THE STRIPPING OF PENETRATION 85-100 ASPHALT FROM SILICATE AGGREGATE ROCKS

—A LABORATORY STUDY—

by

Hollis N. Walker
Highway Materials Research Analyst

Virginia Highway Research Council
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SUMMARY

In Virginia stripping has occurred when certain of the acidic silicate rocks have been used as aggregate in bituminous paving. The purpose of this project was to discover which kinds of silicate aggregate would be most apt to remain well bonded in bituminous mixes and which would be more apt to have a poor bond and become stripped from their binders.

1. Neither the boiling test nor the classical static immersion test differentiated between the bonding abilities of the various types of acidic silicate rocks when used with a penetration 85-100 asphalt binder.

2. If a test which will so differentiate is needed, the heated static immersion test described in this report or one of the tests described in some of the more recent literature (9, 24) might be used for that purpose.

3. By means of the heated static immerson test it was determined that when one quarry is compared with another, the lighter colored, coarse grained aggregates, especially those whose composition is highly acidic and which contain little secondary mineralization, seem more apt to have a poor ability to remain bonded to penetration asphalt. Conversely, it was determined that aggregates which are darker colored and finer grained are more apt to have a good ability to remain bonded to bitumen.

4. Within a single quarry where the influence of secondary mineralization is the same throughout all the material, in all cases tested, the heated static immersion test showed the darker colored and fine grained material to have a better ability to remain bonded to bitumen than did the lighter colored and coarser grained material.

5. Whereas washing may improve the ability to remain bonded to bituminous coatings in the case of some aggregates (#28 and P-55), in the case of highly biotitic aggregates (P-1, P-10, P-51, and P-53) washing may lessen the bonding ability.

6. No exact correlation has been established between the specific mineralogic composition or textural type of a rock and its ability to retain bituminous coating. It is, therefore, recommended

that each source of acidic silicate rocks be considered on its individual merits and no definite prediction of probable behavior in bituminous paving be made until representative samples of the aggregate have been subjected to empirical testing methods.

7. It is further recommended that whenever the run of aggregate from a quarry becomes more coarse grained or lighter in color that type of rock should be restricted to limited use.

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INTRODUCTION

Stripping causes economic loss and is considered as a failure of the technology to predict the probable behavior of the materials composing a bituminous mix. Most failures due to stripping are found in surface treatments, open-graded mixes, and surface courses. The term stripping is used to describe several different types of deterioration in which the aggregate particles become detached from the bituminous binder. The lack of adhesion between the aggregate and bituminous binder is usually thought to be caused by the lack of formation of a proper bond between the 2 materials or the stripping of the binder from the aggregate by an agent such as water. The strength of the bond between the stone and the asphalt is a function of the surface properties of the 2 materials. In Virginia stripping has occurred when certain of the granitic and gneissic rocks of the Piedmont and certain quartzites of the Valley have been used.

The Piedmont area of the state is underlain by a large variety of igneous and metamorphic rocks.(1, 2, 3) The varieties of rock in this area that are suitable for aggregate range in lithologic types from the basalts and diabases, through the many varied granites, gneisses and aplites, to the pegmatites, arkoses, quartz veins and the quartzites. These are all silicate rocks as they are composed of minerals in which silicon dioxide is a major chemical building block. The silicate rocks are classically divided into 2 types: basic and acidic.

The basic silicate rocks are those which are low in the minerals quartz and the acidic, or alkalic feldspars, that is, those feldspars containing potassium and sodium. They are high in minerals containing magnesium and iron, and may contain a large proportion of the calcium bearing feldspars, or so-called basic feldspars. Basic rocks are usually dark in color: black, brown, or green. Basalt and diabase are classed as basic types of rock.

Acidic silicate rocks are composed chiefly of the alkalic and intermediate feldspars, and quartz. Magnesium and iron bearing minerals do occur in these rocks but usually in relatively small quantities. The most common dark colored mineral found in acidic silicate rocks is the dark brown to black mica, biotite. The acidic silicate rocks are therefore usually light in color — white, gray, pink and light brown — and may be streaked or specked with certain dark minerals such as biotite. Quartz veins, granite, and most gneisses and pegmatites are classed as acidic rocks.

A search of the literature revealed that some investigators (4, 5, 6, 7) have considered stripping to be more apt to occur with acidic silicate rocks than with basic silicates. A few investigators (8, 9) obtained contradictory data, and several others (10, 11, 12, 13) reported results which in part seem to support the thesis that basic rocks perform better than acidic rocks but are also, in part, contradictory to this thesis.

An investigation of the performance of silicate aggregates in the pavements of Virginia highways revealed that none of the basic silicate rocks had been reported to have caused stripping, and that only certain of the acidic silicate rocks were thought to have been associated with poor performance, and that other acidic silicate rocks were considered to perform very well.

It was with this background that it was decided to design a project that would discover which kinds of silicate aggregate would be most apt to remain well bonded in bituminous mixes and which would be more apt to have a poor bond with bituminous materials and become stripped from their binders.

PREVIOUS RESEARCH

Adhesion between aggregates of various kinds and bitumen-asphalt-tar binders has been the subject of intensive investigation by many researchers of many different specialities. An excellent summary of the methods used and the results obtained may be found in the state of the art report by Majidzadeh and Brovold (4). They include an excellent bibliography and their summary is more extensive than any attempt that will be made here.

A literature search has not revealed any detailed studies correlating the mineralogic and textural properties of the acidic silicate rocks with their adhesiveness to bituminous binders.

PURPOSE

The purpose of this project was to find whether the knowledge of the mineralogic composition and/or the textural features of silicate aggregate could be used as criteria upon which to base a prediction of the ability of such aggregate to retain its bond with bituminous binders in the presence of water and to ascertain which mineralogic and textural features have a bearing upon this ability.

SCOPE

This project necessitated the design of a simple laboratory test which would make it possible for laboratory personnel to differentiate between the various degrees of bonding ability possessed by different silicate aggregates.

The aggregates studied were, with one exception, those which have been used by the Virginia Department of Highways. All of them meet the specifications for coarse aggregates as outlined in the Highway Department's Road and Bridge Specifications(14). An effort was made to include a wide variety of mineralogic compositions and textural types and a number of aggregates known to have performed well as well as some known to have performed poorly. Fifteen Virginia aggregates were selected (see Figure 1).

In addition to the Virginia aggregates studied, 26 varieties of rock and minerals obtained from a supplier of mineral specimens were test by the same methods to determine whether or not the results from testing these samples would corroborate the results obtained by testing the Virginia aggregate. Petrographically, the basic silicate rocks are classically defined as differentiated from the acidic silicate rocks by the quantity and type of feldspar mineral or minerals present. An effort was made to include all the varieties of feldspar minerals. The other minerals included are those commonly found in the granitic and gneissic rocks of the Piedmont area of Virginia. The rocks included are mainly granites and schists.

A detailed petrographic study was made of all the aggregates and rock and mineral specimens used.

Because of time limitations, the only binder used was an asphalt of 85-100 penetration.

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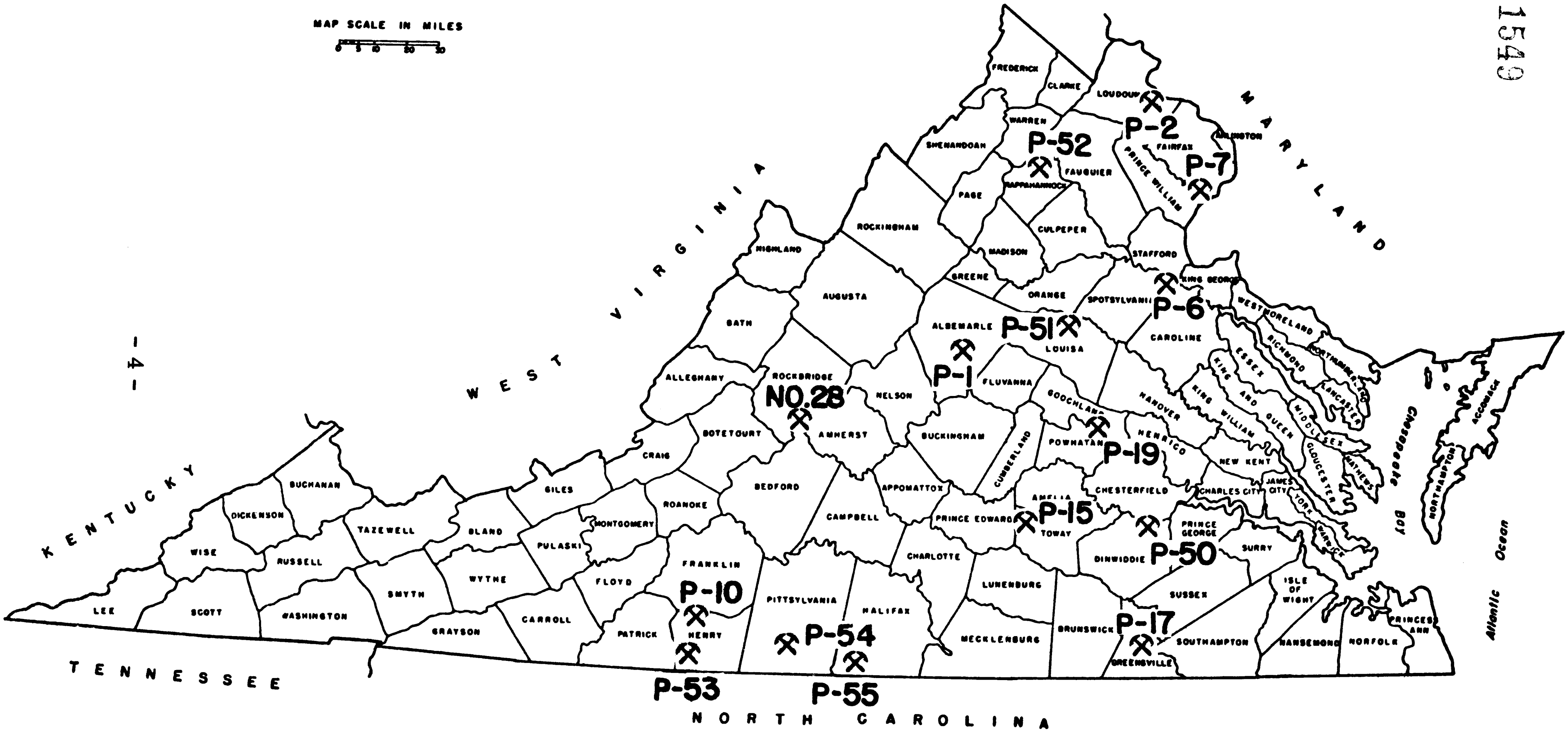

Figure 1. Location of the Virginia aggregates studied.

TEST METHOD

Background

It was necessary to find a simple, quick laboratory test which decisively differentiated between those silicate aggregates known to perform well and those known to perform poorly. An extensive survey of the literature did not reveal that any other workers had designed tests to specifically differentiate between the adhesive characteristics of the acidic silicate rocks. (6, 10, 11, 12, 13, 15) Most of the stripping tests used in the past have been devised to make comparisons between the various asphalts, tars, emulsions and additives rather than to evaluate aggregates and make comparisons between them. Many of the tests, such as the simulated traffic tests, require equipment and/or laboratory space which was not available for use on this project. All methods considered feasible were studied before any decision was made.

The immersion-compression test (16, 17) is one of the better known tests. Its limitations have been discussed by Brown (18) in 1961 and by Field and Phang (19) in 1967. Because the procedure is time consuming and uses sophisticated apparatus, it was not tried for use in this study.

The Riedel-Weber boiling test is one of the older test methods. It has been criticized by several investigators (12, 13, 19) on the grounds that a chemical not normally found in bituminous pavement is used as an active testing agent. The lithium salt photometer test method (15) has been similarly criticized because it is not known whether the lithium salt affects the results of the test or not.

Simple tests which measure resistance to stripping in water have been reported by many authors. These include several different kinds of static immersion tests, immersion tests with agitation and the testing of surface treatment materials by placing them on a bituminous coated plate or dish. (10, 20, 21, 22, 23) Most of these tests were originally designed for testing emulsions but it was felt that they might be adapted for use with 85-100 penetration asphalts to determine the differences between aggregates. Extensive pilot tests were performed with 3 of these tests methods.

Pilot Testing

The Virginia strip test for surface mixtures, or boiling test, (22) was tried with triplicate samples of 7 different aggregates of widely differing composition. The test differentiated between the abilities of the carbonate and silicate aggregates to remain bonded to bituminous coatings but gave the same results with all of the silicate aggregates. Some of these silicate aggregates had shown poor performance, yet the boiling test stripped the bitumen from all of these silicates with equal facility. Various modifications of this test were tried with new sets of silicate aggregate samples, various boiling times, and several methods of curing the samples before test. No boiling method was found which differentiated between the various types of acidic silicate aggregates such as granites and gneisses.

The gravity plus immersion plate test developed by Arnold(20) in 1968 was investigated by running a series of pilot tests. It was found that the aggregate particles which separated from the plate were the ones with the greatest mass and that the failure was in cohesion rather than in adhesion. This test was not further investigated.

The static immersion test(21) was investigated with a similar series of pilot tests. Granitic and gneissic aggregates were used with the bitumen. This test did not differentiate between the aggregates. Stripping was nearly nonexistent. It was felt that this test might be of use in differentiating between the acidic aggregates if the mix specimens were stored in water for longer periods of time, probably several weeks. It was decided to try accelerating this test method by raising the temperature of the water in which the mix specimens were tested.

Development of the Heated Static Immersion Test

The average maximum temperature reached in bituminous pavements in Virginia is considered to be 140°F. This temperature was therefore chosen as the maximum which should be used in accelerating the static immersion test. Numerous pilot runs were made with selections of silicate rocks. Some of these aggregates had been reported to have been used in pavements which had exhibited stripping. Others have been known never to be used in pavements which have deteriorated in this manner. Samples were prepared in triplicate. For each sample 100 grams of aggregate passing the 1/2" sieve but retained upon the 3/8" sieve was heated to 300°F for a minimum of 2 hours to drive off excess moisture and then each was mixed with 5 grams of the bitumen heated to 250°F. After the samples were mixed they were stored on aluminum foil to age overnight. They were then placed in distilled water in individual beakers and the beakers placed in a 140°F water bath.

The surfaces of some varieties of granitic aggregate became exposed more quickly than did the surfaces of others. Very little of the bitumen floated off. It merely pulled back and thickened (see Figure 2).

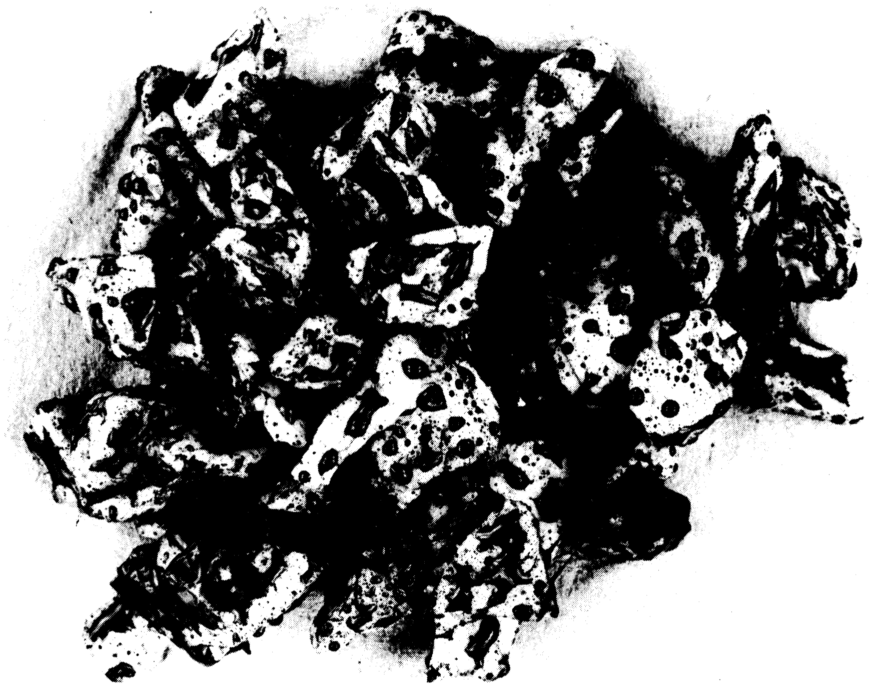

Figure 2. Sample of the mineral quartz after the heated static immersion test; Class E retention of bituminous coating (about actual size).

The time in the water bath was determined by making repeat runs until a time interval was established that created the greatest visually observable differences in the amount of aggregate surface exposed between the various silicate aggregates tested. It is known (24, 25) that visual estimates of surface area lose accuracy severely when the areas viewed are less different from each other than 5% to 95%. Pilot testing determined that 12 minutes was the optimum time for the beakers to remain in the 140°F water bath.

When dry the samples were examined by a panel of observers who judged how the samples should be classed. The following 5 categories were used.

Excellent retention of bituminous coating	Class A
Good retention of bituminous coating	Class B
Average retention of bituminous coating	Class C

Poor retention of bituminous coating	Class D
Very poor retention of bituminous coating	Class E

Classes A, B, and C were passing and Classes D and E failing. Failure was placed at the point at which visually observable differences became more difficult and less accurate, approximately 95%. It was easier for the observers to distinguish between Classes A, B, and C than to distinguish between D and E. The results were compared with the scanty service records available. The few aggregates that had been used in pavement that had exhibited true stripping had under test been stripped so that they were in the D and E Classes. The aggregates of known good performance had not stripped much under test and were in the A, B, and C Classes. Because of its sensitivity to small differences between acidic silicate aggregates and because of its agreement with performance in service, this test was selected for use in this investigation.

Further details of the testing procedure may be found in the Appendix.

PROCEDURES

Preparation of the Samples of Virginia Aggregates

Samples of crushed stone were obtained from each quarry. When feasible each quarry was visited and hand specimens obtained of each lithologic type of rock found.

The crushed stone was sieved and the -1/2" + 3/8" portion reserved for testing. A sample splitter was used to cut out 4 random samples of the aggregate from each quarry. Another portion of the sized aggregate was washed with vigorous agitation in running water until the water ran clean, and 4 washed samples were prepared. A portion of the washed aggregate was examined with a lowpower microscope both when wet and dry. This portion was sorted into whatever lithologic types were represented. Four samples of each type were prepared whenever there was sufficient material available to do so. A total of 238 samples of aggregate and types of aggregate were prepared for testing.

Preparation of the Mineral and Out-of-State Rock Specimens

The specimens of pure minerals and the out-of-state rock specimens were prepared for the testing procedure by crushing and cracking and when necessary cutting with a diamond saw. Four test samples of each kind were desired but the amount of samples available was limited in some cases. A total of 156 samples of minerals and purchased rock specimens were prepared for testing.

Testing

The samples were tested for ability to retain bituminous coating in the presence of water as described under "Development of the Heated Static Immersion Test" and in the Appendix.

The tested samples were carefully examined with the stereoscopic microscope to determine which kind or kinds of aggregate surfaces were apt to lose their bituminous coating.

Eighty-seven thin sections were made from the samples of Virginia aggregates, their source rocks and their lithologic subdivisions. An intensive petrographic examination of these rocks with the stereoscopic and polarizing microscope yielded data concerning the mineralogic composition and the texture of the aggregates. The details of the petrographic data are on file in the Library of the Virginia Highway Research Council.

RESULTS AND DISCUSSION

Samples of Virginia Aggregates

Results of the Heated Static Immersion Test for Stripping

Table I lists the Virginia aggregates tested and the class of retention exhibited by the random unwashed samples and by the random washed samples. Each result shown is the mean of 4 or more samples tested. The results of testing the lithologic subdivisions of these aggregate samples are listed in Table II. Whenever sufficient sample was available, each result is the mean of 4 samples tested.

TABLE I

RESULTS OF THE HEATED STATIC IMMERSION TEST FOR THE RANDOM SAMPLES PREPARED FROM VIRGINIA AGGREGATE QUARRIES

Classes A, B, & C passed the heated static immersion test

Classes D & E failed the heated static immersion test

			Class of Bitumen retention exhibited by	
Quarry No.	Lithology	Remarks	Unwashed Samples	Washed Samples
28	Quartzite (Erwin quartzite)	Most siliceous aggregate studied*	C	B
P-1	Porphryroblastic biotite feldspar gneiss (Lovingston formation)	Known good performance	B	C
P-2	Gabbro (Triassic stock)	Most basic aggregate studied Known good performance	A	B
P-6	Biotite granite with hornblendite dikes (Northern Petersburg granite)	Known good performance Two different lithologies (granite (hornblendite	C	C C) B)
P-7	Feldspathic, quartz-sericite gneiss (Uncertain age)	*	E	C
P-10	Biotite-feldspar gneiss with garnet (Precambrian?)	*	B	C
P-15	Granitic-Adamellite (Columbia granite)	*	E	E
P-17	Granitic-Adamellite (Southern Petersburg granite)	*	E	E
P-19	Granitic cataclastic gneiss with pegmatite veins (Wissahickon gneiss)	*	D	D
P-50	Granitic quartz-feldspar gneiss (Central Petersburg granite)	Not known to have shown stripping	B	B
P-51	Banded biotite-quartz-feldspar (Uncertain age)	Not known to have shown stripping	B	D
P-52	Banded quartz-feldspar gneiss with dikes and pegmatite veins (Virginia Blue Ridge complex)	Not widely used	C	C
P-53	Biotite-feldspar gneiss with garnet (Precambrian ?)	*	B	C
P-54	Fine to medium grained, iron oxide-rich arkose (Triassic)	Not widely used	E	E
P-55	Banded granitic gneiss (Shelton granite gneiss)	Not widely used	E	D

* Deterioration of pavements in which these aggregates have been used has been field judged to be stripping and verbally reported. Further data on aggregates 28, P-10, and P-53 may be found in the discussion which follows.

TABLE II

RESULTS OF THE HEATED STATIC IMMERSION TEST FOR THE LITHOLOGIC SUBDIVISIONS OF THE SAMPLES FROM THE VIRGINIA AGGREGATE QUARRIES

(All samples washed before test
Quarries not listed were not subdivided)

Quarry No.	Class retention of random sample	Lithologic Subdivisions in Random Sample: Description of subdivisions tested	Lithologic Subdivisions in Random Sample: Amount present in random sample	Class of bitumen retention	Subdivisions vs. Random Samples (Lithologic classifications of the subdivisions by comparison with the random sample. The word listed describes the relative degree of bituminous retention by comparison with the random sample): Finer grained	More basic	About the same lithology	More quartz and alkali feldspar	Coarser grained
P-1	C	Mixed composition, medium grained	5/8	C			same		
		Rich in feldspar, coarse grained	1/4	D				worse	worse
		Rich in biotite, fine grained	1/8	C	same	same			
P-6	C	Hornblendite - intermediate to basic feldspar, quartz and horndlende	1/2	B		better			
		Biotite granite - alkali feldspar, quartz and biotite	1/2	C				same	
		Pegmatite vein material, coarse grained	minor	C				same	same
P-7	B	Sericite rich, medium-fine grained	1/2	B	same				
		Mixed composition, medium-coarse grained	nearly 1/4	C					worse
		Coarsest grained, more alkali feldspar, and quartz	nearly 1/4	D				worse	worse
		Chlorite rich, fine grained	minor	A	better	better			
		Quartz masses, coarse grained	minor	C				worse	worse
P-10	C	Mixed composition and texture	nearly 1/3	C			same		
		Biotite rich, coarse grained	nearly 1/3	C		same			same
		Quartz and feldspar, coarse grained	nearly 1/3	D				worse	worse
		Biotite rich, fine grained	1/10	C	same	same			
		Garnet rich, medium grained	minor	C		same			
		Biotite and sillimanite, coarse grained	minor	C		same			same
		With pyrite and hornblende	trace	C		same			
		With diopside	trace	B		better			
P-19	D	Mixed composition, texture	1/2	D			same		
		Pegmatitic: quartz, feldspar coarse grained	1/3	E				worse	worse
		Mixed composition, finer grained	1/6	D	same				
		Zeolites on surface	minor	C		better			
		Biotite rich, medium grained	minor	B		better			
P-50	B	Mixed composition, medium grained	1/2	B			same		
		Chlorite and biotite rich, finer grained	1/4	A	better	better			
		Feldspar rich, coarse grained	minor	B				same	same
		Feldspar rich, fine grained	minor	B	same			same	
		Very coarse grained feldspar, epidosite, trace chlorite	minor	B				same	same
P-51	D	Feldspar rich, coarse grained	4/5	D			same		
		Rich in biotite or hornblende finer grained	1/5	C	better	better			
P-52	C	Mixed composition, medium grained	3/4	C			same		
		Biotite rich, medium grained	1/8	B		better			
		Quartz and feldspar, coarse grained	1/8	C				same	same
P-53	C	Mixed composition and texture	1/2	C			same		
		Quartz and feldspar, coarse grained	1/3	D				worse	worse
		Biotite rich, coarse grained	1/5	C		same			same
		Biotite and sillimanite, coarse grained	minor	B		better			better
		Biotite rich, fine grained	minor	B	better	better			
		With pyroxene, medium grained	trace	B		better			
P-54	E	Medium grained arkose	1/2	E			same		
		Coarse grained arkose	1/4	E					same
		Fine grained arkose with iron oxides and chlorite	1/4	C	better	better			

Discussion of the Results of the Testing of Virginia Aggregates

Unwashed random samples vs. washed random samples

Washing did not improve the bonding ability of all of the aggregates tested. It did improve the bonding ability of 3 of the more acidic aggregates. These are No. 28, P-7, and P-55. Seven of the aggregates showed no difference between the bonding ability of the washed and the unwashed sample groups. The aggregates not appreciably affected by washing are P-6, P-15, P-17, P-19, P-50, P-52, and P-54. These aggregates are all acidic silicate rocks.

The biotite gneisses, (P-1, P-10, P-51, P-53) and the most basic rock tested, the gabbro (P-2), all showed a definite deterioration in ability to remain bonded to bitumen after they had been washed. Although the biotite gneisses are often classed with the acidic silicates, they do contain a larger quantity of the dark mineral biotite and are more basic than the aggregates listed in the preceding paragraph. No explanation for the change in bonding ability with washing is known.

Mineralogic influence on bitumen bonding ability, comparison between quarries

The results from aggregates P-15, P-17, and P-55 indicate that the lighter colored, coarse grained aggregates whose composition is highly acidic and which contain little secondary mineralization are the types of aggregate most apt to have a poor ability to remain bonded to bitumen coatings.

The results from P-1, P-2, P-10, P-51, and P-53 indicate that if a rock may be classed as basic in composition or if it contains appreciable quantities of dark minerals, it is apt to have a good ability to remain bonded to bitumen coatings.

The good performance under test of the samples from P-50 and P-52 appear to the petrographer to be due to well disseminated, fine grained minerals of secondary origin, which permeate all through the rocks of these quarries. The rock in Quarry P-19 also shows much contortion and secondary mineralization. It probably owes its poor performance to the large proportion of coarse grained quartz and feldspar from its pegmatite veins. Quarry P-7 also produces a rock that contains much fine grained mineralization. It probably owes its poor performance to the dense fabric, the quartz-like surface texture, and the particular nature of the fine grained minerals present.

The aggregate from P-6 is a mixture of hornblendite and a pure unaltered granite, an acidic silicate. Its good performance in pavements can be explained by the presence of the dark mineral hornblende. No explanation is offered for the performance of the granitic phase when tested alone.

P-54 aggregate is an arkose and its performance under test indicated that its ability to remain bonded is more influenced by the high percentages of quartz and feldspar present than by the presence of fine grained iron oxides, chlorite, and mica.

The aggregate from Quarry 28 is quartzite. It performed poorly when unwashed and much better when washed. Whereas washing the aggregate from this quarry may make some improvement in its behavior it is not felt that this would provide a complete answer. Samples of aged pavement constructed with this aggregate have been examined. In such samples the bitumen has become brittle and lacking in cohesivity. The aggregate is porous because much of the feldspar has weathered to clay. Some of the components of the bitumen have been drawn deep within the aggregate particles. Too little bitumen remains to hold the aggregate together. If sufficient bitumen was used with this aggregate so that the mixture would retain cohesivity with age, it probable that the pavement would be too "fat" when newly laid. It is possible that selective quarrying in order to avoid the most heavily weathered porous portions might produce an aggregate less apt to absorb bitumen. Less porous portions of the aggregate from this quarry would be composed of fresh unaltered quartz and minor amounts of fresh alkali feldspar. Such an aggregate would be apt to have a poor ability to remain bonded to bitumen.

The biotitic gneisses from Quarries P-10 and P-53 have been reported to have been used in pavements which have shown a form of deterioration which was at first thought to be stripping. Both of these aggregates behaved well under test. This good performance may be attributed to the presence of many small veinlets of calcite as well as to the presence of abundant biotite. The unusual behavior of the mica minerals such as biotite are further discussed later in this report.

Because the ability of the aggregate from a specific locality to remain bonded to bituminous coating seems to be much influenced by the finely disseminated secondary minerals present, and because the quality and quantity of these minerals is very difficult to assess by ordinary petrographic means, it has been concluded that detailed petrographic data will not make possible predictions as to the probable behavior of the aggregate from specific quarries.

Mineralogic influence on bonding ability

The data in Table II show that when the results of testing the various lithologic subdivisions from within a single quarry are examined, the more basic portions and the finer grained portions have exhibited the same or better ability to retain bituminous coatings as has the random sample and (with one exception) the coarser grained and the more quartz and feldspar rich portions of the sample have exhibited the same or worse ability to retain bituminous coating as has the random sample.

Results of the Microscopic Examination of Test Samples

After the panel of observers had completed their examination the samples were examined with a lowpower microscope. It was noted that the stripping was most pronounced at sharp corners and edges of the fragments of aggregate (see Figures 3 and 4). It can be assumed that the original coating of bitumen is because of surface tension, thinner on sharp corners and edges. The original conformation of the coating is probably only one of the reasons for the removal of the coating on the edges and corners. It is recognized that these less massive areas of the fragments might become more quickly warmed in the environment of the test than do the more massive rounded corners and large flat surfaces. If the temperature of the aggregate is significantly higher at the corners and edges, then the stripping caused by raised temperature will be more quickly observable there.

The surfaces of the aggregate which had been exposed by the pulling back of the bituminous coating were carefully examined. It was noted that the exposed areas were frequently cleavage surfaces of feldspars and fractures surfaces of quartz (see Figure 5). Wherever a sliver of biotite or chlorite or muscovite occurred within an area of stripped quartz or feldspar there was usually a droplet of bitumen attached to it.

Figure 3. Macrograph of a fragment of Oligoclase I after heated static immersion test. The whole sample shows Class E retention (5 times actual size).

Figure 4. Macrograph of a fragment of biotite granite (medium coarse grained) after heated static immersion test. The whole sample showed Class E retention of bituminous coating (5 times actual size).

Figure 5. Macrograph of a fragment of red biotite granite (very coarse grained) after heated static immersion test. This fragment is a portion of a microcline crystal. The whole sample showed Class E retention of bituminous coating.

Results for Mineral Specimens and Out-of-State Rock Specimens

The results from the mineral and out-of-state rock specimens were classed in the same way as were the results of the Virginia aggregate samples; Table III lists the data. It can be seen that with one exception the alkali and intermediate fledspars all failed under the conditions of the heated static immersion test. The behavior of Oligoclase IV was probably due to the presence of disseminated calcite. The basic feldspars all passed the test with one exception, Labradorite I. Labradorite I was an unusual variety of this mineral. It was much lighter colored than is usual and its composition was very close to that of andesine. The data from the "other minerals" tested show that the light colored acidic minerals all failed the test and that, with the exception of biotite, the dark colored basic minerals all passed. Among the silicate rocks tested the only rock that passed was the relatively dark colored biotite-muscovite schist.

It was noted above that bitumen adhered well to slivers of the micaceous minerals when these minerals were present in the aggregate rock samples tested. Therefore the behavior of the specimens of the mica minerals were examined very closely. In nature the largest part of the surface area of these minerals is usually the basal cleavage surface. The fragments tested had 4 sawn surfaces to 2 cleavage surfaces. The bitumen adhered well to the cleavage surfaces. The sawn surfaces contained stripped areas, roughly lenticular in shape with their long dimension parallel to the natural cleavage of the mineral fragments (see Figure 6). It appeared that the better the adhesion was to the cleavage surfaces, the worse was the stripping on the sawn surfaces. When mica mineral fragments were split open along the cleavage lines in the middle of these lenticular bare areas, it was found that the bitumen coating had been drawn into the fragments and onto the cleavage surfaces.

It is believed that the deterioration reported to be associated with the highly biotitic aggregates from Quarries P-10 and P-53 was probably caused by absorption of the binder into the biotite, leaving too little interfragment binder, rather than deterioration by a real lack of adhesion, stripping. The use of a larger amount of bitumen has prevented early deterioration of pavements fabricated with these aggregates.

TABLE III

TEST RESULTS FOR MINERAL AND OUT-OF-STATE ROCK SPECIMENS

Variety	Description	Source	Class of Bitumen Retention
Alkali Feldspars (usually from acidic silicate rocks)			
Microcline (I)	Green crystal fragments, (Amazon stone)	Purchased - Colorado	D
Microcline (II)	Massive, gray and cream colored	Purchased - South Dakota	E
Perthite	Massive lavender-gray with sericite alteration disseminated throughout	Purchased - Ontario	E
Anorthoclase	Coarsely crystallized, gray with blue opalescence, very minor biotite and opaque minerals present	Purchased - Norway	E
Albite	White, clevelandite type	Purchased - Virginia	E
Intermediate Feldspars			
Oligoclase (I)	Coarsely crystallized, pale pink	Purchased - South Dakota	E
Oligoclase (II)	Crystal fragments, white to pale pink	Purchased - North Carolina	E
Oligoclase (III)	White, trace biotite	Purchased - Norway	E
Oligoclase (IV)	Pale gray-green, disseminated calcite throughout	Purchased - Ontario	B
Andesine in andesinite	Cream colored, kaolinized with quartz (may be considered as either a rock or mineral)	Purchased - Montana	D
Basic Feldspars			
Labradorite (I)	Pale green to pale gray, translucent massive and fractured	Purchased - New York	E
~~Labradorite (II)~~	Coarsely crystallized, dark gray-green	Purchased - Quebec	A
Bytownite	Coarsely crystallized, ~~pale green and lavender~~	Purchased - Minnesota	B
Anorthite	Coarsely crystallized anorthosite rock, cream-white with black pyroxene	Purchased - California	C
	(Iron stained Anorthosite from same source treated separately)		B
Other Minerals common in Granites and Gneisses			
Quartz	Massive white vein material	Collected - Virginia	E
Hornblende	Coarsely crystallized, greenish-black with minor veins of calcite	Purchased - New York	A
Muscovite (a mica mineral)	Silver-white, large crystal fragments, "books"	Purchased - Maine	C ?
Phlogopite (a mica mineral)	Golden-brown, large crystal fragments, "books"	Purchased - Ontario	E ?
Biotite (a mica mineral)	Shiny black, large crystal fragments, "books"	Purchased - Ontario	E ?
Chlorite	Satiny dark green, chlorite schist (may be considered as either a rock or a mineral)	Purchased - Vermont	A
Schists and Granitic Rocks			
Biotite-muscovite schist	Coarse, well foliated	Purchased - New York	C
Quartz-sericite schist	Medium grained, well foliated	Purchased - California	D
Aplite	Pink, medium-fine grained, granite composition, kaolinized	Purchased - Colorado	D
Biotite Granite	Coarse grained, pink, granite composition	Purchased - Rhode Island	E
White Granite	Coarse grained, quartz monzonite composition	Purchased - North Carolina	E
Red Biotite Granite	Very coarse grained, granite composition	Purchased - Colorado	E

Note: The results of the test with the mica minerals are marked with a question mark to indicate that it is not felt that these results would occur in normally crushed aggregate.

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Figure 6. Macrograph of the sawn side of a fragment of mica after the heated static immersion test. This surface is nearly perpendicular to cleavage direction. The whole sample showed Class C retention of bituminous coating (5 times actual size).

CONCLUSIONS AND RECOMMENDATIONS

Stripping Tests

Neither of the 2 simple tests for stripping, the boiling test(22) and the static immersion test,(21) can differentiate between the bonding abilities of the various types of acidic silicate rocks when used with bitumen binder. If such a test is needed, the heated static immersion test developed in this report or one of the newer tests(19, 25) recently described in the literature should be investigated for use in making evaluations of differences in bonding ability.

Washed vs. Unwashed Aggregate

Washing did not improve the bonding ability of all the aggregates tested, see Table I. Washing improved the bonding ability of 3 of the more acidic aggregates tested

(28, P-7, and P-55). It did not change the bonding ability of 7 aggregates (P-6, P-15, P-17, P-19, P-50, P-52, and P-54). When washed the most basic aggregate, P-2, showed a slight deterioration of its ability to remain bonded. The washed biotite gneisses (P-1, P-10, P-51, and P-53) all showed a definite deterioration of their ability to remain bonded. The highly biotitic aggregates are known to flake off and produce much dust while stockpiled. These aggregates are therefore often washed. The results obtained here probably indicate that these aggregates should not be washed routinely but only as required.

Correlation of Bonding Ability to Mineralogic Composition and Textural Type

Comparison of Bonding Abilities Between Quarries

The lighter colored, coarse grained aggregates, especially those whose composition is highly acidic and that contain little secondary mineralization, seem to be most apt to have a poor ability to remain bonded to semisolid bitumen.

The darker colored and finer grained aggregates seem to be most likely to have good ability to remain bonded.

Because of the difficulty in petrographically assessing fine grained secondary mineralization, no exact correlation has been established between the specific mineralogic composition and textural type of a rock and its ability to retain bitumen coating. It is therefore recommended that each source of acidic silicate rocks be considered on its individual merits and no definite prediction of probable behavior in bituminous paving be made until representative samples of the aggregate have been subjected to empirical testing methods.

Comparison of Varieties of Aggregate from within a Single Quarry

Within a single quarry the portion of the aggregate which is darkest and finest grained will be the aggregate which has the best bonding ability and that portion which is lightest colored and coarsest grained will be the aggregate that has the poorest ability to remain bonded.

It is recommended that whenever the aggregate from a quarry becomes coarse grained and light or pink in color, that type of rock should be restricted to limited use.

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APPENDIX

HEATED STATIC IMMERSION TEST

Equipment:

Oven at 300°F
Scales (±1 gram)
Hot plate 500°F
Copper beaker
Hot plate with surface at 275°F (+15° -5°)
Saucepans, spatulas, tongs, insulated gloves, small containers
Thermometers, aluminum foil
Beakers — 600 ml, glass
Water bath adjustable to 140°F (±0.5°F)
Paper towels, etc.
Stopwatch

Materials:

Four samples of each aggregate or aggregate type tested. The aggregate passed the 1/2" sieve and were retained on the 3/8" sieve. Each sample weighed at least 100 grams but not more than 100 grams plus one fragment of stone.

Semisolid, asphalt, penetration 85-100.

Distilled water, regular grade.

Procedure:

The samples were arrayed in random order by use of a random numbers table. They were then serially grouped into batches of 5 or 6 samples each. The samples in each batch were kept together until the test was completed.

The aggregate samples were placed in individual containers and heated in the 300°F oven for a minimum of 2 hours to drive off excess moisture. The bitumen was heated to 250°F in a copper beaker. Five grams of bitumen were placed in a preheated saucepan and the hot aggregate sample added. They were mixed with a spatula for 2 minutes; during the first 1-1/2 minutes the saucepan was kept on the 275° hot plate. With care, it was possible to produce a complete coating of bitumen on even the most irregular aggregate surface in this length of time. Each sample was stored for 18 to 24 hours on a small piece of aluminum foil in ambient laboratory temperature (approximately 70°F), and protected from settling dust.

Four hundred milliliters of distilled water was brought to 74 ±1^{o}F in each of the 5 or 6 beakers required for the batch. The bottom of each sample was warmed slightly in order to separate it from its foil storage tray and put into the distilled water with the side which had been against the foil placed down.

The beakers were then immersed in the water bath to a level slightly above the level of the distilled water within each. The beakers were spaced so that there was at least a 3-inch thickness of vigorously circulating water between any 2 beakers. The bath was covered. Time elapsed was measured from the time the third sample was placed in the bath until the third sample could be removed from the bath. After 12 minutes the beakers were removed from the water bath. The temperature of the water in the beakers had risen to 131^{o} ±1.5^{o}F. The beakers were allowed to stand undisturbed until they felt lukewarm (about one hour). The water was decanted and the samples pried from the bottoms of the beakers in 1 piece. They were placed on paper towels to dry and finish cooling. Care was taken to keep the same side up as had been up in the beaker and to allow nothing to come in contact with that side.

The samples were examined by a panel of minimum of 3 observers who each independently judged which class of bituminous retention was shown by each sample. The consensus of the panel was arrived at by discussion among the observers. No observer knew the identity or the service history of the specific aggregate samples being examined. The panel of observers for the first group of batches tested consisted of 5 persons, 4 were geologists with experience in estimating surfaces and volumes; the fifth was an engineer. The samples were all ranked in order of the completeness of their bituminous coating. The observers estimated the position of 95% retention of bituminous coating in this rank and samples estimated to retain 95% to 96% of the coating were considered to fall in the passing but average group, Class C. The panel of 5 observers easily distinguished 2 classes of retention better than Class C and 2 classes poorer. Thus, the 5 classes of retention of bituminous coating were defined. A set of samples covering the range of amount of bitumen retained and delineating the individual classes was selected from this first group of samples. This set of samples was retained and used as a standard by which observers of samples tested later were able to make consistent judgements of the amount of bitumen retention. All panels of observers consisted of at least 3 persons. First, each observer made an independent judgement of the degree of bitumen retention then the actual class of bitumen retention reported was arrived at by discussion. The observers had very little difficulty in coming to an agreement when the sample under discussion showed a high ability to retain bituminous coating but had some difficulty when the sample was badly stripped.