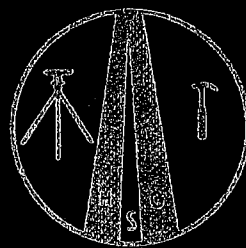


PROCEEDINGS  
OF THE  
FIRST, SECOND, THIRD & FOURTH  
HIGHWAY GEOLOGY SYMPOSIUM

VOL. I



**First Annual Symposium on**

**"GEOLOGY**

**AS APPLIED TO**

**HIGHWAY ENGINEERING"**

**April 14, 1950**

Under the Sponsorship of  
**DEPARTMENT OF HIGHWAYS**  
**RICHMOND, VIRGINIA**

Sig. /

Vol. /

## SYNOPSIS OF FIRST HIGHWAY GEOLOGY SYMPOSIUM

By

W. T. Parrott, Engineering Geologist

Virginia Department of Highways

To foster the exchange of ideas between highway engineers and geologists on problems relating to highway construction, the Virginia Department of Highways sponsored a symposium on "Geology as Applied to Highway Engineering" in Richmond on April 14, 1950.

Attending were representatives of the highway departments of Georgia, South Carolina, North Carolina, Virginia, Kentucky, West Virginia, Maryland and Pennsylvania. Other organizations represented included the United States Geological Survey, the Virginia Geological Survey, the North Carolina Commission of Conservation and Development, the United States Army Engineers, the National Park Service, the United States Department of Agriculture (Soils Engineers), the Bureau of Public Roads, the Engineer School at Fort Belvoir, and faculty members and students from the University of Virginia, Virginia Military Institute, Virginia Polytechnical Institute, and Washington and Lee University.

The meeting was opened with an address of welcome by C. S. Mullen, Chief Engineer of the Virginia Department of Highways. James A. Anderson, Commissioner, Virginia Department of Highways, then outlined the general purpose of the meeting.

The first paper was presented by A. Stinnott of the Ground Water Division, United States Geological Survey. He discussed the various methods of the control of ground water in unconsolidated settlements.

He briefly outlined the geological factors involving the collection and dispersion of ground water with various means of controlling the same in order to prevent damage to highways under construction as well as the elimination of costly maintenance work due to the action of ground water.

Mr. Stinnott's paper was followed by one by Dr. Jasper L. Stuckey, State Geologist of North Carolina. Dr. Stuckey discussed the importance of geological surveys in highway location and design. He gave a brief review of the principals of geology and the formation of various rocks. These rocks were treated from the standpoint of genesis, structure, and weathering, and their direct relationship to the importance in highway engineering. He discussed the importance of geological mapping, bringing out that this particular branch of mapping would enable the highway engineer to visualize the type of material over which his road would pass, enabling him to design the road in order to take care of unfavorable geologic conditions which might otherwise pass unnoticed. Dr. Stuckey emphasized the importance of soils, soil sampling, and soil mapping.

"Roads are founded on geologic materials and built of geologic materials," he concluded. "When the engineer has done his very best construction job, the road is no better than the foundation on which it is laid and the materials of which it is built."

Dr. Stuckey was followed by Mr. D. D. Woodson, Soils Engineer of the Virginia Department of Highways. Mr. Woodson spoke on soils as correlated with parent material. He discussed the various physiographic provinces of Virginia and the principal rock types from which the soils in each of these sections were derived. He gave a

brief account of the action of the resulting soil, its mineralogical content, and the engineering qualities of each of the soils so encountered. He stressed the importance of geological maps which enable the soils engineer to better forecast or correlate the probable action of the soil which overlies its parent rock. He concluded by stating that a close liaison of the work done by the geologist and the soils engineer would go far toward the solution of many problems which confront the soils engineer.

In a lively discussion following Mr. Woodson's paper, the group considered the various aspects of how the types of behavior of the soils in other States reacted in comparison with similar soils found in Virginia.

Robert A. Laurence, Regional Geologist of the United States Geological Survey, presented a paper on geologic factors involving land slides and rock falls. Mr. Laurence classified types of land movement in accordance with <sup>the</sup> classification given by C. F. S. Sharpe: (1) slump, (2) debris fall, (3) debris slide, (4) rock slides, and (5) rock falls. Each type of land movement and geologic conditions which caused it was illustrated. He concluded that, while many slides and rock falls cannot be avoided, a thorough geologic study will often indicate either a way to prevent a slide by changing the location or alignment of the cut or will indicate a method of stabilizing the slide.

Dr. L. W. Currier of the United States Geological Survey gave a paper on Federal participation in geologic materials surveys. He outlined the various types of surveys in which the United States Geological Survey is participating. These surveys, he said, had been

made in Kansas, Wyoming, and Montana. At the present time, he said his organization is cooperating with the Bureau of Public Works in Massachusetts in publishing a geologic map of this State. He emphasized that while the survey is not in the business to map for individuals or consultants, it quite often sends out field parties to work with various State agencies in publishing geologic construction material maps. The various types of maps ranging from the simple spot map to a complete geologic map of an area were illustrated and the value of each shown.

J. C. Stevens of the Virginia Council of Highway Investigation and Research gave a paper on the use of aerial photographs in engineering geology. He pointed out that various land forms could be recognized by their different characteristics. He added that various soil patterns could be interpreted due to their drainage characteristics. In addition to the above mentioned guides, it was pointed out that highway location could be speeded up by the use of these photographs in laying out preliminary base lines. The drainage pattern of the various streams which to some degree give the types of land forms were also discussed. All of the points mentioned in Mr. Stevens' paper were illustrated by slides.

Dr. R. W. Moore of the United States Bureau of Public Roads presented the subject of geophysical methods for subsurface exploration in highway construction. He explained the basic differences between the seismic method and the resistivity method. Each of these methods will give an accurate profile of any proposed road down to solid rock if they are used in a country which is

subjected to leaching such as limestone and dolomite; they will not pick out cavities or solution channels, thus they do not take the place of borings for structures such as dams and bridges.

The final paper was written by Mr. S. E. Horner, chief geologist of the State Highway Commission of Kansas, on "Engineering Geology as Applied to Kansas Highway Problems." Mr. Horner was unable to be present and his paper was read by Dr. Raymond S. Edmundson of the University of Virginia. Subjects discussed by previous speakers were covered and the paper served as an excellent resume of the entire meeting.

Before adjournment, a tour of the Virginia Department of Highways laboratories was conducted.

# # #

PROGRAM

Symposium on Geology as Applied to Highway Engineering

Department of Highways - Auditorium

Richmond, Virginia - April 14, 1950

- 9:00 A.M. Registration - Lobby - Central Office  
Virginia Department of Highways
- Presiding - Mr. W. T. Parrott, Engineering Geologist
- 9:30 A.M. Address of Welcome - C. S. Mullen,  
Chief Engineer - Virginia Department  
of Highways
- 9:40 A.M. Purpose of the Meeting -  
Gen. James A. Anderson, Commissioner  
Virginia Department of Highways
- 9:50 A.M. Groundwater Control as Applied to  
Consolidated Rocks - William M. McGill,  
Virginia State Geologist
- 10:20 A.M. Groundwater Control as Applied to  
Unconsolidated Sediments - A. Sinnott,  
United States Geological Survey,  
Groundwater Division
- 10:50 A.M. The Importance of Geological Surveys  
in Highway Location and Design -  
Dr. Jasper A. Stuckey, North Carolina  
State Geologist
- 11:20 A.M. The Correlation of Soils and Their  
Parent Material - D. D. Woodson, Soils  
Engineer - Virginia Department of  
Highways
- 11:50 A.M. Adjournment for Lunch
- 1:00 P.M. Geologic Conditions Affecting Landslides  
and Rockfalls - Robert A. Laurence -  
Regional Geologist - United States  
Geological Survey
- 1:30 P.M. Federal Participation in Geologic Material  
Surveys - Dr. L. W. Currier, United States  
Geological Survey
- 2:00 P.M. The Use of Aerial Photographs in Engineering  
Geology - J. C. Stevens, Virginia Council  
of Highway Investigation and Research

- 2:30 P.M. Geophysical Methods for Sub-Surface  
Exploration in Highway Construction-  
R. W. Moore, United States Bureau of  
Public Roads
- 3:00 P.M. Engineering Geology as Applied to  
Kansas Highway Problems - S. E. Horner,  
Chief Geologist, State Highway Commission  
of Kansas - to be presented by  
Dr. R. S. Edmundson, University of Virginia
- 3:30 P.M. Business Meeting
- 4:00 P.M. Tour of Laboratories
- 4:45 P.M. Adjournment

**Proceedings  
Second Symposium of**

**"GEOLOGY  
AS APPLIED TO  
HIGHWAY ENGINEERING"**

**February 16, 1951**

Sponsored by  
**VIRGINIA DEPARTMENT OF HIGHWAYS  
RICHMOND, VIRGINIA**

SYMPOSIUM ON GEOLOGY AS APPLIED TO HIGHWAY ENGINEERING

Department of Highways - Auditorium

Richmond, Virginia - February 16, 1951

The Adhesion of Bituminous Materials to  
Highway Aggregates - A. B. Cornthwaite,  
Assistant Testing Engineer, Virginia  
Department of Highways

Geological Enterprise in Virginia -  
Present and Future - Dr. B. W. Cooper,  
Professor of Geology - Virginia  
Polytechnic Institute

The Importance of Geology in Military  
Highway Construction - Frank C. Whitmore, Jr.  
Chief, Military Geology Section, United  
States Geological Survey

Injurious Minerals in Highway Aggregate  
Dr. Duncan McConnell - Professor of Mineralogy  
Ohio State University

What Does the Engineer Expect of the Geologist  
Professor A. T. Granger - Professor of  
Civil Engineering - University of Tennessee

The Use of Plate Bearing Tests in the Thickness  
Design of Flexible Pavements - L. D. Hicks,  
Assistant Engineer Materials and Tests  
North Carolina Department of Highways and  
Public Works

The Control of Groundwater in Consolidated  
Sediments - George D. DeBuchananne - Geologist  
in Charge - United States Geological Survey  
Groundwater Division

The Identification of Rock Types - D. O. Woolf  
Senior Materials Engineer - Bureau of Public  
Roads

The Construction of Highway Bridges and  
Separation Structures in Unconsolidated  
Sediments - Professor Frank W. Wheeler  
Professor of Civil Engineering  
University of Virginia

THE ADHESION OF BITUMINOUS FILMS  
TO  
HIGHWAY AGGREGATES

BY  
A. B. CORNTHWAITE

It is needless, perhaps, to mention the part that mineral aggregates play in the building of our highways. When it is remembered, however, that in our bituminous or black-top roads, aggregates comprise approximately 95% by weight of the system, and that in plain portland cement concrete roads they account for approximately 80% by weight of the structure, it is readily seen that for the tens of thousands of miles of highways in the United States the quantities involved runs into astronomical figures. Added to this amount should be the thousands of tons used in the stabilizing and building up of thousands of miles of unsurfaced county or secondary roads.

For our discussion today, we are not so much interested in the quantity of the mineral aggregate used, but in the relationship of these aggregates to the bituminous materials.

Virginia is geologically blessed by having so many different aggregates of such good quality and quantity for use in building highways. Our aggregates vary from sand and gravel in the Tidewater and Piedmont areas to granites, limestones, gneisses, trap rocks, etc., in the Piedmont and mountainous regions. For each of the different types of aggregates you geologists recognize that there are many different geological formations of different ages which identify rocks of the same general classification.

In our laboratories we classify them by their hardness, or resistance to abrasion, their soundness, or resistance to freezing and thawing, and by their behavior with bituminous materials.

The behavior of these aggregates in highways sometimes leads the highway engineer to believe that they have not been classified into a sufficient number of categories since it often seems that each individual particle behaves differently from the one next to it.

In combining aggregates and bituminous materials to build road surfaces, use is made of three different phases of the bituminous material: solid, semi-solid, and liquid. The solid and semi-solid materials require the use of considerable heat for their proper manipulation, and for that reason they are not readily adaptable to field conditions. They are, however, widely used in central mixing plants where both the aggregate and the bituminous material can be heated to the proper mixing temperatures, mixed, and the resultant mixture then applied to the prepared roadway, rolled into place and the job is complete.

The liquid materials naturally lend themselves to a much easier application and manipulation in the field than either the semi-solid or solid materials and for that reason are more widely used.

It has long been recognized that the presence of water in and around bituminous pavement structures causes more damage than perhaps any other one factor. This is the reason highway

departments build such elaborate drainage structures, and periodically clean and maintain their drainage ditches.

This damage from water may exhibit itself in a number of different ways but of primary interest to us is the fact that the water causes a definite lack of adhesion of the bituminous film to the aggregate surface. Ultimately this loss of adhesion means that under traffic the aggregate particles will be displaced and the pavement begin to deteriorate.

All of you know how difficult it is to wet an oily surface with water - it is practically impossible. This same condition is encountered when trying to coat a wet aggregate surface with bituminous material. Without using a material that has been especially treated, this can't be done either. On the other hand, aggregates which have been coated with bituminous materials and later subjected to excessive moisture will in time tend to lose their bituminous coating which then permits the rapid destruction of the pavement. It is not only the adhesion of the bituminous material to the aggregates that is affected, but the mechanical stability of the road surfaces is also weakened by the loss of cohesion between particles and under traffic the surface is destroyed.

The seriousness of this adhesion problem to highway departments was well demonstrated in Virginia about fifteen years ago when approximately fifty miles of road surfaces were lost due to the entrance of moisture into the pavement structure. This was rather a severe blow and very careful attention has been paid to the problem since that time in order to prevent its

recurrence or to keep this type of damage to a minimum.

It is not intended to give you the impression that Virginia is the only state in the nation faced with the problem of obtaining satisfactory adhesion of bituminous materials to mineral aggregates under all possible climatic conditions. The problem has received nation-wide attention in recent years and has also been studied in many road research laboratories in Great Britain and Europe. The American Society for Testing Materials and the Highway Research Board both have committees actively working on the problem attempting to determine methods of evaluating the resistance of bituminous films to the effect of water, and the relationship between the bituminous films and the aggregate whether it be a question of surface tension, interfacial tension, or a combination of the two. The Bureau of Public Roads has also contributed very materially to this study.

Among highway engineers it is common to express this lack of adhesion by the word "stripping" and the degree of stripping in laboratory studies is considered to be a measure of the adhesive qualities existing between the bitumen and the aggregate.

To improve the adhesion of bituminous films to aggregates certain chemicals have been developed which we call additives and which chemically are closely related in action to the detergents in common use today. By their use the surface tension of the bituminous materials is altered to the extent that it is possible to not only cover and coat wet aggregates but also to enable them to retain that coating under adverse weather conditions. With the liquid bitumens being most widely used, it

is in this field that the use of additives has been most pronounced.

As mentioned before, in order to secure proper coating of the aggregate when using solid or semi-solid bitumens it is generally necessary to heat not only the bituminous material to such a temperature that it will flow readily, but also to heat and dry the mineral aggregate. Both of these conditions are conducive to good adherence of the bituminous film and proper wetting of the aggregate surfaces. This does not mean that the solid materials are immune to the detrimental effects of water but their performance in this respect is generally superior to the liquid bitumens. Since the additives used to improve adhesion are organic compounds and as many are readily decomposed at the mixing temperatures required, the use of these additives in this class of products has been rather limited.

Not to slight the aggregate side of the story, it is also possible to improve the characteristics of the mineral aggregates by treating them with certain chemicals so that better adhesion is obtained. It may be somewhat surprising to the geologist to learn that any material that has existed some few millions of years could possibly be improved, but a great many patents have been issued for these processes.

However, the treatment of aggregates has always seemed to be doing things in the hard way for the reason that we would be treating 95% of the road structure, whereas by the use of additives in the bituminous material it is necessary to treat only 5% of the structure. Also, economically it has been found to be more feasible to treat the bituminous material than to treat

the aggregate. For example, if we assume the additives to increase the cost of the bituminous material by two cents per gallon then for an application rate of 0.25 gallons per square yard the additive would cost 1/2 cent. For treating aggregates the cost may vary from \$.60 to \$1.00 per ton, and if the aggregate is applied at the rate of 25 pounds per square yard the increased cost would be from 3/4 cents to 1-1/4 cents.

There have been a great variety of methods developed whereby the stripping of bituminous materials from aggregates can be studied. These methods can be divided into two rather broad and comprehensive groups. The first group would include those methods in which the coated aggregate particles are immersed in water as individual particles, and in the second group the effect of water on the bitumen coated aggregate is studied by determining the compressive strength of laboratory prepared cylinders.

One of the original water immersion procedures was developed by Victor Nicholson (1) and reported in the Proceedings of the Association of Asphalt Paving Technologists in January, 1932.

In this method the coated aggregate is allowed to cure under certain specified conditions after which the mixture is immersed in water and agitated for fifteen minute periods at temperatures of 77°F., 100°F., and 120°F. The percentage of stripping taking place during each test period is estimated visually. This method received wide acceptance for a number of years but has now been

(1) Adhesive Tension in Asphalt Pavements, its Significance and Methods Applicable to its Determination. Victor Nicholson. Proc., Association of Asphalt Paving Technologist, Jan. 1932.

largely superseded by other methods.

In 1933 Riedel and Weber (2) reported on the results of their studies on the "Adhesiveness of Bituminous Binders on Aggregates" in which the coated aggregate was subjected to the action of boiling water. The primary objection to this procedure has been that this is a condition which would never be obtained in pavements and therefore could not clearly represent what could be expected to happen under normal circumstances. In addition, the aggregate particles used were of small size, minus 10 mesh, and not representative of the sizes commonly used in road building. It does point out, however, the vulnerability of bituminous films of low viscosity, or of those materials that have been heated above their softening points to the action of water.

In recent years the most emphasis has been placed upon static immersion stripping test in which the coated aggregates are immersed in water at room temperature or at slightly elevated temperatures for a period of from 18 to 24 hours. At the end of this time the particles are rated as to the amount of stripping that has taken place during the immersion period. This is the type of test that Virginia follows in determining the compliance of bituminous materials purchased under our adhesion test requirements. As a matter of fact, we have two adhesion tests - in the first test we use a dry dolomite aggregate, which represents a basic type of aggregate, and in the second test we use wet silica

(2) On the Adhesion of Bituminous Binders on Aggregates.  
W. Riedel and H. Weber. Asphalt und Teer, Vol. 33,  
September 13, 1933.

gravel to represent an acid type of aggregate. It is required that the aggregates retain 90% of their bituminous coating after 18 hours immersion.

In 1945, J. T. Pauls and H. M. Rex of the Bureau of Public Roads<sup>(3)</sup> reported on a study they had made in which mixtures of aggregate and bituminous materials were compacted into 4" x 4" cylinders and then tested for compressive strength in the dry state. Other duplicate compacted specimens were immersed for periods up to one week at different temperatures after which their compressive strength was determined. The compressive strength of the immersed specimens expressed as a per cent of the dry compressive strength of duplicate samples is considered to be a measure of the resistance of the mixture to the effect of water. This test has been commonly known as the Immersion-Compression Test and is representative of the second group of methods developed for studying adhesion.

This method has the advantage of permitting many variations by which the effect of different aggregates, sands, mineral fillers, gradation of the aggregates, and types and grades of bituminous material can be studied.

It has the additional advantage of permitting the determination of actual values in pounds of compressive strength of the dry and wet specimens and thus eliminating personal estimations.

The American Society for Testing Materials has recently

(3) A Test for Determining the Effect of Water on Bituminous Mixtures. J. T. Pauls and H. M. Rex. Public Roads, Vol. 24, No. 5, July, August, September 1945.

published this method as a Tentative "Method of Test for Effect of Water on Cohesion of Compacted Bituminous Mixtures", D-1075-49T.

Two methods of evaluating the amount of stripping have commonly been used. One is a visual estimation of the per cent of aggregate remaining coated after the immersion period giving total coverage a value of 100%. The second method is a hand separation of the particles showing any stripping from those remaining completely coated, and determining the per cent of the particles remaining completely coated based on the total weight of the sample under test.

In an effort to find a more suitable method of estimating the amount of stripping some attention is being given at the present time to the evaluation of stripped aggregates by means of comparing them with a series of standard area black and white photographs.

The absorption of water-soluble dyes into the uncoated areas of the stripped aggregate, followed by photo-electric light reflectance measurements, is another possible means of eliminating the human-equation in rating stripping.

In the study of adhesion of bituminous materials to mineral aggregates, two descriptive terms have been applied to the aggregates. Those aggregates which tend to retain their bituminous coating in the presence of water have been called hydrophobic, which means 'water-hating'. It has generally been assumed that the hydrophobic aggregates are the more basic type of rocks such as limestones and dolomites.

Those aggregates which readily lose their coating of bituminous

materials in the presence of water have become known as hydrophyllic, which means 'water-loving'. In general rocks of this type are the acid rocks such as quartzites and granites.

In connection with the Department's State Wide Aggregate Survey, which was started in 1947, the stripping characteristics of some 722 samples of aggregates have been determined. That there is a difference in behavior of the acid and basic type of rocks with bituminous materials is shown in the following table.

STRIPPING RESISTANCE

	<u>Per Cent by Wt.</u>	<u>Per Cent Estimated</u>	<u>No. of Samples</u>	<u>No. of Counties</u>
Limestone	65	89	312	29
Granite	25	64	37	18
Gneiss and Granite Gneiss	32	68	78	22

Note: The stripping resistance has been calculated as an average of the average from each county.

Here it will be seen that for 312 samples of limestone from 29 counties an average value of 65% adhesion was determined when figured by weight, and 89% adhesion when estimated visually. Contrasted to this, for 37 samples of granite from 18 counties and average value of only 25% adhesion by weight and 64% by visual estimation was determined. Also, for 78 samples of gneisses and granite gneisses from 22 counties average values of 32% and 68% adhesion was determined. In this study, the same asphalt and the same procedure was followed throughout.

There are other characteristics besides the mineralogical composition of aggregates which appears to have a great effect upon the degree of adhesiveness of bituminous films to their

surfaces. For example, those aggregates which have a rough texture tend to retain the bituminous film much better than one whose surface is plane or glassy. Aggregates which are porous or highly absorptive also improve the adhesiveness of bitumens.

Mention has been made of the importance of the consistency of the bituminous film in resisting the entrance of water. In addition to consistency the temperature of both the bituminous material and the aggregate at the time of mixing seems to be quite important.

Road surfaces which are laid under the favorable conditions of hot and dry summer weather are much less apt to fail when the new treatment is followed by rainy weather than those surfaces laid during the cool damp days of early spring and late fall and then rained upon. In the Highway Department we recognize this condition by generally specifying that bituminous materials for use in winter or cold weather must meet our Type II Adhesion Test - i.e. - have the ability to coat wet silica gravel and retain that coating during 18 hours continuous immersion. The aggregate in this case is an "acid" type.

The period of time required for the curing or "setting-up" of the liquid bituminous materials is much shorter in summer than it is during the spring and fall. This, of course, means that the loss by evaporation of the solvent or thinner in the bituminous material is greatly accelerated by the high temperatures of summer, resulting in a much more viscous bituminous film that is highly resistant to moisture.

The age of the bituminous film seems to play an important

part also in improving its adhesion to aggregates. Most coated aggregates that have been stored for a considerable length of time will show better adhesion than a freshly mixed sample. Apparently, the adhesive bond between the bitumen and the aggregate becomes more firmly established.

There is another thing not so widely recognized which appears to play a part in obtaining satisfactory adhesion which has been described as a surface effect. In this case bituminous films apparently become set and are highly resistant to the effects of water until the surface has been disturbed through some mechanical action when it is found that the underlying material is as vulnerable to the action of water as the original mixture would have been.

The effects of traffic on a road surface of this nature can be readily visualized during a rain storm. The disruption of the film by traffic permits the ready entrance of moisture into the system, resulting in the displacement of the bituminous material, loss of stability, and finally displacement of the aggregate and loss of the road surface.

In conclusion, I would like to point out that Virginia has been one of the pioneers in focusing attention to the urgent need of improving the adhesion characteristics of our bitumen-aggregate mixtures. We have worked very closely with many of the promoters of the "additives", and, certainly for some of them, have been instrumental in their developing better products. Our laboratories for a long time were the proving grounds of the early products.

If nothing else, we have been instrumental in focusing the attention of the refineries to the necessity of properly selecting the crudes from which the bituminous materials are obtained, and the selection of proper solvents to obtain the best curing properties possible with a resultant increase in resistance to stripping.

Contrary to our solution of the stripping problem where we use only two aggregates to evaluate all of our bituminous materials: - whether they are to meet either Type I or Type II Adhesion Test - our work, and that of all other investigators, has conclusively shown that each combination of bitumen and aggregate is a problem unto itself. Unfortunately, under competitive bidding practices, it is practically impossible to take advantage of this fact and always use the best possible combination.

Definite progress has been made in the solving of the adhesion problem. We have probably overlooked a good bet in not acquainting the geologist with our problem and enlisting his aid. After all, it may be easier to take the mountain to Mohammed than to take Mohammed to the Mountain.

## GEOLOGIC ENTERPRISE IN VIRGINIA---PRESENT AND FUTURE

Byron N. Cooper  
Virginia Polytechnic Institute

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For a few minutes, I would like to consider with you some conditions and situations prevailing in Virginia, which should be the concern of all thinking persons whose enterprise involves the use of earth materials.

Primarily, this conference is concerned with geology as applied to highway engineering. As we all know, geologic science properly applied to engineering procedures is demonstrating its true worth every day. All of us attending this meeting are keenly interested in the particular applications of geological techniques to highway engineering practice. I hope that you will bear with me while I explore with you certain general and, I believe, more fundamental matters involving the potential usefulness of geologic research to all types of enterprise in Virginia.

The daily application of geological principles to engineering practice has doubtlessly convinced all of you of the need for more and more useful information on the rocks, minerals, soils, and topography of Virginia. The engineering geologist does not have the time to do much in the way of basic geological research; he is hired for more immediately urgent purposes.

Where does the engineering geologist get his basic information on earth materials? He gets it largely from publications of the State Geological Survey. Of course, he also gets help from the Federal Geological Survey reports and maps. However, the basic responsibility for investigating the rocks, minerals, groundwater, and topography of Virginia is assigned by law to the State Geological Survey, a division of the Department of Conservation and Development. Most of us know we have a State Geological Survey, and some of us know its personnel and something of what the Survey is doing. How are we in Virginia progressing with our survey of the rocks and mineral resources of the Commonwealth? Are we nearly through with the survey? How long will it take to finish it? Naturally you expect me to answer these questions since I have raised them. Probably also you are expecting to be surprised one way or the other by my answers. Grab onto your seats - every one of you - because you are in for a severe jolt.

First, let us look at topographic mapping. It scarcely needs saying that geological field investigations are largely dependent on availability of topographic base maps. I understand also that topographic maps are still considered helpful to highway planning engineers. With certain exceptions, the making of topographic maps is a 50-50 cooperative arrangement, with the Federal Government matching State appropriations for this special purpose. It scarcely needs saying that a topographic map on a scale smaller than 1 inch equal 1 mile is so

generalized as to be virtually useless for modern field work. Since about 1915, the U. S. Geological Survey has sought to map the civilized parts of this country on an inch-to-the-mile scale with contour intervals ranging from 5 to 50 feet, depending on the local relief. After 35 years mapping on a scale of an inch-to-the-mile, it might be supposed that Virginia would have been more or less completely mapped. Actually, this is far from true. Indeed, parts of Virginia have not been mapped topographically at all - some 3,000 square miles of it. Have you ever tried to find out anything about the topography, bedrocks, or mineral resources of Floyd County? If you have you know what a complete vacuum is.

Parts of Virginia are well mapped. The TVA has graciously taken over the mapping of the Tennessee River drainage area, which includes Scott, Washington, Smyth, Russell, Tazewell, Lee, and parts of adjacent counties in Virginia. Within a few years, this area embracing some 3,500 square miles or 8 per cent of the area of the State will be covered with  $7\frac{1}{2}$ -minute contour maps on a scale of 1:24,000. These maps have already proved of inestimable value in geologic mapping. It is fortunate that so large an area of the State is being mapped in detail without direct cost to Virginia. This is not the only part of the State that is being mapped without direct outlay of State funds. The U. S. Coast and Geodetic Survey naturally has to map the coastal areas of Virginia. The United States Army Corps of Engineers has for deadly serious reasons found it necessary to

make 1:24,000 and 1:25,000 contour maps of a wide strip of the Eastern Seaboard. Taken together, the Coast and Geodetic Survey and Corps of Engineers maps cover an area of about 17,750 square miles or 41 per cent of the total area of Virginia. As a result of these mapping programs, Virginia in 50-50 co-operation with the United States Geological Survey carries on a mapping program that now needs to apply to only half of the total area of the State. But this is not as good as it sounds. Considering that Virginia currently appropriates \$25,000 for topographic mapping, which is matched by Federal funds, we are spending annually just about enough to survey and publish an engraved topographic map of an area of 200 square miles---or about three-fourths of one 15-minute inch-to-the-mile quadrangle. Since there are 38 fifteen-minute quadrangles yet to be mapped on a scale of one inch to one mile, it follows that it will be the year 2,000 before Virginia will have completed her basic mapping program - unless some revolutionary improvement takes place to accelerate this work. We cannot wait that long; the rest of the world moves at a faster pace. I need not remind you that the United States Geological Survey has already decided as a matter of future policy that topographic map coverage on a scale smaller than 1:24,000 is not suited to the present-day needs of thickly settled areas. Now ~~if~~ we consider that we should have 1:24,000 contour maps of all of Virginia to keep pace with future developments, our current budget for topographic mapping projected into the future could not provide 1:24,000

contour maps for all of Virginia before the year 2,100. Virginia ought to be spending \$100,000 a year on topographic mapping to provide for the basic and inescapable needs of 10 and 15 years hence. A mapping program such as the present one---which results in the completion of two 15-minute quadrangle maps every three years is just too slow. Geologists and engineers should be concerned about this situation.

How about basic geologic research in Virginia? Of course, that has been retarded to. Taken together, detailed geologic maps in colors, so far published, cover less than 10 per cent of the State's total area. The geology of a considerable section of the State is very poorly known and has never been studied except by the most generalized of reconnaissance methods such as were in vogue 50 years or more ago. In the rugged Appalachian Mountains west of the Blue Ridge, just one single fifteen-minute quadrangle has been geologically surveyed in detail, written up in conventional bulletin form with an accompanying geologic map published in colors. There are 52 other 15-minute quadrangles and an additional 60  $7\frac{1}{2}$ -minute quadrangles left to study in this way in the Appalachian area of Virginia; 55 fifteen-minute quadrangles to map in the Blue Ridge and Piedmont regions; and approximately 300  $7\frac{1}{2}$ -minute quadrangles lying east of the 78th Meridian in Virginia. Compare this progress with that of some of our neighboring states and you will see that we are moving very slowly.

What sort of work is being done that provides real quantitative information on the chemical and physical properties of bed-rocks and surficial sediments of Virginia? In other words, what work is being done that will provide the engineer with the kind of detailed information that he can so readily use. Very little--painfully little.

Significant geologic details are seldom discovered without detailed geologic mapping. Consider the fact that a great many of our geologic mapping units are many hundreds, and some even thousands of feet thick. Geologists are supposed to map what the Federal Geological Survey geologists lovingly call a geologic formation---which for all essential purposes of mapping is supposed to be a unit.

Have any of you ever seen this formation we call the Wissahickon schist? If you have, you will appreciate the ironic humor I gleaned from a field trip report prepared by one of my students a year or so ago. He commented that the trip covered excellent exposures of all the principal types of rock--igneous, sedimentary, metamorphic, and Wissahickon. Just what good do we geologists do when we map units as generalized as the Wissahickon? Very little good, I think. In the Appalachian Valley there are more than two dozen named stratigraphic "units" each with a thickness of more than 1,000 feet. None of these are geologic formations in any sense of the word. Refining and splitting up of the old mapping divisions of strata has barely started in Virginia. Geological enterprise in Virginia is still

in the "lumping"---not the "splitting" stage.

Every Appalachian Valley geologist has had something to do with a widespread mapping unit known as the Rome formation. Recently I examined 20 geological publications containing descriptions of the Rome formation, and every one of the twenty reports described the Rome as "very heterogeneous". Some spell out heterogeneous in lengthy detail, for example (and I am quoting now from a learned report by my favorite author) "The Rome consists of maroon and green variegated shales and siltstones, ocher-yellow crumbly siltstones, brown arkosic sandstones, salmon-pink to dark-bluish gray limestones, black dolomites, and sharpstone conglomerates." Isn't that a helpful description? Little wonder that one geologist summing up the characteristically diverse features of the Rome formation concluded that "it is homogeneous in its heterogeneity." If an engineer sets out to determine the physical properties of the various geologic "units" delineated on the Geologic Map of the Appalachian Valley he gets into trouble right away. Most of the units the geologist is still mapping embody a variety of rock types. Moreover the engineer is naturally confused by the fact that the same name is applied to different types of rock from place to place. For example, the mapped unit known as the Athens formation is variously a massive, dense, fine-grained limestone just west of Harrisonburg; a heterogeneous succession about one-third black shale and two-thirds black silty limestone near Lexington; at Catawba Sanitorium, a black calcareous silty shale; a thin paper

shale at Raphine; a hard arkosic flagstone north of Wytheville, and a fine-grained sandstone in the Great Knobs country south of Abingdon. Many of our formational units we delineate on geologic maps tell us very little about the types of rock and their spatial relations one to another.

About 20 years ago, the Bureau of Reclamation, largely at the behest of the eminent engineering geologist, Charles P. Berkey, delved in a big way into the microscopic petrography of rocks to be used in great engineering works. The laboratories set up by this agency were able to demonstrate the close relationships existing between rock-forming minerals present, their grain-size, and packing of particles on the one hand with the durability characteristics of various rock formations occurring in the huge reclamation areas of the West. The petrographic laboratories of this Bureau sought, and in many instances, found the answers to many basic problems. What determines the abrasion characteristics of crushed stone? What determines the durability and bonding characteristics of rock used for aggregate? How will a rock stand up under different conditions in tunnels and cuts? How expensive will it be to drill, shoot, and cut through different kinds of rock at various attitudes? What are the weathering characteristics of different rocks in and out of concrete? The answers the petrographers found to these and other questions came the hard way. Needless to say "lumpers" did not figure in the solution of these problems. The answers were found by geologists with strongly developed "hair-splitting" attitudes.

Why has Virginia been so slow in doing vitally necessary detailed geologic work? The Virginia Geological Survey is charged by law with performing the following public services:

Surveying the rock and mineral resources of the State;

Determining geological materials suitable for roadbuilding and methods for utilizing them;

Examination and classification of soils, and investigation of their particular adaptability to various crops;

Preparation and publication of economic and geologic maps of the State;

Preparation of various types of reports on the mineral resources of various districts;

Working out of cooperative arrangements with the Federal Geological Survey for topographic mapping and certain types of geological projects.

Down through the years, the Virginia Geological Survey has never received sufficient funds to perform these duties. The State Geological Survey, I assure you, has done wonders with what funds have been given it to carry on scientific work---but against the rising tide of present-day demands, the Geological Survey is now fighting a losing battle in spite of recent increases in technical personnel. The Geological Survey now needs the help and support of every civic-minded Virginian. Let us not blame our State Geologist or his staff for the prevailing conditions; they have done a good job down through the years. In spite of their efforts, a log jam of unfilled requests for information and of completed and edited reports has built up at the Geological Survey office in Charlottesville. Some completed manuscripts have been awaiting publication for 10 years--for want of printing

funds. One Survey bulletin containing vitally important information sought by industry was taken to the printer in September, 1945, and is in February, 1951, still at the printers. Geological work that is done but not published is indeed a poor investment. The Geological Survey probably has sufficient number of completed reports to use up five times the amount now allowed for printing of its reports.

If Virginia is to get its topographic-mapping program into second gear and if the Geological Survey is to be enabled to carry out the work assigned to it, funds for its operation must be materially increased. How much is necessary? Let us look at what other states are doing.

Michigan, whose annual mineral production, like that of Virginia is hitting close to 170 million dollars, spends about 250,000 dollars for the operation of its geological survey. Tennessee, with an annual mineral production of just about half that of Virginia spends about 30 thousand dollars more per year for its Division of Geology than does Virginia for her Geological Survey, and this in spite of the fact that both the United States Geological Survey and Tennessee Valley Authority carry on rather extensive geological research in Tennessee. Oregon, with a mineral production of slightly less than one-tenth that of Virginia spends almost exactly the sum Virginia spends investigating her mineral resources. Even in Missouri--the "Show Me State"--twice as much is expended for the investigation of mineral resources as is spent in Virginia---but Missouri

produces annually about two-thirds the total value of mineral products produced in Virginia. What needs to be done for the Virginia Geological Survey will not break the State treasury. An adequate appropriation would simply be an investment from which the State would draw immediate, as well as long-range, returns. The scientific work done by the State Geological Survey uncovers sought-after raw materials which lead to new mineral industries. Let us see how this works.

In 1942, the State Geological Survey inaugurated a detailed State-wide study of two common types of rock---limestone and dolomite. One unit of this study was completed as Geological Survey Bulletin 62 and published in 1944. The total cost for all staff salaries on this project, costs of chemical analyses, costs of editing, and charges for printing the report amounted to 7 thousand dollars. The information contained in this little bulletin of about 100 pages was responsible for the development of new plant installations valued at more than 15 million dollars! Three brand new industries in a brief period of five years!

Kimballton---back in 1945 a forgotten little hamlet in Giles County---suddenly became transformed into a beehive of industrial activity. It is now the largest single shipping point for high-calcium chemical lime in the eastern United States. The information provided in the same little inexpensive report was directly responsible for the location of the new Lone Star Cement plant now being built at the northeast end of Tinker Mountain near Roanoke. Numerous other

examples could be cited which would similarly demonstrate that investment of funds in geological work pay big dividends.

Less tangible in terms of dollars and cents worth, but nonetheless real are the many useful services provided by a geological survey to engineering enterprises. The wider and straighter our future highways become, the more and more detailed information on earth materials will be needed to build them as economically and as soundly as possible.

During 1950, agricultural enterprise in Virginia did a 450 million dollar business. To stimulate this industry, Virginia invested during the fiscal year ending June 30, 1950, a total of \$1,591,629 for scientific research and for dissemination of the results of these investigations. The mineral industries of Virginia, producing commodities worth more than one-third the value of all agricultural products sold in 1950, receive nowise comparable support in the way of geological research. The sound practicality of making substantial investments in the future of Virginia agriculture by supporting a strong and vigorous research program in agriculture has been amply demonstrated down through the years. Considering the diversity of Virginia's mineral wealth, the making of substantial investments in the future of Virginia's mineral economy would likewise prove to be sound and fruitful.

The reason why I felt impelled to present this picture to you today is that you individually and as a group are in a position to know how useful geologic science can be. I am

hoping that you will see fit to use all the influence you have to secure the public support and financial appropriations needed by our State Geological Survey for its successful performance. Remember that geological enterprise has no pressure group to champion its accomplishments and to explain fully what is needed in the way of State funds for geological research.

Personally, I believe that it is up to those of us engaged in various enterprises concerned with the utilization of earth materials to publicize the urgent need for more funds for geological research and more funds for geologic and topographic mapping.

Support your Geological Survey. Demand more of it. It can be of terrific service to you, if it is provided with the funds necessary to carry on the work it is supposed to do.

## THE IMPORTANCE OF GEOLOGY IN MILITARY HIGHWAY CONSTRUCTION \*

Frank C. Whitmore, Jr.

The keynote of military highway construction, as of most military engineering operations, is expediency. Routes of communication must be developed as quickly as possible, and the communication network must be maintained no matter what operational conditions develop. Obviously, therefore, a military road is never built unless there is absolutely no road or trail, however rudimentary, that can be developed for military use. Furthermore, if a road must be built, construction procedure is kept as simple and quick as possible. First, the best possible subgrade is located; second, this subgrade is protected by proper drainage; and, third, the absolute minimum thickness of stable courses is added above the subgrade.

The operations of the military highway engineer are further complicated by the enormous traffic fluctuations that occur under military operational conditions. Location and distribution of the maximum traffic load often bears no relation at all to the pre-existing road net; therefore many roads must bear a burden many times greater than that for which they were designed, and, consequently, maintenance and repair requirements are extraordinarily heavy. To avoid increasing the great volume of traffic passing over the roads and to avoid tying up valuable trucks in long hauls of construction materials, local materials must be used.

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\* Publication authorized by the Director, U. S. Geological Survey.

As a result of all these considerations, the approach taken by both the engineer and the geologist must be quite different from that taken by them in civil highway construction: they must use substandard materials as well as makeshift methods. With this necessary difference in viewpoint and the resulting difference in methods of operation, however, the geologist's major contribution does not differ greatly in its basic items from the contribution of the geologist in civil highway construction and maintenance.

He can aid in locating gravel or rock for crushing, to be used for aggregate, surface and base course, and fill. He can determine or predict the drainage properties of bedrock and soil, the depth of overburden and the depth of weathering in bedrock, the probable stability of hillside cuts, the type of banks and bottom of streams (with especial emphasis on their suitability for anchoring <sup>pontoon - p. 2</sup> ponton and other temporary bridges), the susceptibility of ground to frost heaving and landslides, and the location of material suitable for binder.

This type of information is developed by geologists at three general levels in the armed services. These are, in the order of increasingly detailed treatment, the intelligence level, the operational planning level, and the field consulting level. In the first of these an attempt is made to present, by means of maps with accompanying brief texts, the characteristics of soil, rock, and landforms of the area that will affect military construction. In operational planning (usually carried on in the theater of operations), the area being considered is much more

limited in scope, and the problems to be solved are more definite. Accordingly more detailed information is needed, for which reason aerial photographs are likely to be used to a greater extent in construction planning than in studies designed for high-level planning use. At the field consulting level, the geologist works directly with the military engineer in a construction battalion or similar unit; here the problems faced are, of course, very specific indeed. The method of reasoning used by the geologist at all three levels of operation is essentially the same. Legget (1939, p.69) says, "The geologist analyzes conditions as he finds them; the engineer considers how he can change existing conditions so that they will suit his plans."

Besides being a student of things as they are, the geologist is also a student of things as they were, and this greatly increases his value to the engineer. By reconstructing the events that caused the present landscape, it is possible to increase the accuracy of predictions of both surface and subsurface conditions in inaccessible areas: obviously a technique of importance to the military geologist.

Such inductive analysis as this is particularly valuable when the military geologist is dealing with modern environments different from the temperate-climate landscape, which he himself has been trained to regard as the norm. In this connection, we immediately think, of course, of the arctic and tropical environments, many aspects of which have caused the military engineer much trouble in the past. In the tropical Pacific, for example, an extremely widespread soil is friable "lateritic" clay (Figure 1).

When undisturbed it is well drained; when extensively worked without careful moisture control its structure breaks down and it "puddles" and is likely to turn into a morass. An understanding of the processes that formed such a soil, and how they differ from those that formed our temperate soils, leads to the knowledge necessary to insure proper treatment of the soil in construction.

As an example of the use of geologic reasoning in field consultation we may cite the work of James Gilluly of the United States Geological Survey during the Leyte campaign. Gilluly, who was assigned to the Office of the Chief Engineer, Southwest Pacific Area, was asked to develop new sources of road gravel in an area covered by tropical vegetation: a flood plain across which a stream meandered. All convenient sources of gravel in the stream bed had been exhausted; therefore Gilluly decided to search for abandoned stream channels elsewhere on the flood plain, knowing that these must exist and must contain gravel of approximately the same type as that already utilized from the present stream bed. In "prospecting" these abandoned stream meanders which, of course, were covered with vegetation, the area of search was further reduced by using the principle that streams erode on the outside of a meander and deposit on the inside. This reasoning resulted in the location of suitable supplies of gravel buried under vegetation and 2 to 3 feet of soil.

More complex than field consultation is the preparation of engineering studies based upon geologic and soils data. The preparation of a study of one of the Pacific islands in 1944, exemplifies the chain of reasoning followed in the preparation of such a report

dealing with an area that the authors have never seen.

Information on this island was very scanty in 1944. There were a few brief descriptions in German and Japanese of the geology of the island group as a whole; the only available maps were on a small scale, with form lines instead of contours, and of dubious accuracy; there were no geology or soils maps. During the preparation of the report, there became available a series of low-level oblique aerial photographs (Figures 2 and 3). This set became by far the most productive source of geologic information for the island.

The geologists were, of course, familiar with the general outline of the geologic history of the Western Pacific Area and with the types of rock and soil that would result from such a history. With this background, much in the way of detailed information could be deduced from close study of the aerial photographs. In the northern part of the island, for instance (Figure 2), three raised limestone terraces could be distinguished, as well as a broader, lower terrace only a few yards above sea level (foreground of Figure 2). Knowledge of the volcanic activity that accompanied the building of these islands in the geologic past, as well as scattered descriptions, led to the conclusion that the limestone of the three raised terraces was tuffaceous. The lower, younger terrace was concluded to be more nearly pure limestone. Both types of limestone, it was predicted, would be suitable for use as fill, riprap, road metal, and concrete aggregate. The tuffaceous limestone would be less satisfactory for road surfacing than the "pure"

limestone, because it would be more dusty under traffic. Limestone bonds well when used as a surface course and, in its natural state, is porous and drains quickly.

A glance at the aerial photographs shows that the terrace faces are potentially excellent quarry sites.

The residual soils developed on these limestones were estimated to reach a maximum depth of about 5 feet, at the inner margin of the bench in the foreground of Figure 2. Generally, however, the soil would be much shallower than this, and could be easily stripped by dozers, exposing a relatively smooth coral limestone surface for use as an emergency road.

All the facts cited above are obviously useful to the engineer; all were developed from a knowledge of the processes that formed the island.

Figure 3 illustrates two of the soil types defined for the island on the basis of study of the aerial photographs. One of these forms the margin of the island, between the water's edge and the outer edge of the first terrace. It is a coarse-textured soil that has apparently been transported only a short distance. It appears to be well drained and to consist of gravelly sand, sandy loam, or sand.

The soil of the terrace surfaces, on the other hand, is residual: a friable, "lateritic" stony clay or clay loam, such as is mentioned above. These soil types were defined on the basis of knowledge of soils developed elsewhere from similar parent rock and under similar conditions.

Turning for contrast to arctic and subarctic areas, it is again obvious that the military geologist as well as the engineer must cope with physical processes with which he is almost completely unfamiliar, whether he is working on the ground or preparing a research report of the area.

Figure 4 (tundra, northern Alaska) is a scene typical of hundreds of thousands of square miles in the Arctic. Drainage is impeded by perennially frozen ground not far below the surface and, as a result, there is a tendency in many places to build roads on the flanks of ridges, where drainage is somewhat better. This expedient does not avoid all problems either, because of the tendency, in the arctic and subarctic, for surficial materials to move constantly downhill on even the gentlest slope as a result of frost heaving and of the lubrication resulting from the presence in spring and summer of melt water on the surface of the permafrost table, a few feet below the surface of the ground. Study of the processes at work on the constantly changing Arctic landscape has demonstrated that certain landforms are more stable than others (Hopkins and Sigafos, 1951). Identification in air photographs or otherwise of relatively slow-moving parts of the landscape can be of great help in laying out new routes for road construction.

In the field of military construction, it is not enough for the geologist or soil scientist to develop such pertinent facts as have been briefly quoted above, or even to demonstrate their application to the solution of military construction problems. There still remains the problem of presenting the necessary

information succinctly and without extraneous detail. It is the practice in military geology to present as much information as possible on a map or series of maps (Figures 5, 6, and 7), with a very brief accompanying text, on the theory that the user of such reports has no time to spend in close study of a voluminous publication.

The first step in preparation of a military geology report should be the compilation of basic-data maps, such as the geologic and soils maps illustrated in Figures 5 and 6. The information thus presented is then used in the preparation of interpretive maps, of which Figure 7 is an example. It will be noted, of course, that Figure 5 is not a geologic map in the classical sense. It is much simpler: its map units are not formations in the ordinary geologic sense, and they are not defined in terms of geologic age. In preparing a map of this type, map units are defined in terms of common physical properties that have an important effect upon military construction problems; this usually involves combining a number of geologic formations in a single map unit.

The same procedure is followed in preparation of the basic soil map for a military construction study (Figure 6). As in the maps used here as examples, the basic soil map is practically always more complex than the basic geologic map.

Figure 7, showing suitability for airfield construction, is essentially the type of map that would be used for planning road construction and maintenance. Its chief sources were Figures 5 and 6, from which were drawn information concerning soil drainage,

slope, and availability of construction materials. The classification reached after consideration of these factors is, in this case, expressed primarily in terms of suitability for airfield construction. In this particular example it happens that the map-unit classification, ranging from "good" to "very poor", also ranges from the areas of best drainage to those of poorest drainage. It is possible that the presence of extremely uneven terrain, or the lack of construction materials in some areas, would necessitate a less orderly progression in terms of drainage. This illustrates a cardinal principle of military geology: the final answer to a problem of military application of geologic information must be stated as simply as possible, but the geologist must remember that this answer can be reached only by analysis of a multiplicity of factors. No single factor will alone give the answer.

In conclusion, it is the responsibility of the military geologist to predict as closely as possible what the ground conditions are, with particular reference to drainage and suitability for stabilization; where construction materials may be found within a suitable radius; the properties of these materials, and the problems that may be met in extracting them. He does these things on the ground as a consultant working closely with the engineer, and also at a great distance from the area of study, as a contributor to intelligence studies or to pre-operational planning.

Due to the inability to reproduce the photographs, they were not included.

## DETRIMENTAL MINERALS IN CONCRETE AGGREGATE

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I am honored by the invitation to address this group of engineers on this subject. Your interest in this matter probably arises from your desire to produce low cost pavements - low in original cost but also low in maintenance and repairs. You probably like to think about a truly permanent pavement which would withstand heavy traffic, rain and sun, freezing and thawing, and all of the other things that tend to cause destruction of pavements. Being practical, however, you realize that such ideal construction materials do not exist, so you build pavements or highways of various materials, one of which is concrete.

Some people regard concrete as a lifeless material. I like to think of it as something dynamic, rather than static - something which is continually changing. Hydration proceeds rapidly during the first few weeks but continues at a decelerating rate for months if not years. When destructive forces have once begun, their acceleration can become quite pronounced and a good pavement can become a bad pavement in a surprisingly short time. Autogenous healing, presence of unhydrated clinker grains in very old concretes, and other similar evidences seem to suggest that concrete continues to grow (that is, hydrate) during its entire useful life. Nevertheless, concrete has a limited ability to withstand the ravages of time and part of this limitation is related to the aggregate employed.

I wish it were possible to bring to you a more complete picture of the role of aggregate in the life of concrete. Unfortunately only a portion of the picture has been painted to date. Concrete aggregate has been defined as an inert material, usually sand, gravel, crushed stone, etc., which makes up the bulk of concrete when combined with portland cement and water in suitable

proportions. This definition contains a fundamental falacy. In fact if aggregates were strictly inert we would have no occasion for discussing the matter today. Some aggregate materials are highly reactive toward the physical-chemical processes which accompany the hydration of portland cement. On this occasion we can only consider a few typical sources of difficulty in our search for ideal aggregates. Probably no aggregate is completely inert. In fact, if such a completely inert aggregate were to exist, it might be anything but ideal; it might have zero adhesive strength with the cement paste.

We are therefore searching for good aggregates, aggregates that react in favorable ways. The **easiest** approach to this subject is a negative one, i.e. a consideration of some typical bad aggregates in order to see what makes them bad. Facetiously, I might comment that there is another approach to this problem which has been applied with diminishing success in recent years: namely, the assumption that all aggregates are inherently good and any distress which appears in the concrete can be directly attributed to the poor quality of the portland cement, or contamination of the mix water, or the honesty of the contractor, or various other "excuses." Please do not gain the impression that I imply that all diseases of concrete are directly attributable to the aggregate. This is not true and this over-simplification would be as erroneous as blaming all faulty concrete on the cement.

All of you are well aware that sulfate solutions are "bad medicine" for concrete, whether the sulfate comes from chemical wastes, ground water or whatever the source. When I was with the Bureau of Reclamation, we were fabricating mortar bars of various different rocks and minerals in order to obtain data on their behavior with respect to high-alkali cements. I decided to throw in a ringer - so to speak - and requested that alunite ( $KAl_3(SO_4)_2(OH)_6$ ) be used in a set of mortar bars. Alunite is not ordinarily considered a soluble mineral, but what happened to those mortar bars should never happen to any concrete

structure. Although the bars containing the high-alkali cement showed severe distress at very early ages, the low-alkali bars soon were so badly cracked and expanded that we made no further measurements. Alunite is not likely to occur in many potential aggregate deposits but I can assure you that a little of this mineral would go a long way in causing the deterioration of the concrete.

Most of you have heard of Stanton's history-making discoveries concerning certain pavements in California. You realize, of course, that this was the original recognition of what is now loosely called alkali-aggregate reaction. More accurately, it should be called "reaction between certain types of aggregate materials and the alkalies of portland cement." Stanton deduced that there was something unusual about the aggregate of the faulty pavements. It was not long before the siliceous constituents were recognized as the source of the difficulty and various organizations became interested in attempting to learn more about reactive aggregates. Because Parker Dam had exhibited some of the same symptoms of disease that had been observed for the California highways, the Bureau of Reclamation became actively interested in learning the causes, symptoms, and cure or prevention of this disease of concrete. I was one of the "doctors" hired by the Bureau in 1941 to make clinical studies of this disease and to conduct research on its cure or prevention. R. F. Blanks, a rather progressive engineer, and C. P. Berkey (Geologist on the Bureau's Board of Consultants) had sold Chief Engineer Harper on the study of concrete deterioration by petrographic methods. In those days I might add that it took a bit of selling.

What we found out about the diseases of concrete is, in general, readily accessible in the literature. These studies were confined essentially to aggregate materials which react with portland cements containing more than 0.60 percent of soda equivalents. A considerable number of minerals and rocks were found to react with these cements, as is indicated in table 1. We did not confine our investigations to empirical tests but attempted to obtain a general

TABLE I. Rocks and Minerals Which are Deleteriously Reactive with High-Alkali Cements

<u>Reactive Mineral</u>	<u>Chemical Composition</u>	<u>Physical Character</u>
Opal	$\text{SiO}_2 \cdot n \text{H}_2\text{O}$	Amorphous
Chalcedony	$\text{SiO}_2$	Cryptocrystalline fibrous
Tridymite*	$\text{SiO}_2$	Crystalline

Reactive Rocks -1-

Reactive component

<b>Siliceous Rocks:</b>	
Opaline cherts	Opal
Chalcedonic cherts	Chalcedony
Siliceous limestones	Chalcedony and/or opal
<b>Volcanic rocks**:</b>	
Rhyolites and rhyolite tuffs	Volcanic glass, devitrified glass, and tridymite
Dacites and dacite tuffs	
Andesites and andesite tuffs	
<b>Metamorphic rocks:</b>	
Phyllites	Hydromicas (?)
<b>Miscellaneous rocks:</b>	
Any rocks containing veinlets, inclusions, or grains of the reactive minerals listed above	

\* Hornibrook, Insley, and Shuman, 1943, p. 218

-1- Artificial silicate glasses, such as pyrex glass, are known to be reactive

\*\* The volcanic types listed are known to be deleteriously reactive; basalts are known to be innocuous; data regarding trachytes, latites, and phonolites are lacking.

(This is the table which appears on p. 237 of the Engineering Geology (Berkey) Volume published by the Geol. Soc. Amer.)

V O L . 1 S I C . 4

picture of the physical-chemical conditions which contribute to the destruction of the concrete. In this latter connection, I shall merely state that we were able to demonstrate that the expansion, cracking and decline in strength of the concrete was caused by the attack upon certain aggregate materials by the caustic solutions within the hydrating cement which resulted in the formation of gelatinous materials. These gelatinous materials are capable of imbibing water from the concrete and, in doing so, produce osmotic pressures which exceed the tensile strength of concrete. We were successful in measuring these pressures and were also successful in calculating pressures of the same order of magnitude on the basis of well-established laws of physical chemistry. In addition, a chemical test to ascertain reactivity of aggregates with respect to high-alkali cements was devised by the Bureau's Petrographic Laboratory.

Suppose one has, however, a reliable source of low-alkali cement. What aggregates must one avoid if good concrete is to be assured? I can only give you a few helpful clues on this subject. Some aggregates are apparently capable of contributing alkalis to the hydrating cement. Possibly this was the case with alunite. We did not investigate the mechanism of deterioration caused by alunite because we had too many other irons on the fire. However, a recent Bureau memorandum indicates that analcite can release sodium ions and thereby cause adverse reaction if other deleterious materials are present. Analcite is a member of a mineral family known as Zeolites and its behavior is similar to that of artificial zeolites in treatment of water. Since the cement juice of concrete is saturated with respect to calcium ions, analcite can release sodium ions by base-exchange processes. The question of base exchange in concrete is not new; it may have been responsible for deterioration of cast stone and stucco, as described by Loughlin in 1923.

Another interesting case came to our attention. A dolomite, i.e. a fine-grained basic igneous rock somewhat like basalt, was submitted to the

laboratory as a possible aggregate source. Microscopic examination disclosed the presence of about 30 percent of clay, which had formed as the result of hydrothermal alteration of the primary igneous minerals. Wetting and drying tests indicated that this rock was capable of expanding and contracting as much as 0.06 percent and of absorbing and releasing almost 3 percent of water. Under comparable conditions of testing argillaceous (clayey) limestones have been found to show 0.1 percent linear fluctuations. Stratified rocks may show in excess of 5 percent variation in linear expansion depending upon the direction in which the expansion is measured. Expansion is usually greatest when measured perpendicular to the bedding planes.

Sweet and others have discussed the dangers associated with the use of certain weathered cherts and have described some special tests which can be applied to determine their suitability as aggregate. Pyrite and marcasite ( $\text{FeS}_2$ ) can become oxidized, with the formation of sulfuric acid and iron oxides, and thus cause popouts and iron staining. Argillaceous constituents can decrease freezing and thawing resistance. Gypsum can liberate sulfate ions to the cement juices and probably cause formation of calcium sulfo-aluminate with consequent expansion of the concrete.

Coatings on aggregate are another potential source of difficulty. Coatings may consist of silt, clay, gypsum, impure carbonates of lime and magnesia, iron oxides, opal, manganese-containing substances, phosphates, or mixtures. In general, if a vigorous washing treatment will remove coatings, the coatings should be removed. Coatings should be viewed with suspicion until they have been given a clear bill-of-health, because of their possible chemical and/or physical affects on the concrete.

You fully realize that we have not discussed any of the standard tests for aggregate materials. We have not mentioned presence of coal lignite or other types of organic matter. No consideration has been given to so-called

soundness tests, tests for porosity, abrasion, etc. In general we have confined our attention to factors which are likely to escape detection by these methods. These methods of testing probably should and probably will be continued until they are replaced by more adequate methods. In addition to these methods, service histories are a valuable aid in attempting to predict the behavior of aggregates that have been in use for several years.

When considering new, untried aggregate sources or when a new type of portland cement is to be used with older aggregates, it is probably advisable to obtain, if possible, a careful petrographic examination. This report should be made by a petrographer who is familiar with the causes of deterioration of concrete. Unfortunately, the number of petrographers who have interested themselves in this field is not large. Nevertheless, it seems appropriate to mention that the late Professor Holden of Virginia Polytechnic Institute did some fine pioneering work of this sort.

In closing I wish to acknowledge the source of most of the results which I have discussed. Except as otherwise noted these results were obtained by my former associates with the Bureau of Reclamation, amongst whom the names of Roger Rhoades and R. C. Mielenz deserve special mention.

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"WHAT DOES THE ENGINEER EXPECT OF THE GEOLOGIST?"

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"What does the engineer expect of the geologist?"

This question might be answered with considerable truth by saying that many engineers expect many things of many geologists. Such a reply, however, would of course be more flipant than helpful. There appears to be, nevertheless, a slight tinge of flippancy in the question, with its implied presumption that the engineer has a right to expect something of the geologist, and that the geologist is somehow under obligation to do something for the engineer. If there are any relations of obligation between the two professions, they are certainly mutual, and it would therefore be much more appropriate to ask: "How can the geologist be of assistance to the engineer?" This discussion will attempt to give some reasonable answers to the latter question.

Geology covers vast areas - geographically, physically and chronologically - and to a very considerable extent engineering does likewise. The two professions also have large overlapping areas; many engineers use geology regularly in their own practice and probably most geologists do considerable engineering of one kind or another. Examples which come readily to mind are topographic surveying, foundation work and subsurface exploration, which are extensively engaged in by both civil engineers and

geologists. Because of this kinship of activity, and perhaps for other reasons, it is the writer's opinion that civil engineers at least can see eye to eye and have a common viewpoint more nearly with geologists than with any other scientists. This is fortunate with respect to assistance which geologists can render engineers, because to be of much assistance to another it is necessary first to understand his problems and particularly his point of view.

It may be of interest here to consider one characteristic difference between the attitude of the engineer and that of the pure scientist. While definitely interested in scientific theory and knowledge and earnestly desirous of having his constructions soundly based thereon, the engineer is usually concerned primarily with the practical application of such theory and knowledge to the particular business at hand. The scientist, on the other hand, frequently and perhaps usually regards the discovery of scientific fact and the development of scientific theory as ends in themselves, and may be somewhat indifferent as to their practical applications, if any. While this generalization is somewhat faulty, as generalizations usually are, it does at least serve to indicate a real difference in viewpoint between many engineers and many scientists which it will be well to bear in mind in considering cooperation between them.

In order for the geologist to be of assistance to the engineer, therefore, it is necessary first for him to remember that the engineer is seeking a practical, usable and reliable answer to a specific problem. Since there is a great deal in

common between the two professions, and since most geologists are fully as much concerned with practical solutions as are engineers, this should offer no particular difficulty to the geologist.

Since the engineer is always working within definite limits of time and money, he is inclined to be impatient of anything which may appear unnecessary and to contribute nothing to the orderly and rapid solution of his problem. This applies not only to over-lengthy and elaborate investigations, but to unnecessarily verbose and complicated reports. The engineer is not favorably impressed with an appearance of great learning, unless it is obviously of practical significance, and he is no more patient with abstract and complex scientific language in connection with his professional problems than he is with abstruse medical jargon when he is trying to learn from a doctor what is wrong with his health. He will be much more impressed with a simple, concise and precise statement which he clearly understands. This does not, of course, mean that the engineer can afford to be ignorant of all geologic facts or unacquainted with basic geologic terminology, but it does mean that the geologist should use highly specialized terms as little as possible and explain them where necessary.

When an engineer seeks help from a geologist, he expects that the geologist will discuss the problem with him until he understands it, and also understands what the engineer needs to know in order to have the answer; that if sufficient information is not available the geologist will say so in order that