for this report no visible disintegration could be found on any of the cubes. This indicates that in order to produce definite visible results a great number of freezings will be necessary.

IX. EFFECT OF SOAKING IN WATER

As previously stated, the softening effect of water was regarded by Hirshwald as indicative of the durability of stone. It may also have a more important significance in certain cases where the stone is used in bridge piers under heavy loads and strong vibrations. Here it would probably prove disastrous to use a stone of low strength that would be much weakened by the continued saturation at the base.

The compression tests in this report were made on dry cubes and also on cubes after two weeks' soaking in water. A loss in strength is shown in nearly every case, and in some cases the loss is considerable. Table 4 gives a summary of the compression tests on cubes dry, wet, and frozen and the percentage change in strength due to freezing and that due to soaking. It will be noted from this that the loss due to soaking is sometimes greater than the loss in the freezing test, and more general. This may be brought about in two ways or by a combination of these. First, the soaking may cause a weakening of the cementing material holding the individual crystals together; second, it may diminish the friction between these crystals and facilitate a sliding in any given direction. The first effect would be shown by the tensile test, and is the factor determined by Hirshwald. The combined effect is shown by the compression test, since here the specimen fails by shearing off along inclined planes.

X. EFFECT OF REPEATED TEMPERATURE CHANGES

The results obtained in measuring the linear expansion of marble for temperature changes show a phenomenon which indicates that there is a permanent change in the internal structure of the material for each change of temperature. When the sample was measured at ascending temperatures from 0° to 60° C, there was found to be a gradual increase in the coefficient of expansion. As the temperature was lowered the contraction curve was similar to the expansion curve, but did not coincide with it—i. e., the sample did not regain its former length, but remained slightly longer. A number of repetitions of this operation showed for each trial a similar effect, and the length of the specimen increased slightly.

In order to determine whether repeated heatings to temperatures which do not affect the chemical composition of the marble cause any weakening or disintegration, a set of cubes was prepared from a white calcite marble. Eleven of these were tested in the original state, and 18 were repeatedly heated in the electric oven to 150° C. After 50 heatings to this temperature 9 were tested in compression in the same manner as the original cubes. The remaining 9 cubes were heated to this temperature 100 times and then tested.

The following statement shows the compressive strength of marble in various states:

Cube number	Unit strength—		Ultimate strength after 100 heatings at 150° C
	In original state	After 50 heatings at 150° C	
1	9411	8883	9028
2	8951	9505	7742
3	8947	8383	8430
4	9252	9196	8682
5	9125	8932	8567
6	9335	9048	8461
7	8938	8822	9068
8	9089	9329	8276
9	8865	8880	8313
10	9663		
11	9340		
Average	9174	8998	8507

These tests show a loss in strength for the heated cubes as follows:

Cubes heated 50 times to 150° C, loss 1.9 per cent
Cubes heated 100 times to 150° C, loss 7.3 per cent

The result of 30 freezings on this same sample of marble showed a loss of 7.3 per cent in strength. Hence it appears that 30 freezings on this sample produced as much deterioration as 100 heatings to 150° C. These results, however, can not be said to represent the effects of actual weathering, first, because both of these tests were made under arbitrary conditions, which are necessarily more severe than the actual conditions; second, because diurnal temperature changes act continuously while freezing occurs during only a part of the time. Thus it seems that while freezing produces a more serious effect on the stone the limited occurrence of this may tend to equalize the effects, or, on the whole, more harm may be done by temperature changes alone. However, some samples are affected more by freezing than others, and it is possible that different results would be obtained on repeated heatings of different types. Extensive experimentation is necessary to determine these effects, and this should be carried out on types of stone that have been in use under exposure for a long period of time, so that a comparison can be made between the laboratory results and that of actual weathering.

XI. ABSORPTION TESTS

The amount of water which a stone will absorb has often been stated to represent the porosity. This is a misconception, because stone seldom, if ever, becomes completely saturated with water. In the first place, a certain percentage of the pores of every stone are probably isolated; i. e., entirely sealed and could not be filled with water. Those pores which are continuous for a certain distance and are then closed will contain air which will in most cases prevent the entrance of water. Absorption tests and porosity tests made for this report indicate that in 2¼-inch cubes of marble the pore space is often less than one-half filled by 48 hours' immersion. In only one case did the absorption value exceed nine-tenths of the total pore space, and the average ratio of the absorption to the total pore space is about as 2:3. Under actual conditions of exposure, in masonry above the ground, the amount of water absorbed is always much less than this, while in moist ground or in bridge piers, where continuously exposed to moisture or water, the absorption may be higher.

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The absorption value is determined to show the probable effect of weathering. The more water the stone absorbs, other things being equal, the more softening will occur and the more harm will be done by atmospheric acids. It was formerly thought that the higher the absorption the more harm would be done by freezing; but this theory is probably wrong. The effect of freezing depends so much on other considerations that it can hardly be said that the absorption value, especially when considered in the absence of other tests, indicates anything in regard to the effect of freezing.

The procedure in making absorption tests in this investigation was as follows: Cubes were used for this test which were later used for the apparent specific-gravity determination and freezing tests. These cubes were smoothly ground on all faces almost to a polish and the sharp edges slightly rounded. They were placed in an electric drying oven and dried at a temperature of 110° C for 48 hours. After cooling, the cubes were weighed to the nearest 0.01 g and placed in a shallow tray containing about 1 inch of water. Small amounts of water were added at intervals until the cubes were immersed. After 48 hours the cubes were taken out one at a time, carefully dried with a towel, and immediately weighed. The increase in weight represents the amount of water absorbed. The percentage of absorption is usually expressed as the ratio of the weight of water absorbed to the weight of the dry stone. This is not a fair way of expressing this quantity, since the specific gravity of different stones vary considerably, and hence the heavier stones appear to have less absorption than a lighter one, when in reality the reverse may be true. As an illustration, consider a 5 cm cube of a calcite marble with an apparent specific gravity of 2.70 and a 5 cm cube of dolomitic marble with an apparent specific gravity of 2.85. Suppose the first absorbs 1 g of water and the second 1.05 g. The weight of the calcite cube will be $5 \times 5 \times 5 \times 2.70 = 337.5$ g, and that of the dolomite $5 \times 5 \times 5 \times 2.85 = 356.25$ g. The absorption values, according to the usual manner of expression, would be, for the calcite, $1 \times 100 \div 337.5 = 0.296$ per cent, and, for the dolomite, $1.05 \times 100 \div 356.25 = 0.295$ per cent. Hence it appears that the absorption value when expressed in this way is deceptive and does not show the relative amounts of water absorbed by different samples. The example cited is for stones of the same classification—viz, marbles—and here the difference in specific gravity does not vary from one sample to another to a great extent, but, if different kinds of stone are considered, a still greater discrepancy will be apparent. For instance, some igneous stones have specific gravities above 3, while occasionally sandstones run as low as 2. Nevertheless, it has been the practice to express the absorption value for all types of stone as the ratio of the weight of water absorbed to the weight of the stone. This is, no doubt, due to the fact that the determination can be made roughly on odd shapes of stone without further trouble than that of making two weighings.

The proper way of expressing this value is by volume; i. e., the volume of water absorbed by a certain volume of stone. This eliminates the discrepancy caused by the variation in the specific gravity of different stones and at the same time affords a quantity that may be thought of in terms of the pore space. To determine this, however, one must first determine the weight of the water absorbed by the sample and then determine the volume of the sample. The volume of the sample is determined in the apparent-specific-gravity test, and in this investigation one process was avoided by first making the absorption test and then determining the apparent specific gravity of the same cubes. This latter process will be described under specific-gravity tests. Having determined the weight of water absorbed by a test piece and also the volume of the test piece, the absorption value is computed by dividing the weight of the absorbed water expressed in grams by the volume of the cube in cubic centimeters. It is usually more convenient to express this as a percentage ratio so the weight of water is multiplied by 100 and divided by the volume of the specimen. Table 9 gives the absorption values of the samples expressed both by weight and by volume. The lowest percentage-by-volume value obtained in this series was 0.043 on a black marble from Harrisonburg, Va., and the highest 1.193 on a gray marble from Phenix, Mo. This latter sample possesses some properties of a limestone, and until recently was regarded as such, although the composition is nearly pure calcium carbonate, and the polish is very good. The usual limits of absorption for marble appear to be 0.1 per cent and 0.56 per cent, by volume.

XII. APPARENT SPECIFIC GRAVITY

The apparent specific gravity is the specific gravity of the stone, regardless of the pore spaces and the air contained therein. It is the weight in grams of a cubic centimeter of the dry stone.

This value is useful, first, in determining the weight per cubic foot of the stone; second, as an aid to classification; third, for calculating the actual pore space; fourth, for reducing the water absorption of a stone determined by weight to the volume ratio.

The apparent-specific-gravity values in this report were determined on the cubes which were used for the absorption test. Hence the determination required only one additional operation, viz, weighing the cubes suspended in water. The values were computed from the formula $G=\frac{W_1}{W_2-W_3}$ in which G equals the apparent specific gravity, W_1 equals the weight of the dry cube, W_2 equals the weight of cube after soaking in water but dried on the surface with a towel, and W_3 equals weight of the soaked cube suspended in water.

This method eliminates the difficulty otherwise encountered on account of the stone absorbing water while being weighed suspended. This point has been much discussed by different experimenters and different methods have been proposed to avoid it, but this is the only procedure that eliminates the difficulty without introducing other errors. Furthermore, it is very simple, and if determined on the same test pieces that have been tested for absorption only one additional weighing is necessary: viz, that of the wet pieces suspended in water.

A slight error may be made in obtaining the weight of the suspending basket unless the water stands to the same point on the suspending wire when weighed empty and with the stone. In order to eliminate this error, the beaker should be filled nearly full of water while determining the weight of the basket empty; then when ready to weigh the cube, pour out water approximately equivalent to the volume of the cube. This will cause the suspending wire to be immersed to the same point at both weighings.

The weight per cubic foot of the dry stone is obtained by multiplying the apparent specific gravity by 62.5. If the weight per cubic foot of the wet stone is desired, the weight of the absorbed water per cubic foot may be calculated from the percentage of absorption value and added to the weight per cubic foot of the dry stone. To determine the volume absorption value when the absorption has been determined by weight, multiply the latter by the apparent specific gravity of the stone.

Calcite marbles have apparent-specific-gravity values ranging from 2.70 to 2.73, while dolomitic marbles have values between 2.84 and 2.86. Hence this determination furnishes a means of classifying the stone. Furthermore, values between these limits usually indicate the presence of a certain amount of $CaMg(CO_3)_2$ along with $CaCO_3$.

XIII. TRUE SPECIFIC GRAVITY

The true specific gravity is the specific gravity of the solid stone material. It is therefore the weight in grams of a cubic centimeter of stone having the pores filled with solid material of the same composition. This is best obtained by reducing the sample of stone to a fine powder and determining the specific gravity of the particles. The determinations made for this report were made in the Le Chatelier flask, using 58 g samples of the powdered stone passing a 200-mesh sieve. The material was first dried at 110° C and then weighed and sealed in sample boxes until the test was made. By lowering a thermometer graduated to tenths of a degree into the liquid before the zero volume reading and after the final reading the actual temperatures were obtained and the volume corrections were applied to reduce these to a common temperature. Since the quantity desired here is the volume of the powder, it is only necessary that the two volume readings be reduced to the same temperatures. In this method the volume readings were all reduced to 20° C. This procedure was found to give more uniform results than the usual method, due to the fact that a slight difference in the temperature of the gasoline between the two readings greatly magnifies the volume error. This is because the total expansion or contraction of all the gasoline in the flask, about 300 cc, comes into consideration. Assuming the coefficient of expansion for gasoline to be 0.0011, the volume error due to 1° C difference in temperature would be 0.33 cc. On a 58 g sample this would cause an error in the determination of four points in the second decimal place. In the method of setting the flask into water to allow it to come to the same temperature for both readings, the temperature of the water must be kept constant and the flask must be left long enough to come to this temperature. Since this time must be estimated, it is obvious that the method of recording the temperatures of the gasoline and correcting the volumes is more accurate.

This determination on marble powder at the best does not give nearly as accurate results as are obtained in the apparent-specific-gravity tests, and in order to obtain a result that is reliable in the third decimal place three or four tests should be made on the same sample and averaged.

XIV. POROSITY

The determination of the total pore space of stone can be calculated from the results of the true and apparent-specific-gravity tests. Since the apparent specific gravity is the weight in grams of 1 cm^3 of the actual stone, and the true specific gravity is the weight of a cubic centimeter of solid stone, the difference in these two values is the amount of solid stone required to fill the pores of the actual stone. Hence the percentage of pore space is found by the formula $P = \frac{100}{t}(t-a)$, where t is the true specific gravity and a is the apparent specific gravity.

The porosity represents the limiting value of the amount of water the stone can absorb. The theory has been advanced by Hirshwald,[1] that if the absorption value is more than nine-tenths of the total pore space the stone would suffer injury from freezing. This is based on the fact that water expands as the temperature is lowered from 4° C to the freezing point by one-tenth of its volume. Hence if the stone is more than nine-tenths filled with water there will not be space enough to allow for the expansion, and the stone will be subjected to internal stresses which tend to disintegrate it. The relation of the absorption to the total pore space is probably a more important determination in the study of the weathering properties of the stone than any other short of the freezing test.

XV. STAINING TESTS

In order to determine the relative susceptibility of the different marbles to staining and their penetrability, samples were submitted to the following treatment: Cubes of the same dimensions as those used for compressive tests were drilled from the center of one face to the center of the cube with a 3/8-inch drill. After being dried the cubes were placed on a table and the holes filled with a 1:5000 solution of eosin. In a few the stain penetrated through to the exterior faces, and the time required for this was noted. In most cases it had not penetrated to the surface at the end of six hours. At the end of this time the solution was removed from the holes and the cubes were sawed in half, thus exposing the stained area. Several cubes showed no penetration whatever. On those that did the stained area was traced on tracing paper and the areas measured with a planimeter. Table 11 gives the results of this test and also the appearance of the stain. These results show a wide range in

[1] Hirshwald, Bautechnische Gesteinuntersuchungen.

the permeability of the different samples, some staining through in a short time and others showing no penetration after six hours. For comparison the water-absorption values and porosity are given in this table. There seems to be no definite relation between either the absorption and area stained or the porosity and the area stained.

In order to determine whether there is any relation between the staining effects and the results of the freezing tests the percentage changes in strength in the freezing tests are also recorded in Table 11. This shows that several samples that lost considerable strength in freezing also gave large stained areas, but, on the other hand, several samples that were not stained at all showed a considerable loss in freezing. It must be concluded, therefore, that so far as these results are concerned the staining test does not furnish any criterion for predicting the effect of freezing.

XVI. PERMEABILITY TESTS

The pore spaces in marble are conceded to be chiefly concerned in determining the relative durability of different types. The total pore space of the sample does not appear to be a reliable guide to judge what will be the effect of freezing. The absorption value is equally unreliable. It has been advocated that the relation between the absorption value and the total pore space gives a criterion for predicting durability, but this series of tests does not substantiate the theory. Hence it appears that an exhaustive study of the pore spaces is necessary to determine what property or peculiarity makes some stones more susceptible to disintegration than others. Permeability tests have been made on more porous stones, such as sandstones, but we have no records of such tests on marble. An attempt to force water under a pressure of one atmosphere through 1 inch of marble failed entirely. It was found, however, that most samples would allow the passage of air through this thickness quite readily if the sample were dry, but if previously soaked in water no air would pass. To determine the relative air permeability of different samples, 2¼-inch cubes were drilled in the same manner as for the staining tests, and a glass tube 32 inches long, having a short length of rubber tubing on the end, was forced into the hole, forming an air-tight seal. The tube was then filled with mercury and inverted in a small crystallizing dish of mercury. If no air was drawn through the cube, the mercury column would stand at atmospheric pressure—viz, approximately 30 inches—

but, if air passed through, the column would gradually drop. As a matter of rough comparison, the different samples were tested in this way to determine the drop in the mercury during the first 15 minutes. The number of inches drop for the samples tested are recorded in Table 11, under the column headed "Air permeability." The results show that some samples were practically impermeable to air under one atmosphere, while others allow it to pass quite readily. Several samples were repeated a number of times for a check, and it was found that usually a smaller amount of air passed each succeeding time. This same effect was observed by Dr. Parks [2] in experimenting on the water permeability of certain building stones of Ontario. This is evidently due to the pores gradually becoming sealed either with loose particles of stone or by foreign matter being carried into the pores. It is quite reasonable to suppose that the numerous dust particles in the air would be carried into the stone and gradually seal the passages.

It should be noted that in this manner of testing the permeability the difference in pressure is not constant, but gradually drops with the column of mercury. It would be more satisfactory to devise an apparatus for permeability tests that would give a constant pressure no matter how much air passed. But these tests serve to show the relative permeability of the different samples and afford a means of comparing this property with the results of freezing tests. A study of Table 11 shows no relation between the permeability and the loss in strength on freezing. However, these tests should be regarded as preliminary and not conclusive. As stated under freezing tests, the loss in strength in those tests can not always be attributed to the effect of freezing. It is possible that with more extended freezing tests, showing more definitely the effect of freezing, a relation may be established between the permeability of stone and frost action.

XVII. CHEMICAL ANALYSIS

The principal constituents have been determined for the greater portion of the samples of marble included in this investigation for the purpose of establishing their purity and suitability for use in the manufacture of lime, Portland cement, etc. One important problem encountered in the operation of stone quarries is the utilization of the waste products. The increasing use of lime for agricultural purposes may in some cases solve this problem for those operators whose material is suitable for this product.

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[2] W. A. Parks, Report on the Building and Ornamental Stones of Canada, vol. 1.

Sugar refineries, carbonic-acid factories, pulp mills, and iron smelters use marble and limestone refuse. The chemical analysis of these samples given in Table 10 may be of value to such companies in selecting the marble best suited to their uses. Chemical analysis may sometimes be of use in indicating the presence of harmful constituents. White marbles are very easily stained, and the presence of ferrous iron or iron sulphides may cause the surface to become stained through the alteration of these by exposure to the weather.

Chemical analysis is also useful in classifying the stone. The marbles included in this report may be divided into three groups, viz, calcite marbles, dolomite marbles, and serpentine marbles. Calcite ($CaCO_3$) or calcium carbonate contains 56 per cent of CaO (lime) and 44 per cent of CO_2 (carbon dioxide). It effervesces strongly with cold dilute hydrochloric acid and is entirely soluble in cold dilute acetic acid.[3] Calcite marbles differ from the above composition in that they may contain small amounts of silica (SiO_2), alumina (Al_2O_3), iron in the form of oxides, carbonates, or sulphides, and various other constituents.

Dolomite, $CaMg(CO_3)_2$, a carbonate of lime and magnesia, contains 54.35 per cent of $CaCO_3$ (calcium carbonate). It effervesces less readily with cold dilute hydrochloric acid than calcite and is next to insoluble in cold dilute acetic acid.[3] Dolomitic marbles may contain the same impurities mentioned above for calcite marbles.

Serpentine is a marble only in a commercial sense. Dark-colored serpentine is an hydrous silicate of magnesia and iron.[3] Two serpentines have been tested for this report, viz, the widely used serpentine from Roxbury, Vt., and the verd antique from Holly Springs, Ga.

XVIII. VOLUME-RESISTIVITY TESTS

These tests have been made to show the relative value of the different marbles for the purpose of electrical insulators. Since the resistivity is affected considerably by the presence of moisture in the pores of the marble, these tests have been made under different conditions of saturation, and the results, given in Table 12, show the range of resistivity that may be expected. For ordinary conditions of use indoors it is believed that values obtained on samples dried in the laboratory air several days should furnish the information desired.

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[3] T. Nelson Dale, The Commercial Marbles of Western Vermont, U. S. Geological Survey Bulletin 521.

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This determination was made on small slabs of marble 10 by 10 by 1 cm. The method used is known as the galvanometer method and is described fully in Bureau of Standards Scientific Paper 234 by Harvey L. Curtis.

XIX. CARBONIC-ACID TESTS

The following experiments by George P. Merrill, on the effect of carbonic acid on marbles and limestones are taken from the Proceedings of the United States National Museum, volume 49, pages 347–349.

The tests registered below are made with a view of determining not merely the relative suitability of certain calcareous rocks used for building and ornamental work, but, as well, the manner in which the solvent acted. The ultimate aim of the experiments, as is obvious, was to ascertain how the stones would withstand the effects of an atmosphere and its rainfall made acid through absorbed carbonic acid. To make the results appreciable within a certain time it was of course necessary to exaggerate the conditions. The process was as follows: Two samples of each stone selected were cut into the form of cubes approximately an inch in diameter, though without any attempt at exact correspondence in weight. How close the approximation is is shown in the accompanying table of results.

The surfaces of each cube were rubbed with flour of emery on a glass plate as smooth as the nature of the material permitted, but no attempt was made to polish. They were then thoroughly washed and dried at 100° C. The cubes were then suspended by threads, in each case passed but once around the cube, in a large jar of water kept acid by a stream of carbonic acid from a charged cylinder. The water was changed once each week. No attempt was made to have the stream of bubbles constant and continuous, but the direction was changed occasionally to make certain that all were subjected to like conditions. Twice during the trial the cubes were withdrawn and while still suspended dried out by artificial heat and again immersed.

At the end of three months they were withdrawn, dried at a temperature of 100°, and brushed off with a soft fitch brush to remove any loosened granules or dust. The appearance of each cube was carefully noted as to color changes, as well as to the manner in which the solvent acted. The tables below give the weight of the cubes before and after and the loss of material both in weight and in percentage amounts. The first table gives the results of some preliminary tests which were not carried to completion, owing to imperfection of apparatus. They are, however, included here, since so far as they go they are confirmatory of those in the second. The results of both cases agree surprisingly well. It will be noted that, while the amount of material lost in the first series is less than in the second, owing to the shorter period of trial, the two are always in accord. The amount of material lost by solution is not, however, the sole item of importance, nor, indeed, the item of most importance. It will be noted that in some instances a stone losing a certain amount still retains a nearly smooth surface and sharp arrises. Others become roughened, granules loosened to the point of falling away, and the arrises, as a consequence, left ragged. In some of the stones there is a tendency for the smaller interstitial crystals to disappear, leaving the larger standing in relief. The Tennessee samples tested are of the gray and pink spotted varieties. In these the tinted calcite, which, judged from the forms, represents fragmental fossil material, is more refractory than the colorless and is left in slight relief. In the case of the oolitic limestones the oolites are eaten out, leaving the crystalline or interstitial material and the fossil fragments in relief, the outline of the oolite being sometimes preserved by the insoluble impurities. The considerable amount of insoluble material set free from these oolitic cubes during the trial setting to the bottom of the jar as mud or remaining to be brushed off the surface when the cube was dried seems to have come wholly from the oolites, and not from the interstices. It will be noted, as might have been expected, that the dolomitic marbles are not appreciably affected and that the oolitic stones lost during the trial an amount two and three times as great as that of any other of the stones tested. In but one instance was there any marked change in color in any of the samples.

TABLE I.—Preliminary Trial Extending Over Period of 70 Days

Kind and locality	Weight before trial	Weight after trial	Loss of weight	Loss of weight	Remarks
	g	g	g	Per cent	
White crystalline limestone: Marble, Yule, Colo.	45.053 44.313	44.7075 43.8815	0.3455 .4325	0.0077 .0097	Very slightly roughened; no granulation.
White crystalline limestone: Marble, Pickens County, Ga.	42.3935 42.747	41.935 42.3565	.4585 .3905	.011 .009	Slightly roughened; no granulation.
White crystalline limestone: Marble, West Grove, Pa.	46.3455 44.7015	46.2345 44.586	.1110 .1155	.0024 .0026	Effect scarcely appreciable.
Pink crystalline limestone: Marble, Knoxville, Tenn.	50.4485 48.478	49.904 47.9725	.5445 .5055	.0108 .0104	White portions slightly etched, leaving the pink standing in relief.
Gray crystalline limestone: Marble, Concord, Tenn.	45.1075	44.4765	.6310	.012	White portions slightly etched, leaving the pink standing in relief.
White crystalline limestone: Marble, Rutland, Vt.	40.6655 41.1245	40.1185 40.432	.547 .6925	.013 .016	Surfaces appreciably roughened.
Blue crystalline limestone: Marble, Rutland, Vt.	44.444 41.0555	43.8355 40.589	.6085 .4665	.015 .011	Surfaces appreciably roughened; no granulation.
White crystalline limestone: Marble, Carrara, Italy.	38.6165 40.5885	38.114 40.0925	.5025 .496	.013 .012	Surfaces appreciably roughened; like white Rutland.
White crystalline dolomite: Marble, Cockeysville, Md.	38.80 36.507	38.7755 36.4855	.029 .0215	.00062 .00058	Not appreciably acted upon.
White crystalline dolomite: Marble, Tuckahoe, N. Y.	42.0655 41.405	42.0415 41.3795	.0240 .0255	.00056 .0006	Not appreciably acted upon.
Oolitic limestone, Bedford, Ind.	43.5785 41.1475	42.2435 39.8795	1.335 1.268	.0304 .0308	Distinctly roughened and pitted, the fossil fragments left standing in relief.
Oolitic limestone: Bowling Green, Ky.	41.1655 37.8355	40.504 37.1725	.6115 .663	.014 .017	Distinctly roughened and pitted, the oolites being eaten out, leaving surface covered by circular and oval pits often with a slight residual eminence in center.

TABLE II.—Second Trial Extending Over Period of Three Months

Kind of stone and locality	Original weight	Final weight	Loss of weight	Loss in weight	Remarks
	g	g	g	Per cent	
White crystalline limestone: Marble, Yule Creek, Colo.	51.551	50.6465	0.9045	0.017	A very slight roughening of the surface, but no granulation and but slightly attacked on the edges or arrises.
	48.194	47.2465	.9475	.019	
White crystalline limestone: Marble, Pickens County, Ga.	44.034	43.315	.719	.0165	Surfaces very slightly roughened, but no granulation.
	43.6675	42.946	.7215	.017	
White crystalline limestone: Marble, Cherokee County, Ga.	43.3885	42.7335	.655	.015	Surfaces very slightly roughened, a slight yellowing.
	44.400	43.683	.717	.016	
White crystalline limestone: Marble, West Grove, Pa.	47.8385	47.615	.2235	.0047	Surfaces roughened, but no granulation.
	47.9695	47.768	.2015	.0042	
White crystalline limestone: Marble, Proctor, Vt.	44.4945	43.62	.8745	.019	Surfaces distinctly roughened and granulated, small particles loosened and falling away when handled or brushed; arrises roughened.
	44.1085	43.3125	.796	.018	
White crystalline limestone: Marble, Proctor, Vt.	44.974	43.9295	1.0445	.023	
	45.172	44.001	1.171	.026	
White crystalline limestone: Marble, Pittsfield, Vt.	42.536	41.705	.831	.019	
	43.97	42.9715	.9985	.022	
White crystalline limestone: Marble, Carrara, Italy.	43.5085	42.598	.9105	.021	Surfaces distinctly roughened and granulated, small particles loosened and breaking away when handled or brushed; arrises strongly attacked.
	42.462	41.4885	.9735	.023	
Gray crystalline limestone: Marble, Knoxville, Tenn.	46.796	45.8765	.9245	.019	Surfaces roughened by the corrosion of the colorless granules leaving the pink tinted standing in relief. No granulation or mechanical loosening of particles.
	45.1725	44.2975	.875	.019	
Gray crystalline limestone: Marble, Knoxville, Tenn.	44.069	43.226	.843	.019	
	44.3095	43.4545	.855	.019	
Gray crystalline limestone: Marble, Knoxville, Tenn.	45.7165	44.52	1.1965	.026	
	45.5565	44.609	.9475	.021	
Pink crystalline limestone: Marble, Concord, Tenn.	42.7345	41.808	.9265	.021	
	42.9635	42.1675	.796	.0185	
White crystalline dolomite: Marble, Cockeysville, Md.	40.724	40.687	.037	.00091	No perceptible change.
	38.4355	38.3995	.036	.00093	
White crystalline dolomite: Marble, Berkshire, Mass.	45.529	44.8385	.6905	.015	Surfaces distinctly roughened by corrosion along planes of cleavage and color changed to a decided buff.
	45.052	44.378	.674	.015	
White crystalline dolomite: Marble, Lee, Mass.	43.659	43.625	.034	.00077	No perceptible change.
	44.493	44.4415	.0525	.0011	
White crystalline dolomite: Marble, Tuckahoe, N. Y.	43.442	43.4025	.0395	.00091	No perceptible change.
	44.792	44.7465	.0455	.0010	
	46.438	46.3815	.0575	.0012	
	47.053	47.0105	.0425	.0009	
Oolitic limestone, Bedford, Ind.	36.0945	34.493	1.6015	.044	Surfaces much roughened and pitted owing to solution of the oolites leaving the fossil fragments and crystalline material of the interstices in relief; arrises strongly attacked.
	38.3245	36.4495	1.875	.049	
Oolitic limestone, Bowling Green, Ky.	38.4375	37.1775	1.26	.033	The same, only that the stone is more distinctly oolitic and the surface becomes covered with circular and oval pits.
	38.6845	37.44	1.2445	.032	
Oolitic limestone, Salem, Ind.	37.2795	35.39	1.8895	.0506	
	37.45	35.591	1.869	.050	

XX. THERMAL EXPANSION OF MARBLE

The change in volume of marble due to temperature changes is of practical interest in two particular ways: First, in masonry structures the expansion and contraction of the individual members of the different courses tend to crumble and destroy the bonding mortar; second, the unequal expansion and contraction of the crystals tend to weaken and disintegrate the marble itself.

The expansion of marble as well as that of other types of stone has been found to vary considerably from that of the straight-line expansion of the metals, and for different samples of marble at ordinary temperatures the range appears to be from one-fourth to two-thirds that of steel. As the temperature increases the rate of expansion increases, and the curve probably becomes steeper until the point is reached where the chemical composition of the marble is changed. Another peculiarity in the expansion of marble is that when once expanded by heat it does not entirely contract to its original dimensions but retains a part of the increase after the specimen has cooled.

A series of measurements were made by William Hallock of the United States Geological Survey in the year 1890 to determine the thermal expansion of certain rocks. The specimens were 3 feet in length and were measured at temperatures of 20 and 100° C in a water bath by the comparator method. Ten specimens of marble were measured in this series and the results obtained are as follows:

Description of marble	Coefficient of expansion
A fine-grained marble from Rutland, Vt., cut parallel to the bedding	0.00000659
Duplicate sample of the above	.00000661
A rather fine-grained pink marble from Knoxville, Tenn	.00000495
Duplicate sample of the above	.00000525
A medium-grained pinkish mottled sample of "Keowa" marble from the Happy Valley Quarry, Ga	.00000348
Duplicate of the above sample	.00000309
A coarse even-grained sample of "Creole" marble from the Happy Valley Quarry, Ga.	.00001100
A coarse, even-grained, nearly pure white "Cherokee" marble from the Happy Valley Quarry, Ga	.00000740
Duplicate of the above sample	.00000786
Triplicate of the above sample	.00000855

The permanent increase in length was noted in this series of tests which amounted to 0.2 to 0.3 mm for the 3-foot specimens.

The permanent increase was also noted in expansion measurements made by the Ordnance Department of the United States Army in the year 1875. In these experiments the samples, which were 20 inches long, were measured in water at the temperatures of 32 and 212° F. It is also stated that compression tests on the specimens after this heating and cooling in water showed a loss in strength as follows: Granite, 16.3 per cent; marble, 53.8 per cent; limestone, 41.2 per cent; sandstone, 33.1 per cent.

In 1910 experiments were made by N. E. Wheeler which are reported in Transactions of the Royal Society of Canada, Third Series, Volume IV, on samples of diabase, granite, and marble. These measurements were made by the comparator method on cylinders of stone 2.4 cm in diameter and 20 cm long, heated by means of an electric coil. The marble, which was a white Carrara, was measured at temperatures up to approximately 500° C. The same sample was measured consecutively during six different heatings. The total expansion and permanent expansions for the different heatings are indicated in the following table:

Number of heating	Temperature	Total expansion	Permanent expansion
	°C	mm	mm
First	448	1.611	
	19.5		0.732
Second	464	1.810	
	16		.897
Third	463	1.852	
	19		.952
Fourth	504.5	2.119	
	18		1.048
Fifth	478	1.998	
	25		1.074
Sixth	478.5	2.129	
	18		1.095

These experiments, which are given in full in the report referred to above, show the increased rate of expansion for the higher temperatures and the permanent expansion for each heating. The permanent expansion as well as the rate of expansion appears to become less for each successive heating, and the expansion for temperatures between 18 and 60° C appears to become almost negligible at the fifth and sixth heating.

A number of samples were measured by the comparator method at the Bureau of Standards during the year 1917 by L. W. Schad and P. Hidnert. These experiments were made on samples 30 cm long and 1 cm square and a number of readings were taken between the temperatures of −25 and +300° C. A sample of Pittsford Italian marble from Vermont gave the following:

Number of heating	Temperature	Total expansion	Permanent expansion
	°C	mm/m	mm/m
First	300	6.0	
	25		2.7
Second	300	9.7	
	21		3.0
Third	300	13.3	
	23		3.2

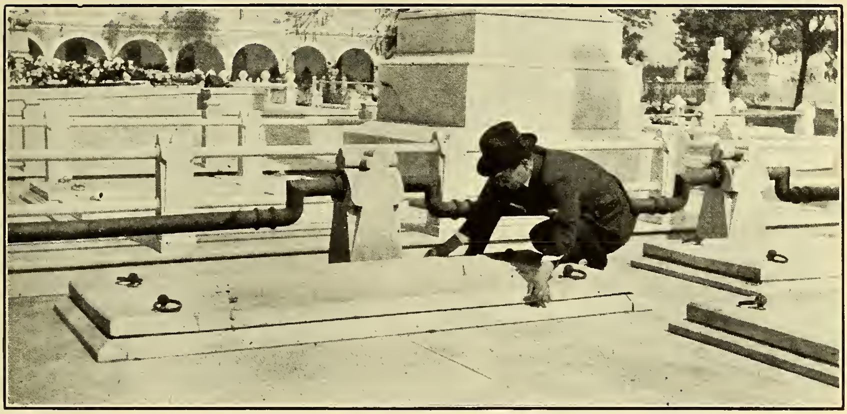

FIG. 5.—*Warped marble in cemetery at Habana, Cuba*

FIG. 6.—*Warped marble in cemetery at Habana, Cuba*

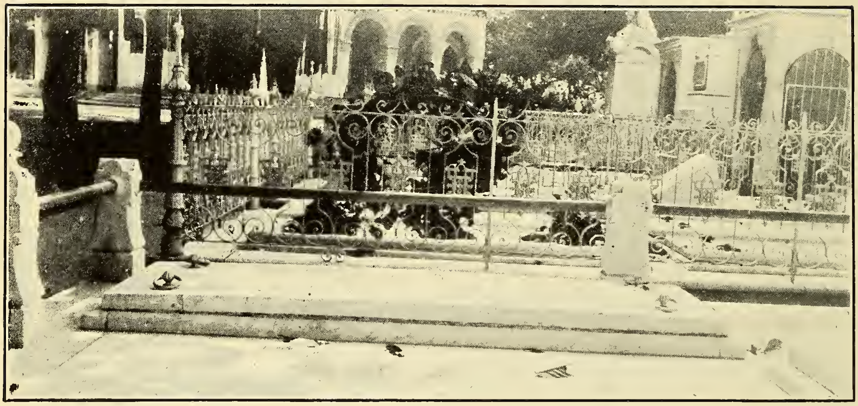

FIG. 7.—*Warped marble in cemetery at Habana, Cuba*

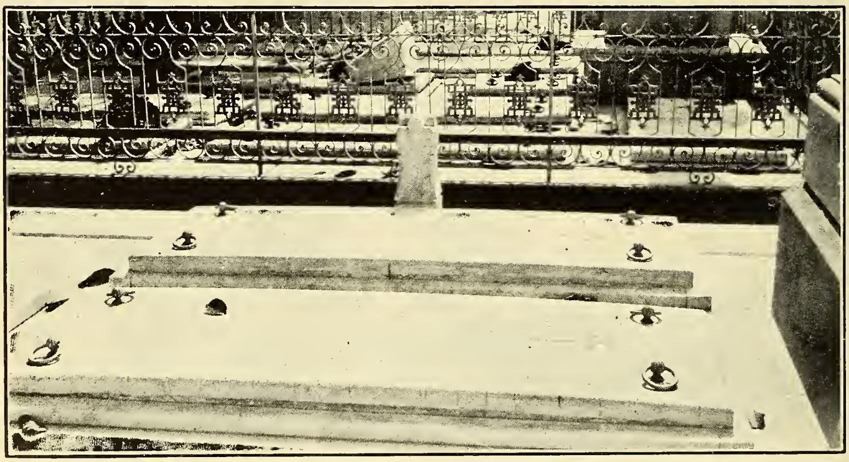

FIG. 8.—*Warped marble in cemetery at Habana, Cuba*

A sample of Florentine blue marble from Vermont, measured successively at the temperatures of 20 and 100, 20 and 150, 20 and 200, 20 and 250, 20 and 300° C, gave the following results:

Number of heating	Temperature	Total expansion	Permanent expansion
	°C	mm/m	mm/m
	20	0.0	
First	100	.85	
	20		0.42
Second	150	1.82	
	20		1.12
Third	200	3.00	
	20		1.86
Fourth	250	4.26	
	20		2.62
Fifth	300	5.77	
	20		3.48

A sample of Dorset, Vt., gray marble was measured at several temperatures between +60 and −40° C. This specimen gave results for temperatures above zero similar to the foregoing. At the lower temperatures the contraction did not continue, as would be expected, but a slight expansion occurred between −4 and −27° for the first run and also between −10 and −40° for the second run. This expansion at the lower temperatures showed a tendency to remain permanent as the temperature was again raised; i. e., the expansion curve remained nearly horizontal as the temperature was raised to zero.

These results, together with those previously obtained, show that it is not practicable to state a coefficient of expansion for marble on account of the peculiar behavior under temperature changes.

It is proposed to publish a report later on the thermal-expansion-of-marble experiments done at this Bureau. This report will probably include the complete data on the samples cited above, together with measurements on a number of other samples.

XXI. WARPING OF MARBLE

Several instances have been noted in which marble has warped to a considerable extent. The most marked of these are to be found in the cemetery at Habana, Cuba. In this cemetery the vaults are covered with slabs of marble from 2 to 3 inches thick. A great number of these cover slabs have warped so much as to be very noticeable.

The accompanying photographs, taken of different slabs in this cemetery, illustrate this warping. Fig. 5 shows a slab which has warped upward at each side. The amount of this is shown by the tape stretched from side to side with a partly opened knife lying on the marble at the center. Fig. 6 shows the same slab with the tape stretched near the middle. Fig. 7 shows a slab warped transversely; i. e., buckled up in the middle and resting on the base only at the ends. Fig. 8 shows two others warped in the same manner.

This warping can not be due to the weight of the slab, since many cases show the warping in the opposite direction to what would occur from this cause. In fact none of the slabs are warped in a way that could be entirely explained by pressures.

The only explanation that appears to account satisfactorily for these instances is to be found in the diurnal temperature changes. The slabs, being exposed to the direct rays of the tropical sun, are heated to perhaps 130 or 140° F. As shown by thermal-expansion measurements on marble, the material once expanded by heat does not entirely contract to its original dimensions. If there should be a slight variation in the marble from one point to another, it is logical to assume that the amount of the permanent expansion would also vary. Hence by the continued heating and cooling of the marble by the sun those parts or layers retaining the greater permanent increase would "outgrow" the other parts and cause warping. When we consider the original formation of marble—i. e., a slow process of sedimentation in which perhaps a thousand years elapsed during the formation of each 1 inch of thickness—it does not seem unreasonable to assume a slight variation in texture for different layers. These slabs are cut parallel to the bedding, which places the bedding planes horizontal; i. e., in the position in which they were originally formed. Hence if the top inch of thickness possesses the property of growing faster from alternate heating and cooling than the lower layers, the slab would curve downward and for the opposite condition the slab would curve upward. It is probable that further study of the thermal expansion of marble will establish the cause of warping.

XXII. THE SAMPLE COLLECTION

A collection of uniform samples representing all the available types of stone would be valuable in showing the general characteristics of the different varieties and also the architectural effects that could be obtained by the combination of different types. In connection with the cooperative investigation of building stones it is the purpose of this Bureau to make up such a collection, which will be kept on file for use by engineers, architects, and others interested.

A number of commercial marbles have been secured and are available for inspection at this Bureau. These samples consist of slabs 8 by 12 by 1 inch, polished on one face. These are displayed in glass cases showing the trade name, producer, and location of quarries.

XXIII. SUMMARY

Sections I to IV explain the cooperative program, the purpose of the work, the method of securing samples, and preparing test specimens.

The methods used in making the strength, freezing, absorption, specific gravity, porosity, staining, and permeability tests for this report are described in Sections V to XVI.

Chemical analyses have been made on 42 samples for the purpose of classification and the determination of harmful elements.

Volume-resistivity determinations have been made on a number of samples to determine their relative value for electrical insulators and the variation of this value under different conditions of moisture.

The results of carbonic-acid tests made by George P. Merrill, of the National Museum, are included in this report, together with his description of the tests.

A few measurements of the thermal expansion of marble were undertaken to establish a coefficient value. These measurements indicate that marble does not expand at a uniform rate as the temperature is raised, and hence it is not possible to state a coefficient of expansion that will hold good for any but small ranges of temperature.

The warping of marble is illustrated by photographs, and a discussion is given of the peculiar warping of some of the slabs illustrated.

The collection of American marbles at the Bureau of Standards is briefly described in Section XXII.

Tables 1 to 12, following, give the results of the various tests, and are so arranged that the properties of the different samples may be easily compared.

XXIV. TABLES 1 TO 12

TABLE 1.—Identification of Laboratory Numbers

Ref. No.	Laboratory No.	Trade name	Producer	Location of quarry
1	3942	Verd Antique	Vermont Marble Co	Roxbury, Vt.
2	3943	Oriental	do	Swanton, Vt.
3	3944	Black Marble	do	Isle Le Motte, Vt.
4	4060	Light Cloud Orvillo	Green Mountain Marble Co	Clarendon Springs, Vt.
5	4400	Pittsford Italian	Vermont Marble Co	Pittsford, Vt.
6	4401	Rutland Italian	do	West Rutland, Vt.
7	4402	West Rutland Green	do	Do.
8	5654	Brandon	do	Brandon, Vt.
9	5655	Rutland Blue	do	Rutland, Vt.
10	5656	Danby	do	Danby, Vt.
11	5657	Dorset Gray	do	Dorset, Vt.
12	5658	Florentine Blue	do	Florence, Vt.
13	5660	Hollister	do	Do.
14	5661	Albertson Blue	do	West Rutland, Vt.
15	5662	Riverside	do	Proctor, Vt.
16	10 206		Burlington Marble Co	Burlington, Vt.
17	10 208		do	Do.
18	5659	Pink Lepanto	Vermont Marble Co	Plattsburg, N. Y.
19	3288	Gouverneur Dark	Gouverneur Marble Co	Gouverneur, N. Y.
20	5949	South Dover	South Dover Marble Co	Wingdale, N. Y.
21	3483	White Beaver Dam	Beaver Dam Marble Co	Cockeysville, Md.
22	3936	Mar Villa	do	Do.
23	2633	Pentellic, Grade A	Alabama Marble Co	Gantt's Quarry, Ala.
24	4947	Alabama White	Alabama Marble Quarries Co.	Sycamore, Ala.
25	3234	Black Marble	Virginia Marble and Stone Co.	Harrisonburg, Va.
26	3235	do	do	Do.
27	4783	Regal Blue	Regal Marble Co	Regal, N. C.
28	3492	Berkshire Marble	South Berkshire Marble Co	Ashley Falls, Mass.
29	3834	West Stockbridge	West Stockbridge Marble Co	West Stockbridge, Mass.
30	3945	Lee White	Lee Marble Works	Lee, Mass.
31	6119	Napoleon Gray	Phenix Marble Co	Phenix, Mo.
32	6981		Cassville Marble & Lime Co	Cassville, Mo.
33	2644	Amicalola	Amicalola Marble Co	Ball Ground, Ga.
34	5950	Etowah	Georgia Marble Co	Tate, Ga.
35	5951	Creole	do	Do.
36	5952	Silver Gray	do	Do.
37	5953	Light Cherokee	do	Do.
38	9032	Mezzotint	do	Do.
39	6490	Georgia Marble	Southern Marble Co	Marble Hill, Ga.
40	6243	Verd Antique	Green Marble Co	Holly Springs, Ga.
41	2634	Victoria Pink	Victoria Marble Co	Knoxville, Tenn.
42	2643	Royal Pink	Royal Marble Co	Do.
43	2645	Appalachian Gray	Appalachian Marble Co	Asbury, Tenn.
44	2960	Phœnix Pink	Cedar Bluff Marble Co	Ebenezer, Tenn.
45	3286	Cumberland Pink	Cumberland Marble Mills Co.	Meadow, Tenn.
46	3287	Cumberland Gray	do	Do.
47	5653	Dark Chocolate	Ross Republic Marble Co	Luttrell, Tenn.
48	4256	Tennessee Marble	Tennessee Marble Quarries Co	Amaico, Tenn.
49	3482	Light Vein	Columbia Marble Co	San Francisco, Cal.
50	2632	Tokeen	Vermont Marble Co	Tokeen, Alaska.

TABLE 2.—Compressive Strength Tests—Specimens Dry

Ref. No.	Tests made	Average stressed area, in square inches	Manner of testing	Compressive strength, in pounds per square inch			Remarks [a]
				Highest	Lowest	Average	
1	2	4. 86	On bed...	25 476	23 352	24 414	Aa
	2	5. 06	On edge..	20 982	19 784	20 383	(1)Ah(2)Aa
2	2	5. 14	On bed...	28 589	27 675	28 132	Ai
	2	5. 06	On edge..	31 279	27 772	29 526	Ai
3	2	5. 12	On bed...	21 473	19 691	20 582	(1)Aj(2)Aa
	2	5. 10	On edge..	21 288	16 275	18 782	Aj
4	2	5. 14	On bed...	13 070	12 670	12 870	(1)Ca(2)Aa
	2	4. 94	On edge..	10 020	9915	9968	Be
5	4	9. 28	On bed...	15 072	13 329	14 269	(1)Aef(2)Ac(3)Aef(4)Ae
	2	12. 28	On edge..	15 797	13 797	14 797	Ac
6	5	9. 87	On bed...	11 212	10 360	10 619	(1)Dc(2)Dcd(3)Dc(4)Ac(5)Dcd
	2	6. 22	On edge..	8984	8611	8798	De
7	3	6. 46	On bed...	12 131	11 674	11 903	(1)Da(2) and (3)Dc
	3	6. 18	On edge..	11 211	9426	10 073	Dc
8	2	5. 16	On bed...	17 353	14 654	16 004	Aa
	2	5. 10	On edge..	10 262	9392	9827	Be
9	2	5. 05	On bed...	9212	8905	9058	Ce
	2	5. 20	On edge..	11 098	11 010	11 054	Ba
10	2	4. 64	On bed...	10 955	10 427	10 691	(1)Be(2)Ca
	2	4. 64	On edge..	10 707	10 409	10 558	Ca
11	2	5. 36	On bed...	9560	8930	9245	Ca
	2	5. 72	On edge..	8029	7672	7850	Cf
12	2	5. 10	On bed...	13 505	12 757	13 131	Ba
	2	4. 97	On edge..	10 759	10 606	10 682	(1)Ba(2)Ca
13	2	5. 14	On bed...	11 362	11 201	11 281	(1)Af(2)Cef
	2	5. 08	On edge..	9333	8979	9156	(1)Ce(2)Cef
14	2	5. 52	On bed...	17 074	16 335	16 704	Aa
	2	5. 41	On edge..	14 119	13 113	13 616	Ae
15	2	5. 40	On bed...	14 365	10 433	12 399	(1)Aef(2)Aa
	2	5. 31	On edge..	12 700	10 665	11 682	(1)Aa(2)Ba
16	1	4. 99	On bed...	19 415	....	19 415	Ai
	1	5. 11	On edge..	31 017	....	31 017	Ai All began to spall at three-
17	2	5. 06	On bed...	51 590	48 820	50 205	Ai fourths the ultimate load
	1	5. 06	On edge..	44 470	....	44 470	Ai
18	2	5. 17	On bed...	14 769	14 491	14 630	(1)Ac(2)Acd
	2	5. 23	On edge..	13 873	11 899	12 886	(1)Ab(2)Ae
19	2	5. 96	On bed...	15 024	14 007	14 516	(1)Acd(2)Aa
	2	4. 90	On edge..	12 716	12 628	12 672	Aef
20	2	5. 16	On bed...	20 616	20 215	20 416	Acd
	2	5. 23	On edge..	20 996	19 890	20 493	Aef
21	2	5. 08	On bed...	21 743	21 501	21 622	Acd
	2	4. 97	On edge..	21 434	20 506	20 970	(1)Acd(2)Aad
22	2	5. 13	On bed...	14 475	10 841	12 658	Ac
	2	5. 16	On edge..	14 553	13 930	14 241	(1)Ac(2)Ae
23	1	4. 93	On bed...	14 744	....	14 744	Ac Both cubes had strain lines
	1	5. 15	On edge..	11 456	....	11 456	Bef perpendicular to bedding
24	2	5. 12	On bed...	18 232	17 342	17 787	(1)Aa(2)Aef
	2	5. 05	On edge..	11 902	11 129	11 515	Aef

[a] Numerals in parentheses indicate the numbers of the test specimens; where no numeral occurs the note refers to all tests under that number: A=explosive break; B=slight explosive break; C=nearly silent break; D=silent break; a=pyramid above; b=pyramid below; c=cone above; d=cone below; e=wedge above; f=wedge below; g=small prisms above and below h=several irregular pieces; i=great number of small pieces; j=several small prisms.

TABLE 2—Continued

[For explanation of symbols in "Remarks" column see footnote (a) on p. 35]

Ref. No.	Tests made	Average stressed area, in square inches	Manner of testing	Compressive strength, in pounds per square inch			Remarks
				Highest	Lowest	Average	
25	1	4.56	On bed...	27 390	....	27 390	Aj All cubes began to spall at three-fourths of ultimate load
	2	4.98	On edge..	26 313	25 050	25 682	Aj
26	2	3.95	On bed...	23 744	21 505	22 624	Ai All cubes began to spall at three-fourths ultimate load
	2	5.02	On edge..	24 302	19 704	22 003	(1)Af(2)Ai
27	2	4.96	On bed...	16 614	14 582	15 598	Ac
	2	5.15	On edge..	14 262	13 555	13 908	Ae
28	2	5.15	On bed...	19 518	18 347	18 933	(1)Ac(2)Acd
	2	5.31	On edge..	18 587	18 458	18 522	(1)Aad(2)Abc
29	2	4.96	On bed...	9364	9286	9325	Cef
	2	5.22	On edge..	9205	8555	8880	Cef
30	2	6.40	On bed...	21 592	18 853	20 222	(1)Aa(2)Af
	2	6.41	On edge..	21 059	15 767	18 413	Ab
31	2	5.11	On bed...	12 310	11 236	11 773	(1)Ba(2)Aa
	2	5.27	On edge..	12 415	12 107	12 261	(1)Aa(2)Ab
32	2	5.06	On bed...	13 055	12 097	12 576	(1)Ae(2)Aa
	2	5.07	On edge..	12 291	11 521	11 906	Aa
33	2	5.43	On bed...	11 339	10 685	11 012	(1)Cef(2)Cc
	2	5.25	On edge..	9993	9851	9922	(1)Ca(2)Ce
34	2	4.95	On bed...	12 171	10 919	11 545	(1)Aa(2)Bc
	2	4.70	On edge..	10 643	9755	10 194	(1)Ce(2)Cc
35	2	5.18	On bed...	12 217	11 055	11 636	Bc
	2	5.12	On edge..	12 572	11 244	11 908	Be
36	3	5.16	(a)	9043	8709	8884	(1)Ce(2) and (3)Cc
37	2	5.35	On bed...	11 161	9127	10 144	Ba
	2	5.13	On edge..	11 033	8800	9916	Ba
38	2	5.43	On bed...	12 492	11 398	11 945	(1)Aa(2)Ba
	1	4.94	On edge..	10 585	....	10 585	Be
39	2	4.56	On bed...	10 697	10 218	10 458	Cc
	2	4.84	On edge..	9409	9079	9244	Cc
40	2	5.00	On bed...	27 827	27 857	28 792	Ae
	2	5.00	On edge..	22 391	21 600	21 996	Af
41	3	4.69	On bed...	18 912	15 283	17 077	Aa
42	3	5.25	...do.......	19 428	15 177	17 664	(1) and (2)Ab(3)Ad. Edges spalled at two-thirds the ultimate load
43	3	5.16	...do.......	18 948	17 205	18 274	(1)Aa(2)Ab(3)Ab
44	3	5.02	...do.......	18 427	15 109	16 473	Aa
45	3	4.85	...do.......	15 925	13 650	14 908	(1) and (2)Ae(3)Ac
46	3	5.09	...do.......	18 658	14 588	17 182	Aa
47	2	5.08	...do.......	16 845	14 718	15 781	Ad
	2	4.95	On edge..	16 766	15 545	16 156	(1)Ad(2)Ab
48	2	6.05	On bed...	18 245	17 082	17 664	(1)Ad(2)Aef
	2	6.05	On edge..	17 238	15 902	16 570	Ad
49	2	5.45	On bed...	25 034	22 037	23 535	Ai Strong odor of H_2S noted at rupture
	2	5.42	On edge..	24 777	21 261	23 019	Ae
50	4	4.24	(a)	14 547	12 255	13 537	Aa Faint odor of H_2S noted at rupture

[a] Direction of bedding not distinguishable.

TABLE 3.—Compressive Strength Tests—Specimens Wet

[For explanation of symbols in "Remarks" column see footnote ([a]) on p. 35]

Ref. No.	Tests made	Average stressed area, in square inches	Manner of testing	Compressive strength, in pounds per square inch			Remarks
				Highest	Lowest	Average	
1	2	5.08	On bed...	25 403	21 960	23 682	(1)Aa(2)Ai
	2	4.96	On edge..	14 000	13 756	13 878	Ai
2	2	5.08	On bed...	25 405	24 125	24 765	Ai
	2	5.04	On edge..	28 814	26 705	27 760	Ai
3	2	5.12	On bed...	18 909	17 990	18 450	Ai
	2	5.00	On edge..	19 446	17 530	18 488	Aij
4	2	5.18	On bed...	12 059	11 953	12 006	(1)Aab(2)Acd
	2	4.98	On edge..	9583	9527	9555	Cef
5	2	5.70	On bed...	14 171	12 459	13 315	(1)and(2)Aef(3)Ac(4)Ae
	2	5.49	On edge..	14 843	14 227	14 535	Ac
6	2	4.36	On bed...	11 184	10 356	10 770	Cc
	2	4.36	On edge..	10 570	9948	10 259	(1)Ccd(2)Ca
7	2	6.31	On bed...	11 592	10 954	11 273	Bef
	2	6.42	On edge..	9439	9086	9262	Bef
8	2	5.03	On bed...	15 465	13 950	14 708	(1)Aad(2)Bc
	2	5.16	On edge..	10 190	10 135	10 162	Be
9	1	4.84	On bed...	8715	....	8715	Ce
	2	5.12	On edge..	8402	7697	8050	(1)Cc(2)Cab
10	2	4.82	On bed...	10 499	10 114	10 306	(1)Bab(2)Cab
	1	5.22	On edge..	9944	....	9944	Ccd
11	2	5.34	On bed...	9353	8160	8756	(1)Cf(2)Ce
	2	5.29	On edge..	8179	7577	7878	Cef
12	2	5.29	On bed...	10 993	10 138	10 565	(1)Af(2)Ab
	2	5.36	On edge..	10 225	9730	9978	(1)Be(2)Ae
13	2	5.35	On bed...	9845	9836	9840	(1)Ca(2)Ba
	1	4.84	On edge..	7894	....	7894	Ce
14	2	5.49	On bed...	15 213	13 978	14 596	(1)Ac(2)Af
	2	5.54	On edge..	14 553	14 493	14 523	Aef
15	2	5.13	On bed...	11 336	9852	10 594	(1)Aa(2)Ae
	2	5.20	On edge..	11 413	9458	10 436	(1)Ca(2)Aa
16	1	4.93	On bed...	25 079	....	25 079	Ai
	2	5.06	On edge..	21 450	15 902	18 676	Ai
17	1	5.33	On bed...	28 906	....	28 906	Ai
	1	5.06	On edge..	36 156	....	36 156	Ai
18	2	5.28	On bed...	14 679	12 963	13 821	Aa
	1	5.26	On edge..	13 954	....	13 954	Ae
19	2	5.90	On bed...	13 184	12 232	12 708	(1)Ac(2)Aci
	2	5.26	On edge..	12 273	11 631	11 952	(1)Aa(2)Ae
20	2	5.16	On bed...	18 631	17 281	17 956	Acd
	2	5.18	On edge..	18 544	17 794	18 169	(1)Acd(2)Ad
21	2	5.21	On bed...	21 672	20 050	20 861	Ai
	2	4.96	On edge..	19 702	19 500	19 601	(1)Aci(2)Ae
22	2	5.10	On bed...	13 158	12 251	12 704	Aa
	2	5.34	On edge..	12 509	12 409	12 459	Ae
23	2	5.13	On bed...	15 700	12 289	13 994	(1)Ae(2)Ac
	1	5.24	On edge..	12 252	....	12 252	Ae
24	1	5.13	On bed...	16 899	....	16 899	Ac
	1	5.18	On edge..	11 482	....	11 482	Ce
25	2	3.83	On bed...	30 870	27 961	29 416	Ai
	2	3.87	On edge..	31 550	25 568	28 559	Ai

TABLE 3—Continued

[For explanation of symbols in "Remarks" column see footnote (a) on p. 35]

Ref. No.	Tests made	Average stressed area, in square inches	Manner of testing	Compressive strength, in pounds per square inch			Remarks
				Highest	Lowest	Average	
26	1	5.02	On bed...	15 061	....	15 061	Aa
	2	5.18	On edge..	13 516	12 965	13 240	(1)Ca(2)Cc
27	2	5.31	On bed...	17 442	16 090	16 766	Ac
	2	4.38	On edge..	17 736	16 650	17 193	Aef
28	2	4.97	On bed...	8535	8471	8503	Dc
	2	4.90	On edge..	8965	8625	8795	(1)Dd(2)Cc
29	2	6.39	On bed...	20 284	18 563	19 424	(1)Ab(2)Ae
	2	6.32	On edge..	19 284	17 210	18 247	Af
30	2	5.11	On bed...	11 869	11 186	11 528	(1)Bb(2)Ab
	2	5.13	On edge..	13 231	12 291	12 761	Ae
31	2	5.12	On bed...	12 231	11 703	11 967	(1)Aa(2)Ab
	2	5.08	On edge..	17 203	15 026	16 114	Aaj
32	2	5.20	On bed...	11 492	10 213	10 852	(1)Cc(2)Ca
	1	5.06	On edge..	9770	....	9770	Cef
33	2	5.02	On bed...	12 766	11 243	12 004	(1)Ac(2)Aa
	2	4.74	On edge..	10 788	9312	10 050	Cc
34	2	5.16	On bed...	11 095	9414	10 254	(1)Bc(2)Cc
	1	5.22	On edge..	10 856	....	10 856	Ba
35	3	5.28	(a)	8677	8350	8587	(1)Ca(2)and(3)Cc
	2	5.30	On bed...	10 233	8719	9476	(1)Bab(2)Ca
36	2	5.32	On edge..	10 907	10 422	10 664	Ba
37	1	5.38	On bed...	10 067	....	10 067	Ca
	1	4.74	On edge..	7804	....	7804	Cef
38	2	4.70	On bed...	9931	9355	9643	Ccd
			On edge..	7856	....	7856	Dcd
39	2	5.12	On bed...	18 672	12 466	15 569	(1)Ah(2)Ae
	2	5.12	On edge..	17 898	16 447	17 172	Ae
40	3	4.54	On bed...	18 429	17 300	17 823	Aa
41	2	4.92	...do.......	17 566	16 862	17 214	(1)Bab(2)Aab(3)Aa
42	3	4.99	...do.......	17 388	16 187	16 892	(1)Aa(2)and(3)Ba
43	3	5.07	...do.......	17 243	16 139	16 515	Ba
44	3	4.98	...do.......	15 230	13 998	14 474	Ba
45	3	5.14	...do.......	19 308	14 180	17 453	(1)Ba(2)and(3)Aa
46	2	5.08	...do.......	15 473	15 347	15 410	Aa
47	1	4.80	On edge..	17 750	....	17 750	Aa
	2	6.06	On bed...	16 603	15 828	16 216	Aa
48	2	6.18	On edge..	16 366	15 160	15 736	Ae
49	2	5.48	On bed...	24 211	23 717	23 964	Aa
	2	5.44	On edge..	23 340	22 859	23 100	(1)Aa(2)Ab
50	4	4.62	(a)	15 097	12 532	13 417	(1)and(2)Cd(3)Bd(4)Bab. (Faint odor of H_2S given off.)

a Direction of bedding not distinguishable.

TABLE 4.—Compressive Strength Tests of Specimens Frozen and Thawed 30 Times

[For explanation of symbols in "Remarks" column see footnote (*a*) on p. 35]

Ref. No.	Tests made	Average stressed area, in square inches	Manner of testing	Compressive strength, in pounds per square inch			Remarks
				Highest	Lowest	Average	
1	2	4.89	On bed...	25 520	24 436	24 978	(1)Ae(2)Ai
	2	5.12	On edge..	20 122	17 838	18 980	(1)Ae(2)Aef
2	2	5.07	On bed...	25 301	22 946	24 124	(1)Ah(2)Ai } All began to spall at three-fourths the ultimate load
	2	5.03	On edge..	29 057	22 420	25 738	Ai
3	2	5.00	On bed...	22 036	19 611	20 824	Agj
	2	5.00	On edge..	20 035	19 881	19 958	Agj
4	2	5.30	On bed...	12 393	12 203	12 298	Ac
	1	5.02	On edge..	8906	....	8906	Ae
5	3	5.63	On bed...	14 660	12 165	13 230	Aa
6	2	4.40	...do.......	10 717	10 701	10 709	Da
	1	4.39	On edge..	10 173	....	10 173	Da
7	2	6.30	On bed...	11 539	11 384	11 461	Da
	2	6.20	On edge..	9466	9305	9385	De
8	2	5.20	On bed...	12 773	11 954	12 363	Aa
	2	5.24	On edge..	8994	8446	8720	Be
9	2	5.04	On bed...	9434	8770	9102	(1)Ca(2)Ce
	2	4.97	On edge..	8808	7325	8066	Ca
10	2	4.82	On bed...	9067	8400	8734	(1)Ca(2)Da
	2	5.00	On edge..	8968	8230	8599	Da
11	2	5.40	On bed...	9068	8372	8720	(1)Ca(2)Ba
	2	5.46	On edge..	7204	7004	7104	(1)Ca(2)Ba
12	2	5.13	On bed...	11 939	10 636	11 288	Ca
	2	5.34	On edge..	11 005	9658	10 332	Ca
13	2	5.05	On bed...	10 404	10 073	10 238	(1)Aa(2)Ba
	2	5.14	On edge..	8159	7489	7824	(1)Be(2)Ce
14	2	5.53	On bed...	15 321	14 109	14 715	Aa
	2	5.52	On edge..	13 829	13 087	13 458	Ba
15	2	5.42	On bed...	10 454	8991	9722	(1)Be(2)Ba
	2	5.16	On edge..	10 577	9213	9895	(1)Cab(2)Ca
16	2	5.05	On bed...	26 535	23 438	24 986	(1)Aa(2)Ai } All began spalling at about two-thirds the ultimate load
17	2	5.26	...do.......	34 677	29 510	32 094	Ai
	1	5.11	On edge..	22 945	....	22 945	Ai
18	2	5.33	On bed...	14 953	13 630	14 292	(1)Ad(2)Aa
	2	5.28	On edge..	13 037	12 994	13 016	Ac
19	2	5.48	On bed...	13 845	12 970	13 408	Aa
	2	5.16	On edge..	11 519	10 456	10 988	Ae
20	2	5.12	On bed...	15 986	15 947	15 966	(1)Acd(2)Ac
	2	5.18	On edge..	17 514	14 533	16 024	(1)Acd(2)Ad
21	2	5.36	On bed...	20 844	17 488	19 166	(1)Ab(2)Aa
	2	5.29	On edge..	24 008	22 724	23 366	(1)Aa(2)Acd
22	1	5.06	On bed...	14 456	....	14 456	Ac
	2	4.94	On edge..	17 002	15 979	16 490	Ae
23	1	5.15	On bed...	17 668	....	17 668	Ac
	1	5.11	On edge..	16 489	....	16 489	Cc
24	2	5.24	On bed...	16 930	16 773	16 852	Aa
	1	4.84	On edge..	13 362	....	13 362	Ba
25	3	4.98	On bed...	27 676	26 329	26 816	Ai Began to spall at about one-half the ultimate load

TABLE 4—Continued

[For explanation of symbols in "Remarks" column see footnote (a) on p. 35]

Ref. No.	Tests made	Average stressed area, in square inches	Manner of testing	Compressive strength, in pounds per square inch			Remarks
				Highest	Lowest	Average	
26	2	4.11	On bed...	22 204	19 250	20 727	Ag Began to spall at about three-fourths the ultimate load
	2	4.02	On edge..	23 302	23 276	23 289	Ag
27	2	5.22	On bed...	13 581	13 298	13 440	(1)Ba(2)Bc
	1	5.15	On edge..	13 120	....	13 120	Ce
28	2	5.17	On bed...	20 260	19 182	19 721	Ac
	2	4.87	On edge..	18 102	17 967	18 034	Ae
29	2	5.02	On bed...	10 235	9612	9924	Ca
	2	4.88	On edge..	8360	8148	8254	Ce
30	2	6.42	On bed...	18 722	18 650	18 686	Aa
	2	6.32	On edge..	21 563	19 559	20 561	(1)Aa(2)Ae
31	2	5.18	On bed...	11 418	9432	10 425	(1)Ba(2)Bc
	2	5.28	On edge..	10 797	9306	10 052	(1)Ba(2)Bef
32	2	5.08	On bed...	14 559	13 213	13 886	Aa
	2	4.98	On edge..	15 112	10 686	12 899	Aa
33	2	5.27	On bed...	14 661	12 558	13 610	Ae
	2	5.00	On edge..	9008	8180	8594	(1)Ce(2)Ca
34	2	4.98	On bed...	11 083	9569	10 326	(1)Bcf(2)Cb
	2	4.84	On edge..	9919	7383	8651	(1)Cef(2)Cde
35	2	5.06	On bed...	10 583	9875	10 229	Ca
	2	4.97	On edge..	10 042	9336	9689	(1)Cb(2)Cd
36	3	5.47	(a)	8685	7699	8116	(1, 2)Cb(3)Cad. Pronounced odor of H_2S at rupture
	2	5.48	On bed...	8888	8416	8652	(1)Ca(2)Cb
37	2	5.29	On edge..	8782	6703	7742	(1)Da(2)Cc
	1	5.31	On bed...	11 316	....	11 316	Ce
38	1	4.84	On edge..	9514	....	9514	Ca
	2	4.83	On bed...	8724	8675	8700	
39	2	4.62	On edge..	9057	8547	8702	
	2	5.06	On bed...	21 521	17 577	19 049	Ab
40	2	5.15	On edge..	17 105	15 376	16 240	(1)Af,(2)Aa
41	3	4.46	On bed...	18 228	15 652	16 551	Ab
42	3	5.11	...do.......	19 459	19 298	19 379	Ab
43	3	4.73	...do.......	18 292	16 612	17 295	(1, 2)Ab,(3)Af
44	3	4.94	...do.......	15 721	15 084	15 508	(1, 2)Ab,(3)Bb
45	3	5.35	...do.......	15 352	13 185	14 595	(1, 2)Db, Cb
46	3	5.22	...do.......	16 705	16 013	16 370	Ab
47	2	5.12	...do.......	15 615	14 715	15 165	(1)Ab, (2)Ade
	2	5.08	On edge..	16 221	14 652	15 436	(1)Aab,(2)Ab
48	2	6.00	On bed...	16 748	15 305	16 026	(1)Aef, (2)Af
	2	5.87	On edge..	15 017	14 513	14 765	(1)Ab,(2)Aa
49	2	5.50	On bed...	24 075	23 451	23 763	(1)Ac(2)Aa. Strong H_2S odor given off at rupture
50	1	5.43	(a)	21 980	....	21 980	Ab
	3	4.21	On edge..	13 598	12 628	13 236	(1,2)Ca(3)Cc. Faint odor of H_2S given off at rupture

a Direction of bedding not distinguishable.

TABLE 5.—Comparison of Average Compressive Strength Obtained by Testing Specimens, Dry, Wet, and Frozen 30 Times, and Change of Weight on Freezing

Ref. No.	Manner of testing	Average compressive strength, in pounds per square inch			Per cent change in strength on—				Per cent change in weight on freezing 30 times	
					Soaking		Freezing 30 times			
		Dry	Wet	Frozen	Loss	Gain	Loss	Gain	Loss	Gain
1	On bed	24 414	23 682	24 978	3.0			2.3	0.01	
	On edge	20 383	13 878	18 980	31.9		6.6		.00	
2	On bed	28 132	24 765	24 124	11.9		14.2		.00	
	On edge	29 526	27 760	25 738	6.0		12.8		.00	0.00
3	On bed	20 582	18 450	20 824	10.4			1.2	.00	.00
	On edge	18 782	18 488	19 958	1.5			6.3		.01
4	On bed	12 870	12 006	12 298	6.7		4.4		.02	
	On edge	9968	9555	8906	4.1		10.6		.02	
5	On bed	14 269	13 315	13 230	6.7		7.3		.03	
	On edge	14 797	14 535		1.8					
6	On bed	10 619	10 770	10 709		1.4		.9	.05	
	On edge	8798	10 259	10 173		16.6		15.6	.06	
7	On bed	11 903	11 273	11 461	5.3		3.7		.04	
	On edge	10 073	9262	9385	8.0		6.8		.04	
8	On bed	16 004	14 708	12 363	8.1		22.8		.00	.00
	On edge	9827	10 162	8720		3.4	11.3		.01	
9	On bed	9058	8715	9102	3.8			.5	.02	
	On edge	11 054	8050	8066	27.2		27.0		.02	
10	On bed	10 691	10 306	8734	3.6		18.3		.02	
	On edge	10 558	9944	8599	5.8		18.5		.00	.00
11	On bed	9245	8756	8720	5.3		5.6		.02	
	On edge	7850	7878	7104		.4	9.5		.02	
12	On bed	13 131	10 566	11 288	19.5		14.0		.01	
	On edge	10 682	9978	10 332	6.6		3.3		.00	.00
13	On bed	11 281	9840	10 238	12.8		9.3		.02	
	On edge	9156	7894	7824	13.8		14.5		.02	
14	On bed	16 704	14 596	14 715	12.6		11.9		.02	
	On edge	13 616	14 523	13 458		6.6	1.2		.01	
15	On bed	12 399	10 594	9722	14.5		21.6		.02	
	On edge	11 682	10 436	9895	10.7		15.3		.02	
16	On bed	19 415	25 079	24 986		29.2		28.7	.01	
	On edge	31 017	18 676		39.8				.01	
17	On bed	50 205	28 906	32 094	42.4		62.1		.01	
	On edge	44 470	36 156	22 945	18.7		48.4			.06
18	On bed	14 630	13 821	14 292	5.5		2.3		.04	
	On edge	12 886	13 954	13 016		8.3		1.0	.03	
19	On bed	14 516	12 708	13 408	12.4		7.6		.04	
	On edge	12 672	11 952	10 988	5.7		13.3		.05	
20	On bed	20 416	17 956	15 966	12.1		21.8		.00	.00
	On edge	20 493	18 169	16 024	11.3		21.8		.00	.00
21	On bed	21 622	20 861	19 166	3.5		11.3		.02	
	On edge	20 970	19 601	23 366	6.5			11.4	.02	
22	On bed	12 658	12 704	14 456		.04		14.2	.02	
	On edge	14 241	12 459	16 490	12.5			15.1	.02	
23	On bed	14 744	13 994	17 668	5.1			19.8	.08	
	On edge	11 456	12 252	16 489		6.9		43.9	.28	
24	On bed	17 787	16 899	16 852	5.1		5.3		.04	
	On edge	11 415	11 582	13 362	.3			16.0	.05	

TABLE 5—Continued

Ref. No.	Manner of testing	Average compressive strength, in pounds per square inch			Per cent change in strength on—				Per cent change in weight on freezing 30 times	
					Soaking		Freezing 30 times			
		Dry	Wet	Frozen	Loss	Gain	Loss	Gain	Loss	Gain
25	On bed	27 390	29 416	26 816		7.4	2.1		0.01	
	On edge	25 682	28 559			11.2				
26	On bed	22 624		20 727			8.4			0.02
	On edge	22 003		23 289				5.8		.02
27	On bed	15 598	15 061	13 440	3.4		13.8			
	On edge	13 908	13 240	13 120	4.8		5.7			
28	On bed	18 933	16 766	19 721	11.4			4.2	.02	
	On edge	18 522	17 193	18 034	7.2		2.6		.02	
29	On bed	9325	8503	9924	8.8			6.4	.04	
	On edge	8880	8795	8254	.9		7.0		.04	
30	On bed	20 222	19 424	18 686	4.0		7.6		.01	
	On edge	18 413	18 247	20 561	.9			11.7	.00	.00
31	On bed	11 773	11 528	10 425	2.1		11.4		.20	
	On edge	12 261	12 761	10 052		4.1	18.0		.24	
32	On bed	12 576	11 967	13 886	4.8			10.4	.06	
	On edge	11 906	16 114	12 899		35.4		8.3	.10	
33	On bed	11 012	10 852	13 610	1.4			23.6	.04	
	On edge	9922	9770	8594	1.5		13.4		.04	
34	On bed	11 545	12 004	10 326		4.0	10.6		.00	
	On edge	10 194	10 050	8651	1.4		15.2		.00	.00
35	On bed	11 636	10 254	10 229	11.9		12.1		.00	.00
	On edge	11 908	10 856	9689	8.8		18.6		.00	.00
36	On bed	8884	8587	8116	3.3		8.6		.10	
37	do	10 144	9476	8652	6.6		14.8		.10	
	On edge	9916	10 664	7742		7.5	22.0		.00	.00
38	On bed	11 945	10 067	11 316	15.7		5.3		.02	
	On edge	10 585	7804	9514	26.3		10.1		.02	
39	On bed	10 458	9643	8700	7.8		16.8			
	On edge	9244	7856	8702	15.0		5.8			
40	On bed	28 792	15 569	19 049	46.0		34.5			.07
	On edge	21 996	17 172	16 240	21.9		26.2			.08
41	On bed	17 077	17 823	16 551		4.4	3.1		.03	
42	do	17 664	17 214	19 379	2.5			9.7	.02	
43	do	18 274	16 892	17 295	7.6		5.4		.03	
44	do	16 473	16 515	15 508		.3	5.8		.02	
45	do	14 908	14 474	14 595	2.9		2.1		.00	.00
46	do	17 182	17 453	16 370		1.6	4.7		.01	
47	do	15 718	15 410	15 165	2.0		3.5		.04	
	On edge	16 156	17 750	15 436		9.9	4.5		.04	
48	On bed	17 664	16 216	16 026	8.2		9.3		.01	
	On edge	16 570	15 763	14 765	4.9		10.9		.02	
49	On bed	23 535	23 964	23 763		1.8		1.0	.02	
	On edge	23 019	23 100	21 980		.4	4.5		.03	
50	([a])	13 537	13 417	13 236	.9		2.2		.02	

[a] Direction of bedding not distinguishable.

TABLE 6.—Transverse Tests

Ref. No.	Tests made	Span, in inches	Average sectional dimensions, in inches		Manner of testing	Modulus of rupture, in pounds per square inch			Remarks [a]
			Breadth	Depth		Highest	Lowest	Average	
1	2	6.00	3.02	1.76	Perpendicular to bed	4843	3932	4388	(1)r,w=½(2)r,w=1¾
	2	10.00	3.06	1.75	Parallel to bed	834	380	607	(1)st,w=1/16–⅛(2)st,w=¼–½
2	2	10.00	2.90	1.74	Perpendicular to bed	4474	4062	4268	(1)r,w=½(2)s,w=0–¼
	2	6.00	2.88	1.75	Parallel to bed	3098	2744	2921	ru
3	2	10.00	2.92	1.72	Perpendicular to bed	3807	3330	3568	(1)r,w=¼(2)ru
	2	6.00	2.92	1.70	Parallel to bed	3718	3622	3670	ru
4	3	6.00	4.09	1.55	Perpendicular to bed	1720	1658	1613	(1)and(2)ru(3)sv,w=¼–⅛
	2	10.00	4.08	1.54	Parallel to bed	1173	1131	1152	(1)s,w=o–¼(2)s,w=½–⅝
5	2	10.00	4.06	1.54	Perpendicular to bed	2086	1980	2033	ru
	3	6.00	4.03	1.56	Parallel to bed	1765	1633	1717	(1)ru(2)r,w=½
6	3	6.00	2.08	2.02	Perpendicular to bed	1227	1168	1197	ru
7	3	10.00	2.49	2.31	.....do	942	862	902	ru
	3	6.00	2.97	2.06	Parallel to bed	659	586	618	ru
8	2	6.00	2.92	1.78	Perpendicular to bed	2906	2532	2719	r,w=⅜
	2	10.00	2.98	1.76	Parallel to bed	1567	1549	1558	r,w=⅜
9	2	5.00	3.08	1.80	Perpendicular to bed	1844	1697	1771	(1)ru(2)s,w=0–⅝
	2	8.00	3.06	1.83	Parallel to bed	1232	1208	1220	ru
10	2	10.00	2.86	2.06	Perpendicular to bed	1563	1485	1524	(1)ru(2)r,w=¼
	2	10.00	2.84	1.80	Parallel to bed	1574	1388	1481	(1)s,w=1–1½(2)r,w=¾
11	2	8.00	2.96	1.80	Perpendicular to bed	1674	1609	1642	ru
	2	10.00	2.96	1.80	Parallel to bed	982	886	934	(1)r,w=¾(2)r,w=⅛
12	1	6.00	3.04	1.78	Perpendicular to bed	1787	....	1787	ru
	2	10.00	3.04	1.82	Parallel to bed	1620	1611	1616	(1)s,w=0–⅛(2)r,w= ⅜

[a] Numerals in parentheses refer to the numbers of the specimens. Where no numerals occur, the same notes apply to all tests under these numbers: r=square break; s=diagonal break; t=irregular break; u=on center line; v=crossing center line; w=distance of break in inches from center line. For example, the letters "ru" indicate that the specimen broke squarely on the center line; sv,w=¼–½ indicate that the break crossed the center line diagonally and intersected the edges of the specimen at one-fourth of an inch on one side and one-half of an inch on the other side of the center line.

TABLE 6—Continued

[For explanation of symbols in "Remarks" column see footnote (a) on p. 43]

Ref. No.	Tests made	Span, in inches	Average sectional dimensions, in inches		Manner of testing	Modulus of rupture, in pounds per square inch			Remarks
			Breadth	Depth		Highest	Lowest	Average	
13	2	10.00	3.10	1.49	Perpendicular to bed	2412	2257	2334	(1)s,w=1/8-1/4(2)ru
	2	8.00	3.06	1.54	Parallel to bed	1362	1305	1334	(1)s,w=0-5/8(2)ru
14	2	5.00	3.04	1.80	Perpendicular to bed	2436	2345	2390	ru
	2	9.00	3.06	1.80	Parallel to bed	1880	1837	1858	(1)s,w=0-3/8(2)ru
15	2	6.00	3.10	1.78	Perpendicular to bed	2603	2218	2410	(1)r,w=1/8(2)ru
	2	10.00	3.08	1.80	Parallel to bed	1288	1237	1262	r,w=1/8
16	2	8.00	3.00	2.74	Perpendicular to bed	1589	1320	1454	(1)t,w=1/2-1 1/2(2)t,w=0-3/4
17	2	8.00	3.07	2.74	do	486	159	322	t,w=1 1/2
18	2	10.00	3.10	1.48	do	2180	2145	2162	(1)s,w=0-1/4(2)ru
	2	8.00	3.11	1.51	Parallel to bed	1000	982	991	(1)s,w=1/4-1/8(2)rw=1/8
19	2	10.00	3.34	1.53	Perpendicular to bed	1664	1305	1484	(1)r,w=1/4(2)s,w=0-1/4
	2	6.00	3.34	1.40	Parallel to bed	1155	1114	1134	ru
20	2	10.00	2.96	1.77	Perpendicular to bed	1075	996	1035	(1)ru(2)s,w=1/8-1/2
	2	6.00	2.96	1.80	Parallel to bed	1574	1419	1496	ru
21	2	10.00	3.06	1.54	Perpendicular to bed	2088	2060	2074	(1)sv,w=1/4-1/4(2)ru
	2	6.00	3.10	1.67	Parallel to bed	2062	1683	1872	ru
22	3	10.00	2.69	1.87	Perpendicular to bed	1874	1793	1834	ru
	3	5.00	2.72	1.50	Parallel to bed	1260	1054	1140	ru
23	3	6.00	3.81	1.52	Perpendicular to bed	2764	1623	2170	(1)ru(2)and(3)s,w=1 1/2-2
24	2	10.00	3.12	1.59	do	3507	3377	3442	(1)su,w=1/2-1/2(2)ru
	2	6.00	3.10	2.07	Parallel to bed	1755	1724	1740	(1)r,w=1/4(2)ru
25	3	10.00	1.93	1.57	Perpendicular to bed	2977	2650	2799	(1)and(2)s,w=0-1/4(2)s,w=0-1/2
26	3	10.00	2.01	1.72	do	2980	1949	2603	(1)ru(2)and(3)r,w=1
27	3	6.00	2.24	1.87	do	2513	2476	2491	ru

28	2	6.00	3.08	1.40	....do....	1916	1835	1876	ru
	2	8.00	3.08	1.49	Parallel to bed....	1488	1468	1478	s,w=0-1/8
29	2	10.00	3.14	1.66	Perpendicular to bed....	1341	1315	1328	(1)s,w=0-1/4(2)ru
	3	6.00	3.09	1.93	Parallel to bed....	1092	945	1031	(1)and(2)ru(3)r,w=3/4
30	2	8.00	3.10	1.72	Perpendicular to bed....	1906	1894	1900	(1)sv,w=1/8-1/8(2)s,w=0-1/2
	2	6.00	3.10	1.74	Parallel to bed....	1109	1020	1064	(1)sv,w=1/8-1/8(2)r,w=1/8
31	2	6.00	3.06	1.78	Perpendicular to bed....	2942	1964	2453	(1)ru(2)r,w=1/8
	2	10.00	3.03	1.80	Parallel to bed....	1577	1453	1515	(1)s,w=1/8-3/8(2)r,w=1/8
32	2	7.00	3.02	1.72	Perpendicular to bed....	2282	1715	1998	(1)s,w=1/16-3/8(2)ru
	2	10.00	3.01	1.74	Parallel to bed....	1547	1479	1513	(1)s,w=1/2-3/4(2)r,w=1 1/4
33	2	10.00	3.06	2.85	Perpendicular to bed....	1705	1488	1596	ru
	2	6.00	2.32	1.98	Parallel to bed....	994	986	990	s,w=0-1/8
34	2	7.00	3.02	1.50	Perpendicular to bed....	1606	1433	1520	(1)ru(2)sv,w=1/8-1/8
	2	7.00	3.03	1.44	Parallel to bed....	1567	885	1226	(1)s,w=0-3/8(2)ru
35	2	10.00	3.00	1.50	Perpendicular to bed....	1536	1320	1428	ru
	1	10.00	3.00	1.46	Parallel to bed....	624	....	624	r,w=2 1/2
36	3	10.00	2.96	1.38	(a)....	1274	507	967	(1)ru(2)s,w=0-3/4(3)r,w=2
37	2	9.00	3.07	1.79	Perpendicular to bed....	1279	1254	1266	(1)r,w=1/8(2)r,w=1/4
38	2	6.00	3.06	1.77	....do....	1769	1275	1522	(1)ru(2)tu
	2	6.00	2.90	2.09	Parallel to bed....	1367	1325	1346	ru
39	2	8.00	2.33	2.18	Perpendicular to bed....	1412	1384	1398	ru
	2	8.00	2.46	2.11	Parallel to bed....	1395	1290	1342	ru
40	2	6.00	3.00	1.79	Perpendicular to bed....	5294	4605	4948	(1)s,w=1/16-3/8(2)st
	2	10.00	3.03	1.82	Parallel to bed....	3567	3300	3434	(1)st(2)s,w=1/2-1 1/2
41	3	12.00	2.95	1.20	Perpendicular to bed....	2690	2185	2447	(1)and(2)s,w=1/4-1/2(3)ru
42	3	10.00	2.74	1.74	....do....	2753	2504	2593	(1)and(2)s,w=1/8-1/4(3)ru
	2	8.00	3.10	1.76	Parallel to bed....	3062	2804	2933	ru
43	3	12.00	2.99	1.83	Perpendicular to bed....	2760	2567	2686	r,w=1/4
	2	10.00	3.08	1.76	Parallel to bed....	3188	3004	3096	ru
44	3	10.00	2.70	1.70	Perpendicular to bed....	2946	2466	2639	(1)sv,w=1/8-1/8(2)and(3)ru
45	3	10.00	2.70	1.72	....do....	2364	2286	2326	ru
	2	8.00	2.99	1.74	Parallel to bed....	2318	2237	2278	ru

a Direction of bedding could not be determined.

TABLE 6—Continued

[For explanation of symbols in "Remarks" column seef ootnote (a) on p. 43]

Ref. No.	Tests made	Span, in inches	Average sectional dimensions, in inches		Manner of testing	Modulus of rupture, in pounds per square inch			Remarks
			Breadth	Depth		Highest	Lowest	Average	
46	3	10.00	2.66	1.74	Prependicular to bed........	2486	2012	2251	ru
	2	10.00	3.07	1.76	Parallel to bed..............	1970	1006	1488	ru
47	2	8.00	3.00	1.48	Perpendicular to bed........	2856	2764	2810	ru
	2	10.00	3.00	1.48	Parallel to bed..............	2785	2582	2684	ru
48	2	8.00	3.04	1.49	Perpendicular to bed........	2958	2706	2832	(1)ru(2)r,w=3/8
	2	6.00	3.08	1.50	Parallel to bed..............	2805	2624	2714	(1)s,w=0-3/8(2)ru
49	2	10.00	3.98	1.52	Perpendicular to bed........	2761	2667	2714	(1)ru(2)s,w=1/4-3/8
	3	6.00	3.95	1.68	Parallel to bed..............	2510	1712	2239	(1)s,w=1/2-5/8(2)and(3)ru
50	3	10.00	4.03	1.55	(a)........................	1822	1556	1709	(1)and(2)ru(3)r,w=1/2

a Direction of bedding could not be determined.

TABLE 7.—Tension Tests

Ref. No.	Tests made	Manner of testing	Tensile strength, in pounds, per square inch		
			Highest	Lowest	Average
1	3	Perpendicular to bed	2490	1051	1609
2	3	.....do	2485	2085	2254
3	3	.....do	1518	1111	1281
4	3	.....do	844	735	779
	3	Parallel to bed	566	485	513
5	3	Perpendicular to bed	933	548	752
	3	Parallel to bed	1075	713	902
6	3	Perpendicular to bed	431	384	413
	2	Parallel to bed	326	301	313
7	3	Perpendicular to bed	416	321	367
	3	Parallel to bed	183	119	154
8	3	Perpendicular to bed	1352	1194	1248
9	3	.....do	520	452	491
10	3	.....do	900	553	695
11	3	.....do	645	544	585
12	3	.....do	703	662	678
13	3	.....do	1059	777	887
	3	Parallel to bed	807	579	678
14	3	Perpendicular to bed	1319	1134	1239
15	3	.....do	1105	844	982
18	3	.....do	1389	1285	1329
19	3	.....do	688	644	666
	3	Parallel to bed	603	521	556
20	3	Perpendicular to bed	456	419	439
21	3	.....do	953	925	940
	3	Parallel to bed	927	853	885
22	3	Perpendicular to bed	853	781	772
	3	Parallel to bed	695	562	636
23	3	Perpendicular to bed	1494	1434	1465
	3	Parallel to bed	981	769	899
24	3	Perpendicular to bed	1817	1683	1771
	3	Parallel to bed	1106	1094	1098
27	3	Perpendicular to bed	1475	1467	1470
28	3	.....do	822	748	785
	3	Parallel to bed	703	671	685
29	3	Perpendicular to bed	652	594	619
	3	Parallel to bed	379	291	328
30	3	Perpendicular to bed	772	513	584
	3	Parallel to bed	569	367	475
31	3	Perpendicular to bed	1212	1077	1155
32	3	.....do	1660	1032	1323
33	3	.....do	802	735	762
	3	Parallel to bed	534	408	453
34	3	Perpendicular to bed	962	850	837
	2	Parallel to bed	538	472	500
35	3	Perpendicular to bed	683	586	641
36	3	([a])	460	416	438
37	3	Perpendicular to bed	988	781	890
39	3	.....do	596	495	556

[a] Direction of bedding not distinguishable.

TABLE 7—Continued

Ref. No.	Tests made	Manner of testing	Tensile strength, in pounds, per square inch		
			Highest	Lowest	Average
39	3	Parallel to bed	324	296	308
40	3	Perpendicular to bed	1862	1043	1351
41	3	.....do	1173	1060	1118
	3	Parallel to bed	1533	1348	1447
42	3	Perpendicular to bed	1541	1218	1424
43	3	.....do	1620	1520	1554
	3	Parallel to bed	1582	1493	1551
44	3	Perpendicular to bed	1474	1348	1424
45	3	.....do	1438	1167	1325
	3	Parallel to bed	1273	692	1007
46	3	Perpendicular to bed	1481	1297	1417
	3	Parallel to bed	1152	879	1034
47	3	Perpendicular to bed	1422	1392	1411
	3	Parallel to bed	1377	1123	1222
48	3	Perpendicular to bed	1618	1284	1489
	3	Parallel to bed	1388	1210	1292
49	3	Perpendicular to bed	1211	1182	1197
	3	Parallel to bed	1270	1165	1204
50	3	(a)	932	893	911

a Direction of bedding not distinguishable.

TABLE 8.—True Specific Gravity, Apparent Specific Gravity, Porosity, and Weight per Cubic Foot

Ref. No.	True specific gravity				Apparent specific gravity				Porosity	Weight per cubic foot
	Tests made	Highest	Lowest	Average	Tests made	Highest	Lowest	Average		
1	....	....	....	....	4	2.824	2.744	2.793	....	174.6
2	4	2.859	2.847	2.854	4	2.836	2.831	2.834	0.70	177.1
3	4	2.786	2.773	2.779	4	2.771	2.758	2.764	.54	172.8
4	3	2.744	2.732	2.737	3	2.715	2.713	2.714	.84	169.6
5	4	2.749	2.733	2.739	2	2.729	2.727	2.728	.40	170.5
6	3	2.728	2.720	2.723	3	2.712	2.711	2.711	.44	169.4
7	7	2.738	2.714	2.729	3	2.717	2.715	2.716	.48	169.7
8	4	....	....	....	4	2.709	2.709	2.709	....	169.3
9	3	2.731	2.714	2.723	4	2.703	2.701	2.702	.77	168.9
10	4	2.734	2.722	2.726	4	2.713	2.712	2.713	.48	169.6
11	....	....	....	....	4	2.709	2.707	2.708	....	169.2
12	....	....	....	....	4	2.700	2.699	2.700	....	168.8
13	3	2.734	2.722	2.728	4	2.713	2.710	2.712	.59	169.5
14	4	2.724	2.714	2.721	4	2.710	2.709	2.710	.40	169.4
15	....	....	....	....	4	2.709	2.706	2.708	....	169.3
16	....	....	....	....	4	2.847	2.842	2.844	....	177.7
17	....	....	....	....	4	2.842	2.840	2.841	....	177.6
18	....	....	....	....	4	2.707	2.703	2.705	....	169.1
19	4	2.762	2.748	2.753	3	2.746	2.738	2.741	.43	171.3
20	4	2.885	2.872	2.879	4	2.864	2.861	2.863	.56	178.9
21	3	2.881	2.873	2.876	3	2.860	2.855	2.858	.63	178.6
22	3	2.877	2.876	2.876	3	2.864	2.852	2.858	.63	178.6
23	3	2.735	2.728	2.732	3	2.719	2.717	2.718	.51	169.9
24	3	2.738	2.728	2.733	3	2.721	2.720	2.721	.44	170.1
25	3	2.738	2.724	2.732	3	2.723	2.716	2.720	.44	170.0
26	4	2.736	2.725	2.729	4	2.717	2.715	2.716	.48	169.8
27	3	2.742	2.731	2.737	3	2.721	2.719	2.720	.62	170.0
28	3	2.883	2.873	2.878	3	2.863	2.859	2.861	.59	178.8
29	3	2.737	2.726	2.731	3	2.714	2.713	2.714	.62	169.6
30	4	2.887	2.870	2.876	4	2.859	2.854	2.856	.70	178.5
31	....	....	....	....	4	2.649	2.641	2.643	....	165.2
32	4	2.723	2.713	2.718	4	2.665	2.651	2.661	2.09	166.3
33	3	2.744	2.741	2.742	4	2.723	2.715	2.719	.84	169.9
34	4	2.741	2.733	2.737	4	2.727	2.725	2.726	.40	170.4
35	3	2.737	2.724	2.730	4	2.720	2.717	2.718	.44	169.9
36	4	2.725	2.718	2.722	3	2.714	2.708	2.710	.44	169.4
37	4	2.728	2.716	2.722	4	2.708	2.698	2.705	.62	169.1
38	....	....	....	....	2	2.716	2.714	2.715	....	169.7
39	4	2.742	2.728	2.734	4	2.726	2.717	2.721	.48	170.1
40	4	....	....	....	4	2.868	2.810	2.844	....	177.8
41	4	2.728	2.716	2.723	3	2.703	2.702	2.703	.73	168.9
42	....	....	....	....	3	2.708	2.705	2.707	....	169.2
43	....	....	....	....	3	2.706	2.705	2.705	....	169.1
44	4	2.725	2.715	2.719	3	2.706	2.705	2.706	.48	169.1
45	7	2.733	2.719	2.726	3	2.706	2.705	2.705	.77	169.1
46	....	....	....	....	3	2.707	2.705	2.706	....	169.1
47	....	....	....	....	4	2.708	2.707	2.708	....	169.2
48	....	....	....	....	4	2.707	2.704	2.706	....	169.1
49	4	2.865	2.844	2.854	3	2.838	2.837	2.838	.58	177.4
50	3	2.734	2.720	2.728	3	2.716	2.715	2.715	.48	169.8

TABLE 9.—Absorption Tests

Ref. No.	Tests made	Per cent of absorption					
		By weight			By volume		
		Highest	Lowest	Average	Highest	Lowest	Average
1	4	0.145	0.121	0.131	0.404	0.338	0.366
2	4	.082	.063	.073	.232	.178	.206
3	4	.230	.178	.203	.635	.491	.560
4	3	.121	.119	.120	.328	.322	.325
5	3	.112	.104	.108	.297	.278	.286
6	3	.144	.132	.137	.390	.358	.372
7	3	.158	.135	.146	.430	.367	.398
8	4	.124	.108	.116	.336	.292	.314
9	4	.207	.195	.201	.559	.526	.543
10	4	.111	.099	.102	.301	.268	.276
11	4	.140	.127	.134	.379	.344	.363
12	4	.201	.149	.186	.542	.402	.502
13	4	.112	.103	.106	.303	.279	.287
14	4	.128	.115	.122	.347	.312	.330
15	4	.120	.083	.103	.325	.225	.279
16	3	.061	.044	.053	.173	.125	.151
17	3	.032	.028	.030	.091	.080	.085
18	4	.170	.161	.164	.459	.435	.443
19	3	.080	.072	.075	.219	.197	.206
20	4	.124	.109	.115	.355	.312	.328
21	3	.093	.089	.091	.266	.254	.260
22	4	.126	.090	.138	.360	.257	.295
23	3	.085	.073	.079	.231	.199	.215
24	3	.062	.054	.059	.169	.147	.160
25	2	.054	.053	.054	.147	.145	.146
26	4	.024	.012	.016	.065	.033	.043
27	3	.063	.057	.059	.173	.156	.163
28	3	.133	.116	.126	.380	.332	.360
29	3	.117	.109	.113	.317	.298	.306
30	4	.143	.141	.142	.408	.403	.406
31	4	.495	.408	.452	1.308	1.079	1.193
32	4	.363	.358	.357	.965	.952	.949
33	3	.103	.069	.085	.280	.188	.232
34	4	.108	.089	.095	.295	.243	.259
35	4	.103	.080	.089	.280	.218	.242
36	3	.160	.115	.131	.434	.312	.355
37	4	.116	.091	.108	.313	.246	.292
38	2	.124	.119	.122	.337	.324	.332
39	3	.103	.099	.100	.280	.269	.272
40	4	.103	.095	.099	.293	.274	.281
41	3	.066	.063	.065	.178	.170	.175
42	3	.042	.030	.037	.114	.080	.100
43	3	.058	.040	.047	.157	.108	.127
44	3	.056	.048	.052	.151	.130	.140
45	3	.095	.085	.091	.256	.230	.245
46	3	.110	.067	.082	.298	.181	.188
47	4	.037	.034	.035	.100	.092	.095
48	4	.078	.072	.075	.211	.195	.203
49	3	.115	.107	.110	.326	.304	.312
50	3	.104	.092	.099	.280	.250	.269

TABLE 10.—Chemical Analysis

Ref. No.	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	Loss on ignition	Insoluble in HCl	CO_2
1	31.28	7.40	1.40	Nil	36.80	Trace	20.87		Nil
2	8.38	1.00	3.52	23.00	17.80	do	41.38		40.00
3	7.64	1.17	6.06	37.60	10.04	0.03	40.12	12.17	38.96
5		.05	.20	54.49	1.33	Trace	43.81	.44	43.65
6		.02	.06	55.86	.34	Nil	43.79	.48	43.78
7		.25	.09	52.70	.29	do	41.71	4.96	41.12
8		.04	.06	54.60	.41	Trace	43.18	2.24	43.94
9		.02	.06	55.90	.27	do	43.90	.34	43.80
10		.03	.10	55.30	.41	do	43.72	.76	43.72
11		.04	.06	55.40	.35	do	43.78	.70	43.46
12		.01	.07	55.60	.44	do	43.86	.30	43.94
13		.03	.09	55.54	.46	Nil	43.81	.24	43.75
14	.40	.03	.20	54.70	.91	Trace	44.00	.23	43.80
15	.26	.01	.10	55.40	.35	do	43.70	.24	43.76
18		.66	.30	53.76	.81	Nil	43.04	1.74	42.91
19		.11	.23	50.97	4.13	do	44.14	.90	43.69
20	.68	.25	.30	31.00	21.13	Trace	47.37	.71	47.12
21		.25	.26	29.99	21.22	do	45.79	2.64	45.43
23		.03	.13	55.54	.51	Nil	43.91	.08	43.35
24		.07	.13	55.38	.38	do	43.13	1.90	42.90
25		.06	.94	51.76	1.38	do	42.06	3.42	41.48
26	2.79	.03	.40	52.50	1.43	Trace	42.90	2.79	42.04
27		.005	.06	53.70	.80	do	43.98	.34	43.54
29		.03	.19	55.48	.28	Nil	43.50	.45	43.35
30	.24	.14	.26	31.40	19.93	Trace	47.60	.20	47.24
31		.03	.30	55.19	.40	Nil	43.87	.40	43.25
32		.02	.08	54.29	.23	do	45.25	.22	43.41
33		.05	.17	53.90	1.21	do	43.25	1.94	39.66
[a] 34		.42	.94	53.23	.92	do	42.20	2.58	42.17
35		.04	.35	54.48	.90	do	43.25	1.48	43.22
36		.04	.09	55.00	.41	Trace	43.37	1.10	43.18
38		.07	.15	54.71	.68	Nil	43.17	1.52	42.69
40	34.98	7.62	7.68	Trace	35.27	Trace	15.16		7.22
41		.06	.14	55.38	Trace	do	43.95	.08	43.52
42		.07	.12	55.74	.27	do	43.90	.10	43.45
43		.06	.26	55.60	.07	do	43.89	.15	43.58
45		.16	.45	55.80	.06	do	43.68	.54	42.65
46		.07	.34	55.52	.35	do	43.87	.32	42.53
47		.17	.51	55.00	.36	do	43.68	.88	43.16
48		.07	.19	55.80	.29	do	43.90	.24	44.02
49		.01	.11	35.00	18.65	Nil	46.93	.09	46.77
50		Trace	.14	55.80	.47	Trace	43.77	.26	43.86

[a] MnO_2=0.007.

TABLE 11.—Staining Tests

Ref. No.	Area stained, in square inches	Appearance of stain	Air permeability	Water absorption, per cent by volume	Porosity	Per cent change of strength in freezing test	
						Loss	Gain
1	0.00	None	3.6	0.366			2.3
2	.00	do	.2	.206	0.70	14.2	
3	.00	do		.506	.54		1.2
4	[a] 2.87	Pink	16.8	.325	.84	4.4	
5	1.78	Pale pink	8.6	.286	.40	7.3	
6	[b] 2.42	Bright red		.372	.44		.9
7	.59	Red	11.6	.398	.48	3.7	
8	2.35	Pale pink		.314		22.8	
9	.81	do	11.5	.543	.77		.5
10	1.72	Pink		.276	.48	18.3	
11	4.18	do	5.6	.363		5.6	
12	1.89	Pale pink	13.0	.502		14.0	
13	.46	Nearly invisible		.287	.59	9.3	
14	.00	None	8.2	.330	.40	11.9	
15	2.82	Pale pink	9.9	.279		21.6	
16	.00	None	0	.151			28.7
18	.00	do	19.9	.443		2.3	
19	.40	Nearly invisible	15.8	.206	.43	7.6	
20	2.43	Pale pink		.328	.56	21.8	
21	1.16	Pink	.0	.260	.63	11.3	
22	.31	Pale pink	9.0	.295	.63		14.2
23	.77	do	4.6	.215	.51		19.8
24	.24	Nearly invisible	.1	.160	.44	5.3	
25	.00	None		.146	.44	2.1	
27	.00	do	7.6	.163	.62	13.8	
28	.00	do		.360	.59		4.2
29	2.87	Pink	16.2	.306	.62		6.4
30	.70	Nearly invisible	.0	.406	.70	7.6	
31	.29	do	.0	1.193		11.4	
32	.45	Pale pink		.949	2.09		10.4
33	[c] 3.01	Pink	20.0	.232	.84		23.6
34	.87	Nearly invisible	2.8	.259	.40	10.6	
35	.34	do	1.2	.242	.44	12.1	
36	3.53	do	20.5	.355	.44	8.6	
37	[d] 3.11	do	12.8	.292	.62	14.8	
38	[e] 2.83	Pale pink	16.6	.332		5.3	
39	1.04	Red	7.9	.272	.48	16.8	
40	.00	None	1.1	.281			
41	.32	Nearly invisible		.175	.73	3.1	
42	.00	do		.100			9.7
43	.20	Pale pink		.127		5.4	
44	.17	Nearly invisible	1.5	.140	.48	5.8	
45	.23	do	2.5	.245	.77	2.1	
46	.00	None	1.5	.188		4.7	
47	.00	do	3.6	.095		3.5	
48	.00	Nearly invisible	.1	.203		9.3	
49	.70	Pale pink	8.8	.312	.58		1.0
50	2.64	do	.1	.269	.48	2.2	

[a] Stain penetrated to 3 exterior faces of cube in 3 hours.
[b] Stain penetrated to 1 exterior face of cube in 5½ hours.
[c] Stain penetrated to 4 exterior faces of cube in 30 minutes.
[d] Stain penetrated to 1 exterior face of cube in 1½ hours.
[e] Stain penetrated to 4 exterior faces of cube in 3 hours.

TABLE 12.—Volume Resistivity

Ref. No.	Condition of specimen	Voltage, direct current	Volume resistivity, ohm-centimeters [a]
1	Immersed in water 48 hours	100	11.0 by 10^6.
	Dried in laboratory several days	200	([b])
2	Immersed in water 48 hours	100	10.0 by 10^6.
	Dried in laboratory air several days	200	2.5 by 10^{11}.
	Immersed in water 48 hours, dried in air 26 hours	200	1.4 by 10^7.
	Immersed in water 48 hours, dried in water 75 hours	200	1.8 by 10^6.
4	Immersed in water 48 hours	70	6.0 by 10^6.
	Dried in oven at 110° C	....	3.0 by 10^{12}.
5	Immersed in water 48 hours	70	2.0 by 10^6.
	Dried in oven at 110° C	70	4.0 by 10^{12}.
6	Immersed in water 48 hours	100	12.0 by 10^6.
	Dried in laboratory air for several days	200	1.8 by 10^{14}.
	Immersed in water 48 hours, dried in laboratory air 26 hours	200	7.3 by 10^{13}.
	Immersed in water 48 hours, dried in laboratory air 75 hours	200	3.9 by 10^{14}.
7	Immersed in water 48 hours	70	9.0 by 10^6.
	Dried in oven at 110° C	70	6.0 by 10^{10}.
8	Immersed in water 48 hours	100	44 by 10^6.
	Dried in laboratory air several days	200	3.5 by 10^{13}.
9	Immersed in water 48 hours	100	7.6 by 10^7.
	Dried in laboratory air for several days	200	9.8 by 10^{13}.
10	Immersed in water 48 hours	100	6.6 by 10^7.
	Dried in laboratory air for several days	200	9.8 by 10^{12}.
11	Immersed in water 48 hours	100	7.6 by 10^7.
	Dried in laboratory air several days	200	6.3 by 10^{12}.
12	Immersed in water 48 hours	100	1.1 by 10^7.
	Dried in laboratory air several days	200	2.2 by 10^{13}.
13	Immersed in water 48 hours	100	8.1 by 10^7.
	Dried in laboratory air several days	200	1.8 by 10^{13}.
15	Immersed in water 48 hours	100	1.1 by 10^8.
	Dried in laboratory air several days	200	5.1 by 10^{13}.
18	Immersed in water 48 hours	100	2.8 by 10^7.
	Dried in laboratory air several days	200	1.4 by 10^{14}.
20	Immersed in water 48 hours	100	2.3 by 10^7.
	Dried in laboratory air several days	200	5.5 by 10^{14}.
	Immersed in water 24 hours, dried in laboratory air 26 hours	200	2.0 by 10^{12}.
	Immersed in water 24 hours, dried in laboratory 75 hours	200	9.7 by 10^{13}.
27	Immersed in water 48 hours	70	9 by 10^6.
	Dried in oven at 110° C	70	1 by 10^{13}.
30	Immersed in water 48 hours	100	1.4 by 10^7.
	Dried in laboratory air several days	200	3.5 by 10^{14}.
	Immersed in water 48 hours, dried in laboratory air 26 hours	200	2.5 by 10^{13}.
	Immersed in water 48 hours, dried in laboratory air 75 hours	200	([c])
32	Immersed in water 48 hours	100	3.5 by 10^6.
	Dried in laboratory air several days	200	1.9 by 10^{13}.
38	Immersed in water 24 hours	100	1.4 by 10^7.
	Dried in laboratory air several days	200	2.4 by 10^{13}.
40	Immersed in water 48 hours	100	7.6 by 10^6.
	Dried in laboratory air several days	200	2.2 by 10^{14}.
41	Immersed in water 48 hours	100	6.4 by 10^6.
	Dried in laboratory air several days	200	1.4 by 10^{13}.

[a] The resistance of volume between two opposite faces of a 1-cm cube of the material.
[b] Sample has a conducting vein, probably pyrites, with low resistance at that point.
[c] Greater than 10^{15}.

TABLE 12—Continued

Ref. No.	Condition of specimen	Voltage, direct current	Volume resistivity, ohm-centimeters
43	Immersed in water 48 hours	100	3.6 by 10^{6}.
	Dried in laboratory air several days	200	0.2 by 10^{13}.
44	Immersed in water 48 hours	100	2.2 by 10^{7}.
	Dried in laboratory air several days	200	1.9 by 10^{13}.
45	Immersed in water 48 hours	100	1.1 by 10^{7}.
	Dried in laboratory air several days	200	2.4 by 10^{14}.
46	Immersed in water 48 hours	100	1.3 by 10^{7}.
	Dried in laboratory air several days	200	1.2 by 10^{14}.
47	Immersed in water 48 hours	100	7.2 by 10^{6}.
	Dried in laboratory air several days	200	2.9 by 10^{13}.
48	Immersed in water 48 hours	100	9.4 by 10^{6}.
	Dried in laboratory air several days	200	1.1 by 10^{11}.
50	Immersed in water 48 hours	70	3.0 by 10^{6}.
	Dried in oven at 110° C	70	2.0 by 10^{12}.

WASHINGTON, December 1, 1918.