1974/100

DEPARTMENT OF
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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

 Record 1974/100

GOOGONG DAM SITE - QUEANBEYAN RIVER N.S.W. - GEOLOGICAL DESIGN INVESTIGATIONS, 1972 and 1973

by

G.B. Simpson

PART 2 - DRILL HOLE INFORMATION

RESTRICTED CANCELLED

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DRILL HOLE INFORMATION

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SUMMARY

The detailed geological design investigation of the Googong Dam Site, 8 km south of Queanbeyan on the Queanbeyan River, commenced in August, 1972. The dam is required to augment the existing water supply of Canberra and Queanbeyan. It is proposed to construct a 58-m high, earth and rockfill dam with a combined spillway channel/rockfill quarry on the right abutment. River diversion will be through a 5 m concrete-lined tunnel in the left abutment. A 10-m high, earth embankment is required in the Phalaris Saddle, north-east of the main dam.

The rocks at the dam site consist of near-vertical beds of dacite and metasediments of Silurian age intruded by Siluro-Devonian granite. The dacite and metasediments have a well-developed cleavage and contain sheared and fractured zones.

The reservoir is mostly underlain by sandstone, slate, and limestone of the London Bridge Formation intruded by granite. No significant leakage paths from the reservoir have been located during the investigation.

Moderately weathered granite and dacite, which are considered sound enough for the dam foundations, are encountered at depths of up to 4 m. The overburden is thicker and more variable on the granite than on the dacite. Pockets of alluvium are present along the banks of the river and these will have to be removed.

No critical rock defects have been observed in the foundations. However, highly weathered sheared and fractured zones will require treatment on both abutments.

In general, fresh and fresh-stained granite and dacite have low permeabilities. Blanket grouting should be carried out to a depth of at least 10 m and the grout curtain should extend to a minimum depth of 25 m below the foundations. The grout curtain should be extended across the spillway crest to a depth of 10 m below the crest foundations.

The diversion tunnel will be excavated through fresh and fresh-stained granite and dacite. It has been estimated that between 10 and 20 percent of the tunnel will require steel support, and some additional rock bolt and mesh support may be necessary. Initial water inflows to the tunnel are expected to be small and restricted to fractured and open-jointed zones.

The foundation rock for the spillway crest lining is considered to be generally sound, although deeply weathered fractured zones may require some treatment.

Sufficient quantities of suitable rockfill material will be available from the spillway excavation. Selection of material may be required in some parts of the quarry to satisfy the size requirements for rip-rap material. Rejection of material in the eastern portion of the upper quarry may be necessary to limit the volume of slate and sandstone to the specified 10 percent of volume of rockfill.

The foundation of the Phalaris Saddle embankment consists of slate and dacite both of which are deeply weathered and sheared. No leakage or foundation problems are expected.

The Googong Dam and reservoir lie in a zone of relatively low seismic activity. The possibility of induced seismicity owing to the filling of the reservoir cannot be entirely discounted; however, ground accelerations resulting from induced seismicity would probably not be of sufficient magnitude to cause damage to the dam embankment or appurtenant structures. It is recommended that local seismicity should be monitored during the filling of the reservoir.

INTRODUCTION

The Googong Dam Site is on the Queanbeyan River, 8 kilometres south of Queanbeyan N.S.W. (Figure 1). The grid reference is BUNGENDORE 274262, 1:50 000 Series Sheet No. 8727-II.

Geological feasibility studies of the Googong Dam Site were carried out in 1954, 1961, and 1970, (Noakes & Burton 1955; Burton, 1963; Saltet 1971). An account of these investigations is included as Appendix 3.

Following the selection of Googong as the site for the fourth dam to augment the water supply for Canberra and Queanbeyan, the Commonwealth Department of Works (CDW) requested a geological design study of the site, and the present investigation commenced in August 1972. The writer, assisted by field-hand V.P. Carberry, carried out the investigation under the supervision of G.M. Burton, E.G. Wilson and E.K. Carter.

The investigations were based on the 1971 CDW design layout; however, the alignment of the proposed diversion tunnel was altered for hydraulic reasons whilst the investigation was in progress, and seismic traverse MM and diamond-drill hole 24 are now offset from the amended line of the proposed tunnel, as shown on the plates.

The proposed dam is an earth and rockfill embankment, 58 m high with a crest length of 336 m. River diversion will be through a concrete-lined tunnel, 5 m in diameter and 220 m long, in the left abutment. The spillway will be excavated through a saddle on the right abutment and will have a crest length of 124 m with a discharge capacity of 152 000 cusecs. The rockfill for the dam will impound 118.6×10^6 m^3 of water with a top water level at RL 663 m. An earth embankment 10 m high will be constructed in the Phalaris Saddle, to the northeast of the dam site. Details of the design are given in Table 1.

TABLE 1: PROPOSED DESIGN DETAILS - GOOGONG DAM

Purpose:	CANBERRA WATER SUPPLY
Locality:	Queanbeyan River South of Queanbeyan, N.S.W.
Design:	To be carried out by DEPARTMENT OF WORKS on behalf of NATIONAL CAPITAL DEVELOPMENT COMMISSION.

TABLE 1 (Contd)

Main Embankment

Type:	Earth-Rockfill	
Height:	58 m (190 ft.)	
Length of Crest:	336 m (1100 ft)	
Volume of Fill Material:	Earth Core	180000 m^3 (235 000 cu.yds.)
	Filters	32000 m^3 (49 000 cu.yds.)
	Rockfill	540000 m^3 (703 000 cu.yds.)

Saddle Embankment

Type:	Earth	
Height:	13.5 m (44 ft)	
Length of Crest:	240 m (790 ft)	
Volume of Fill Material:	Random Earth Fill	37000 m^3 (48 000 cu.yds.)
	Sand Filters	3060 m^3 (4 000 cu.yds.)
	Coarse Rock (Rip-Rap)	4100 m^3 (5 360 cu.yds.)

Spillway

Description	Curved free overflow crest with short coverging concrete lined chute discharging along an unlined channel and then into the Energy Dissipation Pool. (Approach channel and Dissipating Pool excavation are the rock quarries for the Dam).
Length of Crest:	124 m (407 ft)
Crest Level:	R.L. 663 M (2 175 ft) A.H.D.
Discharge during Maximum Probable Flood	4300 m^3/sec (152 000 Cusecs.)

River Diversion

Coffer Dam	Rockfill - Height .... 10 m (33 ft)
Diversion Tunnel	Internal dia. : 5.0 m (16.4 ft) Length (excluding portals) : 220 m (720 ft) - fully concrete lined. Provision will be made for overtopping of the coffer dam and the main embankment during construction, i.e., downstream slope reinforcement.

Outlet Works

Outlet Tower	Reinforced concrete Tower sited above the Diversion Tunnel on an R.C. raft foundation.
Tower W.S. Intakes	6 Intake levels, 1070 (42") dia. butterfly valve closure on each inlet.
W.S. Outlet Pipework	1600 (60") dia. C.L.M.S. main through tunnel.
Max. W.S. Drawoff	363 x 10^3 m^3/day (80 m.g.d.)

FIGURE 1.

LOCALITY MAP
GOOGONG DAM SITE
QUEANBEYAN RIVER, N.S.W

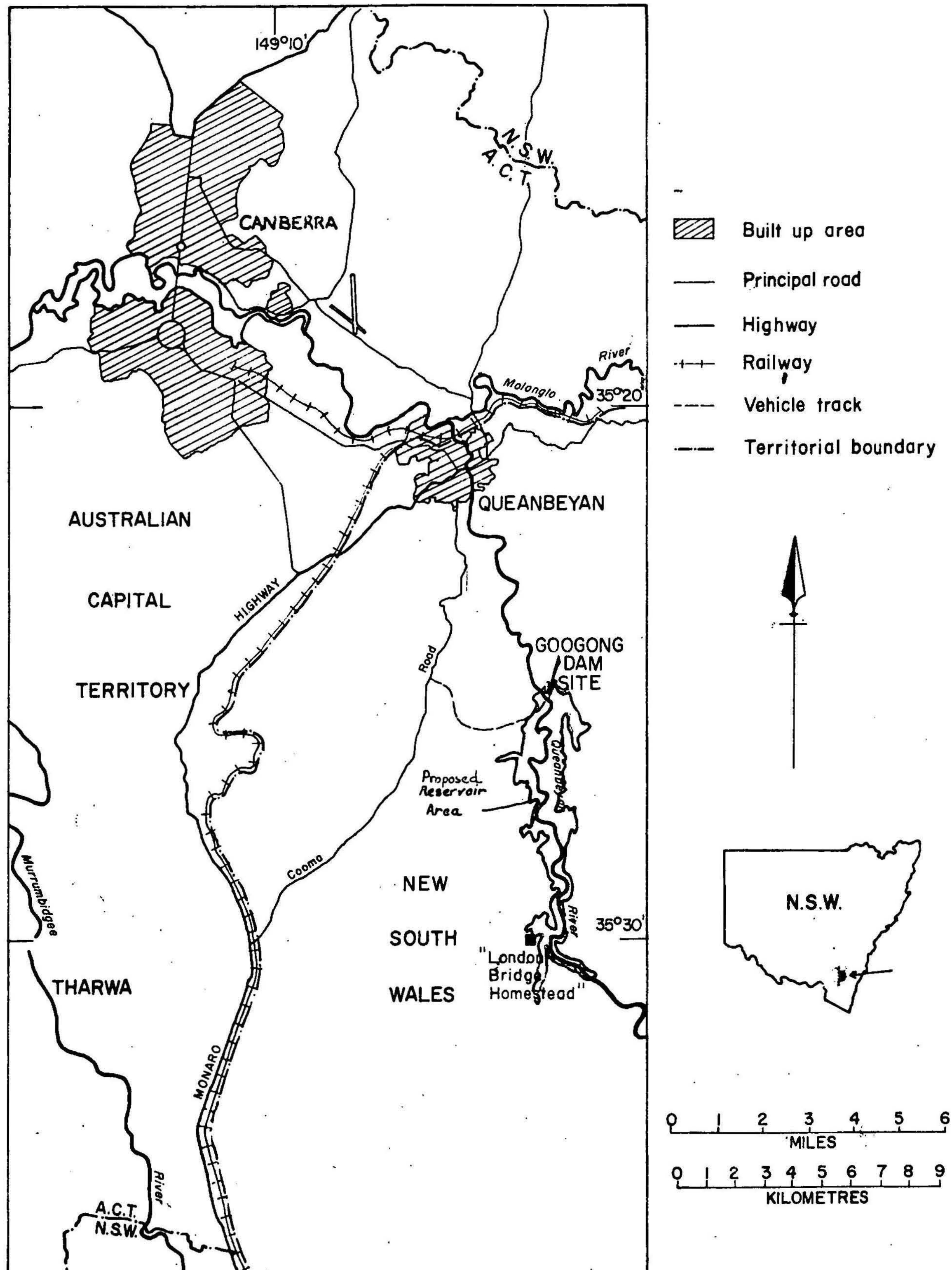

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TABLE 1 (Contd)

Outlet Works (Contd)

River Outlet .... 1070 (42") dia. intake through tunnel plug with butterfly valve closure, 1120 diameter C.L.M.S. pipework in tunnel to a discharge point at the tunnel outlet controlled by 1370 and 300 diam "Howell Bunger" type free discharge valves.

Water Supply and River Outlets interconnected for added flexibility.

Reservoir

Catchment Area .... 875 km^2 (337 sq. miles)
Area of Reservoir at T.W.L. .... 680 ha (1676 acres).
Volume of Reservoir at T.W.L. .... 118.6 x 10^6 m^3 (96 143 acre feet).

METRICATION

Before the design investigation started, CDW decided that reports relating to projects to be constructed after 1 January 1974 should be written using the International system of units (SI units).

The appendices to this report contain factual data from previous reports expressed in Imperial units. It was decided that the conversion of all previous work to SI units was impractical and unnecessary; however, where factual data from these sources have been included in the text or plates of this report they have been converted to SI units. A table of conversion factors is included as Appendix 2.

ACKNOWLEDGEMENTS

Data from previous geological investigations at the Googong Dam Site (Burton 1963; Saltet 1971) have been extensively used in the report. No further acknowledgement of these authors will be given in the text of this report, except where interpretive information has been derived from their reports.

INVESTIGATION METHODS

MAPPING

Geological mapping of the dam site and spillway area was carried out with particular attention to the location and nature of the granite/dacite contact, shear zones, lenses of metasediments, and joint orientations. Field data from the present and previous investigations were plotted on topographic plans at a scale of 1:500 and are presented on Plates 4 and 8.

DIAMOND DRILLING

Diamond-drill holes 22 to 37, totalling 599 metres, were drilled by ARDEC, a division of Dickson Primer Pty Ltd, under contract to CDW. Three holes were drilled along the proposed diversion tunnel route, and eleven within the proposed spillway excavation; in addition, two groundwater observation holes were drilled, one on each abutment downstream from the dam axis.

All the holes were drilled by Mindrill drilling machines, with NMLC triple tube core-barrels with stationary split inner tubes. Holes drilled to test the proposed diversion tunnel, spillway crest, and dam foundations were water pressure tested. Geological logs of diamond-drill holes 1 to 37 and water pressure test results are included in Part 2 of this report (Appendices 10 and 11).

A Craelius rock core orientor was used where information on the orientation of structural defects was required. Joint and fracture orientations were obtained from drill holes along the diversion tunnel, the spillway crest, and maximum cut rock faces in the proposed spillway quarries. The results were corrected for biased sampling and presented as contoured stereographic diagrams (Figs 5 to 7).

GEOPHYSICAL INVESTIGATIONS

No additional seismic refraction surveys were carried out during the design investigations. Previous surveys were carried out in 1962, 1970 and 1972. Wiebenga & Kirton, 1962; Kirton & Wiebenga, 1962; Compagnie Generale de Geophysique (CGG); Taylor & Pettifer, 1972).

An electrical resistivity survey was carried out by the writer in an attempt to determine the continuity of fractured zones that were exposed in costeans 6, 7 and 13 on the right abutments, and in the spillway area;

seismic refraction surveys had failed to detect the fractured zones. Resistivity traverses were made along costeans 12, 13 and 15 (Plate 1) prior to their excavation, but they also failed to detect the fractured zones observed in the completed costeans.

COSTEANING

Costeans 12 to 19 were excavated by a D6 bulldozer using two ripper blades. Four costeans were excavated in the upper spillway area, one in the lower spillway area, two on the left abutment, and one on the right abutment. The costeans were mapped by tape, compass and Abney level from survey control points provided by surveyors of the Department of the Capital Territory. The locations of costeans 12 to 19 are shown on Plate 1.

GROUNDWATER OBSERVATION BORES

Drill holes 38, 39 and 40 were drilled as groundwater observation bores by a BMR Mayhew rotary-percussion rig. The drill holes are 6" diameter vertical holes, and will monitor water levels in the three saddles which present the shortest leakage paths from the proposed reservoir to the Queanbeyan River downstream of the dam. The locations of the drill holes are shown in Figure 2. Observations of standing water levels in the drill holes are included in Appendix 6.

RESERVOIR AREA

GEOLOGY

The geology of the Googong reservoir area was mapped and described by the writer in 1971 (Simpson 1972). The geological map and accompanying notes are included as Plate 3.

LEAKAGE

There are two possible paths of leakage from the reservoir area other than through the dam foundations and the Phalaris Saddle. These are through the Bunyip Saddle, 1500 m southwest of the dam site, and through the Queanbeyan Fault saddle, 500 m northeast of the Phalaris Saddle, at the head of the valley containing the core material deposit. The location of these saddles is shown in Figure 2.

Bunyip Saddle

The configuration of the Bunyip Saddle is such that the minimum horizontal distance from proposed top water level through the saddle is 750 m. The saddle consists of dacite, which shows a strong vertical cleavage striking 020° and is parallel to the reservoir divide at the saddle. Similar rock at the dam site had a low permeability, except in a few zones of open jointing and fracturing where the maximum permeability measured was approximately 300 m per year.

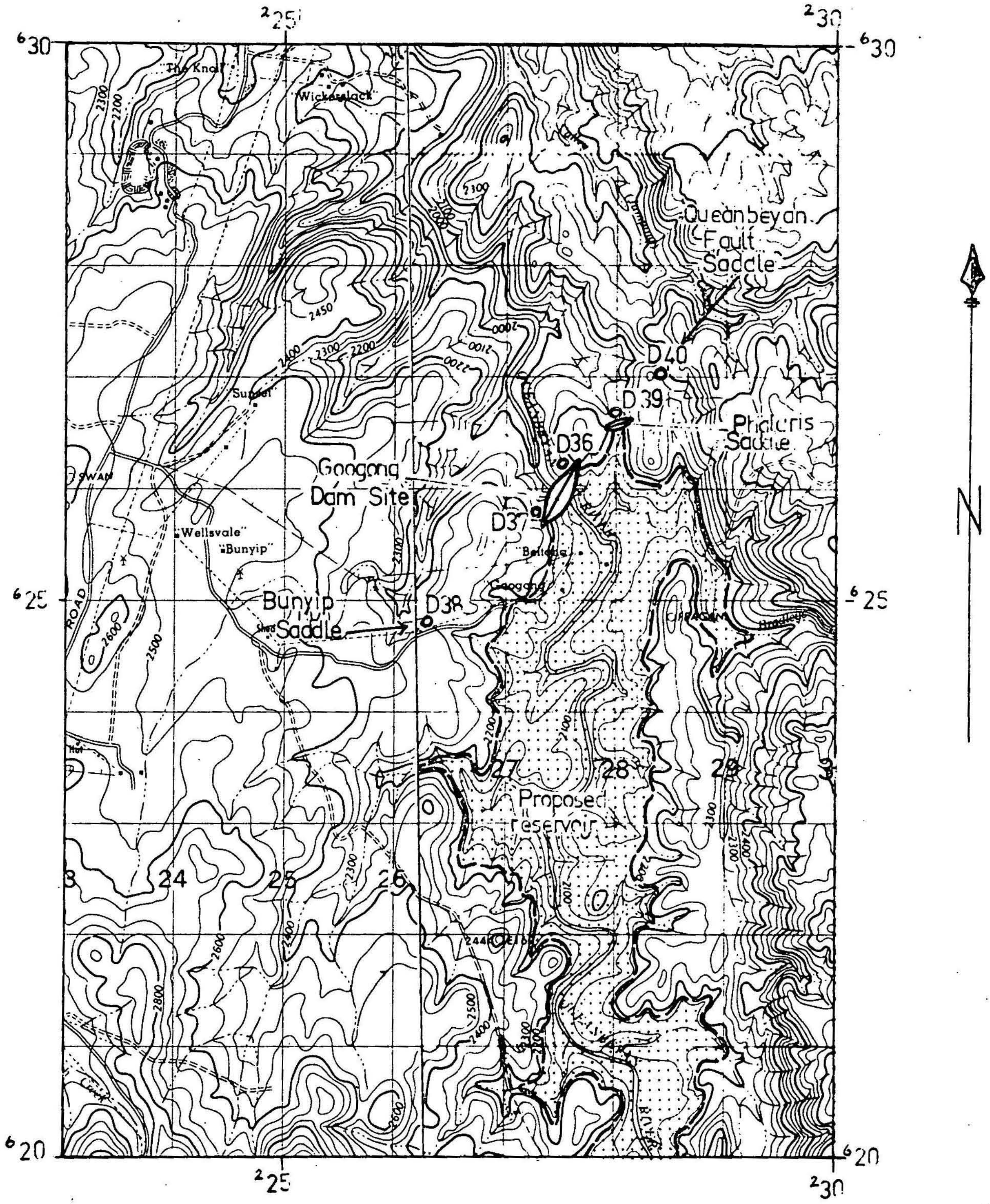
A zone of close vertical jointing, approximately 20 m wide and trending northwest, passes through the saddle near drill hole 38. This zone is continuous and can be traced on aerial photographs and on the ground for more than 800 m on either side of the saddle. The most elevated seepage in the creek, immediately to the north of the saddle, occurs at the intersection of the jointed zone and the creek. The jointed zone may provide a leakage path; however, the permeability of the jointed zone is not known.

Drill hole 38 was drilled in the Bunyip Saddle as a groundwater observation bore; water levels in the hole are listed in Appendix 6, and a geological log of the hole is included in Part 2 of this report. In June 1973, the month following completion of D38, the water level remained constant at a depth of about 15 m, 23 m above proposed top water level. When blow-tested after completion, the hole yielded a constant flow of approximately 1820 litres per hour over a period of 3 hours.

It is considered unlikely that leakage through the saddle will be significant. The stream to the north of the saddle should be monitored for changes in flow during construction and reservoir filling. Water level measurements should be continued in D38, especially during reservoir filling when levels should be taken twice weekly. A pump test should be carried out in D38 to give a measure of the permeability of the dacite in the saddle.

Queanbeyan Fault Saddle

The minimum horizontal distance from the top water level through the saddle to the northeast of the Phalaris Saddle is approximately 1000 m. The Queanbeyan Fault passes through the saddle and the geology is complex. The saddle is underlain by granite, slate, and limestone and numerous quartz veins. The slate has a well-developed cleavage striking approximately north and vertical. The limestone was not observed in outcrop, but was the only rock type intersected by drill hole D40 (Geological log, Part 2). The



GOOGONG DAM SITE

FIGURE 2 -- LOCATION OF GROUNDWATER OBSERVATION BORES

Scale 1 : 50 000

0 1 2 3 4 5 Kilometres

Base map from Australia 1 : 50 000 series, sheets CANBERRA 8727-III and BUNGENDORE 8727-II limestone is silicified and quartz veins are common, and the drilling gave no indication of solution cavities in the limestone. The drill cuttings recovered from D40 below 25 m consisted largely of quartz, which may be derived from quartz veins associated with the Queanbeyan Fault zone.

The drill cuttings became damp at 44 m and the drill hole was wet on completion at 53 m, however, insufficient water was present to carry out a blow test. The water level rose from 53 to 28 m below the ground surface in the 22 days following completion. This suggests that the silicifie limestone and zones of quartz veins may have a low permeability in the region of the drill hole.

Available evidence suggests that significant leakage should not occur through the saddle, however further investigations similar to those recommended for the Bunyip Saddle should be carried out.

DAM SITE GEOLOGY

The rocks at the dam site consist of vertical beds of dacite and metasediments (Colinton Volcanics, Upper Silurian), and the volcanics are intruded by the Googong Granite (Siluro-Devonian). Most of the proposed dam embankment is underlain by dacite, with granite underlying the downstream left bank and toe of the dam. The lower part of the spillway is underlain by granite and the upper part by dacite. The metasediments crop out in the river immediately upstream from the dam site and extend northward beneath the eastern part of the upper spillway (Plates 2, 4, and 8 and Figure 3) (see Appendix 9 for petrological descriptions).

LITHOLOGY

Metasediments

The metasediments immediately east of the gauging weir are thought to be the oldest rocks at the dam site. They crop out as a V-shaped wedge of sandstone, slate, and limestone within the dacite, and as vertical beds or lenses with an average strike of 020° (Plate 2).

No metasediments have been observed in the dam foundations, but minor slate and sandstone lenses are present in the proposed spillway area.

Sandstone. The sandstone is fine to medium-grained, light to dark grey where fresh, and yellow where weathered. Beds are commonly 2 to 30 cm thick. In thin section, rounded to subangular quartz grains are set in a groundmass of fine-grained quartz. Minor amounts of feldspar are present; carbonaceous material is common in some parts.

In drill hole D6 some of the sandstone is calcareous; however, carbonate was not observed in the sandstone cropping out at the surface, and has probably been leached out. Sandstone forms about 30 precent of the metasediments in the V-shaped wedge.

Slate. The slate is dark grey where fresh and brown where weathered, and is calcareous in parts (drill hole D6). Slaty cleavage is well-developed, striking 0201 vertical. In thin section some fine-grained quartz can be distinguished set in a matrix of micaceous material, with variable amounts of carbonate.

Limestone. Grey mottled sandy limestone crops out on the right bank of the river upstream from the gauging weir (Fig. 3). In thin section, well-rounded quartz grains (up to 3 mm diameter) are seen set in a fine-grained matrix of recrystallized carbonate and some quartz (approximately 20%). The limestone passes laterally (along strike) into slate; this may represent a facies change or may indicate complex structural control (see STRUCTURE).

Dacite

Dark blue-grey dacite crops out to the east and west of the metasediments. In hand specimen quartz and feldspar phenocrysts (up to 8 mm diameter) can be seen in a dark-grey groundmass. In thin section a well-defined augen structure can be observed; quartz has a wavy extinction and feldspar is altered to epidote and sericite. The groundmass consists of aphanitic quartz, chlorite, and possibly feldspar. In many places the dacite is silicified and quartz-epidote veins are common. Sulphides are disseminated through the rock, and also in veins and fractures. In this drill holes near the river sulphides are common, but they do not appear to be present in drill holes in the spillway area.

The dacite is probably extrusive, and part of a volcanic (tuffaceous and sedimentary) sequence that was folded to its present complex, steeply-dipping form, probably during the Bowning Orogeny. The dacite has a well-developed cleavage and in some parts a schistosity is developed parallel to the vertical cleavage, which strikes 020°. The cleavage in the dacite is more intense near the metasediment lenses; this may be a reflection of the lower competence of finer-grained dacite tuff that in places grades into the metasediments. Although the dacite and metasediments are intensely cleaved near their contact, no evidence of faulting was observed in drill holes, costeans, or surface outcrop.

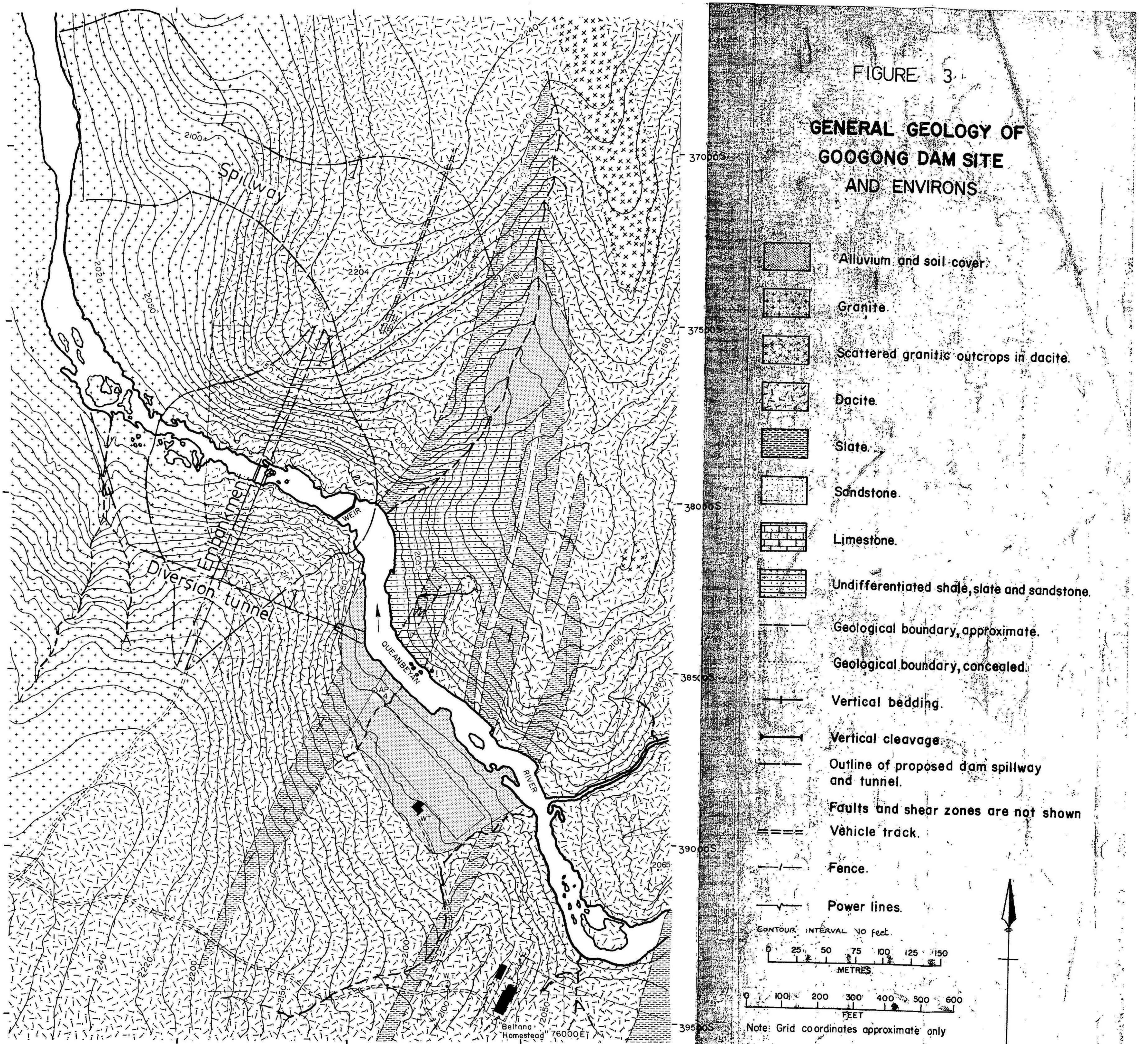


FIGURE 3

GENERAL GEOLOGY OF GOOGONG DAM SITE AND ENVIRONS.

To accompany record 1974/100

Googong Granite

The Googong Granite is the youngest rock at the dam site and crops out to the west of the dacite. In hand specimen the granite is light grey in colour, with quartz and feldspar crystals up to 7 mm diameter, and dark fine-grained micas. The granite is adamellite in composition. (slide No. 73360039, Appendix 9) In thin section, evidence of deformation can be seen: quartz shows wavy extinction and in places is fractured. The granite, particularly on the left bank, is prominently jointed parallel to the 020° vertical cleavage in the dacite (Fig. 4).

The granite/dacite contact has a northerly trend but is variable. In surface outcrop and drill-core it appears to be a normal intrusive contact. The granite has a porphyritic margin up to 5 m wide, consisting of quartz, feldspar, and occasional epidote phenocrysts up to 8 mm diameter set in a fine-grained matrix. The dacite near the contact shows evidence of recrystallization and silicification with a marked increase in quartz phenocrysts.

In drill holes, the contact zone shows a slight increase in jointing and fracturing and joint surfaces are commonly limonite-stained.

In drill hole D33, in the lower spillway quarry, dacite was intersected at intervals within the granite; possibly occurring as xenoliths of country rock in the granite.

STRUCTURE

Folding

The dominant structural trend in the rock cropping out at the dam site is 020° and vertical. This trend coincides with the cleavage of the dacite, the cleavage and much of the bedding of the metasediments, the overall trend of the granite/dacite contact, one of the dominant joint sets in the granite, and the major orientation of quartz-epidote veins in the dacite.

Minor folds in limestone in the reservoir area have a vertical axial plane striking 020°, and they plunge 30° north-northeast. If this fold system also affects the damsite, the V-shaped wedge of metasediments at the damsite may be interpreted as forming the core of an anticline plunging at 30° to the north-northwest beneath the dacite.

The poor correlation between lenses and metasediments exposed in costeans 4, 5, 9, 10, 12, and 15 (Plate 8) may be explained by minor folding of these less competent beds, some of which may have been sheared out along planes parallel to the axial plane cleavage. Alternatively, the metasediments may lense out northwards because of a facies change, or may be sheared out of the sequence by intense deformation.

Detailed geological mapping of the upper spillway excavation and surrounding area during construction may reveal the structure in detail and enable the relation of the dacite and metasediments to be determined.

Faulting

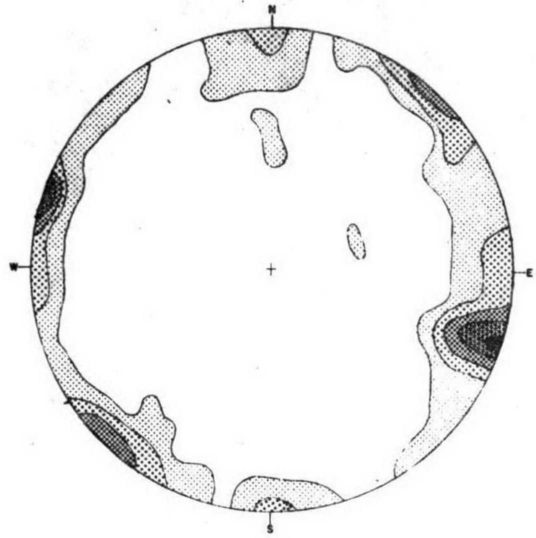
No faults were discovered during the mapping of the dam site and spillway, but sheared and fractured zones are common in the dacite. Sheared zones up to 3 m wide were exposed in costeans in the dam site and spillway area. The sheared zones are marked by an intensification of the cleavage and trend parallel to the 020° vertical cleavage.

Fractured zones up to 4 m wide were intersected in costeans 6, 7, and 13 and drill holes D9 and D17A. They consist of fractured silicified dacite with seams of whie clay up to 40 cm wide, containing angular fragments of slightly weathered dacite. The fractured zones may have been silicified by hydrothermal activity associated with the intrusion of the Googong Granite. It is expected that weathering will be considerably deeper in the fractured zones than in the surrounding dacite, (note the completely weathered dacite between 15 m and 24 m in D9).

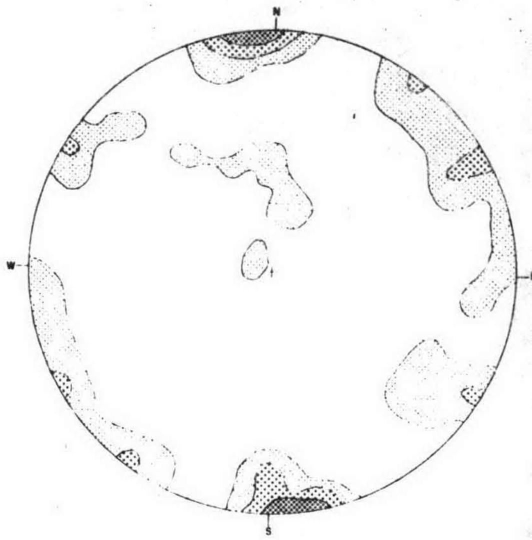
The fractured zones have no apparent surface expression, and were not detected by seismic refraction or electrical resistivity methods; they were only exposed in costeans and drill holes, and have an approximate northwesterly trend but appear to be discontinuous.

Jointing

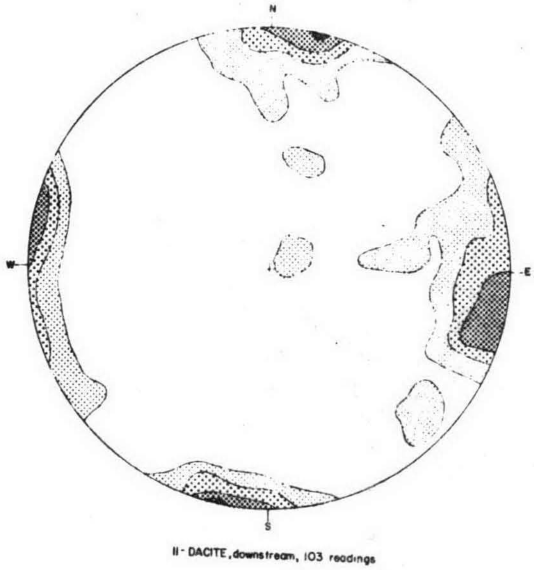
The dacite is moderately closely jointed (see Appendix 1 for joint terminology and description of biased sampling correction). The main set is parallel to the 020° cleavage, and a second, less marked joint set strikes approximately east with near vertical dips (Figs 4 and 7). Joints are mostly tight, limonite-stained and devoid of clay, and some are filled with carbonate. In the spillway section the groundwater level is well below the surface and joints above the watertable are commonly coated with a few millimetres of white clay. Slickensides are sometimes present on joint surfaces.



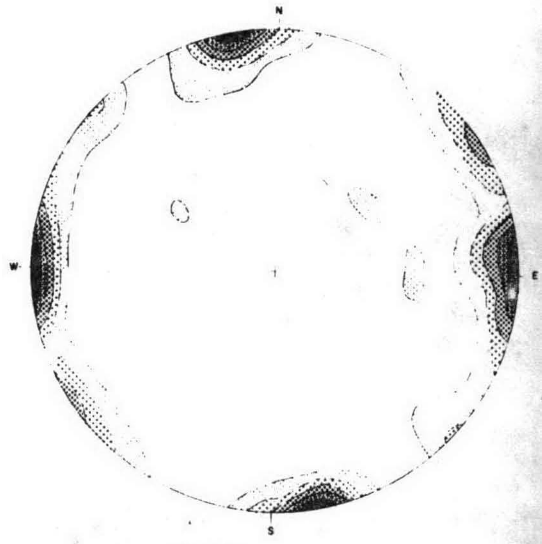
I - GRANITE, 102 readings



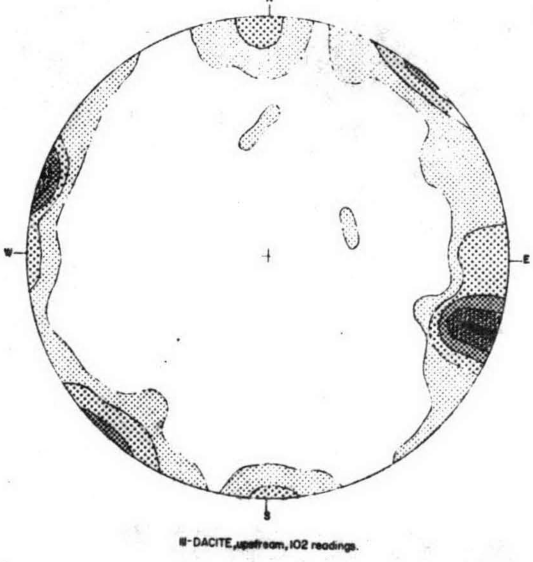
IV GRANITE, 95 readings



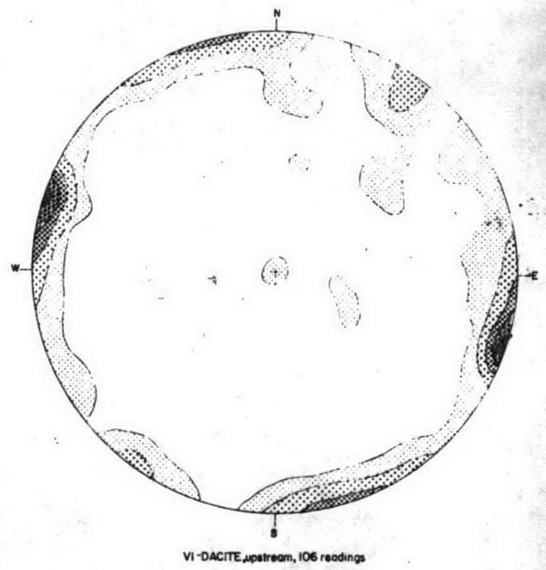
II - DACITE, downstream, 103 readings



V - DACITE, downstream, 93 readings



III - DACITE, upstream, 102 readings.



VI - DACITE, upstream, 106 readings

LEFT BANK

Number of poles per one percent of area

- <1·5
- 1·5-4·5
- 4·5-7·5
- 7·5-10·5
- 10·5-13·5
- >13·5

Diagram numbers refer to locations on map (Plate 1)

RIGHT BANK

GOOGONG DAM SITE
QUEANBEYAN RIVER
N.S.W.

FIG. 4

Lower Hemisphere stereographic projection
of poles of joints and cleavage planes.

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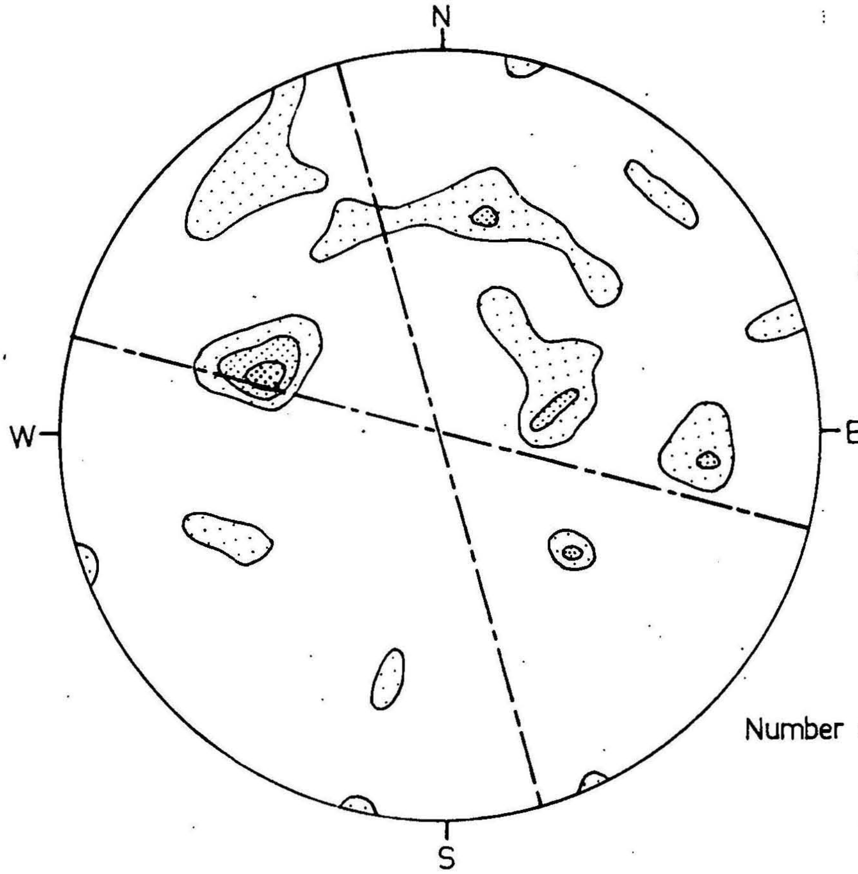


DIVERSION TUNNEL

Poles to joints in granite and dacite

Drillholes 22, 23 and 24

116 readings

Number of poles per one percent of area

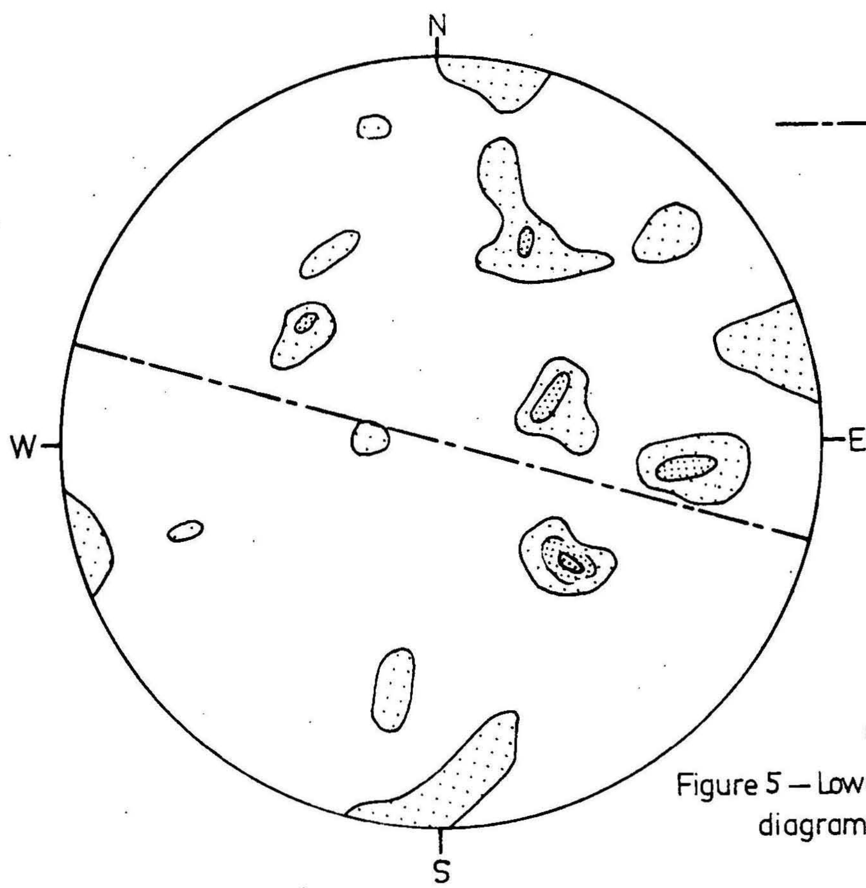
< 2

2—4

4—6

> 6

Direction of tunnel at points of sampling



DIVERSION TUNNEL

Poles to joints in dacite

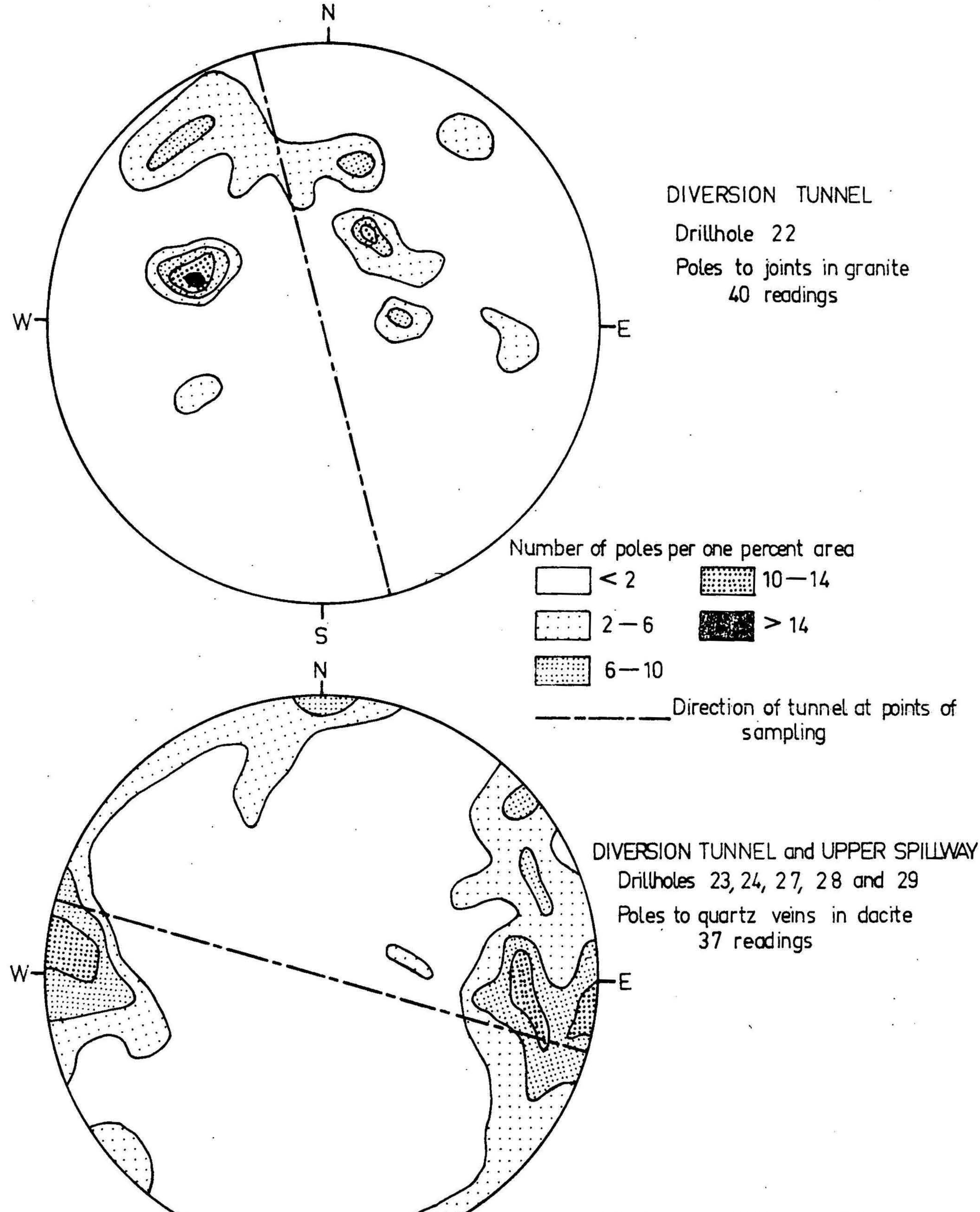
Drillholes 23 and 24

76 readings

GOOGONG DAM SITE

Figure 5 — Lower hemisphere contoured stereographic diagrams of poles to joints along the diversion tunnel

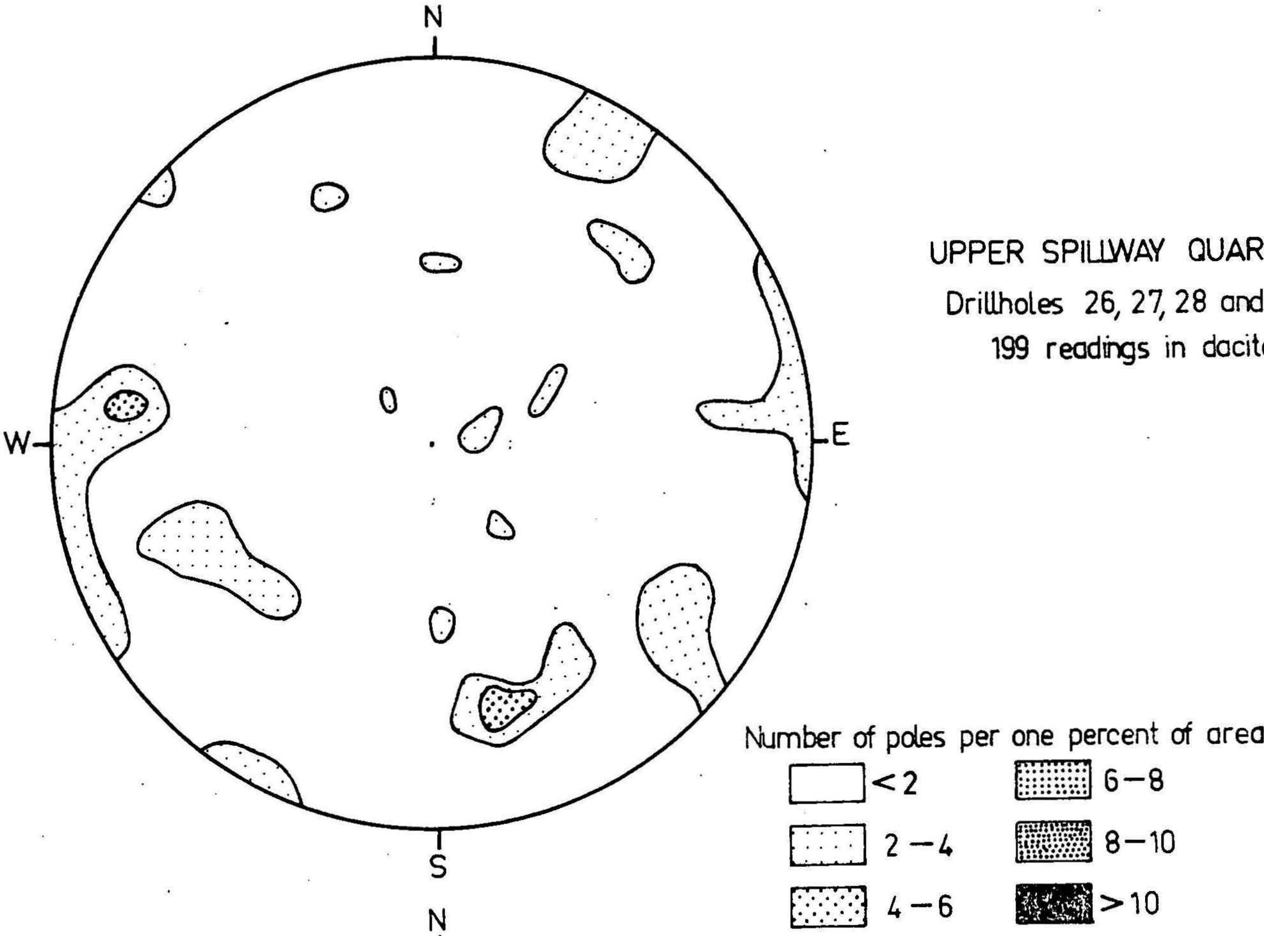
All readings from oriented core (corrected for biased sampling)



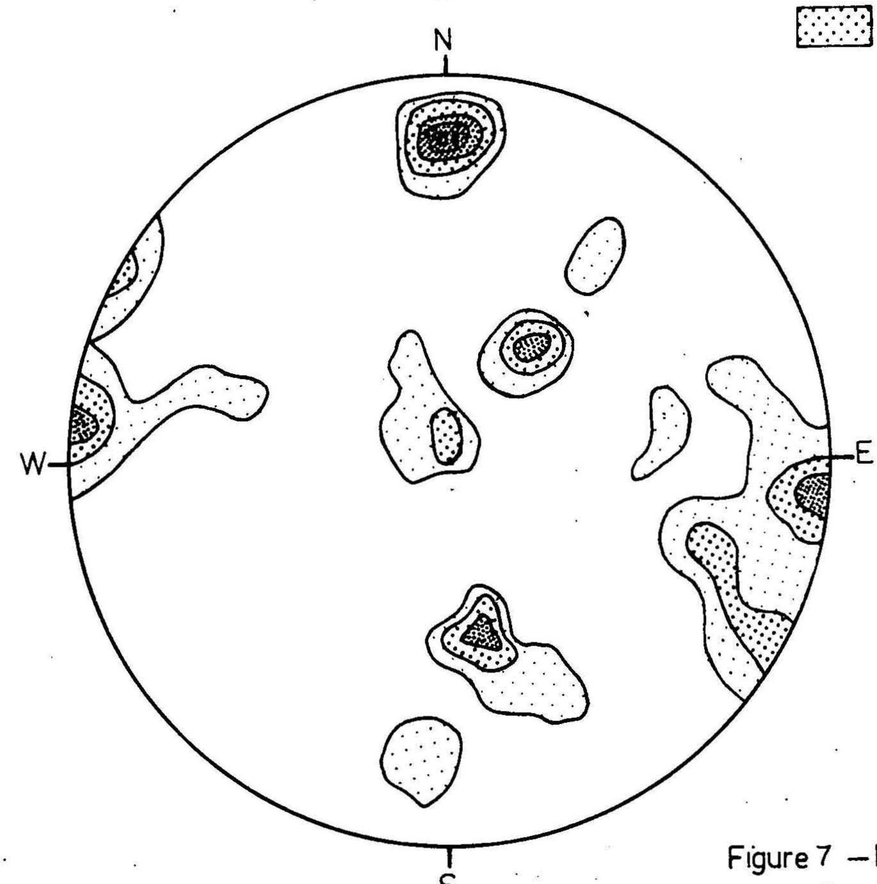
GOOGONG DAM SITE

Figure 6 — Lowerhemisphere contoured stereographic diagrams of poles to joints in granite at the diversion tunnel outlet portal, and poles to quartz veins in the dacite

All readings from oriented core
(corrected for biased sampling)



UPPER SPILLWAY QUARRY
Drillholes 26, 27, 28 and 29
199 readings in dacite



LOWER SPILLWAY QUARRY
Drillholes 32 and 33
59readings in granite

GOOGONG DAM SITE

Figure 7 — Lower hemisphere contoured stereographic diagrams of poles to joints in the spillway area

All readings from oriented core
(corrected for biased sampling)

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In the granite the joints are mostly widely spaced and three major joint sets are recognized; striking east near vertical, north near vertical, and subhorizontal. (Figs 4 and 7).

Quartz-epidote veins

In the dacite, quartz-epidote veins range from 1 mm to 1.5 m wide. The veins show a preferred orientation approximately parallel to the dominant 020° structural trend at the dam site (Fig. 6). The veins are probably associated with the intrusion of the granite. In parts the granite is cut by quartz up to 3 m wide, however, epidote is less common.

WEATHERING

The dacite shows a fairly regular pattern of weathering. In the lower parts of the dam site fresh or slightly weathered dacite crops out at the surface. Higher in the spillway area and further removed from the groundwater level, moderately and highly weathered dacite overlies fresher rock in areas protected from erosion (Plate 5). Deep weathering is encountered in the fractured zones previously described.

In granite the pattern of weathering is more complex. Weathered joints form seams of highly and completely weathered rock in otherwise fresh rock. The seams are not readily detected by seismic refraction methods; however, zones of fresh rock containing weathered joints have a reduced seismic velocity.

A comparision of seismic velocities with those measured in the laboratory on selected rock samples shows that rock defects along the traverse reduce the seismic velocity considerably below that measured in the laboratory. (Appendix 7)

ENGINEERING GEOLOGY

DAM SITE

Weathering profiles

Interpretive weathering profiles (Plate 5) correlate seismic velocities with weathering conditions encountered in diamond-drill holes.

The seismic velocities have been equated to five degrees of weathering in the dacite, as follows.

(a) Velocities up to 400 m/sec are interpreted as soil and completely weathered rock (see Appendix 1 for weathering descriptions).

(b) Velocities between 400 and 1200 m/sec are interpreted as highly weathered rock.

(c) Velocities between 1000 and 3000 m/sec are interpreted as moderately weathered rock.

(d) Velocities between 3000 and 4000 m/sec are interpreted as slightly weathered rock.

(e) Velocities between 4000 and 7000 m/sec are interpreted as fresh and fresh-stained rock.

It should be noted however that the seismic velocity of a rock mass is determined not only by the degree of weathering of the rock, but also by the abundance and condition of rock defects such as joints, faults, and sheared zones.

<u>Removal of overburden</u>

Plate 5, section 1 shows an interpretive geological section along the axis of the dam. Seismic surveys and drill holes indicate that the weathering profile is fairly uniform over most of the foundations, but a general increase in the thickness of weathered rock can be traced from the river bed to the higher parts of the abutments.

On the left abutment moderately-weathered dacite, which is considered sound enough for the foundations of the dam, is encountered between 1 and 2 m below the surface. Granite on the left abutment carries between 2 and 4 m of overburden above moderately weathered rock, but the thickness of the overburden is more variable than on the dacite.

Costeans C3, C17, and C18 (Plate 4), excavated on the left abutment by a D6 bulldozer using 2 ripper blades, had a maximum rippable depth of 1.5 m with an average depth of 1 m. The dacite exposed in these costeans was slightly weathered and moderately weathered, with highly weathered dacite in sheared and fractured zones.

The right abutment is steeper than the left abutment and generally shows a greater variation of the weathering profile. The lower slopes have up to 3 m of overburden overlying moderately and slightly weathered dacite. The middle slopes have up to 1 m of overburden, and the upper slopes between 1 and 2 m of overburden. The thicker overburden on the steep lower slopes probably consists of completely and highly weathered rock overlying open-jointed and blocky, moderately weathered rock; excavation will probably be required to a vertical depth of at least 3 m.

The right abutment shows two distinct outcrop ridges, both up to 30 m wide, trending approximately parallel to the dam axis; between these ridges is an area without outcrop, in which the overburden will be thicker than on the ridges.

The overall predictable form of the weathering profile should allow satisfactory removal of overburden using mechanical scrapers and bulldozers.

In the river bed the overburden has been removed and slightly weathered and fresh rock is encountered at the surface. Large pockets of alluvium are present along the banks of the river at the dam site, and these will have to be removed (Plates 2 and 4).

Foundations

Left abutment. The foundations of the left abutment are mainly of dacite, with granite on the higher and the downstream portions of the abutment. Rock defects so far exposed, are sheared zones, minor fractured zones, and large continuous quartz veins which are commonly fractured near the surface (Plate 4). Clay-filled silicified fractured zones similar to those exposed high on the right abutment have not been observed in the left abutment. The granite/dacite contact, where exposed, is moderately fractured, however, foundation treatment along the contact should be minimal and localized.

Right abutment. The foundations of the right abutment are of dacite, with only a small amount of granite at the downstream toe. No major structural defects have been observed in the lower parts of the abutment; however, some sheared zones may be exposed when the overburden is removed. Sheared zones and silicified fractured zones have been exposed in costeans on the upper right abutment (Plates 4 and 8). No large fractured quartz veins were observed on this abutment.

Treatment of abutments. Excavation and treatment of small fractured zones and pockets of highly weathered rock in sheared zones will be necessary on both abutments. The silicified clay-filled fractured zones, if encountered, should be excavated and back-filled with concrete. Similar treatment of open joints and fissures may be necessary, and some areas, particularly on the steeper right abutment, may require flattening to provide satisfactory bonding with the earth core.

The exploratory adits in the right abutment should be backfilled with concrete where they occupy parts of the core and filter zone foundations, and with rockfill material where they underlie the rockfill zones.

River bed. The foundations in the river bed are mostly of dacite with granite near the downstream toe of the dam. No major structural defects requiring extensive excavation and treatment have been observed in the river section. After removal of alluvial deposits and weathered material, an irregular surface of slightly weathered and fresh rock will be exposed. Removal of large boulders and modification of some slopes may be necessary to achieve satisfactory bonding with the earth core. Open joints and fissures filled with alluvium will require excavation and treatment.

Leakage

The fresh to moderately weathered dacite and granite in the foundations of the dam show no intergranular permeability. Groundwater movement is restricted to fractures, joints, and weathered zones; hence, the permeability is a function of the number, type and orientation of fractures and the degree of weathering.

All 13 drill holes in the dam foundations, totalling 658 m have been water-pressure tested, and only 164 m of test section were found to have permeabilities exceeding 1 lugeon (Table 2). Reliable water pressure test results were obtained in most test sections and the 'Reduction of Field Result' sheets are included in Part 2 of the report (Appendix 11).

Permeabilities in metres per year, have been calculated and plotted as histograms (Plate 6). Although the formula used for the permeability calculations assumes that the rock is isotropic and that water flow in joints is laminar, the permeabilities obtained provide a means of comparing the relative openness of joints in different holes and in various sections of the same hole.

The dacite and granite are strongly fractured and jointed in parts, but water-pressure testing revealed only a few important zones of high permeability. Most of these permeable zones were in the weathered zone above the water table. Below the slightly weathered/fresh rock boundary the joints are almost watertight with only a few zones showing permeabilities greater than 1 lugeon (Plate 6).

Where tested, the silicified fractured zones on the right abutment had permeabilities only slightly higher than 1 lugeon. The fractured zones appear to be discontinuous and are largely clay-filled, but they are not thought to present a significant leakage problem; however, if the clay has been washed out or is subsequently removed, leakage may be appreciable.

The granite/dacite contact, intersected in drill holes 8, 15, 24, and 37, tends to be more fractured than the surrounding rocks; however, water-pressure tests indicate that permeabilities do not increase significantly at the contact; the maximum leakage was 1.5 lugeons in D24.

Grouting

In general, blanket grouting should extend down to fresh-stained rock. The holes should be 10 m deep, spaced at 5 m centres or less. The holes should be planned to intersect the maximum number of joint planes and fractures, and for this purpose an analysis of joints, fractures, and cleavage planes should precede grouting.

The upper surface of tight rock approximates to the fresh/weathered rock boundary, and in general the grout curtain should extend at least 15 m below this boundary on the abutments, and 20 m below the boundary in the river bed. This would provide a grout curtain to a minimum depth of about 25 m below the foundation. The curtain grout holes should be spaced at intervals of 3 m or less to ensure a satisfactory seal. Some second phase curtain grouting may be necessary to close permeable zones indicated by water pressure testing or high grout takes in primary holes.

The grout curtain should be continuous on the left abutment to at least RL 670 m. On the right abutment it should be continuous to the southern wall of the spillway excavation.

TABLE 2 - RESULTS OF WATER-PRESSURE TESTING*

No. of hole	Test section with leakage >1 lugeon (m)	Permeability (lugeons)	Total length pressure tested (m)	Total length with loss higher than 1 lugeon (m)
D1	14.0 to 18.5	12	50.9	4.6
D2	9.5 to 12.2	10		
	14.5 to 17.5	7		
	18.0 to 21.0	3	56.4	35.0
	21.0 to 27.4	4		
	45.5 to 57.5	4		
	58.0 to 65.0	2		
D3	2.5 to 5.5	50		
	6.5 to 9.5	100		
	9.5 to 12.0	30	42.7	24.0
	12.0 to 16.5	70		
	16.5 to 19.5	2		
	19.5 to 26.0	2		
D4	4.0 to 7.0	4	43.6	9.0
	8.0 to 14.0	9		
D5	2.7 to 5.8	85		
	5.8 to 8.8	20		
	8.8 to 11.9	14	27.7	15.9
	11.9 to 14.9	5		
	24.8 to 28.5	3		
D6			68.3	0
D7	5.8 to 8.8	2.5	58.5	6.1
	8.8 to 11.9	5-20?		
D8			57.6	0
D9			58.8	0
D10	2.7 to 5.8	80		
	5.8 to 9.1	60	19.8	12.5
	9.0 to 15.2	9		

* D1 to D19 after J. Saltet, 1971

D22 to D37 1972-73 Investigation

TABLE 2 (Contd)

No. of hole	Test section with leakage >1 lugeon (m)	Permeability (lugeons)	Total length pressure tested (m)	Total length with loss higher than 1 lugeon (m)
D11	16.2 to 22.6	3		
	21.9 to 28.0	6		
	27.1 to 33.2	2.5	35.5	21.3
	31.7 to 37.5	18		
D12			9.1	0
D13			13.7	0
D14			9.8	0
D15	6.1 to 9.1	2		
	9.1 to 12.2	2	37.8	9.1
	12.2 to 15.2	2		
D16	5.8 to 8.8	16	64.3	3.0
D17	7.9 to 11.6	3		
	14.6 to 17.7	2	39.3	6.7
D17A			39.9	0
D18			9.8	0
D19			24.4	
D22	12.2 to 16.8	2	18.9	8.2
	24.4 to 28.0	2		
D23	10.7 to 13.7	50		
	13.7 to 16.8	1.5		
	16.8 to 19.8	19	23.9	18.3
	19.8 to 22.9	15		
	22.9 to 25.9	2		
	25.9 to 29.0	5		
D24	9.0 to 15.0	2		
	36.0 to 39.1	1.5	51	12.1
	48.0 to 51.0	7		
D25	12.4 to 15.9	2		
	15.9 to 19.0	2		
	19.0 to 22.0	2	24.2	12.6
	22.0 to 25.0	4		

TABLE 2 (Contd)

No. of hole	Test section with leakage >1 lugeon (m)	Permeability (lugeons)	Total length pressure tested (m)	Total length with loss higher than 1 lugeon (m)
D26	7.0 to 9.9	5	24.0	12.0
	9.9 to 12.9	4		
	12.9 to 16.0	2		
	16.0 to 19.0	5		
D27	7.0 to 10.0	25	21.1	6.0
	10.0 to 13.0	25		
D28	20.0 to 23.0	25	24.0	18.0
	23.0 to 26.0	25		
	26.0 to 29.0	10		
	29.0 to 32.0	8		
	32.0 to 35.0	2		
	35.0 to 38.0	2		
D31	13.0 to 16.0	2	9.0	3.0
D35	9.0 to 12.4	3	24.0	12.0
	12.4 to 14.6	3		
	14.6 to 18.0	2		
	30.0 to 33.0	2		
D36	8.0 to 11.0	2	45.0	21.0
	11.0 to 14.0	2		
	14.0 to 17.0	3		
	17.0 to 20.0	2		
	20.0 to 23.0	3		
	47.0 to 53.0	5		
D37	7.9 to 11.0	2	45.1	3.1

Permeability values in metres per year, obtained from water pressure tests in drill holes intersecting the spillway crest foundations are plotted as histograms on section 6B of Plate 10. Most of the significantly permeable zones were in the weathered zone, with only a few located below the maximum excavation depth along the crest (R.L. 663m). The grout curtain should be extended across the spillway crest to a depth of at least 10 m below the spillway crest excavation level. The holes should be at 3 m intervals or less and second phase grouting may be necessary where indicated by water pressure test results or high grout takes.

DIVERSION TUNNEL

It is proposed to excavate the diversion tunnel through the left abutment. The proposed route and approximate portal locations are shown in Plate 4. An interpretive geological section along the tunnel route is included in Plate 7. The section shows expected rock types and weathering conditions at tunnel level. Some prominent geological features observed in surface outcrop and diamond drill core have been tentatively projected to tunnel level. The proposed tunnel has an excavated diameter of approximately 6 m and is 220 m inlength. Tunnel invert is at RL 615.76 m at the inlet portal and RL 614.66 m at the outlet protal.

Inlet portal

The proposed inlet protal is at approximately chainage 35 m. The portal will be excavated in fresh-stained dacite with a rock cover above the tunnel crown of approximately 4 m of fresh-stained, 3 m of moderately weathered, and 1 m of highly weathered dacite.

The approach channel to the inlet portal will be excavated in fresh-stained, slightly weathered, and moderately weathered dacite. Drill core from drill hole 23indicates that the dacite is mostly moderately to highly jointed with occasional fractured zones up to 50 m wide. Whilst clay was not observed on joint planes in drill hole 23, clay may be present in joints in the dacite closer to the river. Joint orientation analysis based on measurements from surface outcrop (Fig. 4), and oriented drill-core from D23 (Fig. 5), has not revealed any unfavourably oriented rock defects. In general, unsupported slopes of 2:1 (vertical:horizontal) will be feasible in fresh-stained and moderately weathered rock along the inlet channel. Rock bolt and wire mesh support may be required in fractured zones or areas of close continuous jointing. Slopes of 4:1 will generally require rock bolt and wire mesh support.

Initial groundwater inflows to the tunnel near the inlet portal, calculated from water pressure test results in D23, are expected to be in the order of 18 litres per minute per 10 m of tunnel. The higher permeabilities appear to be associated with fractured zones. The potentiometric surface in D23 is approximately 2 m above tunnel crown and the initial water inflows near the portal are expected to decrease significantly as the tunnel face advances away from the portal. The groundwater level near the tunnel will be lowered by tunnel drainage.

Outlet portal

The proposed outlet portal is at approximately chainage 255 m. The portal will be excavated in fresh-stained and slightly weathered granite with an overburden of approximately 9 m of moderately and highly weathered granite.

The outlet channel will be excavated in soil, completely weathered and moderately weathered granite. Drill core from D22 indicated that the moderately weathered granite contains fractured and jointed zones of highly and completely weathered rock, commonly containing kaolinitic clays. Although no critically oriented rock defects are indicated by joint analysis of oriented core from D22, (Fig. 6), it may be difficult to maintain slopes of 2:1 (vertical:horizontal) in the moderately weathered granite in the outlet channel; rock bolts and mesh support, and possibly some benching may be necessary to stabilize slopes. Rock bolt and mesh support will be necessary to support slopes of 4:1 near the outlet portal.

Initial water inflows into the tunnel near the outlet portal, based on the water pressure test results from drill hole 22, are expected to be in the order of one litre per minute per 10 m of tunnel. The groundwater potentiometric surface is approximately 2 m below the proposed tunnel crown and the small initial inflows near the portal are expected to decrease as the tunnel progresses.

Tunnel line

The tunnel has a minimum rock cover of approximately 7 m at the inlet portal, and a maximum rock cover of approximately 33 m at chainage 150 m. The rock types and weathering conditions expected along the tunnel route are shown in Plate 7.

Tunnelling conditions in the dacite are not expected to differ substantially from those observed in the adits on the right abutment. The dacite in the adits has a well defined cleavage, is generally tightly jointed with a few narrow (<20 cm wide) sheared and fractured zones. The granite is generally less fractured than the dacite; unbroken core lengths up to 4 m long were recovered from drill hole 24 at tunnel level. Drill core from drill hole 24 showed an increase in fracturing near the granite/ dacite contact and the fracture surfaces were limonite stained.

Sulphides, mostly pyrite and chalcopyrite, in drill core are associated with quartz veins in the granite and dacite. Disseminated sulphides were observed in the dacite groundmass in thin section.

Concentrations of sulphides are low in core recovered from tunnel level. Oxidation may occur where sulphides are exposed on fractured surfaces in the tunnel; however, the small amounts of sulphide present are not expected to adversely affect the concrete lining of the tunnel.

Overbreak and support

In fresh and fresh-stained granite and dacite, rock breakage will largely be controlled by joints, fractures and possibly quartz veins. Where joints are intersecting and continuous, the rock will be blocky and some overbreak is to be expected, particularly if defect surfaces are clay coated; however overbreak will generally be associated with fractured and sheared zones. Quartz veins in the dacite show a preferred north-south strike and a near vertical orientation. (Fig. 6).

An analysis of joints in oriented core from drill holes along the tunnel line did not find unfavourably oriented joint sets (Figs 5 and 6).

An estimate of support requirements in the tunnel has been partly based on Rock Quality Designations (RQD), measured in drill core from holes along the tunnel line, in accordance with Deere et al., 1969, (Table 3). Steel sets will be required for the support of some fractured zones, and rock bolts will be required in loosely jointed or blocky ground.

TABLE 3

TUNNELLING CONDITIONS, BASED ON EXPLORATORY DIAMOND DRILLING-GOOGONG DIVERSION TUNNEL

HOLE	Rock type and weathering	RQD%*	Support	Initial water inflow per 10m length of tunnel (litres per minute)
22 Outlet Portal	Fresh and Fresh-stained granite	90 (Excellent)	Occasional steel sets	1
23 Inlet Portal	Fresh and Fresh-stained dacite	89 (Excellent)	Occasional steel sets	18
24 chainage 190	Fresh and Fresh-stained granite	93 (Excellent)	Occasional steel sets	8

* See RQD Explanation in Appendix 1.

Note 1: RQD figures quoted represent the length from 5 m above the tunnel to tunnel invert level. It must be stressed that rock conditions away from the drill hole may change, and that RQD and water inflow values quoted may therefore not be representative. The table gives the conditions expected from results obtained from diamond drilling.

Note 2: Estimates of the initial volume of water flowing into the tunnel were derived from water pressure tests by a method explained in appendix 11.

Note 3: Excellent quality rock, as defined by the RQD value (Deere et al., 1969), will normally require no support, but some support may be required if the joints or fractures are open or have been weathered.

Drill holes along the tunnel line indicate that in fresh and fresh-stained rock the joint surfaces are mostly tight and devoid of clay; although some defect surfaces are slickensided, particularly near sheared zones in the dacite. Support will generally not be required in rock of this quality.

Fracture zones greater than 30 m wide have been observed, on average every 20 m, in fresh and fresh-stained drill core from drill holes 22, 23 and 24. Similar fracture zones at tunnel level may require support. If rock conditions observed in the drill holes are representative of the tunnel line it is estimated that approximately 10 to 20 percent of the tunnel will require steel support at 4' centres. The tunnel near the portals may require more closely-spaced support, particularly at the outlet portal where the moderately weathered/fresh-stained rock boundary is close to the tunnel crown.

If rock conditions observed in drill hole 24 near the granite/dacite contact are continuous to tunnel level, steel sets may be required for approximately 20 ft of the tunnel in the contact zone.

<u>Groundwater</u>

Water pressure testing in drill holes along the tunnel indicates that water inflows to the tunnel will be small and mostly restricted to fractured zones. Drill hole 24 intersected the granite/dacite contact a few metres above the tunnel crown. Although the intensity of fracturing increased near the contact there was no significant increase in permeability. The calculated initial water inflow to the tunnel in the region of drill hole 24 is of the order of 8 litres per minute per 10 m length of tunnel. Initial inflows are expected to decrease as the tunnel face advances away from the point of inflow, owing to the lowering of the groundwater table by tunnel drainage.

<u>SPILLWAY</u>

The spillway will be excavated in a saddle on the right abutment. It will consist of a curved free overflow crest 124 m long, with a short converging concrete-lined chute discharging along an unlined channel into an energy dissipating pool. Crest level will be at RL 663 m and the spillway will have a discharge of 4300 m^3/sec (152 000 cusecs) during maximum probable flood.

The geology of the spillway area is shown in Plate 8. Interpretative geological sections through the spillway are included in Plates 9 and 10.

It is proposed that the spillway excavation will provide all the rockfill material for the dam embankment. The availability of sufficient quantities of suitable rock from the spillway quarries is discussed later in this report under 'CONSTRUCTUION MATERIALS'.

Foundations

Section 6A, (Plate 10) is an interpretative geological section across the spillway near the crest. The spillway crest will be founded mostly on fresh and fresh-stained dacite with some smaller areas of slightly weathered and moderately weathered dacite.

The dacite is strongly cleaved and jointed, the almost vertical cleavage striking 020°. Silicified fractured zones were exposed in costeans 6, 11 and 13. The fractured zone in costean 13, if continuous, will intersect the spillway crest near drill hole 26; however; drill hole 26 does not intersect any features similar to the fractured zone in costean 6, the fractured zones may require some additional treatment.

The spillway lining discharge lip will be founded on fresh-staínded and slightly weathered dacite towards the left bank of the spillway, and moderately weathered dacite towards the right bank. No major defects in the dacite have been exposed near the lip.

Spillway approach channel walls

Sections 7 and 8 (Plate 10) are interpreted geological sections along the north and south walls of the spillway approach channel and crest lining structure. The spillway approach channel walls will be concrete-lined for a distance of only 30 m upstream from the spillway crest, and the concrete wall lining will mostly abut against moderately weathered dacite, in which the dominant cleavage and joint planes strike approximately at right angles to the walls. No critically oriented rock defects were detected by the joint analysis of oriented core (Fig. 7); however silicified fractured zones may be exposed in the south wall and may require treatment.

The unlined portion of the north wall of the spillway approach channel (approximately 160 m) will be formed mostly in fresh-stained, slightly weathered and moderately weathered dacite, with some near vertical beds of slate. Slopes of 4:1 (vertical:horizontal) may generally be achieved and maintained in this material without support; however, some instability may be found at such slopes in the highly and completely weathered rock in the upper part of the wall and such sections should have slopes gentler than 4:1. Erosion of the slate beds by wave action may be more rapid than erosion of the surrounding dacite and some treatment may be necessary.

No critically oriented rock defects which might cause massive instability of excavated slopes have been observed in the upper spillway quarry area (Fig. 7).

Unlined channel downstream from spillway discharge lip

The unlined channel will be excavated to a depth of between 2m and 8m, in soil, moderately weathered and slightly weathered granite (Plate 9).

Excavation will be mostly achieved by D9 bulldozer, however, blasting may be necessary in the deeper parts of the excavation on the northern side of the channel.

No major problems of erosion in the unlined channel are foreseen, however, dental treatment of sheared and weathered seams may be necessary to prevent excessive scouring.

Inspections of the unlined channel should be made at regular intervals during periods of continuous spillway operation and immediately after large floods.

Lower spillway quarry

The lower spillway quarry will be located in granite. No critically oriented defects are indicated by joint analysis in the spillway area. (Fig. 7). Slopes of 2:1, as designed, should generally be achieved and maintained in fresh to moderately weathered granite without support.

PHALARIS SADDLE EMBANKMENT

It is proposed to construct an earth embankment approximately 10 m high, across the Phalaris Saddle. The crest of the embankment will be at RL 670 m and will be 240 m in length. The geology of the saddle and an interpretative geological section along the embankment axis are shown in Plate 11.

Foundations and overburden

The foundations of the embankment are dacite and slate with granite cropping out on the right abutment 12 m from the end of the embankment. The dacite/slate boundary dips at approximately 60° to the east-northeast, and the strong deformation of the rocks at the boundary has produced a chlorite schist (drill hole 19). Weathering, as observed in D19, is deep with highly weathered dacite to a vertical depth of 17 m at the contact zone.

The thickness of material overlying weathered rock along the embankment axis does not generally exceed 1 m, except near the dacite/ slate boundary where it ranges to 3 m. This material may be marginally thicker towards the upstream and downstream toes of the embankment.

Leakage through saddle

Water pressure testing in D19 resulted in leakages of less than 1 lugeon; consequently, the slate and dacite may be considered watertight in the weathered zone.

Drill hole 39 was drilled approximately 100 m north of the saddle, as a groundwater observation bore (Fig. 2), and a geological log of the hole is included in Appendix 9. The hole was drilled entirely in dacite and yielded a constant flow of 2300 litres per hour for 3 hours when blow-tested. The standing water level remained constant at 7.3 m below the ground surface during the period May to July 1973.

It is recommended that a pump test be carried out in D39 to obtain a measure of the permeability of the dacite near the saddle. During reservoir filling the creek to the north of the saddle should be monitored for changes in flow and water level observations in D39 should be made twice weekly.

Embankment material

The earthfill material for the embankment will be obtained from the area immediately south of the embankment. The deposit has been investigated in detail by CDW Central Testing and Research Laboratories (CTRL) and described in a Technical Report (in prep.). Rockfill for facing the embankment will be obtained from the spillway quarry excavation.

SEISMICITY

The Googong Dam and reservoir lie in a zone of relatively low seismic activity. The Australian National University recorded only one tremor, with an epicentre near the Googong Dam Site, in the period 1960-70. The tremor occurred in 1969 and had a magnitude of 2.1 on the Richter scale; it may have been the result of the release of stress across the Queanbeyan Fault. In the Snowy Mountains area a tremor of this magnitude occurs, on average, every three months.

The Bureau's Geophysical Branch monitored the seismicity at the Googong Dam Site from September to December 1971. The sensitivity of the array was sufficient to record microtremors as low as 0.3 magnitude (Richter scale); however no natural tremors originating from within 10 km of the dam site or along the Queanbeyan Fault were recorded (Cull, 1972).

Considerable evidence exists that the filling of reservoirs can cause increased seismicity in areas of low, or non-existent seismic activity. Two factors seem to be involved.

1) The extra load of the water in the reservoir upsetting the pre-existing delicate equilibrium in the crust.

2) the influence of water along fault planes, causing an increase in fluid pressure, which reduces the effective normal stress across the fault. The normal stress and the friction coefficient are the main factors determining stability at a fault. (Gough & Gough, 1970).

The Googong reservoir will be small compared with most reservoirs which are known to have initiated seismic activity; however, the reservoir is on the down-thrown side of the Queanbeyan Fault, and the load of the reservoir, combined with the effect of any leakage of water into the fault zone may increase seismicity.

The possibility of increase seismicity owing to the filling of the Googong reservoir cannot be entirely discounted; however, ground accelerations resulting from induced seismicity would probably not be of sufficient magnitude to cause damage to the dam embankment or appurtenant structures. It is recommended that a monitoring system similar to that used in 1971 by BMR, be installed near the dam before reservoir filling commences. This will not only add to the existing knowledge of seismicity associated with reservoir filling, but may also provide important evidence for assessing claims of earthquake damage in the period after reservoir filling.

CONSTRUCTION MATERIALS

ROCKFILL

It has been proposed to obtain the required rockfill material from the spillway excavation. The geology of the spillway is shown on Plate 8, and interpretive geological sections on Plates 9 and 10. A detailed description of the rock types in the spillway area is given in 'DAM SITE GEOLOGY'.

Suitability of rockfill

Lower spillway quarry. The lower spillway quarry will be excavated in granite. Mechanical rock tests (Appendix 7) indicate that moderately weathered granite ranges in compressive strength from 55 000 to 111 000 kpa, and is acceptable for use as rockfill. Drill holes 20, 21, 32, 33 and 34 indicate that an overburden of between 1 and 5 m of highly and completely weathered granite will have to be removed. It has been estimated that 30 percent of the granite from the quarry will be moderately and slightly weathered, and that 70 percent will be fresh and fresh-stained.

Sulphides, associated mostly with quartz veins, are present in small quantities in the granite, and were intersected in drill hole 37 on the left abutment; however, drill core from the quarry area did not intersect any vein sulphides and rejection of the granite from the quarry should not be necessary.

Upper spillway quarry. This will be mostly excavated in dacite. In the eastern part of the proposed quarry the dacite is interbedded with lenses of slate and sandstone. The slate and sandstone are more deeply weathered than the dacite, and are strongly cleaved; they will in general be unsuitable as rockfill.

Moderately weathered dacite ranges in compressive strength from 22 000 to 66 000 kpa and is considered generally suitable for rockfill, however, this material having a lower compressive strength than the granite should preferably be placed in the higher levels of the embankment. Costeans and drill holes indicate that approximately 1 m of overburden will have to be removed from the quarry area, and it is estimated that approximately 80 percent of the dacite from the quarry will be slightly and moderately weathered and that 20 percent will be fresh and fresh-stained. The dacite has a well-developed cleavage and is moderately jointed.

Size distribution analysis - Upper spillway quarry

The following estimate of percentage size distribution of rockfill from the upper spillway quarry was calculated from observations based on a modified RQD method. Whereas RQD is based on the percentage of core lengths greater than 10 cm, this method measured the percentages of core lengths within the following four ranges (see Appendix 1 for definition of RQD).

Less than 20 cm	-	66%
20 to 60 cm	-	27%
60 to 100 cm	-	5%
Greater than 100 cm	-	2%

This estimate is considered to underestimate the percentage of large sizes because the breakage of core across discontinuous rock defects would be greater during drilling than would the breaking of quarry rock during blasting.

Approximately 4 percent of the material from the upper quarry will be required for rip-rap. The rip-rap material should be well-graded with the greatest percentage in the range greater than 60 cm. The estimate of percentage size destributions gives a probable minimum of 7 percent for the range greater than 60 cm, and therefore sufficient rip-rap material should be available, although selection of material may be necessary in some parts of the upper quarry.

Material from fractured zones in the dacite will mostly be unsuitable as rockfill, however, it is estimated that this material would probably constitute less than 5 percent of the volume of the proposed quarry.

Samples of granite and dacite drill core taken at 2 m intervals from drill holes in the spillway excavation were analysed for sulphide content (Appendix 8). The sulphur content of the rocks was found to be less than 0.05 percent, and this is considered too low for rejection of the rock for use as rockfill. Vein sulphides in the dacite were only intersected by drill hole 31.

<u>Quantities of rockfill</u>

Approximately 540 000 m^3 of rockfill are required for the main embankment; assuming a 30 percent bulking factor, approximately 415 000 m^3 of suitable rock will be required.

<u>Lower quarry</u>. The calculated volume of the designed lower spillway quarry is approximately 219 000 m^3, of which an estimated 44 000 m^3 is assessed as overburden to be stripped from the quarry area, leaving approximately 175 000 m^3 of suitable rock.

Upper quarry. The remainder of the rockfill, approximately 240 000 m^3, is to be won from the upper spillway quarry. Excavation, as designed to RL 660 m would provide approximately 261 000 m^3 after stripping, but would include the following volumes of unsuitable rock, approximately 8 percent slate and sandstone and up to 5 percent fractured material. The volume of suitable rock, approximately 226 000 m^3, from the upper quarry is approximately 14 000 m^3 short of the required quantity. The extra 14 000 m^3 of suitable rock could be obtained from the quarry floor upstream from the spillway crest by excavating to RL 659 m instead of RL 660 m.

Upper quarry alternative. In the eastern part of the upper quarry, slate and sandstone constitute up to 50 percent of the rock, and large quantities will be rejected in order to limit the volume of slate and sandstone to the specified 10 percent of the total volume of rockfill. This procedure would require expensive sorting operations, and the rejection of all the rock to the east of easting 223130 should be considered. To obtain the required volume of rockfill, the quarry upstream of the crest could be excavated to a greater depth.

CONCRETE AGGREGATE

Fresh granite and dacite from the spillway excavation should generally be suitable for use as concrete aggregate. Appendix 7 shows that the fresh granite ranges in compressive strength from 130 000 to 264 000 kPa and fresh dacite from 85 000 to 156 000 kPa.

Sulphides are present in the dacite and granite, but not in large amounts. Rock containing sulphide veins will generally be recognised during quarrying, and should not be used as aggregate. Concrete aggregate is also available from the 'Readymix' Cooma Road Quarry approximately 7 km by road from the dam site, but it should be established that such aggregate will conform to the specifications required.

IMPERMEABLE CORE MATERIAL

The proposed borrow area for impermeable core material is in a valley, to the east of the Phalaris Saddle, at the foot of the Queanbeyan Fault scarp.

The Central Testing and Research Laboratories (CTRL) of CDW has carried out three investigations of the deposit including seismic refraction surveys, augering, back-hoe and hand excavated pits, and materials classification and testing (CTRL 1970; 1972; 1973).

The core material deposit consists mainly of weathered in situ slopewash, probably derived from the fault scarp. Some suitable material may be derived from beneath the slopewash and would consist of weathered rock in the fault zone which passes through the valley.

FILTER MATERIAL

No borrow areas for filter material were investigated. However, sand and gravel deposits along the Queanbeyan River, within a reasonable distance of the dam site may provide sufficient suitable material.

Fine aggregate (maximum particle size 2 mm), which may be required for grouting and pneumatically applied mortar and concrete, may also be available from the alluvial deposits of the Queanbeyan River.

CONCLUSIONS

General

1. The rocks at the dam site consist of near vertical beds of dacite and metasediments intruded by granite. The metasediments crop out as a V-shaped wedge in the dacite immediately upstream of the dam site and extend into the extreme eastern part of the spillway excavation.

2. No significant leakage paths from the reservoir have been located during the investigation.

3. The Googong Dam and reservoir are in a zone of relatively low seismic activity.

4. The possibility of increased seismicity owing to the filling of the reservoir cannot be entirely discounted. However ground accelerations resulting from induced seismicity are not expected to be of sufficient magnitude to cause major damage to the dam embankment and appurtenant structures.

Embankment foundations

1. The dam embankment will be mostly underlain by dacite, with granite underlying the downstream left bank and toe of the dam, and the lower spillway area.

2. The dominant structural trend in the rocks at the dam site is 020° and vertical. This is reflected in the dacite cleavage, the bedding and cleavage of the metasediments, the overall trend of the granite/dacite contact,

one of the major joint sets in the granite, and the major orientation of quartz-epidote veins in the dacite.

3. Moderately weathered granite and dacite is considered sound enough for the foundations of the proposed rockfill embankment.

4. Overburden up to 4 m thick is present on the foundations, being thickest in the higher areas of the abutments. Overburden should be removed satisfactorily by bulldozers and mechanical scrapers. Removal of alluvium and some loose boulders in the river bed will be necessary.

5. Fractured zones, pockets of highly weathered rock in sheared zones and open joints and fissures will require excavation and possibly treatment on both abutments.

Foundation permeability

1. Groundwater movements in the foundation rocks are restricted to fractures, joints, and weathered zones.

2. The silicified fractured zones, where water pressure tested, showed permeabilities only slightly higher than 1 lugeon and are not thought to present any significant leakage problem.

3. The granite/dacite contact showed a maximum permeability of 1.5 lugeon where it was water-pressure tested.

4. The boundary of tight rock approximately corresponds to the fresh/weathered rock boundary, and the grout curtain should extend at least 15 m below this level on the abutments and 20 m below it in the river bed.

5. Water pressure testing of the spillway crest foundations revealed a few permeable zones. It will be necessary to extend the grout curtain across the spillway crest to a depth of at least 10 m.

Diversion tunnel

1. The diversion tunnel will be excavated in mostly fresh and fresh-stained granite and dacite. The dacite has a well-developed cleavage striking approximately at right angles to the tunnel line, and is generally tightly jointed with a few narrow sheared and fractured zones. The granite is generally less fractured than the dacite.

2. Some overbreak may occur along the tunnel in fractured zones and in blocky and seamy ground. No critically oriented rock defects which might cause massive instability in the tunnel or approach channels have been detected.

3. It has been estimated that approximately 10 to 20 percent of the tunnel will require steel support. Rock bolts and mesh may be required to support blocky ground.

4. Initial water inflows to the tunnel should be small and mostly limited to fractured zones.

5. No major problems in establishment of the tunnel portals is foreseen.

6. Unsupported slopes of 2:1 should be feasible in moderately weathered dacite in the tunnel inlet channel. Some rock bolt and mesh support may be required in highly weathered zones and in blocky ground.

7. Slopes of 2:1 in moderately weathered granite in the tunnel outlet channel will require support owing to the presence of highly and completely weathered seams. Slopes of 4:1 will require rock bolt and wire mesh support.

Spillway

1. In general the spillway crest lining will be founded on sound rock, however silicified clay-filled fractured zones may be encountered, particularly in the southern wall of the channel and in the foundations of the crest structure.

2. Slopes of 4:1 may generally be maintained in moderately weathered rock in the spillway approach channel. Highly and completely weathered rock slopes should not exceed 2:1.

3. Slate lenses exposed in the north wall of the spillway approach channel may be subject to rapid erosion by wave action and may require treatment.

Phalaris Saddle embankment

1. The foundations of the Phalaris Saddle embankment are of highly weathered dacite and slate. The rocks are weathered to a greater depth at the dacite/slate boundary.

2. Overburden on the foundations is up to 3 m thick.

3. Water pressure testing in D19 indicated that the slate and dacite are watertight in the weathered zone.

Construction materials

1. Moderately weathered granite and dacite from the spillway excavation is considered sound enough for use as rockfill; however moderately weathered dacite has a lower compressive strength and is less suitable for placement in

the lower levels of the embankment. Sufficient quantities of rockfill are available from the spillway excavations for the main embankment.

2. Between 1 and 5 m of overburden will have to be removed from the lower spillway quarry, and approximately 1 m from the upper quarry.

3. Slate and sandstone in the upper quarry will generally be unsuitable as rockfill.

4. No major problems in fragmentation of the rocks in the spillway excavation are envisaged. Some careful blasting and possibly selection may be required to achieve satisfactory size gradings of rip-rap material from the upper quarry.

5. In order to reduce the quantity of poor material from the upper quarry, it may be necessary to reject all rock excavated east of easting 223130 and to obtain better quality rock by excavating the quarry floor upstream of the spillway crest.

6. Fresh granite and dacite from the spillway excavation should be suitable as a source for concrete aggregate, however rock containing sulphide veins should not be used for this purpose.

7. Sand and gravel deposits along the Queanbeyan River, within a reasonable distance of the dam site may provide suitable filter material and fine aggregate.

RECOMMENDATIONS

Leakage monitoring

1. The stream to the north of the Bunyip Saddle, the Queanbeyan Fault Saddle and the Phalaris Saddle should be monitored for changes in flow during dam construction and reservoir filling.

2. Regular water level measurements should be continued in drill holes 36 to 40, especially during reservoir filling, when levels should be taken twice weekly.

3. Pump tests should be carried out in drill holes 38, 39 and 40 to ascertain the permeability of the rocks.

Embankment foundations

1. The dam foundations should be stripped to expose moderately weathered rock and geologically mapped in detail.

2. Fractured zones and pockets of highly weathered rock in sheared zones should be excavated and treated.

3. Silicified clay-filled fractured zones where encountered will require excavation and backfilling with concrete.

4. The exploratory adits in the right abutment should be backfilled with concrete in the core and filter zones and with rockfill material in the rockfill zones.

5. Pockets of alluvium along the river bed foundations should be removed and some slopes in the stream-bed may require flattening to ensure satisfactory contacts in the core zone.

Permeability and grouting

1. Blanket grout holes should be approximately 10 m deep and spaced at 5 m centres or less. An analysis of joints, fractures and cleavage planes should be carried out, before grouting, to determine the orientation of grout holes for optimum intersection of joints and fractures.

2. The grout curtain should penetrate the foundations to a minimum depth of 25 m, with holes spaced at 3 m intervals or less. Some second phase grouting may be required to ensure a satisfactory seal.

3. The grout curtain should be continuous parallel to the axis of the dam from RL 670 m on the left abutment to the southern wall of the spillway excavation on the right abutment, and should be extended beneath the spillway crest to a minimum depth of 10 m below the spillway crest foundations.

Construction materials

1. The rock from the spillway excavation east of easting 223130 may need to be rejected as rockfill owing to the high percentage of slate and sandstone.

2. Rock from the spillway excavation which contains sulphide veins should not be used as a source of concrete aggregate.

Seismicity

1. A seismic recording system for monitoring earth tremors should be installed near the dam site before reservoir filling commences.

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In the course of the investigation the site was visited by Mr J.B. Cooke, an American consultant engineer for CDW, and by Mr B. Gale of the Snowy Mountains Engineering Corporation. Their appraisals of the site were valuable and are taken into account in this report.

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APPENDIX 1 - DEFINITION OF TERMS

WEATHERING OF ROCK

FRESH	No discolouration or loss in strength
FRESH-STAINED	Limonitic staining along fractures, rock otherwise fresh and shows no loss of strength
SLIGHTLY WEATHERED	Rock is slightly discoloured, but not noticeably lower in strength than the fresh rock.
MODERATELY WEATHERED	Rock is discoloured and noticeably weakened; N- size drill core generally cannot be broken by hand across the rock fabric.
HIGHLY WEATHERED	Rock is discoloured and weakened; N - size drill core can generally be broken by hand across the rock fabric.
COMPLETELY WEATHERED	Rock is decomposed to a soil, but the original rock fabric is mostly preserved.

PERCUSSIVE STRENGTH OF ROCK

STRONG TO VERY STRONG	Cannot be broken by repeated blows with a hammer
MODERATELY STRONG	Rock broken by 3 or 4 blows.
WEAK	Rock broken by one blow.

HARDNESS OF ROCK

HARD TO VERY HARD	Impossible to scratch with knife blade.
MODERATELY HARD	Shallow scratches with knife blade.
SOFT	Deep scratches with knife blade.

BEDDING

LAMINATED	Less than 10 mm thick
THINLY BEDDED	10 to 100 mm thick
THICKLY BEDDED	Greater than 100 mm thick.

DESCRIPTIVE TERMINOLOGY FOR JOINT SPACING (after D.U. Deere)

VERY CLOSE	Less than 5 cm.
CLOSE	5 to 30 cm.
MODERATELY CLOSE	30 cm to 1 m.
WIDE	1 m to 3 m.
VERY WIDE	Greater 3 m.

ROCK QUALITY DESIGNATION (RQD) - Sum of the total length of core recovered, counting only those pieces of core which are 10 cm in length or longer, and which are hard and sound.

ENGINEERING CLASSIFICATION OF INTACT ROCK (after D.U. Deere)

VERY HIGH STRENGTH	Greater than 221 000 kPa.
HIGH STRENGTH	110 000 to 221 000 kPa
MEDIUM STRENGTH	55 000 to 110 000 kPa
LOW STRENGTH	27 000 to 55 000 kPa
VERY LOW STRENGTH	less than 27 000 kPa

BIASED SAMPLING CORRECTION OF JOINT READINGS

All joint readings obtained from oriented drill core were corrected for biased sampling. The number of poles plotted on a stereographic net for each joint orientation was equal to 2 cos where is the angle between the joint plane and the plane normal to the core axis. The maximum number of poles plotted for any one joint reading was 23 where was equal to 85°.

APPENDIX 2 - CONVERSION FACTORS

LENGTH	1 cm = 0.394 inches
	1 m = 3.28 feet
	1 km = 0.621 miles
VOLUME	1 litre = 0.22 gallons
	1 cubic metre = 1.31 cubic yards
	1 acre foot = 1230 m^3
AREA	1 square metre = 10.8 square feet
	1 hectare = 2.47 acres
PRESSURE	1 kilopascal = 0.145 pounds per square inch
MASS	1 kilogram = 2.20 pounds
	1 tonne = 0.984 tons
PERMEABILITY	1 lugeon = 10 feet per year
VELOCITY	1 metre per second = 3.28 feet per second.

APPENDIX 3

PREVIOUS INVESTIGATIONS

The Googong Dam Site was first studied in the 1920's. Between 1920 and 1939 the site was explored by several shafts, adits, and auger holes; the locations of the excavations still accessible are indicated on Plate 1.

1954; In 1954 the Googong Dam Site was considered for Canberra's second water supply dam and BMR provided geological information on the site at the request of CDW. G.M. Burton and M.A. Randal mapped the site under the supervision of L.C. Noakes, and Noakes and Burton (1955) reported on the investigation. The Bendora Dam Site on the Cotter River was preferred at that time and was subsequently constructed.

1961; In 1961 CDW requested BMR to undertake geological investigations to assess the feasibility of the Googong and Corin (Cotter River) dam sites. The proposed height of the Googong Dam was 45 m, and Burton mapped the site in greater detail than in 1954. Several costeans were dug by hand, and diamond-drill holes 1 to 4 (totalling 222 m) were drilled by the Snowy Mountains Authority (SMA). The geology of the Phalaris Saddle (400 m northeast of the proposed dam) was mapped and described by Burton, who reported on the complete investigation (Burton 1963).

Seismic surveys were carried out in 1961 and 1962 by W.A. Wiebenga and M. Kirton (Wiebenga & Kirton 1962; Kirton & Wiebenga 1962) of the Geophysical Branch of BMR. The 1962 survey included three traverses on the Phalaris Saddle. The locations of traverses at the dam site are shown on Plate 1, and traverses at the Phalaris Saddle on Plate 11.

In 1963 Corin Dam Site was preferred, and was selected as the third dam to augment the Canberra water supply.

1970; In April 1970, CDW requested BMR to make a geological feasibility study of the Googong Dam Site. J.A. Saltet, assisted by G.B. Simpson, carried out the investigation under the supervision of Burton and E.K. Carter (Saltet, 1971). The height of the proposed dam was increased to approximately 58 m and most of the investigations were directed towards a rockfill dam with a combined spillway and rockfill quarry on the right bank of the river.

Detailed geological mapping was continued at the dam site and was extended to include the spillway area. Diamond-drill holes 5 to 21 were drilled by SMA; seventeen holes in the dam site and spillway areas and one hole, D19, in the Phalaris Saddle. All drill holes were water pressure tested. To facilitate surface mapping and to determine ripper performance in the spillway/quarry area, eleven costeans were excavated, nine by D6 bulldozer and two by hand, (C1 to C11, Plate 1).

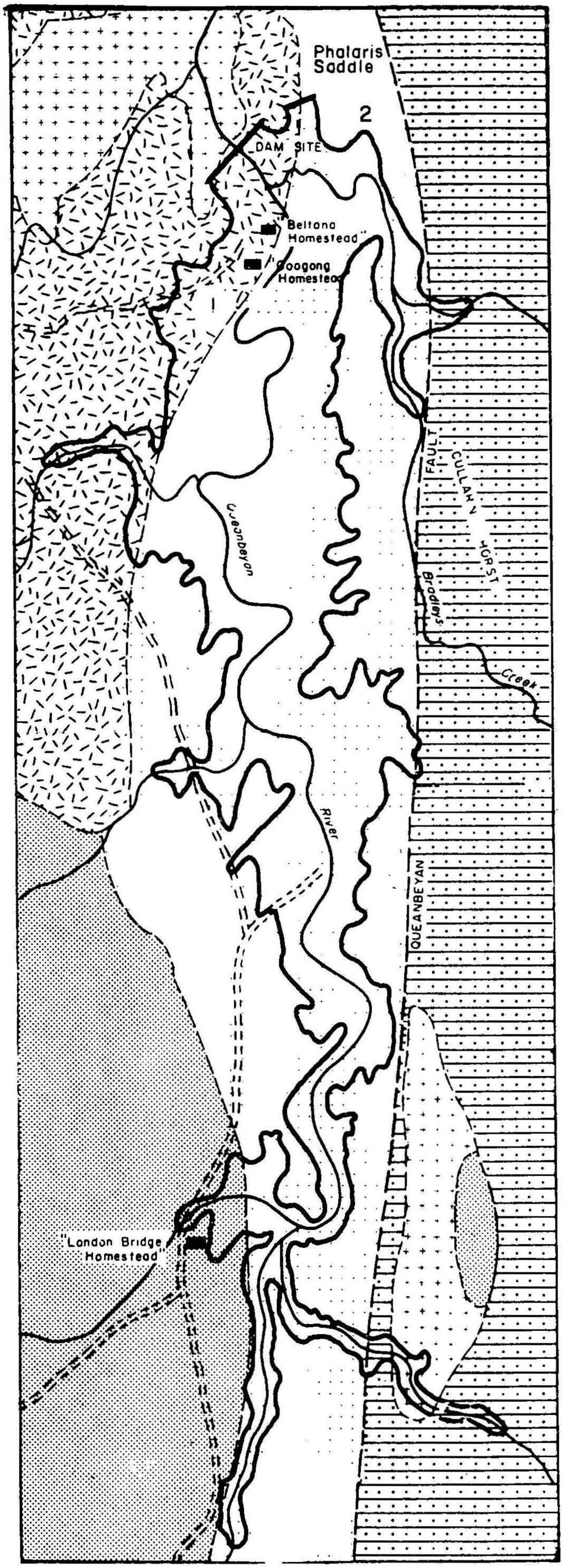
The storage area was geologically mapped by Simpson (Plate 3) and a separate report prepared (Simpson 1972).

The Compagnie Generale de Geophysique (CGG), under contract to CDW, carried out a seismic refraction survey of the proposed diversion tunnel and the spillway/quarry area, totalling 2850 m inlength (CGG, 1970). The location of the traverses are shown on Plate 1.

The position of the proposed spillway was relocated during the latter part of the investigation. Consequently the drill holes and seismic surveys did not give the desired coverage of the final spillway area.

SUPPLEMENTARY SURVEYS

A seismic refraction survey totalling 1219 m of traverses, was carried out in the lower spillway/quarry area by J.F. Taylor and G.R. Pettifer of BMR in May 1971 (Taylor & Pettifer 1972), to supplement the data obtained during the feasibility investigation.



GOOGONG DAM SITE
QUEANBEYAN RIVER
N.S.W.

GENERAL GEOLOGY
OF STORAGE AREA

- Googong Granite and other granites. Silurian-Devonian
- Keewong Quartz Porphyry. Upper Silurian
- Colinton Volcanics. Upper Silurian
- London Bridge Formation. Upper Silurian
- Undifferentiated meta sediments Upper Ordovician

---- Geological boundary
---- Fault, Position approximate
Top level of storage area
=== Vehicle track
1 Alternative quarry site
2 Core material borrow area

Kilometres
0 1·5 2·5
0 1 1·5
Miles

Geology modified from
CANBERRA 1:250,000
SHEET SI 55-16

Appendix figure 1

APPENDIX 4

PHYSIOGRAPHY

The Queanbeyan River and its tributaries flow within a valley that opens out downstream from London Bridge until it is approximately 1.5 km wide immediately upstream of the dam site. The valley has a gently to strongly rolling topography, and is almost entirely underlain by Upper Silurian metasediments and volcanics, which are intruded by Siluro-Devonian granite.

Higher ground within the valley is mainly underlain by quartzite, sandstone, and granite. The lower parts of the valley are generally underlain by slate. The dacite, being more resistant to weathering tends to form ridges.

The east side of the valley is bounded by the Queanbeyan Fault scarp. The fault is probably a high angle reverse fault; an assessment of the displacement from the present physiography would indicate a possible throw of about 100 m (Burton, 1963). The course of the Queanbeyan River has probably been determined to some extent by a preference for the more easily eroded zone of sheared Silurian sediments and volcanics near this major fault. It's valley is parallel to, but offset from, the fault between London Bridge and Queanbeyan.

The west side of the valley is partly marked by the Beltana Fault which traverses the Colinton Volcanics and the London Bridge Formation.

The main characteristics of the Queanbeyan valley indicate maturity, however evidence of rejuvenation is present. The river in the south of the reservoir area is confined to a meandering gorge with tributary creeks having well-defined nick points. Where the river passes over more resistant rocks, rapids and small waterfalls are common. The stretches of river between the rapids have established a temporary base level and are being agraded with the deposition of alluvium, which in some places gives rise to a braided river pattern. The rejuvenation is probably the result of major changes in base level on a regional scale, however some minor adjustments to base level may have resulted from movements associated with the Queanbeyan Fault and other faults in the area.

The dam site lies where the river has cut a gorge through a ridge of dacite striking 020°; the valley widens out in the storage area, where dacite interbedded with less resistant metasediments forms the undulating valley floor.

The dam site profile is asymmetrical. The right abutment is a steep convex slope; the steeper part of the slope is formed by two cliffs of dacite, one (upstream) 25 m wide, and the other (downstream) 30 m wide; the cliffs are separated by a 15 m zone, also dacite, which is steep, but lacks outcrop. As there is no apparent difference in rock type, the lack of outcrop in the central zone is probably due to more intense shearing, but this has not been conclusively established.

The left abutment, being on the inside of the curve of the river, is not as steep as the right abutment. The left abutment has average slopes between 10° and 20° and the right abutment between 20° and 30° from the horizontal.

APPENDIX 5

REGIONAL GEOLOGY

The Googong Dam Site and storage area lie in a belt lie in a belt of Palaeozoic metasediments and metavolcanics of the greenschist facies intruded by granite and porphyry (Appendix fig. 1).

The most likely order of age from oldest to youngest is: Undifferentiated metasediments (Ordovician), on the horst to the east of the Queanbeyan Fault; London Bridge Formation (Upper Silurian), which underlies the largest part of the storage area; Colinton Volcanics (Upper Silurian) cropping out at the dam site and in the northwest part of the storage; Keewong Quartz Porphyry (Upper Silurian), in the extreme west and southwest of the storage; Googong Granite (Siluro-Devonian), which lies immediately northwest of the dam site. Granite probably of the same age, crops out in the extreme southeast of the storage area.

Undifferentiated Ordovician metasediments occupy the Cullarin Horst to the east of the Queanbeyan Fault. They consist of fine to medium-grained felspathic greywacke interbedded with slate. Only a minor part of the storage area, the upper volley of Bradley's Creek, is underlain by this formation.

The London Bridge Formation also consists of metasediments; they comprise fine to medium-grained quartzite, and sandstone, dark grey slate commonly interbedded with the sandstone and quartzite and partly silicified limestone lenses at the top of the sequence (Veevers, 1953). Small granite intrusions, shown on Plate 3 are numerous; most of them are lenticular in shape and concordant with the meridionally striking sediments (see Plate 3).

The Colinton Volcanics consist of metavolcanics and metasediments of the greenschist facies and include dacite with interbeds of slate, quartzite, and limestone. They are described in more detail under 'DAM SITE GEOLOGY'. The volcanics underlie most of the proposed rockfill dam. The nature of the contact between the volcanics and the London Bridge Formation is not known but at the dam site it appears to be conformable.

The deformation of the Ordovician and Silurian rocks is complex, Stauffer (1964) distinguished four phases occurring during the Bowning Orogeny. Near the dam site and storage area the bedding and cleavage strike approximately north and dip steeply or vertically. The metamorphic grade is low (quartz-albite-muscovite-chlorite sub-facies).

The Keewong Quartz Porphyry was first described by Sharp (1949). It shows well developed schistosity, striking approximately 020° and dipping vertically. Veevers (1951) regards the porphyry as a crystal tuff.

The Googong Granite which crops out downstream of the axis of the proposed dam is described in detail under 'DAM SITE GEOLOGY'. Granite probably of the same age crops out in the extreme southeast of the storage area. The granite intrusions in the London Bridge Formation are probably of the same age as the Googong Granite.

APPENDIX 6

WATER LEVEL OBSERVATIONS IN DRILL HOLES

APPENDIX TABLE 1

WATER LEVEL OBSERVATIONS IN DRILL HOLES

Date	D 15 LEFT ABUTMENT		D 5 LEFT ABUTMENT		D 6 RIGHT ABUTMENT	
	R.L. of water table (Metres)	Height above river (Metres)	R.L. of water table (Metres)	Height above river (Metres)	R.L. of water river (Metres)	Height above river (Metres)
9. 6.71	657.5	47.5	615.4	5.4	616.0	6.0
18. 6.71	654.4	44.4	615.5	5.5	616.1	6.1
25. 6.71	654.4	44.4	615.5	5.5	616.1	6.1
30. 6.71	654.4	44.4	615.4	5.4	616.1	6.1
7. 7.71	654.1	44.1	615.4	5.4	616.0	6.0
15. 7.71	654.0	44.0	615.4	5.4	616.0	6.0
30. 7.71	653.9	43.9	615.4	5.4	616.0	6.0
3. 8.71	662.3	52.3	615.4	5.4	616.0	6.0
1. 9.71	653.4	43.4	615.4	5.4	616.1	6.1
17. 9.71	653.3	43.3	615.3	5.3	616.1	6.1
24. 9.71	653.2	43.2	615.4	5.4	616.1	6.1
1.10.71	653.2	43.2	615.4	5.4	616.1	6.1
8.10.71	653.1	43.1	615.4	5.4	616.0	6.0
15.10.71	656.2	46.2	615.3	5.3	616.1	6.1
20.10.71	653.9	43.9	615.3	5.3	616.0	6.0
29.10.71	668.1	58.1	615.3	5.3	616.0	6.0
3.11.71	656.9	46.9	615.3	5.3	615.9	5.9
17.11.71	654.4	44.4	615.4	5.4	616.0	6.0
24.11.71	653.7	43.7	615.4	5.4	616.0	6.0
7.12.71	655.1	45.1	615.4	5.4	615.9	5.9
15.12.71	654.4	44.4	615.4	5.4	615.9	5.9
14. 1.72	658.4	48.4	615.4	5.4	615.9	5.9
24. 1.72	661.1	51.1	615.6	5.6	616.0	6.0
8. 7.72	660.6	50.6	615.6	5.6	615.9	5.9
23. 2.73	661.1	51.1	-	-	-	-
26. 3.73	-	-	615.9	5.9	-	-
6. 4.73	-	-	-	-	616.0	6.0
8. 5.73	-	-	615.9	5.9	-	-

APPENDIX TABLE 1 (cont.)

WATER LEVEL OBSERVATIONS IN DRILL HOLES

Date	D 7 RIGHT ABUTMENT		D 8 RIGHT ABUTMENT		D 35 RIGHT ABUTMENT	
	R.L. of water table (Metres)	Height above river (Metres)	R.L. of water table (Metres)	Height above river (Metres)	R.L. of water table (Metres)	Height above river (Metres)
[illegible]. 1.72	614.0	4.0	620.6	10.6	-	-
24. 1.72	613.8	3.8	620.6	10.6	-	-
[illegible]. 2.72	613.8	3.8	620.1	10.1	-	-
[illegible]. 2.72	613.8	3.8	620.1	10.1	-	-
6. 4.73	613.8	3.8	620.6	10.6	-	-
23. 2.73	-	-	-	-	646.9	36.9
[illegible]. 3.73	-	-	-	-	642.6	32.6

Date	D 22 DIVERSION TUNNEL		D 23 DIVERSION TUNNEL	
	R.L. of water table (Metres)	Height above river (Metres)	R.L. of water table (Metres)	Height above river (Metres)
23. 2.73	609.7	0	612.8	2.8
[illegible]. 3.73	610.0	0	610.8	0.8
[illegible]. 5.73	610.2	0.2	613.3	3.3

APPENDIX TABLE 1 (cont.)

WATER LEVEL OBSERVATIONS IN DRILL HOLES

Date	D36 RIGHT ABUTMENT		D37 LEFT ABUTMENT	
	R.L. of water table (Metres)	Height above river (Metres)	R.L. of water table (Metres)	Height above river (Metres)
30. 1.73	646.6	36.6	645.6	35.6
23. 2.73	639.4	29.4	646.9	36.9
23. 3.73	638.9	28.9	644.2	34.2
6. 4.73	638.9	28.9	647.9	37.9
8. 5.73	638.9	28.9	650.6	40.6
6. 6.73	638.7	28.7	643.9	33.9
19. 6.73	638.5	28.5	642.7	32.7
13.12.73	639.2	29.2	651.5	41.5
7. 1.74	638.8	28.8	650.3	40.3
16. 1.74	639.3	29.3	655.6	45.6
23. 1.74	639.2	29.2	655.1	45.1
4. 2.74	639.3	29.3	650.9	40.9
11. 2.74	639.3	29.3	649.5	39.5
19. 2.74	639.4	29.4	648.7	38.7
8. 3.74	639.2	29.2	652.5	42.5
14. 3.74	638.2	28.2	650.7	40.7
20. 3.74	639.3	29.3	649.2	39.2
29. 3.74	639.2	29.2	647.6	37.6
17. 4.74	-	-	655.6	45.6
25. 4.74	-	-	655.6	45.6
29. 4.74	-	-	655.6	45.6
8. 5.74	-	-	655.8	45.6
16. 5.74	639.9	29.9	655.6	45.6

APPENDIX TABLE 1 (cont.)

WATER LEVEL OBSERVATIONS IN DRILL HOLES

Date	D 38 1500 m S.W. of Dam (Fig. 2)		D 39 PHALARIS SADDLE		D 40 500 N.E. of PHALARIS SADDLE (Fig. 2)	
	R.L. of water table (Metres)	Height above river (Metres)	R.L. of water table (Metres)	Height above river (Metres)	R.L. of water table (Metres)	Height above river (Metres)
6. 6.73	684.2	74.2	655.7	45.7	-	-
19. 6.73	684.8	74.8	655.7	45.7	680.4	70.4
13.12.73	688.2	78.2	660.1	50.1	679.4	69.4
7. 1.74	687.2	77.2	659.5	49.5	678.9	68.9
16. 1.74	687.3	77.3	659.6	49.6	679.3	69.3
23. 1.74	687.2	77.2	659.4	49.4	679.4	69.4
4. 2.74	687.1	77.1	659.3	49.3	679.4	69.4
11. 2.74	687.0	77.0	659.2	49.2	679.3	69.3
19. 2.74	687.0	77.0	659.1	49.1	679.2	69.2
8. 3.74	687.0	77.0	659.0	49.0	679.7	69.7
14. 3.74	687.0	77.0	659.0	49.0	679.1	69.1
20. 3.74	687.0	77.0	658.9	48.9	678.2	68.2
29. 3.74	687.0	77.0	658.7	48.7	679.0	69.0
17. 4.74	688.4	78.4	-	-	-	-
25. 4.74	688.2	78.2	-	-	-	-
29. 4.74	688.2	78.2	-	-	-	-
8. 5.74	688.7	78.7	660.6	50.6	-	-
16. 5.74	689.4	79.4	660.5	50.5	679.7	69.7
5. 6.74	690.1	80.1	660.6	50.6	-	-

APPENDIX 7

LABORATORY MEASUREMENTS ON DRILL CORES

Introduction

Appendix 7 describes the measurements of mechanical properties carried out on 20 NM size drill core samples from the spillway excavation, and one sample from D15 in the left abutment.

The testing was carried out by Dr M. Idnurm of the Rock Measurement Group, BMR.

Geology

Nine of the samples were of dacite and twelve of granite. The weathering of the samples varied from fresh to moderately weathered and details and results are given on the accompanying table.

All samples tested were selected on the basis of being defect free, that is, the absence of any defects visible to the naked eye, such as joints, shears or any other natural or induced weaknesses.

Measurement techniques

(a) Elastic properties

The elastic properties were measured on drill core samples approximately 11 to 18 cms long. The samples were in a laboratory-dry condition.

The longitudinal sound velocities were determined from the transmission times of a sound pulse using a Cawkell ultrasonic instrument type UCT2. The pulse consisted of a damped sine wave of frequency 150 kHz.

Young's modulus and Poisson's ratio were calculated from the longitudinal velocity and the resonance frequency of the drill core sample. A Cawkell instrument type SCT4 was used for the resonance measurements. The elastic moduli consequently represent the dynamic rather than the static values. The experimental errors in velocity and Young's modulus have been estimated to be within 5 percent, and in the Poisson's ratio, within 10 percent.

(b) Hardness.

Hardness was determined by the Shore scleroscope method which measures the height of rebound of a diamond-tipped weight from a flat test surface. A total of 64 readings were obtained from the end faces of each sample and the average of these taken as the Shore hardness. The reproducibility of the average value between different series of tests was found to be 2 Shore units. The samples were tested in a laboratory-dry condition. Appendix table 2 lists for comparison the values of Shore hardnesses of several common rock types. This table was compiled from the information given in a U.S. Bureau of Mines report on their investigation No. 4727.

(c) Uniaxial compressive strength.

The length to diameter ratio of the samples for the compressive strength tests was 2:1. The specimen ends were surface ground to a flatness within 0.001" (highest to lowest point). The ends were parallel within ½°. No lubricant was used on the end facies. The samples were tested in a laboratory-dry condition. The loading rate on the samples was 390 kg/cm^2/sec. Hardened tool steel platens (Rockwell hardness C65) were used. The platen surfaces were prepared such that no roughness could be detected by running a finger nail across the surface.

(d) Logarithmic decrement.

The logarithmic decrement is indicative of rock "quality" and depends on the cohesiveness of rock fabric. Logarithmic decrement is defined by:

$$\text{Logarithmic decrement} = \frac{\pi \Delta f}{fo}$$

where: f is the width of the resonance curve measured between the 71% amplitude points on the curve, and fo is the resonance frequency.

TABLE 2

SHORE HARDNESS RANGE IN COMMON ROCK TYPES

Rock type	Shore hardness	No. of locations of sample collection
Granite	90-100	5
Basalt	69-84	1
Quartzite	81 (one value only)	1
Limestone	27-66	4
Sandstone	31-65	3
Shale	34-58	2

APPENDIX 8

RESULTS OF ROCKFILL BULK SULPHIDE TEST

Drill core from drill holes 10, 11, 21 and 25 to 34 are sampled at 2 m intervals to obtain a bulk sample of the rockfill. Approximately 70 2-inch samples constituted the bulk sample and were submitted to the BMR chemistry laboratory for sulphide analysis. The bulk sample was crushed, ground and thoroughly mixed. Four random samples were taken from the crushed and analyzed for sulphide content.

The sulphur content was too low to be measured, by the analytical method used, and would therefore be less than 0.05 percent.

APPENDIX TABLE 3

GOOGONG DAM SITE - Results of mechanical rock tests of diamond drill core

Sample No.	Hole No.	Depth (m)	Rock type and weathering	Specific gravity	Shore hardness shore units (standard deviation)	Longitudinal velocity (m/sec)	Young's modulus (kpa x 10^{-3})	Poisson ratio	Compressive strength (kpa)	Logarithim decrement
71/129	11	34.75	Dacite - fresh	2.77	64 (28)	5630	6.9	0.29	1430 x 10^2	0.05
71/131	20	2.44	Granite moderately weathered	2.64	68 (17)	4200	3.2	0.33	1050 "	0.07
71/132	20	11.73	Granite slightly weathered	2.65	74 (15)	4900	4.7	0.31	660 "	0.07
71/135	10	8.84	Dacite slightly weathered	2.66	72 (8)	4770	5.0	0.27	1160 "	0.04
71/136	10	16.76	"	2.68	82 (12)	5520	6.9	0.26	1290 "	0.04
71/137	20	13.10	Granite - fresh	2.66	78 (19)	5000	5.8	0.24	1510 "	0.03
71/138	20	22.70	"	2.71	96 (14)	5630	6.8	0.29	2640 "	0.04
71/139	20	30.30	"	2.68	98 (20)	5930	8.1	0.25	1300 "	0.03
71/140	21	7.32	Granite slightly weathered	2.70	96 (12)	5690	7.3	0.26	2380 "	0.03
71/141	21	12.05	Granite - fresh	2.68	99 (14)	5660	7.2	0.26	2270 "	0.03
71/142	10	1.52	Dacite moderately weathered	2.62	55 (14)	4740	4.7	0.28	660 "	-
71/143	10	5.79	"	2.63	51 (13)	4280	3.2	0.34	370 "	0.07
71/144	10	6.10	"	2.63	54 (17)	4270	3.8	0.29	480 "	0.05
71/145	10	6.71	"	2.67	50 (18)	4710	3.7	0.36	220 "	0.08
71/146	11	33.22	Dacite - fresh	2.77	63 (20)	5140	5.7	0.29	850 "	0.04
71/147	11	33.53	"	2.79	78 (10)	5720	7.6	0.27	1560 "	0.04
71/148	11	33.83	"	2.77	78 (21)	5610	7.5	0.24	1550 "	0.02
71/149	15	5.18	Granite moderately weathered	2.65	85 (19)	4520	4.0	0.31	1110 "	0.06
71/150	20	5.79	"	2.64	60 (13)	4700	4.6	0.29	550 "	0.05
71/151	20	7.01	"	2.59	51 (15)	3890	2.2	0.38	-	0.09
71/152	20	7.62	Granite slightly weathered.	2.68	95 (17)	5580	6.8	0.28	2300 "	0.03

APPENDIX 9

PETROLOGY

by

W.R. Morgan & G.B. Simpson

The rock description are arranged in three parts: first, descriptions of specimens collected from outcrops in the vicinity of the dam site, and second descriptions of core samples from Diamond Drill Holes 1 and 2 at the dam site (the petrographic descriptions in these two parts are by W.R. Morgan, and are by a few remarks on their petrology). The third part includes a description of the Googong Granite by G.B. Simpson.

1. OUTCROP SPECIMENS

One group of outcrop specimens was collected in 1954, and the thin sections were submitted for examination in 1960; the hand specimens were not available for examination. The localities are shown on Plates 1, 4 and 8.

R.9327. Silicified dacite porphyry

The thin section (7395) shows phenocrysts, ranging in size from 0.2 mm to 3.5 mm, enclosed in a fine-grained groundmass that has an average grain-size of 0.08 mm. The quartz phenocrysts are embayed, and are strained and cracked. Tabular albite phenocrysts are moderately sericitized. Porphyritic crystals of ferro-magnesium minerals (possible hornblende) are replaced by sericite, chlorite, and nontronite. The groundmass is composed of finely intergrown quartz grains that enclose numerous minute flakes of sericite. Very thin anastomasing veins of sericite material cut the rock. Accessory zircon and leucoxene were noted.

R.9328. Silicified dacite porphyry

In thin section (7396) this specimen is seen to be fairly similar to R.9327. The main differences are the finer grain-size of the groundmass (0.02 mm) and that the ferro-magnesium minerals (biotite and possible hornblende) are pseudomorphed by epidote and small amounts of leucoxene. Some accessory apatite was noted. The rock is cut by thin anastomosing veins of sericite material.

R.9329. Silicified and sheared dacite porphyry.

The thin section (7397) shows phenocrysts of quartz and albite enclosed by a fine-grained groundmass of finely intergrown quartz. The rock is cut by a thick shear zone composed of intergrown quartz grains that show strong strain patterns; a vein containing quartz and small amounts of euherdal tabular epidote has been emplaced along the sheer zone.

R.12830. Veined dacite porphyry.

The thin section (5025) shows phenocrysts, ranging in size between 0.1 mm and 5.0 mm enclosed in a fine-grained granular and flow-textured groundmass that has an average grain-size of 0.03 mm.

The anhedral quartz phenocrysts are embayed and have pseudo-inclusion: some of the smaller quartz grains are angular, and may be pyroclastic. Andesine phenocrysts are tabular to anhedral, and are commonly sericitized; some crystals are strained and micro-fractured. Subhedral amphibole and biotite are pseudomorphed by epidote, leucoxene, nontronite, and chlorite.

The groundmass is formed of granular quartzo-feldspathic material, and leucoxene, and flaky sericite and nontronite. The flaky minerals are strung out in flow trails which swirl around the coarse grains. Octahedra of black iron ore, and prisms of accessory zircon and apitite are present.

The phenocrysts and the groundmass are cut by thin veins containing sericite, nontronite, and rare zeolite. In places, the veins occupy microfractures in the phenocrysts. In groundmass the veins occur as very narrow diffuse zones in which the flaky minerals are oriented parallel to the flow-texture. The vein minerals commonly form narrow fringes around quartz and andesine phenocrysts.

A visual estimate of the percentage of minerals present is:- andesine: 54, quartz: 25, pseudomorphed ferro-magnesium minerals: 10, sericite and nontronite: 10, black iron ore: 1.

Certain of the angular quartz grains appear to be tuffaceous, although the shapes of most of the phenocrysts, and the pressure of the flow-texture suggest that the rock is a lava. It is probable that the rock is a dacite porphyry containing some tuffaceous material.

R.12831. Devitrified dacitic crystal tuff

In the thin section (5026), coarse grains of quartz, feldspar, and rare fragments and altered ferro-magnesium minerals are enclosed by a fine-grained, dominantly felsitic groundmass.

The coarse grains of quartz are angular, and commonly corroded: they frequently show strained extinction. Somewhat saussuritized oligoclase forms tabular to anhedral crystals that, in some places, occur as interlocking clusters. Rare intergrowths of epidote, leucoxene, and chlorite may represent altered ferro-magnesium minerals. The groundmass is composed mainly of finely intergrown quartz that encloses minute flakes of muscovite and chlorite, and grains of leucoxene. Accessory apatite and zircon were observed. A rounded rock fragment, probably trachyte, andesite was observed to be composed of medium-grained tabular plagioclase crowded into a fine-grained feldspathic and leucoxenic groundmass. The rock is cut by irregular veins containing fine opaque dust.

R.12832. Dacite porphyry.

The thin section (5027) shows coarse, anhedral to subhedral phenocrysts ranging between 0.3 mm to 3.0 mm in size, enclosed in a fine to medium-grained xenomorphic-inequigranular groundmass whose average grain-size is 0.05 mm.

The phenocrysts are composed of quartz, plagioclase and rare ferro-magnesium minerals. Rarely, quartz occurs as euhedral prisms, but more commonly it forms anhedral, strongly corroded crystals. Tabular anhedral grains of plagioclase are somewhat saussuritized and silicified. Rare pale green chlorite forms anhedral flakes.

The groundmass is composed of fine to medium-grained somewhat intergrown grains of quartz and plagioclase. The intergrown nature of these two minerals seems to be granoblastic, suggesting that some contact metamorphism has taken place. Granular epidote and leucoxene, and flakes of green chlorite are present.

The rock is cut by thin diffuse zones of granular epidote.

R.12835. Sheared and granulated dacite porphyry, or dacite tuff

In this section (5030), coarse shattered and granulated grains of quartz and oligoclase are enclose in a fine-grained groundmass. The groundmass is composed of quartz which forms granular, commonly elongated and intergrown grains that show a sheer fabric, although the present form of the intergrowths suggest that recrystallization has taken place after the shearing. Subhedral to tabular crystals of epidote that are present appear to have been formed subsequently to the shearing.

R.12836. Dacitic tuff.

The thin section (5031) is seen to contain medium to coarse grains of quartz and feldspar, whose sizes range between 0.1 mm and 2.0 mm, enclosed in a fine-grained groundmass. The coarse grains of oligoclase are anhedral to tabular, and many show micro-fracturing. Quartz forms angular anhedral grains that sometimes show corroded margins. The groundmass is composed of granoblastic, somewhat intergrown grains of oligoclase and quartz. Small amounts of calcite occur in granular aggregates and rare veins.

R.12837. Veined and saussuritized dacite porphyry.

The thin section (5032) has coarse phenocrysts of andesine, quartz, and pseudomorphed amphibole, and their sizes range between 0.2 mm and 4.5 mm. They are enclosed in a fine-grained granular groundmass whose average grain-size is 0.05 mm.

Quartz phenocrysts are anhedral, and have embayed margins; several show strained extinction. Andesine forms tabular to anhedral, often strongly saussuritized crystals that are commonly microfractured. Amphibole is now pseudomorphed by intergrowths of nontronite, black iron ore, and uncommon epidote.

The groundmass is composed of fine, intergrown quartz grains enclosing minute flakes of sericite and grains of epidote. Accessory black iron ore and zircon are present.

The groundmass is cut by numerous thin and irregular veins containing fine flaky nontronite. A few thicker veins of yellow epidote cut the rock.

W.B. Dallwitz in 1961 briefly examined a second group of three slides made from field specimens.

Dallwitz named the rocks as tabulated below:

Specimen Number	Slide Number	Name
R.8808	7176	Sheared acid ashstone
R.8807	7175	Dacitic crystal tuff
R.8809	7177	Granodiorite porphyry (thick flow or intrusion).

2. CORE SAMPLES.

These samples are from Diamond Drill Holes 1 and 2 at the dam site; their thin sections were examined in September, 1962.

D.D.H. 1.

R.9213. (Depth, 2 feet 9 inches): The thin section (7343) shows that the rock is silicified vitric and crystal dacitic tuff. The crystals range in size from 0.15 mm to 5.0 mm, and are enclosed in a fine groundmass that has an average grain-size of 0.02 mm. The crystals consist of embayed and strained quartz moderately sericitized tabular ablite, and a small amount of biotite that is now completely pseudomorphed by granular epidote and some leucoxene. Some of the albite forms multiple grains. The groundmass is composed of finely intergrown quartz grains.

R.9330. (Depth, 30 feet): The thin section (7398) shows that the rock is a silicified vitric and crystal tuff. Angular to sub-angular grains of moderately strained quartz, roughly tabular crystals of albite and potash feldspar, and somewhat distorted flakes of biotite are enclosed by a very fine-grained groundmass composed of finely intergrown quartz grains and minute sericite flakes. The feldspar and quartz grains have embayed margins, and the biotite is pseudomorphed by sericite, epidote, and chlorite. The crystals and grains range up to 4.5 mm in diameter, and the groundmass has an average grain-size of 0.01 mm.

R.9331. (Depth, 133 feet 3 inches): In thin section (7399) the specimen is seen to be silicified tuffaceous dacite porphyry. The phenocrysts range from 0.15 to 4.5 mm, and are enclosed in a fine groundmass that has an average grain-size of 0.03 mm. The phenocrysts consist of embayed quartz, tabular, somewhat sericitized albite and slightly distorted biotite that is completely pseudomorphed by sericite, leucoxene, and nontronite. The groundmass consists mostly of finely intergrown quartz grains enclosing numerous minute flakes of sericite. Two or three xenoliths that are present are rounded, and have a diameter of about 3 mm; they consist of dioritic material and contain granoblastically intergrown stumpy laths of sodic plagioclase 0.5 mm in length. The rock is cut by thin, diffuse anastomosing veins containing sericitic material.

D.D.H. 2.

R.9396. (Depth, 109 feet 6 inches): The thin section (7436) shows the rock to be a silicified tuffaceous dacite, or ignimbrite. The phenocrysts range from 0.2 mm to 3.2 mm diameter, and consist of embayed and strongly strained quartz, rounded albite crystals and embayed crystals of somewhat kaolinised potash-feldspar. The rare ferro-magnesian minerals are replaced by leucoxene and epidote. The groundmass has an average grain-size of 0.02 mm, and consists almost entirely of fine intergrown quartz grains; rare leucoxene and epidote were observed. In places there is a faint relict flow texture in the groundmass around a few of the phenocrysts. The rock is cut by two veins, 1 and 2 mm thick, composed of fine granular epidote.

R.9404. (Depth, 187 feet 9 inches): In thin section (7465) the rock is seen to be a divitrified and silicified albite dacite porphyry. The phenocrysts range from 0.3 mm to 5.0 mm in size, and are enclosed in a fine-grained groundmass (forming 60% of the specimen) that has an average grain-size of 0.01 mm. The phenocrysts of tabular, strongly sericitized albite (20%), stained and embayed quartz (10%), subhedral biotite (5%), and strongly kaolinised potash feldspar (5%). Biotite is pseudomorphed by leucoxene, sericite, and nontronite. The groundmass consists of irregularly intergrown quartz grains that enclose numerous minute flakes of sericite. Besides the phenocrysts, the groundmass encloses a xenolith of altered andesitic material that measures 3 mm across. The irregular veins range from 0.03 mm to 0.05 mm in thickness and mostly consist of calcite; some contain, in addition, fine green chlorite, and fragments of quartz and feldspar that are derived from the porphyry.

REMARKS

All the specimens described are dacitic lavas and tuffs, although in some of them small xenoliths of intermediate igneous rocks were noted; it is possible that these are cognate. The groundmass of most of the specimens is silicified; this may be due to diagenesis, but other evidence suggests that it may be due to contact metamorphism or metasomatism. Some of the specimens have been sheared; in these the sheared materials appears to have recrystallized to a granoblastic texture, suggesting reheating subsequent to the shearing. In one specimen (R.12834) veining by epidote occurred after the shearing took place. This evidence suggests that the volcanic succession in this locality has been intruded, resulting in slight contact metamorphism and some metasomatism. Prior to this, some of the volcanics were sheared or faulted.

3. GOOGONG GRANITE

Thin section 73360037 - Specimen taken from drill hole 22 at a depth of 20 m.

The thin section shows the rock to be an Adamellite. The rock is holocrystalline with phenocrysts of quartz up to 5 mm across, orthoclase and plagioclase feldspar up to 3 mm across and biotite pseudomorphed by chlorite and epidote up to 1 mm across. Quartz shows wavy extinction and is commonly fractured with quartz felspar and chlorite infilling. The Orthoclase feldspars are also fractured and show partial alteration to kaolin. The plagioclase feldspar is of albite-oligoclase composition and is partially altered to sencite and epidote. The rock is cut by veins of quartz and epidote up to 1 mm across.

Smaller phenocrysts, mainly of quartz and minor feldspar, up to 1 mm show less fracturing and alteration and may be the result of late stage crystallization.