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**PROGRESS REPORT No.3
ON FREEZING & THAWING
OF CONCRETE
IN THE AUTOMATIC FREEZER**

**MARCH-1956
No.10**

**Joint
Highway
Research
Project**

**PURDUE UNIVERSITY
LAFAYETTE INDIANA**

by

J.F. McLaughlin

Progress Report No. 3

on

FREEZING AND THAWING OF CONCRETE IN THE AUTOMATIC FREEZER

TO: K. B. Woods, Director
Joint Highway Research Project

March 13, 1956

FROM: Harold L. Michael, Assistant Director

File: 5-5-11-1
C-36-375

Attached is Progress Report No. 3 on the investigation of aggregate durability being carried out in the automatic freezer. Data on eleven aggregate sources are reported.

It is suggested in the report that the remaining eight aggregate sources which were included in the original proposal for this work be sampled and tested in a like manner.

Respectfully submitted,

Harold L. Michael, Assistant Director
Joint Highway Research Project

RLM:ojg

Attachment

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FREEZING AND THAWING OF CONCRETE
IN THE
AUTOMATIC FREEZER

by

J. F. McLaughlin

Research Engineer

Joint Highway Research Project

File 5-5-11-1

C-36-378

Purdue University

Lafayette, Indiana

March 13, 1956

PROGRESS REPORT NO. 3 ON FREEZING AND
THAWING OF CONCRETE IN AUTOMATIC FREEZER

INTRODUCTION

On August 4, 1953 a plan of study was approved by the Advisory Board of a Joint Highway Research Project in which it was proposed that a rather comprehensive series of tests be made to evaluate the durability of certain concrete coarse aggregates. This was to be done by means of freezing and thawing tests on concrete beams made with the aggregates under consideration and further, the automatic freezer, which was put into operation at that time, was to be used to expose the beams.

The proposed test series was to be conducted in a standardized manner that would represent a possible design for acceptance tests of aggregates; the following specific purposes were enumerated:

1. Evaluation of the freezing-and-thawing durability of various aggregate sources as requested by the State Highway Department,
2. Correlation of freezing and thawing test results between the old and new freezers,
3. Development of durability information helpful in selecting a standard aggregate or aggregates for specification use,
4. Determination of the feasibility of using immersed instead of vacuum saturated materials in the durability testing (to eliminate the exception of Silurian reef materials in northern Indiana from the present

vacuum saturation technique).

It was suggested that tests be conducted on the coarse aggregates tabulated below, deletions and additions being made when necessary during the progress of the work.

<u>Source No.</u>	<u>Location</u>	<u>Remarks</u>
9-53	Cass Co. Stone Co. Logansport	Investigation authorized by Advisory Board, May 26, 1953.
9-23	Frame Stone Co. Reepert Quarry	
9-15	Old Kenneth Quarry	Tests requested by Mr. F. F. Havey
-	Stuntz & Yeoman, Kokomo	
1-15	Mashberger Stone Co. Linn Grove	Good field performance.
67-23	O. & I. Stone Co. Greencastle	Good field performance.
60-19	Midwest Rock Products Co., Spencer	Good field performance.
90-15	Erie Stone Co., Bluffton	Reef phase - good performance.
24-35	Erie Stone Co., Huntington	Reef phase - good performance.
49-10	American Aggregates Corp., Indianapolis	Average field performance.
79-10	Western Indiana S. & G. Co., Lafayette	Average field performance.
20-10	Deal Gravel Co., Elkhart	Average field performance.
35-25	Erie Stone Co., Huntington	Bad performance - abandoned.
3-15	Mashberger Stone Co., Elizabethtown	Bad performance.
40-35	Paul Frank Quarry, H. Vernon	Bad performance.

<u>Source No.</u>	<u>Location</u>	<u>Remarks</u>
70-6S	Rush Co. Stone Co., Moscow	Doubtful lab. durability.
82-1G	Bedford Rugent Co., Evansville	Bad performance.
83-1G	Standard Materials Corp., Clinton	Poor performance.
84-1G	Terre Haute Gravel Co., Terre Haute	Poor performance.
62-5S	Mulzer Bros. Stone Co., Darty	No record.

Several progress reports and memoranda concerning this project have already been presented to the Advisory Board. This report summarizes the information presented previously and presents the results of current work.

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SCOPE

This report includes the freezing and thawing test results of all of the eleven aggregate sources that have been tested. These sources are the following: 1-1S, 3-1S, 9-1S, 9-2S, 9-5S, 35-3S, 40-3S, 62-5S, 67-2S, 82-1G, and 84-1G.

Average ASTM durability factors at 300 cycles of freezing and thawing are reported for the various ledge combinations (in the case of most stones) or stockpile samples that were tested. Graphs of loss in relative E versus cycles of freezing and thawing are included. In addition, such other information concerning the materials that was obtained in sampling or in laboratory testing is also presented, i.e., descriptions of ledges, abrasion and soundness test results, specific gravity and absorption.

OUTLINE OF WORK

Sampling

The sampling of the gravel sources which were tested in this series was carried out by personnel of the Joint Highway Research Project. The sampling of the quarries was done jointly by personnel of the Indiana State Highway Department and the Joint Highway Research Project.

Gravel samples were relatively easy to deal with; they were brought in to the laboratory, tested for specific gravity and absorption, and then incorporated into concrete mixes. The mineralogic composition of the gravels was also determined. In the case of the stones, however, each quarry presented a different problem. The individual ledges had to be identified and sampled. A decision was made in each case relative to the ledge combinations that would be included in any concrete mix. For instance, in the Meshberger Quarry at Columbus (or Elizabethtown), nine ledges were identified and these were subdivided into four groups for the purposes of freeze-thaw testing. Ledges 1 through 4 made up the first sample, ledges 5 and 6 the second, ledges 7 and 8 the third, and the fourth sample of concrete was made up using material from ledge 9. On the other hand, source 67-2S, known to be very homogeneous with respect to the properties of concrete made from the stone, was sampled only from the stockpiles.

For those quarries for which the information is available, descriptions of the ledges and the general sampling scheme is given in the Appendix. The results of abrasion and sodium sulphate soundness tests, which were performed by personnel of the Bureau of Materials and Tests on

ledge samples, are also included in the Appendix.

In all cases save one, the ledge samples were taken to the Bureau of Materials and Tests laboratory in Indianapolis for crushing, sizing and blending the materials from the various ledges in the proper proportions. The material was then shipped to the JHRP laboratory.

Laboratory Testing

Samples of the stone ledges and of the gravel stockpiles were tested for specific gravity and absorption using the vacuum saturation technique. The degree of saturation for the material in this condition was also found in most cases.

All aggregates were vacuum saturated before being incorporated in concrete mixes. A water-cement ratio of 0.46 to 0.50 by weight was used. The cement factor was kept constant at 6 bags per cubic yard and the slump was three to four inches. Air contents were determined gravimetrically, using a 0.1 cubic foot measure for the unit weight test. Three concrete beams, 3 x 4 x 16 inches, were made from each mix. Curing was by immersion in water for 13 days following removal of the specimens from the molds one day after casting. A minimum of two and generally three mixes were made for each aggregate sample tested.

The freezing and thawing exposure was carried out in the automatic freezer. Approximately seven cycles per day of the fast freeze in air, thaw in water cycle were obtained (ASTM C291-52T). Periodic determinations of the relative dynamic modulus of elasticity of the specimens were made to measure the amount of deterioration. The end point for the exposure adopted in this test series is 50 percent relative E or 300 cycles of freezing and thawing.

TEST RESULTS

A summary of the test results for the eleven sources of aggregate is shown in Table 1. This table shows the source, the combinations of ledges that were used to test the aggregate in concrete, ledge thicknesses, the results of the specific gravity tests, and the average ASTM durability factors¹ at 300 cycles of freezing and thawing for each type of concrete. This grand average for a sample is generally computed from three mix averages which are based on three beams each.

Further information concerning some of the samples is found in the Appendix, i.e., ledge descriptions and abrasion and soundness test results.

The freezing and thawing test results are shown graphically in Figures 1 through 26. The curves for the individual mix averages are shown in Figures 1 through 18. Each curve in each of the first eighteen figures represents the average result of freezing and thawing three concrete beams fabricated from a single concrete mix. The air content of each mix is indicated on the graph. Data on individual mixes were not available for all of the aggregate sources covered in this report; some work, done previously by others, is reported only on the basis of grand averages.

Figures 19 through 26 show the grand average curves for the materials from all eleven sources. They were obtained by averaging the several mix averages for each aggregate combination. A grand average line generally

¹ Durability Factor (DF) = $\frac{P_N}{M}$ where:

P = relative dynamic modulus of elasticity at N cycles, percent,
N = number of cycles at which P reaches the specified minimum value for discontinuing the test or the specified number of cycles at which the exposure is to be terminated, whichever is less, and
M = specified number of cycles at which the exposure is to be terminated.

represents the results of three mixes, a total of nine beams. Average air contents are also indicated on these graphs.

Finally, the durability factors (ASTM - 300 cycles) for the mixes are shown in Table 2. In addition to the average air content and durability factor for each combination, which also appeared in Table 1, Table 2 contains the air content and durability factor for each mix so that some concept of the mix-to-mix variability can be had. As indicated earlier, these individual mix data were not available in a few cases.

Table 1
Aggregate Data

Aggregate Source	Lab Sample Number	Ledge No.	Ledge Thickness (feet)	Absorption %	Bulk Dry Sp. Gr.	Deg. of Saturation %	Avg Absorption for sample in concrete	Avg Bulk S G for sample in concrete	Avg Deg Sat for sample in concrete	Avg. ASTM DF 300 cycles
9-55, Cass Co. Stones	2032-A	1	15	-	Tests on combined material only	-	3.19	2.59	88	88
		2	2	-		-				
		3	2	-		-				
		4	5	-		-				
9-25 Keopert	2032-B	5	8	-	"	-	5.65	2.46	100	32
		6	4	-		-				
		7	9	-		-				
Quarry	2033-A	1	4	0.59	2.67	76	2.73	2.63	91	69
		2	8 to 9	3.74	2.56	88				
		3	10	2.69	2.65	96				
		4	3	3.70	2.60	100				
9-15 Kenneth	2033-B	5	7	9.10	2.28	100	4.66	2.53	98	65
		6	8	3.39	2.61	94				
		7	6	5.14	2.51	100				
3-13 Hoshberger	2033-C	Stock-pile	-	3.95	2.57	-	3.95	2.57	-	62
		See sample description								
Columbus	2034	1	2	4.86	2.40	95	5.85	2.45	100	31
		2	6	3.25	2.50	99				
		3	4	5.24	2.46	100				
		4	4	5.83	2.44	100				
40-35 Paul Frank	2035-A	5	6	8.29	2.30	100	5.43	2.47	100	24
		6	6	2.57	2.64	100				
		7	6	1.58	2.70	89				
		8	12	4.17	2.45	97				
North Vernon	2035-B	32	32 (Stockpile)	3.68	2.56	91	3.68	2.56	91	26
		10 (Dump)	3 to 4	1.49	2.73	89				
62-55 Mulzer Derby	2036-A	1	6	0.67	2.66	73	2.37	2.58	90	68
		2	6	3.13	2.52	93				
		3	2 1/2	4.66	2.51	100				
Paul Frank	2036-B	4	6	8.30	2.29	95	5.77	2.44	97	50
		5	6	3.24	2.59	99				
		6	7	1.16	2.74	92				
		7	12	4.80	2.50	97				
2037-A	2037-A	1	10	1.99	2.68	90	1.98 in concrete tests	Stockpile sample used		100
		2	15	1.91	2.70	92				
		3	10	2.05	2.68	93				
62-55 Mulzer Derby	2038	1	6	1.51	2.60	85	1.80	2.61		83
		2	4	2.37	2.60	100				
		3	1	0.72	2.66	71				
		4	8	1.91	2.61	90				
9-25 Keopert Quarry	2040-A	5	8	1.21	2.63	94	2.69	2.60	84	99
		1								
		2								
67-25 Greencastle	2040-B	3					2.94	2.64	97	65
		4								
84-16 Terre Haute	Control	-	-	0.70	2.68	-	0.7	2.68	-	97
82-16 Bedford Nugent	Walker Study	-	-	2.99	2.63	-	2.99	2.63	-	96
82-16 Bedford Nugent	Walker Study	-	-	2.82	2.57	-	2.82	2.57	-	33
82-16 Bedford Nugent	Walker Study	-	-	2.77	2.50	-	2.77	2.50	-	2

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Fig. 16

Fig. 17

Fig. 18

Fig. 19

Fig. 20

Fig. 23

Fig. 24

Fig. 25

Fig. 26

Table 2

ASTM Durability Factors at 300 Cycles of F & T

Aggregate Source	Sample No.	Mix No.	Air Content	Dur. Factor	Aggregate Source	Sample No.	Mix No.	Air Content	Dur. Factor
9-5S Cass Co. Ledges 1-4	2032 A	1 2 3 4 Mean	4.7 4.7 3.4 3.7 4.1	95 89 86 83 88	40-3S Paul Frank Ledges 4&5	2036 B	1 2 3 Mean	3.8 3.8 3.2 3.6	68 45 39 50
9-5S Cass Co. Ledges 5-7	2032 B	1 2 3 Mean	4.2 4.9 3.9 4.4	40 30 30 30	40-3S Paul Frank Ledge 6	2036 C	1 2 3 Mean	4.8 5.3 5.0 5.0	91 89 79 86
9-2S Keepport Ledges 1-4	2033 A	1 2 3 Mean	4.7 4.3 3.8 4.2	100 99 24 60	40-3S Paul Frank Ledge 7	2036 D	1 2 3 Mean	4.6 4.6 3.2 4.2	100 99 98 98
9-2S Keepport Ledges 5-7	2033 B	1 2 3 Mean	4.6 4.7 3.6 4.4	74 67 53 65	9-2S Keepport Ledges 1&2	2040 A	1 2 3 Mean	4.6 3.3 4.6 4.2	98 99 100 99
9-2S Keepport Stockpile	2033 C	1 2 3 Mean	4.4 3.8 3.7 4.0	74 61 51 62	9-2S Keepport Ledges 3&4	2040 B	1 2 3 Mean	4.0 4.6 4.8 4.5	84 81 39 65
9-1S Kenneth Ledge Sample	2034	1 2 3 Mean	3.5 4.4 3.3 3.7	37 38 20 31	67-2S Greencastle Stockpile	Control	1 2 3 Mean	4.6 4.0 3.6 4.6 4.2	97 95 99 99 97
3-1S Meshberger Ledges 1-4	2035 A	1 2 3 Mean	3.7 4.0 3.5 3.7	65 46 33 47	1-1S Meshberger Stockpile	2037	1 2 Mean	3.9 5.5 4.7	100 100 100
3-1S Meshberger Ledges 5&6	2035 B	1 2 3 Mean	3.3 4.0 4.6 4.0	26 25 22 24	62-5S Mulser Derby	2038	Mean	4.3	83
3-1S Meshberger Ledges 7&8	2035 C	1 2 Mean	3.9 4.1 4.0	73 71 72	35-3S Erie Terre Haute	Walker Study	Mean	4.8	96
3-1S Meshberger Stockpile (Ledge 9)	2035 D	1 2 Mean	3.4 4.0 3.7	31 19 26	84-1G Bedford Nugent	Walker Study	Mean	8.3	33
40-3S Paul Frank Ledges 1-3	2036 A	1 2 3 Mean	4.6 3.9 4.0 4.2	84 63 57 68			Mean	5.4	2

DISCUSSION

9-2S - Keepport Quarry

In a previous report, the data shown in Figure 3 were included. The extreme variation of one of the three mixes in the series from the other two (i.e., durability factor of 24 for the mix with 3.8 percent air versus durability factors of 100 and 99 at 4.7 and 4.3 percent air respectively) led to the suggestion that the top four ledges in the Keepport Quarry be re-sampled. While the lower air content of the mix having the durability factor of 24 could explain some of the discrepancy in the results, reference to Table 1 shows that the top two ledges were markedly different from ledges 3 and 4 in the degree of saturation observed (76 and 88 versus 96 and 100). It was possible that inadequate mixing of the materials could have contributed to the observed variance.

These four ledges were re-sampled and new tests were conducted. For the second test series, the stone from ledges 1 and 2 was tested separately from the material from ledges 3 and 4. These results are shown in Figures 15 and 16 and the grand averages are shown in Figure 25. The concrete made from ledges 1 and 2 was highly durable and very little variation was observed among the three mixes. The average durability factor at 300 cycles of freezing and thawing was 99 and the range was only 2. Ledges 3 and 4, however, had an average durability factor of 65 and a range in durability factor of 45. One of the three mixes showed very low durability but in this case one cannot assign the cause to low air content because the mix with the lowest durability factor had the highest air content of the three. It appears that one must infer that the material from ledges 3 and 4 is inherently more variable with respect

to its freeze and thaw durability, and this is reflected in the test data.

9-5S - Cass Co. Stone and 9-1S - Kenneth Quarry

The results of the tests on material from the Cass Co. Stone Co. (9-5S) and from the old Kenneth Quarry have also been reported previously but not on the basis of durability factor at 300 cycles of freezing and thawing. In the previous report, the following statements were made relative to these materials:

"Both source 9-1S (sample 2034) and the lower ledges of source 9-5S (2032-B) have very poor durability. Considering the differences in air contents, the 9-5S sample probably should be rated below 9-1S in durability."

"The upper ledges of source 9-5S (Sample 2032-A) were intermediate in durability."

In Table 2, it may be seen that the aggregate from the upper ledges of 9-5S had a mean durability factor of 88, that from lower ledges 30, and the aggregate from source 9-1S was found to have a durability factor of 31.

1-1S - Linn Grove and 67-2S - Greencastle

The aggregates from sources 1-1S and 67-2S showed excellent durability (Figures 17, 18, 23, and 26). The average durability factors for these aggregates were 100 and 97 respectively.

3-1S - Columbus and 40-3S - North Vernon

Material from source 3-1S was tested in four parts, i.e., aggregate from ledges 1-4 was combined for one sample, ledges 5 and 6 the second, ledges 7 and 8 the third, and ledge 9 the fourth. Figures 7 through 10 contain the individual mix curves for this source and the averages are

shown in Figure 21. In computing the average curves and durability factors for samples 2035-C (ledges 7 and 8) and 2035-D (ledge 9), only two of the three mixes were included. It was felt that the mix having 2.7 percent air was too low and the one having 5.6 percent air was too high to be averaged with the other two.

Source 40-37 was also tested in four parts: ledges 1-3, 4 and 5, 6, and 7. These individual results are shown in Figures 11 through 14 and the average results are in Figure 22.

A comparison of the ledges between the Meshberger quarry at Columbus and the Paul Frank quarry at North Vernon is shown in Figure 27. There is perhaps reasonable agreement for a number of the ledges, but the results from Meshberger ledge 9 differ widely from its counterpart, Paul Frank ledge 7. The aggregate from the Meshberger quarry had a durability factor of only 26 while that from the Paul Frank quarry had a durability factor of 99. One is forced to conclude that formations may be similar enough in certain geologic characteristics to be called by the same name and yet produce concrete of very different qualities.

62-53 - Mulzer Bros., Derby and 35-23 Erie

Sources 62-53 and 35-23 were tested by Walker in connection with his work on stone-gravel blends. They had durability factors of 83 and 96 respectively, indicating, we would assume, good to excellent durability (see Figure 24).

82-1G - Bedford Nugent and 84-1G - Terre Haute

Sources 82-1G and 84-1G, the only gravels included in this report, were also tested by Walker. The durability results are shown in Figure 24;

the aggregates had durability factors of 2 and 33 respectively indicating potentially poor durability in freezing and thawing.

SUMMARY

Eleven of the nineteen aggregate sources that were included in the original plan of study have been tested. The laboratory freeze-thaw durability of these materials ranges from excellent in the case of sources 67-2S and 1-1S, to poor in the case of materials such as those tested from sources 82-1G, 84-1G, 9-1S. Other sources such as 9-2S and 40-3S contain ledges that have good durability while other ledges have intermediate to poor durability.

The following list is a ranking of the materials tested on the basis of durability factor at 300 cycles of freezing and thawing. Air contents are included because variations in that factor cannot be eliminated and in cases where one material is ranked slightly above another but has a somewhat higher air content, it is possible that the difference is caused by the air and not by any real difference between the materials.

<u>Source</u>	<u>DF</u>	<u>% Air</u>
1. 1-1S - Stockpile	100	4.7
2. 9-2S - ledges 1 and 2	99	4.2
3. 40-3S - ledge 7	99	4.2
4. 67-2S - Stockpile	97	4.2
5. 35-3S - Stockpile	96	4.8
6. 9-5S - ledges 1-4	88	4.1
7. 40-3S - ledge 6	86	5.0
8. 62-5S - Stockpile	83	4.3
9. 3-1S - ledges 7 and 8	72	4.0
10. 9-2S - ledges 1-4	69	4.2
11. 40-3S - ledges 1-3	68	4.2

	<u>Source</u>	<u>DF</u>	<u>% Air</u>
12.	9-23 - ledges 3 and 4	65	4.5
13.	9-23 - ledges 5-7	65	4.4
14.	9-23 - Stockpile	62	4.0
15.	40-33 - ledges 4 and 5	50	3.6
16.	3-15 - ledges 1-4	47	3.7
17.	84-16 - Stockpile	33	8.3
18.	9-15 - See Appendix	31	3.7
19.	9-53 - ledges 5-7	30	4.4
20.	3-15 - ledge 9	26	3.7
21.	3-15 - ledges 5 and 6	24	4.0
22.	82-10 - Stockpile	2	5.4

Note that entry number 10 for 9-23 includes ledges 1-4. The second time this quarry was sampled, the material was tested in two parts. Ledges 1 and 2 were very durable (entry No. 2) but ledges 3 and 4 were not (entry 12).

With the completion of the work reported, all of the aggregates that have been sampled have been tested. It is suggested that steps be taken to obtain samples from the remaining eight sources. The same test methods that have been used in the past would again be employed. Freezing and thawing data are also being collected for many of these aggregates with the concrete beams wrapped in aluminum foil. While one cannot say at present that this method has advantages, it is being studied by other laboratories and it seems advisable to note the effect of the method on Indiana aggregates.

APPENDIX

Description of Ledges Sampled and Additional

Aggregate Test Data*

- (1) Sample 2032 - Cass Co. Stone Co., Logansport, Indiana. Sampled by Lewis, Sutton, and Sprankle, June 5, 1953.

Ledge 1 - Top 15 feet. Tan to gray, medium grained, medium bedded with some calcite crystals and some chert. Percent wear - 32.8; percent loss, sodium sulphate - 6.9.

Note: Samples are from Kokomo Formation and no samples were taken from the upper Kenneth Formation which is about 20 feet of light gray stone which is not to be worked as this formation has been removed to an approximate 30 acre area.

Ledge 2 - 2 feet. Light gray thinly bedded, laminated, porous, medium grained. Percent wear - 26.6; percent loss, sodium sulphate - 3.7.

Ledge 3 - 2 feet. Tan, thinly bedded, porous coarse grained. Percent wear - 27.9; percent loss, sodium sulphate - 14.9.

Ledge 4 - 5 feet. Tan to light gray, medium bedded, medium grained and no inclusions noted. Percent wear - 31.3; percent loss, sodium sulphate - 5.2.

Ledge 5 - 8 feet. Light gray, thinly bedded, fine grained, very porous. Percent wear - 53.2; percent loss, sodium sulphate - 40.9.

Ledge 6 - 4 feet. Thinly bedded, banded, striped asphalt inclusions or thin partings. Tan to dark gray in color. Percent wear - 25.1; percent loss, sodium sulphate - 7.9.

Ledge 7 - 9 feet. Tan to gray, laminated. Medium gray. Percent wear - 29.4; percent loss, sodium sulphate - 12.9.

Note: Stockpile sample obtained for ledges 5-7. Individual ledge samples taken for ledges 1-4.

- (2) Sample 2033 - France Stone Co. (Keeport) Logansport, Indiana. Sampled by Lewis and Sutton, Nov. 3, 1953.

Ledge 1 - Top 4 feet. Dark gray, massive, fossiliferous limestone with calcite seams and inclusions. Percent wear - 29.9; percent loss, sodium sulphate - 4.5.

* Information from J.H.R.P. field books and test reports of State Highway Commission of Indiana, Bureau of Materials and Tests.

Ledge 2 - 8 feet. Tan to yellow, weathered, thin bedded dolomitic limestone with high macro-porosity and many small calcite crystals.

Percent wear - 29.5; percent loss, sodium sulphate - 5.3.

Ledge 3 - 10 feet. Gray to tan, medium bedded, fine grained dolomitic limestone. High macro-porosity.

Percent wear - 21.6; percent loss, sodium sulphate - 1.0.

Ledge 4 - 3 feet. Similar to 3 but with some laminations or color banding more tan in color.

Percent wear - 23.7; percent loss, sodium sulphate - 4.0.

Ledge 5 - 7 feet. Light gray, medium bedded, fine grained finely laminated. Varies to tan in some places.

Percent wear - 27.6; percent loss, sodium sulphate - 14.0.

Ledge 6 - 8 feet. Dark gray to tan, heavily laminated fine grained dolomitic limestone. Many calcite seams and small crystals.

Percent wear - 2.6; percent loss, sodium sulphate - 13.0.

Ledge 7 - 6 feet. Tan to yellow, weathered, macro-porous dolomitic limestone, probably originally laminated but mostly obscured now by weathering. Fine grained, many small calcite crystals.

Percent wear - 28.0; percent loss, sodium sulphate - 11.0.

- (3) Sample 2034 - Kenneth Quarry (abandoned), Logansport, Indiana. Sampled by Lewis and Sutton, November 3, 1953.

The sample taken represents approximately 20 feet above water and below Kenneth formation. All material fine grained, medium bedded, gray to tan, laminated dolomitic limestone.

- (4) Sample 2035 - Messberger Quarry, Columbus, Indiana. Sampled by Lewis, Sutton and Smith, November 18, 1953.

Ledge 1 - Top 2 feet. Tan, coarse grained fossiliferous limestone.

Percent wear - 28.3; percent loss, sodium sulphate - 4.1.

Ledge 2 - 6 feet. Gray to tan, fine grained, fossiliferous, thick bedded with chert seam near center. Separated from ledge 3 by a wavy seam of shaly material, $\frac{1}{2}$ -inch thick.

Percent wear - 40.2; percent loss, sodium sulphate - 9.1.

This ledge was resampled for additional wear and soundness tests which gave the following results:

Percent wear - 37.4; percent loss, sodium sulphate - 16.0.

Ledge 3 - 4 feet. Gray, fine grained, thick bedded, contains some wavy bands of smooth, fine grained material.

Percent wear - 25.8; percent loss, sodium sulphate - 23.7; percent loss, freezing and thawing - 2.7.

Ledge 4 - 4 feet. Gray, thick bedded, some wavy marks resembling coarse laminations.
Percent wear - 29.0; percent loss, sodium sulphate - 35.0; percent loss, freezing and thawing - 0.9.

Ledge 5 - 6 feet. Grayish, sometimes chalky, massive, wavy calcite inclusions.
Percent wear - 29.3; percent loss, sodium sulphate - 17.0; percent loss, freezing and thawing - 1.3.

Ledge 6 - 6 feet. Gray, fine grained, massive, laminated.
Percent wear - 22.8; percent loss, sodium sulphate - 5.6.

Ledge 7 - 6 feet. Dark gray to brown, massive, mottled to striped with blue.
Percent wear - 18.7; percent loss, sodium sulphate - 1.0.

Ledge 8 - 12 feet. Gray to tan, massive, coarse grained limestone.
Percent wear - 48.5; percent loss, sodium sulphate - 56.1.

This ledge was resampled for additional wear and soundness tests which gave the following results:
Percent wear - 61.5; percent loss, sodium sulphate - 34.0.

Ledge 9 - 32 feet total, 5 feet in 2nd level, remainder makes up all of 3rd level. Dark brown massive, porous in places, tiny calcite inclusions. Some darker material lower down, large calcite inclusions scattered through face.
Percent wear - 37.6; percent loss, sodium sulphate - 16.0; percent loss, freezing and thawing - 0.7.

This ledge was resampled for additional wear and soundness tests which gave the following results:
Percent wear - 32.9; percent loss, sodium sulphate - 4.0.

Ledge 10 - 3 or 4 feet exposed in sump. Actual depth of ledge unknown. Blue-gray, mottled, fine grained limestone.
Percent wear - 24.0; percent loss, sodium sulphate - 1.9.

- (5) Sample 2036 - Paul Frank Quarry, North Vernon, Indiana. Sampled by Lewis, Sutton, and Smith, November 18, 1953.

Ledge 1 - Top 6 feet. Dark gray, coarse grained, fossiliferous, massive. Beechwood overlain by New Albany shale.
Percent wear - 40.2; percent loss, sodium sulphate - 8.8.

This ledge was resampled for additional wear and soundness tests which gave the following results:
Percent wear - 27.0; percent loss, sodium sulphate - 4.0.

Ledge 2 - 6 feet. Dark brown, medium grained, massive, mottled with blue. Chert inclusions, some a foot or more across, hard in center with soft white layer or shell around them. Some entirely soft material (smaller ones).
Percent wear - 40.0; percent loss, sodium sulphate - 20.0; percent loss, freezing and thawing - 3.4.

This ledge was resampled for additional wear and soundness tests which gave the following results:
Percent wear - 39.4; percent loss, sodium sulphate - 22.0; percent loss, freezing and thawing - 2.0.

Ledge 3 - 3 feet. Lighter brown to tan, fine grained, massive, calcite inclusions.
Percent wear - 24.7; percent loss, sodium sulphate - 16.2.

This ledge was resampled for additional wear and soundness tests which gave the following results:
Percent wear - 23.8; percent loss, sodium sulphate - 12.0.

Ledge 4 - 6 feet. Tan, medium grained, massive. Grades from tan mottled with blue into grayish-tan, almost chalky, with wavy calcite faces.
Percent wear - 26.3; percent loss, sodium sulphate - 14.5.

Ledge 5 - 7 feet. Gray-brown, fine-grained, massive, finely laminated.
Percent wear - 24.3; percent loss, sodium sulphate - 7.7.

Ledge 6 - 7 feet. Tan, mottled with blue, medium grained, massive.
Percent wear - 22.9; percent loss, sodium sulphate - 1.3.

Ledge 7 - 12 feet. Dark brown, massive, calcite inclusions, in places porous (Geneva).
Percent wear - 27.5; percent loss, sodium sulphate - 2.3.

- (6) Sample 2037 - Mashberger Quarry, Linn Grove, Indiana. Sampled by Lewis and Sutton, November 27, 1953.

Ledge 1 - Top 10 feet. Brown, granular, thin bedded with dark, irregular separations.

Ledges 2 and 3 - Total of 25 feet. Brown, granular, massive.

- (7) Sample 2038 - Mulzer Quarry, Derby, Indiana. Sampled by Sutton, Moosmiller, Walker, Venters and Lewis, October 20, 1954.

Ledge 1 - Top 6 feet. Gray, dense, granular, fossiliferous, numerous calcite faces.

Ledge 2 - 4 feet. Gray, dense, fine grained.

Ledge 2a - 1 foot. Gray, dense, coarse grained, fossiliferous.

Ledge 3 - 8 feet. Similar to ledge 2.

Ledge 4 - 8 feet. Similar to ledge 2a. Some dark streaks that may be carbonaceous in nature.