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NATIONAL BUREAU OF STANDARDS REPORT

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A STUDY OF THE PROPERTIES OF THE
U.S. CAPITOL SANDSTONE

by

Arthur Hockman and D. W. Kessler

Report to the
Architect of the Capitol

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Abstract

Various physical tests were made on nine samples of Aquia Creek sandstone cored out of the exterior walls of the original portion of the U.S. Capitol. One of the purposes of the study was to determine if the sandstone had been affected by weathering to depths greater than the depths of the spalling. The physical tests were supplemented by chemical analysis on 3 specimens taken from 3 different depths of one core, and by petrographic studies on several other cores. Observations were made on a few structures also of Aquia Creek sandstone, to determine if repeated painting has contributed to the spalling of the Capitol stone.

The results of the laboratory studies indicate that much of the exterior sandstone of the Capitol is of poor quality, but the stone has not been seriously affected by weathering to depths greater than 1/2 inch. If this depth is removed by means of suitable tooling, the sandstone should be serviceable for many more years. However, it will be necessary to continue painting the stone in order to prevent further erosion of blocks of inferior quality. An alternative treatment would be to re-face the old walls with a more durable stone.

It is believed that painting has contributed, indirectly, to the spalling now seen on many blocks, but in general, it has prevented more serious weathering of the poor quality blocks.

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1. INTRODUCTION

At the request of the Architect of the Capitol, a study was made of the properties of the exterior stone (Aquia Creek sandstone) in the original portion of the United States Capitol.

Three cores of stone taken from the east side of the Capitol on August 7, 1956, were submitted to this Bureau for test. Since this group of samples did not afford enough material for all the tests desired, six additional cores were requested. Three of the additional samples were cored from the walls on the west side and three from the east side of the building. A plan drawing of the Capitol was supplied showing the approximate locations where the nine samples were cored.

The cores were approximately 2 1/4 in. in diameter and ranged in length from 6 1/2 in. to 12 in. Table 1 gives the dimensions, date of removal and approximate location of each core in the building.

Table 1. Sample Cores Tested

Core No.*	Length	Date taken	Location in Capitol
	in.		
C1	12	8/7/56	Center steps, south exposure
C2	12	8-7-56	South portico pier, east exposure
C3	11	8-7-56	South central portion, east exposure
C4	11	9-11-56	Central portion, west exposure
C5	10 1/2	9-11-56	Central portion, north exposure
C6	12	9-11-56	Central portion, west exposure
C7	9 1/2	9-11-56	Southeast portion, east exposure
C8	9 1/2	9-11-56	Southeast portion, south exposure
C9	9 1/2	9-11-56	East portion, east exposure

*The core numbers in table 1 and in the following tables correspond to the numbers supplied by the Architect's Office.

All the samples, except C7 and C8, were received in sound condition. Sample C7 was split into two pieces along its long dimension and C8 was broken into approximately 3 1/2 and 6 in.

lengths. However, parts of these broken cores were usable in many of the tests.

Seven cores were used in the flexural strength tests before they were cut into smaller test specimens for compression, absorption, specific gravity, etc. Four cores were cut into 1-in. lengths and then re-cored into smaller specimens, 1 in. in diameter in order to study the properties of the stone in relation to the distance from the weathered surface. It was necessary to reduce the size of some of the samples by recoring them to a smaller diameter (1 3/4 in.) to adapt them to the test method for sonic modulus of elasticity. The latter cores were also used for capillarity and freezing and thawing tests. (Figure 1)

In order to obtain some information on the value of paint as a preservative for Aquia Creek sandstone, studies were made on the performance of this stone in the U.S. Capitol and other old Government structures. In this connection, use was made of some studies made previously on the White House and on the old columns (now replaced) in the U.S. Treasury building.

This report presents in detail data obtained from physical, chemical and mineralogical tests, with brief descriptions of the methods and procedures. Standard procedures were followed wherever possible and references to published standards are given. Conclusions are drawn and appropriate recommendations are made wherever definite indications are obtained. A summary is included to present the main findings in brief form.

2. PHYSICAL TESTS

2.1 Compressive strength

2.1.1 Test specimens and procedure

Cores C1, C2, and C5 were cut into 1-in. sections which were re-cored into smaller cores, 1 in. in diameter for compressive strength and other determinations at various distances from the exposed surface to the back ends of the sample cores. It was not possible to make such detailed studies on all the samples, but portions of cores C3, C6, and C8 were also tested for compressive strength as shown in table 2.

The ends of the test specimens were ground until they were flat, parallel to each other, and perpendicular to the side of the cylinder.

After the specimens were dried in an oven at 105 deg C and cooled to room temperature, they were tested in a Baldwin-Southwark 75,000-lb capacity hydraulic testing machine. The load was applied at a rate of 100 lb per sq in. per sec until failure occurred. Except for the smaller size of the specimen the test method was essentially the same as the ASTM Standard C170-50, Compressive Strength of Natural Building Stone.

2.1.2 Test results

The compressive strength, C, of each specimen was calculated as follows:

$$C = \frac{W}{A}$$

where,

W = total load in lb
A = calculated area of bearing surface in sq in.

Table 2 gives the compressive strengths of the various specimens cut from sections at different distances from the painted surface as indicated. Since these test specimens were cut with their lengths parallel to the lengths of the original cores, the direction of loading was parallel to the natural bedding of the stone and therefore the values are probably somewhat less than the strength of the stone as it is loaded in the building.

Table 2. Compressive strength

Sample	Distance of specimen from painted surface in inches*								
	1	2	3	4	5	6	7	8	9
	psi	psi	psi	psi	psi	psi	psi	psi	psi
C1	10,300	10,700	10,700	11,400	10,400	10,200	10,100	9,400	9,500
C2	3,400	2,500	3,000	3,600	3,000	3,000	---	---	---
C3	---	---	---	4,900	6,100	6,600	---	---	---
C5	2,200	2,300	1,600	2,000	1,800	2,000	1,900	2,000	---
C6	---	---	---	3,000	2,900	2,800	---	---	---
C8	---	---	---	3,500	2,300	3,100	3,300	3,500	---

*The distances from the painted surface given in this and subsequent tables are approximate and represent the distance of the ends of the specimens furthest from the painted surface.

The large variation in strength values among the individual samples obtained in this test gives some information on the variation in quality of the stone. For comparison purposes, the compressive strength of one of the most widely used sandstones from Amherst, Ohio, averages 9,000 psi; whereas, the average strength value obtained for all specimens of the Capitol stone tested was 4,600 psi. This value is in the range of compressive strengths for high quality concrete.

There is little indication in the strength tests that the stone near the painted surface is weathered more than that 8 or 9 in. back from this surface.

2.2 Flexural strength

2.2.1 Test specimens and procedure

Flexural strength tests were made on seven of the nine cores submitted. These tests were made on the original sample cores before they were cut up for the other tests, such as compression, absorption, etc. Two tests were made on each of cores C2 and C3 by loading them off-center on short spans, as shown in figure 2. In this manner flexural strength values were obtained at various distances from the painted surface, the closest being 3 in. and the furthest 8 in., as indicated in table 3.

After the specimens were dried for 24 hr at 105 deg C and cooled to room temperature, they were tested in a Baldwin-Southwark 60,000-lb capacity hydraulic testing machine. The cylindrical specimen was laid on supporting knife edges with the bedding of the stone perpendicular to the direction of loading. The load was applied at approximately 1000 lb per min until failure occurred. A similar test method is described in ASTM Standard C99-52, Modulus of Rupture of Natural Building Stone.

2.2.2 Test results

The modulus of rupture, R, in lb per sq in. of each specimen was calculated as follows:

$$R = \frac{8WL}{d^3}$$

where,

W = breaking load in lb
L = length of span in in.
d = diameter of the specimen in in.

Table 3 gives the flexural strengths (modulus of rupture) of the seven samples tested.

Table 3. Flexural strength

Sample No.	Span	Distance of fracture from painted end	Modulus of rupture
	in.	in.	psi
C1	10	5	1,900
C2	9	4	1,150
C2	6.5	8	940
C3	6	3	1,890
C3	5.5	6	1,800
C4	9	5	360
C6	10	5	340
C8	6	3	830
C9	5.5	3	1,800

The flexural strength values were rather low when compared with those of most sandstones. For the two cores, C2 and C3, which were broken at different distances from the painted surface, the results for greater depths were lower than those closer to the weathered face. Such results may be attributed to natural variations in the stone. It is also possible that the stone was originally laid with the better faces of blocks exposed to the weather.

2.3 Shearing strength

2.3.1 Test specimens and procedure

Because of the relatively large size of the specimen required for this test and the scarcity of sample material, only one core (two specimens) was tested for this property.

The specimens were rectangular bars, 5 in. long, 1.6 in. wide and 1/4 in. deep (figure 1-B). After the specimens were dried in an oven at 105 deg C for 24 hr and cooled to room temperature, they were tested in a Baldwin-Southwark 60,000-lb capacity hydraulic testing machine with the aid of the modified Johnson shear tool. This method is described in ASTM Standard C102-36, Shear Testing of Natural Building Stone.

2.3.2 Test results

The shearing strength, S, in lb per sq in. was computed by the formula:

$$S = \frac{W}{2A}$$

where,

W = maximum load in lb indicated by the testing machine

A = area in sq in. of the center section of the specimen

Table 4 gives the shearing strengths in psi of the two specimens tested:

Table 4. Shearing strength

Sample No.	Location in core	Shearing strength
		psi
C4-1	5 in. from painted end	436
C4-2	10 in. from painted end	460

A knowledge of the shearing strength of the stone may be of value in the event that metal anchors are used in facing the stone with a veneer.

2.4 Abrasive hardness

2.4.1 Test specimens and procedure

This property was determined on cores Nos. 5 and 9, using the standard method for testing the abrasive hardness of stone as developed at the National Bureau of Standards. This method usually employs a 2-by 2- by 1-in. rectangular specimen. However, because of the cylindrical shape of the

sample cores, test specimens were prepared in the form of disks, 2 1/8 in. in diameter and 1 in. thick (figure 1-C). These were cemented to 2- by 2- by 1/2-in. wooden blocks in order to adapt them to the testing machine.

In this test, the stone specimens are held on a revolving cast iron disk under a constant pressure of 2 kg (4.4 lb) and made to revolve for 5 min at half the speed of the grinding disk. The abrasive is artificial corundum No. 60, which is fed to the disk at a constant rate. The amount of wear is determined by weighing the oven-dried specimens before and after the test.

This method is described in detail in ASTM Standard C241-51, Abrasion Resistance of Stone Subjected to Foot Traffic.

2.4.2 Test results

The abrasive hardness values, (H_a), were computed by the formula:

$$H_a = \frac{10\ (W_s + 2{,}000)\ G}{2{,}000\ W_a}$$

where,

W_s = the original weight of the specimen
G = bulk specific gravity
W_a = loss of weight in grams

Table 5 gives the abrasive hardness values (H_a) of several specimens cut at various distances from the painted surface of each of the two samples tested.

Table 5. Abrasive hardness

Sample No.	Distance of specimen from painted surface, in. 1	2	3	4	5	6	7	8
	H_a	H_a	H_a	H_a	H_a	H_a	H_a	H_a
C5	1.3	1.4	1.4	1.2	1.2	1.3	1.2	1.2
C9	6.9	6.9	7.2	7.1	6.6	---	---	---

The results obtained on sample C5 indicate a very low resistance to abrasion, whereas, the results obtained on sample C9 are equal to values obtained on good quality building stone. Tests made on specimens cut at different distances from the paint show no significant variations.

2.5 Toughness

2.5.1 Test specimens and procedure

This property, also referred to as impact resistance, was determined on seven of the nine sample cores submitted. The test specimens were cylinders 1 in. in diameter and 1 in. high, the same size as those used in the compression test (figure 1-A). The ends of the cylinders were ground flat and parallel.

After the specimens were dried in an oven at 105 deg C for 24 hr and cooled to room temperature they were tested on a Page impact apparatus. In this machine the specimen is mounted on a heavy cast iron base. A steel plunger with the lower end rounded rests on the specimen, and a 2 kg weight is dropped on the plunger by a motor driven sprocket chain. The height of the first drop is 1 cm and each succeeding drop is increased by 1 cm until failure occurs. Since the force of the impact is concentrated on the center of the specimen by hemispherical contact of the plunger, the specimen usually breaks in three or four approximately equal segments.

This method is described in ASTM Standard D3-18, Toughness of Rock.

2.5.2 Test results

Table 6 gives the toughness values of the specimens cut at various distances from the painted surface of each of the seven samples tested.

Table 6. Toughness

Sample No.	Distance of specimen from painted surface, in.							
	1	2	3	4	5	6	7	8
	Height of drop causing failure, cm							
C2	2	2	3	3	3	3	-	-
C3	-	-	-	5	4	5	-	-
C4	2	2	2	1	2	2	-	-
C6	-	-	-	3	2	2	-	-
C7	4	3	4	4	4	5	5	5
C8	-	-	-	2	3	3	3	-
C9	6	6	8	7	6	-	-	-

The values obtained in this test give an indication of the tenacity of the stone. Results obtained on samples C3, C7, and C9 are reasonably high for sandstone, whereas, the other values are low. There appears to be no significant change in values from the painted surface to greater depths in the core.

2.6 Absorption

2.6.1 Test specimens and procedure

This property was determined on all of the nine cores submitted. Most of the test specimens were cylinders 1 in. in diameter and 1 in. high, while the others were disks approximately 2 1/4 in. in diameter and 1 in. thick (figure 1-A,C). Specimens were cut from cores C1, C5, and C7 at one inch intervals from the exposed ends to the back. Many of the specimens used for the absorption studies were utilized later for the compressive strength and hardness tests.

The test specimens were dried in an oven at 105 deg C, and after being cooled in a desiccator to room temperature were weighed to the nearest 0.01 gm. They were then immersed in distilled water at room temperature for 48 hr, surface dried, and weighed again.

Except for the small size of the specimens, the test is the same as that described in ASTM Standard C97-47, Absorption and Bulk Specific Gravity of Natural Building Stone.

2.6.2 Test results

The percentage of absorption, by weight, of each specimen was calculated as follows:

$$\text{Absorption } (\%) = \frac{(B - A)100}{A}$$

where,

A = weight of the dried specimen
B = weight of the specimen after immersion

Table 7 gives the absorption values of the specimens cut at various distances from the painted surface of each of the nine samples tested.

Table 7. Absorption

Sample No.	Distance of specimen from painted surface, in. 1	2	3	4	5	6	7	8	9
	%	%	%	%	%	%	%	%	%
C1	5.83	5.67	5.66	5.37	5.73	5.81	5.89	5.98	6.02
C2	11.55	---	---	11.90	12.03	12.11	---	---	---
C3	---	---	---	7.23	7.48	---	---	---	---
C4	13.18	13.34	13.28	13.33	13.49	13.29	---	---	---
C5	12.50	12.58	12.56	12.67	12.55	12.59	12.34	12.50	---
C6	---	---	---	11.93	11.94	12.03	11.98	11.94	12.01
C7	11.38	11.48	11.28	11.41	11.36	11.35	11.34	11.05	---
C8	---	---	---	13.46	13.32	13.21	---	---	---
C9	8.29	8.42	8.15	8.07	8.09	---	---	---	---

The values obtained on samples C1, C3, and C9 are near the average values for sandstone but the results obtained on the remaining specimens are quite high. Tests made at different depths from the weathered surface afford no definite indication that the stone is in better condition several inches from the paint than at about 1 in. therefrom.

2.7 Bulk specific gravity

2.7.1 Test specimens and procedure

This property was determined on all nine samples submitted. The test specimens were the same 1-in. and 2 1/4-in. cylinders used in the absorption test. After drying for 24 hr at 105 deg C and cooling in a desiccator the specimens were weighed to the nearest 0.01 gm for the dry weight in air. They were then soaked in distilled water for 48 hr, surface dried and weighed for the wet weights in air, after which they were weighed suspended in water to determine their volumes.

2.7.2 Test results

The bulk specific gravity values were computed from the formula:

$$\text{Bulk specific gravity} = \frac{A}{B - C}$$

where,

A = weight of the oven-dried specimen
B = weight of the soaked and surface-dried specimen
C = weight of the soaked specimen in water

Table 8 gives the bulk density results obtained on specimens cut at various distances from the painted end of each of the nine samples tested.

Table 8. Bulk specific gravity

Sample No.	Distance of specimen from painted surface, in. 1	2	3	4	5	6	7	8	9
	gm/ml								
C1	2.090	2.091	2.089	2.090	2.075	2.072	2.065	2.062	2.056
C2	1.872	---	---	1.851	1.848	1.852	---	---	---
C3	---	---	---	2.026	2.017	---	---	---	---
C4	1.784	1.785	1.784	1.786	1.782	1.789	---	---	---
C5	1.839	1.840	1.835	1.831	1.837	1.833	1.837	1.833	---
C6	---	---	---	1.844	1.818	1.834	1.836	1.840	1.840
C7	1.863	1.848	1.856	1.852	1.853	1.860	1.856	1.862	---
C8	---	---	---	1.793	1.791	1.799	---	---	---
C9	1.989	1.988	1.996	1.999	2.000	---	---	---	---

The bulk specific gravity values obtained on all the specimens tested are somewhat low, indicating a lower unit weight for this stone as compared to that of most of the common sandstones used for building purposes. Generally, the better grade of sandstones have higher bulk specific gravities than obtained on these specimens.

2.8 True specific gravity and porosity

2.8.1 Test specimens and procedure

These properties were determined on three of the nine samples submitted. Since porosity is derived from the bulk and true specific gravity values, it was necessary first to determine the true specific gravities.

These determinations were made on 55.00 gm powdered samples by determining the volumes with Le Chatelier flasks. First, about 200 gm of fragments representative of each core were ground in a porcelain mortar until all of the 200 gm passed a No. 100 sieve. The powdered material was dried in a shallow glass dish for 24 hr at 105 deg C, and stored in a desiccator until tested.

Briefly described, the test method consists of taking an initial reading of a volume of kerosene in the Le Chatelier flask, adding the 55.00 gm of sample, removing entrapped air, followed by a final reading of the volume. Each test was made over a 24 hr period at constant temperature, the latter never varying more than 0.1 deg C between the first and last volume readings.

The difference between the first and final readings taken on the Le Chatelier flask, represents the volume of liquid displaced by the weight of sample used in the test.

2.8.2 Test results

The true specific gravity was calculated as follows:

$$\text{True specific gravity} = \frac{\text{weight of sample in gm}}{\text{displaced volume in ml}}$$

Porosity values, P, were computed from the bulk specific gravity and true specific gravity by the formula:

$$P = \frac{(D_a - D_b)\,100}{D_a}$$

where, D_a and D_b are respectively the true specific gravity and bulk specific gravity. This method gives the total pore space regardless of whether the pores are open or closed.

Table 9. True specific gravity and porosity

Sample No.	True specific gravity	Porosity
	gm/ml	percent
C1	2.494	16.72
C3	2.503	19.26
C5	2.547	27.92

The porosity values obtained for samples C1 and C3 are near normal for sandstone; however, the value for sample C5 is quite high.

2.9 Elasticity by sonic method

2.9.1 Test specimens and procedure

The dynamic modulus of elasticity by sonic methods was determined for six of the nine samples submitted for test. The specimens were in the form of cylinders, approximately 2 1/2 in. long and 1 3/4 in. in diameter (figure 1-D). This property was determined wherever possible on specimens taken near the painted and back ends of each core tested. The specimens were first tested in an oven-dried condition, and later four of the six samples were tested after 10 and 20 cycles of freezing and thawing.

The test procedure followed was essentially that as outlined in ASTM Standard C215-55T, Tentative Method of Test for Fundamental, Transverse, Longitudinal and Torsional Frequencies of Concrete Specimens.

2.9.2 Test results

The dynamic modulus of elasticity, E_D, using the longitudinal velocity was computed by the equation:

$$E_D = (2nl)^2 \rho$$

where,

n = longitudinal frequency
l = length of specimen in in.
ρ = weight/in.^{3}/g, g = 386 in./sec^2

Table 10 gives the modulus of elasticity values determined for samples in the original condition and after 10 and 20 cycles of freezing and thawing.

Table 10. Dynamic modulus of elasticity (longitudinal vibrations)

Specimen No.	Position of specimen in core	Original	After 10 freezings	After 20 freezings
		psi	psi	psi
C2-a	near paint	1.48×10^6	1.56×10^6	1.57×10^6
C2-b	near back	1.49	1.54	1.55
C3-a	near paint	2.54	2.81	2.77
C3-b	near back	2.30	2.60	2.56
C4-a	near paint	0.887	---	---
C4-b	near back	0.887	---	---
C6-a	near paint	1.67	1.71	1.71
C6-b	near back	1.58	1.61	1.61
C7-a*	near paint	2.25	---	---
C7-b	near middle	2.15	---	---
C7-c	near back	2.23	---	---
C8-b	near back	1.23	1.39	1.36

*Specimens C7, a,b,c, were rectangular bars 2 1/2 by 5/8 by 3/8 in. All other specimens were cylinders 2 to 3 in. in length and 1 3/4 in. in diameter.

The values of modulus of elasticity shown in table 10 are quite low and variable. The fact that the values increased slightly after 10 and 20 severe cycles of freezing and thawing is contrary to the usual findings and could not be accounted for in this case. When two specimens of the same sample were tested, one near the paint and one near the back, no significant differences were obtained.

2.10 Capillarity properties

As a further means of comparing the condition of the stone near the painted surface with the stone at depths of about 12 inches back of the weathered surface, it was decided to apply a test for capillarity properties. This test had been used in experiments on mortars and a few types of stone, and the results reported in NBS Building Materials and Structures Report No. 139, "Studies of Stone-Setting Mortars," page 22.

2.10.1 Test specimens and procedure

The specimens were 1 3/4 in. in diameter and the lengths varied from 2 to 3 inches. These were prepared by coring the original samples down to a smaller diameter, and the lengths varied because in some cases it was not possible to make them all 3 in. long.

The conditions of the tests are illustrated in figure 3, A and B. Test A determines the absorption when the specimen is standing on one end on a plastic sponge which is immersed in water nearly to the top. In test A absorption takes place entirely by capillary suction. Test B measures the absorption for the same period (one minute) when the specimen is in contact with water on bottom and sides, i.e., all faces except the top are immersed. The areas in contact with water in each case are determined for comparison with the absorption results.

2.10.2 Test results

The weights of water in grams absorbed during test B are divided by the corresponding weights absorbed during test A. These ratios are compared with the area ratios a_2/a_1 in contact with water in tests A and B. Such comparisons are believed to afford some information on the nature of the pores of the stone, i.e., whether the pores communicate and form continuous channels or whether there are numerous dead-end channels.

Table 11 gives the capillarity values obtained on two specimens of each of 4 cores.

Table 11.

Capillarity test values on 4 cores (original condition)

Specimen No.*	Test A	Test B	Absorption ratios B/A	Area ratios a_2/a_1
	gm	gm		
C2-1	4.10	22.01	5.4	7.8
C2-3	3.94	23.65	6.0	8.0
C3-1	.69	7.43	11.8	7.3
C3-3	.97	8.74	9.0	7.0
C6-1	3.14	22.49	7.2	7.8
C6-3	5.45	18.30	3.4	6.7
C8-1	.91	10.53	11.6	5.9
C8-3	2.03	16.08	7.9	7.5

*Specimen 1 of each core represents the stone near the painted surface while specimen 3 represents the stone 9 to 12 inches back of the exposed surface.

When the B/A ratios are considerably less than the corresponding a_2/a_1 ratios it is indicated that there is some retardation of the rate of absorption per unit of area in test B as compared to that in test A. The reason for such retardation is that the air in the pores of the dried specimen, which escapes through the top of the specimen in test B, has difficulty in finding its way out when absorption is taking place from the other faces. In materials that show such retardation there is apt to be more damage from frost action because the pores do not always act as continuous passages.

One specimen, C6-3 in table 11, gave such indication while all others show reasonably close agreement between the B/A and a_2/a_1 ratios. Similar indications are also shown in tables 2, 6 and 7 that sample C6 was of somewhat better quality near the weathered face that at greater distances back of that face.

2.11 Effects of freezing and thawing

These tests were made to determine if specimens taken near the painted surface would show more deterioration in this test than specimens at greater distances from that face. This was done as another means of determining whether the surface stone has undergone more severe deterioration in the building than that at considerable depth.

2.11.1 Test specimens and procedure

The specimens were the same as those used in the capillarity tests reported in table 11.

The freezing procedure consisted of soaking the specimens for 48 hours, then placing them in trays containing about 1 in. of water in the freezing chamber. The freezing temperature was -10 deg C and the specimens were left in the chamber until the water was entirely frozen. Thawing was done slowly by removing the trays from the freezing chamber and standing them in the room at about 23 deg C until the ice was entirely melted. This is a severe test, and the specimens were subjected to 20 cycles.

2.11.2 Test results

Since a limited number of freezings does not, ordinarily, produce visible deterioration, the changes in capillarity, sonic elasticity, absorption, and bulk specific gravity were used as criteria for judging the amount of injury produced by the freezing cycles. Comparison of the results obtained on the specimens cut from near the painted surface with those obtained on specimens near the back ends of the cores gives some information on the weathering that had occurred near the surface of the building. In making this comparison, it was assumed that the stone in the Capitol 9 in. or more from the surface had not been appreciably affected by weathering and, hence, represents the stone in its fresh condition.

Table 12.

Changes in capillarity test values after freezing and thawing cycles

Specimen No.	Capillarity test values before freezing			Capillarity test values after 10 freezings			Capillarity test values after 20 freezings		
	Test A	Test B	B/A	Test A	Test B	B/A	Test A	Test B	B/A
	gm	gm		gm	gm		gm	gm	
C2-1	4.10	22.01	5.4	5.30	22.51	4.2	5.47	22.95	4.2
C2-3	3.94	23.65	6.0	4.70	24.03	5.1	4.90	24.18	4.9
C3-1	.69	7.43	11.8	.70	7.25	10.4	.82	7.69	9.4
C3-3	.97	8.74	9.0	1.03	8.61	8.4	1.18	8.91	7.6
C6-1	3.14	22.49	7.2	4.28	22.36	5.2	4.86	22.18	4.6
C6-4	5.45	18.30	3.4	6.30	18.12	2.9	6.65	18.13	2.7
C8-1	.91	10.53	11.6	1.10	10.80	9.8	1.49	11.44	7.7
C8-3	2.03	16.08	7.9	2.90	15.62	5.4	3.12	16.50	5.3

Table 13. Calculated percentage changes in capillarity test values after 20 freezing and thawing cycles

Specimen No.	Changes in Test A values	Changes in Test B values	Changes in B/A ratios
	percent	percent	percent
C2-1	+33.4	+4.3	-22.2
C2-3	+24.4	+2.0	-18.3
C3-1	+18.9	+3.5	-20.4
C3-3	+21.7	+1.9	-15.6
C6-1	+54.8	-1.4	-36.1
C6-4	+22.0	- .1	-20.6
C8-1	+63.8	+8.6	-33.6
C8-3	+53.8	+2.6	-33.0

Table 14. Changes in absorption and bulk specific gravity (G) after freezing and thawing cycles

Specimen No.	Test values before freezing cycles		Test values after 10 freezing cycles		Test values after 20 freezing cycles	
	Absorption	G	Absorption	G	Absorption	G
	percent		percent		percent	
C2-1	12.20	1.842	11.67	1.839	12.04	1.837
C2-3	11.88	1.840	12.04	1.839	12.03	1.838
C3-1	6.65	2.037	6.90	2.033	6.92	2.034
C3-3	7.05	2.022	7.32	2.022	7.28	2.022
C6-1	11.20	1.853	11.10	1.848	11.13	1.848
C6-4	11.53	1.849	11.29	1.848	11.36	1.846
C8-1	12.65	1.795	12.98	1.791	12.90	1.793
C8-3	12.80	1.793	13.17	1.791	13.06	1.790

Table 15. Percentage changes in absorption and volume after freezing and thawing cycles

Specimen No.	Changes in absorption after		Volume increases after	
	10 freezings	20 freezings	10 freezings	20 freezings
	percent	percent	percent	percent
C2-1	-4.3	-1.3	0.16	0.27
C2-3	+1.3	+1.3	.05	.11
C3-1	+3.8	+4.1	.20	.15
C3-3	+3.8	-3.3	.00	.00
C6-1	+1.0	- .6	.27	.27
C6-4	+2.1	-1.5	.05	.16
C8-1	+2.6	+2.0	.22	.17
C8-3	+2.9	+2.0	.11	.05

The results in tables 12 and 13 show that the test A values changed considerably faster due to freezing than the test B values. This resulted in the B/A ratios becoming smaller. All of the B/A ratios changed less for cores cut furthest from the painted surface than for those cut adjacent thereto. Changes in absorption during the freezing test were small and erratic. Volume changes as indicated by bulk specific gravity determinations indicated that appreciably greater swelling occurred for specimens cut next to the painted surface than those from considerable depth within the stone (tables 14 and 15).

Since none of the other physical tests such as compression, flexure, toughness, absorption, density, etc. show any definite progressive weathering from the painted surface to greater depths, it must be assumed that there has been no serious weathering, due to the long exposure, to depths greater than the depth of spalling.

2.12 Petrographic analysis

A petrographic examination was made on all of the nine samples submitted for test. The investigation consisted in determining:

1. Identification and relative abundance of mineral constituents present
2. Identification and relative bonding of the cementing agents holding the minerals together
3. Alteration of the minerals
4. Textural differences
5. The effect of paint on the surface of the stone

The identification of the mineral constituents was accomplished using microscopic methods and oil immersion techniques supplemented with X-ray analysis. Thin sections were made from specimens cut from core No. C1 to determine the structure and cementing agents present in the stone. Specimens approximately 1 in. square and 1/4 in. thick cut from each of the nine samples were studied under the microscope and photographed.

Background data concerning Aquia Creek sandstone was obtained from various scientific publications dealing with the geologic and mineralogic formation of the rocks from which the stone was quarried. The four most important of these publications are Bulletin IV, Virginia Geological Survey 1912, The U.S. Geological Survey's Annual Report (1893-94), Bulletin Geological Survey No. 141, 1895, and Johns Hopkins University Circular Vol. XV, 1895.

The nine samples submitted show considerable variations, both in composition and in texture. In general, the color of the specimens when observed on a fresh surface is light gray with occasional stains of brownish yellow. These stains were produced by the alteration of minerals containing iron, forming hydrous iron compounds. The variation in textures of the samples can be readily observed from the photographs of the nine specimens, magnified 10 times, representing each of the nine samples (figures 4-A, B and C). The difference in the textures of the specimens is due primarily to a difference in specimen porosity. In some specimens it appears that large voids were formed at the time of lithification of the deposit, as exemplified in figure 4-B (C-5). In other specimens many of the voids may be there as a result of leaching of soluble constituents after the sandstone had lithified as shown in figure 4-A (C-2).

The samples showed some variations in their mineral content but, in general, the constituent minerals have an average estimated value of the following in volume percent:

Quartz - - - - - - - - - - - - - - - -	45%
Feldspar - - - - - - - - - - - - - - - -	25%
Kaolin - - - - - - - - - - - - - - - -	20%
Magnetite, sphene, garnet, micaceous material and hornblende	10%

Quartz is the major constituent of the sandstone. The individual quartz grains are gray, milky or clear in color, and have an average size range of 1/16 to 1/32 in. in their longest diameter. Geometrically the grains tend to have rounded surfaces suggesting abrasion from water action. Feldspar and its major decomposition product, kaolin, with minor amounts of magnetite, sphene, micaceous materials and hornblende make up the remainder of the constituents. For the most part, the feldspars are badly altered to kaolin and, in many areas, the feldspar grains are completely decomposed. In figure 5 one can observe the decomposed feldspar areas as fine-grained birefringent portions of the photograph. Figure 6 shows the typical alteration products of the feldspar under 200 diameter magnification. The clear grains are quartz with some micaceous materials, while the darker, cloudy areas consist of the clay mineral, kaolin.

The major cementing agent holding the individual grains together appears to be a secondary silica deposited by circulating ground waters. Under the microscope the silica appears to be amorphous in character. Small amounts of hydrous iron oxide with some calcium carbonate were observed interstitially between grain boundaries. In many areas where the feldspar has been badly altered, micaceous materials are present at

the grain boundaries and possibly act as cementing agents. In general, the cementing agents may be described as poor to fair, for in some specimens the stone was so friable that it could easily be broken between the fingers. In other specimens the stone was quite firm and could not be broken easily.

The painted surface of the stone was examined carefully to determine any possible mineralogical alteration caused by the paint or volatile oils which may have penetrated the interior of the stone. Some of the specimens examined contained 11 coats of paint which had the appearance of adhering firmly to the stone. There was slight discoloration for a distance of about 1/16 in. in the stone's interior, apparently caused by the paint oil; otherwise, the stone's interior had a fresh appearance. It does not appear, from the specimens examined, that the paint had any adverse effect on the constituent minerals or the cementing agent in the stone.

2.13 Chemical analysis

Sample No. C3 was selected for a complete chemical analysis. For this purpose, three specimens, each 2 1/2 in. in diameter and 3/8 in. thick were cut from the painted surface, middle and back end of the core. Table 16 gives the results of the chemical analysis obtained for the three specimens of sample C3.*

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*The analysis was made by Lee C. Peck and Edwin G. Tomasi of the U.S. Geological Survey, Denver, Colorado.

Table 16. Chemical analysis - core C3

	Location of specimen in core		
	Near paint	Middle	Near back
	percent	percent	percent
SiO_2	83.81	84.07	84.39
Al_2O_3	8.01	7.89	7.82
Fe_2O_3	.47	.49	.48
Fe O	.12	.10	.12
Mg O	.11	.11	.11
Ca O	.14	.11	.11
Na_2 O	.10	.13	.15
K_2 O	3.13	3.12	3.16
H_2 O-	1.25	1.46	1.39
H_2 O+	1.88	1.66	1.60
T_i O_2	.50	.46	.42
CO_2	.00	.01	.00
P_2 O_5	.02	.02	.02
Mn O	.00	.00	.00

The chemical as well as the mineralogical studies reflect the nature of this stone. It is an "Arkose" sandstone formed from the talus of a decaying granite. The feldspars, in passing over to kaolin due to weathering are responsible for the light color of the stone. Being formed near tidewater, it probably never had sufficient overburden to compact the layers into dense stone.

There are no indications in either the chemical or mineralogical analyses that the stone has been injured by the paint. One interesting finding in the microscopic studies is that the sample examined showed only eleven coats of paint. The records are reported to show that the building has been painted 34 times. This may be interpreted to mean that some of the paintings did not cover the entire building.

3. STUDIES ON EFFECT OF PAINT AS A PRESERVATIVE

3.1 Observations on the Capitol Building

The Capitol shows a large amount of spalling which pits the surface to various depths, usually about 1/8 in. but sometimes 3/8 in. and more. Usually the pitting is confined to individual blocks which are probably the poorer grades of stone. Apparently all of the stone from the quarry was used as it was taken out regardless of quality, but evidence was obtained in the tests that the better faces of the blocks were turned outward to expose the ones of better appearance. A considerable number of the blocks in the building show no pitting, and these may have performed well without any paint. This last statement is based mainly on the results of observations on other uses of the same stone where it was not painted.

3.2 Observations on the White House

The following statements are based on an examination made eight years ago. The exterior stone in the White House is the same as that in the Capitol and it evidently came from the same quarry, i.e., the Government quarry located on an island in the estuary of Aquia Creek near the Potomac River. Sample cores were taken from the White House at the time of this study but all these cores were taken from the part that was said to have been exposed to the most severe part of the fire of 1814. Tests on these cores indicated that the stone was in sufficiently good condition to be kept in service. There were no replacements of stone in the restoration of the building. No pitting of the stone in the White House was found like that exhibited in the stone of the Capitol. Statements obtained indicated that the exterior had been painted every four years. However, it was found that occasional replacements of weathered blocks had been made from time to time.

3.3 Columns of the U.S. Treasury Building

The old columns of the U.S. Treasury Building were originally of Aquia Creek sandstone. These were replaced with granite columns about 42 years ago. It is recalled that the sandstone columns were deeply eroded but this erosion was confined to relatively small areas. A large part of the stone showed little weathering. These columns were not painted. It seems likely that areas of deep erosion would have developed on the Capitol stone if painting had been omitted, since so much of the stone appears to be of poor quality. A similar inference can be drawn from recent observations on the sandstone gate-posts described in section 3.6.

3.4 Old Patent Office Building

The exterior of the original portion of the old Patent Office Building was faced with Aquia Creek sandstone. The south and north walls of this portion can still be seen. The south wall shows only slight weathering but some blocks in the north wall are scaling considerably. Deep erosion as noted in the old Treasury columns was not found on this building. The sandstone on the south face has weathered less than the marble wings which were constructed at least 12 years later. No definite conclusions could be drawn from observations made on this building except that where the sandstone is of good quality it performs well without paint.

3.5 Bulfinch gatehouses

The Bulfinch gatehouses, formerly on the Capitol grounds and presently located on Constitution Avenue at 15th and at 17th Streets, are constructed of Aquia Creek sandstone. It is probable that these two buildings were never painted. Photographs were taken of them and reproduced here to illustrate the good condition of the stone (figures 7, 8 and 9). There is not much evidence of weathering except near the ground and at occasional small pits or vugs which may have been filled originally with friable, clayey material which was later removed by weathering.

3.6 Capitol gateposts

The gateposts once situated on the Capitol grounds and now located on 15th and Constitution, are examples of badly deteriorated Aquia Creek sandstone. Figures 10 and 11 illustrate this condition in two of the gateposts. Since some of the blocks in the Capitol have been shown by tests to be of inferior quality, it is likely that such blocks would have eroded very much like the gateposts if no painting had been done on the Capitol stone.

3.7 Relation of paint to spalling

The question has been raised as to whether painting could have contributed to spalling. No evidence was found in either the chemical or mineralogical studies to indicate that there had been injury to the stone due to mineral alterations near the paint. If there had been any chemical injury due to the paint it is evident that it would have occurred over the entire surface. Most of the spalls are small and thin and many blocks are not spalled.

When this stone is painted the oil penetrates at least 1/16 inch and forms a rather effective seal. This greatly reduces the absorption of rain water but in a large building it is almost certain that water can find places to enter, such as defective joints between blocks or at the tops of walls. If water is admitted at places it will spread through the walls and the paint prevents evaporation at the surface. Under such conditions there is apt to be spalling due to frost action. Cases are known where spalling of stone occurred after the stone had been coated with waterproofing materials.

No definite reasons can be given as to why the stone in the White House has resisted weathering better than that in the Capitol. The beveled blocks in the Capitol may have contributed to absorption but it seems more likely that painting of the White House has been done more thoroughly.

4. RECOMMENDATIONS

Since none of the physical tests other than freezing tests showed any significant differences between the stone near the surface and that represented by the depth of the cores, i.e., 9 to 12 inches within the stone, it must be assumed that there has been no prominent deterioration to depths greater than the depths of spalling. It is believed, therefore, that if about 1/2 inch of the stone is removed by suitable tooling that the walls would be serviceable for many years. It would be necessary to continue painting to prevent erosion of the inferior blocks. It would probably be more satisfactory to re-face the old stone with a more durable stone where it is to be left exposed to the weather.

5. SUMMARY

Physical tests made on nine samples of sandstone taken from the exterior walls of the U.S. Capitol show a large range in quality of the stone. Only three of the nine samples could be regarded as good quality stone, whereas the other six ranged from medium to poor.

An effort was made to determine if the weather has seriously affected the stone to appreciable depths. Small specimens 1 inch long were tested in order to give some data on progressive deterioration from the painted surface to the depths represented by the lengths of the sample cores. Such tests as compressive strength, toughness, abrasive resistance, absorption, specific gravity and elasticity did not reveal any consistent differences between the specimens taken near the

surface and those at considerable depths. For this reason, freezing and thawing tests were made on four samples in which one specimen from each sample was cut from the painted end of the core while the other was cut from the opposite end to represent the stone furthest from the weathered surface. Four pairs of these specimens were subjected to 20 cycles of freezing and thawing, of a severe nature, to determine if the surface material would be deteriorated more in the test than the stone 9 to 12 in. within the blocks.

As a criterion for judging the effects of the freezing cycles, absorption, density, elasticity, and capillarity tests were made before and after 10 and 20 freezing and thawing cycles. The absorption and elasticity tests indicated no consistent differences in the effects obtained on the specimens from near the surface and those from the back ends of the cores. However, the specific gravity and capillarity tests did indicate that specimens representing the first 3 inches of stone from the exposed surface were deteriorated somewhat more than those at 9 to 12 inches back. It is believed that these differences are not serious.

Chemical and mineralogical examinations indicate that the stone is an arkose sandstone which was rather poorly compacted and, hence, quite porous. Chemical alteration of the feldspars has produced considerable amounts of kaolin which, in isolated areas, is responsible for the soft spots occurring in the stone.

A study was made of the effects of painting the stone. This was done by studying the effects of weathering on the Capitol and the White House, both of which have been painted at frequent intervals, and on other old structures made of the same stone that had not been painted. The results indicate that, where a structure contains blocks of poor stone, it is better to paint at reasonable intervals in order to prevent deep erosion on the less weather-resistant parts. Since tests have proven that the stone in the Capitol ranges from poor to good, it appears that painting has been advantageous. The relatively good preservation of the stone in the White House is believed to be due to thorough painting.

Although painting helped to preserve inferior blocks of stone in the Capitol, it contributed indirectly to spalling of the surface. Over most of the surface the paint formed a seal which greatly reduced the absorption of rainwater but it also interfered with evaporation in cases where water entered the walls through defective joints between blocks. The freezing of wet stone, with the surface sealed, caused spalling of the surface.

Chemical and petrographic studies failed to show that the paint had any adverse effects on the stone or any of its constituent minerals.

The writers believe that the sandstone is sufficiently sound to justify further service if about 1/2 in. of the surface is removed by tooling. However, if this is done and the stone is to be left exposed to the weather, it would be necessary to keep it painted as has been done in the past. A preferable treatment and probably a less costly one over a period of several years would be to re-face the old walls with a more durable stone. The old stone is sufficiently sound to anchor a new facing thereto but metal anchorage should be provided.

The writers acknowledge the assistance of Alvin Van Valkenburg, Jr. of the Bureau's Mineral Products Division who made the petrographic studies described in section 2.12.

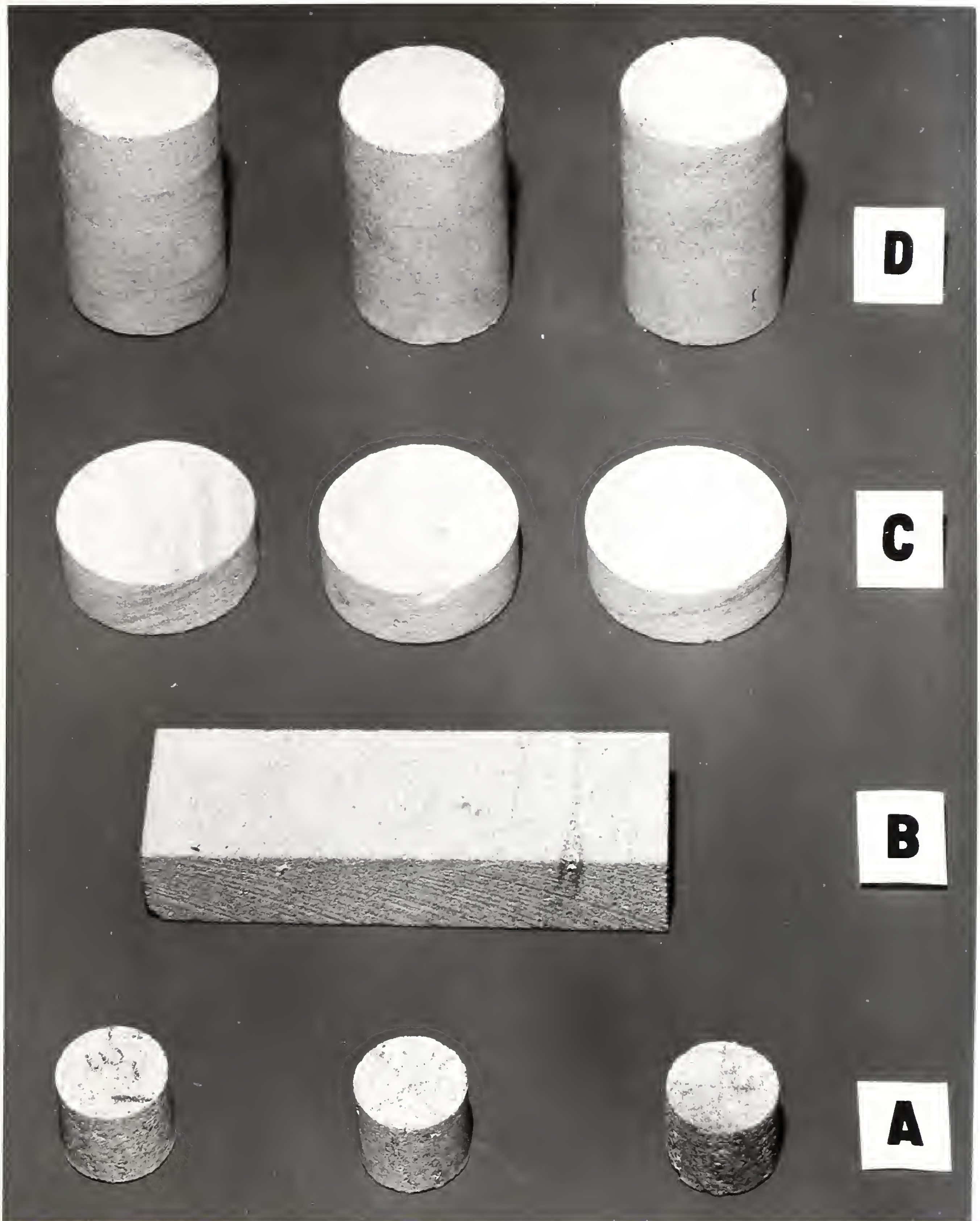

Fig. 1. Test specimens used in the determination of the physical properties of the U. S. Capitol sandstone:
(A) Compression, absorption, specific gravity, toughness.
(B) Shearing strength.
(C) Abrasive hardness, absorption, specific gravity.
(D) Elasticity, capillarity, freezing cycles.

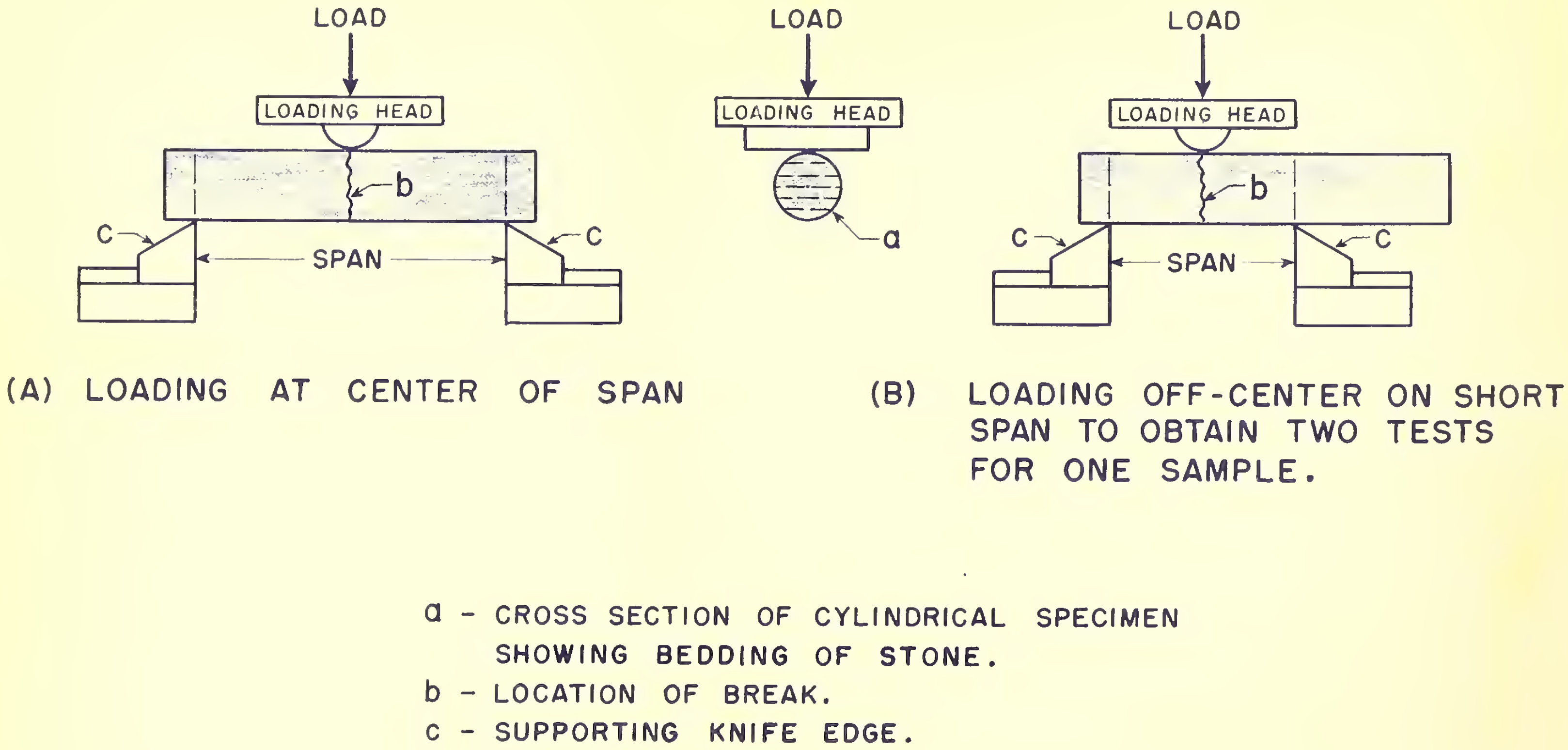

FIGURE 2. DIAGRAM SHOWING METHOD OF LOADING CYLINDRICAL TEST SPECIMENS IN FLEXURAL STRENGTH TEST.

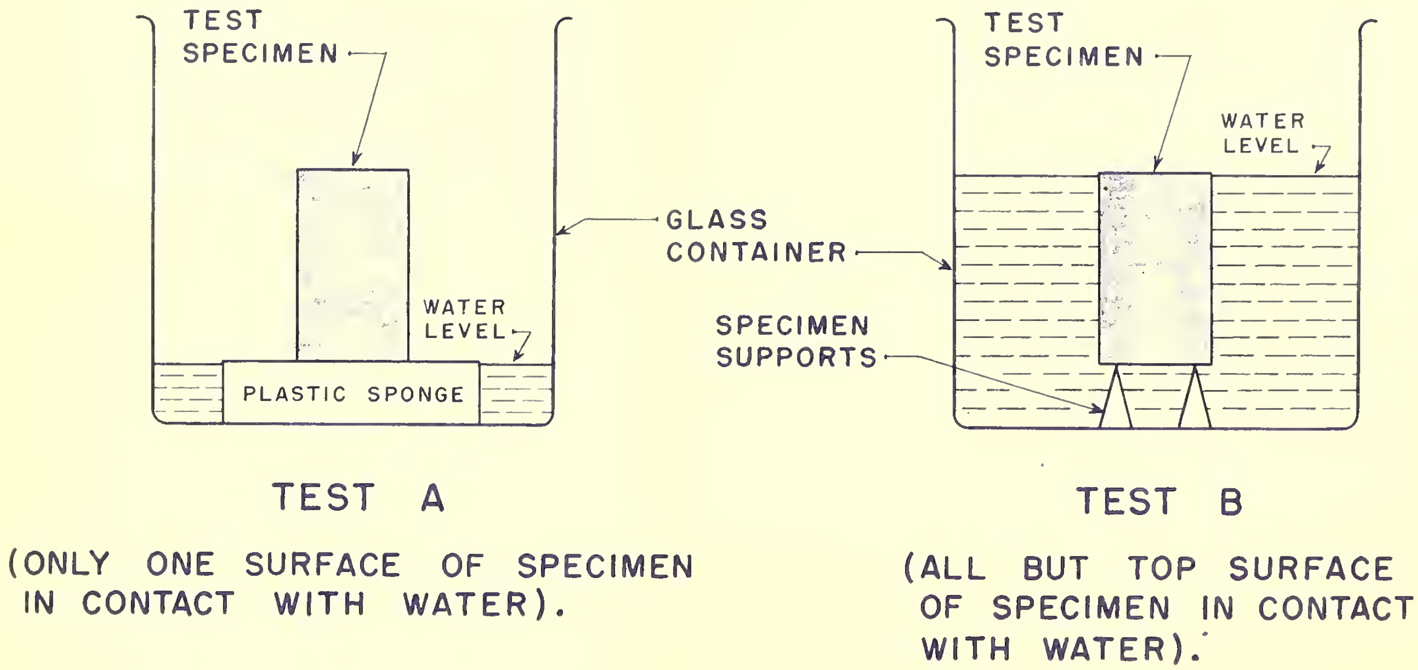

FIGURE 3. DIAGRAM SHOWING CONDITIONS OF TESTS A AND B IN THE DETERMINATION OF CAPILLARY PROPERTIES OF THE SANDSTONE SAMPLES.

C-1

C-2

C-3

Fig. 4-A. Photographs of sections of samples C-1, C-2, and C-3, showing the variation in texture of the U. S. Capitol sandstone. (magnification, 10 X)

C – 4

C – 5

C – 6

Fig. 4-B. Photographs of sections of samples C-4, C-5, and C-6, showing the variation in texture of the U. S. Capitol sandstone. (magnification, 10X)

Fig. 5. Photograph of thin section of sample C-1 showing the decomposed feldspar areas as fine-grained birefringent crystals, exemplified in the two circled areas. (magnification 10 X)

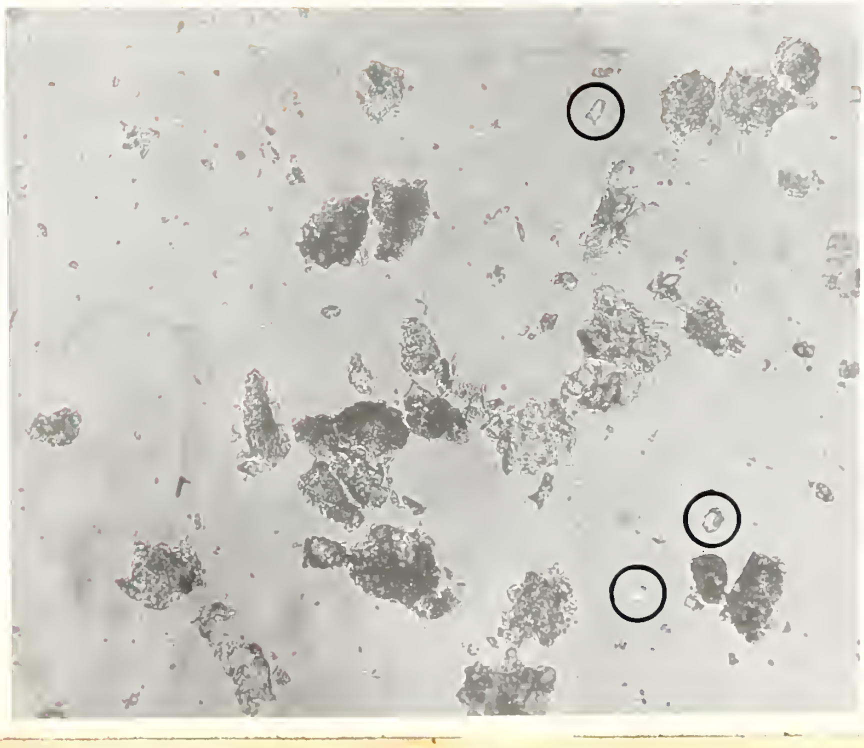

Fig. 6. Photograph of powdered specimen, representing material from samples of the Capitol sandstone, showing typical alteration products of the feldspar. Encircled clear grains are quartz; dark areas are kaolin. (magnification 200 X)

Fig. 7. View of Bulfinch gate house at Constitution Avenue and 17th Street, Washington, D. C. Photograph shows the excellent state of preservation of the unpainted Aquia Creek sandstone after about 125 years of exposure.

Fig. 8. View of Bulfinch gate house at Constitution Avenue and 15th Street, Washington, D. C. Photograph shows the excellent state of preservation of the unpainted Aquia Creek sandstone after about 125 years of exposure.

Fig. 9. Close-up view of a section of the east side of the gate house described in Fig. 8.

Fig. 10. View of gatepost at the southeast corner of Constitution Avenue and 15th Street, Washington, D. C. illustrating the advanced state of disintegration of unpainted Aquia Creek sandstone after about 125 years of exposure.

Fig. 11. View of gatepost at the southwest corner of Constitution Avenue and 15th Street, Washington, D. C. illustrating the advanced state of disintegration of unpainted Aquia Creek sandstone after about 125 years of exposure.

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