METHOD OF PETROGRAPHIC EXAMINATION OF AGGREGATES FOR CONCRETE[1,2]

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SYNOPSIS

A detailed description of the method for petrographic examination of aggregates for concrete as it has been developed for use by the Concrete Laboratories of the Corps of Engineers is presented. The differences in procedure which depend upon the nature of the sample submitted and the purposes of the examination are described. Suggestions are made concerning the features to be delineated, the amount of material to be examined, and the organization and presentation of the results of the examination. It is hoped that the information presented will serve to clarify the concept of what is meant by petrographic examination of aggregates and, perhaps, ultimately, contribute to greater uniformity in the making of such examinations.

There does not appear to have been a previous presentation of a outline of the method by which a qualified petrographer may apply the knowledge and techniques of geology to the examination of various types and conditions of material that are considered for use as aggregates for concrete. There are an increasing number of engineering organizations that are undertaking the application of petrographic methods to the study of concrete aggregate, an increasing number of petrographers who are being confronted with the need to examine concrete aggregates, and an increasing number of engineers who are called upon to evaluate petrographic data. It is therefore felt desirable to present a detailed statement of the method for petrographic examination of aggregates for concrete as it has been developed for use by the seven concrete laboratories of the Corps of Engineers.

In a previous paper[4] the use of petrographic methods for the identification of reactive constituents in concrete aggregate was discussed. The merits of petrographic examination of concrete aggregate materials and the results of such examinations have been dealt with in a number of papers, many of which are included in this bibliography.

The method as set forth here represents the most recent product of work begun more than a decade ago by Elliot P. Rexford, the first concrete laboratory petrographer of the Corps of Engineers, whose last paper[5] gives a valuable summation of his long experience. To him and to the other petrographers with whom the authors have been associated, appreciation is expressed for much

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[1] Presented at the Fifty-third Annual Meeting of the Society, June 26-30, 1950.
[2] Approved for presentation and publication by the Office, Chief of Engineers, U.S. Army.
[3] Head, Petrography Section and Chief, Special Investigations Branch, respectively, Concrete Research Division, Waterways Experiment Station, Jackson, Miss.
[4] B. Mather, "Petrographic Identification of Reactive Constituents in Concrete Aggregates," *Proceedings,* American Society for Testing and Materials, V. 48, pp. 1120-1127 (1948).
[5] E. P. Rexford, "Some Factors in the Selection and Testing of Concrete Aggregates for Large Structures," *Transactions,* American Institute Mining and Metallurgical Engineers, V. 187, No. 3, pp. 395-405 (1950). (Technical Publication 2837 H).

assistance; they include: W. L Donn, Rosalind Ravitch, George Townsend, Louis Moyd, Pauline Moyd, Jeanne Weiser, O. G. Alessio, N. B. Dodge, R. A. Dunkerley, and R. V. Tye.

This method has been editorially modified from that published as CRD-C 127-50 in the Handbook for Concrete and Cement issued by the Waterways Experiment Station.

EXAMINATION AND CLASSIFICATION

This method outlines the procedures to be employed in the petrographic examination of samples representative of materials proposed for use as aggregates in concrete. The scope of such an examination may be limited as in the case of preliminary examinations, or complete, as in the case of final examinations.

Preliminary Examination

The preliminary examination is designed to assist the field geologist in judging which of apparently suitable aggregate sources contain material of sufficiently promising quality to warrant further and more complete investigation. Such preliminary examinations should be used as a part of the process of elimination in the survey of economically available aggregate sources when other evidence is not available as a basis for sound initial judgment of quality. The value of a preliminary petrographic examination will be dependent largely upon the adequacy of the samples provided, upon the data on the deposit (amount of material, predictable difficulties in working, etc.) which are provided with the samples, and on the proposed use of the material. The results of such an examination should not be used alone as a basis for final acceptance of a material.

Complete Examination

The complete petrographic examination is designed to constitute an integral part of the comprehensive study of the suitability of an aggregate material for the use for which it is proposed. The value of such an examination will be greatly influenced by the adequacy of the procedures used in obtaining the samples which are submitted for examination.

The specific procedures employed in petrographic examination of any sample of aggregate material depend to a large extent both on the purpose of the examination and on the nature of the sample submitted. The purposes to be served by petrographic examination are as follows:

Properties

The delineation of all physical and chemical properties that may be observed by petrographic means which bear on the quality of the materials for their intended use.

Classification

The description and classification of materials present in samples of aggregate will logically include identification of the rocks in the sample. Identification is usually a necessary step towards recognition of the properties which may be expected to influence the behavior of the materials in their intended use. It is not an end in itself. Rock of any type may perform well or poorly as concrete aggregate depending on the physical conditions of the aggregate, and on its physical and chemical properties as compared to the matrix in which it may be placed.

The data developed by a petrographic examination can provide a basis for predicting quality, provide an explanation of the results obtained from performance tests, and give information on factors not at present capable of being investigated by performance tests. The usefulness of any petrographic examination to the agency requesting it will depend largely on three factors:

1) The representativeness of the samples provided.
2) The information accompanying the samples, which should include the location, type of sampling, extent of deposit (if known), name of geologic formation (if known).
3) The petrographer's degree of understanding of the information needed by the agency requesting the examination. It should be the responsibility of the agency requesting the examination to make its needs clearly and specifically known to the laboratory. It should be the responsibility of the petrographer to understand and make use of the information available to him. This information will frequently include the results of elementary tests on the sample, chemical tests of potential reactivity, and freezing and thawing of concrete containing the aggregates under test.

APPARATUS AND SUPPLIES

Specimen Preparation

The apparatus and Supplies consist of:

1) Diamond saw, preferably with 14-in. blade,
2) Horizontal grinding wheel, preferably 16 in. in diameter,
3) Polishing wheel, preferably 8 to 12 in. in diameter,
4) Abrasives: silicon carbide grit No. 100, No. 240, FFF; emery such as American Optical Co. M-303, and M-304,
5) Prospector's pick,
6) Microscope slides, clear, noncorrosive, 25 by 45 mm. in size,
7) Canada balsam, neutral, in xylol,
8) Xylol,
9) Glycol phthalate,
10) Small laboratory oven,
11) Plate-glass squares about 12 in. on an edge for thin section grinding,
12) Thin-section holder,
13) Jones rifle sampler with pans,
14) Micro cover glasses, noncorrosive, square 12-18 mm, 25 mm, etc., and Plattner mortar.

Specimen Examination

The apparatus and supplies consist of:

1) Polarizing microscope with mechanical stage; low-, medium-, high-power objectives, objective centering devices; eyepieces of various powers; full- and quarter-wave compensators; quartz wedge;
2) Microscopic lamps;
3) Stereoscopic microscope with paired objectives and paired oculars to give final magnifications from about 6 X to about 60 X;
4) Magnet, preferably alnico, or an electromagnet;
5) Needleholder and points;
6) Dropping bottle, 60 ml. capacity;
7) Petri culture dishes;
8) Smooth straight-pointed forceps;
9) Lens paper;

10) Immersion media, n = 1.410 to n = 1.785 in steps of 0.005;
11) Abbé refractomer;
12) Sodium arc lamp;
13) Zirconium arc lamp;
14) Wratten light filters;
15) Counter;
16) Photomicrographic camera and accessories

Examples of the above-listed items are shown in Figs. 1 to 8.

Note—The apparatus and supplies listed above and illustrated in Figs. 1 to 8 comprise a recommended selection. It is not intended that the specific items listed and illustrated must necessarily be provided. It is however regarded as essential that an adequate selection be provided to enable the use of all of the procedures described in this method for the examination of the particular types of samples that are to be studied.

Samples

Samples for petrographic examination should be taken by or under the direct supervisions of a geologist familiar with the requirements of aggregates for concrete and in general following the requirements of A.S.T.M. Methods of Sampling Stone Slag, Gravel, Sand, and Stone Block for Use as Highway Materials (D 75-48).[6] The exact location from which the sample was taken, the geology of the site, and other pertinent data should be submitted with the sample.

Undeveloped quarries should be samples by means of cores, drilled through the entire depth expected to be productive of sound material. Drilling of such cores should be in a direction which is essentially normal to the dominant structural feature of the rock. Massive material may be sampled by "NX" cores. Thinly bedded or complex material should be represented by cores not less than 4 in. in diameter. There should be an adequate number of cores to cover the limits of the deposit proposed for the work under consideration. The entire footage of the recovered core should be included in the sample and accurate data given as to elevations, depths, and core losses.

Operating quarries and operating sand and gravel deposits in which stock piles of the material produced are available, should be represented by not less than 100 lb. or 300 pieces, whichever is larger, of each size of material to be examined. Samples from stock piles should be composed of representative portions of larger samples collected with due consideration given to segregation in the piles.

Exposed faces of non-producing quarries, where stock piles of processed material are not available, should be represented by not less than 4 lb. from each distinctive stratum or bed with no piece weighing less than 1 lb., or by drilled core as described in the first paragraph of this section.

Undeveloped sand and gravel deposits should be samples by means of test pits dug to the anticipated depth of future economic production. Samples should consist of not less than the following quantities of material which are representative of the deposit:

[6] 1949 Book of A.S.T.M. Standards, Part 3, pp. 758.

Sieve Size	Quantity	
	Lb.	pieces
6 to 12 in.	…	[a]
3 to 6 in.	…	300[a]
1 1/2 to 3 in.	400	
3/4 to 1 1/2 in.	200	
No. 4 to 3/4 in.	100	
Sand	50	

[a] Not less than one piece from each apparent type of rock.

The amount of material actually studied in the petrographic examination will be determined by the nature of the examination to be made and the nature of the material to be examined, as discussed in the next section.

TYPES OF MATERIAL

As previously noted, the specific procedures used in any petrographic examination depend to a large extent on both the purpose of the examination and on the nature of the sample submitted. The procedures to be selected will be those that will give adequate information on the properties and classification of the materials contained in the sample examined. When the intended use of the aggregate is known, the specific methods used in a petrographic examination will depend on the type of sample and the complexity of the sample. The samples considered in this test method may be classified into two groups.

Natural gravel and natural sand

This group includes those materials in which the particle shape and particle surface of the finished graded aggregate result chiefly from natural processes.

Drilled core, ledge rock, crushed stone, and manufactured sand

This group includes those materials in which the particle shape and particle surface of the finished graded aggregate result chiefly from the manufacturing process.

Methods for the examination of samples of the first and second groups will be discussed in more detail. Many of the procedures described for the examination of materials of one group will be applicable to some samples in the other group.

PROCEDURE FOR PETROGRAPHIC EXAMINATION OF NATURAL GRAVEL AND SAND

Samples

Samples of gravel and natural sand for petrographic examination should be sieved according to A.S.T.M. Method of Test for Sieve Analysis of Fine and Coarse Aggregates (C 136-46)[7] to provide samples of each sieve size. In the case of sands an additional portion should then be sieved, without being washed and test according to A.S.T.M. Method of Test for Amount of Material Finer Than No. 200 Sieve in Aggregates (C 117-49)[8] to provide a sample of the material passing the No. 200

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[7] 1949 Book of A.S.T.M. Standards, Part 3, p. 763.

[8] 1949 Book of ASTM Standards, Part 3, p. 748.

sieve. The results of the sieve analysis of each sample made according to A.S.T.M. Method of Test for Sieve Analysis of Fine and Coarse Aggregate (C 136-46)[6] should be provided to the petrographer making the examination and used in calculating results of the petrographic examination. Each sieve fraction should be examined separately, starting with the largest size available. Rocks are more easily recognized in larger pieces; the breakdown of a heterogeneous type present in the larger sizes may have provided particles of several apparently different types in the smaller sizes; some important and easily confused types may be recognizable using the stereoscopic microscope if they are first recognized and separated in the larger sizes, but may require examination using the petrographic microscope if they are first encountered in the smaller sizes. The number of particles of each sieve fraction examined will be fixed by the required precision of determination of the less abundant constituents.[9] It is believed that at least 300 particles of each sieve fraction should be identified and counted in order to obtain reliable results. Precise determinations of small quantities of an important constituent will require counts of larger samples.

Examination of natural gravel

Coatings—The pebbles should be examined to establish whether exterior coatings are present. If the are, it should be determined whether the coatings consist of materials likely to be deleterious in concrete (opal, gypsum, easily soluble salts, organic matter). It should also be determined how firmly the coatings are bonded to the pebbles.

Rock types

The sieve fraction should be sorted into rock types by visual examination. If all or most of the groups present are types easily identifiable in hand specimen by examination of a natural or broken surface, and by scratch and acid tests, no further identification may be needed. Fine-grained rocks which cannot be identified megascopically or which may consist of or contain constituents known to be deleterious in concrete should be checked by examination with the stereoscopic microscope. If they cannot be identified by that means, they should be examined using the petrographic microscope. The amount of work done in identifying fine-grained rocks should be adapted to the information needed about the particular sample. Careful examination of one size of a sample, or information from previous examination of samples from the same source, will usually make apparent the amount of additional detailed microscopic work required to obtain information adequate for the purpose.

Condition

The separated groups belonging to each rock type should be examined to determine whether a further separation by physical condition is necessary. If all of the particles of a rock type are in a comparable condition, that fact is noted. More frequently particles in several degrees of weathering will be found in a group. They should be sorted into categories based on condition and on the expectation of comparable behavior in concrete. The types of categories intended are: (a) fresh dense; (b) moderately weathered; (c) very weathered: or (a) dense; (b) porous (or porous and friable).

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[9] Assuming that the field sampling and laboratory sampling procedures are accurate and reliable, the number of particles examined, identified, and counted in each sieve fraction will depend on the required accuracy of the estimate of constituents present in small quantities. The numbers given in this method are minimal. They are based on experience and on statistical considerations discussed in the following two references:

G.G. Simpson and A. Rowe, 1939, "Quantitative Zoology," McGraw-Hill Co., Inc., New York, N.Y., pp. 182-185.

A.L. Dryden, Jr., 1931, "Accuracy in Percentage Representation of Heavy Mineral Frequencies," *Proceedings,* Natural Academy of Sciences U.S., V. 17, No. 5, May, pp. 233-238.

It is usually impractical to recognize more than three conditions per rock type, and one or two may be sufficient. An important constituent present in large quantities may sometimes require separation into four groups by condition. The conspicuous example is chert when it is the major constituent of a gravel sample. It may be present as dense, unfractured chert; as vuggy chert; as porous chert; and as dense but highly fractured chert. The determination of which of these four conditions characterizes a particle may be expected to have an important influence on prediction of the behavior of the particle in concrete.

Sequence of Examination of Sizes

Examination of the largest size usually indicates the major groups of constituents in a gravel and the principal considerations which are likely to affect the suitability of the aggregate for the intended use. The other sieve fractions should then be examined in order of diminishing size, separated into rock types, and counted. As new groups appear, they should be identified and counted. Changes in the condition of each group from sieve fraction to sieve fraction should be recorded. Ordinarily it will not be necessary to examine in detail the material passing the No. 4 sieve in a gravel sample, unless it amounts to more than 5 percent of the nominal No. 4 to 3/4-in. size range, or unless inspection suggests that it contains constituents which may be expected to have an important effect on the suitability of the aggregate for the intended use.

Record

Notes should be taken during the examination. Each rock-type should be described; the relevant features may include:

1) Particle shape,
2) Particle surface,
3) Grain size,
4) Texture and structure, including observations of pore space, packing of grains, cementation of grains,
5) Color,
6) Mineral composition,
7) Significant heterogeneities,
8) General physical condition of the rock-type in the sample, and
9) Presence of constituents known to cause deleterious chemical reaction in concrete.

Particle counts should be recorded so that tables can be made for inclusion in the report. When the examination has been completed, the notes should contain enough information to permit the preparation of tables and descriptions. Tables should be prepared showing the composition and condition of the samples by sieve fractions, and the weighted average composition, based on the gradation of the sample as received and on the distribution of constituents by sieve fractions. Descriptions of constituent groups should be prepared containing the relevant features among those listed in the preceding paragraph.

Examination of natural sand

The procedure for the examination of natural sand is similar to that for the examination of gravel, with the modifications necessitated by the differences in particle size.

Sizes coarser than No. 30

Each sieve fraction present that is coarser than the No. 30 sieve should be reduced in the Jones riffle until a split or splits containing at least 300 particles are obtained. The reduced sample of each sieve fraction should be examined, and its constituents identified, and counted using the stereoscopic microscope. It is convenient to spread out the sample in a flat-bottomed glass dish such as a Petri dish and manipulate the grains with a forceps and dissecting needle. The identification of grains in the coarser sand sizes is often easier when the grains are just submerged in water. The submergence lessens reflection from the outer surfaces and may show diagnostic features that cannot be seen when the grains are dry. There are exceptions to this generalization. Where identification is difficult, the examination includes examination of the natural surface (dry and wet), examination of a broken surface (dry and wet), and scratch and acid tests. Only after all of these steps have been taken and the grain is still unidentified should the petrographer resort to the petrographic microscope. Grains which cannot be identified using the stereoscopic microscope or which are suspected of consisting of or containing substances known to react deleteriously in concrete should be set aside to be examined with the petrographic microscope. If the question of reaction with the minor alkalies of portland cement is important in the examination of the sample, certain additions to the procedure are indicated. If the coarser sand sizes contain fine-grained possibly glassy igneous rocks, several typical particles of each variety of such rocks should be selected for more thorough examination. The petrographer should determine the presence or absence of glass by crushing typical grains and examining them in immersion media using the petrographic microscope. In difficult or especially important cases, it may be necessary to break suspected grains, make immersion mounts of part of the grain and a thin section of another part. Where the sand contains chert and the potential reactivity of the chert is an important consideration, a number of chert particles from the fractions retained on the No. 30 sieve should be set aside for determinations of the index of refraction.

Sizes finer than No. 30

The sieve fraction finer than the No. 30 sieve should each be reduced in a Jones riffle to about 4 or 5 g. The volume will usually be less than a level teaspoonful. In some gradations the fraction retained on the No. 100 and No. 200 sieves may be present in such small amounts that reduction is unnecessary. These splits should be further reduced on a miniature Jones riffle or by coning and quartering with a spatula on a clean sheet of paper. A representative portion of each reduced split should be mounted in immersion oil on a clean glass slide and covered with a clean cover glass. No entirely satisfactory method of reducing a split to about 300 grains is known. The reduced split can be sampled by spreading it in a thin layer on glass or clean paper, dragging the end of a dissecting needle moistened in immersion oil through the sample, and transferring the grains that adhere to the needle to a drop of immersion oil on a clean slide. If this is done carefully, a fairly representative sample will be obtained. If the dissection needle is magnetized steel, a concentration of magnetic minerals may result. It is usually necessary to make several mounts of the No. 50 and No. 100 sieve fractions to obtain at least 300 grains of each. The index of the immersion oil should be selected to make the identification of the important constituents as easy and as definite as possible. Practice at the Waterways Experiment Station is to use an immersion oil with an index of or just below the lower index of quartz (1.544). The slide should be mounted on a petrographic microscope equipped with a mechanical stage. Several traverses should be made, and each grain that passes under the cross hair should be identified and counted. Care should be taken to move the slide on the north-south adjustment between traverses so that no grain should be counted twice. Each sieve fraction passing the No. 30 and retained on the No. 200 sieve should be examined in this way. Ordinarily, the material passing the No. 200 sieve is mounted on a slide following the procedure described above, examined using the petrographic microscope, and its composition estimated. If an unusually large amount of this size is present, or if it contains constituents that may be expected to have an important effect on the suitability of the aggregate for the intended use, it should be counted.

PROCEDURE FOR PETROGRAPHIC EXAMINATION OF DRILLED CORE, LEDGE ROCK, CRUSHED STONE, AND MANUFACTURED SAND

Drilled core

Each core should be examined and a log prepared showing footage of core recovered, core loss and location; location and spacing of fractures and parting planes; lithologic type or types; alternation of types; physical condition and variations in condition; toughness, hardness, coherence; obvious porosity; grain size, texture, variations in grain size and texture; type or types of breakage; presence of constituents capable of deleterious reaction in concrete. If the size of the core permits, the probability that the rock will make aggregate of the required maximum size should be considered. If the surface of the core being examined is wetted it is usually easier to recognize significant features and changes in lithology. Most of the information usually required can be obtained by careful visual examination, scratch and acid tests, and hitting the core with a hammer. In the case of fine-grained rocks, it may be necessary to examine parts of the core using the stereoscopic microscope, or to prepare thin sections of selected portions. Some considerations and procedures are more applicable to particular rock-types than to others. Ordinarily, the layered rocks considered for concrete aggregate will be limestone, and occasionally metamorphic rocks, such as phyllite or schist. One of the most important questions arising in the examination of limestone is that of the presence, type, and distribution of argillaceous impurities. Limestones which contain intercalated thin beds of soft shale may make suitable sources of aggregate if the shale is so distributed that it does not prevent manufacture of the required maximum size, and if the shale can be eliminated or reduced in processing. Where argillaceous impurities are present, it should be determined whether they actually consist of clay minerals or of other minerals in clay sizes. If they do consist of clay mineral, it should be established whether the clay minerals include members of the montmorillonite group (swelling clays).[10] In the examination of fine-grained igneous rocks, particular attention should be directed to the nature of the groundmass. This examination should include determination of the presence or absence of opal, chalcedony, natural glass and clay minerals of the montmorillonite group; if any of these are found the amount should be estimated; if natural glass if found the type should be determined.

Ledge rock

The procedure in examination should be the same as for core samples to the extent that the spacing of samples and size of the individual pieces allow. If the sample consists of a relatively large quantity of broken stone produced by blasting, it is desirable to inspect the whole sample, estimate the relative abundance of rock types or varieties present, and sample each type before further processing. Subsequent procedure should the same as given below for crushed stone.

Crushed stone

The procedure for examination of crushed stone should be similar to that for core, except that necessary quantitative data should be obtained by particle counts of the separated sieve fractions.

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[10] G.F. Loughlin, 1928, "Usefulness of Petrology in the Selection of Limestone," *Rock Products,* V. 31, No. 6, pp. 50-59.

Manufactured sand

If no samples of the rock from which the sand was produced are available, the examination procedure should be similar to that for natural sand, with particular emphasis on the amount and extent of fracturing developed by the milling operations.

CALCULATIONS

The composition of each sieve fraction of a heterogeneous sample and the weighted sample should be calculated as follows:

1) The composition of each sieve fraction shall be expressed by summing the total number of particles of that fraction counted, and calculating each constituent in each condition as a percentage of that total (amount, as number of particles in percent, in each sieve fraction). It is convenient to calculate and record the percentages to tenths at this stage. An example of these calculations is given in the upper half of Table I.
2) The percentage by weight of the sieve fraction in the whole sample (individual percentages retained on consecutive sieves) shall be obtained from the gradation of the sample as determine by A.S.T.M. Method (C 136-46)[6] (Individual percent retained on sieve in Table I).
3) By multiplying the percentage of the constituent in the sieve fraction, determined under (1) by the percentage of the sieve fraction in the whole sample, obtained in (2), the percentage in the whole sample of that constituent in that size shall be obtained (weighted percentage of constituents in each sieve fraction, Table I). It is convenient to calculate and record these percentages to tenths.
4) By adding the weighted percentages of each constituent in each sieve fraction, the weighted percentage of each constituent in the whole sample shall be obtained (see under weighted composition of sample in Table I).
5) A table shall be constructed to show the composition of each sieve fraction and the weighted composition of the whole sample. Values shall be reported to the nearest whole number. Constituents amounting to 0.5 % or less of a sieve fraction or of the whole sample shall be reported as traces. Table II is an example constructed from the data obtained in Table I. As a convention, the total in each sieve fraction and the total in the whole sample shall each be 100 % without the traces. Difficulties in abiding by this convention can usually be avoided by grouping minor constituents of little engineering importance. It is preferable to tabulate constituents known to react deleteriously in concrete so that their distribution will be apparent from inspection of the table, even though the amount in the whole sample or in any fraction is very small.

REPORT

The report of the petrographic examination should consist of two principal parts, the summary and the detailed report as indicated in Appendix A. The summary report customarily consists of two paragraphs that summarize, respectively, the essential data needed to identify the sample as to source and proposed use, and the features of the material as revealed by the examination. The complete report records the test procedures employed, the data developed on the composition of the material, and a description of the nature and features of each important constituent of the sample, accompanied by such tables and photographs as may be required to present adequately the findings of the examination.

Since it is improbable that the engineer who must make the ultimate decision as to the suitability of a material for use as concrete aggregate will be a geologist or petrographer, it is highly undesirable that the terminology used in the summary report be simplified to the greatest extent compatible with an adequate presentation of the data. A list of rock and mineral names is given in Appendix B. It is suggested that insofar as practicable the terms used in the summary reports be those included in this list. The petrographic report should be a statement of the findings of the examination. When the sample has been found to possess properties or constituents which are known to have specific unfavorable effects in concrete those properties or constituents should be described qualitatively and, to the extent practicable, quantitatively. The unfavorable effects that may be expected to ensue in concrete should be mentioned also. When appropriate, it should be stated that a given sample was not found to contain any undesirable features. The report should not, however, contain a general statement of opinion by the petrographer concerning the quality of the material. The petrographer should avoid such general statements of opinion because they are subjective and therefore not properly a part of a report of objective findings, and since they can properly be made only when data on different materials can be compared in connection with the requirements for a specific use.

APPENDIX A

PETROGRAPHIC REPORT

X Summary — Detailed

Symbol: PORT-3 6088	**Project:** McNary Dam	**Date report Submitted:** April 15, 1948	**Initials:** KM
Serial No. : PORT-3 G-1, S-1	**Source:** G-1, Berrian Island, Washington Shore S-1; 50 % Berrian Island, 50 % Jones-Scott Pit, Oregon Shore		

Sample

On February 17, 1948, two samples, one consisting of 3 bags of natural gravel, and the other of 3 bags of sand, were received. Information accompanying the samples stated that the source of the gravel was Berrian Island, Washington Shore, and the sources of the sand were 50 percent Berrian Island, Washington Shore, and 50 percent Jones-Scott Pit, Oregon Shore. CRD Serial No. PORT-3 G-1 was assigned to the gravel and CRD Serial No. PORT-3 S-1 to the sand.

Summary

Petrographic examination has been made of samples of natural gravel of 1-in. maximum size from Berrian Island, Washington Shore (PORT-3 G-1) and of sand produced by combining material from Berrian Island, Washington Shore with that from the Jones-Scott Pit, Oregon Shore (PORT-3 S-1). The coarse aggregate is tough dark rounded gravel consisting principally of basalt, with andesite, rhyolite, quartzite, quartz, chert, granite, and gabbro. The fine aggregate is composed of similar rocks and of the minerals derived from them: basalt, feldspar, quartz, ferromagnesian minerals, ore and accessory minerals, and clay. About 5 percent of the coarse aggregate consists of rhyolite and andesite containing acid and intermediate natural glass and ryholite containing tridymite; about 20 percent of the coarse aggregate consists of basalt containing intermediate natural glass, with a minor amount of basalt containing basic natural glass. Some of the particles of glassy basalt also contain small amounts of secondary chalcedony and opal. Approximately 27 percent of the fine aggregate consists of basalt, andesite, and rhyolite containing intermediate or acid glass, particles of natural glass, and chalcedony. Acid and intermediate natural glass, tridymite, chalcedony, and opal have all been shown to be reactive with the minor alkalies of portland cement.

PETROGRAPHIC REPORT

—Summary X Detailed

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Test Procedure

Representative portions of each sieve fraction of the gravel were examined and sorted megascopically and with the stereoscopic microscope. Forty-five thin sections were prepared and studied using the petrographic microscope. A large number of powders were examined using the petrographic microscope, to determine the mineral composition of particles and to determine the index of refraction of natural glass detected in the thin sections. Several photographs were taken.

Representative portions of each sieve fraction of the sand were examined and sorted with the help of the stereoscopic and petrographic microscopes.

Composition

The coarse aggregate is dark rounded natural gravel, composed principally of fine-grained volcanic rocks with some quartzite, chert, quartz, mylonite, granite, and gabbro. The sand is composed of fragments of similar rocks and of the minerals derived from them. The most abundant rock-type in the gravel and the sand is basalt. About half of the basalt pebbles in the gravel contains natural glass; a few contain chalcedony or opal. Rhyolite and andesite containing glass and rhyolite containing tridymite amount to approximately 5 percent of the sample. Almost all of the gravel is dense, tough, and unweathered. The sand is more weathered than the gravel, and many of the basalt particles are partially coated with clay. The composition of the gravel and the sand is shown in Tables III and IV, and the constituents will be described later.

Volcanic rocks without glass

A wide variety of types are included here; the pebbles range from acid types such as rhyolite, rhyolite and quartz porphyry though andesite to basic types, principally basalt.

Rhyolite and rhyolite porphyry — The particles in this group are rounded, usually pale in color, smooth, and hard. Most are buff, light gray, or white on freshly broken surfaces. Almost all have porphyritic texture with phenocrysts of quartz, orthoclase, or acid plagioclase in a fine-grained groundmass. In many, the groundmass consists largely of spherulites of radially crystallized feldspar and quartz; in others, the groundmass consists of a granophyric intergrowth of feldspar and quartz. All of the particles in this group are completely crystalline, and almost all are dense and tough.

Andesite and altered andesite — Most of the pebbles in this group are rounded, greenish-gray, fine-grained, and dense. Some of them are porphyritic, with phenocrysts of intermediate plagioclase or of augite in a groundmass composed of microlites of plagioclase. The groundmass in some is felted; in others, the feldspar microlites show parallel orientation and flow structure. Several of the pebbles in this group are altered andesites, in which the original ferromagnesian minerals have been replaced by minerals of the chlorite group. All the particles in this class are completely crystalline, and almost all are dense and tough.

Basal t— Approximately 20 percent of the gravel consists of rounded pebbles of tough dark green, gray, or black basalt. The majority of the crystalline basalts studied in thin section are composed of laths of calcic plagioclase with interstitial pyroxene and ore minerals. A minority contain olivine as well as pyroxene. Some contain large quantities of interstitial ore minerals which make the groundmass entirely opaque and raise the specific gravity of the particles.

Volcanic rocks with glass or tridymite

This group includes pebbles of light-colored rhyolite, greenish andesite, and dark, sometimes vesicular, basalt. All of them contain materials which are known to be reactive with the minor alkalies of portland cement.

Rhyolite and andesite — The rhyolite and andesite are generally similar to those described in the paragraph above, but contain interstitial natural glass of intermediate or acid composition. In one thin section of a rhyolite, sparse phenocrysts of orthoclase and sodic plagioclase were scattered in a spherulitic groundmass containing small crystals of tridymite.

Basalt—The basalt particles which contain natural glass are gray, dark green, or black. Some contain phenocrysts which can be seen with the naked eye; others are apparently structureless and break with conchoidal fracture. Some are vesicular, with the rims of the vesicles bleached; in a few the vesicles have been filled with hisingerite, chalcedony (Fig. 9), opal, or clay minerals of the montmorillonite group. The crystalline constituents of these pebbles are the same as those of the basalt without glass, but the crystals are generally smaller, and the groundmass is made up of glass (Fig. 10(*a*)) or contains patches of glass (Fig. 10 (*b*)). The glass varies in color from pale yellow through tan and brown to black. It is believed that the dark color is due to minute diffused particles of opaque ore minerals. Almost all of the natural glass in the basalt pebbles has indices of refraction below 1.57; in a few particles glass of index above 1.57 was detected.

Miscellaneous

A wide variety of rock and mineral fragments amount to approximately 25 percent of the gravel and 7 percent of the sand. In the coarse aggregate, tough fresh quartzite particles are the most abundant constituent of this group. Quartz is a consistent minor constituent of the coarse and the fine aggregate. Chert composed of microcrystalline quartz is present in the gravel. Minor amounts of chalcedony were found in the sand. Pebbles of mylonite, granite, and gabbro are present in the coarse aggregate. In the sand, quartzite particles, clay, calcite, ore minerals, and accessory mineral such as zircon were assigned to this group.

APPENDIX B

LIST OF ROCK AND MINERAL NAMES FOR USE BY CONCRETE LABORATORY PETROGRAPHERS

Rock Names

Group terms

1. Igneous rocks
2. Volcanic rocks
3. Basic igneous rocks
4. Acid igneous rocks
5. Basic volcanic rocks
6. Acid volcanic rocks
7. Glassy volcanic rocks
8. Porphyry
9. Metamorphic rocks
10. Sedimentary rocks
11. Carbonate rocks

Major rock types

1. Granite
2. Granodiorite
3. Diorite
4. Gabbro
5. Basalt

$\left\{\begin{array}{l}\text{6. Rhyolite}\\ \text{7. Andesite}\end{array}\right\}$ Felsite

8. Pumice
9. Gneiss
10. Schist
11. Marble
12. Quartzite

13. Limestone
14. Shale
15. Slate
16. Siltstone
17. Chert
18. Sandstone
19. Graywacke
20. Conglomerate

Varietal or minor rock names

1. Syenite
2. Pegmatite
3. Gabbro-diorite
4. Amphibolite
5. Diabase
6. Serpentine
7. Dacite

8. (-) porphyry
9. Glassy (-)
10. Gneissic (-)

11. Argillaceous limestone
12. Arenaceous limestone
13. Cherty limestone
14. Shaly limestone
15. Oolitic limestone
16. Siliceous limestone
17. Magnesian limestone
18. Dolomitic limestone
19. Lithographic limestone
20. Chalk
21. Mudstone
22. Argillite
23. Phyllite
24. Argillaceous sandstone
25. Calcareous sandstone
26. Arkose
27. Arkosic quartzite
28. Coal
29. Lignite
30. Clay-ironstone

Mineral Names [a]

Group terms

1. Accessory minerals
2. Carbonate minerals
3. Clay minerals
4. Secondary minerals
5. Ferromagnesian minerals
6. Volcanic glass (a rock constituent but not a mineral)
7. Feldspar
8. Mica
9. Limonite
10. Wad
11. Amphibole
12. Pyroxene
13. Zeolite
14. Sulfides

Major minerals (and rock components)

1. Quartz
2. Chalcedony (a mixture of a mineral and a mineraloid)
3. Opal (a mineraloid)

13. Chlorite
14. Calcite
15. Dolomite

4. Tridymite	16. Pyrite
5. Cristobalite	17. Hematite
Feldspar	
6. Orthoclase	18. Magnetite
7. Plagioclase	19. Gypsum
8. Microcline	20. Kaolin
Pyroxene	Volcanic Glass (not a mineral)
9. Augite	21. Acid Volcanic Glass
Amphibole	
10. Hornblende	22. Basic Volcanic Glass
Mica	
11. Muscovite	23. Intermediate Volcanic Glass
12. Biotite	
Varietal Terms and Less-Frequent Minerals	
1. Gold	20. Sodalite
2. Graphite	21. Olivine
3. Zircon	22. Montmorillonite
4. Garnet	23. Biedellite
5. Apatite	24. Halloysite
6. Allanite	25. Serpentine
7. Sphene	26. Alunite
8. Epidote	27. Bytownite
9. Fluorite	28. Andesine
10. Tourmaline	29. Labradorite
11. Galena	30. Albite
12. Pyrrhotite	31. Anorthite
13. Marcasite	32. Perthite
14. Sphalerite	33. Microperthite
15. Chalcopyrite	34. Aragonite
16. Analcite	35. Siderite
17. Natrolite	36. Barite
18. Laumontite	37. Glauconite
19. Nepheline	

[a] The terms given in this list have been used in petrographic reports issued by the Concrete Research Division, Waterways Experiment Station, or occur in published literature on concrete aggregates.

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Figure 1 — Equipment for examination of samples at low magnifications.

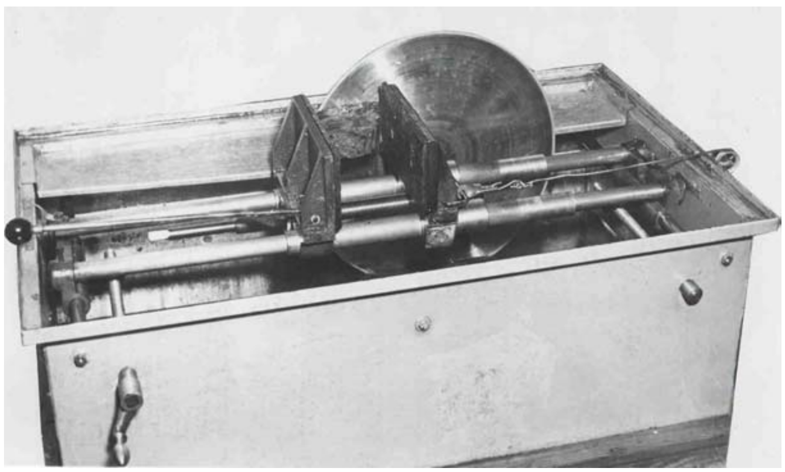
Figure 2 — Diamond saw.


Figure 3 — Horizontal lap for grinding and smoothing sawed surfaces of rock.

Figure 4 — Grinding thin section blank on horizontal lap.

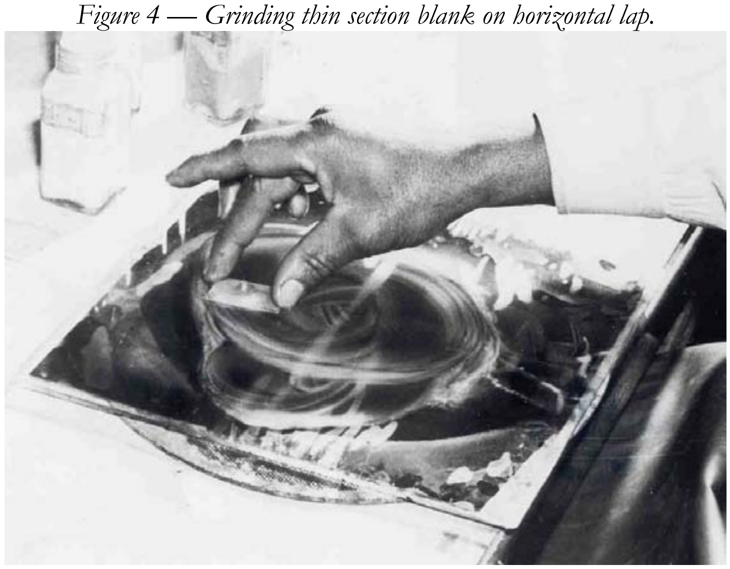

Figure 5 — Final grinding of thin section on glass plate.

Figure 6 — Petrographic microscope for examination of thin sections or powder mounts, index, media, counter.

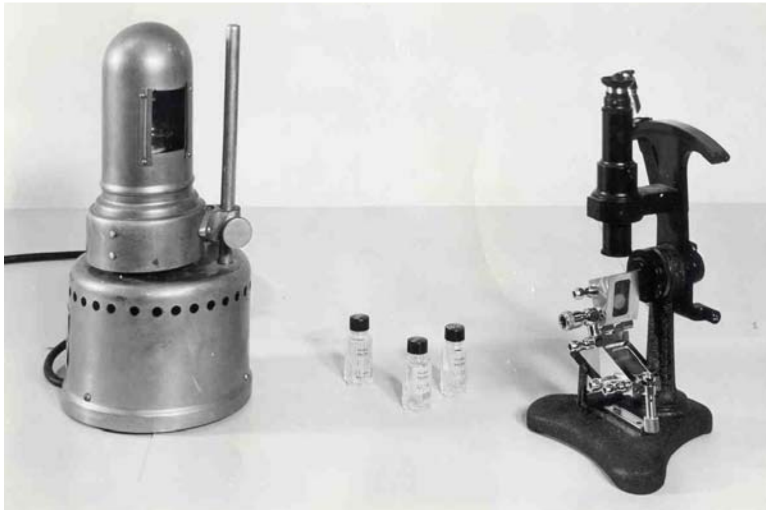

Figure 7 — Sodium arc lamp and abbé refractometer for calibrating index media.

Figure 8 — Photomicrographic camera in use over petrographic microscope.

Table I—Calculation of results of particle counts

Constituents	Composition of fractions retained on sieves shown below							
	3/4-in.		1/2-in.		3/8-in.		No.4	
	Number of particles	%	Number of particles	%	Number of particles	%	Number of particles	%
A_1	250	50.0	200	40.0	150	30.0	50	10.0
A_2	50	10.0	100	20.0	125	25.0	100	20.0
A_3	10	2.0	50	10.0	75	15.0	100	20.0
B_1	107	21.4	70	14.0	62	12.4	32	6.4
B_2	76	15.2	53	10.6	19	3.8	87	17.4
B_3	—	—	20	4.0	43	8.6	96	19.2
C_1	5	1.0	5	1.0	20	4.0	20	4.0
C_2	2	0.4	2	0.4	6	1.2	10	2.0
C_3	—	—	—	—	—	—	5	1.0
Totals	500	100	500	100	500	100	500	100
Individual % retained on sieve		17.4		32.6		29.5		20.5

	Weighted percentages of constituents in each sieve fraction				Weighted composition of sample	
	3/4-in.	**1/2-in.**	**3/8-in.**	**No.4**		
A_1	8.7	13.0	8.9	2.1	32.7	64.6 (total A)
A_2	1.7	6.5	7.4	4.1	19.7	
A_3	0.4	3.3	4.4	4.1	12.2	
B_1	3.7	4.6	3.7	1.3	13.3	31.8 (total B)
B_2	2.6	3.5	1.1	3.6	10.8	
B_3	—	1.3	2.5	3.9	7.7	
C_1	0.2	0.3	1.2	0.8	2.5	3.6 (total C)
C_2	0.1	0.1	0.3	0.4	0.9	
C_3	—	—	—	0.2	0.2	
Total in sieve fraction	17.4	32.6	29.5	20.5		
Total in sample, condition 1					48.5	
Total in sample, condition 2					31.4	
Total in sample, condition 3					20.1	

Table II—Composition and Condition of an Aggregate Sample (Table Constructed from Calculations Shown in Table I)

Constituents	Amount, as number of particles in percent							
	In fractions retained on sieves shown below [a]				In whole sample [b]			
	3/4 in.	1/2 in.	3/8 in.	No. 4	Condition 1	Condition 2	Condition 3	Totals
A	62	70	70	50	33	20	12	65
B	37	29	25	43	13	11	8	32
C	1	1	5	7	2	1	trace	3
Total	100	100	100	100	—	—	—	100
Weighted average, condition 1					48	—	—	—
Weighted average, condition 2					—	32	—	—
Weighted average, condition 3					—	—	20	—

[a] Based on count of 500 particles in each sieve fraction.
[b] Based on gradation of the sample as received, and on the distribution of constituents by sieve fractions shown at the left above. (If the petrographic report forms part of a complete investigation of the sample, including a report of the gradation, the gradation need not be shown. If the petrographic report is to be submitted alone, the gradation of the sample should be included with it).

Table III—Composition of Gravel from Berrian Island, Washington Shore (PORT-3 G-1)

Constituents	Amount, as number of particles, in percent
Volcanic rocks without glass: (Basalt, andesite, rhyolite and rhyolite porphyry)	50
Volcanic rocks with glass or tridymite:	
Basalt containing glass	20
Andesite and rhyolite with glass, rhyolite with tridymite	5
Miscellaneous: (Granite, gabbro, quartzite, myolinite, quartz, chert)	25
Total	100

Table IV—Composition of Sand Proposed for Use in McNary Dam (PORT-3 G-1)

Constituents	Amount as number of particles, in percent [a]						
	In fraction retained on sieves shown below:						In whole sand [b]
	No. 8	No. 16	No. 30	No. 50	No. 100	No. 200	
Volcanic rocks with glass; glass; chalcedony	39	37	32	23	8	3	27
Volcanic rocks without glass	50	44	47	11	11	10	32
Feldspar	4	5	8	47	47	56	23
Quartz	6	7	6	11	6	4	7
Ferromagnesian mineral (Pyroxene, amphibole, olivine, mica)	—	1	2	1	15	15	4
Miscellaneous (Sediments; clay; ore and accessory minerals)	1	6	5	7	13	12	7
Total	100	100	100	100	100	100	100

[a] Based on the examination of 500 particles in each sieve fraction.
[b] Based on grading of the sand as received, and on the distribution of constituents by sieve fractions shown the left above.

Figure 9 — Basalt pebble from Berrian Island, Washington shore (Port-3 G-1)
Photomicrograph of glassy vesicular basalt (X 450, crossed nicols), showing vesicle filled with chalcedony at center. Much of the dark gray groundmass is somewhat devitrified natural glass.

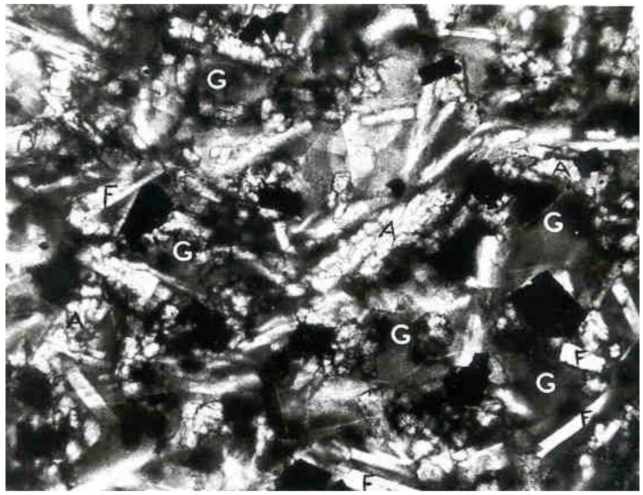

Figure 10(a) — Photomicrograph of glassy basalt (X 200, plane polarized light), constituents indicated by letters: A = augite, F = plagioclase feldspar, G = glass. The black polygons are ore minerals. Almost all of the medium to dark gray groundmass is intermediate natural glass.

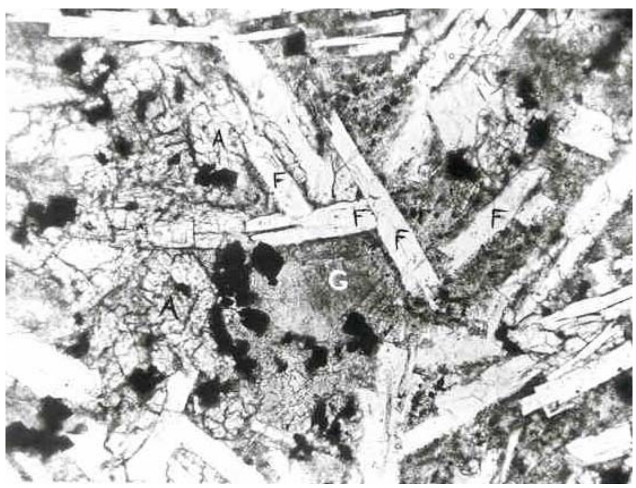

Figure 10 (b) — Photomicrograph of glassy basalt (X 200, plane polarized light). The constituents are the same as those shown above, but the crystals are larger and less glass is present.

Figures 10(a) and (b) — Basalt pebbles from Berrian Island, Washington Shore (Port-3 G-1).