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CANADA

DEPARTMENT OF MINES AND TECHNICAL SURVEYS

OTTAWA

MINES BRANCH INVESTIGATION REPORT IR 61-104

EVALUATION OF CALIFORNIAN 'FEATHEROCK' FOR USE AS EXTERIOR WALL FACING MATERIAL

by

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MINERAL PROCESSING DIVISION

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COPY NO. 7

SEPTEMBER 1961

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W.G. Leslie[*], J.A. Soles[**] and N.G. Zoldners[***]

SUMMARY OF RESULTS

"Featherock" is a lightweight, vesicular rock of volcanic origin.

The average compressive strength of Featherock perpendicular to the banding was 561 psi, and flexural strength on the dark-coloured variety was 359 psi.

The rock has a high initial rate of absorption (IRA=67g/min/30 sq in.), but a low saturation coefficient (S_c=0.38). It has a high resistance to freezing-thawing and wetting-drying exposure.

Mortar bond tests showed excellent adherence of Featherock to mortar even after 200 cycles of freezing and thawing in saturated conditions.

Featherock is moderately reactive with alkaline solution and, therefore, could deteriorate if a high alkaline cement is used in the mortar.

The tests indicate that Featherock should withstand moderately severe climatic conditions as an exterior facing material.

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INTRODUCTION

This investigation was undertaken at the request of the Central Mortgage and Housing Corporation, Ottawa, to evaluate the suitability of "Featherock" as exterior wall facing material exposed to specific Canadian climatic conditions.

Featherock is being quarried in the Sierra Nevada mountains some 90 miles east of Yosemite Park in California. It is widely used in the U.S.A. as veneer for lightweight masonry, and in rock gardens as ornamental stone.

A Toronto firm, A.G. Reilly and Associates, is promoting in Canada this natural lightweight building stone and is seeking approval to use it in residential housing projects subject to CMHC building control.

DESCRIPTION OF SAMPLES

Featherock samples were received for study in the form of four 2 x 4 x 20 in. cut slabs, shown in Figure 1. The banded structure of this material is produced by alternating dark and light layers. Two slabs had relatively finer cellular structure and were silver grey in colour, while the other two slabs had coarse cellular structure and were dark grey to charcoal in colour.

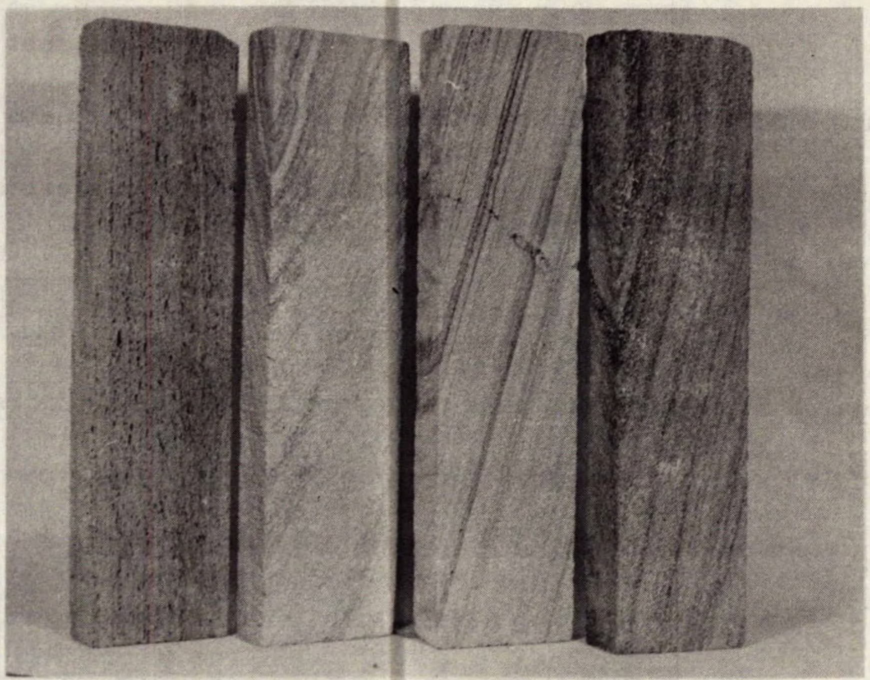

Figure 1. Featherock slabs. Note the cellular texture and distinctive banding.

PURPOSE AND SCOPE OF THE INVESTIGATION

The purpose of this investigation was to determine the suitability of Featherock for use as facing stone or veneer masonry on exterior walls of houses exposed to different weathering conditions such as wetting-drying and freezing-thawing.

Durability and volume stability of the rock, and bond strength with the mortar under changing weathering conditions are the primary requirements for good exterior veneer masonry material. The high void content, extreme lightness, and siliceous appearance of the hand specimens suggested that the following tests should be made:

(a) A petrographic study, to determine the mineralogy, structure, and texture of the rock.

(b) Flexural and compressive strength determinations.

(c) Specific gravity, absorption, and rate-of-absorption tests.

(d) Freezing-and-thawing tests on rock specimens.

(e) Wetting-and-drying tests on rock specimens.

(f) Freezing-and-thawing tests on mortar bonded rock specimens.

(g) Alkali reactivity tests.

TEST METHODS AND PROCEDURES

Standard test methods and procedures as specified by the American Society for Testing and Materials (ASTM) and by the British Standards Association were used in the course of this investigation. Other methods were used and procedures devised for tests not available in the standards.

Test specimens were examined by a petrologist to determine the mineralogical composition of the material. Photomicrographs and thin sections were prepared to study structural properties of the material.

Flexural strength of the material was tested according to the ASTM Standard Test Method C99-52, by the centre-point loading of 2 x 2 x 8 in. prism test specimens in a Tinius Olsen Super "L" testing machine. The sensitivity of this machine is 2 lb per dial division. To avoid undue crushing of material under the pressure, cardboard pieces were inserted under all knife edges. All prisms were tested perpendicularly to the rock banding.

Portions of prisms broken in flexure were cut into 2 x 2 x 2 in. cubes and tested for compression according to the ASTM Standard Test Method C170-50. The load bearing surfaces were protected by cardboard instead of capping. Cubes were tested in two directions - perpendicular and parallel to the banding.

Bulk specific gravity and the density of Featherock were determined volumetrically by weighing wax-coated oven-dry test specimens submerged in water.

To assess durability of Featherock, 2 x 1-1/2 x 16 in. test specimens were subjected to cyclic freezing and thawing, and to repeated wetting and drying. Stainless gauge points were cemented to each bar end for measuring changes of length. All bar specimens were weighed and measured in room-dry condition, then soaked in tap water for 48 hours prior to commencement of the durability tests.

Initial weight and length measurements for freezing-and-thawing test were taken on the pre-soaked bar specimens after pre-conditioning them at 40°F for 1 hour in the freeze-thaw cabinet. The test specimens were then subjected to repeated cycles of freezing in air at 0 $\pm$ 3°F and thawing in water at 40 $\pm$ 3°F, according to the ASTM Method C291-57T, eight cycles in 24 hours. Test specimens were weighed and measured for length changes once a week.

Initial "wet" measurements for wetting-and-drying test were made on the 48 hours pre-soaked bars at the room temperature. The test specimens were then placed in a drying oven at 122 $\pm$ 2°F for 44 hours and subsequently were cooled in a desiccator at room temperature for 4 hours. At this point the first cycle ended and the "dry" measurements were taken. To complete one full cycle of wetting and drying required 96 hours or 4 days according to the British Standard 1881:1952, Part 16. Cycles were repeated until no further significant length changes in "dry" measurements were observed. At the end of cycling test specimens were soaked in tap water for 4 days before taking final "wet" measurements.

A special test was used to evaluate the durability of mortar bond between water-soaked Featherock veneer and brick wall base under freezing and thawing conditions.

Six 1-1/2 x 2 x 4 in. prisms of Featherock were bonded each to a brick with a layer of mortar. Three different mortar mixtures were used. Natural sand, of a grading shown in Table 1, was used in all mortars. Other ingredients used were Portland cement, hydrated lime, and a specified mortar plasticizer (Omicron) mixed in proportions shown in Table 2.

TABLE 1

Gradation of Mortar Sand

Sieve No.	% Retained	Cum. % Retained	Cum. % Retained, ASTM C144-52T
+ 16	20	20	0 - 40
+ 30	30	50	30 - 65
+ 50	25	75	65 - 85
+ 100	15	90	85 - 98
Pan	10	100	---

TABLE 2

Proportions of Mortar Mixes

Mortar Mixes	Proportions by volume	Cement, g	Hydrated Lime, g	Sand, g	Omicron, g	Water, c.c.	Flow %
A	1:4	500	--	1830	6	310	114
B	1:4	500	--	1830	--	320	113
C	1:1:5	500	229	2287	--	450	114

Featherock samples and bricks were pre-soaked in water before bonding, to avoid absorption of moisture from the mortar. Two test specimens were prepared with each type of mortar by placing the bricks of Featherock in identical mortar beds moulded on one side-face of separate bricks. The test specimens were placed in a plastic wrap for 24 hours and then were removed from the wrap and stored in the standard fog curing room. After 3 days of moist curing, the specimens were kept in a dry-storage room at 70°F and 50% R.H. for 10 days. After this 14 day curing procedure, the specimens were hung with Featherock side down on a specially designed rack in the freezer, for exposure to freezing-and-thawing cycling.

The six test specimens were hung on two horizontally supported rods passed through the holes of the bricks, at such a level that the Featherock specimens were completely immersed in water during the thaw cycle, as shown in Figure 2. The same set-up during the freezing cycle, with water drained and test specimens turned up a little, is shown in Figure 3.

The freeze-thaw apparatus used in this study conforms to ASTM C291-57T for rapid freezing in air and thawing in water of concrete test specimens.

The potential reactivity of Featherock with alkali in cement mortars was tested according to the ASTM Chemical Method of Test C289-57T, by digesting a -50 + 100 mesh crushed sample in 1.00N NaOH solution and analyzing the filtrate for SiO_2 content and reduction in alkalinity.

Table 3 shows the number and size of specimens tested, the tests conducted, and the related specifications.

Figure 2. Mortar bond specimens positioned in the freeze-thaw cabinet during the thawing cycle.

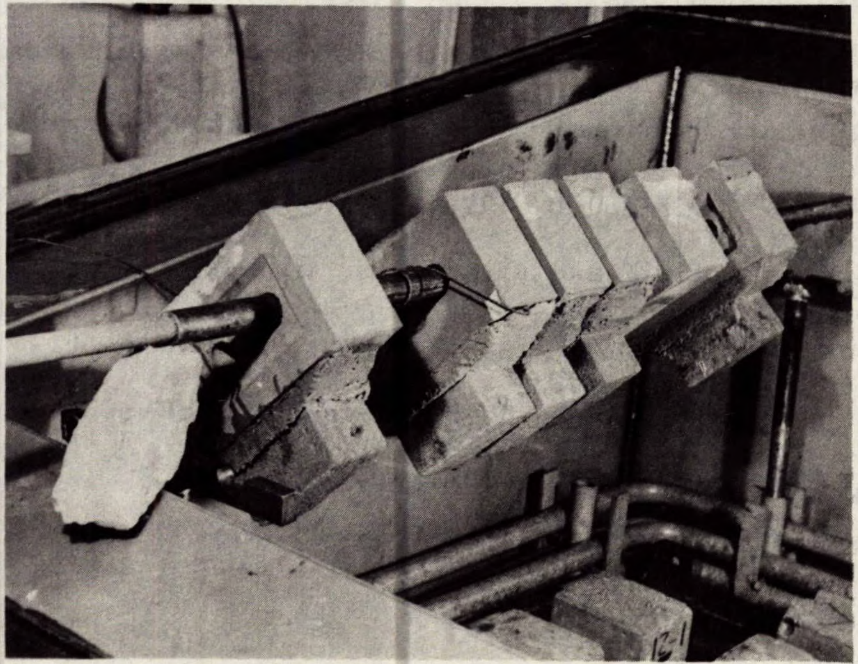

Figure 3. Mortar bond specimens (turned upward) during freezing cycle. Note specimens of Featherock bonded to bricks.

TABLE 3

Test Specimen Sizes and Tests Performed

Number of Specimens	Dimensions of Specimens	Type of Test	Specification ASTM
6	2 x 2 x 8 in.	Flexural strength	C99-52
12	2 x 2 x 2 in.	Compressive strength	C170-50
3	2 x 2 x 3 in.	Per cent absorption	C97-47
2	--	Init. rate of absorption	C67-57
3	1 1/4 x 1 1/4 x 4 in.	Rate of absorption and drying	C67-57
4	50 g ground	True specific gravity	C135-47
3	2 x 1 1/2 x 16 in.	Freezing and thawing	C291-57T
3	--	Wetting and Drying	Brit. Std. 1881:1952
6	2 x 1 1/2 x 4 in.	Mortar bond test	Orig. method
1	400 g crushed	Alkali reactivity	C289-57T

RESULTS AND DISCUSSION

Petrography of Featherock

The samples consisted of highly vesicular, glassy material similar to some natural scorias or volcanic glasses. Even to irregular banding, indicating change of composition or density, is pronounced.

A thin section revealed that the material is predominantly glass, containing a few small fragments of unidentified crystalline material and minute, prismatic inclusions or voids (Figures 4, 5). The latter are oriented parallel to the borders of vesicles, suggesting that the glass was mobile prior to freezing. The rock is a scoriaceous volcanic glass.

Flexural and Compressive Strength

Flexural and compressive strength test results are compiled in Table 4, showing computed averages for the light coloured rock.

Test results show that Featherock of the light coloured variety has only 70% of the strength in flexure and 67% of the strength in compression (parallel to banding) of the dark variety. The light variety was stronger in compression parallel to banding but the dark rock was stronger perpendicular to banding; it was about twice as strong as similarly oriented light coloured Featherock.

The ratio of flexural versus compressive strength of this material is highly significant.

Test results from Table 4 show that the light coloured Featherock had an average compressive strength of 267 psi and flexural strength of 233 psi. The strength of the darker material was 561 psi and 368 psi, respectively. The ratio of flexural to compressive strength in these two cases was 0.87 and 0.65.

TABLE 4

Flexural and Compressive Strength Test Results

2 x 2 x 9 in. Beams			2 x 2 x 2 in. Cube Test Specimens				
Beam Test No.	Rock Colour Shade	Flexural Strength, psi	Cube Test No.	Rock Colour Shade	Direction of Load ⊥ or ∥	Compressive Strength, psi Individual	Average
1	Light	233	1-a	Light	⊥	256	)
			1-b	Light	⊥	279	) 267
2	Light	239	2-a	Light	∥	285	)
			2-b	Light	∥	288	)
							) 309
3	Light	286	3-a	Light	∥	352	)
	Average	253	3-b	Light	∥	313	)
4	Dark	351)	4-a	Dark	⊥	507	)
		) 368	4-b	Dark	⊥	584	) 561
5	Dark	386)	5-a	Dark	⊥	636	)
			5-b	Dark	⊥	516	)
6	Dark	342	6-a	Dark	∥	416	)
							) 400
	Average	359	6-b	Dark	∥	384	)

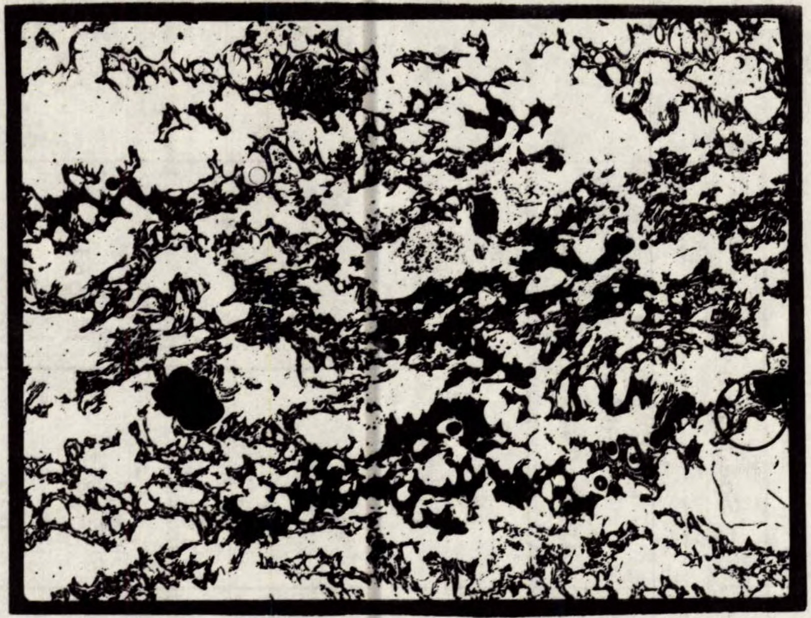

Figure 4. Photomicrograph of section of Featherock, showing glass (shards) and porous structure. The darker glass is part of a dark band traversing the specimens; here, minute inclusions are more abundant. Magnification 6X.

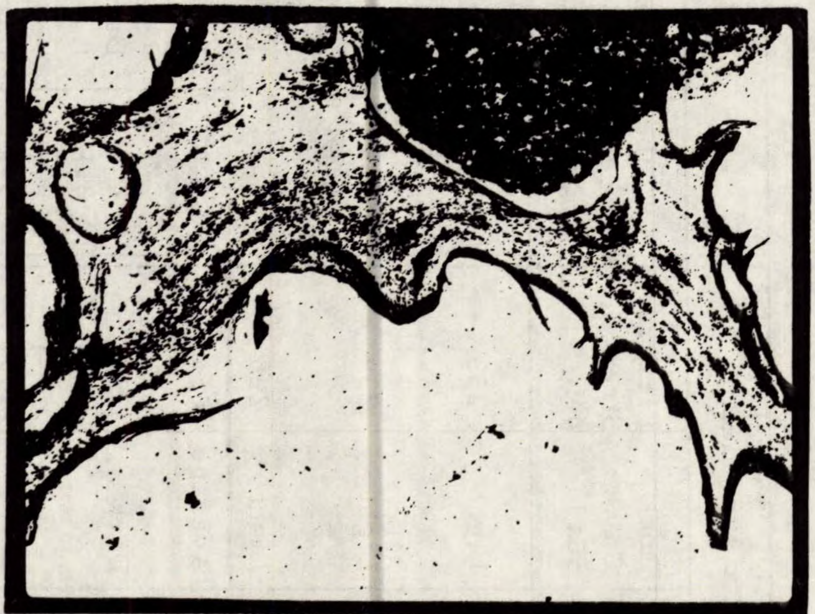

Figure 5. Circled section in Figure 4. Note streaming of minute inclusions parallel to boundaries of enclosing glass. Magnification 60X.

For manufactured autoclaved cellular concretes made by various processes this ratio for corresponding compressive strengths as shown by Graf[1] is 0.64 and 0.43.

Strength ratios for commercial cement-silica autoclaved cellular concrete, according to information compiled by Valore[2], ranges from 0.2 to 0.33, about one third of the values obtained in the tests on Featherock.

The surprisingly high flexural strength ratios of the Featherock material could be attributed to the higher cohesiveness of the vesicular volcanic glasses as compared with the much lower cohesiveness of the artificial cement-silica mortars. This is an important point in evaluating the structural strength of this material for use in the house building industry.

Specific Gravity, Density and Absorption

The test results of the bulk and the absolute specific gravities, density, different absorption tests and the coefficient of saturation are shown in Table 5. Each value was averaged from the results obtained on at least three test specimens selected to represent the different varieties of the Featherock.

Test results indicated that Featherock is a highly porous material, which preserves its buoyancy even after several days of submersion in tap water.

The average total porosity calculated from the values of bulk and absolute specific gravities was about 70 per cent.

Absorption after 24 hour immersion in tap water was only 20.8% by volume, or less than 1/3 of the total pore space. This is an indication that most of the pores were impermeable under normal soaking conditions, and therefore rain water would not be driven through Featherock Veneer into a wall structure it is facing.

The high initial rate of absorption (IRA) of this material requires that prior to laying, Featherock has to be soaked in water to prevent it from absorbing moisture from the mortar.

Freezing-and-Thawing Tests

The results of freezing-and-thawing tests compiled in Table 6 show that specimens gained weight by absorption up to 234 cycles. At that time one bar broke and the others started to lose weight.

After 300 cycles of freezing and thawing only slight softening of the material and surface pitting was noted on the otherwise unharmed Featherock test specimens.

Only an insignificant volume change was measured on test bars during the exposure to freezing and thawing. The average expansion after 315 cycles was 0.0023 in., or 0.015 per cent, which is a negligible amount for this type of test. Gray[3] considers a rock core expansion of 0.1% in 50 cycles, or 0.60% in 300 cycles to be excessive.

TABLE 5

Specific Gravity and Absorption Test Results on Featherock

No.	Tests Conducted on Featherock	Test Results	Standard Test Methods
1	Bulk Specific Gravity, (Oven dry basis)	0.70	Volumetric method by wax-coated specimens
2	Oven-Dry Density	45 lbs/ cu ft	
3	Absolute Specific Gravity	2.29	ASTM C135-47
4	Initial Rate of Absorption - IRA	67g per min per 30 sq in	ASTM C67-60
5	Absorption, 24 hr tap water		
	(by weight	32.1%	ASTM C67-60
	(by volume	20.8%	
6	Absorption, 5 hr boiling (by weight	83.9%	
	(by volume	54.5%	ASTM C67-60
7	Saturation Coefficient	0.38	ASTM C67-60

TABLE 6

Freezing-and-Thawing Test Measurements

Cycles	1 - F		2 - F		3 - F	
	Weight, lb.	Measure, in.	Weight, lb	Measure, in.	Weight, lb.	Measure, in.
Room-Dry	1.191	.0449	1.150	.0543	1.261	.0129
0	1.623	.0434	1.547	.0530	1.698	.0129
60	1.700	.0432	1.561	.0526	1.732	.0118
118	1.674	.0449	1.550	.0534	1.742	.0126
176	1.724	.0450	1.615	.0529	1.793	.0134
234	Broken		1.610	.0532	1.813	.0132
292	1.734	-	1.597	.0549	1.810	.0149
315	1.751	-	1.588	.0551	1.792	.0153
	+1.128	-	+0.041	+.0021	+0.092	+.0024

The good frost resistance of Featherock observed in these tests may result from its property to resist complete saturation when absorbing water. Its ratio of absorption by 24 hour submersion in boiling water (54.5% by volume) is the "saturation coefficient" of the material. It is defined generally as the ratio of easily filled to total fillable pore space. This indicates that much of the pore space is represented as cells not easily permeated by water under normal wetting conditions. Unfilled pore space relieves the water pressure developed by expansion on freezing, and provides protection to the material exposed to freezing and thawing in a saturated condition.

Wetting-and-Drying Tests

The results of wetting and drying tests are shown in Table 7.

Test results compiled in Table 7 show that after 3 cycles of wetting and drying only little differences in "dry" measurements were observed and the test was discontinued. The "dry" measurements after 3 cycles show an average linear expansion of 0.0006 in. or 0.004% over the initial wet measurements. This is a rather small expansion and would not be detrimental to the veneer masonry.

TABLE 7

Wetting-and-Drying Test Measurements

Cycles	1 - W		2 - W		3 - W	
	Weight lb.	Measure in.	Weight lb.	Measure in.	Weight lb.	Measure in.
Original Room-Dry:	0.955	0.0295	1.348	0.0423	1.280	0.0343
Initial Wet Measures:	1.303	0.0288	1.600	0.0424	1.675	0.0344
1st Cycle, Oven-Dry:	0.954	0.0296	1.345	0.0430	1.287	0.0344
2nd Cycle, Oven-Dry:	0.953	0.0293	1.346	0.0423	1.283	0.0344
3rd Cycle, Oven-Dry:	0.953	0.0292	1.346	0.0429	1.287	0.0354
Expansion, inches		0.0004		0.0005		0.0010

Mortar Bond Tests

In this special test the rock specimens were soaked in water during each thawing cycle and subsequently frozen in saturated condition. Water was not in direct contact with the mortar portion of the test specimens.

After 200 cycles of freezing and thawing the test was discontinued. All test samples still exhibited a very good bond between the mortar and the Featherock.

The Featherock-mortar sections shown in Figure 6 were obtained by cutting across two test specimens after 200 freeze-thaw cycles. These photographs reveal the depth of mortar penetration into the porous surface of Featherock, and the excellent bond with this material.

Differential freezing stresses produced on the ends of Featherock specimens nearest the cooling fan caused some pitting, visible in Figure 3. These cavities did not influence the test results.

Alkaline Reactivity

Chemical analyses of the alkaline reactivity test solutions are given in Table 8. A plot of SiO_2 digested vs reduction in alkalinity of the solutions is shown on the reactivity comparison chart of Figure 7. The plot indicates that the rock is moderately reactive, and would be classified as deleterious according to this test. Low alkali cements should therefore be used for affixing the Featherock to surfaces exposed to moisture.

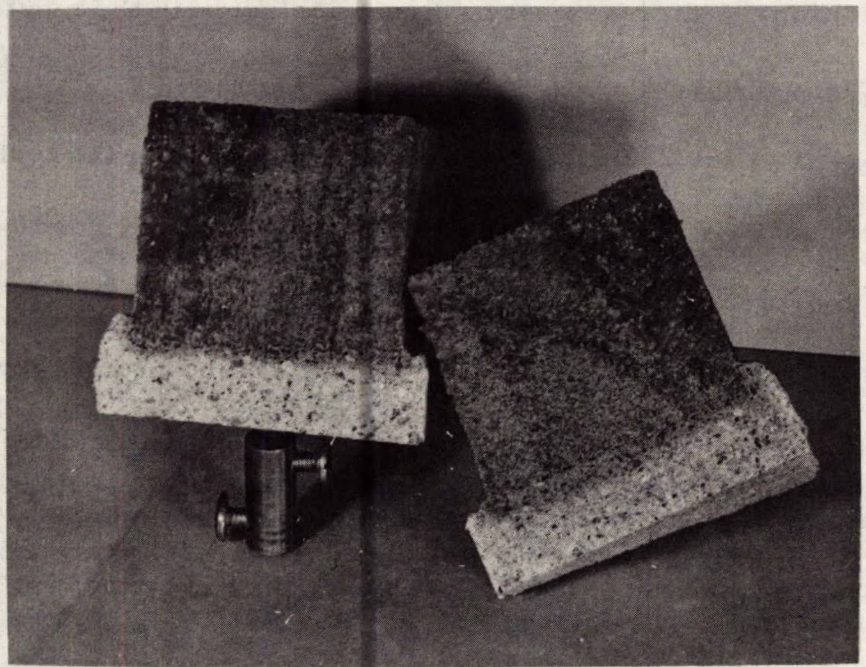

Figure 6. Featherock-mortar sections showing depth of mortar penetration into porous surface of the material.

TABLE 8

Analyses* of NaOH Solutions After Digestion of Featherock

Sample	Tot. SiO_2 mM/ml	SiO_2 from Sample (S-4)	Reduction in Alkalinity (mM/ml)
1	103	80	50.7
2	113	90	58.2
3	94	71	46.1
4 (Std)	23	-	-

* By Analytical Chemistry Section, Mineral Sciences Division.

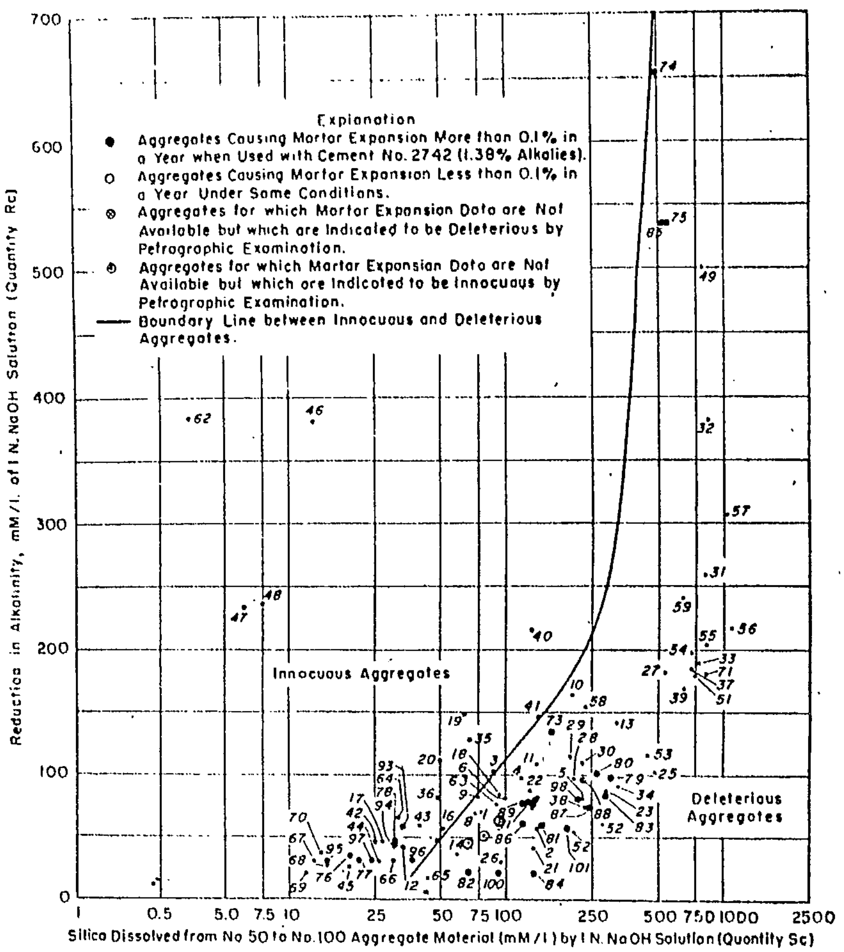

Figure 7. Illustration of Division between Innocuous and Deleterious Aggregates on Basis of Reduction in Alkalinity Test (After Mielenz and Witte)[4]

⊙ Plot of Featherock Analysis

CONCLUSIONS

1. Featherock is a lightweight, highly absorptive, naturally vesicular material with a low saturation coefficient and good durability. It resists exposures to both freezing-thawing and wetting-drying conditions.

2. Due to its high porosity Featherock is a friable material with

a remarkably high ratio of flexural to compressive strength, ranging from 0.65 to 0.87. The dark coloured variety has about twice the compressive strength of the silver grey variety, and about 40 per cent higher flexural strength.

3. Adherence of Featherock to portland cement and portland cement-lime mortars under freeze-thaw conditions was excellent. Due to its high initial rate of absorption Featherock must be pre-soaked prior to laying in mortar.

4. Featherock is moderately reactive in alkali solutions. A cement with alkali content below 1% should be specified for all mortars used with this material.

5. Featherock may be used safely as facing stone or veneer masonry on exterior walls of houses exposed to normal Canadian climatic conditions.

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