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#124

RELATIVE RESISTANCE TO THERMAL AND MECHANICAL SHOCK OF VARIOUS 26-A MODIFIED AGGREGATES USED IN BITUMINOUS CONCRETE RESURFACING

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INTRODUCTION

This investigation was initiated as a result of correspondence from the Construction Division dated May 26, 1948, in which Mr. Tom Humphries, Assistant Road Construction Engineer, reported evidence of cracked surface stone in a bituminous concrete resurfacing project.

The project concerned was Construction Project 11-20, C2 on US-112 west from Galien, in which limestone of 26-A gradation from Dolese and Shepherd of Joliet, Illinois, was used as coarse aggregate.

It was suggested that the Research Laboratory undertake a study of this aggregate, determine if possible the causes of the observed cracking, and draw conclusions accordingly.

In order to make the study as complete as possible, it was decided to extend the scope of the investigation to include other limestones in addition to Dolese and Shepherd, and some natural gravels for comparison.

Inasmuch as the cracking noted west of Galien and subsequently in other areas appeared before the recap in any case had been subjected to much heavy traffic, it seemed probable as pointed out by Mr. Humphries that cracking had been caused by one or more of the stresses accompanying construction procedure, to a certain extent, perhaps, intensified by subsequent cycles of freezing and thawing.

Construction stresses which would appear to have the greatest effect on a coarse aggregate used in bituminous concrete resurfacing would include (1) the thermal shock imparted to an initially cold and wet aggregate by passage through the rotary dryer at normal or higher drying temperatures, and (2) the stresses produced when the bituminous mix is compacted by rollers.

Scope

A series of 26-A modified coarse aggregates from 9 different sources was run through a laboratory model rotary dryer at temperatures from 50 to 100 degrees higher than those prevailing in construction practice, (between 500 and 550 degrees F exit temperature) This was to simulate the higher temperatures used during late fall months, when cold, wet aggregates are encountered. It was decided to evaluate Dolese & Shephard aggregates first using the higher temperatures before making the decision whether or not to evaluate the same aggregate at lower temperatures. Both limestones and natural gravels were included. Conditions were made to simulate actual field conditions. Compaction by rollers was duplicated by compression of aggregates to 300 p.s.i. and 400 p.s.i. and release. A total of 25 cycles of freezing and thawing were carried out, both with and without previous compression. Gradations were made at 11 significant steps, and aggregate breakdown was measured by increase in per cent of material passing Nos. 4 and 10 sieves.

Results

The evidence accumulated in the investigation indicates that Dolese and Shephard aggregate is no more subject to cracking than many other limestones, although limestones in general are not as resistant to cracking as are natural gravels. The performance of any aggregate was found to depend a great deal upon its actual grading, resistance to cracking being found to vary several hundredfold within the 26-A (Modified) gradation.

The text of this report contains several photographs illustrating the type of breakdown under study, taken both in the field and in the laboratory. Cracking of coarse aggregate seems to be a more or less general condition with bituminous concrete resurfacing, and apparently exists in all degrees from very little cracking to pronounced cracking.

LABORATORY INVESTIGATION

General

Coarse aggregates of the 26-A Modified class selected for investigation are listed in Table I. It will be noted that of the 9 aggregates included, 6 were limestone of a calcitic or dolomitic nature, whereas 3 were gravel.

Initial gradings showed that all aggregates were well within the grading requirements of 26-A Modified specification, with the possible exception of aggregates Nos. 1 and 6. Table II shows the gradings of all 9 aggregates.

A laboratory-size rotary dryer was designed and built, as shown in Figure 1. The essential qualifications of the dryer were such that it would simulate the action of a plant dryer as closely as possible in all respects other than batch size.

Compaction under rollers was simulated at 300 p.s.i. and again at 400 p.s.i. by compression of the aggregate in a steel cylinder by means of a steel piston connected through a dynamometer ring to a hydraulic jack.

The laboratory procedure was carried out as follows:

Laboratory Procedure, Original Grading

The original sample of aggregate was quartered down to two samples to provide material for two different test procedures, designated throughout the tests as "A" and "B". Each sample weighed about 2500 grams and had the same gradation. The samples were washed, dried to constant weight and the gradings repeated. Thereafter they were soaked in water for 24 hours.

TABLE I

AGGREGATES INCLUDED IN INVESTIGATION

Sample Number	Class*	Laboratory Number	Description
1	L	48 A-5	Dolese and Shephard - McCook Quarry - Cook County, Illinois. 26-A Modified.
2	L	48 A-6	National Lime and Stone - Piqua, Ohio (Findley, Ohio) - Stock at Plant (Mid-America Engineering Co.) - Crushed Limestone. 26-A Modified. M 30-1, C9, 46-3[illegible], C8, 46-48, C1.
3	G	48 A-7	American Aggregate - Green Oak - Stockpile at Asphalt Plant - Detroit Asphalt Paving - Crushed Stone. 26-A Modified. M 47-15, C18.
4	G	48 A-8	E. [illegible]. Brady - Rogers City - Stockpile at Big Cut Pit - Crushed Gravel. 26-A Modified. Research.
5	G	48 A-9	Petoskey Portland Cement Co. - Petoskey - Stockpile of 10-A in yard - Crushed Stone. 10-A Research.
6	L	48 A-10	Inland Lime and Stone Co. - Manistique - Stockpile at J. H. Baker and Sons dock at Port Huron. 26-A Modified.
7	L	48 A-11	Wallace Stone Co. - Bayport - Stockpile at Plant. Crushed Limestone. 26-A Modified.
8	L	48 A-12	Allied [illegible] Corporation - Drum ond Island - Stockpile at Midland Contracting Co. plant at Bay City - Crushed Limestone. 26-A Modified.
9	L	48 A-13	Lincoln Stone - Joliet. 26-A Modified.
10	L	-------	France Stone

* L = Limestone

G = Gravel

TABLE II

GRADINGS OF AGGREGATES USED IN INVESTIGATION

Sieve	Size	26-A (Modified) Specification	Aggregates Used in the Study								
			1	2	3	4	5	6	7	8	9
Passing	5/8 inch	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Passing	1/2 inch	90 – 100%	97.8	94.8	98.5	98.3	95.0	99.8	99.1	98.8	99.7
Passing	No. 4	0 – 25%	30.9	12.9	19.0	8.9	8.1	26.7	2.0	13.1	4.7
Passing	No. 10	0 – 10%	9.0	3.8	7.8	3.0	4.9	5.5	1.3	3.0	3.7

Both samples were then chilled under water to 35 degrees F., the water decanted, and the samples run successively through the hot rotary dryer in contact with the flame. Time of passage through the dryer, R.P.M. of dryer and position of flame were adjusted to make conditions comparable to field conditions. Aggregate exit temperature was kept from 500 to 550 degrees, simulating the higher temperatures expected during late fall months when cold, wet aggregates are encountered. After cooling, grading tests were repeated.

From this point, sample A was reserved for freezing and thawing in water.

Sample B was subjected to crushing action before entering the freeze and thaw durability tests. The entire amount of sample B was loaded to a static pressure of 300 p.s.i. and tested for gradation afterward to learn the extent of breakdown. All of the sieve fractions were then recombined, the sample loaded to 400 p.s.i. and again tested for gradation.

Weighed portions of material retained on a No. 4 sieve were then taken from both samples A and B for freezing and thawing in water in order to determine whether previous exposure to high compressive stresses would have any noticeable effect on the subsequent durability of the aggregate. It was found that these stresses were without significance in altering resistance to subsequent freezing and thawing cycles.

Synthetic Gradings

The above procedure was carried out with representative samples of each of the 9 aggregates as received. However, since there was such wide variation in original gradings, synthetic samples of aggregates Nos. 1, 2, 7 and 9 were made up with gradings matching that of aggregate No. 3. No. 3 was chosen as having a typical 26-A Modified grading.

The same laboratory procedure as described above was then carried out with the synthetically recombined aggregates, all of the latter starting out with identical gradation.

Freezing and Thawing Cycles

A total of 25 cycles of freezing and thawing (A.A.S.H.O. Designation: T 103-42) were carried out on samples of all aggregates both before and after compression, but in all cases after passage through the rotary dryer. Freezing and thawing was done under water.

RESULTS OF THE LABORATORY INVESTIGATION

Results of the investigation are shown in Tables III through V.

Reference to Table III shows a variation from 22% to 222% in the increase in material passing Nos. 4 and 10 sieves after compression at 300 p.s.i., and from 43% to 496% after compression at 400 p.s.i. These values, however, are for the aggregates as received, whose gradings are listed in Table II, and are not necessarily indicative of what they would be if the aggregates all had the same grading.

This thought is exemplified by reference to Table IV, which lists comparable results for the 5 aggregates whose gradings were made the same. In Table IV, the corresponding values run from 21% to 39% and from 46% to 86%. It is felt that these values are more reliable than those listed in Table III, although their order is substantially the same in both tables.

The above results illustrate how widely different may be the behavior of the same aggregate as a consequence of changing its grading only moderately, even though both gradings lie within present specifications. Tests indicate that the breakdown of the aggregate under compression increases as the amount retained on the No. 4 sieve increases - which is in agreement with the work of Shelburne.* This may well be the most significant fact to come out of the entire investigation.

* See Bibliography

Freezing and thawing data are shown in Table V. It will be seen in Table V that the values do not necessarily follow the same order shown in Tables III and IV. Variations from 0.7 and 5.7 are shown in the percentage increase in material passing No. 4 sieve due to breakdown by 25 cycles of freezing and thawing under water, both with and without previous compression to 400 p.s.i. and release.

The fact that the order of rating the aggregates on the basis of freezing and thawing data does not follow closely the order based on thermal and compressive stresses alone is indicative of the possibility that an aggregate may possess excellent resistance to freezing and thawing and yet fail under heat shock or compaction, and vice-versa.

Dolese & Shephard aggregate, which had been under a certain degree of suspicion as a result of field observations, is seen to enjoy a fairly favorable rating based on the laboratory tests. Because of this it was considered unnecessary to evaluate this aggregate on the basis of breakdown at lower temperatures.

Table VI lists the aggregates studied in the order of their final rating. They are divided into 3 groups on the basis of all laboratory data obtained in the study. Group 1 is considered good, group 2 fair, and group 3 poor.

CORRELATION WITH FIELD BEHAVIOR

The accompanying photographs show the surface conditions of bituminous concrete resurfacing projects using 3 different limestone aggregates of 26-A (Modified) grading. A glance at these photographs is sufficient to indicate the presence of considerable cracking in the coarse aggregate.

It is apparent, however, that Dolese & Shephard aggregate is by no means unique among limestones in demonstrating this type of failure. As a matter of fact, the aggregate in Figures 2 and 3 appears to be in better condition than that in Figures 6 and 7.

TABLE III

AVERAGE PER CENT INCREASE IN MATERIAL PASSING NOS. 4 AND 10 SIEVES

AFTER HEATING AND COMPRESSION TO 300 AND 400 p.s.i.

(Aggregates as Received - Gradings as Listed in Table II)

Aggregate	Per Cent Increase After Heating and Compression to	
	300 p.s.i.	400 p.s.i.
(1) Dolese & Shephard	22	43
(3) American Agg. Green Oak	21	46
(4) E. P. Brady Rogers City	23	68
(6) Inland Lime & Stone J. H. Baker	45	88
(8) Allied Sales Bay City	46	104
(5) Petoskey	50	120
(2) National Piqua, Ohio	62	147
(9) Lincoln Stone Joliet, Illinois	120	284
(7) Wallace Bay Port	222	496

TABLE IV

AVERAGE PER CENT INCREASE IN MATERIAL PASSING NOS. 4 AND 10 SIEVES

AFTER HEATING AND COMPRESSION TO 300 AND 400 p.s.i.

(Artificial Grading to Match Aggregate No. 3)

	Aggregate	Per Cent Increase After Heating and Compression To 300 p.s.i.	400 p.s.i.
(3)	American Agg. Green Oak	21	46
(1)	Dolese & Shephard	27	60
(9)	Lincoln Stone Joliet, Illinois	35	70
(7)	Wallace Bay Port	33	77
(2)	National Piqua, Ohio	39	86

TABLE V

PER CENT INCREASE IN MATERIAL PASSING NO. 4 SIEVE

AFTER 25 CYCLES OF FREEZING AND THAWING*

Aggregate	Per Cent Increase No Prior Compression	Per Cent Increase Previously Compressed at 400 p.s.i.
(2) National Piqua, Ohio	0.7	0.7
(8) Allied Sales Bay City	1.0	1.0
(3) American Agg. Green Oak	0.8	1.7
(4) H. P. Brady Rogers City	1.0	1.7
(1) Dolese & Shephard	1.2	1.3
(9) Lincoln Stone Joliet, Illinois	1.7	1.3
(5) Petoskey	3.2	3.0
(6) Inland Lime & Stone J. H. Baker	3.7	5.3
(7) Wallace Bay Port	5.7	5.7

* Aggregates previously passed through rotary dryer.

TABLE VI

FINAL GROUPING OF AGGREGATES

Aggregate	Class	Group
(3) American Aggr. Green Oak	Gravel	Group 1
(4) E. P. Brady Rogers City	Gravel	
(1) Dolese & Shepherd	Limestone	Group 2
(5) Petoskey	Limestone	
(6) Inland Lime & Stone J. H. Baker	Limestone	
(8) Allied Sales Bay City	Limestone	
(2) National Pique, Ohio	Limestone	Group 3
(9) Lincoln Stone Joliet, Illinois	Limestone	
(7) Wallace Bay Port	Limestone	

The field surveys of several bituminous resurfacing projects indicate that continued search in the field may bring to light other projects containing fractured aggregates which are more widespread and more complete than hitherto suspected, and secondly, that Dolese & Shephard and Wallace stone aggregate occupy the same relative positions in field ratings as in the laboratory rating. This would lend support to the view that all other aggregates rated in the laboratory would have the same ratings in the field.

CONCLUSIONS

To the extent that the laboratory findings may be considered applicable to field conditions the following conclusions appear warranted as a result of this investigation:

1. On the basis of a dozen field inspections cracking of the coarse aggregate in bituminous concrete resurfacing does not appear to be uncommon although the degree of cracking may vary considerably.

2. Aggregates of the limestone class, calcitic or dolomitic, or mixtures of the two, offer considerably less resistance than do the natural gravel aggregates to the combined thermal and compressive stresses accompanying normal construction practice in bituminous concrete recapping.

3. Laboratory data indicate that Dolese & Shephard aggregate is no worse in respect to resistance to construction stresses than any other limestone stidied.

4. The same aggregate may vary in its resistance to construction stresses depending upon where its actual grading lies within the grading tolerances of the present 26-A Modified specification. This leads to the question, should these tolerances be lowered?

5. Aggregates possessing high resistances to freezing and thawing may possess low resistance to thermal and compressive stresses accom-

panying construction procedures, and vice-versa.

6. Previous compression of the aggregate was without significant effect on resistance to subsequent cycles of freezing and thawing in these tests.

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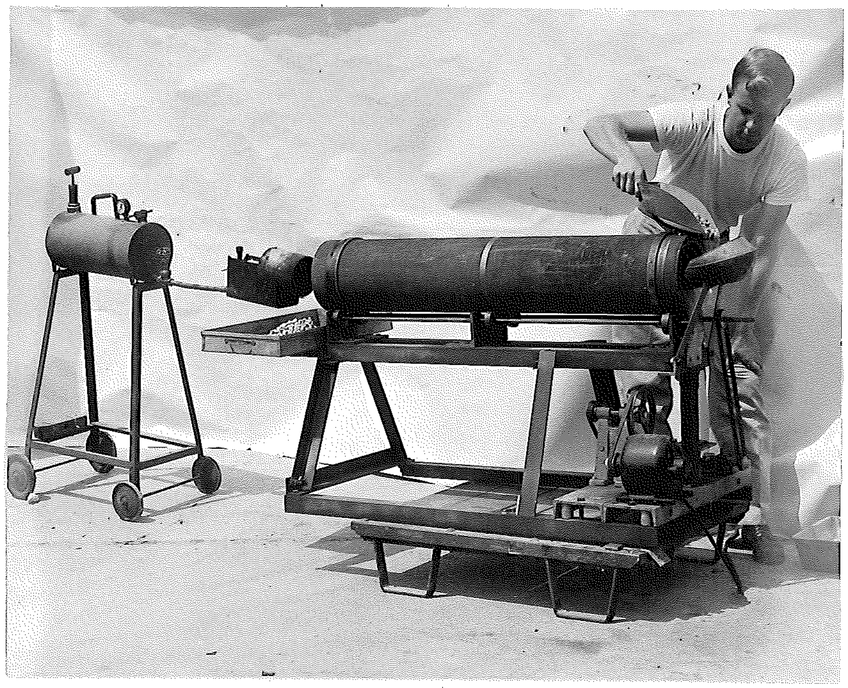

Figure 1. Laboratory Model Rotary Dryer Used in Investigation

Figure 2. Dolese & Shephard Aggregate in Resurfacing
1 mile east of Three Oaks on M-60 .

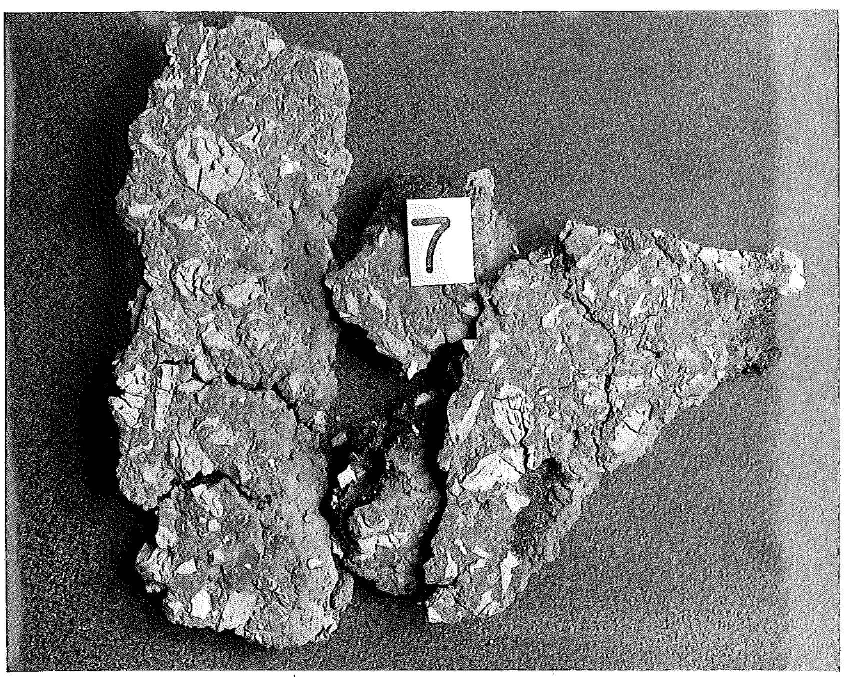

Figure 3. Sample of section of Recap from area 1 mile
east of Three Oaks on M-60. (See Figure 2.)
6-12-48

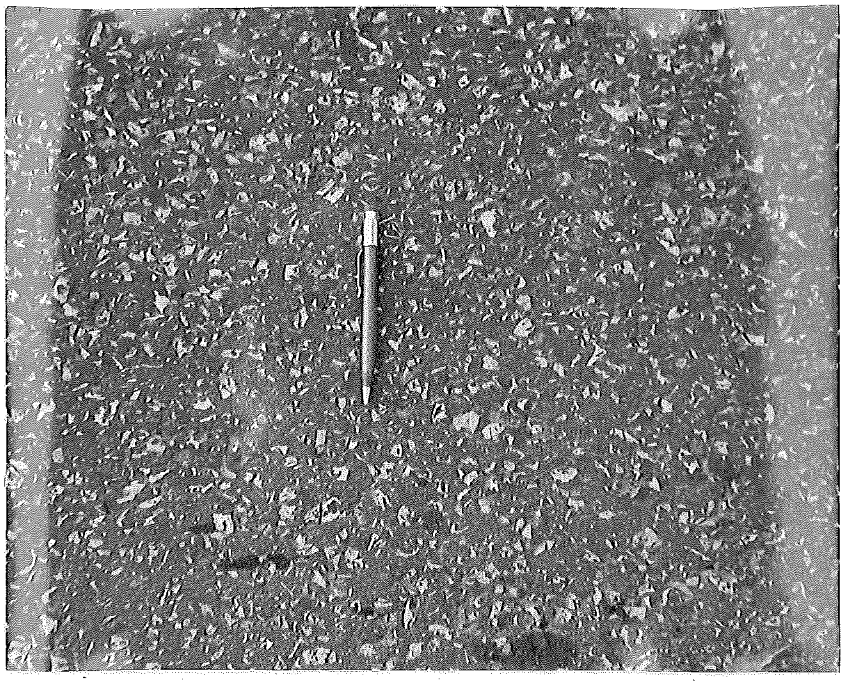

Figure 4. View showing Dolese & Shephard aggregate on Bituminous Concrete Resurfacing 1/4 mile west of Three Oaks on M-60 & US-112.

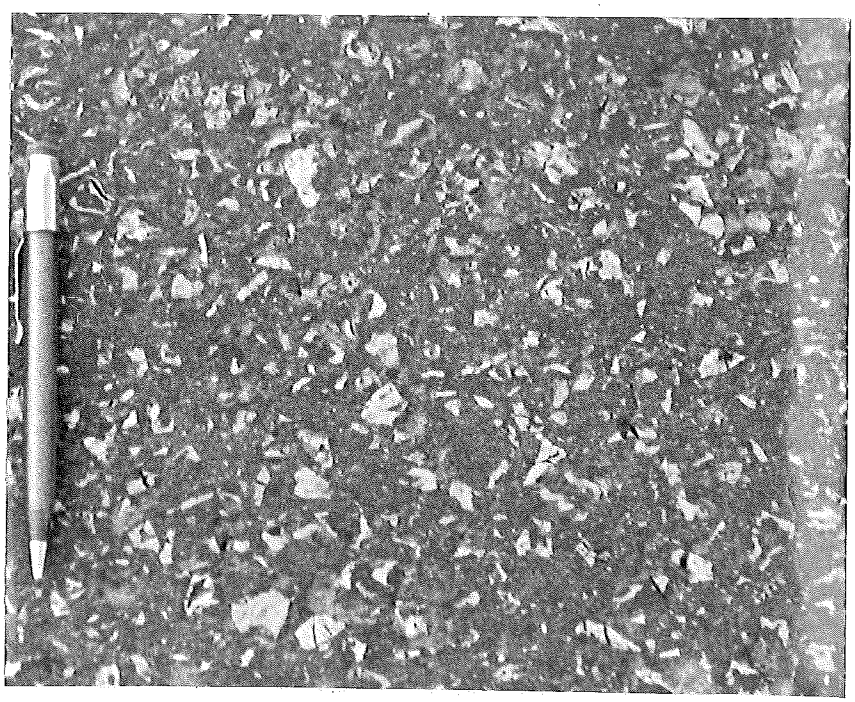

Figure 5. Portion of Figure (4) enlarged.

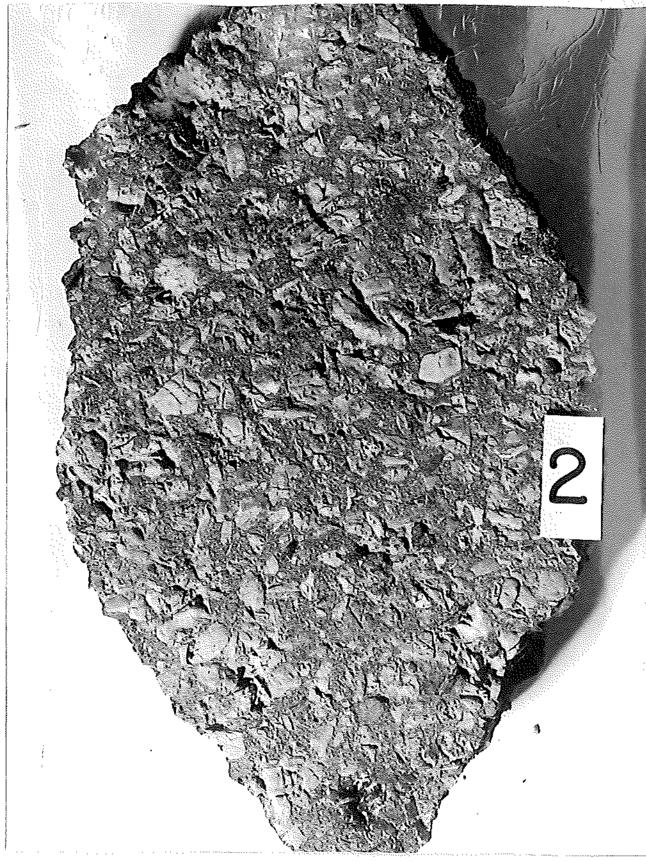

Figure 6. Sample of Section of Bituminous Concrete re-surfacing from area at east limits of Union, Const. Proj. 14-15, C7, removed 10-28-48. France Stone.

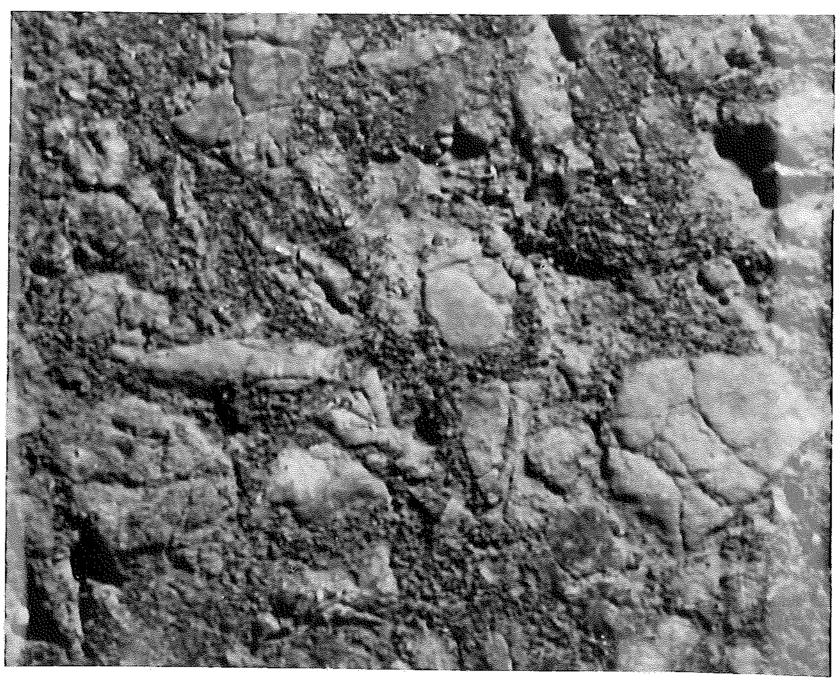

Figure 7. Portion of Figure (6) enlarged.

Figure 8. Sample of Bituminous Concrete Resurfacing from area on US-12 just east of Five Points, 3 miles east of Adamsville, Const. Proj. 14-15, C6, France Stone.

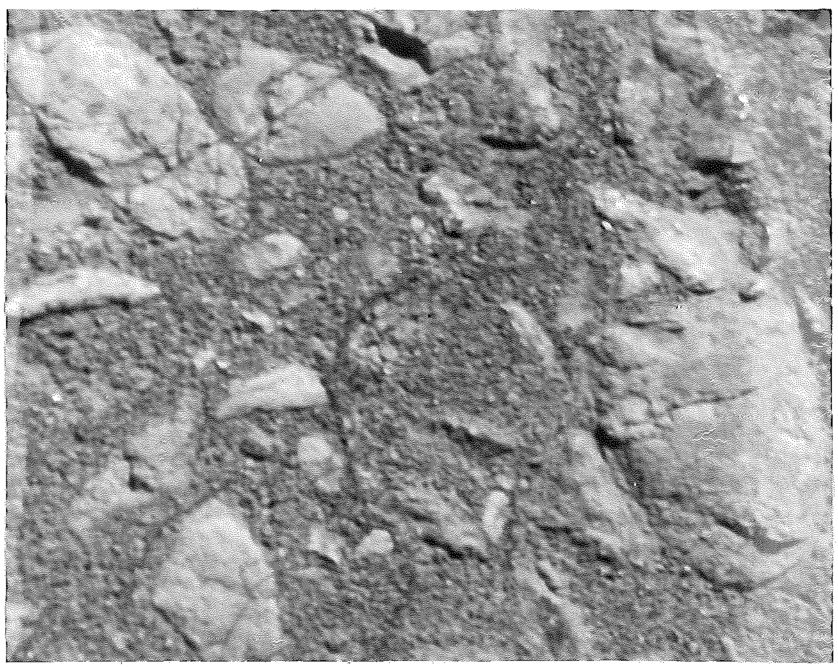

Figure 9. Portion of Figure (8) enlarged.

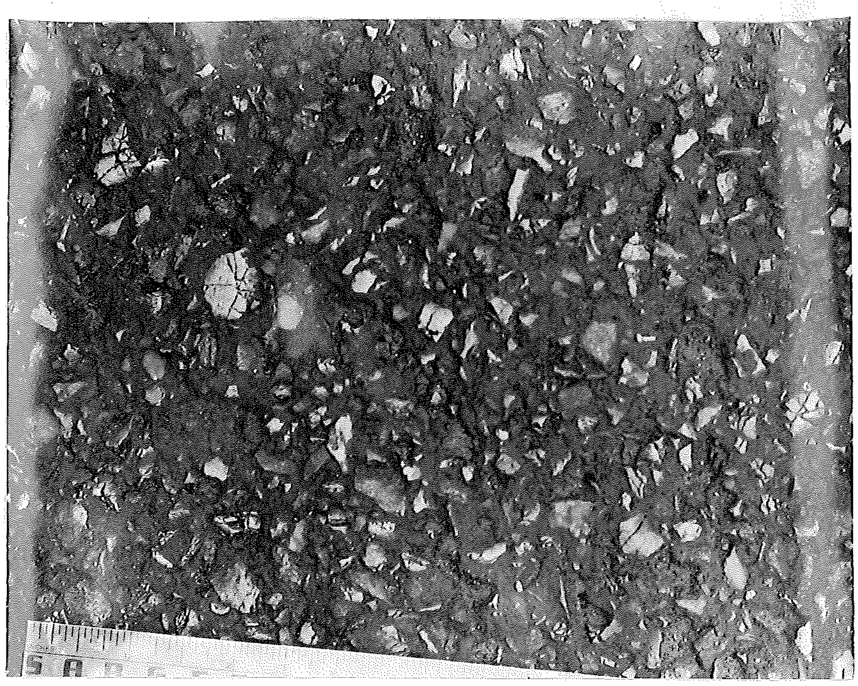

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Figure 10. Condition of surface of Recap at intersection of US-10 & M-21 in Flint, Const. Proj. M 25-38, C3, taken 2-23-49. Wallace Limestone, Bay Port.

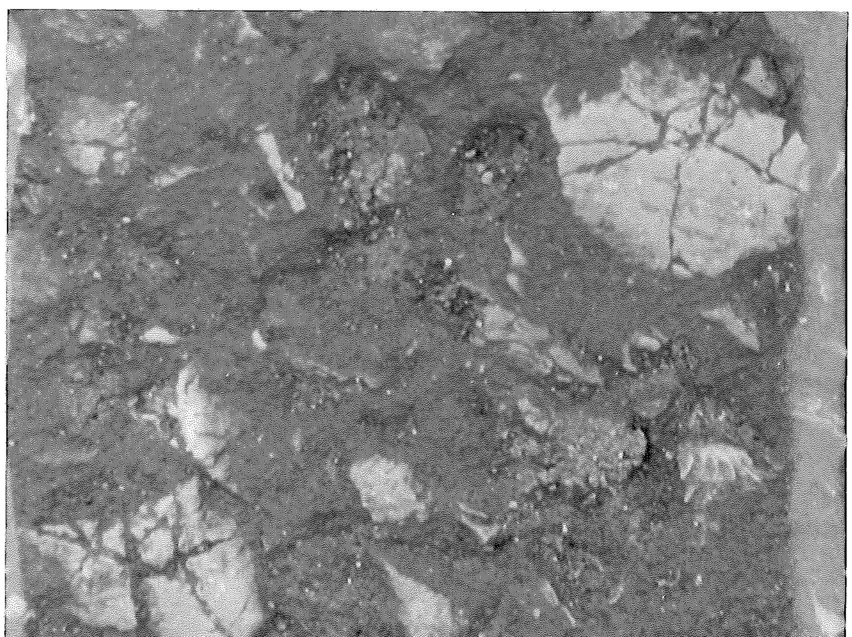

Figure 11. Portion of Figure (10) enlarged.

Figure 12. Condition of Surface of Recap on US-10 north of Flint, Const. Project F 25-4, C11, taken 2-23-49. Wallace Limestone.

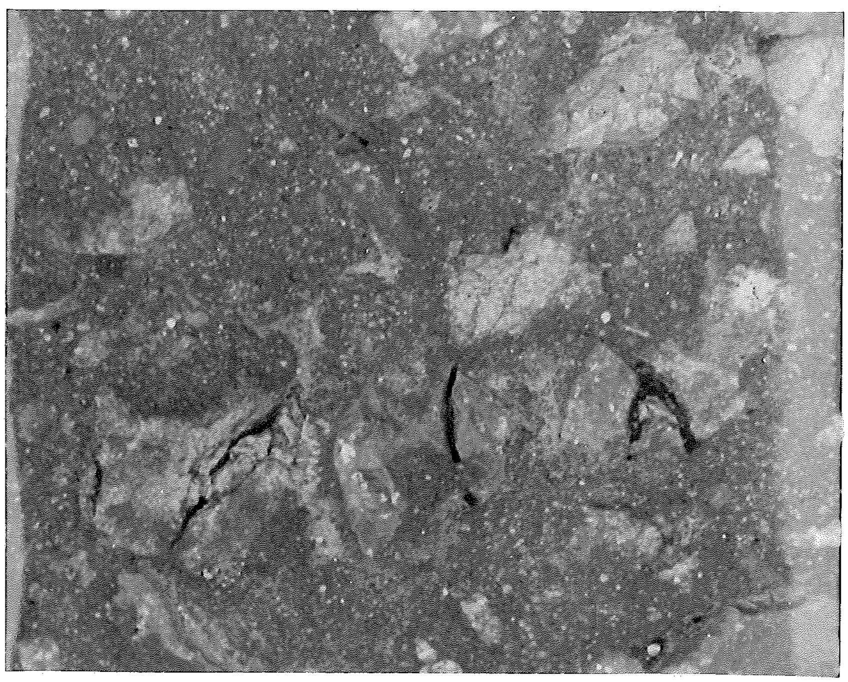

Figure 13. Portion of Figure (12) enlarged.

Figure 14. Wallace Limestone in Recap on M-57 1/2 mile west of US-10, Const. Project M 25-42, C3. Taken 2-23-49.

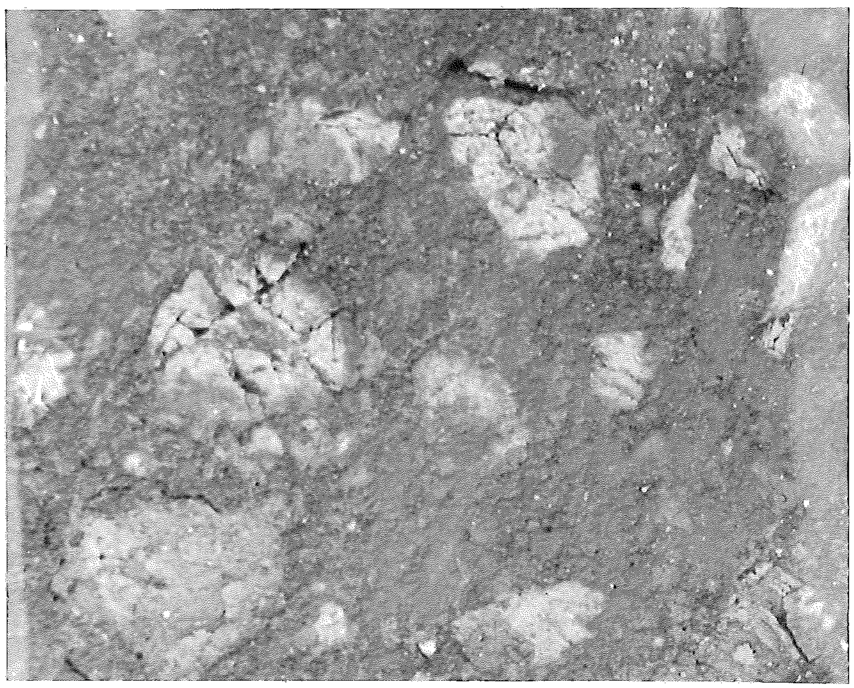

Figure 15. Portion of Figure (14) enlarged.

Figure 16. Wallace Limestone in Recap on US-10 north of Flint, Const. Proj. F 25-4, C11. Shows condition on 2-23-49.

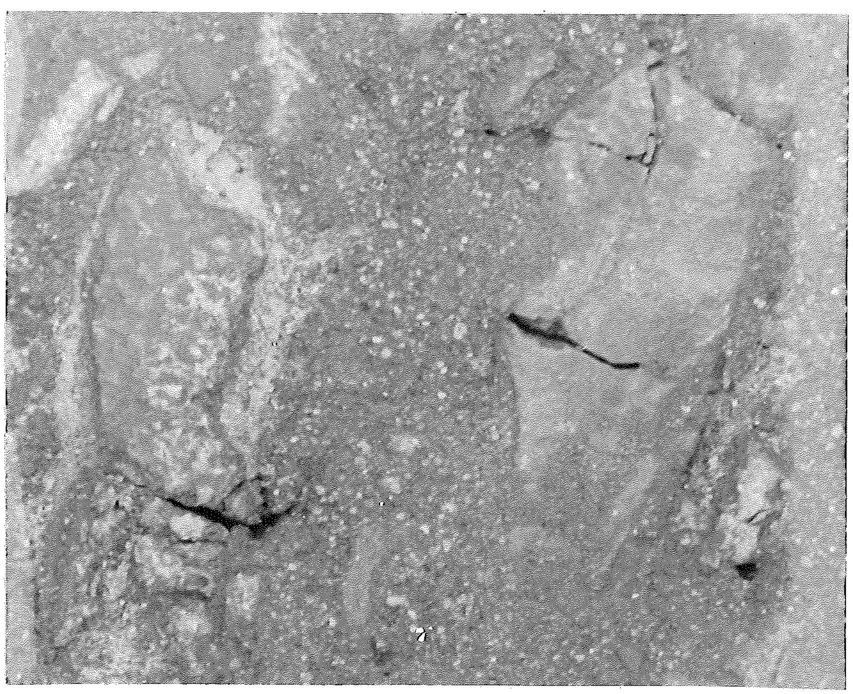

Figure 17. Portion of Figure (16) enlarged.