DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
George K. Burgess, Director

TECHNOLOGIC PAPERS OF THE BUREAU OF STANDARDS, No. 350
[Part of Vol. 21]

A STUDY OF PROBLEMS RELATING TO THE
MAINTENANCE OF INTERIOR MARBLE

BY

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July 23, 1927

PRICE 35 CENTS

\$1.25 PER VOLUME ON SUBSCRIPTION

Sold only by the Superintendent of Documents, Government Printing Office
Washington, D. C.

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1927

A STUDY OF PROBLEMS RELATING TO THE MAINTENANCE OF INTERIOR MARBLE

By D. W. Kessler

ABSTRACT

Cleaning preparations in present-day use have been studied to determine the extent of injury that may be caused by harsh grits and such salts as sodium carbonate, sodium bicarbonate, and trisodium phosphate. These salts are present in many trade cleaning materials and have been shown to have an injurious effect, due to their crystallizing action, which may manifest itself after a considerable period of frequent use. The abrasive action of the usual type of grit was found to be of little consequence when such is used on marble floors, but will prove injurious to polished marble.

The harmful action of neutral salt solutions on marble may present itself in other ways than from their use in cleaning. They may penetrate the slabs in soda-fountain counters where many different salt solutions are splashed against the marble or reach it at the floor line. In the case of damp walls, small amounts of various salts are dissolved from the masonry walls or carried into the marblework by the ground water. Many different salts were shown to have severe effects when allowed to crystallize within the marble. Those which appear to have the most severe action are sodium chloride, sodium sulphate, magnesium sulphate, sodium carbonate, sodium bicarbonate, ammonium carbonate, and trisodium phosphate.

Means of sealing the backs of marble slabs before use under severe conditions have been studied. The results indicate that wax solutions do not form a perfect seal, and such treatments can not be relied upon to prevent injury under continual exposures, such as may occur on damp walls. Paraffin applied by a heat treatment seems to be fairly efficient as well as very durable.

Many experiments have been made to develop methods of eliminating various kinds of stains from marble, which resulted in practical means of treating the more usual stains occurring on the marblework of buildings, such as iron, tobacco, bronze, ink, linseed oil, lubricating oil, pitch, and general service stains.

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I. INTRODUCTION

This research was undertaken cooperatively by the National Association of Marble Dealers and the Bureau of Standards, and has for its object the solution of certain practical problems which are occasionally encountered in the installation and care of interior marble. While the greatest part of the program was concerned with the action of various types of cleaning preparations on different marbles and methods of removing accidental stains, considerable attention has also been given to the following problems:

1. The effect of exposure to various salt solutions and such conditions as may arise in soda-fountain counters.
2. The effect of damp wall conditions on interior marble.
3. Treatments for marble before installation under severe and unusual service conditions.
4. The development of a cleaning preparation to meet all requirements of usage and prove satisfactory under practically all conditions.
5. The effect of hard waters and methods of eliminating the hardening elements.

Chemical analyses reported herein were made under the direction of F. W. Smither, of the Bureau of Standards, who also supplied many valuable suggestions in connection with various phases of the research.

II. CLEANING PREPARATIONS

In the study of cleaning materials in present-day use on interior marbles a collection of representative trade preparations was obtained for experimental purposes. Seventeen trade preparations were analyzed to determine the various ingredients which are employed. The most widely used preparations were found to be of the scouring type, containing from 30 to 90 per cent of grit, from 2 to 9 per cent of soap, from $\frac{1}{2}$ to 50 per cent of carbonates of soda, and from 1 to

40 per cent of water. The grit generally employed consists of volcanic ash which is a fine, flaky silica glass occurring in nature. Crushed quartz is sometimes used as a scouring agent. All but two of the materials examined of this type appear on the market as fine, gray powders, the others being sold in the form of a paste. The high limit of the water content cited above was found in one of the paste preparations.

Preparations of the nonscouring type—that is, those preparations entirely soluble in water—are of more variable composition and may be subdivided into two classes; namely, those consisting mainly of soap and those consisting mainly of alkaline salts, such as trisodium phosphate, carbonates of soda, etc. Trisodium phosphate preparations are rather extensively used for marble cleaning and are probably next in importance to preparations of the scouring type. One liquid soap which has come into the marble cleaning field and one preparation consisting of trisodium phosphate, sodium perborate, and soap were tested. The following table gives the results of chemical analyses on the samples which were studied:

Chemical analyses of cleaning preparations

[Constituents indicated in percentages by weight]

SCOURING TYPE

Designation	Grit	Alkaline carbonate	Anhydrous soap (by difference)	Volatile at 105° C.
A.....	1 28.9	52.4	5.1	13.6
B.....	1 49.8	2.0	9.2	39.0
C.....	1 73.1	12.4	2.7	11.8
D.....	1 85.8	8.1	3.2	2.9
E.....	1 62.8	15.4	4.6	17.2
F.....	1 92.2	.4	6.4	1.0
G.....	1 78.1	11.4	2.6	7.9
H.....	1 66.3	8.9	5.2	19.6
I.....	2 81.1	13.2	1.8	3.9
J.....	1 73.1	15.6	7.7	3.6
K.....	2 51.4	36.4	2.6	3 7.4

NONSCOURING TYPE

Designation	Trisodium phosphate (Na ₃ PO ₄) ⁴	Alkaline carbonate	Borax	Ammonia (NH ₃)	Soap anhydrous	Free alkali (NaOH)	Insoluble matter	Sodium perborate	Moisture and combined water (by difference)
A'.....	42.5	2.5	0.9	0.6					53.5
B' ⁵									
C'.....	6 49.8			.6	25.5		5.0		19.1
D'.....	10.0				62.5	0.3		9.5	17.7
E' ⁷					8 10.4				86.7
F'.....	22.6	16.8							60.6

¹ Volcanic ash.

² Crushed quartz.

³ This sample contained 2.2 per cent of starchy material (with a small amount of protein).

⁴ Calculated from total P₂O₅.

⁵ Technical trisodium phosphate.

⁶ This figure includes sulphur compounds (probably hydrosulphites) and a small amount of borax.

⁷ Material also contained 2 per cent of glycerol, 0.2 per cent of potassium chloride, 0.6 per cent of unsaponified matter, and 0.1 per cent of carbonate.

⁸ Potash soap.

It will be noted from the range in compositions that a rather wide choice of detergents may be employed. From the fact that materials of the scouring type are by far the most extensively employed for cleaning marble floors, it may be assumed that this type is more satisfactory for removing the kind of dirt found on floors. However, it was not the main object of this study to compare the cleaning merits of different preparations, but to determine the possible injurious effects which may result from a long period of use on marble.

The first consideration which appeals to the casual observer of cleaning preparations is the effect of the scouring grits. All of the commonly used grits are relatively hard materials and will abrade marble. No better proof of this may be cited than the fact that sand is used as the abrasive in marble plants for cutting and grinding the marble. The hardness of crushed quartz is the same as that of sand while volcanic ash is probably slightly less hard. The following list of minerals showing the hardness values as rated on the Moh's scale is of interest in this connection:

Mineral	Hardness	Mineral	Hardness
Talc.....	1	Dolomite.....	3.5-4
Graphite.....	1-2	Magnesite.....	3.5-4.5
Gold.....	1-3	Fluorite.....	4
Soapstone.....	1-4	Platinum.....	4-4.5
Gypsum.....	1.5-2	Apatite.....	5
Sulphur.....	1.5-2.5	Orthoclase.....	6
Rock salt.....	2.5	Pyrite.....	6-6.5
Galena.....	2.5	Quartz.....	7
Silver.....	2.5-3	Beryl.....	7.5-8
Mica.....	2.5-3	Topaz.....	8
Serpentine.....	2.5-4	Emery.....	9
Calcite.....	3	Diamond.....	10

The Moh's scale expresses the hardness of minerals only in a relative sense. Thus, fluorite would scratch all the minerals preceding it in the list but would be scratched by the succeeding minerals. Marbles, in general, correspond to the hardness of calcite, but dolomitic marbles may be a little harder than this, while the verde antique marbles, corresponding to serpentine in the list, vary in hardness from 2.5 to 4, being in some cases softer than calcite marbles and in other cases a little harder. The hardness of sand is the same as quartz in the list, glass is about 6, and carborundum 9.5. As pointed out above, the Moh's hardness values are not quantitative, and it should not be assumed that glass, which has a hardness of 6, is twice as hard as marble, which has a hardness of 3. Rosiwal has shown by grinding tests that there are much greater differences in the hardness values as we approach the harder minerals. The results of his tests give the comparative values of the usual reference minerals as follows:

Diamond.....	140, 000
Carborundum.....	1, 000
Topaz.....	175
Quartz.....	120
Feldspar.....	37
Apatite.....	6. 5
Fluorite.....	5
Calcite.....	4. 5
Gypsum.....	1. 25
Talc.....	. 33

These determinations indicate that quartz is about twenty-six times as hard as marble. Assuming that glass is of the same hardness as feldspar would lead to the conclusion that volcanic ash, which is a glassy material, is about eight times as hard as marble.

The practical importance of this difference in hardness between marble and the grits is probably not as great as one, at first thought, may assume it to be. While such hard grits evidently do abrade marble under the mopping action, the rate is so slow as to be almost inappreciable on marble floors. The main considerations in this connection are as follows: First, the effect of such grits under foot traffic, and, second, the effect on polished marble.

Evidently a hard grit left on the floor would accelerate the rate of wear, and it is very doubtful if such grits are very thoroughly removed from the surface by the usual rinsing process. Hence, it is of some importance to determine how much the use of such grits may affect the life of a marble floor.

Polished marble is not cleaned frequently like marble floors, and such cleaning as is necessary does not usually require the use of a scouring preparation. However, polished marblework is often cleaned with such preparations. It is quite natural for the cleaning squad to assume that a cleaning preparation for use on marble floors will also prove satisfactory on polished marble.

Volcanic ash, quite naturally, comes into use as a detergent grit because it occurs in nature in the desired state of fineness and is relatively cheap. Deposits are known in several Western States, but the principal demand at this time is supplied from Nebraska. This material has been placed on the market under such designations as "Nebraska silicate," "geyserite," "diamond polish," etc.

The following chemical analysis, taken from an article by G. P. Merrill in the *American Journal of Science*, vol. 32, was made on an average sample of volcanic ash from Nebraska:

SiO ₂	68. 91
Al ₂ O ₃ and Fe ₂ O ₃	6. 12
CaO.....	3. 44
Na ₂ O.....	3. 09
K ₂ O.....	. 36
SO ₃	8. 88
Ignition loss.....	8. 75

The microscope shows the material to consist mainly of thin flakes, but some of the particles resemble ground pumice. Most of the flakes exhibit the transparent amorphous character of glass, but others show interference colors, extinction, and other characteristics of quartz grains. The analysis given above seems to indicate that a considerable amount of calcite may be present, but none of the samples examined in this study showed any tendency to effervesce with acids.

Figures 1 to 3 are photomicrographs of three samples of volcanic ash showing a magnification of 150 diameters. It will be noted that the sample shown in Figure 2 is somewhat freer from pumiceous fragments than the other two. Figure 4 is a similar enlargement of a crushed quartz grit. This is seen to consist of granular fragments and very few flaky particles. One may naturally infer that this type of grit would be somewhat more efficient as a scouring agent because of its having more sharp edges on the particles. However, by the same reasoning it appears that it would give a more severe abrading action.

In the following table is given the results of sieve analyses of the grits from various trade preparations:

Sample from preparation designated	Percentage passing sieve—			
	No. 60	No. 80	No. 100	No. 200
B.....	96.5	93.0	88.9	67.0
C.....	100.0	100.0	98.4	88.0
D.....	99.2	98.6	97.5	83.0
E.....	98.0	94.6	90.0	64.0
F.....		98.7	97.9	72.4
G.....	97.2	95.3		
H.....	99.5	98.3	98.3	85.0
I.....	100.0	95.7	91.5	72.5

The first seven of these are volcanic ash grits and the last is crushed quartz. These analyses show that most of the preparations have particles which are retained on the 60-mesh screen. Such particles, if left on the floor, are apt to produce rather prominent scratches under foot traffic. This can be easily demonstrated by placing a few such particles on a piece of marble and stepping on them in such a way as to move the particles under foot.

Comparative abrasion tests made on the apparatus shown in Figure 5, using various grits on the same samples of marble, gave the following abrasion losses in 30 minutes grinding:

	Grams
Grit A (volcanic ash).....	1.36
Grit B (volcanic ash).....	1.30
Grit C (volcanic ash).....	.92
Grit D (crushed quartz).....	2.21
Crushed marble.....	.51
Crushed soapstone.....	.57
Crushed gypsum.....	.00
No. 60 emery.....	4.82

FIG. 1.—Photomicrograph of volcanic ash grit from trade cleaning preparation E. Magnification, 150

FIG. 2.—Photomicrograph of volcanic ash grit from trade cleaning preparation F. Magnification, 150

FIG. 3.—Photomicrograph of volcanic ash grit from trade cleaning preparation H. Magnification, 150

FIG. 4.—Photomicrograph of crushed quartz grit from trade cleaning preparation I. Magnification, 150

This apparatus consists of a grinding lap which is revolved at the rate of 100 r. p. m., a device for holding the test pieces on the lap under a constant pressure, and a means of feeding the abrasive at a uniform rate.

The marble specimens used were weighted before and after 30 minutes grinding to determine the amount of abrasion. The results indicate that the crushed quartz grit is about twice as severe as the volcanic ash grits, that crushed marble and crushed soapstone are less than half as severe as volcanic ash, and that gypsum does not

FIG. 5.—Abrasion apparatus used to determine the abrading action of various grits

abrade at all. The test made with No. 60 emery for comparison indicates that it abrades more than twice as fast as crushed quartz and about four times as fast as the volcanic ash grits.

While the above tests give a fairly good representation of the abrasive action of different grits under severe conditions, such as under foot traffic, it is of considerable interest to determine how they act on marble in the actual scrubbing process. In order to obtain some information on this point a scrubbing apparatus was designed consisting of a weighted device carrying two fiber brushes and a means of feeding the scrubbing preparations. The brushes were moved back and forth by a suitable mechanism over the marble

test pieces. The total weight on the two brushes was 3 pounds, and the length of the scrubbing period was three hours. The marble specimens, which were 4 inches square, were laid adjoining each other in a row and the stroke of the brushes was sufficient to scrub all at one time. Three small slabs were used because this size could be weighed to considerable precision whereas a single slab as large as three of these was too heavy for a delicate balance. Brushes were used instead of a mop because of the difficulty found in feeding the scrubbing preparations by mechanical means to a mop. The tendency was for the mop to "run dry"; that is, to push the scrubbing grits off the surface. This tendency was not so apparent with the brushes. The abrasion loss was determined by measuring the dry weights of the pieces before and after three hours scrubbing. In order to reduce the error due to absorption by the marble of some of the soluble matter in the cleaning preparations, the specimens were soaked in water for a few hours before being submitted to the scrubbing test, then dried in the oven before making the final weight determination. Tests were made in this manner on several trade cleaning preparations and also on some experimental preparations employing softer grits. The results are given in the following table:

Abrasion losses in scrubbing tests

Designation of cleaning preparations	Designation of marble	Abrasion loss (three hours' scrubbing)
		<i>Grams</i>
C.....	10	1.10
D.....	10	.70
E.....	10	.49
F.....	10	1.58
H.....	10	.94
I.....	1	.77
I.....	1	1.53
J.....	10	1.16
K.....	1	.59
M.....	1	.64
Soapstone grit through—		
No. 100 sieve+10 per cent soap.....	10	.15
No. 100 sieve+10 per cent soap (different sample).....	1	.35
Do.....	1	.39
Soapstone grit through No. 100 sieve.....	1	.33
Limestone grit through No. 100 sieve+10 per cent soap.....	1	.15

These tests indicate a definite amount of abrasion for all the grits tried, and considerably more for the hard grits than for the experimental grits; namely, soapstone and limestone. The amount of abrasion in the tests with a soapstone grit was surprisingly high when considered in connection with the relative hardness of this grit and marble. It will be seen in the table of hardness values on page 594 that the hardness of soapstone is 1 to 4, while that of marble is 3. This rather unexpected result is, no doubt, due in part to the presence in the grit of quartz particles which have a hardness of 7. However, there appears to be another factor that is partly concerned. In scrubbing with a soapstone grit, as in this test, it was noted that

the grit readily spread and exhibited a tendency to cling to the surface. In other words, a smaller portion of the grit which was fed to the scrubber was pushed ahead of the brushes than with the other types. With some other materials it was found to be a difficult matter to keep the grit on the marble; that is, the brushes simply pushed it aside instead of drawing it under. Therefore, when the soapstone grit was employed the greater portion of it was actually used as an abrading agent, but in case of some of the others a large portion was not utilized in this way. It appears that this feature would prove a strong point in favor of the soapstone grit in actual scrubbing operations, since it indicates that a smaller quantity of the grit would be required and probably less work would be necessary.

In order to obtain some information as to how the soapstone grit compared with volcanic ash under conditions similar to those where a mop is used, a small mop was made consisting of several layers of Canton flannel and weighted to 3 pounds. This was moistened, dipped into the dry cleaning powder, and then pushed back and forth by hand along a certain path on a slab of polished marble. After each 10 strokes the mop was moistened and dipped in the cleaning powder. For each cleaning preparation the number of strokes were counted until the first signs of scratching or dulling of the polish were observed. In this procedure it was the purpose to keep a sufficient amount of the grits under the mop; that is, as nearly as possible the same amounts in all tests. As pointed out above in the case of the mechanical device, it was not possible to keep similar amounts of different preparations under the brushes. In this respect, at least, the hand test is believed to be more to the point. The weak point in this, however, is in judging just when the polished surface begins to show effects of abrasion. A clear white marble slab was chosen for the purpose and the tests were made side by side so that the results could be readily compared. The results obtained are as follows:

Designation of cleaning preparation	Number of strokes causing visible scratches on polished marble	Designation of cleaning preparation	Number of strokes causing visible scratches on polished marble
D.....	150	M.....	50
E.....	140	Soapstone grit through No. 100 sieve	
I.....	50	+10 per cent soap.....	2,000
K.....	40	Limestone grit through No. 100 sieve	
L.....	60	+10 per cent soap.....	200

Preparations D, E, and K utilize volcanic ash for the grit and I, L, and M utilize crushed quartz. The tests indicate that the crushed quartz abrades marble under the mop about three times as fast as the volcanic ash grits. The soapstone grit showed a very slow abrasive action, while the powdered limestone appeared to be slightly

less severe than the volcanic ash grits. This test was intended to represent a very mild scrubbing action, since the total weight on the mop was only 3 pounds. It appears from these results that a scrubbing powder utilizing a soapstone grit could be used on polished marble for a long period of time without appreciable injury, since the tests were stopped when the first signs of scratching were noted.

The results given in the table on page 596 are of interest in that they afford some information on the comparative amounts of wear on marble floors due to a small amount of grit being left on the surface. In this connection it was deemed worth while to make some tests under actual traffic conditions. For this purpose a set of forms were made to hold a considerable number of small marble slabs on the treads of a staircase. Each morning these were swept clean, as well as the rest of the flight above, then the test pieces were sprinkled lightly with the particular grit in question. This somewhat exaggerated amount of grit was, of course, abraded against the marble under foot traffic. The test slabs, which were carefully weighed in the dry state before placing, were removed at the end of 25 days, dried, and weighed again. The following table gives the results of these experiments on 27 small slabs of marble No. 10 exposed first to abrasion with a volcanic ash grit and then to a soapstone grit. The variation in the results obtained on different pieces in the same test is due to the fact that those pieces to the front of the treads received the greatest wear, while those to the back were worn very little. The total loss in weight for the entire group, as tested with one grit, affords a value which may be compared with the loss for a similar group tested with a different grit, since the marbles were the same in all cases and the traffic conditions may be assumed to be reasonably constant.

Wear on marble specimens on stairway

[Marble No. 10 was used in these tests]

Piece No.	Amount of wear in 25 days		Piece No.	Amount of wear in 25 days	
	Volcanic ash grit on marble	Soapstone grit on marble		Volcanic ash grit on marble	Soapstone grit on marble
	<i>Gram</i>	<i>Gram</i>		<i>Gram</i>	<i>Gram</i>
1.....	0.56	0.25	16.....	0.09	0.35
2.....	.08	.00	17.....	.26	.70
3.....	.01	.13	18.....	.08	.00
4.....	.04	.00	19.....	.04	.08
5.....	.03	.00	20.....	.18	.20
6.....	.28	.25	21.....	.13	.13
7.....	.14	.60	22.....	.41	.03
8.....	.09	.10	23.....	.05	.00
9.....	.13	.08	24.....	.11	.00
10.....	.00	.08	25.....	.03	.08
11.....	.76	.05	26.....	.28	.03
12.....	.31	.43	27.....	.43	.13
13.....	.06	.05			
14.....	.06	.03			
15.....	.33	.15	Total loss.....	4.91	3.93

Although hard grit cleaning materials are not intended for use on polished marble, it is nevertheless a fact that they are frequently used for this purpose. If such cleaning preparations were used on all parts of the polished marblework of a building so that all of the marble is scoured to the same extent, the effect would not be especially undesirable. When a spot of dirt appears on the wall work and attracts the attention of the cleaning squad, it is usually scrubbed until clean. When a grit cleaner is used on some parts of the polished marble in this way, the polish is removed from these parts and they present a poor appearance in contrast with the original finish.

Another consideration which makes the use of such grits undesirable, even on marble floors, is their effect on the marble mop slab at the base of the wall work. This practically always consists of polished marble. In cleaning with mops and hard grits the mops are rubbed against this polished surface and the polish is soon injured. An examination of buildings, where marble floors are cleaned with grit cleaners, will usually show that the polish on the base of the wall work is injured from the floor line upward for 3 or 4 inches. The dirt which collects at the base of the wall is difficult to reach with the mop and hence the cleaning squad is apt to press the mop with considerable force against the wall. Black marbles, and some others which are frequently used for base slabs, show a marked contrast between the polished and unpolished surfaces, hence they are apt to show the injurious effects of hard grits.

In order to show how readily the polish may be injured by vigorous scouring with various kinds of grits, the slab in Figure 6 was scrubbed along certain paths marked with numerals at the top. A mop was made by attaching a piece of felt 2 inches long and $\frac{5}{8}$ inch wide to a handle and weighted with a 10-pound weight. Each test consisted of 100 strokes along a path with the weighted mop. The surface of the marble was moistened and sprinkled lightly with the cleaning preparations at the start and after each 10 strokes. The tests labeled 1 and 2 were made with cleaning preparations containing volcanic ash, and 3, 4, and 5 were made with powdered marble, soapstone, and gypsum, respectively. The last three consisted of the powdered material passing a 100-mesh sieve mixed with 5 per cent of soap powder. In order to make the abraded parts of the marble show more clearly in a photograph, the whole slab was crosshatched with a pencil. Where the polish was removed the pencil marks show distinctly, but on the polished part they are very faint. This shows that the greatest abrasion was caused by the volcanic ash grits, the marble grit caused slightly less, the soapstone an appreciable amount, while the gypsum produced practically no effect. Unfortunately a gypsum grit would not prove satisfactory for use in a cleaning preparation where soap is used because it is slightly soluble in water. This would

produce hardness in the water, which would cause trouble where soap is to be used. The effect of hard waters will be discussed under a separate heading.

FIG. 6.—Abrading action of various grits on polished marble

III. PHYSICAL EFFECT OF ALKALINE SALTS IN CLEANING PREPARATIONS

By reference to the table of chemical results on page 593 it will be noted that practically all of the trade cleaning preparations contain alkaline salts, such as sodium carbonate, sodium bicarbonate, tri-sodium phosphate, or sodium borates. These materials have a detergent action in cleaning, as well as a softening effect on the water. The solutions of such salts would not be expected to appreciably injure the marble in a strictly chemical sense. A piece of marble could be soaked in a strong solution of such salts for months without causing any noticeable alteration. However, if the marble is alternately soaked in such a solution and dried an entirely different phenomenon occurs. The effect in this case is not chemical but purely physical. The salt solutions penetrate the marble, but in

drying only the water evaporates, leaving the salt within. Crystals of the salt form in the pores of the marble and as the crystals increase in size a pressure is exerted from within. The severity of such action is probably not generally appreciated. Several materials which are more porous and weaker than marble will begin to crumble under such treatment within a short time. A similar action takes place when a porous material is soaked in water and frozen. The quarryman in winter sometimes finds his freshly quarried blocks of stone disrupted by frost. The action of salt solutions on porous materials is similar in some respects to frost action. When a material is soaked with a salt solution and dried, the salt forms crystals on or slightly below the surface, hence the greatest stress occurs near the surface. When a material is saturated with water and frozen, ice crystals form wherever there is water, hence the material is stressed on the interior as well as near the surface. Frost action usually manifests itself by splitting the stone along weak seams. The crystallizing action of salts usually results in crumbling or spalling the material in shallow layers near the surface.

The action of salt solutions is familiar to many in different ways. Many make a practice of thawing ice from their stone or concrete steps in winter by sprinkling a layer of common salt on the ice. As the ice thaws the salt is dissolved and often penetrates the step. Rapid disintegration of the steps usually results from such practice. In the Western States, where there is a large amount of alkaline salts in the ground water, the salts creep up into the lower courses of masonry buildings and cause decay in a similar manner. A case is on record where a contractor in erecting a fine building of limestone used common salt to thaw ice out of the Lewis holes in blocks of stone before hoisting them into place. Soon afterwards the stonework began to scale and crumble and much of it was injured. In a certain hospital a solution of common salt was used to spray the toilet stalls to disinfect them. Both marble and slate stalls were treated in this way until it was observed that the slabs were falling to pieces.

In considering the effect of cleaning preparations on marble the presence and effect of soluble salts should not be overlooked. Only a few actual cases have been found where marble has shown disintegration from such causes, but this is probably due to the fact that marble is a strong and dense material and very resistant to such action. Figures 7 to 10 illustrate what sometimes does occur and what may occur in any case where such detergents are used unless special precautions are taken to avoid it.

In order to test the effects of various salts found in cleaning preparations, an apparatus was constructed to simulate, as nearly as practical conditions would permit, the actual conditions of scrub-

bing. This is shown in Figure 11 to consist of a broad-faced wheel which holds 36 small slabs of marble around its periphery. Below this wheel is a drum 6 inches in diameter and 6 inches long covered with soft felt tubing. This is mounted on a framelike lever so that

FIG. 7.—Disintegration of a marble stairway due to the use of a cleaning preparation containing sodium carbonate

it can be counterweighted to press the drum against the marble at any pressure desired. The pressure was adjusted to 1 pound per square inch of contact for all tests. The lower part of this drum dips into a pan containing the cleaning preparation under test. The

large wheel is geared down to a very low speed, so that it makes only four turns in 24 hours. The scrubbing drum revolves about 40 times per minute and carries the cleaning preparation up from the

FIG. 8.—Disintegration of marble steps due to the use of a cleaning preparation containing sodium carbonate

pan, thus scrubbing each marble slab for 10 minutes each time it passes the scrubber. As the large wheel rotates a little farther, the

FIG. 9.—Disintegration of a marble floor due to the use of a cleaning preparation containing sodium carbonate

scrubbed slabs of marble come to another small drum which rinses the surface with plain water. The function of this apparatus is to first scrub the marble, rinse the surface, and finally allow it to dry

before the next scrubbing. In order to aid the drying process two electric fans were used to blow currents of air on the marble.

While this apparatus was designed mainly for the purpose of determining the effect of various salts in the cleaning preparations, it

FIG. 10.—Disintegration of a marble floor due to the use of a cleaning preparation containing sodium carbonate

also gave some results of value on the action of the grits in preparations of the scouring type. The effects of the salts on the marble were determined partly by examining the scrubbed material and comparing it with the unscrubbed portion of the slabs, but mainly by comparing the strength of the scrubbed material with that of the original or

unscrubbed specimens. The original samples of marble submitted by the producers consisted of slabs 1 foot by 2 feet by $\frac{7}{8}$ inch thick. These were polished on one face. From these the specimens for test were prepared by sawing the original slabs into five strips 4 by 12

FIG. 11.—Apparatus used for making long period scrubbing tests on marble

inches in size, as shown in Figure 12. Strips Nos. 1, 3, and 5 of each sample were used for the scrubbing test, while Nos. 2 and 4 were tested to determine the strength and elasticity of the original material. These determinations were made on the apparatus shown in Figure

14 built especially for this purpose, since the testing machines available, being constructed for heavier work, were not sensitive enough for small specimens. This apparatus consists of a 600-pound capacity

FIG. 12.—Manner of cutting sample slabs of marble into test specimens

platform scale, sensitive to 1 ounce, and a means of applying the load through a knife-edge as shown in Figure 13. The specimens were supported on two similar knife-edges mounted 11 inches apart on the scale platform. A special set of 10 weights was made corresponding

FIG. 13.—Manner of supporting and loading specimens in the flexure tests

to 10-pound loads. By means of these the load on the specimen could readily be increased in 10-pound increments up to the breaking point. When the required load was more than 100 pounds, as was

usually the case, the small weights were replaced by one 100-pound weight and the 10-pound increments added again up to the breaking point. The elastic properties were determined simultaneously with the strength measurements by reading the deflection of the slab at the center for the various loads. Figure 13 illustrates the manner of loading the slabs and the symbols used for the dimensions concerned. From the load W causing the specimen to break, the cross-sectional dimensions of specimen and span l , the modulus of rupture was computed by means of the formula $R = \frac{3Wl}{2bt^2}$. By plotting the deflection readings for various loads a curve was obtained similar to

FIG. 14.—Flexure testing apparatus in operation

those illustrated in Figure 15. The modulus of elasticity E is computed from this curve by means of the formula $E = \frac{W'l^3}{4dbt^3}$, the symbols having the same significance as above. The letter " d " which does not appear above, is the deflection reading caused by any chosen load W' . It will be noted in Figure 15 that the curves do not start from the zero point due to the fact that the deflection apparatus was set to zero when the specimen was under a load of 10 pounds, this being done because it was very difficult to adjust both the load and deflection apparatus to zero at the same time. When the stress-strain curve was obtained, as shown in Figure 15, a corrected curve was drawn from the zero point parallel to the proportional part of the curve and the coordinates of some convenient point on this line were used

for computing the E values. This is in accordance with the procedure usually followed for tests of this nature.

The scrubbing test was made on 12 samples of marble, represented by three specimens each; that is, the wheel when mounted for the test held 36 specimens. The apparatus was run continuously for one month with each cleaning preparation tested. At the end of this time each specimen had received 120 scrubblings of 10 minutes' duration. This length of test was determined largely by practical considerations, but it was estimated that the actual scrubbing was equivalent to that which the marble in floors would normally receive

FIG. 15.—Stress-strain curves from a set of flexure tests on a sample of marble in the original condition and after scrubbing with a trade cleaning preparation

in 50 years. However, it should be pointed out that the crystallizing action due to the salts in the cleaning preparations would not represent more than two years of normal service conditions. Many marble floors which are scrubbed daily would probably produce more crystallizing action in one year than was developed in this test. Probably the amount of salt solution absorbed during this test would be more than that absorbed during an ordinary scrubbing of a floor, but in the latter case the actual conditions are more favorable to a severe crystallizing action due to the longer drying period.

In Tables 1 to 9 the strength and elasticity results are given as determined on the original marble and on the marble after scrubbing

with different preparations. The two determinations made on the marble from a particular sample in the original condition were averaged and assumed to represent the original strength. This average was compared with the average of the three determinations on the scrubbed specimens from the same sample to determine the effect of scrubbing. It will be noted that in some cases a higher strength was obtained on the scrubbed material. Most cases of this kind could be accounted for by one of the tests on the original material falling considerably below the average of all the tests. Such specimens were probably faulty due to weak veins or invisible strain lines. However, it was decided that all the determinations should be used regardless of such indications. In the mean values for a complete test, comprising 24 specimens in the original condition and 36 after scrubbing, such inequalities are believed to be largely eliminated. Considering the average values for the original material as compared with the average of the scrubbed material for each test the following results are indicated:

The results given in Table 1 are from a test made on the cleaning preparation designated "C" in the table of compositions on page 593. This preparation contains less than 3 per cent of anhydrous soap and about 12 per cent of alkaline carbonate. It is used rather extensively in the Eastern and Northeastern States. About three-fourths of the weight consists of the scouring ingredient. The ingredient of particular interest in this test is the carbonate of soda. The test was made on the marbles whose serial numbers are given in the first column of the table. A description of the marbles as designated by serial numbers is given in Table 13, page 667. In all tests of this series, the group of marbles, chosen for test with each particular cleaning preparation, was such as to represent the entire range of characteristics, as colors, textures, etc. The average strength in flexure of the original marble in this test was found to be 2,293, while that of the scrubbed samples was 2,136, indicating a loss of strength of 6.8 per cent, which is indicative of injury from the sodium carbonate. The effect on the elastic constants appears to be rather uncertain. The average values indicate for this test a gain for "E" of 2.5 per cent. The crystallizing action was apparent on the surface of some of the marbles by loosened small flakes or grains. The effect of the scouring agent on the polish was apparent within a short time.

Table 2 gives the results on a preparation which is extensively used in all parts of the country. The composition of this, as shown under the designation "D" on page 593, is similar to that for the preceding material except that it contains less of the alkaline salts and a larger amount of the grit. For this reason it may be expected to produce less effect on the marble due to crystallization. The average

strength for the original material was 1,823 and that for the scrubbed material 1,740, indicating a loss of 4.6 per cent. In this test as well as the preceding a gain in the "E" values is indicated. This effect will be reserved for later discussion.

The results given in Table 3 were obtained on an experimental preparation similar to material "D," except that the alkaline carbonate was reduced to a fraction of 1 per cent and the grit and soap contents were increased accordingly. The alkaline salt was added in an amount assumed to be necessary for water-softening purposes. Since no change in physical properties could be expected from the use of soap alone, this test was run mainly to substantiate the belief that no injury would result. The results fully justify this belief, since the difference between the average values obtained for the scrubbed material and the original is practically negligible.

Table 4 contains the results obtained in a test with preparation "E," a widely used trade material. This preparation contains 15 per cent of alkaline carbonates, consisting of sodium carbonate and sodium bicarbonate. It is interesting to note that in this test a very small loss of strength was indicated. On the other hand, some of the samples showed plainly a surface scaling due to the action of the salts. Since this rather high percentage of salts caused only a small effect on the strength, it was deemed worth while to study the action of this combination of salts in a more severe test, the results of which form the latter part of this chapter.

In Table 5 are given the results of a test on a trade material which is used to a large extent on marble in the Southern States. This material is similar in most respects to material "C," except that it contains more soap and less sodium carbonate. The results are consistent with those from tests on other materials of this type in that a loss of strength was indicated, and on some of the specimens the crystallizing action of the salts produced visible effects.

Table 6 gives the results of a test on a trade preparation which is mainly a trisodium phosphate composition. This preparation belongs to the nonscouring type, since no grit was present. The strength of solution used in scrubbing was maintained between 1 and 2 per cent. The results indicate a loss in strength of nearly 12 per cent and a slight decrease in the elastic constants.

Table 7 gives the results of a test on a trade preparation which has been rather extensively used in cleaning marble floors and to some extent on wall work. It is essentially a trisodium phosphate composition. The strength of the scrubbing solution was about 1 per cent. The results obtained are consistent with those for the preceding material; namely, they indicate a loss in strength of 6 per cent and a decrease in the elastic constants.

In some experiments, which will be described later, it was found that the alkalinity from cleaning preparations could be rinsed from the surface of the marble very easily after scrubbing if the marble was first moistened with clean water before applying the scrubbing material. This was assumed to be due to the preliminary dampening which prevented absorption of the cleaning preparation. This led to the belief that the crystallizing effect of salts in the preparations could be overcome by first rinsing the marble. In order to prove this assumption, a test was made similar to those above in all respects except that the direction of rotation of the specimen wheel was reversed. This caused the rinsing to take place before the scrubbing. In order to magnify the effect, a 10 per cent trisodium phosphate scrubbing solution was used, which is much stronger than that usually employed. The results of the test are shown in Table 8. The slight increase in strength is, no doubt, due to the natural variation of the marble and hence should be disregarded. As far as strength is concerned it appears that the preliminary rinsing fully overcame the action of the salts. A rather unexpected occurrence which developed in this test will be described, since it affords added evidence of the severe action which such solutions produce. The scrubbing drum and the rinsing drum were each 6 inches wide, so the middle 6 inches of each specimen was subjected to scrubbing, leaving 3 inches on each end of the pieces which was neither scrubbed nor rinsed. This was so intended in order that the ends of the marble specimens would afford a means of comparing the original material with the scrubbed portion after the test was completed. After this test had been in progress for several days a narrow zone on the marble slabs about one-half inch outside of the scrubbed portion began to present a dull appearance as though it were abraded. An examination of the machine parts was made to determine if anything was rubbing against the marble where these zones appeared. It was finally concluded that some of the salts were creeping out through the marble and crystallizing on the border of the dampened portion of the specimens. The distance of this zone from the scrubbed portion varied slightly in various marbles, and the width of the zone was not the same for different materials. The location of this action was such that it would not influence the strength of the slabs in the flexure test, it being in all cases more than 3 inches away from the middle where the specimen breaks. This phenomenon is sometimes noted in cases of efflorescence on the lower courses of buildings. Near the ground the efflorescence seldom shows, due to the fact that the masonry is damp and the salts are held in solution. At some zone above where the dampness disappears the salts begin to crystallize and form efflorescence. In such cases the salts are probably carried up into the masonry by the ground water.

Table 9 gives the results of a test on a liquid soap preparation which has been used in some localities on marble. The composition as given in the table on page 593 shows that no ingredients are present which would be expected to affect the strength. This assumption is fully justified by the results, since no appreciable change in properties was found.

TABLE 1.—*Cleaning preparation C*

Serial No. of marble	Test No.	Original marble				Scrubbed marble			
		Modulus of rupture		Modulus of elasticity (E)		Modulus of rupture		Modulus of elasticity (E)	
		Individual tests	Average	Individual tests	Average	Individual tests	Average	Individual tests	Average
1-----	1	2,650	-----	8,580,000	-----	2,620	-----	8,590,000	-----
	2	2,030	-----	8,210,000	-----	2,340	-----	8,820,000	-----
	3	-----	2,340	-----	8,395,000	2,120	2,360	8,050,000	8,487,000
4-----	1	4,350	-----	11,960,000	-----	3,990	-----	11,670,000	-----
	2	3,960	-----	11,310,000	-----	3,680	-----	11,970,000	-----
	3	-----	4,155	-----	11,635,000	3,490	3,720	12,000,000	11,880,000
5-----	1	1,700	-----	10,580,000	-----	1,300	-----	10,800,000	-----
	2	-----	-----	-----	-----	440	-----	-----	-----
	3	-----	1,700	-----	10,580,000	1,750	1,163	11,740,000	11,270,000
9-----	1	2,430	-----	11,270,000	-----	1,940	-----	10,130,000	-----
	2	-----	-----	-----	-----	1,640	-----	10,000,000	-----
	3	-----	2,430	-----	11,270,000	1,590	1,723	9,140,000	9,757,000
11-----	1	1,400	-----	4,180,000	-----	1,630	-----	5,960,000	-----
	2	1,490	-----	4,020,000	-----	1,490	-----	5,630,000	-----
	3	-----	1,445	-----	4,100,000	1,700	1,607	6,870,000	6,153,000
13-----	1	2,620	-----	10,950,000	-----	2,760	-----	11,120,000	-----
	2	2,620	-----	10,930,000	-----	2,470	-----	10,160,000	-----
	3	-----	2,620	-----	10,940,000	2,460	2,563	10,270,000	10,497,000
15-----	1	2,260	-----	9,500,000	-----	1,890	-----	8,400,000	-----
	2	2,100	-----	9,460,000	-----	2,260	-----	9,650,000	-----
	3	-----	2,190	-----	9,480,000	1,640	1,930	8,310,000	8,787,000
16-----	1	2,140	-----	7,580,000	-----	2,140	-----	8,070,000	-----
	2	2,040	-----	6,800,000	-----	2,260	-----	7,520,000	-----
	3	-----	2,090	-----	7,190,000	2,080	2,160	7,570,000	7,720,000
18-----	1	2,130	-----	7,590,000	-----	2,390	-----	7,940,000	-----
	2	-----	-----	-----	-----	2,100	-----	8,270,000	-----
	3	-----	2,130	-----	7,590,000	1,800	2,097	8,320,000	8,177,000
23-----	1	1,580	-----	6,610,000	-----	2,120	-----	8,230,000	-----
	2	2,110	-----	8,960,000	-----	1,620	-----	8,730,000	-----
	3	-----	1,845	-----	7,785,000	2,280	2,007	10,000,000	8,987,000
25-----	1	2,240	-----	10,540,000	-----	2,420	-----	11,240,000	-----
	2	2,330	-----	10,880,000	-----	2,190	-----	10,810,000	-----
	3	-----	2,285	-----	10,710,000	1,880	2,163	9,520,000	10,523,000
Average		-----	2,293	-----	9,061,000	-----	2,136	-----	9,294,000

Indicated change in strength on scrubbing = -6.8 per cent.

Indicated change in E on scrubbing = +2.5 per cent.

TABLE 2.—Cleaning preparation D

Serial No. of marble	Test No.	Original marble				Scrubbed marble			
		Modulus of rupture		Modulus of elasticity (E)		Modulus of rupture		Modulus of elasticity (E)	
		Individual tests	Average	Individual tests	Average	Individual tests	Average	Individual tests	Average
3	1	1,960	-----	8,840,000	-----	1,930	-----	6,820,000	-----
	2	1,880	-----	9,110,000	-----	2,160	-----	10,660,000	-----
	3	-----	1,920	-----	8,975,000	-----	2,170	9,770,000	9,083,000
4	1	4,350	-----	11,310,000	-----	4,270	-----	11,790,000	-----
	2	-----	-----	-----	-----	3,560	-----	11,470,000	-----
	3	-----	4,350	-----	11,310,000	4,320	4,050	11,730,000	11,663,000
5	1	1,850	-----	10,000,000	-----	970	-----	7,810,000	-----
	2	1,290	-----	9,430,000	-----	-----	-----	-----	-----
	3	-----	1,570	-----	9,715,000	600	785	7,720,000	7,700,000
6	1	930	-----	1,520,000	-----	940	-----	2,730,000	-----
	2	1,220	-----	2,400,000	-----	1,190	-----	3,580,000	-----
	3	1,150	-----	3,260,000	-----	1,180	-----	3,950,000	-----
	4	1,250	1,135	2,300,000	2,370,000	1,170	1,120	3,430,000	3,422,000
12	1	1,300	-----	3,060,000	-----	980	-----	4,120,000	-----
	2	970	-----	3,200,000	-----	1,050	-----	4,960,000	-----
	3	880	-----	3,210,000	-----	890	-----	3,220,000	-----
	4	550	925	1,020,000	2,622,000	670	898	2,770,000	3,768,000
13	1	2,300	-----	10,000,000	-----	2,400	-----	9,850,000	-----
	2	2,460	-----	10,600,000	-----	2,360	-----	10,400,000	-----
	3	-----	2,380	-----	10,300,000	2,340	2,367	10,400,000	10,217,000
15	1	1,460	-----	9,580,000	-----	2,500	-----	10,000,000	-----
	2	2,400	-----	10,370,000	-----	2,140	-----	9,670,000	-----
	3	-----	1,930	-----	9,980,000	2,400	2,345	10,140,000	9,903,000
18	1	1,570	-----	6,220,000	-----	1,410	-----	7,060,000	-----
	2	1,700	-----	6,030,000	-----	1,200	-----	4,030,000	-----
	3	-----	1,635	-----	6,125,000	1,100	1,237	7,300,000	6,130,000
19	1	1,380	-----	3,330,000	-----	1,280	-----	4,340,000	-----
	2	1,230	1,305	2,920,000	3,075,000	1,100	1,190	5,530,000	4,935,000
26	1	2,440	-----	11,020,000	-----	2,420	-----	10,820,000	-----
	2	2,320	-----	11,000,000	-----	2,160	-----	10,620,000	-----
	3	-----	2,380	-----	11,010,000	2,560	2,380	11,420,000	10,953,000
27	1	1,910	-----	4,120,000	-----	1,790	-----	5,570,000	-----
	2	1,220	-----	2,970,000	-----	1,270	-----	4,540,000	-----
	3	1,800	-----	5,660,000	-----	1,910	-----	5,220,000	-----
	4	1,780	1,678	5,080,000	4,458,000	1,760	1,682	5,330,000	5,165,000
29	1	840	-----	6,220,000	-----	990	-----	2,940,000	-----
	2	500	670	2,920,000	4,570,000	480	735	1,720,000	2,330,000
Average		-----	1,823	-----	7,042,000	-----	1,740	-----	8,854,000

Indicated change in strength on scrubbing = -4.6 per cent.

Indicated change in E on scrubbing = +25.8 per cent.

TABLE 3.—Cleaning preparation F

Serial No. of marble	Test No.	Original marble				Scrubbed marble			
		Modulus of rupture		Modulus of elasticity (E)		Modulus of rupture		Modulus of elasticity (E)	
		Individual tests	Average	Individual tests	Average	Individual tests	Average	Individual tests	Average
1-----	1	2,570	-----	8,630,000	-----	2,130	-----	6,130,000	-----
	2	2,760	-----	8,360,000	-----	2,030	-----	7,240,000	-----
	3	-----	2,665	-----	8,495,000	2,110	2,090	8,380,000	7,250,000
4-----	1	4,260	-----	11,880,000	-----	3,840	-----	12,030,000	-----
	2	2,870	-----	12,030,000	-----	3,520	-----	11,660,000	-----
	3	-----	3,565	-----	11,955,000	4,280	3,880	11,330,000	11,673,000
5-----	1	1,140	-----	11,180,000	-----	1,780	-----	10,750,000	-----
	2	1,440	-----	11,360,000	-----	1,220	-----	11,600,000	-----
	3	-----	1,290	-----	11,270,000	1,520	1,507	11,000,000	11,117,000
6-----	1	2,060	-----	11,500,000	-----	1,720	-----	11,240,000	-----
	2	1,500	-----	9,940,000	-----	1,870	-----	10,270,000	-----
	3	-----	1,780	-----	10,720,000	880	1,490	7,900,000	9,804,000
9-----	1	1,580	-----	9,430,000	-----	2,500	-----	12,250,000	-----
	2	2,200	-----	10,310,000	-----	2,100	-----	10,970,000	-----
	3	-----	1,890	-----	9,870,000	1,980	2,193	9,830,000	11,023,000
11-----	1	1,390	-----	4,010,000	-----	1,460	-----	5,130,000	-----
	2	1,280	-----	3,970,000	-----	1,390	-----	4,180,000	-----
	3	-----	1,335	-----	3,990,000	1,220	1,357	4,480,000	4,597,000
15-----	1	1,760	-----	9,500,000	-----	2,040	-----	10,810,000	-----
	2	2,330	-----	10,000,000	-----	1,690	-----	9,220,000	-----
	3	-----	2,045	-----	9,750,000	1,640	1,790	8,850,000	9,627,000
16-----	1	1,940	-----	7,960,000	-----	1,920	-----	7,220,000	-----
	2	2,120	-----	7,170,000	-----	2,470	-----	7,320,000	-----
	3	-----	2,030	-----	7,565,000	2,110	2,167	7,100,000	7,213,000
18-----	1	830	-----	4,960,000	-----	1,850	-----	7,400,000	-----
	2	1,460	-----	7,300,000	-----	-----	-----	-----	-----
	3	-----	1,145	-----	6,130,000	1,800	1,825	7,050,000	7,225,000
20-----	1	2,460	-----	8,780,000	-----	2,420	-----	9,020,000	-----
	2	2,760	-----	9,440,000	-----	2,140	-----	8,040,000	-----
	3	-----	2,610	-----	9,110,000	2,360	2,307	8,120,000	8,393,000
30-----	1	2,660	-----	9,140,000	-----	2,640	-----	9,370,000	-----
	2	2,480	-----	9,300,000	-----	2,270	-----	7,400,000	-----
	3	-----	2,570	-----	9,220,000	2,360	2,423	9,420,000	8,730,000
Average-----		-----	2,084	-----	8,916,000	-----	2,093	-----	8,787,000

Indicated change in strength on scrubbing=+0.4 per cent.

Indicated change in E on scrubbing=-1.4 per cent.

TABLE 4.—Cleaning preparation E

Serial No. of marble	Test No.	Before scrubbing				After scrubbing			
		Modulus of rupture		Modulus of elasticity (E)		Modulus of rupture		Modulus of elasticity (E)	
		Individual tests	Average	Individual tests	Average	Individual tests	Average	Individual tests	Average
1.....	1	2,000	-----	6,170,000	-----	2,020	-----	6,110,000	-----
	2	2,320	-----	6,500,000	-----	2,380	-----	7,210,000	-----
	3	-----	2,160	-----	6,333,000	2,540	2,310	8,000,000	7,110,000
3.....	1	2,330	-----	8,300,000	-----	2,200	-----	6,820,000	-----
	2	2,230	-----	6,870,000	-----	2,180	-----	6,410,000	-----
	3	-----	2,280	-----	7,585,000	2,100	2,160	5,910,000	6,380,000
6.....	1	1,750	-----	12,500,000	-----	1,800	-----	11,200,000	-----
	2	1,820	-----	11,570,000	-----	1,730	-----	10,930,000	-----
	3	-----	1,785	-----	12,035,000	1,320	1,620	10,720,000	10,950,000
10.....	1	830	-----	2,080,000	-----	1,040	-----	3,460,000	-----
	2	1,070	-----	2,450,000	-----	830	-----	2,640,000	-----
	3	-----	950	-----	2,255,000	820	900	2,760,000	3,950,000
11.....	1	1,420	-----	4,411,000	-----	1,310	-----	4,380,000	-----
	2	1,350	-----	3,700,000	-----	1,510	-----	3,940,000	-----
	3	-----	1,385	-----	4,055,000	1,380	1,400	4,670,000	4,330,000
13.....	1	2,390	-----	8,040,000	-----	2,460	-----	7,800,000	-----
	2	2,390	-----	9,240,000	-----	2,260	-----	6,910,000	-----
	3	-----	2,390	-----	8,640,000	2,440	2,390	7,730,000	7,480,000
16.....	1	1,880	-----	6,540,000	-----	2,450	-----	7,230,000	-----
	2	1,780	-----	6,330,000	-----	1,800	-----	7,050,000	-----
	3	-----	1,830	-----	6,435,000	1,900	2,050	6,670,000	6,983,000
17.....	1	1,740	-----	5,430,000	-----	1,760	-----	5,810,000	-----
	2	1,770	-----	5,130,000	-----	1,760	-----	6,620,000	-----
	3	-----	1,755	-----	5,280,000	1,760	1,760	6,200,000	6,210,000
25.....	1	2,160	-----	11,270,000	-----	600	-----	5,070,000	-----
	2	-----	-----	-----	-----	1,420	-----	7,000,000	-----
	3	-----	2,160	-----	11,270,000	2,360	1,460	11,270,000	7,780,000
26.....	1	2,180	-----	9,600,000	-----	2,280	-----	9,950,000	-----
	2	2,220	-----	10,340,000	-----	2,310	-----	10,100,000	-----
	3	-----	2,200	-----	9,970,000	2,300	2,300	10,610,000	10,220,000
30.....	1	2,230	-----	10,130,000	-----	2,580	-----	10,200,000	-----
	2	1,930	-----	10,220,000	-----	2,680	-----	9,750,000	-----
	3	-----	2,080	-----	10,175,000	2,050	2,440	10,000,000	9,983,000
Average.....		-----	1,907	-----	7,639,000	-----	1,890	-----	7,398,000

Indicated change in strength on scrubbing = -0.9 per cent.

Indicated change in E on scrubbing = -3.1 per cent.

TABLE 5.—Cleaning preparation H

Serial No. of marble	Test No.	Original marble				Scrubbed marble			
		Modulus of rupture		Modulus of elasticity (E)		Modulus of rupture		Modulus of elasticity (E)	
		Individual tests	Average	Individual tests	Average	Individual tests	Average	Individual tests	Average
1-----	1	2,330	-----	7,930,000	-----	2,240	-----	6,680,000	-----
	2	2,250	-----	5,930,000	-----	1,960	-----	6,940,000	-----
	3	-----	2,290	-----	6,930,000	2,080	2,090	7,240,000	6,953,000
2-----	1	2,310	-----	8,930,000	-----	2,270	-----	8,570,000	-----
	2	-----	2,310	-----	8,930,000	2,040	2,155	7,950,000	8,260,000
11-----	1	1,320	-----	3,630,000	-----	1,350	-----	5,720,000	-----
	2	1,230	-----	3,800,000	-----	1,320	-----	5,070,000	-----
	3	-----	1,275	-----	3,715,000	1,380	1,350	4,700,000	5,163,000
14-----	1	1,800	-----	6,510,000	-----	1,240	-----	4,110,000	-----
	2	1,670	-----	6,450,000	-----	1,150	-----	2,950,000	-----
	3	-----	1,735	-----	6,480,000	1,100	1,163	2,960,000	3,340,000
16-----	1	2,440	-----	6,560,000	-----	1,970	-----	6,710,000	-----
	2	2,110	-----	6,410,000	-----	2,180	-----	7,570,000	-----
	3	-----	2,275	-----	6,485,000	2,070	2,073	7,810,000	7,363,000
19-----	1	1,140	-----	3,020,000	-----	1,280	-----	4,570,000	-----
	2	1,600	1,370	4,140,000	3,580,000	1,820	1,550	4,480,000	4,525,000
23-----	1	2,520	-----	10,970,000	-----	2,620	-----	11,200,000	-----
	2	2,090	-----	11,060,000	-----	2,030	-----	10,780,000	-----
	3	-----	2,305	-----	11,015,000	1,780	2,143	10,970,000	10,983,000
24-----	1	2,620	-----	10,100,000	-----	2,290	-----	9,270,000	-----
	2	-----	-----	-----	-----	2,530	-----	9,360,000	-----
	3	-----	2,620	-----	10,100,000	1,920	2,247	8,070,000	8,880,000
25-----	1	2,290	-----	11,300,000	-----	2,050	-----	11,700,000	-----
	2	-----	2,290	-----	11,300,000	1,810	1,930	11,400,000	11,550,000
26-----	1	2,380	-----	10,930,000	-----	2,440	-----	10,700,000	-----
	2	2,220	-----	10,650,000	-----	2,160	-----	9,500,000	-----
	3	-----	2,300	-----	10,790,000	2,330	2,310	9,780,000	9,993,000
29-----	1	1,000	-----	3,030,000	-----	520	-----	1,880,000	-----
	2	-----	1,000	-----	3,030,000	910	715	2,370,000	2,125,000
Average-----			1,979		7,487,000		1,793		7,194,000

Indicated change in strength on scrubbing = -9.4 per cent.

Indicated change in E on scrubbing = -3.9 per cent.

TABLE 6.—Cleaning preparation A'

Serial No. of marble	Test No.	Original marble				Scrubbed marble			
		Modulus of rupture		Modulus of elasticity (E)		Modulus of rupture		Modulus of elasticity (E)	
		Individual tests	Average	Individual tests	Average	Individual tests	Average	Individual tests	Average
1-----	1	2,840	-----	8,940,000	-----	2,350	-----	7,300,000	-----
	2	2,980	-----	8,770,000	-----	2,460	-----	7,920,000	-----
	3	-----	2,910	-----	8,855,000	2,070	2,293	7,860,000	7,693,000
5-----	1	2,440	-----	12,200,000	-----	1,730	-----	10,600,000	-----
	2	1,830	-----	10,370,000	-----	1,280	-----	11,900,000	-----
	3	-----	2,135	-----	11,285,000	1,850	1,620	10,500,000	11,000,000
6-----	1	1,580	-----	11,170,000	-----	1,670	-----	10,500,000	-----
	2	-----	-----	-----	-----	990	-----	7,700,000	-----
	3	-----	1,580	-----	11,170,000	880	1,180	7,780,000	8,660,000
9-----	1	1,840	-----	10,300,000	-----	260	-----	-----	-----
	2	1,290	-----	11,500,000	-----	1,560	-----	12,400,000	-----
	3	-----	1,565	-----	10,900,000	1,640	1,153	12,400,000	12,400,000
11-----	1	1,100	-----	3,430,000	-----	1,090	-----	3,900,000	-----
	2	1,160	-----	3,790,000	-----	1,200	-----	4,200,000	-----
	3	-----	1,130	-----	3,610,000	1,200	1,163	4,000,000	4,030,000
16-----	1	1,850	-----	6,400,000	-----	1,910	-----	7,050,000	-----
	2	1,960	1,905	6,620,000	6,510,000	1,590	-----	7,240,000	-----
	3	-----	-----	-----	-----	1,910	1,803	7,620,000	7,303,000
18-----	1	1,480	-----	6,200,000	-----	1,030	-----	4,370,000	-----
	2	900	-----	2,820,000	-----	650	-----	1,960,000	-----
	3	-----	1,190	-----	4,510,000	1,050	910	4,140,000	3,490,000
20-----	1	2,720	-----	9,060,000	-----	2,400	-----	9,120,000	-----
	2	2,690	-----	8,870,000	-----	2,420	-----	9,820,000	-----
	3	-----	2,705	-----	8,965,000	2,530	2,450	9,280,000	9,407,000
24-----	1	1,540	-----	11,500,000	-----	2,150	-----	11,480,000	-----
	2	1,740	-----	11,800,000	-----	2,050	-----	11,000,000	-----
	3	-----	1,640	-----	11,650,000	2,320	2,173	10,730,000	11,070,000
30-----	1	2,770	-----	11,050,000	-----	2,740	-----	10,500,000	-----
	2	2,970	-----	11,340,000	-----	2,530	-----	11,000,000	-----
	3	-----	2,870	-----	11,185,000	2,480	2,583	10,700,000	10,703,000
Average--		-----	1,963	-----	8,864,000	-----	1,733	-----	8,576,000

Indicated change in strength on scrubbing=−11.7 per cent.
Indicated change in E on scrubbing=−3.4 per cent.

TABLE 7.—Cleaning preparation B'

Serial No. of marble	Test No.	Original marble				Scrubbed marble			
		Modulus of rupture		Modulus of elasticity (E)		Modulus of rupture		Modulus of elasticity (E)	
		Individual tests	Average	Individual tests	Average	Individual tests	Average	Individual tests	Average
2	1	2,810	-----	10,000,000	-----	2,310	-----	6,790,000	-----
	2	2,530	-----	9,410,000	-----	2,320	-----	6,890,000	-----
	3	-----	2,670	-----	9,705,000	2,140	2,257	6,220,000	6,633,000
3	1	2,570	-----	6,340,000	-----	1,900	-----	5,220,000	-----
	2	2,220	-----	6,270,000	-----	1,970	-----	5,650,000	-----
	3	-----	2,395	-----	6,305,000	1,950	1,940	5,710,000	5,537,000
6	1	1,680	-----	8,730,000	-----	1,240	-----	9,170,000	-----
	2	885	-----	9,260,000	-----	1,070	-----	9,780,000	-----
	3	-----	1,282	-----	8,995,000	1,390	1,233	11,000,000	9,983,000
9	1	1,560	-----	11,020,000	-----	1,320	-----	8,890,000	-----
	2	1,640	-----	11,670,000	-----	1,220	-----	11,130,000	-----
	3	-----	1,600	-----	11,345,000	1,550	1,363	11,230,000	10,417,000
10	1	1,390	-----	2,500,000	-----	1,180	-----	2,080,000	-----
	2	960	-----	1,390,000	-----	1,070	-----	2,020,000	-----
	3	-----	1,175	-----	1,945,000	1,160	1,137	1,860,000	1,987,000
15	1	2,200	-----	8,940,000	-----	2,190	-----	10,640,000	-----
	2	2,060	-----	9,480,000	-----	1,730	-----	8,720,000	-----
	3	-----	2,130	-----	9,210,000	1,930	1,950	10,000,000	9,787,000
17	1	1,650	-----	6,270,000	-----	1,670	-----	6,350,000	-----
	2	1,570	-----	5,950,000	-----	1,440	-----	5,370,000	-----
	3	-----	1,610	-----	6,110,000	1,450	1,520	6,660,000	6,127,000
21	1	1,090	-----	5,420,000	-----	890	-----	5,480,000	-----
	2	740	-----	4,820,000	-----	840	-----	4,500,000	-----
	3	-----	915	-----	5,120,000	930	887	5,070,000	5,017,000
22	1	610	-----	-----	-----	1,290	-----	-----	-----
	2	470	540	-----	-----	910	1,100	-----	-----
	3	-----	-----	-----	-----	-----	-----	-----	-----
26	1	2,370	-----	10,700,000	-----	2,310	-----	11,340,000	-----
	2	2,320	-----	12,280,000	-----	2,300	-----	11,230,000	-----
	3	-----	2,345	-----	11,490,000	2,300	2,303	11,550,000	11,370,000
29	1	440	-----	2,080,000	-----	600	-----	1,180,000	-----
	2	500	-----	2,690,000	-----	800	-----	3,640,000	-----
	3	-----	470	-----	2,385,000	260	553	1,900,000	2,240,000
30	1	2,900	-----	10,630,000	-----	2,330	-----	11,050,000	-----
	2	2,700	-----	11,630,000	-----	2,570	-----	11,370,000	-----
	3	-----	2,800	-----	11,130,000	2,250	2,383	11,320,000	11,247,000
Average		-----	1,661	-----	7,613,000	-----	1,552	-----	7,304,000

Indicated change in strength on scrubbing = -6.6 per cent.
Indicated change in E on scrubbing = -4 per cent.

TABLE 8.—Cleaning preparation B'

[Marble rinsed with clear water before scrubbing]

Serial No. of marble	Test No.	Original marble				Scrubbed marble			
		Modulus of rupture		Modulus of elasticity (E)		Modulus of rupture		Modulus of elasticity (E)	
		Individual tests	Average	Individual tests	Average	Individual tests	Average	Individual tests	Average
4.....	1	3,890	-----	11,720,000	-----	2,950	-----	11,970,000	-----
	2	3,370	-----	12,180,000	-----	3,730	-----	12,260,000	-----
	3	-----	3,630	-----	11,950,000	3,450	3,377	11,970,000	12,067,000
5.....	1	1,530	-----	9,160,000	-----	1,990	-----	11,030,000	-----
	2	440	-----	2,790,000	-----	1,670	-----	9,530,000	-----
	3	-----	985	-----	5,975,000	260	1,307	-----	10,280,000
6.....	1	1,200	-----	-----	-----	1,350	-----	9,370,000	-----
	2	700	-----	6,600,000	-----	1,870	-----	11,200,000	-----
	3	-----	950	-----	6,600,000	1,250	1,490	10,500,000	10,357,000
7.....	1	1,110	-----	1,940,000	-----	1,060	-----	1,930,000	-----
	2	1,080	-----	2,030,000	-----	1,140	-----	2,030,000	-----
	3	900	1,030	2,030,000	2,000,000	910	1,037	1,920,000	1,960,000
10.....	1	2,190	-----	6,760,000	-----	2,020	-----	7,000,000	-----
	2	2,220	-----	6,970,000	-----	2,080	-----	6,830,000	-----
	3	-----	2,205	-----	6,865,000	2,200	2,100	6,740,000	6,857,000
11.....	1	1,590	-----	6,700,000	-----	1,550	-----	6,260,000	-----
	2	1,560	-----	5,980,000	-----	1,600	-----	6,640,000	-----
	3	-----	1,575	-----	6,340,000	1,620	1,590	5,880,000	6,260,000
12.....	1	840	-----	1,830,000	-----	1,030	-----	2,240,000	-----
	2	1,390	-----	2,330,000	-----	930	-----	1,570,000	-----
	3	1,330	1,187	2,190,000	2,117,000	1,270	1,077	2,660,000	2,157,000
15.....	1	2,160	-----	10,260,000	-----	1,800	-----	10,170,000	-----
	2	1,510	-----	8,730,000	-----	2,040	-----	9,760,000	-----
	3	-----	1,835	-----	9,495,000	1,690	1,840	10,000,000	9,977,000
17.....	1	1,640	-----	4,730,000	-----	1,620	-----	6,160,000	-----
	2	1,580	-----	4,930,000	-----	1,540	-----	5,000,000	-----
	3	-----	1,610	-----	4,830,000	1,540	1,567	5,960,000	5,707,000
20.....	1	2,810	-----	8,440,000	-----	2,660	-----	8,220,000	-----
	2	2,620	-----	8,730,000	-----	2,780	-----	8,750,000	-----
	3	-----	2,715	-----	8,585,000	2,770	2,737	8,450,000	8,473,000
21.....	1	620	-----	4,000,000	-----	1,240	-----	5,880,000	-----
	2	-----	-----	-----	-----	600	-----	2,560,000	-----
	3	-----	620	-----	4,000,000	1,310	1,050	5,900,000	4,780,000
30.....	1	2,560	-----	9,610,000	-----	2,100	-----	10,000,000	-----
	2	2,280	-----	8,550,000	-----	2,250	-----	9,230,000	-----
	3	-----	2,420	-----	9,080,000	2,630	2,327	11,040,000	10,090,000
Average.....	-----	-----	1,730	-----	6,486,000	-----	1,792	-----	7,414,000

Indicated change in strength on scrubbing=+3.6 per cent.
Indicated change in E on scrubbing=+14.3 per cent.

TABLE 9.—Cleaning preparation E'

Serial No. of marble	Test No.	Original marble				Scrubbed marble			
		Modulus of rupture		Modulus of elasticity (E)		Modulus of rupture		Modulus of elasticity (E)	
		Individual tests	Average	Individual tests	Average	Individual tests	Average	Individual tests	Average
2	1	2,420	-----	7,550,000	-----	2,220	-----	7,270,000	-----
	2	2,530	-----	8,670,000	-----	2,700	-----	7,970,000	-----
	3	-----	2,475	-----	8,110,000	2,610	2,510	9,300,000	8,180,000
4	1	3,220	-----	11,560,000	-----	3,800	-----	11,930,000	-----
	2	3,500	-----	11,820,000	-----	2,870	-----	12,230,000	-----
	3	-----	3,360	-----	11,660,000	3,950	3,540	11,880,000	12,013,000
5	1	1,470	-----	10,500,000	-----	950	-----	10,240,000	-----
	2	-----	-----	-----	-----	1,220	-----	12,000,000	-----
	3	-----	1,470	-----	10,500,000	1,520	1,230	10,700,000	10,980,000
7	1	1,010	-----	1,920,000	-----	850	-----	1,640,000	-----
	2	760	-----	1,530,000	-----	890	-----	1,420,000	-----
	3	880	883	1,600,000	1,683,000	660	800	1,340,000	1,467,000
10	1	890	-----	2,210,000	-----	680	-----	1,830,000	-----
	2	800	-----	1,270,000	-----	770	-----	2,320,000	-----
	3	-----	830	-----	1,740,000	1,000	817	2,200,000	2,117,000
11	1	1,520	-----	9,320,000	-----	1,670	-----	5,800,000	-----
	2	1,550	-----	5,680,000	-----	1,480	-----	5,280,000	-----
	3	-----	1,535	-----	7,500,000	1,500	1,550	5,850,000	5,643,000
12	1	900	-----	3,200,000	-----	890	-----	2,530,000	-----
	2	1,320	-----	3,180,000	-----	1,210	-----	2,670,000	-----
	3	-----	1,110	-----	3,190,000	420	840	-----	2,600,000
15	1	1,530	-----	10,200,000	-----	1,630	-----	8,500,000	-----
	2	1,650	-----	10,400,000	-----	1,670	-----	7,610,000	-----
	3	-----	1,590	-----	10,300,000	1,730	1,677	8,370,000	8,160,000
16	1	1,520	-----	6,200,000	-----	2,110	-----	7,120,000	-----
	2	1,960	-----	6,250,000	-----	1,880	-----	6,460,000	-----
	3	-----	1,740	-----	6,225,000	1,920	1,970	7,060,000	6,880,000
20	1	2,540	-----	10,300,000	-----	2,400	-----	8,600,000	-----
	2	2,620	-----	8,620,000	-----	2,300	-----	8,420,000	-----
	3	-----	2,580	-----	9,460,000	2,300	2,333	8,320,000	8,447,000
30	1	2,480	-----	7,780,000	-----	2,560	-----	8,940,000	-----
	2	2,290	-----	8,800,000	-----	2,360	-----	9,860,000	-----
	3	-----	2,385	-----	8,290,000	2,600	2,517	9,970,000	9,590,000
Average		-----	1,814	-----	7,151,000	-----	1,799	-----	6,916,000

Indicated change in strength on scrubbing = -0.8 per cent.

Indicated change in E on scrubbing = -3.3 per cent.

The following table gives a summary of the results of the long-period scrubbing tests:

Cleaning preparation	Type	Alkaline salts present (per cent)	Loss of strength in scrubbing tests	Remarks
C	Scouring	12.4 Na ₂ CO ₃	Per cent 6.8	
D	do.	8.1 Na ₂ CO ₃	4.6	
E	do.	15.4 Na ₂ CO ₃ and NaHCO ₃	.9	
F	do.	.4 Na ₂ CO ₃	0	
H	do.	8.9 Na ₂ CO ₃	9.4	
A'	Nonscouring	1.5 solution mainly Na ₃ PO ₄	11.7	
B'	do.	1.0 solution Na ₃ PO ₄	6.6	
B'	do.	10.0 solution Na ₃ PO ₄	0	Surface rinsed with clear water before scrubbing.
E'	do.	.2 KCl	.8	

The above results afford very good evidence that the alkaline salts frequently employed in cleaning preparations are injurious to marble.

In the long-period tests with the scrubbing machine it is doubtful if the marble specimens were as thoroughly dried between scrubblings as the marblework of buildings would dry from one cleaning to the

FIG. 16.—Results of crystallization tests on five samples of marble with sodium carbonate and sodium bicarbonate solutions

next. This thorough drying would cause a more severe crystallizing action in the marble of buildings after cleaning with a preparation containing a salt than was obtained in the above test. Hence, a test was made with five different marbles by soaking the slabs in salt solutions and then drying them in the oven to obtain a thorough crystallization of the salts. This test was made on one set of speci-

mens using a 10 per cent solution of sodium carbonate and also on a duplicate set using a mixture of equal parts of sodium carbonate and sodium bicarbonate made to the same strength. The tests were made on slabs of marble the same size as those used for the scrubbing test. Three specimens of each marble were submitted to the crystallization tests and three similar ones of each material were retained in the original state for determining the strength and elasticity. The specimens, submitted to the crystallizing action were soaked and dried 50 times. At the end of 50 cycles some of the marbles were in an advanced stage of disintegration, as illustrated in Figure 16. The top row of slabs were submitted to the action of sodium carbonate, the middle row to the sodium carbonate and sodium bicarbonate mixture, and the bottom row shows the materials in the original state. After 50 cycles the slabs were tested for strength and elasticity. The results are given in Table 10. The first column gives the serial numbers of the marbles, and the second column gives by letter designations the results obtained for the different conditions as follows:

TABLE 10.—*Tests to determine the effect of crystallizing sodium carbonate and sodium bicarbonate solutions in the pores of marble*

Marble No.	Test	Modulus of rupture			Modulus of elasticity (E)		
		Highest	Lowest	Average	Highest	Lowest	Average
		<i>Lbs./in.²</i>	<i>Lbs./in.²</i>	<i>Lbs./in.²</i>	<i>Lbs./in.²</i>	<i>Lbs./in.²</i>	<i>Lbs./in.²</i>
2.....	A	910	870	890	1,990,000	1,938,000	1,964,000
2.....	B	900	730	815	2,430,000	2,180,000	2,305,000
2.....	C	2,600	2,570	2,585	11,170,000	10,200,000	10,685,000
16.....	A	1,670	1,440	1,555	6,100,000	5,280,000	5,690,000
16.....	B	1,790	1,410	1,600	5,690,000	4,080,000	4,890,000
16.....	C	2,180	2,080	2,130	7,290,000	7,150,000	7,220,000
17.....	A	1,170	930	1,050	6,580,000	6,560,000	6,570,000
17.....	B	1,610	1,580	1,595	5,340,000	4,740,000	5,040,000
17.....	C	1,870	1,630	1,750	6,720,000	5,660,000	6,190,000
20.....	A	630	510	570	1,680,000	1,650,000	1,670,000
20.....	B	870	770	820	2,540,000	1,600,000	2,070,000
20.....	C	2,540	2,380	2,460	10,100,000	9,100,000	9,600,000
30.....	A	1,450	1,250	1,350	4,860,000	4,420,000	4,640,000
30.....	B	1,580	1,440	1,510	4,770,000	4,530,000	4,650,000
30.....	C	2,900	-----	2,900	10,760,000	-----	10,760,000

Test A.—Specimens soaked in a 10 per cent solution of sodium carbonate and dried; 50 cycles.

Test B.—Specimens soaked in a 10 per cent solution of equal parts sodium carbonate and sodium bicarbonate; 50 cycles.

Test C.—Specimens of marble in original state for comparison.

Summary of results from Table 10

Marble	Loss in strength		Decrease in E	
	Test A	Test B	Test A	Test B
	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>
2.....	65	68	82	78
16.....	27	25	21	32
17.....	40	9	—6	19
20.....	77	67	82	78
30.....	53	48	57	57
Average.....	52.4	43.4	47.2	52.8

The results indicate that the action of the sodium-carbonate solution was somewhat more severe than the mixture of that salt with sodium bicarbonate. The loss of strength due to the first varied from 27 to 77 per cent with an average loss of 52.4 per cent. The strength loss in the test with the two salts varied from 9 to 68 per cent with an average of 43.4 per cent. These results agree with those obtained in the scrubbing tests on cleaning materials containing similar salts. The effects on the elastic constants were pronounced in most cases, but since these values are calculated from the elastic curves for the lower loads they are not as apt to indicate deterioration as the strength values. In one case it will be noted that a material which was weakened 40 per cent showed an increase in the elastic constant.

An examination of the different marbles showed that the salts manifest themselves differently on different marbles. For instance, marbles Nos. 16 and 17 were badly disfigured on the surface, but the strength of these suffered a smaller loss than any of the others. Marble No. 2 was not visibly injured except at the more prominent veins and some of the specimens were not appreciably affected in appearance, yet all showed a large loss of strength. The fracture showed a marked difference in appearance from that of the original material and the grains were more friable. Marble No. 20 was less affected in appearance than any other in the test, but the strength loss was greatest of all.

While this series of tests in which the specimens were soaked in salt solutions and then dried evidently gave conditions which are more severe than those of actual scrubbing with similar solutions, it serves to illustrate certain facts, as follows: Different marbles are affected in different ways, and some marbles may be seriously affected before visible results are apparent.

IV. EFFICIENCY OF CLEANING PREPARATIONS

While it is not the prime object of this research to determine the relative cleaning merits of different preparations, it appears that the research would be incomplete if that phase of the subject were completely ignored. Everyone concerned in the purchase of cleaning materials is confronted with various claims of merit from salesmen, on the one hand, and the personal preference of the cleaning squad, on the other. While the purchasing agent is usually aware of the fact that many different preparations will clean satisfactorily, he is more concerned with the effects on the marble due to a long period of use.

In considering the efficacy of different cleaning preparations it is necessary to take the main requirements into account. It may be fair to assume that 90 per cent of the cleaning is done on floors. Of

course, the type of dirt found on floors may vary to some extent from one location to another, even in one building, but the greater part of the matter to be removed will prove to be small dry particles which find lodgment in the uneven places of the surface. The deposit may appear to be ground into the surface by foot traffic. In order to obtain a comparative test on various preparations, it is necessary to test them side by side under identical conditions. Evidently the first consideration in making a comparative test of this kind is that the marble shall all be soiled to the same extent and by the same kind of dirt. In order to obtain a number of slabs with which to make this experiment, the scheme previously described was used; namely, that of placing the marble on the treads of a stairway. A white marble of uniform texture was selected for the tests. After the slabs had been thus submitted to traffic conditions for six weeks without cleaning they were removed and lightly brushed to remove the loose particles. The tests were then made with different preparations, as indicated below, by making four strokes with the weighted brushes described on page 599. Each trade cleaning preparation was mixed to the concentration recommended by the producer. After the slabs were all subjected to the scrubbing they were placed in the order of their cleanliness. In the following list the one which showed the best results is placed first. The same letter designations employed on page 593 for the trade preparations are used here. An experimental preparation of soap and soapstone grit is designated "Q."

First series of tests

Designation of preparation	Composition	Rating in this test
Q.....	90 per cent soapstone grit, 10 per cent soap.....	1
D.....	85 per cent volcanic ash, 8 per cent Na_2CO_3 , 3 per cent soap.	2
E.....	63 per cent volcanic ash, 15 per cent Na_2CO_3 and NaHCO_3 , 5 per cent soap.....	3
E'.....	Liquid soap.....	4
C.....	73 per cent volcanic ash, 12 per cent Na_2CO_3 , 3 per cent soap.....	5
I.....	81 per cent crushed quartz, 13 per cent Na_2CO_3 , 2 per cent soap.....	6
L.....	A grit cleaner.....	6

Second series of tests

Designation of preparation	Composition	Rating in this test
E'.....	Trisodium phosphate.....	1
Q.....	90 per cent soapstone grit, 10 per cent soap.....	2
E'.....	Liquid soap.....	3
E.....	63 per cent volcanic ash, 15 per cent Na_2CO_3 and NaHCO_3 , 5 per cent soap.....	4
J.....	A grit cleaner.....	5

While these tests are probably too limited to justify definite conclusions, there is one indication worthy of mention. In both series

of tests the soapstone grit gave excellent results. This is consistent with the conclusion reached in testing this grit for abrasive action referred to on page 600. Due to the mild abrasive action of this grit it seems to be an excellent material for use in a cleaning preparation for marble of all finishes.

V. RINSING

Considerable stress has been placed heretofore on the importance of thorough rinsing after the scrubbing has been done. This is, no doubt, caused by the belief that a part of the detergent solutions left on the surface of marble may produce some undesirable effect either chemically or otherwise. All the common cleaning preparations or detergents used on marble are of an alkaline nature or produce an alkaline condition when dissolved in water. Assuming that this condition is due to the formation of sodium hydroxide (NaOH) or potassium hydroxide (KOH) in the cleaning solutions, one may ask how these compounds can attack marble. Applications of such chemicals in strong solutions to marbles produce no visible reactions. However, if a few drops of such solutions are placed on a polished surface of marble and left until the solution dries it will be found that the polish has been injured. Under ordinary conditions of cleaning it is very doubtful if this would happen, due to the very low concentration of alkali in the solutions used. In a well-known process of manufacturing caustic soda, milk of lime is added to a solution of soda ash. The reaction which occurs is as follows:

The right-hand side of this equation represents the two materials concerned when a solution of caustic soda is dropped on marble. This indicates that, in order to make the caustic solution react with marble, the direction of the above reaction would have to be reversed. In accordance with the law of mass action this may be done by concentrating the OH ions. When a caustic solution is left to evaporate on the surface of marble, it becomes more and more concentrated as evaporation proceeds. At a certain point it begins to reduce some of the marble to calcium hydroxide, which is again converted to calcium carbonate in the presence of the sodium carbonate formed by the original reaction. While this is seen to be a possibility in case of strong caustic solutions, it appears to be a very remote possibility under actual conditions of cleaning. Aside from the possibility of injury to the marble caused by poor rinsing, it is undesirable to allow any of the detergents to be left on the marble. Soaps produce slipperiness and grits increase the rate of wear on floors.

Rinsing is the easiest part of the process to slight and the hardest to supervise. One can readily see if the cleaning is well done, but a considerable amount of the detergent may be left on the marble and remain invisible. A means that might well be adopted for securing better rinsing is to employ a scouring grit of darker color than the marble. Small amounts of this could be more easily noticed on most marbles used in floors.

As shown in the previous chapter, the crystallizing action of salts in cleaning preparations may be obviated by rinsing the marble with clear water before applying such detergents. Experiments have also indicated that the final rinsing can be more easily and thoroughly performed if this practice is followed. Another advantage of this practice is that a smaller amount of detergent would be necessary.

VI. DISCOLORATION DUE TO CLEANING MATERIALS

While cleaning preparations may sometimes cause discolorations on marble, it seems probable from the results of this research that there are more cases of discoloration which should be attributed to infrequent use of cleaning materials. However, there are possibilities of discoloration which should be guarded against where it is desired to maintain the marble in its original state.

Probably the most common way in which the appearance of marble is marred is through the use of hard water and a cleaning preparation containing soap. A waxy film may be gradually deposited on the marble due to the reaction of such water with the soap, the extent of which will depend on the amount of hardness in the water and the composition of the cleaning preparation employed. The deposition of calcium soap, magnesium soap, or in some cases an appreciable amount of iron soap may result. These compounds are insoluble, waxy substances which adhere with considerable tenacity to the marble. Calcium and magnesium soaps are white and hence would not be as detrimental to the appearance of white marble as to the dark tones, but in any case they are apt to detract from the original brilliancy. Iron soap carries the brown color characteristic of iron salts, and the use of a water containing an appreciable amount of iron in solution is apt to produce undesirable results. It is not the best practice to add the softening agents simultaneously with the soap for some of the soap will react with the hardness constituents before they are removed from the water. The best practice is to soften the water before adding soap. The subject of water softening will be discussed in Chapter VII.

If soap solutions penetrate the marble and remain there for a long period of time, slight yellowing of the marble may result. This is due to the soap yellowing with age. This slight effect would probably not become apparent on marble floors. In any case it can be

prevented by dampening the marble with clear water before applying the soap.

Occasionally a cleaning preparation is found which contains some coloring matter added, no doubt, to impart a distinctive appearance. When the coloring matter is strong enough to impart a perceptible color to the cleaning solution, it is apt to impart a similar color to the marble after a long period of use. Impurities in a cleaning preparation which do not settle out of the solution should be regarded with some suspicion. The discoloration of marble from such causes may be largely overcome, as suggested above, by dampening the surface with clear water before applying the detergent.

A cause of discoloration which has manifested itself in certain cases is that due to the cleaning preparation dissolving some of the solid matter on the marble and carrying it into the pores. Certain oily matter, such as road asphalt, tar, etc., may cause stains in this way. Cleaning preparations containing a considerable amount of alkaline salts are apt to dissolve or emulsify a part of this oily matter and cause stains which is an additional reason for limiting the use of alkaline salts on marble.

Ammonia water is sometimes used to clean polished marble. Some hold the opinion that this may cause marble to turn yellow. A test made with ammonia water in contact with one face of a white marble slab for a year resulted in the marble turning yellow. However, occasional applications to the surface of polished marble caused no change in appearance.

VII. HARD WATERS AND THEIR RELATION TO MARBLE CLEANING

Hard waters are readily distinguished by their action on soap. Soft waters lather freely, but the dissolved mineral matter in hard waters interferes with the lathering quality. When soap is added to a hard water, the hardness constituents of the water react with a part of the soap until they are used up; thus the water is softened at the expense of the soap. It is usually a matter of economy for this reason alone to soften water before adding soap. The principal elements found in water supplies which cause hardness are calcium and magnesium. Other elements of less importance, but often present in appreciable amounts, are iron and aluminum. All of these elements react with soap forming insoluble substances which are of a "waxy" or "gummy" nature and cling with tenacity to any object met with in the cleaning process. Nearly everyone is familiar with such substances as a gummy deposit on the sides of the washbowl or bathtub.

Evidently such by-products of the cleaning process should not be overlooked in marble-cleaning operations, especially in that large

area of the country which is supplied with hard water. The undesirable results thus obtained from the use of soap have led some to discontinue its use entirely and employ other detergents. When properly used, a pure white soap seems to afford the safest and most feasible means of cleaning marble. The softening of hard water to render it suitable for use in cleaning marble offers no particular difficulty, and since the quantity of water used for such purposes is small the expense may be almost negligible. The additions necessary for the usual city water supply are so small that the greatest difficulty may be in avoiding an excess of the chemicals employed. Lime and soda ash are extensively used for softening water. These are not well adapted to use in the usual cleaning process as employed in buildings, hence more feasible materials may be resorted to. Laundries usually resort to so-called "zeolite" automatic softeners which are installed in the water line. These employ what is known as "exchange silicate." As hard water passes through a bed of exchange silicate the hardening elements are taken up and sodium salts are released. The exchange silicate finally loses its power of exchange and has to be regenerated by a treatment with sodium chloride. Exchange silicates are found in nature and are often made synthetically. Due to the small amount of soft water required for cleaning interior marble and the simplicity of other means which can be employed, it would hardly seem feasible to install this type of softener, even in the largest buildings, unless soft water is also desirable for other purposes.

The following procedure is suggested as being accurate enough for ordinary cleaning requirements: Make up a stock solution of trisodium phosphate of definite strength, such as 2 pounds of the crystals to the gallon of water. By means of a graduate add 1 ounce of the stock solution to the pail of hard water and stir thoroughly. Dip up a half pint or more in a glass vessel and dip a bar of pure white soap into this several times until a small amount of suds is formed. Examine this before a light to see if any insoluble soap is formed. Increase the addition to the pail ounce by ounce, testing the water each time until no curdy substance is formed. When the hardness is overcome, the water should readily form suds which should persist for several minutes without further addition of soap or agitation. In adding softening agents, the water to be softened should be warm, else the softening process will not take place satisfactorily.

Other materials may be used for softening purposes than those suggested above. A solution made by dissolving 12 ounces of lye and 4 ounces of soda ash in 4 gallons of water would meet the requirements in most cases. The amount of this solution required in any particular case can be determined experimentally as suggested above.

These materials are of low cost and are more easily obtained in most localities than trisodium phosphate. However, more care should be exercised in making the proper addition, since an overdose of this solution would prove more serious than an overdose of the trisodium phosphate.

According to available data on city water supplies, the following States have very hard waters: Arizona, Florida, Illinois, Indiana, Iowa, Kansas, Nebraska, Oklahoma, and South Dakota.

Another group of States, the waters of which are hard but appreciably softer than that of the above group, consists of Arkansas, California, Colorado, Michigan, Minnesota, Missouri, Ohio, North Dakota, New Mexico, Texas, Utah, Wisconsin, and Wyoming.

A third group of States may be classed as having moderately hard waters: Idaho, Kentucky, Montana, Nevada, Pennsylvania, Tennessee, and West Virginia.

The remaining States have comparatively soft waters, namely: Alabama, Connecticut, Delaware, Georgia, Louisiana, Maine, Maryland, Mississippi, Massachusetts, North Carolina, New York, New Hampshire, New Jersey, Oregon, Rhode Island, South Carolina, Virginia, and Washington.

The above groupings are based on the average hardness of the large water supplies and show approximately the areas in which waters may be expected to be very hard, hard, moderately hard, and comparatively soft. However, certain cities in the various areas may have waters which vary greatly from that indicated above. As a rule, surface waters are much softer than ground waters. Waters from shallow wells in limestone areas are invariably hard, while, as a rule, waters from localities where there is no limestone are comparatively soft. For more definite information on the hardness of any particular water supply one may consult the local municipal authorities, the local State geological department, or the United States Geological Survey at Washington, D. C.

VIII. ACTION OF VARIOUS CHEMICAL SOLUTIONS ON MARBLE

Due to the adaptability of marble to many different uses it is apt to be exposed to a great variety of conditions. Hence, it becomes of considerable importance to determine what conditions are injurious to marble, how far marble may be expected to resist severe exposures, and what precautions may be taken to overcome injurious action. The conditions to be considered in this discussion are those which may affect the appearance or permanence of interior marble. For a great variety of uses marble has been employed for such long periods of time and has so proven its merits in actual service that no laboratory study could add much of value to our knowledge con-

cerning its behavior under ordinary service conditions. Marble wall work, in general, is conceded to be permanent, and, with reasonable care, will retain its original appearance almost indefinitely. In very rare cases, however, conditions have been known to arise which were harmful to marble wall work. The common use of marble in floors and steps has proven it to be reasonably resistant to wear and entirely satisfactory for the purpose; but even in such uses occasional trouble is experienced. A field in which marble has found extensive use is that of the soda fountain. In this use marble is frequently

FIG. 17.—Samples of marble from soda fountains and wainscot which were disintegrated by salt solutions

exposed to very severe conditions, and it is remarkable that the marble does not more frequently show serious injury.

The above-mentioned uses of marble have been rather closely studied by inspecting numerous installations exemplifying various conditions of exposure. The few cases in which trouble was observed were given special attention to determine what the source of trouble was. All cases of disintegrated marble examined were found to be such as to indicate the action of crystallizing salts. Due to the fact that the salts are usually carried into marble by water—that is, in solution—one should ordinarily expect trouble only from such salts

as are soluble in water. Since the porosity of marble is low (usually less than 1 per cent), if the pore space was completely filled with a particular salt its amount would be so small as to bear an insignificant ratio to the total weight of the marble; hence a quantitative analysis may not prove of much value. In Figure 17 are shown a few pieces of disintegrated marble which were received for study. Nos. 8, 14, and 32 were from the die slab of soda fountains. Several chips from the spalled surface were collected and analyzed for comparison with a sample of the same slab taken from a part which was not disintegrated. The results of the analyses are as follows:

Marble No. 8

	Sound portion	Decayed portion
SiO ₂	0.24	1.08
Iron and aluminum oxides.....	.32	.40
CaO.....	55.25	53.70
MgO.....	.16	2.12
CO ₂	43.30	43.04
Ign. loss.....	44.00	43.60
Cl.....	Trace.	Trace.
SO ₃	(1)	(1)
P ₂ O ₅	(1)	(1)

¹ None detected.

Marble No. 14

	Sound portion	Decayed portion
SiO ₂	0.28	0.26
Iron and aluminum oxides.....	.34	.42
CaO.....	54.90	52.04
MgO.....	.13	3.06
CO ₂	43.92	43.84
Ign. loss.....	44.20	44.42
Cl.....	Trace.	Trace.
SO ₃	(1)	(1)
P ₂ O ₅	(1)	(1)

¹ None detected.

A remarkable indication of the two analyses is that in both cases the disintegrated portions showed a lower lime and higher magnesium-oxide content than the sound portions. Geologists hold the theory that limestones or calcite marbles are converted into dolomites when long exposed to sea water. If there was a slight dolomitization of the marbles above, as indicated by the analyses, the only explanation that can be offered is that the magnesium was introduced from some of the solutions dispensed at the fountain. Ice-cream salt usually contains magnesium compounds as impurities or "Pluto water" contains magnesium sulphate. It seems possible that such chemical changes occurring within the pores of the marble could account for the spalling. Chemical changes occurring within the pores of the marble due to the penetration of interacting solutions would not

seem to be as likely to produce harmful results as the physical action due only to crystallization. Other points of interest in connection with the action of crystallizing salts are as follows: (1) Do different salts act in the same way or to the same extent? (2) Are some marbles more resistant to such action or does the physical structure of marble have a bearing on the amount of injury which may occur? (3) If a slab of marble is exposed to a salt solution at some point, how far through the marble will the salt be diffused and show harmful results?

The first attempt to obtain information on these points consisted in placing various salt solutions in cup-shaped cavities in blocks of

FIG. 18.—Series of tests to determine the effects of various salt solutions on marble

marble. Aside from the difficulty of obtaining blocks of marble of the desired size for such a test, the conditions did not simulate actual service conditions. For instance, interior marble usually consists of slabs 1 inch or less in thickness. Parts of these slabs may be exposed to a salt solution splashed from ice-cream buckets containing brine.

A test was finally designed which consisted of sealing a slab of marble to the top of a glass vessel, as shown in Figure 18. A circular groove in the marble was made to allow the top of the glass to be inserted about one-fourth inch. This groove was filled with hot asphalt and the glass set in while still hot, which gave a good seal. A hole through the marble slab enabled the glass to be filled with any

desired solution. In order to keep the solution in contact with the marble, a glass tube having a short length of rubber hose on the end was forced into the hole. The solution was then introduced

FIG. 19.—Tests with sodium chloride (a), a trade cleaning preparation containing sodium carbonate and sodium bicarbonate (u), and a trade cleaning preparation consisting mainly of trisodium phosphate (w)

through the glass tube and the level maintained slightly above the top surface of the marble slab. The first series of tests was made with slabs of marble 6 inches square, as shown in Figure 18. These tests served to show the action of various salts on mar-

ble, but on account of the small size of slab no idea was obtained as to how far the salts would be diffused through the marble from the areas of contact. Hence, another series of tests was started which employed the same procedure on slabs 3 feet long by 8 inches

FIG. 20.—Tests with sodium carbonate (b), sodium bicarbonate (c), ammonium carbonate (l), and a trade cleaning preparation containing sodium carbonate and sodium bicarbonate (u)

wide. The glass vessels were sealed at each end of these. These tests are shown in Figures 19 to 26 by photographs taken after 12 months' duration. Those in Figures 27 to 30 were continued over a period of 18 months.

It was not found possible to show by photographs all the points of interest in connection with these tests. After they had stood for several weeks in the laboratory most of the slabs exhibited a growth of crystals on the top surface. In some of the tests a large growth

FIG. 21.—Tests with trisodium phosphate (g), a trade cleaning preparation containing sodium carbonate and sodium bicarbonate (u), and sodium nitrate (h)

of crystals formed on the top surface and in others only very slight amounts were noticeable. The manner in which these deposits formed afforded some interesting information in regard to the porosity of different marbles. Some permitted an easy penetration

of the solutions through all parts with equal facility, while others showed a strong resistance to penetration except along strain lines or veining material. In some cases the deposit appeared in fine,

FIG. 22.—Tests with sodium nitrate (h), ammonium oxalate (m), copper sulphate (o), and a trade cleaning preparation containing soap and sodium carbonate (v)

silky threads as though it had been forced by very great pressure through very fine openings. During humid weather many of these deposits deliquesced and the original appearance was destroyed. Since it was not desirable to clean the tops of the slabs, a considerable

amount of dust collected along with the deposits of salt, giving an unsightly appearance. Hence, before the photographs were taken to illustrate the final condition it was necessary to clean the marble, and for this reason the illustrations show only the spalled or crumbled parts of the marble and very little of the efflorescence.

FIG. 23.—Tests with potassium chloride (i), sodium chloride (a), sodium nitrate (h), ammonium sulphate (k), and ammonium chloride (j)

Following is a discussion of the tests carried out with the several solutions and marbles:

(a) Tests with sodium chloride—10 per cent solution.—In Figure 27 the tests marked a show the results obtained on 10 slabs of marble

during 18 months' exposure. The tests on marbles Nos. 16, 24, and 29 gave a large amount of spalling, on Nos. 2 and 25 somewhat less, while the other tests showed only slight effects. Figure 19 shows

FIG 24.—Tests with ammonium carbonate (l), sodium carbonate (b), a trade cleaning preparation consisting mainly of trisodium phosphate (w), sodium sulphite (f), and sodium chloride (a)

similar tests (marked a) on long slabs, which were in progress one year. In this set a marked amount of defacement occurred on marbles No. 6, 26, and 30, and appreciable attacks on Nos. 4 and 10.

Figure 24 shows the same test on Nos. 18 and 20, with severe action on the former and very little on the latter. Figure 23 shows another test on marble No. 15 exhibiting rather deep disintegration. It will

FIG. 25.—Tests with Rochelle salt (r), a trade cleaning preparation containing sodium carbonate and sodium bicarbonate (u), calcium sulphate (p), a trade cleaning preparation containing soap and sodium carbonate (v), a trade cleaning preparation consisting mainly of trisodium phosphate (w), and commercial trisodium phosphate (g)

be noted from the illustrations that different marbles are attacked by this salt in a somewhat different way or to a different extent. Those marbles of a very compact nature having seams or strain lines are

apt to spall quite readily along these seams or lines. Some of the more permeable marbles afforded a ready passage of the solutions through the pores, but were not greatly affected. Some of the

FIG. 26.—Test with a trade cleaning preparation consisting mainly of trisodium phosphate (w), ammonium sulphate (k), ammonium chloride (j), and ammonium oxalate (m)

very compact and uniform texture marbles, like Nos. 4 and 26, prevented any appreciable penetration for several weeks, but were considerably injured by the small penetration that finally occurred. The long slabs show in one case that the solution penetrated along

the marble at least 9 inches from the place of contact. This test is of interest in connection with the use of marble in soda fountains where solutions of salt are frequently spilled on the floor or, probably in some cases, splashed against the back of the marble. If

FIG. 27.—Tests with sodium chloride (a) and sugar (s)

contact with the salt solution is made only at the floor line it may cause decay of the marble, not only near the floor, but for several inches upward. Another feature of these tests which should be pointed out is the fact that there is no injury to the surface of the

marble directly in contact with the brine, because this surface is continually wet, and hence no crystallization can occur there. In the tests on some of the more porous marbles, as No. 16 in Figure 27,

FIG. 28.—Tests with sodium bicarbonate (c), sodium carbonate (b), and ammonium carbonate (l)

the greatest injury was caused, not directly opposite the solution, but a little farther toward the edges. This is evidently because the part of the marble directly opposite the solution was somewhat

damp, due to the greater porosity, and hence conditions for crystallization were more favorable where the marble was dry.

(b) *Tests with sodium carbonate—10 per cent solution.*—In Figure 28 are shown six tests with this salt on various marbles. While the effect was similar to that of common salt none of the tests showed as great an amount of disintegration. The very uniform texture marbles were not appreciably injured, while those containing veins or strain lines were spalled considerably along such features. Figure 20 shows five tests with this salt on the long slabs. Only two of these showed an appreciable amount of injury, and in each case the salt followed a vein for about 15 inches from the place of contact and gave an appreciable amount of spalling. In Figure 24 is shown a test on marble No. 18 in which considerable disintegration occurred.

(c) *Tests with sodium bicarbonate—10 per cent solution.*—Figure 28 shows four tests on this salt, three of which exhibit ill effects. In these cases the action was confined to those parts of the marble containing veins or strain lines. Figure 20 shows three tests on the long slabs. Only one of these shows definite signs of crumbling, and this occurred along a vein.

(d) *Tests with a mixture of equal parts of sodium carbonate and sodium bicarbonate—10 per cent solution.*—The results of tests with this mixture are illustrated in Figures 27 and 29. Spalling occurred in both cases which was similar to that caused by the salts acting separately. This combination of salts is used in some of the trade preparations which are widely employed in marble cleaning.

(e) *Tests with sodium sulphate—10 per cent solution.*—Figure 29 shows three tests with this salt, two of which exhibit rather severe action. Marble No. 11 was apparently unaffected by this salt. This salt is the one most commonly leached out of various masonry materials and may find entrance to marble attached to masonry walls where the moisture conditions are favorable.

(f) *Tests with sodium sulphite—10 per cent solution.*—Figure 24 shows three tests with this salt on long slabs. Marbles Nos. 9 and 22 were spalled rather deeply, while No. 20, being a more uniform texture and free from strain lines, was apparently unaffected.

(g) *Tests with trisodium phosphate—10 per cent solution.*—Figure 30 shows three tests designated *w* on a trade cleaning preparation of this composition. Two of these indicate a slight amount of spalling while the third showed no ill effects. Tests on the long slabs shown in Figures 20 and 25 were labeled *g*. In the latter, only marble No. 17 was appreciably injured, this being deeply spalled. In this the action was apparent for about 3 inches away from the place of contact. The trade preparation *w* of this composition was also tested on three marbles shown in Figure 19. None of these showed ill

effects. The tests on this salt are of interest because it is frequently applied to marble as a cleaning material.

(h) *Tests with sodium nitrate—10 per cent solution.*—Four tests were made with this salt on the long slabs. These are shown in

FIG. 29.—Tests with magnesium sulphate (q), sodium sulphate (e), ammonia water (n), and a mixture of equal parts sodium carbonate and sodium bicarbonate (d)

Figures 21, 22, and 23. An appreciable amount of injury was caused on marbles Nos. 25 and 30 while the other tests showed no ill effects, although the salt penetrated profusely, giving an efflorescence of fine, silky threads.

(i) *Tests with potassium chloride—10 per cent solution.*—Four tests with this salt are shown in Figure 23. Marbles Nos. 5 and 24 were spalled considerably, the former along the yellow veins and the latter along strain lines.

(j) *Tests with ammonium chloride—10 per cent solution.*—Two tests with this salt are shown in Figure 26 and one in 23. Marbles Nos. 15 and 29 were spalled appreciably while No. 3 was not apparently injured in this way. Due to the hygroscopic nature of this salt the crystals which formed on the slabs deliquesced in damp weather. The solution is slightly acidic and, therefore, the marble was attacked chemically to some extent. As long as this salt remains dry it does not have this chemical effect. Some of the iron in Marble No. 29 was attacked, resulting in a brown discoloration.

(k) *Tests with ammonium sulphate—10 per cent solution.*—Five tests with this salt are shown in Figures 23 and 26. None of these exhibited any definite spalling, but all showed an appreciable amount of etching. This occurred in damp weather when the salts deliquesced as described above.

(l) *Tests with ammonium carbonate—4 per cent solution.*—Three tests with this salt are shown in Figure 24. Spalling was marked on marble No. 22 and appreciable on No. 9. Two tests with this salt are also shown in Figure 28, which exhibited a considerable amount of spalling. This salt sometimes is employed in cleaning preparations.

(m) *Tests with ammonium oxalate—4 per cent solution.*—Figure 22 shows three tests with this salt and 26 another. None of these indicated any tendency to spall the marble and very little efflorescence was formed.

(n) *Tests with ammonia water.*—Four tests are illustrated in Figure 29. The object of this test was to determine if marble is discolored by ammonia water. One test on marble No. 3 showed a marked yellowing, which was not observed in the other tests. An unexpected result was noted on marble No. 2, which showed slight indications of spalling along some rather prominent veins through the slab. Since ammonia water evaporates without forming crystals to any appreciable extent when left standing in the air, it was assumed that no crystallizing effect would be noted on the marble. It seems possible that where slow evaporation occurs, as in these tests, an appreciable amount of ammonium carbonate might form. The action of the latter on marble has already been illustrated.

(o) *Tests with copper sulphate—10 per cent solution.*—Four tests with this salt are illustrated in Figure 22. This solution penetrated the marble very slowly and showed a slight spalling action in only one case. Apparently the copper solution carbonates when it enters the marble, forming a relatively insoluble compound. The wash from bronze statuary contains a small amount of copper which discolors marble and in some cases causes disintegration.

(p) *Tests with a saturated solution of calcium sulphate.*—One test made with this salt on marble No. 10 is shown in Figure 25. No effects on the marble were evident and no efflorescence was noted. This test was intended to give some information on the action of plaster of Paris when used in setting marble against damp walls. Another test with plaster of Paris will be described later.

(q) *Tests with magnesium sulphate—10 per cent solution.*—Four tests are shown with this material in Figure 29, three of which produced a severe spalling action. Marble No. 20 was apparently unaffected. This salt is frequently present as an impurity in various masonry materials, and may be leached into marble attached to damp walls.

(r) *Tests with Rochelle salt—10 per cent solution.*—Figure 25 shows one test with this salt on marble No. 17. This salt penetrated very slowly, and several months elapsed before any injury to the marble was apparent. The spalling which finally occurred was not very prominent. This salt has been prescribed for use on marble in one of the methods for removing iron rust. The results of this test indicate that such application would not cause appreciable injury to the marble.

(s) *Tests with sugar—10 per cent solution.*—A test on marble No. 8 with a sugar solution is shown in Figure 27. No definite crystallizing action could be discerned from a casual examination of the test specimens. Numerous round spots from 1 to 3 millimeters in diameter appeared which could not be washed away. These gave the appearance of mold which had occurred on or slightly below the surface. Low magnification showed that the surface at these spots was roughened as though etched by drops of acid. Under a strong magnification the surface appeared to be spalled or fractured in many places as though it had received numerous blows with a pointed tool. It seems likely that this effect was due to crystallizing action.

(t) *Tests with soap solutions.*—Figure 30 shows six tests on various marbles with soap solutions. The aim of this test was to determine if the soap would discolor marble. Yellow laundry soaps, castile and white toilet soaps were used. An excess of soap was used to maintain a strong solution. On marbles Nos. 11 and 20 there appeared to be a slight yellowing, while the others showed no effects. Castile soap was used in the tests which gave indications of yellowing.

(u) *Tests with a trade cleaning preparation containing soap, sodium carbonate, and sodium bicarbonate.*—Eight tests are shown with this preparation in Figures 19, 20, and 21. Marbles Nos. 2, 17, and 29 showed large amounts of spalling due to the salts. On the first-mentioned marble the salts followed a vein in the marble for 12 inches or more and produced spalling. An appreciable amount of yellowing occurred on marble No. 10 in Figure 19 which, however, can not be

said to be definitely due to the soap. The asphalt used in sealing the glasses to the marble is slightly affected by such solutions, so it is possible that the discoloration was due to it.

FIG. 30.—Tests with soap solutions (t), a trade cleaning preparation containing soap and sodium carbonate (x), and a trade cleaning preparation consisting mainly of trisodium phosphate (w)

(v) Tests with a trade cleaning preparation containing soap and sodium carbonate.—A test with this preparation on marble No. 24 is shown in Figure 22. A very small amount of spalling occurred

along a vein. This being a very dense marble and the preparation containing only a small percentage of the salt, no very marked crystallizing action was evident.

(w) *Tests with a trade cleaning preparation consisting mainly of trisodium phosphate.*—Three tests with this preparation are shown in Figure 19. The marbles used in these tests are all very dense and very little of the solutions came through. No ill effects were observed.

(x) *Tests with a trade preparation containing 20 per cent of soap and 40 per cent sodium carbonate—10 per cent solution.*—Three tests with this preparation are illustrated in Figure 30. Marble No. 3 was considerably yellowed and Nos. 17 and 25 were slightly pitted. It is probable that the yellowing was caused by the asphalt used for sealing, this being somewhat affected by such solutions. It seems rather remarkable that with so much sodium carbonate present no more spalling was produced. Possibly the strong soap solution interfered with the salt penetration.

IX. DISCUSSION OF RESULTS OF SALT SOLUTION TESTS

Since one object in this series of tests was to determine if different neutral salts would disintegrate marble when allowed to crystallize in the pores, some general observations on this point may not be out of place. It will be noted from the foregoing tests that more attention was paid to sodium chloride, sodium carbonate, and trisodium phosphate than any others. These salts were of interest because of their frequent contact with marble, the first being used in ice-cream containers where the solution may be splashed on the marble-work of soda fountains, and the last two because of their extensive use in cleaning preparations. While the application of the latter to marble has been studied in the scrubbing tests and shown to have a detrimental effect in many cases, the tests under discussion also have a bearing on this point, since they represent in a more conclusive way the crystallizing action of these salts. A general survey of the tests as a whole indicates that sodium chloride has a more severe action than any other of the salts experimented upon. Practically all of the marbles tested with this salt were injured and some were badly defaced within the comparatively short period of the tests. This is strongly evidenced on marble No. 26 in Figure 19. This marble is one of high strength, low porosity, and low permeability. The test referred to showed that the salt solution penetrated along the slab and caused a great deal of spalling several inches from the point where the solution entered. This marble has been long used for exterior exposures and has shown good weather-resisting qualities. Marbles Nos. 16 and 24 in Figure 27 also exhibit the severe action of this salt. A point of interest in this test is the fact that marbles Nos. 11 and 20 were only slightly affected by this action. The main

points of difference between these two marbles and those which were severely attacked are in elasticity and permeability. A more permeable material permits a more ready passage of the solution. This may minimize the effect of crystallization in two ways: First, the top surface of the slab is maintained in a damper condition due to the conduction of more moisture; second, crystals forming in the pores near the surface under pressure may be more readily forced out of the marble. Modulus of elasticity values for these marbles are rather low indicating that they yield more readily to pressure than those with higher moduli. This would also tend to facilitate the extrusion of crystals forming near the surface. A close examination of the efflorescence on these slabs gave evidence that crystals of salt were extruded. In some cases, broad paperlike deposits were formed above strain cracks and in other cases the marble crystals were "walled in" by a thin white sheet of salt.

The disrupting action of any salt in crystallizing in a confined space may depend on the strength of the salt crystal in comparison with that of the confining material and also on the crystal habits of the salt. Sodium chloride always tends to crystallize in a cubical form. This form of crystallization would probably cause the salt to exert more pressure in crystallizing in marble than a salt that forms fibrous or elongated crystals.

A further examination of the tests seems to indicate that magnesium sulphate produced almost as severe results as sodium chloride. Although the number of tests with this salt was limited to four, all except one showed rather extensive disintegration. Closely following this salt in severity of action the tests indicate that sodium carbonate, sodium bicarbonate, and sodium sulphate are about equally destructive. The action of these salts appears to be identical with that of sodium chloride, and those marbles which are more resistant to one are also more resistant to another. This statement should be qualified by the statement that the presence of veins or strain lines usually reduces the resistance of the marble to such attack.

Ammonium carbonate produced rather severe spalling in some of the tests, but hardly as prominent as that of sodium carbonate. Trisodium phosphate in these tests showed less tendency to spall the marble than any other detergent salt employed. However, it should be pointed out that this observation does not entirely agree with the results obtained in the scrubbing tests, where the trisodium phosphate detergents caused a marked loss in strength in the marble.

In general, it may be said that when any salt solution is allowed to penetrate the marble in such a way that the salt may form crystals in the pores, spalling is apt to occur. In cases where there is constant or intermittent exposure to such action for a number of years, as where brine solutions are splashed against the marble or where a cleaning

preparation containing a high percentage of salts are constantly used without proper precautions, disintegration of the marble is practically certain to occur in time. The attacks produced by such action are so severe that no masonry material can long resist them.

X. CRYSTALLIZATION ACTION IN DAMP WALLS

In the preceding tests strong solutions of known salts were allowed to penetrate marble in order to determine the effects. The question has arisen as to whether very weak solutions of certain salts would produce injury to marble under the conditions which sometimes occur

FIG. 31.—Efflorescence on clay brick (top row), natural cement mortar (cylindrical specimens), limestone and sandstone (prisms) leached from the specimens with pure water

in buildings. Interior marble may be attached to damp masonry walls, as those below grade. In such cases the ground water which carries various inorganic salts in solution may pass through the main wall and deposit the salts in the marble. All masonry materials contain small amounts of soluble salt which can be leached out by percolating waters. Figure 31 shows specimens of brick, concrete, limestone, and sandstone with deposits of efflorescence leached from the individual pieces. These deposits of efflorescence were brought to the surface by merely causing pure water to leach through the various pieces for a few months. The salts making up the deposits illustrated are mainly sodium sulphate, magnesium sulphate, and calcium sulphate. When water continually percolates through a

wall containing such materials, the soluble matter is slowly carried out and deposited where the water finally evaporates. On a marble-faced wall conducting moisture to the interior the crystallizing action would occur on the marble.

Some tests were devised to determine if such slow percolation of water could account for ill effects on interior marble. A number of marble boxes were made to contain the masonry wall materials under consideration. Representative samples of practically all the masonry materials which commonly make up the backing of walls were employed in these tests, as follows: Two samples of clay brick, one sand-lime brick, one Portland cement concrete, one lime, one plaster of Paris, and four natural cement mortars. The boxes were 8 by 10 by 6 inches inside, each side and the bottom being made of a different kind of marble. The joints were made watertight by sealing with pitch. The first tests were made by crushing the sample of backing material into fragments, which were placed in the boxes. The box was then kept filled with water to leach the soluble matter out of the backing material and permit it to seep through the marble. It was later found more expedient to bind the fragments together with a small amount of cement and plaster the mixture around the inside of the test boxes. A lining was thus made of the backing materials about 2 inches thick, and the remaining space was kept filled with water. Since only enough cement was used to hold the fragments of backing materials in place, the water could pass through the lining of the boxes very readily; but the marble, being very dense, permitted a very slow penetration of the water. Hence, the action was much slower than it would have been had more porous materials than marble been used in making the boxes. Several weeks elapsed before any efflorescence was observed on the outside of any of the boxes and on certain very dense marbles none was observed throughout the whole period of the test.

While the results in most cases were not prominent enough to show very well in a photograph, in some cases a very definite amount of spalling occurred. Since the thickness of the lining, or the total amount of material representing the backing wall, was very small and the period of test comparatively short, it may be considered that a very slight amount of spalling affords good evidence of what might occur on a much larger scale under actual service conditions.

Test No. 1.—Figure 32 shows at the top a test on marble No. 17 with plaster of Paris. On account of the grimy appearance of this slab at the end of the test it was washed before photographing, hence the efflorescence was removed. The polish was entirely destroyed in spots, and the surface was raised somewhat along several meandering lines as if something had burrowed beneath the surface. While these were not prominent to the sight, one could readily feel them as

rough ridges on the surface. Plaster of Paris, on complete hydration, is assumed to form the compound $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, which is fairly soluble in cold water, and hence it may be expected to cause such trouble when used under damp conditions.

Test No. 2.—The lower part of Figure 32 shows a test on marble No. 16 with sand-lime brick used as the backing. This slab was also washed before the photograph was made and the efflorescence was removed. A great quantity of this efflorescence appeared within a few weeks after the test was started. Several rather prominent pits were caused in the marble by this action. Other tests with sand-

FIG. 32.—Test by leaching water through plaster of Paris into marble No. 17 (D), and through sand-lime brick into marble No. 16 (A)

lime brick were made on marbles Nos. 2, 4, 5, 15, 18, 20, 25, and 26. A red discoloration occurred on No. 2. No noticeable effects occurred on marbles Nos. 4, 15, 18, 20, 25, and 26. A slight deposit of efflorescence was formed along some of the veins in marble No. 5.

Test No. 3.—The top part of Figure 33 shows a test with one of the long-used natural cements on marble No. 9. This showed an appreciable amount of scaling along several seams through the slab. These seams or fissures are of rather frequent occurrence in this marble and pursue irregular courses, sometimes following the border of the white parts, but more often they are entirely in the gray or black portions.

Similar but less prominent results were obtained on marble No. 22. Marble No. 11 appeared to suffer no ill effects; No. 20 was discolored slightly in a few places which appeared to be caused by the wood dowels used in fastening the slabs together. Marble No. 30 was slightly pitted in places, the amount being so slight as to be perceptible to the touch, but only visible with a lens.

Test No. 4.—At the bottom of Figure 33 is shown a test on marble No. 5 with a Portland cement concrete. A prominent deposit of efflorescence was formed on the yellow veins of this slab, but no definite signs of spalling were noted. Other marbles concerned in this

FIG. 33.—Test by leaching water through a natural cement mortar into marble No. 9 (G), and through a Portland cement mortar into marble No. 5 (E)

test were Nos. 4, 15, and 20. None of these showed any signs of spalling, but No. 20 was considerably discolored near the wood dowels. This discoloration has been discussed under the section of this report relating to stain removal. This stain did not present any particular difficulties, since it yielded very readily to the eradication methods described later.

Test No. 5.—Figure 34 shows at the bottom a test on marble No. 17 with a salmon-colored clay brick which is in extensive use in the Middle West. A considerable deposit of efflorescence collected on this marble, which roughened the surface to some extent. Although

the spalling was not very pronounced, the polish of the marble was considerably marred. Marble No. 16 in this test was similarly affected on certain areas where the efflorescence seemed to penetrate more readily than on other parts. Marbles Nos. 11, 15, and 25 were not appreciably injured, except that the first was slightly discolored.

Test No. 6.—At the top of Figure 34 is shown a test with a masonry cement mortar. This is a natural cement produced in the South and is rather extensively used for setting brick masonry. The slab of marble No. 9 in the photograph shows results similar to

FIG. 34.—Test by leaching water through a natural cement mortar into marble No. 9 (C), and through a salmon colored clay brick into marble No. 17 (B)

those obtained on the same marble with another brand of natural cement, as described under test No. 3. Marble No. 11 in this test appears to have been injured appreciably. The polish was removed in several places and the dividing lines between the crystals were rendered much more prominent. Under a magnifying glass these lines gave the appearance of etchings. Marble No. 20 in this test did not show any definite signs of injury. No. 22 showed a small amount of efflorescence along several strain lines which caused some roughening of the surface at such places. Marble No. 30 was pitted in a few places to a slight extent, giving the appearance of small

craters in the surface. These pits were usually less than a millimeter in diameter.

Test No. 7.—Figure 35 shows at the top a test on another masonry cement which is made in the eastern portion of the country. The slab of marble No. 10 shown in the photograph was not visibly affected except for the discoloration, which was probably due to the wood dowels. Marble No. 3 was spalled to a slight extent along a green vein. No. 11 was not injured in appearance. No. 16 was spalled rather prominently in a few places. No. 22 showed some

FIG. 35.—Tests by leaching water through a masonry cement into marble No. 10 (H), and a similar test on marble No. 2 with a natural cement mortar (F)

efflorescence along the yellow veins, but very little injury accompanied this.

Test No. 8.—The lower part of Figure 35 shows a test with another natural cement produced in the Middle West. The slab of marble No. 2, as illustrated, exhibited an appreciable amount of pitting along the green veining material shown in the center. No. 11 was somewhat discolored by a general yellowing which could not well be ascribed to the dowels. This slab also showed signs of injury to the marble similar to that described under test No. 6. No. 16 showed rather large amounts of efflorescence which was accompanied by

spalling of the surface. No. 20 was discolored by the dowels as described in test No. 2, but was not otherwise visibly affected. No. 22 was injured to some extent by the crystallizing effects along a few strain lines and veins.

In this test the mortar lining near the top of the box was badly crumbled and disintegrated by the efflorescence that formed there.

Test No. 9.—This consisted of a test with hydrated lime on marbles Nos. 9, 18, 20, 24, and 26. While an efflorescence was formed on some of these marbles, no very definite injury occurred except on No. 9. No. 24 showed some indication of a slight spalling along some of the veins, but the polish on this slab remained in excellent condition.

Test No. 10.—This was a test with a normal Portland cement mortar on marbles Nos. 9, 18, 20, 24, and 26. The surface of No. 9 was roughened slightly by very small spalls along certain veins or seams, such as was found in foregoing tests on this marble, although to a less extent. No. 24 was spalled appreciably along certain irregular lines which appear to be the more permeable parts of this marble.

Test No. 11.—This was a test with a hydraulic lime, manufactured in the Middle West and used to a considerable extent in brick and stone masonry. Marble No. 15 lost its polish in several areas, and several veins through the slab were rendered more prominent, as though there had been appreciable action along them. Marble No. 17 was deeply cracked at the corners and suffered an almost complete loss of the polish. Marble No. 2, which had rather prominent veins running perpendicular to the face of the slab, was split along these in two places. These cracks finally became so deep that the box would no longer hold water and the test had to be discontinued. Large yellow stains also appeared on this slab, which may have been caused by the dowels. Marble No. 6 was also split in a manner similar to No. 2. No. 26 showed a loss of the polish over about one-half of its surface. The mortar itself was crumbled near the top of the box where the salts crept up and crystallized.

Test No. 12.—This was a test with a red clay brick on marbles Nos. 2 and 26. In this the brick fragments were used without a cementing material. It did not produce any visible results on the marble worthy of mention. It is believed that the soluble matter did not penetrate these marbles to an appreciable extent, due to the manner in which the test was made. However, there was considerable efflorescence formed on the brick fragments at the top, hence, it seems probable that if this test had been made by binding the crushed fragments together and plastering the mass on the inside of the box a more definite result would have been obtained.

A general survey of the results obtained in this series of tests shows that in several cases very prominent amounts of disintegration were produced on the marble. Considering the comparatively short period of time over which these tests were extended and the small amounts of material used to represent the backing wall, it may be concluded that wherever marble is to be attached to a wall which is apt to conduct an appreciable amount of dampness, special precautions should be taken to prevent the ill effects which may result.

XI. PROTECTING MARBLE AGAINST THE ACTION OF SALT SOLUTIONS

Builders of fine structures are usually interested in maintaining them in their original state and especially in preventing abuse of the ornamental features. To apply cleaning preparations containing a considerable amount of soluble salts to marble without proper precautions is little short of abuse. There are two ways in which such injury to marble may be avoided, first, to refrain from using such cleaning preparations; second, if the use of such is deemed necessary, to rinse the surface with clear water before applying the preparation. Of the two choices the first is far better, but in the second case the extra step of preliminary rinsing is offset by a saving in the amount of cleaning materials. The manner in which this step prevents harmful action has already been discussed in another chapter of this paper.

The question also arises of preventing scaling on the marble of soda fountains. Is it possible to prevent or minimize the effect of occasional splashes of brine or other salt solutions? Many treatments have been advocated from time to time which are intended to seal the pores of such materials and prevent the penetration of moisture. Some of these, such as varnish, leave a film on the surface, while others precipitate a wax within the pores. The value of any such treatment depends on the thoroughness with which it forms a seal and its durability. Those which leave a film on the surface are not apt to be as durable as those which are absorbed, since the former are more exposed to the destructive elements. Rather extensive experiments were made on penetrating materials to determine their effectiveness and durability when exposed to the weather. Although the experiments were made by treating more porous materials than marble, it is believed that those treatments which proved most durable on coarser stone would also be found best on marble. The types of treatments employed in the tests were as follows: Paraffin dissolved in light mineral spirits, fatty oils in petroleum distillate, aluminum stearate in petroleum distillate or turpentine, thin varnishes, fluosilicate solutions, casein glue, and aluminum stearate

mixtures in an aqueous solution, cellulose nitrate solutions, and solutions which react with each other to precipitate a waxy substance in the pores. The results of these tests, which are reported in Bureau of Standards Technologic Paper No. 248, indicate that the most effective treatment of this type consists of paraffin dissolved in a light solvent like benzol or gasoline. While this treatment discolors marble to some extent and for this reason would not be desirable for use on the exposed surface of polished marble, it would seem to

FIG. 36.—Apparatus used for determining the permeability of marble under hydrostatic pressure

be a satisfactory treatment for the unexposed surface of slabs. In view of this, a few permeability tests have been made on marble specimens before and after treatment by this process to determine how much the permeability could be reduced. The term permeability is used in this sense to designate the rate of flow of water through a definite area and thickness of marble. The apparatus shown in Figure 36, which was used in making these tests, consists of a specimen container *A* and an accumulator *B* for maintaining the desired water pressure. The specimens shown at *C* are 3 inches in diameter

and one-half inch thick. These are sealed in the specimen container with a special grade of asphalt around the edge and the water pressure is brought on the top face. The lower part of the container consists of a cup-shaped casting, the top of which is brought to a sharp edge, forming a catch basin 2 inches in diameter. This screws into the container until the top of the cup makes a firm contact with the lower face of the specimen. With a given water pressure on the top face of the specimen one can determine the rate at which the water flows through into the container below. In cases of a rapid flow through the specimen the water is drawn off and measured in a graduate, but with very compact materials where the flow is slow the water is absorbed in a suitable desiccant placed in the cup and the amount measured by weighing the desiccant. Experiments with this apparatus on marble gave the following results:

Marble No.	Condition	Water pressure in pounds per square inch				
		1.2	50	100	150	200
		Flow rate in cubic inches per square foot of surface per hour, one-half inch thickness of stone				
1.....	Natural state.....	0.00	-----	1.12	-----	1.43
2.....	do.....			.90	-----	
11.....	do.....	.35	10.8	28.0	-----	31.4
31.....	do.....	.06	11.3	19.6	26.6	-----
11.....	Treated ¹	.003	.11	.45	-----	
31.....	do. ¹	.011	-----		.08	-----

Specimen treated with 2 coats of a 10 per cent solution of paraffin in benzol.

It will be noted from the above results that the permeability values of different marbles vary greatly. Nos. 11 and 31 are both domestic marbles which have been extensively used for exterior work and have shown excellent weathering qualities. These two marbles were chosen for testing the wax treatments because a more definite indication could be obtained on such materials than those of a more compact and less permeable nature. The tests indicate that while the treatments greatly reduced the amount of water passing through at different pressures the seal in no case was perfect. Until a treatment can be devised that will entirely prevent the penetration of liquids or solutions it seems that one can not be sure of absolute protection against the action of salt solutions. However, any treatment that will reduce the permeability as much as that indicated will greatly reduce the harmful action and be well worth utilizing. Where the marble is exposed to an occasional splash of brine or other salt solutions, as is the case in soda-fountain counters, such treatment would probably meet all the requirements. On a damp wall where one face of the slab is continually exposed to dampness it is doubtful if this treatment would be of much value.

A series of tests on slabs of marble continually exposed to brine solutions is shown in Figure 37. The top row was treated with a 3 per cent solution of paraffin, second row with a 5 per cent solution, third row with molten paraffin, and the bottom row left untreated. It will be noted that the salt came through all except those treated with molten paraffin.

FIG. 37.—Tests on various marbles to determine the effectiveness of paraffin solution and hot applications of paraffin for preventing the penetration of salt solutions

The foregoing test is an exaggerated example of what might occur on a damp wall. Where the slab has a conducting medium, such as plaster of Paris, connecting it with the main wall, the salts could come through and cause injury. The injury referred to is apt to be confined to those parts of the slabs where plaster of Paris forms a conducting medium. As marble wall slabs are usually so connected with the wall only at the corners, the injury is apt to occur at such parts. Wherever marble slabs are to be set on walls that are

apt to conduct dampness it would seem advisable to treat with molten paraffin those parts of the slabs which are to be joined to the wall.

XII. DESCRIPTION OF MARBLES EMPLOYED IN THE EXPERIMENTS

The samples of marbles used in these experiments were chosen from the more popular varieties in present-day use and are believed to represent fairly well the entire field of domestic and foreign marbles. Table 11 gives the results of absorption and apparent specific gravity tests. The absorption tests afford some information as to the relative porosity values and the specific gravity determinations enable one to compute the bulk weights which are given in the last column of Table 11. Table 12 supplies the results of strength and elasticity tests. This table is a summary of the results on the original marble obtained in connection with the long-period scrubbing tests. Methods of procedure in these tests have been described in Chapter III.

It will be noted that the absorption by weight determinations vary from the very low value 0.04 to 4.84 per cent. The lowest absorption indicates a porosity of about 0.5 per cent, or less than 1 cubic inch of void space in a cubic foot of the material. The highest absorption indicates a porosity of over 13 per cent, or more than 200 cubic inches of void space to the cubic foot. Modulus of rupture values vary from 440 to 4,800 lbs./in.² These values indicate that a bar of the strongest material 1 inch square in section laid on supports 10 inches apart would break under a load of 320 pounds at the middle, while a similar bar of the weakest marble loaded in the same way would break under a load of about 30 pounds. If a marble having a modulus of rupture of 2,000 lbs./in.² were cut into a slab 1 inch thick it would break under its own weight if supported at points 161 inches apart. The marble of lowest strength in the series would break under its own weight if a 1-inch slab were laid on supports 77 inches apart. Modulus of elasticity values indicate the relative stiffness of the different materials. Consider a bar of marble 1 inch square in section and 100 inches long to be supported at the ends and loaded at the center with a load of 10 pounds. If the modulus of elasticity of the marble is 12,000,000, the bar will sag about one-fifth of an inch under the load. If the bar is made of a marble whose modulus of elasticity is 2,500,000, the sag would be approximately 1 inch.

Modulus of elasticity values were computed from curves similar to those illustrated in Figure 15. These curves show the deflection of the specimens for definite loads applied at the middle of slabs supported as shown in Figure 14. The curves in this figure are nearly

straight lines; that is, the deflections were proportional to the loads. However, with many marbles this type of curve is not obtained. The more thoroughly crystallized marbles when loaded in this way give a curve which bends downward; that is, the deflections increase at a greater rate than the load. In such cases the modulus of elasticity is computed from the part of the curve that indicates proportional deformations. Usually the part of the curve for the lower loads is fairly straight, and hence the elasticity constants given in Table 12 are for the lower loads. Reference was made in Chapter III to the fact that elasticity values determined on marble after a long period of scrubbing with certain detergents appeared to increase in some cases and to decrease in others, while the strength values may have changed in reverse order. This was probably due to the fact that the elastic constants had to be computed in most cases for the low loads. Probably computations based on the deflections corresponding to higher loads, as three-fourths of the breaking load, would have shown variations in the elastic constants more similar to the variations in strength.

TABLE 11.—*Absorption and apparent specific gravity determinations*

Marble No.	Percentage of absorption by weight				Apparent specific gravity				Average weight per cubic foot dry (pounds)
	Number of tests	Highest	Lowest	Average	Number of tests	Highest	Lowest	Average	
1	7	0.10	0.09	0.10	3	2.711	2.710	2.711	169.4
2	3	.07	.06	.06	2	2.715	2.713	2.712	169.5
3	3	.10	.08	.09	3	2.713	2.711	2.712	169.5
4	6	.07	.04	.06	3	2.718	2.714	2.715	169.7
5	6	.36	.12	.20	3	2.732	2.711	2.719	169.9
6	10	.15	.06	.11	3	2.704	2.701	2.703	168.9
7	3	.17	.16	.16	1			2.710	169.3
8	4	.50	.41	.45	4	2.665	2.651	2.661	166.4
9	6	.30	.22	.26	2	2.816	2.805	2.810	175.6
10	7	.19	.13	.16	3	2.714	2.709	2.712	169.5
11	4	.18	.14	.16	3	2.705	2.705	2.705	169.1
12	6	.15	.11	.14	3	2.712	2.710	2.711	169.4
13	3	.09	.09	.09	2	2.716	2.715	2.716	169.6
14	3	.12	.10	.11	2	2.727	2.715	2.721	171.1
15	6	.23	.18	.21	3	2.697	2.695	2.696	168.4
16	5	2.79	2.56	2.68	3	2.587	2.572	2.582	161.3
17	6	4.84	4.43	4.66	3	2.471	2.460	2.465	154.2
18	6	.73	.37	.52	3	2.720	2.686	2.705	169.1
19	3	.15	.09	.12	2	2.718	2.718	2.718	169.8
20	3	.09	.09	.09	2	2.713	2.710	2.712	169.5
21	10	1.75	1.32	1.46	3	2.388	2.366	2.380	148.8
22	3	.30	.14	.23	2	2.692	2.690	2.691	168.0
23	6	.56	.29	.41	3	2.690	2.672	2.679	167.4
24	3	.28	.24	.26	1			2.717	169.7
25	10	.26	.15	.21	3	2.694	2.687	2.691	168.1
26	6	.07	.07	.07	3	2.701	2.699	2.700	168.8
27	3	.12	.11	.12	2	2.715	2.713	2.714	169.5
28	2	.21	.20	.20	2	2.668	2.667	2.668	166.7
29	8	.97	.73	.86	3	2.762	2.723	2.739	171.1
30	12	.26	.09	.17	3	2.721	2.716	2.718	169.9

TABLE 12.—Transverse strength and modulus of elasticity

Marble No.	Modulus of rupture				Modulus of elasticity, E			
	Number of tests	Highest	Lowest	Average	Number of tests	Highest	Lowest	Average
		Lbs./in. ²	Lbs./in. ²	Lbs./in. ²		Lbs./in. ²	Lbs./in. ²	Lbs./in. ²
1-----	10	2,980	2,000	2,470	10	8,940,000	5,930,000	7,802,000
2-----	5	2,810	2,310	2,520	5	10,000,000	7,550,000	8,910,000
3-----	6	2,330	1,880	2,200	6	9,110,000	6,270,000	7,620,000
4-----	7	4,350	2,870	3,640	7	12,180,000	11,310,000	11,780,000
5-----	10	2,440	440	1,510	10	12,200,000	2,790,000	9,757,000
6-----	13	2,060	700	1,360	14	12,500,000	1,520,000	6,770,000
7-----	6	1,110	760	960	6	2,030,000	1,530,000	1,840,000
8-----	3	1,970	1,280	1,740	3	7,980,000	6,100,000	7,130,000
9-----	7	2,430	1,290	1,790	7	11,500,000	9,430,000	10,800,000
10-----	8	2,220	800	1,290	8	6,970,000	1,270,000	3,200,000
11-----	12	1,590	1,100	1,380	12	9,320,000	3,430,000	4,880,000
12-----	9	1,390	550	1,050	9	3,210,000	1,020,000	2,560,000
13-----	6	2,620	2,300	2,490	6	10,950,000	8,040,000	9,960,000
14-----	2	1,800	1,670	1,740	2	6,510,000	6,450,000	6,480,000
15-----	12	2,400	1,460	1,950	12	10,400,000	8,730,000	9,700,000
16-----	12	2,440	1,520	1,900	12	7,960,000	6,200,000	6,700,000
17-----	6	1,770	1,550	1,640	6	6,270,000	4,730,000	5,410,000
18-----	7	2,130	830	1,440	7	7,590,000	2,820,000	5,870,000
19-----	4	1,380	1,140	1,270	4	4,570,000	3,020,000	3,830,000
20-----	8	2,810	2,460	2,650	8	10,300,000	8,440,000	9,030,000
21-----	3	1,090	740	820	3	5,420,000	4,000,000	4,750,000
22-----	2	610	470	540	4	11,060,000	6,610,000	9,400,000
23-----	4	2,520	1,580	2,080	3	11,800,000	10,100,000	11,130,000
24-----	3	2,620	1,540	1,970	6	11,300,000	10,540,000	11,000,000
25-----	6	2,440	2,160	2,270	6	11,030,000	9,600,000	10,590,000
26-----	6	2,440	2,180	2,290	4	5,660,000	2,970,000	4,460,000
27-----	4	1,910	1,220	1,680	2	13,280,000	9,830,000	11,560,000
28-----	2	4,800	3,900	4,350	5	6,220,000	2,080,000	3,390,000
29-----	5	1,000	440	660	12	11,630,000	7,780,000	9,850,000
30-----	12	2,900	1,930	2,520				

TABLE 13

Marble No.	Classification	Color	Texture	Remarks
1 ¹ -----	Calcite-----	White with occasional dark or green veins.	Medium grained..	A strong, dense and rather rigid marble.
2 ¹ -----	..do-----	White with dark or green veins.	..do-----	Do.
3 ¹ -----	..do-----	Creamy white.....	..do-----	Do.
4 ² -----	Graphitic calcite.	Black.....	Fine grained.....	Very strong, dense, rigid, and inclined to brittleness.
5 ² -----	..do-----	Black with yellow veins.....	..do-----	Usually weak and rather porous along the veins.
6 ² -----	Calcite-----	Creamy gray.....	..do-----	Usually dense and rigid but of uncertain strength, somewhat brecciated.
7 ¹ -----	..do-----	White with green clouds..	Medium grained..	A rather open structure, flexible, and of moderate strength.
8 ¹ -----	..do-----	Gray.....	Medium grained (fossiliferous).	A strong and rather rigid material.
9 ² -----	Dolomite....	Black, white, and gray variegated.	Fine grained.....	Variable strength, rigid.
10 ² -----	Calcite-----	White with dark veins....	Medium grained..	Variable strength, flexible rather open structure.
11 ¹ -----	..do-----	..do-----	Coarse grained....	Open, granular structure, flexible, moderate strength.
12 ¹ -----	..do-----	White with network of dark veins.	Medium grained..	Rather open structure, flexible, moderate strength.
13 ² -----	..do-----	White with frequent dark clouds.	..do-----	A strong, rigid, marble of uniform quality.
14 ² -----	..do-----	..do-----	..do-----	Rather open granular structure, uniform strength and elasticity.

¹ Domestic marble.

² Imported marble.

TABLE 13—Continued

Marble No.	Classification	Color	Texture	Remarks
15 ²	Calcite.....	Creamy gray.....	Fine grained.....	A hard, rigid material of variable strength.
16 ¹	Dolomite.....	Yellowish pink.....	do.....	Rather porous, but strong and uniform in quality.
17 ¹	do.....	Yellow.....	do.....	Porous, sometimes friable, but fairly strong.
18 ²	Serpentine..	Red, purple, and green variegated.	do.....	Rather porous and of uncertain strength.
19 ¹	Calcite.....	White with dark veins...	Medium grained..	Rather open granular structure, moderate strength, flexible.
20 ²	do.....	White with frequent dark clouds.	do.....	Rather open structure, uniform strength and elasticity.
21 ²	Calcite (travertine).	Buff.....	Fine grained.....	Porous, variable strength and elasticity.
22 ¹	Calcite.....	Gray with yellow veins...	Fine grained (fossiliferous).	Porous and weak along the veins, ground mass dense and strong.
23 ²	do.....	do.....	do.....	Dense, but of variable strength and elasticity.
24 ²	do.....	do.....	do.....	Do.
25 ²	do.....	do.....	do.....	Do.
26 ¹	do.....	Pink.....	Medium grained (fossiliferous).	A dense, rigid marble of uniformly high strength.
27 ¹	do.....	White, dark veins.....	Medium grained..	Open granular structure, moderate strength, flexible.
28 ¹	Serpentine..	Green.....	Fine grained.....	Very dense and rigid, high strength perpendicular to bedding, but rather weak along the cleavage.
29 ²	do.....	Green and white.....	do.....	Rather porous and of uncertain strength.
30 ²	Calcite.....	Dark gray.....	Medium grained (fossiliferous).	A dense, rigid marble, uniformly high strength.
31 ¹	do.....	White with broad green veins.	Medium grained..	Rather open structure, moderate strength.
32 ¹	do.....	Red with frequent white fossils.	Medium grained (fossiliferous).	Rather porous, moderate strength.

¹ Domestic marble² Imported marble

Table 13 gives certain data in regard to the different marbles, which were derived from the physical tests or general observations. Marbles with a high modulus of elasticity are classed as rigid and those of low modulus are classed as flexible. By "open structure" as used in this table is meant a type of porosity which permits a rather easy passage of water through the material. The term "dense" is applied to materials which show a high resistance to the passage of water. Marbles Nos. 31 and 32 were not tested for strength or absorption and the remarks pertaining to these properties were estimated from general appearances.

XIII. TREATMENT OF STAINS ON MARBLE

While practically every type of stain can be removed from marble without appreciable injury to either the texture or color, the eradication of old stains which have been long neglected may require considerable patience. Stains from oils which have penetrated deeply and oxidized in the marble are probably the most stubborn of all. In such cases it is a matter of repeating the treatment day after day until the desired results are attained. It is not always

possible to determine what the staining matter is, and hence the treatment sometimes has to be a matter of experimentation. Usually the staining matter will be found to exist in a stable form, and its removal may require several applications of a solvent which does not appreciably affect the marble. A considerable variety of chemicals may be applied to marble without appreciable injury, but acids or those chemicals which develop an acid condition should be carefully avoided. Even weak acids, such as oxalic and acetic, may show their effects on the surface if left on the marble for a considerable length of time. In polishing processes where oxalic acid is used the operator is always careful to thoroughly rinse the surface as soon as the desired finish is obtained. On the other hand, oxalic acid has been rather frequently employed in ordinary cleaning processes where good results are claimed for it. There can be little doubt that it may prove an effective cleaner, since each application would inevitably dissolve a thin film of marble from the surface. This will soon result in destroying the polish and later in a rough surface. Serpentine, commonly called "verde antique marbles," are not readily attacked by acids, and hence their judicious use on this type of marble is not apt to produce harmful results. For instance, an iron stain on such marbles could be readily removed by applying dilute phosphoric acid. Likewise the dolomites are not so readily attacked by acids, and hence a somewhat wider choice of chemicals may be employed on this type of marble. Domestic marbles now in use which belong to this latter type are as follows: "South Dover" (N. Y.), "Lee" (Mass.), "Swanton" (Vt.), "Beaver Dam" (Md.), "Kasota" (Minn.), and "Columbia" (Calif.).

Usually stains can not be readily removed by merely applying the proper chemical to the surface or by scrubbing the stained part. This is due to the fact that stains penetrate to some degree and can not be reached by the mop. In general, it is necessary to resort to a poultice or bandage. By a poultice is meant one or more chemicals mixed with a fine inert powder to a pasty or mortar consistency. This is applied to the stained part of the marble with a brush or trowel in a layer of considerable thickness. The bandage treatment consists of soaking a layer of cotton batting or a few layers of cloth in a chemical solution and pasting this over the stain. There are two ways in which a stain may be eradicated, first to dissolve the staining matter and draw it out by capillary suction or drive it back from the surface; and, second, to convert the coloring matter by a chemical reaction into a form which does not show as a stain. In removing an oil stain it is usually necessary to apply a solvent and draw the dissolved oil out. An iron stain is more satisfactorily treated by applying a reducing agent. Evidently in this case the stain would reappear in time unless means were taken to prevent the reoxidation

of the iron. This is readily accomplished by an application of sodium citrate solution. Some chemicals used for removing stains are very unstable and decompose under certain conditions. Such chemicals sometimes produce stains of their own which may be more troublesome than the original. This is particularly true of the hydrosulphite ($\text{Na}_2\text{S}_2\text{O}_4$) used in removing iron stains. A method for using this chemical is described under the subject of iron stains. This has proven entirely trustworthy, but unless the procedure is rather closely followed one may obtain a yellow stain. If the poultice is left on several hours a black stain may develop, which is probably due to the formation of a sulphide of iron. Some staining matter in the pores of marble is easily dissolved by a surface scrubbing and apparently removed, but as the marble dries the stain may reappear. Tobacco stains scrubbed with a solution of washing soda may disappear in this way, but only temporarily. This is due to the solvent driving the staining matter into the marble. In such cases it usually reappears stronger than at first due to the concentration of a larger amount of the stain at the surface as the marble dries. The chief function of a poultice is to draw dissolved staining matter out of the marble. In some cases a porous paper or blotter pasted to the stained surface after the proper solvent has been applied may be made to answer the purpose of a poultice. When a stain has to be treated with a very volatile solvent, such as benzol, ether, acetone, etc., it has been found best to use a slab of marble or some other stone over the solvent. This prevents a rapid evaporation of such solvents and therefore prolongs their action and also affords a capillary action similar to a poultice. When a slab of stone is so used, it should be thoroughly dry.

The greater number of formulas following have been developed in the laboratory by experiments on old stained marble supplied from buildings or marble stained especially for the purpose. These formulas have been checked several times in the laboratory as to performance, and appear to be entirely practical for general use.

It may be not possible in some cases of staining to determine the type of stain. Many stains are yellow or brown, resembling iron rust. Oil stains when new resemble the oil itself, but after a considerable period of time they are apt to become yellow or dark brown. Copper and bronze stains are usually green; however, it is quite certain that bronze sometimes causes brown stains. This may be due to the iron or manganese content of the bronze or there is a possibility that it is caused by the alteration of fine particles of pyrites in the marble. In some of the experiments on copper stains, which were made by a solution of copper sulphate, a brown stain was found on the marble after the copper stain had been removed. This brown stain yielded readily to the treatment for iron stains

which indicates that it was caused by the alteration of some element in the marble, since the copper salt applied was "chemically pure." Copper solutions attack marble to some extent. This was evidenced in the experiments and it may be observed on marble bases for bronze statuary, which have been exposed to the weather for several years.

The term "service stains" may be used to describe a type of discoloration which occurs on interior marble when it is not properly cleaned. Such discolorations may vary in intensity from a slight yellowing of the surface to very prominent or ugly brown stains. The cause of these is not well understood, and it seems quite likely that there is no single cause for all cases. Some are inclined to attribute such discolorations to "burning" with the polisher or gritting machine. It seems quite evident, however, that some cases of "yellowing" are due mainly to the conditions of exposure and lack of an occasional cleaning. It is practically impossible to find a structural material that will not become badly soiled if it is entirely neglected for a few years. Whatever the cause of service stains or degree of soiling, it is usually possible to bring the marble back to its original appearance.

Marble in certain parts of buildings is apt to become stained from the perspiration or oil from the hands. Such discolorations sometimes become very prominent and resemble iron stains. This stain is not as difficult to remove as those caused by lubricating oil or linseed oil.

Marble setters sometimes place excelsior back of slabs when placing them in the wall. Under damp conditions the wood will rot and finally produce a chocolate-colored stain on the face of the slab. When pine wood burns in contact with marble, pitch from the wood may penetrate the marble and produce a stain which is almost black. The eradication of such stains is a slow process, but in many cases it may be entirely practical.

1. TREATMENT OF IRON STAINS

Iron stains can usually be recognized by their resemblance to iron rust or by their position with respect to steel members of the structure.

Method No. 1.—Dissolve 1 part sodium citrate in 6 parts of water. Add to this an equal volume of glycerin and mix thoroughly. Mix a part of this liquid with whiting to form a paste just stiff enough to adhere in a thick coating to the marble. Apply this to the stained marble with a putty knife or trowel. This will remain soft for a few days, but when it becomes dry it should be replaced with a new layer or softened by the addition of more of the liquid. While this treatment is entirely free from injurious effects its action may be too slow to be practical in cases of intense stains. Ammonium citrate may be used in the above formula instead of sodium citrate to obtain some-

what quicker results, but, due to the development of an acid condition, it may injure the polished surface to a slight extent.

Method No. 2.—For deep and intense iron stains it is more satisfactory to employ sodium hydrosulphite ($\text{Na}_2\text{S}_2\text{O}_4$). Before applying the hydrosulphite to the stain the marble should be soaked for a few minutes with a solution of sodium citrate made by dissolving 1 part of the citrate crystals in 6 parts of water. The best way to apply the citrate solution is to dip a white cloth or piece of cotton batting into the solution and paste it over the stain for 10 or 15 minutes. If the stain is on a horizontal face, sprinkle a thin layer of the hydrosulphite crystals over it, moisten with water, and cover with a stiff paste of whiting and water. If the stain is on a vertical face, place a layer of the whiting paste on a plasterer's trowel, sprinkle on a layer of the hydrosulphite, moisten slightly, and apply it to the stain. Leave this on for one hour and remove. If the stain is not all removed, repeat the operation. Unless the stain is deep, one treatment will remove it. When the stain disappears, rinse the surface thoroughly with clear water and make another application of the citrate solution as at first. This treatment is apt to dim the polish somewhat due to a slight etching effect. However, it is not usually a difficult matter to repolish the treated portion with a piece of chamois skin and some "putty powder," which can be obtained from a marble setter. Moisten the chamois skin in water, dip it into the dry putty powder, and rub the marble vigorously until the desired polish is obtained.

Experiments have been made to develop a preinstallation treatment for marble to resist discoloration from iron stains. This work has indicated that marble treated with a sodium citrate solution is very difficult to stain with iron. One part of the citrate crystals dissolved in 10 parts of water gives a solution of the desired strength. The marble should be fairly dry before the application is made in order to secure satisfactory penetration. This treatment can be applied to the exposed face of marble as well as the back, since it causes no change in appearance. In treating marble to be joined to steelwork it would seem advisable to treat the edge of the slab and also the back for a few inches away from the joint.

2. COPPER OR BRONZE STAINS

Such stains are found on marble bases of bronze statuary or other places where the wash from bronze, copper or brass runs over the marble. The stain is nearly always green, being due to the formation of the carbonate of copper, but bronze work apparently causes a brown stain in some cases. The green stains may be eradicated in the following way:

Method No. 1.—Mix together in the dry form 1 part of ammonium chloride (sal ammoniac) and 4 parts of powdered talc. Add ammonia water and stir until a paste is obtained. Place this over the stain and leave until dry. When working on polished marble, use a wooden paddle to scrape off the poultice, but on a dull finish a trowel may be used. A stain of this kind that has been collecting for several years may require several repetitions of this procedure to completely remove it. Sometimes aluminum chloride is employed in the above procedure instead of sal ammoniac.

Method No. 2.—Dissolve 8 ounces of potassium cyanide in 1 gallon of water. Saturate a thick white cloth in the solution and place it over the copper stain. When the cloth has become dry, soak it again in the cyanide solution and repeat the operation until the stain disappears. Sometimes it may be advantageous to combine this and the method above; that is, remove the greater part of the stain with the poultice and finish with the cyanide solution. This solution is very poisonous if taken into the system.

3. INK STAINS

Inks are of various compositions, and each type may require a different treatment. Ordinary writing inks usually consist of galloannate of iron, a blue dye, a mineral acid, phenol, and a gum or glycerin. Such an ink may etch the surface of marble due to the acid content. A stain from this type of ink may be removed as follows:

Stains from writing inks.—Make a strong solution of sodium perborate in hot water. Mix this with whiting to a thick paste which is applied in a layer $\frac{1}{4}$ inch thick, and leave until dry. If some of the blue color is visible after this poultice is removed, repeat the process. If only a brown stain remains, treat it by method No. 1 for iron rust. Sodium perborate can be obtained from any druggist. Repolish the surface if necessary as described under method No. 2 for iron rust.

Synthetic dye inks.—Many of the red, green, violet, and other bright-colored inks are water solutions of synthetic dyes. Such inks contain no acid and do not etch marble. Stains made by this type of ink can usually be removed by the sodium perborate poultice described above under method No. 1. Often the stain from such inks can be removed by applying ammonia water on a piece of cotton batting. Javelle water may also be effectively used in the same way as ammonia water or mixed to a paste with whiting and applied as a poultice. A mixture of equal parts of chlorinated lime and whiting reduce to a paste with water may also be used as a poulticing material for this type of stain.

Prussian blue inks.—Some blue inks contain Prussian blue, which is a ferrocyanide of iron. Stains from this type of ink can not be removed by the perborate poultice, Javelle water, or chlorinated lime poultice. Such stains yield to a treatment of ammonia water applied on a layer of cotton batting. A strong soap solution applied in the same way may also be effective.

Indelible ink.—This type of ink often consists entirely of synthetic dyes. Stains from dye inks may be treated as outlined above for that type. However, some indelible inks contain silver salts which cause a black stain. This may be removed with ammonia water applied on a layer of cotton batting. Usually several applications will have to be made.

4. TOBACCO STAINS

Method No. 1.—The grit scrubbing powders, commonly used on marble, terrazzo, and tile floors are usually satisfactory for application as a poulticing material on this type of stain. Stir the powder into a pail of hot water until a mortar consistency is obtained. Mix this thoroughly for several minutes, then apply to the stained marble in a layer about one-half inch thick. Leave this on until dry. If working on polished marble, scrape off the poultice with a wooden paddle; on dull finished surfaces a trowel may be employed. In most cases two or more applications of the poultice will be necessary.

Method No. 2.—If the scrubbing powders called for in method No. 1 are not at hand, the following procedure may be used. Make up a soap solution by dissolving about 1 cubic inch of soap in a quart of hot water. In another vessel make up a solution of sodium carbonate by dissolving one large tablespoonful of soda ash or two tablespoonfuls of washing soda to the pint of water. Combine equal parts of these two solutions and apply a portion of it to the stained surface with a mop, or saturate a piece of cotton batting in the liquid and place it over the stain for a few minutes. Make up a poultice by mixing a portion of the soap and soda solution with powdered talc or whiting. Apply this to the stain and leave until dry. Scrape it off as described above and repeat if necessary. Powdered talc is preferable to whiting, since it holds the moisture longer and thus prolongs the action of the active chemicals. It also has the advantage of being easier to remove from the marble after it has dried. Whiting is apt to cling so firmly that it has to be moistened before it can be scraped off. This is an undesirable feature, since the dried poultice contains the staining matter, and if it has to be soaked loose from the surface some of the staining matter is apt to be driven back into the marble. If the paste is made of the proper consistency, it can be applied with a paintbrush, which makes the process easier in case a large area is to be covered. A whiting paste has the desired

brushing properties, but in order to make the talc poultice work well as a brushing coat it is necessary to add a little sugar. About one teaspoonful to each pound of talc will usually give the desired results. Powdered talc in the raw state is of low cost, but is not always easily obtained. When only a small amount is required, one may employ the cheaper grades of talcum powders or purchase the unscented grades from automobile tire distributors.

Method No. 3.—The following formula will be found to be somewhat more efficacious than either of the foregoing: Dissolve 2 pounds of trisodium phosphate crystals in 1 gallon of hot water. Mix the contents of a 12-ounce can of chlorinated lime to a paste in a shallow enameled pan by adding water slowly and mashing the lumps. Pour this and the trisodium phosphate solution into a stoneware jar and add water until approximately 2 gallons are obtained. Stir well, cover the jar, and allow the lime to settle. For use add some of the liquid to powdered talc until a thick paste is obtained, and apply as a poultice $\frac{1}{4}$ inch thick with a trowel. If it is desired to apply this with a brush, add about one teaspoonful of sugar to each pound of powdered talc. When dry scrape off with a wooden paddle if working on polished marble, or use a trowel if on dull finishes. This mixture is a strong bleaching agent and is corrosive to metals, hence in using it care should be taken not to drop it on colored fabrics or metal fixtures.

This formula is also valuable for treating other stains and will be frequently referred to in the following methods. Trisodium phosphate may be purchased at most drug stores, at chemical supply houses, or laundry supply houses.

5. URINE STAINS

Use method No. 3 as outlined above for tobacco stains. Some parts of the stain may prove stubborn, in which case saturate a layer of cotton batting in the liquid and paste over that part of the marble. Resaturate the cotton if necessary.

Where polished marble has long been exposed to the action of urine, the polish will usually be injured. To restore the polish, moisten a piece of felt cloth or chamois skin with water, dip it into some FF carborundum or emery flour and rub the marble surface until the surface appears perfectly smooth and somewhat glossy. Then use some putty powder in the same way until the desired polish is obtained. When applying the putty powder use a new piece of felt or chamois skin.

6. FIRE STAINS

Often in the case of fires the marble is not appreciably injured but may be badly discolored from the smoke or pitch from burning wood. Sometimes it is entirely feasible to restore the original appearance

by the following process: First scour the surface with powdered pumice or a grit scrubbing powder to remove the surface deposit, then make up a solution of trisodium phosphate and chlorinated lime as described in method No. 3 for tobacco stains. Fold a white Canton flannel cloth to form three or four layers and saturate it in the liquid. Paste this over the stain and cover it with a piece of pane glass or a scrap slab of marble, making sure the cloth is pressed firmly against the marble. Resaturate the cloth as often as necessary. Deep pitch stains are difficult to remove, and hence several treatments will be necessary. To restore the polish, use the method described above under method of treating urine stains.

7. LUBRICATING-OIL STAINS

Lubricating oil penetrates quite readily, and if accidentally dropped on the surface of marble it should be mopped off with a cloth and covered with fuller's earth or other dry powdered material, such as hydrated lime or whiting. In some cases a layer of dry Portland cement will serve the purpose. The oil that has penetrated may usually be removed in this way if treated soon after the stain occurs. However, when the oil has remained on the marble for a considerable period of time and thoroughly oxidized it will prove very difficult to remove. Such stains can usually be removed as follows:

Method No. 1.—Cut a piece of white Canton flannel somewhat larger than the stain and saturate it in a mixture of equal parts of acetone and amyl acetate. Place this over the stain and cover with a piece of pane glass, or preferably a small slab of marble. If the stain is on a slab of marble in the wall, it will be necessary to improvise a means of supporting the cloth and its covering in place. Usually it will not be a difficult matter to arrange a prop of some kind to answer the purpose. When the cloth becomes dry, it should be again saturated and covered as at first. Old oil stains are difficult to remove and their treatment may require a great deal of patience. The solvent may spread the stain somewhat, in which case a larger cloth should be used. In covering the saturated cloth with a piece of glass the stain is driven into the marble, while if a dry slab of marble is used instead of the glass some of the oil will bedrawn into it.

Method No. 2.—A method frequently used in marble mills consists in mixing a solvent, such as benzol or gasoline, with a dry powder to form a paste which is plastered over the stain. Hydrated lime, marble dust, whiting or similar material may be used for this purpose. While this method is said to be satisfactory for such oil stains as occur around the mills, it acts slowly on old oil stains which have dried and oxidized. In the mills the marble is apt to be full of "quarry sap" or water used in the fabricating processes, and oil accidentally

dropped on the surface does not penetrate to the same degree as in thoroughly seasoned marble in buildings.

Method No. 3.—Lubricating-oil stains can be removed with more facility where the following method can be used. Place a layer of asbestos fiber about one-fourth inch thick over the stained portion, saturate it with amyl acetate, and cover with a scrap slab of marble. Place on top of the auxiliary slab a hot iron of about the temperature used for pressing fabrics. Apply more of the amyl acetate as the asbestos becomes dry and reheat the iron as often as necessary. A few layers of Canton flannel may be used instead of asbestos fiber if care is taken not to scorch the cloth. Stains from scorched cloth may be removed by the same method recommended for fire stains.

8. LINSEED-OIL STAINS

This type of stain is usually found around plumbing fixtures where putty has been used. The linseed oil from the putty may spread for some distance through the marble and produce a stain that is very difficult to remove. The oil in oxidizing forms a "resinous matter" which practically seals the pores and effectively prevents the penetration of any solvent which may be applied. Although putty has been frequently used for filling around pipes where they pass through the marble, its use for this purpose is objectionable because of the stains that are apt to occur. Grafting wax has been found to be a more desirable material for the purpose, due to the fact that it does not stain the marble and can be easily removed in case the piping has to be changed.

Experiments have been made on several treatments applied to the inside walls of openings through marble to prevent the penetration of linseed oil from putty. The only application of this kind that was found effective consisted of sodium silicate. At least two applications of the sodium silicate should be made, the first consisting of the commercial silicate diluted with twice its volume of water, and the second consisting of the undiluted silicate. This should be applied with a brush, and ample time should be allowed for each application to dry.

Method No. 1 recommended for use on lubricating-oil stains will slowly dissolve this "resinous matter" and reduce the stain, but it is not well adapted to use around plumbing fixtures. It is sometimes satisfactory to bleach the coloring matter in such stains as follows:

Method No. 1.—Cut a piece of thick white cloth or a layer of cotton batting to fit around the fixture. Saturate this with hydrogen peroxide and paste it over the stain. The bleaching action may be accelerated by moistening another cloth in ammonia water and placing this over the first. Repeat the operation as described until the discoloration is removed.

Method No. 2.—Mix together in the dry state the following: One part trisodium phosphate, 1 part sodium perborate, and 3 parts powdered talc. Make a strong soap solution in hot water and add enough of this to the dry mixture to form a thick paste. Cover the stain with the paste and leave until dry. The same material can be used over again by reducing it to a paste with some more of the soap solution. In some cases it may be found desirable to alternate this treatment with method No. 1 for lubricating-oil stains.

Method No. 3.—Combine equal parts of wood alcohol and a 10 per cent solution of trisodium phosphate. Make a paste of this mixture and asbestos fiber sufficient to cover the stain with a layer one-fourth inch thick. Place a scrap slab of marble over this and apply a hot iron as described in method No. 3 for lubricating-oil stains. A few repetitions of this process may be necessary in cases of very pronounced stains.

9. ROTTEN-WOOD STAINS

Marble setters sometimes place excelsior behind slabs of marble. Under damp conditions the excelsior will rot and finally cause a chocolate-colored stain on the marble. It seems entirely possible that wood in the framework of buildings might sometimes cause similar stains. This type of stain is readily distinguished from most other stains by its position or color, it being of a much darker color than that due to iron rust or tobacco. The best treatment found for this type of stain is that recommended for fire stains. The action may be accelerated by first scrubbing the surface thoroughly with glycerin diluted with four times its volume of water.

10. COFFEE STAINS

Coffee stains can be removed by saturating a cloth in glycerin diluted with four times its volume of water and pasting it over the stained portion. Javelle water, or the solution used on fire stains, will also prove effective.

11. IODINE STAINS

This stain will gradually disappear of its own accord within a few weeks time. It may be quickly removed by applying alcohol and covering with whiting or talcum powder. If the stain is on a vertical wall, mix the talcum to a paste with alcohol, apply some alcohol to the stain, and then cover it with the paste. One application will usually prove sufficient.

12. BARIUM SULPHIDE STAINS

This chemical and other alkaline sulphides may be present in preparations used for removing superfluous hair. When dropped on marble, it sometimes leaves a yellow stain. This may be removed

by applying a weak solution of potassium cyanide. Dissolve a teaspoonful of potassium cyanide in a glass of water, saturate a piece of cotton batting in the liquid, paste it over the stain, and leave until dry. One or two applications will usually suffice. The cyanide is very poisonous if taken into the system.

13. PERSPIRATION STAINS

Secretions from the hands or oil from the hair may produce stains on marble. The stain is brown or yellow and may be mistaken for an iron stain. The best treatment found is that recommended for fire stains. Bad stains of this kind are rather stubborn and may require several treatments.

14. GENERAL SERVICE STAINS

When the entire marblework of a building takes on a dingy or somewhat yellowish appearance, it is quite likely to be due to improper or insufficient cleaning. If certain slabs become yellow while adjacent slabs remain free from discoloration, the trouble was probably caused in the original finishing of the marble. Such discolorations are not usually hard to remove by poultice methods, or they may yield to a surface scrubbing with Javelle water. Javelle water can usually be purchased at drug stores or may be prepared as follows:

Dissolve 3 pounds of washing soda in 1 gallon of water. Mix the contents of a 12-ounce can of chlorinated lime to a paste in a shallow enameled pan by adding water slowly and mashing the lumps with a spatula or pointing trowel. Add the paste to the soda solution, make up to 2 gallons by adding water, and place in a covered stone-ware jar to settle. Pour off the clear liquid when required for use and dilute with six times its volume of clear water. Use this to wash the marble the same as a soap or other scrubbing solution is used. In using this solution it is advisable to first rinse the marble with clear water before scrubbing with Javelle water. This is a strong bleaching material, hence it should not be allowed to drip on colored fabrics. This is not recommended for general cleaning purposes, but its occasional use on stained marble is believed to be entirely safe.

Poulticing with commercial grit scrubbing powders, such as those commonly used for cleaning marble floors and described in Chapter II, will prove satisfactory for removing most stains of this class. In poulticing with these the material is slowly stirred into a pail of hot water until a thick paste of mortar consistency is obtained. A small addition of whiting will add somewhat to the working qualities of the poultice. This is applied to the marble with a trowel in a layer $\frac{1}{4}$ inch thick or more and allowed to remain until dry, when it is scraped off with a wooden paddle.

Since such discolorations are apt to cover a considerable area, it will be found more expedient to use a poultice that may be applied with a brush instead of a trowel. Method No. 3 for tobacco stains is well adapted to this purpose.

XIV. CONCLUSIONS

1. Various cleaning preparations have been studied with a view of determining the effects on marble of certain ingredients from a long period of use. The laboratory experiments, as well as an examination of actual installations of marble, have indicated that injury may result from injudicious use of harsh grits or from such salts as sodium carbonate, sodium bicarbonate, and trisodium phosphate.

2. The usual type of grit employed in trade cleaning preparations is not appreciably injurious to marble floors or other unpolished marble. Polished marble should rarely be cleaned with preparations containing a scouring agent or abrasive which is harder than the marble.

3. As a rule, the volcanic ash grits are less severe in their abrading action than crushed quartz. This is evidently due to the difference in shape of the particles.

4. While it is seldom if ever necessary to use a cleaning preparation of the scouring type on polished marble, when it is in stock for cleaning the floors of a building it is apt to be wrongly used on the polished marblework. For this reason a preparation of this type is desirable which has a grit that will not injure polished marble. Available minerals which seem to meet this requirement are soapstone and talc.

5. A trial preparation consisting of 90 per cent powdered soapstone and 10 per cent soap powder appeared to be as effective in cleaning marble floors as any of the present trade preparations. Such a composition can be used on polished marble without appreciable injury.

6. Injury which may result from the frequent use of such detergents as sodium carbonate, sodium bicarbonate, or trisodium phosphate is mainly a physical effect due to these salts crystallizing in the pores. This action has been demonstrated to be severe enough to cause disintegration of marble when such salts are employed without proper precautions.

7. Experiments have indicated that marblework may be safely cleaned with such detergents if the surface is rinsed with clear water before applying the cleaning solution.

8. Although soap has been found objectionable for use on marble in certain instances, the present study has indicated that if used with soft water it will give entirely satisfactory results and prove to be the safest detergent for general service.

9. Preparations containing a coloring ingredient of different color than the marble may gradually impart their color to the marble. This, however, may be prevented by a preliminary rinsing, as described in conclusion 6.

10. Ammonia water has been used to some extent in cleaning polished marble, but a limited number of tests in this investigation have indicated that it may cause yellow discolorations.

11. Acids dissolve marble, and even the use of such weak acids as oxalic will prove injurious. Although cleaning of interior marble with acids has been practiced to some extent it is usually done through ignorance of the real effects.

12. Stains which have penetrated the marble usually have to be removed by means of a poultice treatment. Several types of stain demand special treatment, and there is no single cure for all cases. Methods have been found for eradicating practically all of the common stains occurring on interior marble.

13. Marble may be subjected to the injurious action of salt solutions from other sources than cleaning materials. In soda-fountain counters various solutions may be splashed against the back of the vertical slab or reach it at the floor line. Marble attached to damp walls is often exposed to a similar condition due to the percolating water taking up a small amount of soluble matter from the masonry walls and slowly depositing it in the marble.

14. Experiments on treatments for the back of slabs to be installed under severe conditions, such as on damp walls, have indicated that marble may be effectively sealed by paraffin applied in the molten state and driven into the pores by heat.

15. Marble for installation under less severe conditions or where it is only occasionally exposed to the splash of salt solutions, as is usually the case in soda-fountain counters, may be satisfactorily protected by applying two or three coats of paraffin dissolved in gasoline or benzol.

16. Marble to be set adjacent to steelwork in a building should be treated with a solution of sodium citrate to prevent staining.

WASHINGTON, April 10, 1927.