STATE OF OHIO
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGICAL SURVEY
Horace R. Collins, Chief

Report of Investigations No. 73

POTENTIAL USE OF OHIO LIMESTONES AND DOLOMITES FOR ARCHITECTURAL AGGREGATE

by

David A. Stith

Columbus

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GEOLOGY SERVES OHIO

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INTRODUCTION

Purpose and scope

In recent years the Ohio Division of Geological Survey has received a number of requests for sources of aggregate having specific colors for use in exposed-aggregate concrete. As a result of these requests an investigation was initiated to determine the requirements for aggregate used in architectural concrete and the suitability of Ohio-produced aggregates for such use. This type of aggregate is hereafter referred to as architectural aggregate and, although referring primarily to material suitable for vertical wall application, includes also material which may be used for terrazzo.

Following a literature search for the physical requirements of architectural aggregate, 20 samples were collected from selected quarries. The samples were subjected to physical tests for absorption, soundness, and hardness. The texture, color, and impurities of the samples were determined by physical and microscopic examination. The tests and specifications used in this study apply only to architectural aggregate and should not affect a decision on the aggregates involved for any other use.

Acknowledgments

The writer would like to express his appreciation to the managements of those quarries contributing samples to this study and to Mr. Arnold Morse of the Portland Cement Association, Columbus, Ohio. Thanks are also extended to Dr. Kamran Majidzadeh, Civil Engineering Department, The Ohio State University, for the use of the Department's freeze-thaw machine.

USE OF AGGREGATE IN ARCHITECTURAL SURFACES

The use of exposed-aggregate surfaces has become quite common in architectural design. These surfaces are both precast and cast in place, with the decorative aggregate either dispersed throughout the concrete or concentrated in a facing layer. Methods of achieving the surface texture include aggregate transfer (the aggregate is placed on forms coated with adhesive and the concrete poured; when the forms are removed the aggregate remains embedded in the concrete), use of chemical retarders to remove surface cement, bushhammering (dressing the surface with a tool with pyramidal points, driven by an electric hammer), sandblasting, and polishing.

The sizes and types of aggregate material used are as varied as the methods of emplacing it. The size of aggregate used in wall facings and terrazzo ranges from sand to cobbles and flagstones. Depending upon the color and textural affect desired, the aggregate used could be alluvial gravel or crushed granite, quartz, various other highly colored silicate rocks and minerals, marble, limestone, or dolomite, as well as ceramics and certain nonreactive glasses.

PHYSICAL REQUIREMENTS FOR ARCHITECTURAL AGGREGATE

General statement

Many articles concerning architectural aggregate and terrazzo use descriptive terms such as "hard" or "durable" or specify that the material have "low absorption" or "meet the specifications for high quality portland cement concrete aggregate." This practice is acceptable for properties like color and size since they are determined by the desired effect in a given job. Other properties, such as hardness and soundness, are of critical importance for all types of architectural aggregate and require some quantification.

The most important physical properties are color, hardness, absorption, soundness, particle shape and size distribution, and impurities. The following sections are the result, to a large extent, of a literature review of the requirements for architectural aggregate and terrazzo.

Color

Color is probably the most frequently stressed property of architectural aggregate since it directly affects the appearance of the exposed surface. Acceptable material should have esthetically pleasing, uniform, and relatively permanent color.

Hardness

Hardness as applied to crushed stone is a rather ambiguous term. It can refer to the stone's resistance to abrasion, to impact, to scratching, to compression, or, in general, to any physical deformation. The methods of hardness evaluation most commonly used for concrete aggregate are the Los Angeles and Deval tests, which evaluate aggregate resistance to impact and abrasion by rotation of the material in a sealed container.

Aggregate in a wall is not subject to the same degree of abrasion as aggregate in a highway and therefore hardness is not as critical in architectural aggregate as in highway aggregate. The overall strength of the concrete, however, probably should be equal to or greater than the strength of that used for roadmaking because of the difficulty in repairing large structures. It is important, therefore, to ascertain that the aggregate is not so brittle or soft that it breaks up in handling and mixing to the point that the percentage of fines increases enough to reduce the overall strength of the concrete.

The hardness test used for this study was devised by the American Society for Testing and Materials (ASTM D 1865-61T) and is designed to evaluate resistance of aggregate to wear during handling rather than after incorporation in concrete. The test differs from the Los Angeles test by not having steel balls mixed with the aggregate and from both the Los Angeles and Deval tests by abrading by impact from vertical drop rather than by continuous rotation. Although it is described as a hardness test for aggregate for built-up roofs, the 20 percent maximum loss specified for this type of aggregate by ASTM D 1863-61T should be applicable to architectural aggregate as well. A hardness loss of 50 percent by the Los Angeles test has been set as acceptable by Cutcliffe and Dunn (1967) but the writer does not necessarily imply that this is exactly equivalent to a 20 percent loss by the test used in this study. Aggregate for terrazzo should be evaluated by the Los Angeles test with a maximum allowable loss of 50 percent or even less because of the high abrasion to which such material will be subjected.

Soundness

Perhaps the most critical property of architectural aggregate is its soundness. This is an approximation of an aggregate's resistance to mechanical weathering and is evaluated by several tests involving freezing and thawing or solution and crystallization of a salt. In addition to economic and structural considerations, the different weathering conditions to which standard concrete and exposed-aggregate concrete are subjected necessitate different aggregate specifications. Aggregate in a highway is surrounded by a shell of mortar but the surface layer of aggregate in an architectural panel is exposed to the elements. Each particle in such panels may have as much as one-half of its surface area exposed and is thus subjected directly to both wet-dry and warm-cold cycling. Consequently, the soundness specifications for architectural aggregate should be higher than those for standard concrete aggregate.

Soundness can be evaluated in a number of ways: by repeated soaking in Na_2SO_4 or $MgSO_4$ solution and drying in air; by slow or rapid freezing and thawing in air, water, or brine; by observation of the weathering characteristics of natural and manmade outcrops; and by study of the past performance record of an aggregate. Cutcliffe and Dunn (1967) have suggested limits of 10 percent loss in 10-cycle $MgSO_4$ testing and 3 percent loss in 25 cycles of freezing and thawing in brine. The present study used limits in a similar range in comparable tests: 5 percent loss in 5 cycles of Na_2SO_4 testing and 3 percent loss in 50 cycles of rapid freezing and thawing in water.

One of the factors influencing soundness is water absorption. It is rather difficult to assess the effects of absorption alone on the performance of an aggregate and no specific limits have been set for architectural aggregate. In general, the absorption should be low since high absorption promotes weathering and staining. Research in Great Britain has indicated that aggregate with greater than 1.5 percent absorption was generally less sound than aggregate with less than 1.5 percent absorption (Shergold, 1954). Other work (Lewis and others, 1953; Verbeck and Landgren, 1960; and Yedlosky and Dean, 1961) has shown that the size of the average pore space and the percentage of saturation have an influence as great as or greater than absorption on the soundness of aggregate. Rocks with submicroscopic or capillary pores would be more susceptible to weathering than rocks with higher total absorption but with coarser pores through which the water could migrate. Also, rocks that easily become completely saturated on exposure to the elements would tend to be less sound than those which become only 90 to 95 percent saturated or less.

Particle shape and size distribution

The shape and size of the aggregate particles are, to a large degree, not as critical as some of the other properties. The shape should be roughly equidimensional; an excess of thin, flat, or platy particles should be avoided. Each particle should be fairly rough and angular to promote adherence of the cement. Foremost consideration of size is the avoidance of an excess of dust and fine particles which lower the strength of the concrete. Usable sizes range from sand to cobble as well as flagstone but are usually restricted to one or two narrow ranges. When a wider range of sizes is employed, the distribution should be fairly uniform rather than concentrated at one point of the range (Kessler, Hockman, and Anderson, 1943). If very coarse aggregate is used, sand-sized particles, of either an appropriately colored aggregate or normal quartz, should be included in the blend to assure adequate concrete strength.

Impurities

Finally, the aggregate should be free from any impurities that could damage either the appearance or the strength of the concrete. Shale, clay, pyrite, chert, gypsum, iron minerals, bituminous material, or any other reactive material present in amounts greater than 1 percent is considered excessive and disqualifies the aggregate.

PROCEDURE

Quarry selection

A list was compiled of all limestone and dolomite units from which aggregate is produced in Ohio (Ohio Department of Industrial Relations, 1967). Quarries were then selected to provide samples of as many of these units (appendix, table B) and to have as wide a geographic coverage of the State as feasible (fig. 1). Field examination of the selected quarries resulted in the collection of 18 carbonate samples representing 3 stratigraphic units from eastern Ohio and 12 units from western Ohio. Some samples were composed of material from a single unit and others of material from two or more units, depending on the method of quarrying. Two silica samples, a conglomerate and a sandstone, were collected for comparison with the carbonates (appendix, tables A, B).

Sample collection

Stockpiles were sampled at all selected quarries for gross samples ranging from 50 to 100 pounds, depending on maximum particle size. Where available, ASTM aggregate sizes #4 (¾ to 1½ inches) or #467 (3/16 to 1½ inches) were sampled in order to obtain the maximum amount of aggregate of the sizes (between ⅜ and 1½ inches) required for the projected tests with the minimum amount of laboratory crushing and waste.

FIGURE 1.—Locations of quarries from which samples were obtained.

Sample preparation

Each gross sample was reduced by splitting to a laboratory sample of 18 to 26 pounds. Material greater than 1½ inches was removed, crushed to minus 1½ inches, and returned to the laboratory samples which were then sieved on 1-, ¾-, ½-, and ⅜-inch sieves. Samples for the physical tests were prepared from the different size fractions of each laboratory sample.

Physical tests

Hardness test.—To provide a measure of the handling hardness of the samples, ASTM D 1865-61T, "Hardness of Mineral Aggregate for Use on Built-Up Roofs," was modified as follows: the diameter of the test pipe was increased from 2 to 4 inches; the sample used was 500 grams of ½- to ¾-inch aggregate instead of 225 grams of ¼- to ⅜-inch aggregate; the test sieve used was a ¼-inch instead of a #6 sieve.

The apparatus consisted of a pipe, 4 feet long by 4 inches in diameter, mounted to permit 360-degree rotation about an axis perpendicular to the length. The ends of the pipe were covered by removable threaded caps. Each sample was placed in the pipe and rotated for 200 revolutions (400 half-turns). The pipe was stopped in a vertical position at each half-turn to allow the sample to drop cleanly to the other end of the pipe. At the end of the test the sample was sieved on ½- and ¼-inch sieves. Loss was determined by subtracting the amount retained above the ¼-inch sieve from the original weight.

Absorption test.—Absorption testing was performed according to ASTM C 127-59. The test samples, each consisting of approximately five kilograms, were washed, dried at 100° to 110°C, and weighed. Each sample was soaked in water for 24 hours, then dried on towels in such a manner that only the particle surfaces were dry and evaporation was held to a minimum. The saturated, surface-dry weights were obtained and then each sample was dried to constant weight and the absorption calculated from the saturated and second dry weights. The second dry weight was used because some of the samples contained shale which slaked during soaking.

Na_2SO_4 soundness test.—Soundness testing followed the procedures outlined in ASTM C 88-61T. A saturated solution was prepared from sufficient anhydrous Na_2SO_4 to maintain an excess of crystals. This solution was kept at 20° to 22°C during testing. Each sample consisted of two size ranges of particles, where sufficient material was present in each size fraction. The coarse sample contained approximately 1,000 grams of 1- to 1½-inch aggregate and 500 grams of ¾- to 1-inch aggregate and the fine sample was composed of approximately 670 grams of ½- to ¾-inch aggregate and 330 grams of ⅜- to ½-inch aggregate. The samples were washed free of dust, dried, weighed, and immersed in the solution for 16 to 18 hours. After soaking, the samples were drained for 15 minutes and oven dried at 100° to 110°C. The cycle of soaking, draining, and drying was performed five times for each sample. At the completion of the fifth cycle the samples were washed free of sulfate (determined by test with $BaCl_2$), dried, and sieved. The coarse sample was sieved on a ⅝-inch sieve and the fine on a 5/16-inch sieve. Loss was determined by subtracting the amount retained on the test sieve from the original sample weight.

Freeze-thaw soundness test.—The freeze-thaw procedure was devised by the writer and patterned after tests outlined by Cutcliffe and Dunn (1967) and Huang (1959). The samples were composed of approximately 1,000 grams of 1- to 1½-inch aggregate and 500 grams of ¾- to 1-inch aggregate in the coarse size and approximately 200 grams of ½- to ¾-inch aggregate and 100 grams of ⅜- to ½-inch aggregate in the fine size. The samples were washed free of dust, dried at 100° to 110°C, and weighed. They were then placed in copper pans, covered with approximately ⅛ inch of water, and placed in the freeze-thaw machine.

A Logan (or Utah) freeze-thaw machine was used for this test. It consisted of a chest-type insulated container with a horizontal freezer plate. The copper pans were placed on the freezer plate, separated from each other by electric strip heaters. A felt pad saturated with water was placed between the sample pans and the freezer plate for increased conductivity.

Both cycle control and temperature recording were automatic. The cycle controls were set for limits of 0° and 40°F and the temperature was recorded continually against time on a seven-day recording thermometer. A dummy sample of limestone aggregate contained separate thermocouples for cycle control and recording thermometer. Each set of samples was tested for 50 cycles. The cycles varied slightly from 4 to 4½ hours and temperature ranged from 1° to 4°F minimum and 42° to 44°F maximum. However, cycle time and temperature limits stayed fairly constant for each run and changed only when the machine was turned off and on.

At the end of 50 cycles the samples were dried at 100° to 110°C, sieved over the original base sieve (¾- or ⅜-inch), and weighed. The loss was determined by subtraction of the tested sieve weight from the original weight.

Munsell color determination.—Color was determined by separating the five-kilogram absorption samples into distinct color groups and comparing these groups with the 1954 Munsell soil color charts.

RESULTS

Hardness

Only three samples failed the hardness test and two of these could be considered marginal (appendix, table C). The Berea Sandstone (2041) had a substantial loss of 51.8 percent while the two Cedarville Dolomite samples (2028 and 2043B) had losses of 20.7 percent and 22.2 percent. All of the remaining samples were well below the suggested maximum 20 percent loss.

Absorption

Absorption results on carbonate samples ranged from 0.5 to 3.0 percent (appendix, table C). The Sharon Conglomerate pebbles (2040) were understandably low at 0.4 percent as was the Berea Sandstone (2041) high at 5.9 percent. Of the 20 samples tested, 6 had absorption of less than 1.5 percent. The absorption results will be compared with the soundness results in the following two paragraphs.

Na_2SO_4 soundness

Ten samples failed the Na_2SO_4 soundness test but three of these could be considered marginal (appendix, table C). Correlation of the soundness results with the absorption data is fair (table 1). Four of the samples with less than 1.5 percent absorption had acceptable soundness losses and the remaining two were marginal. Six of the samples with greater than 1.5 percent absorption passed, and eight failed, although one was marginal. However, of the six passing samples with greater than 1.5 percent absorption, five were dolomites exhibiting macroporosity: Cedarville Dolomite (2028 and 2043B), Guelph Dolomite (2032), and undifferentiated Niagaran dolomite (2034 and 2044). The remaining sample was a dolomite with normal intergranular porosity: Dundee Formation-Detroit River Group (2031). It appears that the average pore size in the coarse dolomites was large enough that crystallization (or freezing) did not disrupt the stone as it did in rocks with normal porosity or microporosity. This coincides with the data of Verbeck and Landgren (1960) and Yedlosky and Dean (1961). The relationship of the Na_2SO_4 soundness and absorption of the 15 samples with normal porosity or microporosity agreed fairly well with the work of Shergold (1954).

TABLE 1.—*Correlation of absorption and Na_2SO_4 soundness results*

	Absorption < 1.5 percent		Absorption ≥ 1.5 percent	
	Passed Na_2SO_4	Failed Na_2SO_4	Passed Na_2SO_4	Failed Na_2SO_4
Coarsely porous dolomites	0	0	5	0
Quartz, sandstone, and dense to slightly porous carbonates	4	2 (both marginal)	1	8 (1 marginal)

Freeze-thaw soundness

Only four samples failed the freeze-thaw soundness test but one other, at 2.9 percent, was just below the failing mark of 3 percent (appendix, table C). The same five samples either failed or were marginal in the Na_2SO_4 soundness test. Poor correlation was found between the freeze-thaw and absorption results (table 2). All four samples that failed the freeze-thaw test had greater than 1.5 percent absorption but the Brassfield Formation (2042), with 2.9 percent loss, was well below 1.5 percent absorption.

TABLE 2.—*Correlation of absorption and freeze-thaw soundness results*

	Absorption < 1.5 percent		Absorption ≥ 1.5 percent	
	Passed freeze-thaw	Failed freeze-thaw	Passed freeze-thaw	Failed freeze-thaw
Coarsely porous dolomites	0	0	5	0
Quartz, sandstone, and dense to slightly porous carbonates	6 (1 marginal)	0	5	4

Munsell color

Over one-half of the samples had colors that were considered acceptable or fair. The Sharon Conglomerate pebbles (2040) were not assigned Munsell colors because of insufficient range of the charts used. The Guelph Dolomite (2032), Cedarville Dolomite (2043B), and undifferentiated Niagaran dolomite (2034) were white to very light gray with minimal iron staining or none at all. The Cedarville Dolomite (2028) and the Columbus Formation (2030A and 2035) were slightly grayer but still acceptable in color. The laboratory sample of the Brassfield Formation (2042) was white but the gross sample contained material with bituminous staining as well as with various quickly weathering red and green colors (appendix, tables B, E).

CONCLUSIONS

The samples tested varied widely in their suitability for architectural aggregate, as shown by the summary of results in table 3. Sharon Conglomerate (2040) and Berea Sandstone (2041) were included in the project only for comparison. The Sharon pebbles, with a history of use for architectural aggregate, show good test results. The Berea, however, is totally unsuited for architectural aggregate although it has given very satisfactory use as dimension stone since the 1800's.

Two of the carbonates tested, Guelph Dolomite (2032) and one of the Niagaran samples (2034), had good test results as well as acceptable white to light-gray color. They should be good sources of architectural aggregate.

The Cedarville Dolomite, with marginal hardness, could well provide acceptable aggregate material if care is taken in handling or if the formation has a greater hardness in locations other than those sampled. The Columbus Formation has a light color that would be appropriate if it is found in an area where the rock is a little sounder. Likewise, the very white color characteristic of the lower part of the Brassfield Formation in the western portion of the State would be highly suitable if present in an area where the formahas greater soundness and is free of bituminous staining.

These evaluations must not influence the choice of these aggregates for any use other than exposed-aggregate concrete. The specifications used in this project are proposed for architectural aggregate only and reflect the very high quality of material needed for this product. Several of the formations not specifically mentioned above, particularly those with good color but marginal test results or good test results but only fair color, may have slightly different properties in areas of the State other than the test sample locations, and may be potentially good sources of architectural aggregate.

TABLE 3.—*Summary of results*

Overall results	Sample number	Formation	Remarks
Good	2032	Guelph Dolomite	Good test results, good color
	2034	Undifferentiated Niagaran rocks	Good test results, good color
	2040	Sharon Conglomerate	Good test results, good color
Fair	2028	Cedarville Dolomite	Marginal hardness, good color, trace of iron staining
	2030A	Columbus Formation	Marginal Na_2SO_4, good color
	2043B	Cedarville Dolomite and Springfield Dolomite(?)	Marginal hardness, good color, trace of iron staining
	2044	Undifferentiated Niagaran rocks	Good test results, fair color
Poor	2027	Tymochtee Formation and Greenfield Dolomite	Good test results, poor color
	2029	Delaware Limestone	Marginal Na_2SO_4, poor color, trace of bituminous staining
	2030B	Columbus Formation and Detroit River Group	Failed Na_2SO_4; fair color
	2031	Dundee Formation and Detroit River Group	Good test results, fair color; pyrite
	2033	Tymochtee Formation	Failed Na_2SO_4; poor color; >1 percent bituminous staining
	2035	Columbus Formation	Failed Na_2SO_4; good color
	2036	Maxville Limestone	Failed Na_2SO_4 and freeze-thaw; fair color; minor shale
	2037	Vanport limestone	Failed Na_2SO_4 and freeze-thaw; poor color; iron staining; siliceous
	2038	Putnam Hill limestone	Good test results, poor color
	2039	Vanport limestone	Good test results, poor color
	2041	Berea Sandstone	Failed Na_2SO_4, freeze-thaw, and hardness; good color
	2042	Brassfield Formation	Marginal Na_2SO_4 and freeze-thaw; good color; iron and clay minerals; bituminous staining
	2043A	Laurel Dolomite, Euphemia Dolomite, and Springfield Dolomite	Failed Na_2SO_4 and freeze-thaw; fair color

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APPENDIX

TABLE A.—*Sampling locations*

Sample designation[1]	Township	County	Ohio coordinate system location		
			x (ft)	y (ft)	zone
66-2027	Mifflin	Pike	1,779,000	399,000	south
12-2028	Springfield	Clark	1,612,000	701,000	south
21-2029	Scioto	Delaware	1,821,000	222,000	north
72-2030	York	Sandusky	1,903,000	588,000	north
87-2031	Milton	Wood	1,621,000	609,000	north
88-2032	Crawford	Wyandot	1,760,000	475,000	north
46-2033	Richland	Logan	1,655,000	296,000	north
54-2034	Jefferson	Mercer	1,401,000	324,000	north
25-2035	Franklin	Franklin	1,837,000	727,000	south
60-2036	Newton	Muskingum	2,102,000	668,000	south
79-2037	Dover	Tuscarawas	2,270,000	306,000	north
85-2038	Franklin	Wayne	2,158,000	369,000	north
50-2039	Poland	Mahoning	2,642,000	493,000	north
28-2040	Thompson	Geauga	2,398,000	736,000	north
47-2041	Amherst	Lorain	2,069,500	618,500	north
68-2042	Harrison	Preble	1,423,000	685,000	south
57-2043	Madison	Montgomery	1,496,000	642,700	south
14-2044	Richland	Clinton	1,658,000	539,000	south

[1] The first two digits of each sample designation are Ohio Division of Geological Survey file numbers and refer to the county where the sample was collected. The final four digits are the actual sample number and are used alone throughout the text and remainder of the appendix.

TABLE B.—*Sample descriptions*

Sample number	Rock unit	Thickness (ft)	Description	Remarks
2027	Tymochtee Formation	2-15	Dolomite, gray to bluish-gray to dark-gray, fine-grained, thin-bedded to shaly, dense	Sample composed of both formations; Tymochtee thinning from east to west in quarry
	Greenfield Dolomite	27-28	Dolomite, gray to tannish- and brownish-gray, fine-grained, medium- to thick-bedded, dense to porous	
2028	Cedarville Dolomite	50+	Dolomite, light-gray to white, coarse-grained, massive, porous	
2029	Delaware Limestone	15	Limestone, light-gray to gray, fine- to medium-grained; trace of chert nodules, pyrite, and bituminous staining	
2030	Columbus Formation	6-15	Dolomite, light-gray, fine- to medium-grained, massive, soft	2030A from the upper 6-15 feet of the Columbus; 2030B from the lowest 13 feet of the Columbus and the upper 5.5 feet of the Detroit River
		12	Dolomite, light-gray, medium-bedded, cherty	
		13	Dolomite, light-gray to white, fine-grained, thick-bedded to massive	
	Detroit River Group	27	Dolomite, light-gray to grayish-brown, thin- to medium-bedded; organic laminae; contorted laminae in places; basal 8 feet browner than upper 19 feet	
2031	Dundee Formation	20-27	Dolomite, light-gray, thin- to medium-bedded, sugary	Dundee and Detroit River quarried in separate lifts but some Dundee remixed with Detroit River
	Detroit River Group	10	Dolomite, light-gray to tannish-gray, sublithographic; small to large vugs with crystalline calcite and pyrite present	
		35	Dolomite, light-gray to brownish-gray, fine-grained, thick-bedded	
2032	Guelph Dolomite	45-55	Dolomite, white to light-gray, fine- to coarse-grained, massive, porous; upper 5-10 feet weathered and thin bedded	
2033	Tymochtee Formation	30	Dolomite, light- to dark-gray and light-brownish-gray (mottled and banded), fine- to medium-grained, thin- to medium-bedded, dense; few shale partings and carbonaceous laminae; abundant bituminous staining	
2034	Undifferentiated rocks of Niagaran age	8-9	Limestone?, brownish-gray to dark-gray, thin- to medium-bedded, inaccessible	Lower 40 feet not presently worked
		80-90	Dolomite, white to light-gray to light-tannish-gray, fine- to medium-grained, thin-bedded to massive, porous	
2035	Columbus Formation	40	Limestone, light-gray to white, fine-grained, thick-bedded to massive, fossiliferous	Sample includes material from only the upper two levels worked, the upper Columbus
2036	Maxville Limestone	15	Limestone, light- to medium-gray, sublithographic, thin- to medium-bedded; 1- to 2-inch shale beds in lowest 6 feet	

TABLE B.—*Sample descriptions*—Continued

Sample number	Rock unit	Thickness (ft)	Description	Remarks
2036	Maxville Limestone (continued)	4	Breccia, dark-gray to brown, fine- to medium-grained; platy limestone intraclasts in punky light-gray limestone matrix; base mainly intraclasts with matrix percentage increasing toward top	
		1½	Limestone, gray, fine- to medium-grained, medium-bedded	
		3	Dolomitic limestone, medium- to dark-gray, medium-grained, slightly argillaceous	
2037	Vanport limestone	≈5	Limestone, light- to dark-gray, medium-grained, argillaceous, siliceous	Production bench covered by spoil; inaccessible
2038	Putnam Hill limestone	3-5	Limestone, medium- to dark-gray, medium-grained, thin- to medium-bedded, slightly fossiliferous	
2039	Vanport limestone	21	Limestone, medium- to dark-gray, medium- to coarse-grained, medium- to thick-bedded; 6- to 8-inch nodular argillaceous zone 5 feet above base	
2040	Sharon Conglomerate	15-20	Sandstone, reddish-brown, medium- to coarse-grained, thin- to thick-bedded, very friable; conglomeratic in places; sparse shale layers 1 to 2 inches thick	Sample composed of +⅜-inch pebbles from conglomerate
2041	Berea Sandstone	200+	Sandstone, light-gray to white, medium- to coarse-grained, friable	Quarry unavailable for inspection
2042	Brassfield Formation	8	Limestone, gray to light-reddish-brown, medium- to coarse-grained, thin- to medium-bedded, fossiliferous; discontinuous greenish-gray clay stringers	Laboratory sample composed of hand-picked specimens of lower Brassfield without bituminous staining
		9-11	Limestone, white to light-gray, medium- to coarse-grained, thick-bedded to massive, fossiliferous; flecked with light red; intermittent bituminous staining	
2043	Cedarville Dolomite	14+	Dolomite, light-gray to gray, medium- to coarse-grained, massive, porous	Section measured by Klosterman and Alberts (*in* Horvath and Sparling, 1967). 2043A from lower bench of quarry: Laurel, 5-7 feet of Euphemia, 3-4 feet of Springfield (Euphemia and Springfield measured by writer); 2043B from upper bench of quarry: Cedarville and possibly some Springfield
	Springfield Dolomite	±9	Dolomite, light-gray to white, fine-grained	
	Euphemia Dolomite	±4	Dolomite, mottled light-gray and gray, medium-grained, slightly porous	
	Laurel Dolomite	±4	Dolomite, light-gray, soft; covered by spoil	
2044	Undifferentiated rocks of Niagaran age	50	Dolomite, light-gray to gray, fine- to medium-grained, thin-bedded to massive, slightly porous	

TABLE C.—*Physical test results*

Sample number	Hardness loss (percent)	Absorption (percent)	Loss in Na_2SO_4 soundness test (percent)			Loss in freeze-thaw soundness test (percent)		
			¾- to 1½-inch fraction	⅜- to ¾-inch fraction	Total sample[1]	¾- to 1½-inch fraction	⅜- to ¾-inch fraction	Total sample[1]
2027	10.3	1.3	3.0	--[2]	3.0	0.4	0.9	0.4
2028	20.7	2.6	1.4	2.7	1.7	1.6	1.4	1.6
2029	10.2	0.8	5.2	--	5.2	1.8	2.6	1.9
2030A	13.5	2.3	5.2	--	5.2	1.0	--	1.0
2030B	13.0	3.0	6.6	--	6.6	0.9	--	0.9
2031	13.6	2.6	2.9	--	2.9	1.4	0.4	1.2
2032	12.4	1.7	3.0	--	3.0	1.0	0.6	1.0
2033	11.0	1.7	8.8	--	8.8	2.3	2.4	2.3
2034	12.6	2.2	3.9	1.5	2.7	0.8	0.9	0.8
2035	14.2	1.7	9.3	--	9.3	0.5	1.9	0.7
2036	10.8	1.6	5.5	9.4	7.4	5.9	5.3	5.6
2037	13.2	1.5	13.9	6.5	10.6	10.4	10.0	10.2
2038	9.6	0.7	1.5	2.2	1.7	0.9	1.4	1.0
2039	13.2	0.5	1.6	2.7	2.1	1.3	2.8	2.0
2040	14.4	0.4	5.2	2.6	3.4	6.7[3]	0.9	2.7
2041	51.8	5.9	13.7	--	13.7	4.3	11.0	5.4
2042	14.7	0.8	5.2	5.9	5.6	3.4	2.4	2.9
2043A	14.9	1.5	12.6	12.2	12.4	5.8	7.5	6.4
2043B	22.2	2.3	0.9	1.0	0.9	0.4	1.1	0.6
2044	15.4	2.1	3.1	2.6	3.0	1.1	1.3	1.1

[1] Adjusted for results of sieve analysis (appendix, table D).
[2] Size fraction not tested.
[3] Several whole pebbles passed test screen: incomplete sieving before test, actual loss <2.7 percent.

TABLE D.—*Sieve analyses*

Sample number	Material in each size fraction (percent)				
	1- to 1½-inch[1]	¾- to 1-inch	½- to ¾-inch	⅜- to ½-inch	<⅜-inch
2027	42.2	49.8	6.9	0.8	0.3
2028	49.2	25.5	15.3	5.3	4.6
2029	54.8	33.2	8.7	1.5	1.8
2030A	49.6	38.4	8.0	2.2	1.9
2030B	59.0	31.8	5.0	1.8	2.3
2031	43.9	38.6	12.8	2.1	2.5
2032	55.6	31.0	9.2	2.2	2.0
2033	43.6	39.9	10.2	2.9	3.5
2034	26.1	24.6	30.1	13.0	6.3
2035	65.2	18.9	9.6	3.7	2.6
2036	29.5	21.8	23.0	12.8	12.9
2037	22.2	33.5	29.9	4.1	10.2
2038	36.8	37.5	14.0	4.2	7.5
2039	19.6	34.1	32.2	11.2	3.0
2040	6.6	24.5	59.1	9.1	0.6
2041	54.8	28.4	11.1	2.2	3.4
2042	38.0	8.9	26.5	10.6	15.9
2043A	44.2	17.4	19.5	7.0	11.8
2043B	52.4	16.8	14.1	5.5	11.1
2044	41.1	35.5	13.0	4.1	6.4

[1] All +1½-inch material in the laboratory sample crushed to -1½ inches before sieve analysis run.

TABLE E.—*Munsell color*

Sample number	Percent of sample	Munsell number	Munsell name and remarks
2027	23	10*YR* 5.5/1	Gray
	22	10*YR* 6/1	Gray to light gray
	11	5*Y* 4.5/1	Gray
	11	*N* 5.5/0	Gray
	7	10*YR* 5/2	Grayish brown
	6	5*Y* 7/1.5	Light gray
	6	5*Y* 5.5/1	Gray
	5	*N* 6/0 + 5*B* 6/1	Mottled gray and bluish gray
	8	--	Various mottlings of above colors
2028	70	5*Y* 7/1	Light gray
	17	5*Y* 6.5/1	Light gray
	10	2.5*Y* 8/2	White; slight iron staining
	3	*N* 7/0	Light gray
2029	53	*N* 5.5/0	Gray
	19	5*Y* 7.5/1	Light gray; trace of bituminous staining
	15	5*Y* 6.5/1	Light gray
	7	5*Y* 5/1	Gray
	6	*N* 7.5/0	White, rounded, weathered or highly abraded
2030A	100	2.5*Y* 7.5/2	Light gray (white)
	Trace	5*Y* 6.5/1	Light gray
2030B	40	2.5*Y* 7/2	Light gray
	31	5*Y* 6.5/1	Light gray
	8	2.5*Y* 5/2	Grayish brown
	7	2.5*Y* 7.5/2	Light gray (white)
	6	2.5*Y* 6.5/2	Light brownish gray
	1	2.5*Y* 8/2	White
	Trace	*N* 8/0	White
	6	5*Y* 7.5/1 + *N* 7/0	Mottled light gray and white
2031	30	2.5*Y* 6/2	Light brownish gray
	27	5*Y* 6.5/1	Light gray
	16	5*Y* 6/1	Light gray
	15	5*Y* 7/1	Light gray
	6	5*Y* 5/1	Gray
	2	*N* 6/0	Gray
	1	*N* 7/0	Light gray
	Trace	2.5*Y* 5/2	Grayish brown
	2	--	Miscellaneous mottlings, black organic stylolite surfaces, and crystalline calcite and pyrite
2032	32	5*Y* 8/1	White
	23	*N* 7.5/0	Light gray
	18	2.5*Y* 8/2	White
	14	*N* 7/0	Light gray
	12	2.5*Y* 7/2	Light gray
2033	19	2.5*Y* 6/2	Light brownish gray; all colors with trace to minor amounts of bituminous staining
	15	5*Y* 6/1	Light gray
	8	10*YR* 5.5/1	Gray
	6	5*Y* 4.5/1	Dark gray
	14	*N* 6.5 to 7.5/0	Banded light gray
	5	*N* 6/0 + *N* 6.5/0	Mottled gray and light gray
	30	--	Miscellaneous mottled and banded grays and dark grays
	3	--	Miscellaneous mottled light grays and whites

TABLE E.—*Munsell color*—Continued

Sample number	Percent of sample	Munsell number	Munsell name and remarks
2034	29	10*YR* 8/1	White
	18	2.5*Y* 8/1	White
	18	*N* 7.5/0	Light gray
	12	2.5*Y* 6.5/2	Light brownish gray
	9	2.5*Y* 8/2	White
	9	*N* 7/0	Light gray
	2	5*Y* 6/1	Gray
	2	5*Y* 4.5/1	Dark gray
2035	80	2.5*Y* 7.5/2	Light gray (white)
	10	10*YR* 6/1	Light gray
	5	5*Y* 6/1	Light gray
	5	2.5*Y* 7/2	Light gray
2036	30-35[1]	5*Y* 6.5/1	Light gray
	30-35[1]	10*YR* 5.5/1	Gray
	30[1]	5*Y* 7.5/1	Light gray
	<5[1]	*N* 3/0	Very dark gray
2037	75	5*Y* 4.5/1	Gray; iron staining
	11	5*Y* 4/1	Dark gray
	8	5*Y* 5.5/1	Gray; iron staining
	6	--	Miscellaneous light grays; iron staining; weathered
2038	100	*N* 4.5/0	Gray
	Trace	5*Y* 6/1	Gray
	Trace	*N* 3/0	Very dark gray
2039	60[1]	5*Y* 6/1	Gray
	40[1]	*N* 4/0	Dark gray
	Trace	5*Y* 8/1	White
2040	90[1]	--	Milky quartz
	10[1]	--	Varicolored quartz: blue, bluish green, and rose
2041	100	5*Y* 8/1	White
2042	Laboratory sample: Lower Brassfield only		
	100	*N* 8.5/0	White
	Gross sample: Upper and Lower Brassfield		
	abundant	*N* 8.5/0	White; solid color plus white flecked with 5*R* 5 to 6/6 and 10*R* 5 to 6/6, light red to red, bituminous staining
	moderate	5*YR* 6/3	Light reddish brown
	moderate	*N* 6/0	Gray
	moderate	5*GY* 6.5/1	Greenish gray
	minor	5*Y* 7/2	Light gray
	minor	5*G* 7/1	Light greenish gray; clay
	minor	5*G* 6/1	Greenish gray; clay
2043A	29	5*Y* 7/1	Light gray
	22	*N* 7/0	Light gray
	15	5*Y* 6.5/1	Light gray
	13	2.5*Y* 6.5/2	Light brownish gray
	13	*N* 5/0	Gray
	2	5*Y* 5/1	Gray
	1	2.5*Y* 7/2	Light gray
	3	*N* 5/0 + 2.5*Y* 7/2	Mottled gray and light gray
	1	--	Mottled light gray; iron staining

TABLE E.—*Munsell color*—Continued

Sample number	Percent of sample	Munsell number	Munsell name and remarks
2043B	22	2.5*Y* 8/1	White
	8	*N* 7/0	Light gray
	6	2.5*Y* 7.5/2	Light gray, weathered
	2	2.5*Y* 7/2	Light gray
	2	*N* 5.5/0	Gray
	59	*N* 7 to 8/0 + 2.5*Y* 8/1 to 2	Mottled light grays and white with varying degrees of light yellow iron staining (up to 2.5*Y* 7/4)
2044	49	*N* 6.5/0	Light gray
	23	5*Y* 7/1	Light gray
	18	2.5*Y* 5.5/2	Gray
	10	2.5*Y* 7/2	Light gray

[1] Percentage estimated.