1944/25
c. 3

COMMONWEALTH OF AUSTRALIA.

DEPARTMENT OF SUPPLY AND SHIPPING.

MINERAL RESOURCES SURVEY.

REPORT No. 1944/25.

GEOLOGICAL REPORT ON THE COTTER DAM AND THE AGGREGATE USED IN THE CONCRETE FOR THE DAM.

By

P.B. NYE - ASSISTANT DIRECTOR.
AND
H.B. OWEN - GEOLOGIST.

15 AUG 1944

CANBERRA.

1220. By Authority: L. F. JOHNSTON, Commonwealth Government Printer, Canberra.

DEPARTMENT OF SUPPLY AND SHIPPING.

MINERAL RESOURCES SURVEY BRANCH.

GEOLOGICAL REPORT ON THE COTTER DAM AND THE AGGREGATE USED IN THE CONCRETE FOR THE DAM.

Report No.1944/25.

TABLE OF CONTENTS.

		Page.
I.	INTRODUCTION.	1
II.	THE QUARRIES.	1
III.	THE ROCK.	1
	1. Introduction.	1
	2. Description of Rock.	2
	a. Specimen from Centre of Southeastern Quarry.	2
	b. Specimen from Northwestern part of the South-eastern Quarry.	2
	c. Specimen from Centre of Northwestern Quarry.	2
	d. Specimen submitted by Department of the Interior.	2
	3. Jointing, etc.	3
	4. Sulphide Minerals.	3
	a. Pyrite.	3
	b. Galena.	3
IV.	THE CRACKS.	3
V.	FEATURES OF ROCKS LIKELY TO AFFECT THEIR USE AS AN AGGREGATE IN CONCRETE.	4
	1. Minerals likely to undergo chemical change.	5
	2. Minerals and Features likely to affect the strength of the Concrete.	6
	a. Weathered Felspar.	6
	b. Chlorite-Biotite.	6
	3. Minerals and Features Likely to Affect the Concrete through the Shape and Surfaces of Pieces of Aggregate.	6
	a. Shape of Pieces.	6
	b. Surface of Pieces.	6
	4. Expansive Reaction Between Aggregate and Cement.	6
	a. General.	6
	b. Glass and Fine Particles of the Groundmass	6
	c. Decomposed felspar.	7
	d. Chlorite.	7
VI.	STRUCTURAL FEATURES NEAR DAM SITE.	7
VII.	CONCLUSIONS.	8
VIII.	RECOMMENDATIONS.	8

GEOLOGICAL REPORT ON THE COTTER DAM AND THE AGGREGATE USED IN THE CONCRETE FOR THE DAM.

REPORT NO. 1944/25.

I. INTRODUCTION.

In a memorandum dated 28th February, the Superintending Civil Engineer (Mr. L. Thornton) of the Department of the Interior stated that cracks were showing in the Cotter dam, and that these were serious enough to warrant an investigation as to whether there were minerals in the aggregate likely to cause expansion on decomposition. He also forwarded two samples of the sand and one of the rock that were used in the concrete. He also stated that he had heard that copper pyrites occurred plentifully in the stone.

An examination of the sand was made by the Chief Geologist (Dr. N.H. Fisher) and the results were forwarded by the Director (Dr. H.G. Raggatt) on the 16th March. The Director also stated that an examination of the quarry would be made before a report was submitted on the stone.

Visits were made to the Cotter dam and the adjacent rock quarries, and this report embodies the results of those visits and of subsequent investigations.

The cracks in the dam are not necessarily due to factors which can be detected by geological investigation, e.g. they may be entirely due to constructional defects. Nevertheless all possible geological factors likely to affect the stability and strength of the dam were investigated and, even though it was subsequently found that some of them could have little or no effect on the dam, they are discussed in this report.

II. THE QUARRIES.

The dam is built on the Cotter River, approximately half a mile west from the junction of that river with the Murrumbidgee River, and is a straight wall with its long axis bearing 25° magnetic (or N.25°E mag.). Downstream from the dam, the river has a general south-easterly course for a few hundred yards. Near the dam, the river flows through a gorge and there are good sites for quarries.

Two stone quarries were found. The larger one is situated about 100 yards downstream from the dam and on the south-western side of the river. It is adjacent to the footbridge over the river and will be referred to as the Northwestern Quarry. The smaller quarry is approximately 100 yards farther downstream on the same side of the river and will be referred to as the Southeastern Quarry.

No other quarries were found. It is not known if stone was used from any other source, e.g. the excavation for the foundations of the dam. If there are no other quarries or sources, the greater part of the stone used in the concrete must have come from the Northwestern quarry. It is assumed that the stone from the Southeastern quarry was used for the concrete even though farther away, because there is no other apparent use for it.

The quarries are small and irregular, and were formed as the result of the removal of a small thickness of rock from the steep side of the gorge in which the river flows.

III. THE ROCK.

1. Introduction. In the vicinity of the dam and the quarries, there is only one rock formation present. It is a massive rock generally resembling a medium-grained igneous rock and to which "porphyry" can be given as an appropriate and convenient field name.

2. Description of Rock. In the quarry, the unweathered rocks are grey in colour and contain small phenocrysts of quartz, felspar and a ferro-magnesian mineral in a fine-grained groundmass.

Specimens from the central parts of each quarry, and from the northwestern part of the Southeastern quarry, were examined under the microscope with the following results:

(a) Specimen from Centre of Southeastern Quarry.

Phenocrysts.

Quartz. Fractured and containing blebs of glass and inclusions of altered biotite and apatite. Somewhat corroded. Shows some strain.

Felspar. Shows both Carlsbad and albite twinning with glassy inclusions in some crystals. Mainly plagioclase (oligoclase dominant), but some orthoclase. Approximately half of the felspar phenocrysts are weathered to cloudy, and more or less opaque, masses. The remainder of the felspar is less weathered, a small proportion being only a little altered.

Biotite. Almost wholly altered to chlorite with a small amount of a greyish opaque unidentified mineral.

Groundmass. Microcrystalline, felspathic, but contains some greenish chlorite and possibly some devitrified glass. Apatite also present.

Secondary Minerals. Pyrite developed adjacent to one biotite phenocryst. Specimen is crossed by a vein of granular secondary quartz which traverses a quartz phenocryst and surrounds a felspar crystal.

(b) Specimen from northwestern part of the Southeastern Quarry.

Similar rock to specimen (a), but quartz phenocrysts more corroded. Much pyrite is present in cubes and is developed adjacent to altered biotite and in cracks in a quartz phenocryst. Some pyrite is embedded in groundmass. Pyrite is pale in colour and fine-grained.

(c) Specimen from Centre of Northwestern Quarry.

Similar rock to (a) and (b), but no pyrite visible in section, and a small proportion of the felspar has undergone alteration to sericite.

(d) Specimen submitted by Department of the Interior.

Similar to (a), (b) and (c), but quartz very corroded. No pyrite.

From the examination of the four thin sections, the average mineral composition of the rock appears to be:

Phenocrysts.	Per cent.
Quartz	15
Felspar	17
Biotite, chlorite and sericite	7 (including not more than 0.5 per cent of the unidentified mineral)
Groundmass.	60 (felspathic, but contains some quartz and fine grains of biotite-chlorite)
Pyrite. Secondary quartz apatite, etc.	1
	100

The rock is a quartz-felspar-biotite porphyry (or granodiorite porphyry), and consists of phenocrysts of the above three minerals (or their alteration products) in a fine groundmass composed mainly of felspar.

3. Jointing etc. Though generally massive the rock contains numerous joints. The jointing is not very regular in distribution, direction and amount. There are two sets of major joints, viz. those trending northerly and easterly respectively. Very narrow quartz veins containing pyrite occur in some of the joints. Brown and yellow oxidation products (limonitic) of the pyrite are also associated with some of the prominent joints.

It is possible that some of the most prominent joints may represent small faults. Further information on the strike and dip of the joints is given in section VI.

4. Sulphide Minerals.

(a) Pyrite. In the Southeastern quarry, and particularly in the northwestern portion, a yellow metallic mineral was relatively plentiful. The mineral occurs in the rocks alongside the major joints. In a few cases quartz veins, about an eighth of an inch wide, were present in the joints. The mineral was pyrite (iron sulphide), and no evidence of chalcopyrite (or copper pyrites-sulphide of iron and copper) was obtained. In the vicinity of joints with which the pyrite is associated, brown and yellow iron oxidation products are prominent.

A close inspection of the Northwestern quarry revealed only a small amount of pyrite in the rock. A narrow vein of quartz and pyrite occurs in an east-west joint. However, the presence of brown and yellow staining suggests that there is probably more pyrite in the Northwestern quarry than was found during the field examination. Examination in the office of specimens collected from the quarry confirmed this view, small pieces of pyrite being found in at least half of the specimens collected.

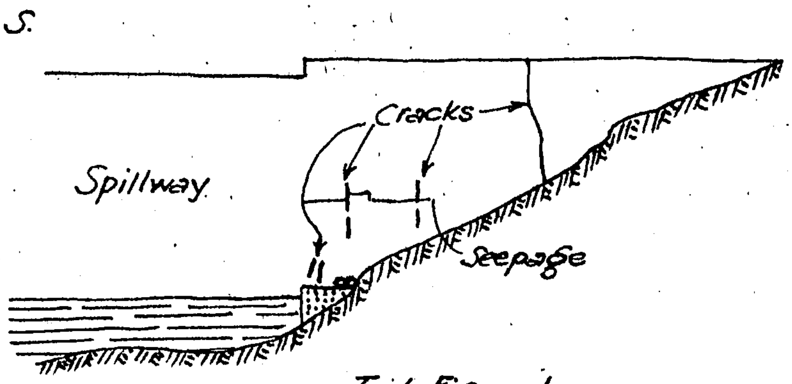
The pyrite occurs generally in small pieces ranging up to possibly one-twentieth of an inch in size, but the larger pieces or clusters of crystals range up to about one quarter inch in maximum dimension. It also occurs as thin films (probably in joints) up to three-eighths of an inch in maximum dimension.

The content of pyrite in the rock in the Northwestern quarry is small and visual examination suggests that it probably does not exceed 1 in 10,000. If specimens with the most pyrite are selected from the northwestern part of the Southeastern quarry, faces of 1 square inch can be obtained with a pyrite content up to 5 per cent, and small pieces of rock will have a pyrite content of 1 to 2 per cent. An estimate made of the pyrite content of a rock section (specimen (b)) under the microscope was approximately 1 per cent. These figures indicate the maximum pyrite content of pieces of rock which might have entered the concrete aggregate.

(b) Galena. A piece of galena (lead sulphide) was found in a specimen collected from the northwestern part of the Southeastern quarry. Its maximum dimension was about one-eighth of an inch. No other pieces of galena were observed.

IV. THE CRACKS.

The most noticeable cracks are in the northern part of the dam. The most prominent of these trends almost at right angles to the dam and has a strike of 305°. It is visible under the water on the upstream side of the raised path and appears to have a maximum width of about half an inch at the surface of the dam, but much smaller at very shallow depths. Its course along the raised path has been covered with cement mortar, but it is visible on the downstream face as a nearly vertical crack extending from the top of the face for a depth of about 30 feet to the rock forming the side of the gorge.



Text Figure 1.
Sketch elevation of northern portion of downstream face of Cotter Dam
Scale 1" = 40' (approx.)

Several less prominent and less extensive cracks occur to the west of the main crack near the bottom of the downstream face (see text figure 1). On the lower part of this face there are incrustations formed of thin layers of a brownish-white substance. These incrustations have been formed by deposition from solutions that have traversed the concrete. There is little doubt that the substances deposited were derived largely from the concrete by percolating water.

The incrustations are most plentiful below a horizontal line about 20 feet above the outlet pipes. Water seeps slowly from this line which apparently represents the surface between two pourings of concrete. Most of the incrustation is derived from the water percolating through this and other horizontal joints, but some is derived from water percolating through the cracks.

Samples of the incrustations were examined and were found to be calcium carbonate with little or no impurities. The general processes involved in the solution and deposition are probably as follows:

As soon as a crack is formed or a joint permits passage of water, water from the dam and, to a very much less extent, rainwater, would percolate along them. The water would contain dissolved carbon dioxide (derived from the atmosphere) forming a weak solution of carbonic acid. This solution would attack calcium compounds and form calcium carbonate which is then dissolved as calcium bicarbonate. On exposure to the atmosphere when the downstream face of the dam is reached, the action which is reversed and calcium carbonate deposited, the excess carbon dioxide being released. The process is identical with that involved in the formation of stalactites and stalagmites in caves in limestones, and it would remove appreciable amounts of material from the concrete of the dam (the incrustation would possibly represent only a portion of the total amount removed).

V. FEATURES OF ROCKS LIKELY TO AFFECT THEIR USE AS AN AGGREGATE IN CONCRETE.

There are many features of rocks which are likely to affect the durability, soundness and strength of concrete in which they are used as aggregates. Hoff (1940) discusses generally the application of petrology to aggregates for concrete. The features referred to above include the mineral and rock composition, structure and surface texture of the rock, cleavage of constituent minerals, and degree of weathering. These features are likely to affect the concrete in many ways such as liability to chemical change (oxidation, solution, etc.) the shape and kind of surface and strength of pieces of aggregate. The possibility of expansive reaction between aggregate and cement is probably the most important chemical factor.

In the concrete for the Cotter dam, a crushed aggregate was used, the rock being the porphyry described above. No information is available about the brand or brands of cement used and the chemical composition of same.

Only those features of the rock which are likely to have affected the concrete will be discussed below.

1. Minerals likely to undergo chemical change. The only minerals in the rock which would be likely to undergo chemical change are the sulphides present, viz. pyrite and galena.

Sulphides oxidise and weather more readily than rock-forming minerals and should, therefore, be undesirable constituents of aggregates for concrete. No references are available at present on the effect of sulphide minerals on concrete. It can be safely assumed, however, that aggregate with an appreciable sulphide content would be avoided for use in concrete.

Pyrite is the only sulphide present in sufficient quantity in the quarries from which the aggregate used in the Cotter dam was obtained, to justify consideration. Pyrite oxidises in moist air and forms ferrous sulphate and sulphuric acid. The ferrous sulphate oxidises to other sulphates. These products are soluble in water and would, therefore, be moved by any water circulation in the concrete. They, and particularly the acid, would attack the concrete. If any calcium carbonate is present, gypsum and ferric oxide (eventually yielding limonite) would be formed. The sulphuric acid would probably also produce gypsum by attacking other calcium-bearing constituents of the cement or aggregate.

The above oxidation refers to that assumed to occur in the upper parts of orebodies. The conditions in concrete would be different insofar as there is little, if any, circulation of water and air (residual mixing-water would be present), the amount of pyrite would be less and the particles of pyrite would be protected more or less by the enclosing cement.

Any ferric sulphate formed in the above actions would assist in the oxidation of more pyrite and also of other sulphides, e.g. galena.

It is possible that the actions referred to above would result in the alterations of parts of the concrete and tend to disintegrate it. It is not known if the oxidation of the pyrite represents an expansive reaction, but it is possible that it does so. Such an action, together with the deposition of gypsum in cracks and joints would cause internal strains that might result in rupture and chipping.

If pyrite in cement oxidises, it is probable that the products of oxidation would enter cracks in the cement whether the cracks were caused by the oxidation of the pyrite or by other means. Presence of limonite and gypsum in some or all of the cracks would, therefore, indicate that pyrite was being oxidised.

Although the filling of the cracks would not be examined, it has been found that the incrustation on the face of the dam and covering the cracks, consists of nearly pure calcium carbonate and contains neither limonite nor gypsum. It is clear, therefore, that oxidation products from pyrite are not reaching the face of the dam and it is probable that pyrite is not being oxidised.

2. Minerals and Features Likely to Affect the Strength of the Concrete. The only minerals and features that need to be considered are the weathered or altered felspar and the biotite-chlorite.

a. Weathered Felspar. Assuming that all the alteration is due to weathering the altered felspar would consist mainly of kaolin (one of the main constituents of clay) which has little strength. As the Porphyry contains about 30 to 35 per cent. of altered felspar (see pp.2 and 7) it is possible that its strength has been reduced appreciably below that of the unweathered rock.

b. Chlorite-Biotite. These minerals would have little strength in directions parallel to their perfect basal cleavage. They are present in amount not exceeding 7 per cent. and as their grain-size is much less than the size of pieces of aggregate, it is unlikely that their presence has affected appreciably the strength of the aggregate and the concrete.

3. Minerals and Features Likely to Affect the Concrete through the Shape and Surface of Pieces of Aggregate.

a. Shape of Pieces. Pieces of aggregate consisting largely, if not wholly, of phenocrysts of felspar and chlorite-biotite, would tend to be flat because they would probably be formed by breakage along cleavage faces. These minerals are present to the extent of 17 and 7 per cent. respectively and so represent 24 per cent. of the rock. However, the number of pieces of aggregate conforming to the size of the phenocrysts would represent a much smaller proportion of the aggregate and it is unlikely that the content of flat pieces would be sufficient to affect the strength of the concrete.

There are no other textural and structural features of the rock which would yield undesirable flat pieces.

b. Surface of Pieces. The only minerals likely to adversely affect the surface of pieces of aggregate are felspar and chlorite-biotite. Where these minerals are broken along the cleavage, they would present smooth surfaces, which unless roughened during the crushing and handling, might slightly affect the bond with the cement. The combined percentage of felspar and chlorite-biotite phenocrysts has been given above as 24, but not all phenocrysts would break along the cleavage and not all of the phenocrysts would appear on the surface of pieces of aggregate. It is probable that the proportion of the surface of pieces that would be occupied by cleavage faces of phenocrysts would not exceed 5 per cent.

4. Expansive Reaction Between Aggregate and Cement.

a. General. Alderman (1943) reviewed American literature on the subject of expansive reaction between aggregate and gave a list of constituents of natural aggregate materials which may enter into expansive reaction in concrete. Of the materials and minerals in that list, it can be stated that the only ones present in the aggregate used in the Cotter dam and likely to enter into expansive reaction are the fine particles of the groundmass and the decomposed felspar. The alkali content of the cement is important in this matter (high alkali cements are more likely to cause expansive reaction), but will not be further discussed in this report.

b. Glass and Fine Particles of the Groundmass. Any glass left in the rock is restricted to small blebs in the phenocrysts of quartz and felspar. The amount is so small, that any possible action by it can be disregarded.

The groundmass constitutes about 60 per cent. of the rock, and is microcrystalline so the rock as a whole can be considered to contain a similar proportion of fine grains or particles. The use of the word particles is not intended to convey that the groundmass is an aggregate of loose particles.

The fine grains or particles are mainly felspar and further reference is made to this mineral in the next sub-section.

c. Decomposed felspar. The porphyry contains 17 per cent. of felspar as phenocrysts, and the groundmass (representing 60 per cent of the rock) consists mainly of felspar. The porphyry, therefore, contains a total of 60 to 70 per cent of felspar. Of the felspar in the phenocrysts about 50 per cent is wholly or mainly altered. Assuming that the felspar in the groundmass is altered in similar proportions, the total amount of altered felspar in the porphyry is approximately 30 to 35 per cent.

d. Chlorite. The chlorite group of minerals is not included in Alderman's list of minerals etc., likely to have an expansive reaction with cement. In a discussion Stanton (1941) includes prochlorite as one of the minerals which are non-reactive. In the light of our present knowledge, it can only be assumed that the chlorite in the porphyry will be non-reactive.

VI. STRUCTURAL FEATURES NEAR DAM SITE.

In order to determine if there were any major structural features in the porphyry near the dam and particularly near the northern end where the cracks are, a fairly close examination was made.

At the northern end of the dam, the most prominent structural feature is a major joint with possibly some faulting associated with it. It strikes at 45° (all bearings given are magnetic) and dips at 85° to the southeast. West of the northern abutment, joints strike at 0° and dip to the west at 45°. Immediately east of the northern end the joints strike about 20° and dip to the east at 50°.

On the northeastern side of the river and 200 to 300 feet east from the dam, the main jointing strikes at 70° and dips at 60° to 70° to the south. A similar set of joints is present on the southwestern side of the river and immediately on the downstream side of the dam. There is, in addition, near the latter place a major joint striking at 315° and dipping to the southwest at 25°. A less prominent joint with a similar strike, but dipping to the north appears to have had faulting associated with it.

In the Northwestern quarry, the main joints have the following strikes and dips - strike 20° and dip east at 60°; strike 350° and dip west at 45°; and strike 90° to 110° and vertical dip. In the Southeastern quarry, the main joints strike at 10° and dip east at 55° and strike at 80° and dip north at 60°, and a less prominent joint strikes at 50° and dips northwest at 70°.

It is obvious, therefore, that the observed major jointing near the dam and the quarries includes a set with general northerly strikes and another with general easterly strikes. As the strike of the main crack (and probably also the minor parallel ones) is 305°, it does not agree in strike with either of the above. To the southeast of the southern end of the dam there are, however, two joints are striking 315° and the other about 300°. As far as they could be examined, the rocks near the cracked part of the dam appear to be free from any except minor jointing and it is unlikely that there is a major joint present with a strike of 305°.

In general, therefore, the conclusion must be drawn that the cracking of the dam is not due to slight movement along northwesterly trending major joints or faults. Further, the major joint or fault at the northern end of the dam and striking at 45° is unlikely to have affected the dam in any way.

VII. CONCLUSIONS.

The rock used as an aggregate for the Cotter dam is a quartz felspar-biotite porphyry with much of the felspar weathered or altered and the biotite altered to chlorite. The rock has a small content of pyrite which, however, is much greater in the northwestern part of the Southeastern quarry.

The minerals that have to be considered from the view-points of stability and strength are pyrite, weathered felspar and chlorite-biotite, and from the viewpoint of possible expansive re-action, the weathered felspar. The structural features of the rock in the vicinity of the dam have also to be considered.

Pyrite. If rock from the Southeastern quarry was used, the possible effect of pyrite on concrete has to be considered. If it was not used, it is unlikely that the small pyrite content of the rock from the other quarry would cause any serious defect.

No information is available at present as to the effect on concrete of an aggregate, some pieces of which are likely to contain up to 2 per cent. of pyrite. There is no doubt, however, that pyrite is an objectionable constituent because of the possibility of its oxidation and the action of the oxidised products on the concrete.

Investigation of the cracks did not reveal any limonite or gypsum, and the incrustation on the dam surface near the cracks is almost pure calcium carbonate. If the pyrite is oxidising, none of the products are entering the cracks and emerging on the surface of the dam. In general, it appears, therefore, that the pyrite is not oxidising and affecting the dam, but this cannot be regarded as having been proved.

Weathered Felspar and Chlorite-Biotite. These minerals have little strength and are present to the extent of 37 to 43 per cent. They would tend to reduce the strength of the aggregate and, therefore, the strength of the concrete. The question as to whether the aggregate has sufficient strength is an engineering problem and need not be further considered here.

Expansive Reaction between Aggregate and Cement. Of the materials and minerals known to have an expansive reaction with cement and listed in Council for Scientific and Industrial Research Bulletin No.161, the only one present in the Cotter aggregate and likely to have affected the concrete is weathered or altered felspar, the content being 30 to 35 per cent. The effect of the fine-grained groundmass has also to be considered in this respect. These two statements are made without taking into consideration the composition of the cement which is not known.

Tests would be necessary to determine whether any expansive reaction is likely to occur.

Structural Features. It appears unlikely that there are major northwest trending joints in the bedrock near the cracked part of the dam and that there could have been any movements in the bedrock along such joints, which would have caused the formation of the cracks.

VIII. RECOMMENDATIONS.

It is recommended that -

1. Enquiries be made by the Department of the Interior -

(a) To ascertain whether any of the rock from the Southeastern quarry was used in the concrete.

(b) To ascertain the source of the cement used and to obtain a sample of a cement with a composition as near as possible to that used in the Cotter dam.

2. If rock from the Southeastern quarry was used as aggregate, laboratory tests be made by the Council for Scientific and Industrial Research to determine the effect, if any, on concrete of pieces of aggregate with a pyrite content ranging up to 2 per cent.

3. Because of the large content of weathered felspar and chlorite-biotite, tests be made by the Department of the Interior to determine whether the strength of the aggregate is satisfactory.

4. As the weathered felspar and fine-grained groundmass may possibly cause expansive reaction with the cement, laboratory tests be undertaken by the Council for Scientific and Industrial Research to determine the possible effect of these factors on the concrete. For this purpose, it would be necessary to use sample of cement obtained under 1(b) above. For any such tests, the Mineral Resources Survey would undertake to collect the required samples of rock (aggregate).

5. If further concrete work is to be done at the present dam, or any proposed dam nearby this Branch be asked to examine possible quarry sites in the vicinity to select as suitable an aggregate as possible. If the rock is a porphyry similar to that at the Cotter dam, it would be selected with as little pyrite, altered felspar, fine groundmass and chlorite as possible.

6. Dependent on the results of any tests made under recommendations 2 and 4, similar tests be made of any porphyry aggregate selected in accordance with recommendation 5.

REFERENCES.

Alderman, A.R., 1943. Bull. C.S. & I.R. 161.
Hoff, John C., 1942. Colorado School of Mines Quarterly, Vol. 37, No.3, 39.
Stanton, T.E., 1941. Proc. American Soc. Civil Eng. 67, 1403.

(P.B. Nye.)
Assistant Director.

(H.B. Owen)
Geologist.