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COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1962/140

GEOLOGICAL INVESTIGATION OF
DAMSITE E, UPPER COTTER RIVER, A.C.T. 1961

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RECORDS 1962/140

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SUMMARY

Damsite E is one of two possible sites for a dam to store 14,000 million gallons of water which, together with the other two reservoirs on the Cotter River, would supply the needs of a population in Canberra of a quarter of a million. It is located on the Cotter River just downstream from the confluence of Kangaroo Creek with the Cotter River, access being provided by 6 miles of bush track from the Forestry road which links the Mount Franklin road with the Orroral valley. Preliminary geological mapping of the site was carried out on a scale of 50 feet to 1 inch, though later detailed mapping of outcrops and costeans was plotted at 20 feet to 1 inch. Diamond drilling and water pressure testing of six holes totalling 800 feet was carried out, and the total length of costeans excavated was 900 feet.

The location of Damsite E was selected because of the favourable topography, the strong foundations indicated during a [illegible], preliminary survey, and the high storage capacity available as a result of widening of the river valley just upstream from the site. The investigation was planned to determine whether the site is suitable for the construction of a dam 200 feet high (the minimum height necessary for the required storage capacity), and if so, the type of dam most suited to the conditions of the site.

The country rock at the damsite consists dominantly of folded beds of quartzite, silicified quartz sandstone and siltstone, laminated siltstone, and shale, all with north-westerly strikes, and dips mostly steeper than 50°. These rocks form the upper part of a succession that extends well upstream and downstream from the site, but is terminated about 1,000 feet to the west of the river by the Cotter Fault. This fault is a major regional structure which has been traced for many miles in the Cotter valley, and at the damsite downfaults the sequence described above against older rocks, dominantly phyllite, to the west.

The folding, faulting and jointing at the damsite are all consistent with a regional compression in an east-north-east / west-south-west direction. The folds located at the damsite plunge gently to the south-east, and the cores of those on the east bank are cleaved and sheared. Faulting is dominant on the east bank, and has caused the downfaulting of a large block of Tidbinbilla Quartzite which is very broken and openly jointed. This outlier of Tidbinbilla Quartzite is not folded, but dips regularly to the south-west at 25° to 35°. The northern boundary of the outcrop is marked by a fault plane which continues down the hillside and is apparently terminated against a fault zone that strikes parallel to the river. Shear and longitudinal joints are well developed in the sandstone and quartzite of the area, particularly in the Tidbinbilla Quartzite, the joint pattern being consistent with the forces which caused folding and faulting. On the west bank, a joint system parallel to the Cotter Fault is also developed.

The soil and scree cover over the area is up to 15 feet thick near the river, but on the hillside is usually less than 5 feet thick. Alluvium deposits of unknown thickness occur on the river banks.

Beneath the overburden, the zone of weathered bedrock is quite shallow, except in well jointed and broken zones, along which weathering penetrates to depths of up to 80 feet. Weathering also extends to greater depths in the cores of the folds on the east bank.

The quartzite and silicified quartz sandstone which predominate at the damsite are quite strong, and would form good foundations were it not for the jointing and the presence of silty and shaly interbeds along which movement could take place under strong stresses. These defects are particularly serious in the area of the Tidbinbilla Quartzite outcrop, which would form the eastern abutment of a thin arch dam. The western abutment would be similarly jointed, though to a lesser extent, and there is strong evidence for a fault zone below the river bed. The foundation conditions are therefore considered unsuitable for the construction of a thin arch dam.

Water pressure testing indicated moderate to high leakages through open joints in the foundations, and an effective grout curtain will be necessary, extending down to the present water table at least, and 50 feet below the river. Grout takes can be expected to be high. Leakage from the reservoir along the Cotter Fault is not expected, though further testing is required.

A seismic survey at the site confirmed the weathering in the cores of the folds on the east bank, and the low velocities obtained for bedrock reflect and prevalence of jointing in the foundation rock. Calculations of moduli of elasticity and compressive strength were also made, based upon the seismic velocities obtained.

It is concluded that a rock-fill dam would be the type of structure best suited to the conditions of the site, and the search for appropriate construction materials has been undertaken. Adequate quantities of rock-fill material are expected to be present close to the damsite. For economy of materials and ease of construction in two stages, a homogeneous rock-fill dam with a concrete or steel lining on the upstream face is preferred to one with an impermeable earth core.

Whichever type is constructed, it is proposed that the spillway be excavated out of the silicified quartz sandstone on the west bank. Bedding planes and most of the joint planes dip in a westerly direction, and so excessive excavation will not be necessary to remove the danger of rockfalls. Attention is, however, drawn to McConnell and Hosking's suggestion that the spillway be on the east bank, and that the Tidbinbilla Quartzite excavated be used for rockfill. This suggestion was made because of the proximity of the Cotter Fault zone, the boundary of which is only about 15 feet west of the proposed spillway wall.

INTRODUCTION

In December, 1945, a geological survey was made of four possible damsites in the Cotter valley (designated Sites A, B, C and D) in response to a request by the Department of the Interior, Canberra. Early the following year, a geological examination was made of a fifth site on the Cotter River, designated Damsite E, which was not considered as suitable as Sites B or C. It was finally decided to construct a thin arch dam at Site C to provide domestic water for Canberra; this was completed in 1961, and has since been named the Bendora Dam.

The extraordinarily rapid growth of Canberra over the past 10 years, however, has necessitated further provision for domestic water storage. It is proposed that sufficient water be stored to supply the needs of a population of a quarter of a million, and to meet this demand a reservoir with a capacity of 14,000 million gallons is required. With this aim in sight, geological investigations, including diamond drilling, have been carried out at two possible damsites at the request of the Department of Works. One of these sites, called the Googong Damsite, is situated on the Queanbeyan River 6 miles upstream from Queanbeyan, and the other is Damsite E on the Cotter River. In the light of these and other investigations, a decision as to which of the two sites is the more suitable will be taken by the appropriate authority.

LOCATION AND ACCESS.

The Cotter River rises in mountainous country near the southern border of the Australian Capital Territory and flows north for about 35 miles to its confluence with the Murrumbidgee, 10 miles west of Canberra.

The location of Site E is 200 feet downstream from the junction of Kangaroo Creek with the Cotter River; this is 16 miles from the source of the Cotter River and 9 miles upstream from the Bendora Dam (Plate 1).

Access to Site E has been made much easier by the construction between 1957 and 1960 of a Forestry road linking the Mount Franklin road with the Orroral Homestead. This extension of the Mount Franklin road crosses the Cotter River below the Old Cotter Homestead, follows the river downstream for 4 miles and then crosses the eastern divide into the Orroral valley. The road passes within 6 miles of Site E, and in March 1961, an access track to the damsite was constructed by the Department of Works. The distance from Canberra to Site E is 55 miles via Tharwa and the Orroral valley, and 72 miles by the Mount Franklin road. Under dry conditions, it would be possible to travel to the damsite in an ordinary vehicle, but after heavy rain it is necessary to use a four-wheel drive vehicle, preferably with a winch, on the 6 miles of access track.

MAPPING

L.C. Noakes and T.D. Dimmick spent four days in the area in 1946, during which time a plane table survey of the site, extending to 60 feet above the river, was made.

Geological features outside this area were plotted directly on to air photographs.

In 1958, the site was visited by N.H. Fisher, L.C. Noakes and D.E. Gardner, when a compass, tape and Abney level traverse was made along the proposed axis to a height of 200 feet above the river bed. This indicated that there were no obvious features which would rule out the construction of a dam at site E.

During April and May, 1961, preliminary geological mapping of the damsite was carried out on a scale of 50 feet to 1 inch by J.K. Hill and D.J. Ives, control for this survey being established by plane table tacheometry supplemented by compass, tape, and Abney level traverses. On the basis of this mapping, a programme of diamond drilling and costeaning was drawn up and initiated in July, 1961. More detailed mapping on a scale of 20 feet to 1 inch was later carried out by D.E. Gardner and E.J. Best to assist the interpretation of folding and faulting which was suspected from the preliminary examination. For the convenience of this report, the map of topography and general geology combined has been reduced to a scale of 100 feet to 1 inch (Plate 3), and the scale of the detailed geological map has been reduced to 40 feet to 1 inch.

DRILLING

The diamond drilling programme was started at the end of July, 1961, and continued until the beginning of November. During this time, six holes were drilled and water pressure tested, the total length of drilling being 800 feet. The positions of the drill holes are shown on the geological maps (Plates 3 and 4) and the geological logs of these holes are given in Appendix 3.

Drilling was carried out by Snowy Mountains Hydro-Electric Authority drillers, using two Boyles drilling machines owned by the Authority. A triple split inner tube core barrel was used in all holes and gave exceptional core recovery in badly broken and decomposed zones. The size of the core barrel used throughout was NMLC except in holes P-1B and P-2, where caving was serious enough to necessitate reducing the size of the core to BMLC at depths of 87 and 44 feet respectively.

In order to obtain a record of the core in an undisturbed state, each lift was photographed, while still in the split inner tube, by the drillers. A less detailed, but more compact, record was obtained by photographing the full core boxes.

WATER PRESSURE TESTING.

Water pressure tests to determine the tightness of the rock were carried out in all drill holes, using mechanical packers to seal off the test sections. Initially, 20 foot sections were tested, but because of high water losses, the test sections were reduced in length to ten or five feet in five of the drill holes. This measure was only partially successful, due to the low capacity of the pumps used. It was not possible to pump enough water into the test sections to build up a wide range of pressures, with the result that often only one or two readings were possible for each test section.

The calculations of the corrected water pressure test results are shown in Appendix 4, and the graphical representations of these results are illustrated in Plate 5.

COSTEANING

The original programme of costeaning and pitting was carried out between May and October, 1961, and additional costeans were excavated during the last three months of 1961 in an effort to elucidate the structure of the east bank.

Costeans have been excavated on both sides of the river in the vicinity of the proposed dam axis. In addition to providing information on the lithology and structure of the area, they have given an indication of the thickness of soil and scree material overlying bedrock. The locations of all costeans and pits are shown in Plates 3 and 4.

PHYSIOGRAPHY

The Cotter River flows in a northerly direction through the mountainous country occupying the western half of the Australian Capital Territory. Its course has been determined partly by the trend of the Cotter Fault, and partly by the northerly strike of the metamorphic rocks across which the river flows for much of its length.

The topography of the Cotter valley changes quite markedly in the vicinity of Kangaroo Creek. Downstream from this tributary, the river flows in a narrow, youthful valley with overlapping spurs and steep river sides, whereas upstream from Kangaroo Creek, the valley is considerably wider and is quite straight. The slopes of the upper part of the valley are not as steep as those downstream, the valley floor being much wider and containing extensive alluvial flats. The river gradient is greater in the wider reaches of the valley, however; the average gradient for the ten miles upstream from Damsite E is 54 feet per mile, whereas between Damsite E and the Bendora Dam the average gradient is 42 feet per mile.

This change in topography is explained on the basis of stratigraphy and structure. Above Kangaroo Creek, the dominant rock type is granite, and the gentler topography probably reflects its lower resistance to weathering and erosion. Temporary base levels of erosion, established by gorges in the metamorphic rocks downstream from Kangaroo Creek, enabled the upper part of the valley, which lay mainly in granite and along the Cotter Fault, to widen its bed. During this period, extensive alluvial flats were built up, and the presence of large alluvial fans indicates that for considerable periods, the Cotter River was too sluggish to remove the coarser material delivered by the tributaries in flood.

REGIONAL GEOLOGY.

The general geology of the Cotter valley has been described in some detail in two Records by L.C. Noakes (1946/12 and 1946/26). The distribution of the geological units recognised in the relevant portion of the Cotter valley is shown in Plate 2, and the following is a brief account of the regional geology.

On the western side of the valley, metamorphic rocks are dominant, consisting mainly of sericite phyllite with some interbedded sheared quartzite. The regional structure of these beds is quite consistent along the Cotter valley - northerly strike with an average dip of 60° to the west - but there are some lithological changes.
In the Kangaroo Creek area, a greater number of sandy and possibly tuffaceous phases occur than in downstream areas. The succession is regarded as Ordovician, but no fossils have been found in the area. Farther downstream, Upper Ordovician (Eastonian) graptolites have been found in rocks of similar lithology.

On the downthrow or eastern side of the Cotter Fault in the region of Kangaroo Creek, the rock types range from quartzite and sandstone to finely banded shale and slate. Some of the quartzite and sandstone have been sheared, and the succession has been thrown into a series of pitching folds. The degree of contact metamorphism is low, however, surprisingly so in view of the proximity of the Murrumbidgee Granite. The relationship of these rocks to those on the western side of the Cotter Fault is not clear. Before faulting took place, they may have belonged to the same sequence.

The Tidbinbilla Quartzite crops out mainly on the eastern side of the river, and in places is seen to rest unconformably upon the underlying succession. It consists of massive quartzite beds with occasional silicified shaly bands. In the Kangaroo Creek area, the Quartzite occurs in outliers standing out as prominent bluffs, but their relationship with the underlying rocks has been obscured by normal faulting. The dominant rock type is a buff coloured, massive, impure, partially silicified sandstone or quartzite; the beds strike northerly and dip from 15° to 35° to the west.

Four separate areas of granite are shown in Plate 2; the rock type in each is biotite granite with little or no other ferromagnesian minerals. Because their interrelationships have not been clearly established and each forms a discrete outcropping body, a formal name has been given to each granite body, but it is probable that they are all related at depth.

The dominant structural feature of the area is the Cotter Fault, which has been traced southwards from Bushrangers Creek to a point two miles south of Kangaroo Creek. The fault extends into the granite country at the head of the Cotter River, though it is less prominent than in the metamorphic rocks downstream. It is considered to be a high angle reverse fault, and the main movement appears to have occurred at about the time of the granite intrusion in late Silurian time. The throw of the fault has not been determined, but the fact that no Tidbinbilla Quartzite has yet been found in the Cotter valley west of the fault suggests a throw of considerable magnitude.

DAMSITE GEOLOGY

LITHOLOGY

The country rock at the damsite consists dominantly of folded beds of quartz sandstone, quartzite, quartz siltstone, laminated siltstone and shale, with a north-westerly strike and dips mostly steeper than 50°. These rocks extend for at least a mile both upstream and downstream. Their western boundary is the Cotter Fault which is located about 1,000 feet west of the river at Site E; here, the rock types mapped at the damsite are faulted against phyllite. An outlier of Tidbinbilla Quartzite also occurs at the site, and forms a prominent bluff 180 feet above the river on the east bank. The attitude of this formation is quite regular, dipping south-south-west at between 25° and 35°.

In outcrop, the quartz sandstone of the older succession generally forms steeply sloping slabs or prominent rocky ribs. It ranges in grain size from very fine to coarse, and the shape of the grains varies from well rounded to sub-angular. The grains consist entirely of quartz of mixed parentage, and have authigenic outgrowths which occupy all voids.

Numerous flat flakes and fragments of shale up to 5 cm. long occur scattered throughout the sandstones, and frequently they are aligned sub-parallel to the bedding. In hand specimens, similar argillaceous material appears to form the matrix of the sandstones, but microscopic investigation shows this to be the result of impaction of shale fragments by the quartz grains. The amount of shaly material in these quartz sandstones varies from insignificant amounts to 25% of the rock, and small impacted fragments are much more common than the larger flakes. A characteristic occurrence of the shale fragments may be seen in the two prominent outcrops of coarse grained sandstone adjacent to station A1 (Plate 4). Large angular fragments of grey-green shale, 1 to 5 cm. across, occur scattered throughout the sandstone and impart a brecciated appearance to the rock.

Most beds of quartz sandstone are thick (2 to 10 feet), massive and very uniform, the bedding planes being clean or thinly covered with silty material. Other bedding plane features shown by these beds are irregular ripple markings, generally of large wave-length (5 to 8 cm.) and amplitude (1 to 2 cm.); thin interbeds of shale and slate; and graded bedding, which is more prevalent in the fine-grained sandstones.

Silicification is evident in most of the sandstones, and some are so highly silicified that they might be more correctly termed quartzite. The quartzite rocks are harder, more massive, and more resistant to weathering than the sandstone, and included flakes of shale are rare.

Quartz siltstone occurs as massive beds, and apart from the difference in grain size and darker colour - a medium to dark bluish grey - is similar to the quartz sandstone.

Finely laminated siltstone and shale have two modes of outcrop in the area:-

1. As thin interbeds (less than 2 feet thick) between successive beds of massive quartz sandstone.

2. As wide outcrops, part of a thick succession of thinly bedded shale, siltstone, and fine-grained quartz sandstone.

In the first category, the laminae are from paper thin to 5 mm. thick, and show cross bedding, graded bedding, and slumping features. In places the thin interbeds are cleaved and sheared, particularly in the area of faulting on the east bank, downstream from the dam axis. Stresses in the beds at the time of faulting were relieved by the shearing of the more incompetent silty interbeds, while the competent sandstones remained intact; i.e. movement has occurred along the silt and shale bands.

Rocks of the second category occur as low-lying, partly buried exposures and outcrops, mainly on the east bank. Near the proposed dam axis, the width of the outcrop is only about 100 feet, but 300 feet downstream, the succession crops out over most of the east bank up to at least 200 feet above the river. Cross bedding, graded bedding and slumping are also common in these finely laminated siltstones and shales, and bending of laminae around included flakes of other rock was noted in a few exposures. The bedding planes are generally smooth and regular and often exhibit a micaceous sheen; asymmetrical micro-ripples with a wave length of 2 mm. or less are also present and display the finest detail. In several areas, these beds are highly indurated and give rise to upstanding outcrops of hard, brittle, strongly cleaved slate. The fine quartz sandstone which is interbedded with the laminated siltstone, shale and slate is similar to the more massive beds described earlier, except that banding and shaly partings are much more abundant.

Pyrite is found in all types of rock at the damsite, though it is most common in the massive beds of sandstone and siltstone. It occurs in the following forms :-

1. Single cubes up to 2 mm. across disseminated throughout the rock.

2. Clusters, up to 10 mm. across, of pyrite crystals.

3. Pods of disseminated pyrite up to 30 mm. long by 10 mm. wide.

4. Irregular areas of disseminated pyrite associated with pods.

The clusters of pyrite, which are approximately spherical, appear to be restricted to the massive sandstone and quartzite. Petrological examination reveals thin sinuous lines of pyrite which seem to represent channelways of sulphide solutions that developed between the quartz grains, for the clusters are developed at points along these channels.

The pods of disseminated pyrite are most frequently found in the siltstone and shale. In the specimen examined under the microscope, each pyrite cube is rimmed with growths of small muscovite flakes, and pressure shadows have been developed in the muscovite as a result of metamorphism of the rock indicating that pyrite enrichment preceded metamorphism.

Pyrite is also present in the sheared siltstone at the bottom of drill hole P-1. The siltstone is surprisingly fresh, compact and water-tight, but the shearing is well shown by polished fracture surfaces, many of which have 'smears' of crushed pyrite on them.

The Tidbinbilla Quartzite consists of hard, strong, silicified, coarse to medium grained quartz sandstone, which in many places is similar to massive sandstone of the underlying unit. The main points of distinction are:-

1. Shale and slate are not present in the Tidbinbilla Quartzite.
2. The Tidbinbilla Quartzite, as its name implies, is generally more highly silicified than the underlying beds.
3. The Tidbinbilla Quartzite is massive and generally more thickly bedded than underlying sandstone.
4. Joints, most of them with slickensides, are strongly developed in the Tidbinbilla Quartzite, indicating considerable deformation and adjustment. The main outcrop is traversed by numerous major open joints and consists largely of masses of displaced blocks and slabs fitting loosely together.

Although in areas downstream from Damsite E the Tidbinbilla Quartzite rests unconformably on the older beds, the boundary between the two formations is not exposed at Damsite E because of major faulting. The western margin of the Tidbinbilla Quartzite outlier is marked by a series of normal faults, but because of the similarity between the two main formations it is not possible to indicate the contact of the Tidbinbilla Quartzite and the older succession precisely.

Deposits of alluvium occur in the area mapped, particularly at the confluence of the Cotter River and Kangaroo Creek. A pit was dug in the area between the two rivers in an effort to determine the thickness of alluvium, but had to be abandoned at a depth of 6 feet, due to the influx of water, while still in alluvium. River deposits also occur on the banks and bed of the Cotter River near the proposed axis, particularly on the west bank where drill hole P-1 indicated a thickness of 15 feet. On the east bank, some of the alluvium has been over-ridden by soil and scree - this is well shown at the bottom end of the costean between stations X and L where alluvium is exposed beneath 9 feet of soil cover. The alluvium consists of medium to coarse sand, intermixed with gravel and boulders of biotite granite, phyllite, shale and quartz sandstone.

STRATIGRAPHY

The geologic structure of the area is so complicated by folding and faulting that it has been impossible to obtain any detailed knowledge of the stratigraphical succession at the damsite. Elucidation of the stratigraphy is made more difficult by the extensive lateral variations in rock type, caused by [illegible] lensing out of beds. It was hoped that the detailed mapping would locate one or more marker beds which would facilitate correlation, but the few distinctive beds that were mapped appeared to be only locally developed. Thus, a distinctive quartz sandstone with large angular flakes of shale was found only in the two outcrops near station A1, and a characteristic quartz sandstone with well rounded, white quartz grains was found in one of the costeans and nowhere else. It can be generally stated that siltstone and shale predominate in the lower beds exposed at the damsite, and quartz sandstone becomes more common in the younger beds: many more exposures are required before any detailed knowledge of the stratigraphy can be obtained.

STRUCTURE

Folding

On the west bank of the Cotter River, a tight, flatly plunging anticline with moderately steeply dipping limbs (60° to 70°) is exposed 30 feet above the river, and has been mapped farther uphill in the costean that follows the contours. In the main outcrop, the rock type in the nose of the fold is shale which has been strongly sheared and crushed. Only fine-grained quartz sandstone is exposed in the costean, however, and the fold is well shown by curved bedding planes.

Outcrops of quartz sandstone on the west bank 400 feet downstream from the proposed axis dip to the south-west, therefore a synclinal axis probably lies somewhere between these outcrops and the anticlinal axis. A costean was dug from the pit west of station B towards station F in an effort to locate the syncline, but owing to the thickness of soil cover in this area, bedrock was not reached. Therefore, the two dip and strike measurements in the vicinity of station EE form the only factual evidence for the presence of a syncline on the west bank.

On the east bank, the geology is more complicated and from the evidence available it is not possible to say definitely whether the variations in dip, particularly in the costeans, are due to true folding or drag against adjacent faults. The overall pattern of dips, however, indicates an anticline (marked by the cleaved shale band) and a syncline farther up the slope.

The anticline is well exposed at the lower end of the T-shaped costean, where the dip of the cleaved shale is seen to swing round from south-west, through south, to the east. The dips indicate that the anticline plunges at 15° to the south-south-east; the widening of the shale outcrop in a northerly direction is consistent with this interpretation, but is possibly due to the topography.

The axial plane of the anticline is shown by the cleavage to dip steeply to the east-north-east. The laminated shale is sheared near the axis of the fold; displacements of up to 25 mm. have been observed, and polished sections of some specimens of the shale show signs of either incipient shear or boudinage on a small scale.

The axis of the syncline farther up-slope is not clearly defined in any of the outcrops or costeans, but is inferred from the reversals of dips in a north-easterly direction to coincide with the shear zone which has been traced from near station A17 across the two high-level costeans. The rocks in this area are massive quartz sandstone, and consequently there are few bedding observations on which to base interpretation of structure.

A small tight anticline is well exposed 40 feet east-north-east of station A17. The limbs consist of finely banded, strongly cleaved shale (tending to slate in places) the laminae of which show many minor folds and contortions. The flexure is thought to be due to the dragging of beds against a nearby major fault.

In the costean on the east bank near stations A2 and A3, several reversals of dip direction may be seen, yet the strike remains fairly constant. Three small faults have been located in this costean, but have produced little dislocation; the reversals of dip are therefore assumed to be due to minor folds on the west limb of the major anticline on the east bank.

Faulting.

On the east bank, there are two dominant systems of faults, one trending east-north-east and the other north-north-west. The faults form the boundaries of the prominent outcrop of Tidbinbilla Quartzite, and have resulted in the downthrow of these arenitic beds against the sequence of finer grained sandstones, siltstones and shales lower in the stratigraphic succession. The fault planes bounding the main outcrop dip almost vertically, but the western side of the bluff is strongly broken by a series of normal faults that dip east-north-east at 50°, and associated minor faults and open joints that strike east-north-east. The downfaulted beds are highly silicified, presumably through the early introduction of silica along the faults.

The main fault bounding the Tidbinbilla Quartzite to the north continues down-slope towards the river, and is delineated by a wide outcrop of cleaved and contorted shale between stations A24 and A17. Dragging of beds against the fault is clearly evident in this outcrop, and induration and shearing of the shale has produced a hard, brittle slate. Below (west of) A17, the fault plane is only exposed near the river where a massive fine-grained sandstone bed is faulted against cleaved shale. This massive sandstone bed continues for 50 feet to the south, but is abruptly terminated to the west by a steeply dipping planar surface which is silicified and veined by quartz, and is therefore probably a fault plane striking north-north-east.

Diamond drill holes P-1 and P-1B penetrated several thin zones of crushed and decomposed bedrock, suggesting that a fault zone passes beneath the river at these points. Correlation of the broken zones in the two holes indicates that the fault zone trends parallel to the river at the proposed axis. The probable fault mentioned at the end of the preceding paragraph is presumably part of this fault system as it has a similar strike.

Costeans on the east bank have exposed several faults and shear zones, as shown on the detailed map (Plate 4). The faults exposed in the T-shaped costean may be correlated with those in the short parallel costean, and are seen to form part of the north-north-west system of faulting; they dip very steeply. The most prominent of these fractures is the shear zone which has been traced towards station A17 and which coincides approximately with a synclinal axis. The shear zone is 8 feet wide in the short costean, and is shown up well in a seismic profile along the proposed axis of the dam.

The large upstanding outcrop of quartz sandstone 100 feet south-east of drill hole P-3 shows faulting and major jointing identical to that of the Tidbinbilla Quartzite, and its southern boundary is particularly steep and abrupt. This suggests the presence of a fault plane that strikes west-south-west along the slight depression down the hillside which may reflect the fault. There are no outcrops down-slope to verify this possibility and insufficient time was available to prove or disprove the fault by costeaning. However, the existence of the fault is a distinct possibility which should be borne in mind in later investigations.

Similarly, faulting is suspected in the area around station J. Two fault planes and numerous major joint planes have been mapped, but again there is insufficient outcrop to enable the main pattern of faulting to be determined. Joint measurements indicate a fault pattern similar to that in the Tidbinbilla Quartzite.

On the west bank, faulting on a large scale is not apparent. Costeaning revealed only one fault plane, which dips at 65° to the west-south-west, and is accompanied by a quartz vein 6 inches wide. The extensive outcrop of massive quartz sandstone which forms a rib all the way up the hillside shows increasingly strong fracturing and silicification towards the Cotter Fault.

Jointing.

The dominant rock type in the area is massive quartz sandstone, in which jointing is invariably moderately to very well developed. In many outcrops, bedding planes and joint planes are difficult to distinguish, particularly in the massive outcrop on the west bank where bedding planes are scarce.

Major joints are widely spaced (more than 2 feet apart), are straight or only slightly curved, and generally persist for at least 25 feet.

Numerous zones of closely spaced minor joints occur between some of the major fractures. Slickensides are commonly present on the joint faces, indicating considerable local adjustment, but no overall pattern of movement was recognised.

In sandstones of the older succession, joint planes are either tight or slightly open. The Tidbinbilla Quartzite, on the other hand, is traversed by numerous major open joints and quartz veins, and considerable movement has taken place resulting in abundant slickensides and loosely fitting blocks of quartzite. Gaping and slickensiding of joints initiated by orogenic movements persist to a depth of at least 80 feet in the Tidbinbilla Quartzite, but near the surface gravity settlement has caused later movements along many of these joints; this has resulted in the jumbled mass of quartzite blocks which forms the bluff face of the Tidbinbilla Quartzite outcrop.

Stereograms of the joint pattern at several outcrops were constructed to determine whether the same joint system persists throughout the area. Poles of the joint planes were plotted on an equal area net, and their distribution accentuated by contouring the stereograms. Five areas were treated by this method and the results are shown in Plate 8.

The first feature to be noted from these results is the dissimilarity of stereogram no. 5 compared with the others. This refers to the two prominent outcrops near station A5 which could not be fitted into the geology of the surrounding area very well, being very coarse blocks of sandstone surrounded by fine grained sandstones and siltstones. It was thought that they may possibly be large blocks of Tidbinbilla Quartzite which have fallen downhill, and to test this theory the stereogram was superimposed on that of the Tidbinbilla Quartzite and rotated about a vertical axis until the groups of bedding poles coincided. In this position, the strike and dip of bedding in the isolated outcrops were identical with those of the Tidbinbilla Quartzite, and the areas of concentration of the joint poles coincided almost exactly; this proved that the outcrops are, in fact, fallen blocks of Tidbinbilla Quartzite. It should be noted that, in a general case, rotation of the poles on the stereogram about a horizontal axis parallel to the strike is necessary before the rotation of the direction of strike; in this way the dips of bedding on the two stereograms are made equal first. In the case described above, this was unnecessary as the dip of bedding of the isolated outcrops is the same as that of the Tidbinbilla Quartzite.

Another feature of stereogram no. 5 is that, although measurements were taken from two apparently separate outcrops, only one definite pattern was produced on the stereogram and interpreted as above; this indicates that only one large block fell down the hillside. Either the two outcrops are joined below the surface, or they separated just before reaching their present position and still maintain the same orientation.

Of the remaining four stereograms, the one representing the joint pattern of the Tidbinbilla Quartzite shows the best grouping, with three sets of vertical joints striking at 058°, 083° and 160°* ......

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* All bearings and directions in this report are magnetic.

and one set of joints with a strike of 150°and dips ranging between 50°and 70°. The sets of vertical joints are clearly related, and coincide exactly with the fracture pattern to be expected as a result of east-north-east - west-south-west compressive forces. Such compression would produce a set of longitudinal joints and two sets of shear joints, with the axes of any resultant folding bisecting the obtuse angle between the shear joints. In the stereogram, the longitudinal joints strike at 160° and the shear joints at 058° and 083° respectively. The axes of any folding would therefore strike at $(58^\circ + 83^\circ)/2 + 90^\circ$, i.e. at 160½°; this corresponds exactly with the longitudinal jointing, and also with the strike of the anticlinal axis on the east bank.

The other two stereograms of areas of the east bank do not show the overall picture as well as the Tidbinbilla Quartzite, but concentrations of joint poles do occur which coincide closely with those of stereogram no.2. The shear and lognitudinal joints represented in these two stereograms (nos. 3 and 4) are not vertical, but dip very steeply towards the south-south-east and east-north-east respectively. This indicates a regional tilting towards the south-east of the area down-slope from the Tidbinbilla Quartzite, amounting to some 15° as read from stereogram no. 3, and is confirmed by the plunge of the anticlinal axis measured in the T-shaped costean. There is no trace of a vertical joint system which would coincide with that of the Tidbinbilla Quartzite; this tilting is therefore attributed to large scale regional folding, and not to the unconformity at the base of the Tidbinbilla Quartzite.

Stereograms 2 and 3 also show a set of joints with strikes between 145° and 150°, and dips ranging from 45° to 70° to the north-east. These joints are not connected with the system resulting from regional compression, but are reflected by a series of normal faults in the bluff face of the Tidbinbilla Quartzite. The faults and the parallel joints seem to have occurred during the period of downfaulting of the younger beds, but why movement did not take place along the vertical longitudinal joints already formed is not clear.

Although stereogram no. 1 represents 200 joint measurements from the silicified sandstone outcrop on the west bank, a clearly defined pattern is not at once obvious. However, bearing in mind the anticlinal axis located during mapping and the proximity of the Cotter Fault, a pattern does emerge from the contoured stereogram. There are two concentrations of almost vertical joints with strikes of 030° and 072°, these being shear joints associated with the folding. The strike of the fold axes as calculated from these strikes is 141°, which agrees well with the field data. In contrast to the east bank, however, longitudinal joints are not developed.

The main concentration of joint poles represents a set of joints with northerly strikes and dips ranging from vertical to 70° to the west. This system is undoubtedly associated with the Cotter Fault, to which it is parallel.

The remaining set of joints represented on the stereogram strikes at 070° and dips 40° to the north-north-west. The origin of this system is unknown, as it is not related to either the folding or the Cotter Fault.

WEATHERING

Two classes of soil and scree-covered areas have been distinguished; their areal distribution is shown in Plate 3. In one class, no outcrops occur, and observations in pits and costeans indicate that the soil and scree cover is at least 3 feet thick and in places as much as 12 feet. The other class consists of coarse, blocky scree and talus heaps, with occasional outcrops of bedrock, and is seldom more than 4 feet thick.

On the east bank, overburden does not exceed 3 feet in thickness in the area of the proposed axis. Beyond a point 100 feet upstream from the axis, however, the depth of soil and scree increases near the river and is at least 10 feet thick over the lower slopes of the hillside. On the west bank, the depth of overburden near the proposed axis is generally greater than on the east bank, particularly in the region of the bulldozed benches. At the costean across the slope the overburden depth is 4 feet, and this increases down-slope to between 6 and 10 feet at the middle bulldozed bench and 12 feet at the lower end of the axial costean.

Partial weathering of bedrock extends to 15 feet below the bedrock surface in drill hole P-1 and to 25 feet in hole P-1B. In the other drill holes, however, the weathered zone is not as clearly defined, the degree of weathering depending upon the abundance of open jointing and broken zones. Jointed quartz sandstone was encountered in P-3, and in this hole weathering extends to 85 feet below the surface, with occasional patches of fresh rock where the sandstone is not strongly jointed. In P-4 , on the other hand, fine-grained sandstone and laminated siltstone are dominant, and although the hole passes through an anticlinal axis, the rocks are only weathered adjacent to the occasional broken zones. In the absence of jointing and faulting, the arenaceous rocks are not strongly weathered near the surface, and partial weathering continues only for a few feet below bedrock surface. In argillaceous rocks, advanced weathering occurs locally to at least 5 feet below the bedrock surface, and partial weathering probably extends for another 10 feet or so. Weathering along joints and faults extends to considerable depths, however, e.g. in hole P-1 from 141'7" to 142' 2" (vertical depth 70'9" to 71' 1") the core consists of clayey, decomposed bedrock.

ENGINEERING GEOLOGY

The location of Damsite E was selected because of the favourable topography, the strong foundations which were expected from the outcrops of quartz sandstone and quartite, and the high storage capacity available as a result of widening of the river valley just upstream from the site. The proposed axis indicated in Plates 3 and 4 is the only location to take advantage of all these factors, as moving the axis upstream would increase the crest length of the dam considerably. Downstream, the river falls quite rapidly, and a substantially higher dam would be needed to store the same volume of water.if the axis is moved in this direction.

The investigation was planned to determine whether the site is suitable for the construction of a dam 200 feet high, and if so, the type of dam most suited to the conditions of the site. The profile at the proposed axis is suitable for the construction of a thin arch dam, the cheapest type to build. A thin arch dam requires sound foundations and particularly strong abutments, however, and if these are not present, the choice between a concrete gravity and a rock fill dam has to be made. The choice would depend upon the profile of the site, foundation conditions, availability of material suitable for use as rock-fill, impermeable core and concrete aggregate, as well as other factors. It is possible that any dam on the site will be constructed in two stages, first to a height of 150 feet above the river, and later to 200 feet. In this case, a rock-fill dam with a concrete or steel membrane on the upstream face would be favoured.

FOUNDATIONS

East bank.

Outcrops on the east bank consist dominantly of massive, fine to coarse grained quartz sandstone which has been partly silicified, and locally grades into quartzite. Finer grained rocks occur generally as thin interbeds between the massive sandstone, but there is one large outcrop of cleaved shale, forming the core of an anticline, which varies in width from 40 feet to at least 150 feet farther north. Apart from this large outcrop, cleaved shale occurs locally adjacent to fault planes, and as thin interbeds in the massive sandstone.

Where quartz sandstone is exposed at the surface, it is generally unweathered, hard to moderately hard, and very strong to moderately strong, depending upon the degree of silicification. The most highly silicified area is the large outlier of Tidbinbilla Quartzite high up on the bank; the rock here is fresh, very hard and very strong. Near the river, prominent outcrops of very hard and strong, medium to coarse grained, silicified sandstone are also fresh even at the surface. Farther up-slope, however, costeans have exposed mainly unsilicified, fine-grained quartz sandstone beneath the soil and scree cover. This sandstone is weathered in many places to a soft, yellow-brown rock which crumbles when struck with a hammer, instead of breaking cleanly.

There are minor zones of silicified sandstone, associated with small faults and shear zones, amongst the weathered sandstone, but even in these the sandstone is weathered to a yellow-brown colour although it is moderately hard and strong. The depth of weathering of the unsilicified sandstone is not known, but is probably not great, as the rock is quite compact and open joints are not evident.

The arenaceous rocks are strong, particularly those that are highly silicified. The compressive strength of fine-grained sandstone is greater than that of coarse-grained sandstone, and a high degree of silicification results in a stronger bonding of grains and hence a high compressive strength. The thick succession of unsilicified sandstone on the east bank consists of fine-grained rocks which grade locally into siltstone, and so has a compressive strength comparable to the silicified, though coarser-grained, sandstone.

In considering the ability of these arenites to withstand the forces exerted by a dam structure, the thin interbeds of silty and shaly material become important as possible planes of weakness. These interbeds are particularly well seen in outcrops 200 feet downstream from the proposed axis and between 80 feet and 200 feet above the river, and it is evident that movements of beds of massive sandstone took place along these interbeds at the time of regional folding and faulting. As a result, the original silt and claystone bands have been altered to cleaved shale and slate which now constitute zones of potential weakness should large forces be exerted on the sandstone. This potential weakness in the foundation rocks is important if an arch dam is contemplated, as the area described above would form the east abutment of the dam and would be subjected to much higher stresses than in the case of a gravity or rock-fill dam.

Faulting and open jointing has had a profound effect on the massive sandstone and quartzite, particularly the Tidbinbilla Quartzite, with regard to their suitability as foundations for a major dam structure. The large bluff of Tidbinbilla Quartzite is bounded by faults, and in the process of being downfaulted was broken up by a series of smaller faults and major joints, so that it now consists of a mass of large, loosely fitting blocks. The lower boundary of the outcrop is 180 feet above the river and only 30 feet downstream from the proposed axis; a thin arch structure would abut almost directly on to the outlier. From the evidence of drill hole P-3, the well-jointed quartzite continues to a depth of at least 100 feet below the surface, and would be very unsuitable as an abutment for a 200-foot high thin arch dam. With a concrete gravity dam, stresses are transferred to the foundations only, and at the elevation of the Tidbinbilla Quartzite outcrop, the pressures would be quite low as the structure would not be very high in this area. The pressure exerted by a rock fill dam would be even smaller because of the much larger foundation area over which pressure would be distributed.

The cleaved shale exposed in the core of the anticline is moderately hard in outcrop, but fissile and therefore quite weak. The fissility along bedding planes is due to the very thin laminae, which vary from 5 mm. to paper-thin. In a few places the rock is stronger owing to thicker bedding or to "bonding" of the laminae by weathering or chemical action. The shale also readily parts along cleavage planes, and to a lesser extent along two minor joint systems. The cleavage is parallel to the axial plane of the folds and dips very steeply to the east; the angle between the bedding and cleavage planes ranges from 20° to 90°, depending upon the location with respect to the fold axis. Away from the axis, the measured angle is 35° to 40°, and the shale breaks into small angular pieces, whereas at the crest of the fold the laminae are horizontal and cleavage planes vertical and the rock breaks into rectangular slabs. Cleavage planes and shear displacements are intensely developed near the fold axis, producing a crushed zone where weathering is deeper than elsewhere.

Induration of the shale has in places given rise to upstanding outcrops of hard, brittle, strongly cleaved slate. Slaty rock is also developed along the main east-west fault plane (Plate 3, coordinates 020S, 320E). In view of the upstanding outcrops, it would appear that the depth of weathering is not as great as in the main shale outcrop. The slate associated with the main fault was not encountered in drill hole P-5, the fault being represented by two zones of core loss in medium-grained quartz sandstone at 64 feet and 84 feet from the collar of the drill hole; no broken or crushed zones are present.

River bed.

The core from drill hole P-1 shows many broken zones, particularly between 30 and 60 feet (inclined) from the surface, and several thin zones of crushed, weathered and decomposed bedrock were found. This, together with the poor water pressure test results down to 110 feet, suggested a fault zone below the river, and P-1B was drilled in an attempt to verify this possibility. Again, several broken and crushed zones were disclosed, and poor water pressure test results were obtained between 40 feet and 90 feet. The zone of faulting has not been traced on the river banks, and so its exact location is not known; it is probably parallel to the river at the proposed axis. Silicification of the outcrops low on the east bank presumably is associated with this fault zone.

The rocks encountered in the drill holes below the river were fine-grained sandstone and siltstone near the surface, grading to medium-grained, very hard and strong quartzite at a depth of 30 feet below the river bed. The quartzite is very strong with only occasional weathered joints, and therefore would provide good foundations. The main trouble, due to the faulting, would be the excessive leakage below the dam structure; this is considered in a later section.

West bank.

The west bank consists dominantly of massive, medium to coarse grained, silicified sandstone, with minor developments of finer grained rocks on the lower slopes near the anticlinal axis. Where the anticlinal axis is exposed in outcrop, the core of the fold consists of cleaved shale and siltstone; uphill the rocks higher in the succession crop out at the surface, and these are fine to medium grained, thickly bedded sandstone with thin, shaly partings between beds. Farther uphill, the sandstone becomes coarser and more silicified, and forms a prominent outcrop right up to the Cotter Fault. The fault zone is reflected by a slight depression in the topography, and immediately west of the fault, sericite phyllite is the dominant rock type. The Cotter Fault crops out well above the crest of the dam, however, and cannot affect the foundations of the damsite.

The core of the anticline was investigated by drill hole P-4, which indicated that cleaved shale and siltstone is not as extensive as was thought from the outcrops. The core of the fold 15 feet below the outcrop consists of almost fresh, fine-grained sandstone to siltstone which shows graded bedding, and contains no badly broken zones. The cleaved shale and siltstone bed exposed at the surface is shown by the drill hole to be only about 6 feet thick. A few thin, laminated siltstone beds have been mapped in outcrops and in the axial costean, but cleaved shale and slate is sparse on the west bank.

The foundations of the west bank therefore consist almost entirely of massive quartz sandstone which is highly silicified, and thus very hard and strong, near the Cotter Fault. Jointing is moderately developed in the main outcrop up to the proposed reservoir water level, and increases towards the Cotter Fault. As on the east bank, this has the effect of weakening the abutment for a thin arch structure, but does not greatly affect the foundation conditions for a concrete gravity or rock-fill dam. Weathering extends to some depth along major joint planes, but the outcrops are generally fresh with only a thin weathered zone extending laterally a few inches from each joint plane. Excavation of weathered material will therefore not be very extensive, and will probably only be necessary on the lower slopes where fine grained rocks occur below the soil and scree.

If a rock fill dam is constructed at Site E, it is proposed that the spillway will be excavated in the massive quartz sandstone outcrop 200 feet above the river on the west bank. This excavation will be quite a major operation, and the slope of the resulting rock face will determine the amount of material to be removed. The steepest slope possible, consistent with safety from rock falls, is desired, and this will be determined mainly by the attitude of bedding and jointing. The joint pattern stereogram for this outcrop shows that bedding and most of the major joint planes dip away from the proposed rock face, i.e. in a westerly direction, and so a steep face, with a consequent minimum of excavation, should form a stable spillway wall.

As a result of an inspection of construction materials sources, however, A.D. McConnell and A.D. Hosking of the Snowy Mountains Hydro-Electric Authority suggested in a report (McConnell and Hosking, 1962) that the spillway be excavated at the eastern end of the dam, as the proposed spillway location on the west bank will entail excavation of quartz sandstone to within about 15 feet of the Cotter Fault zone. The excavation on the east bank would be in Tidbinbilla Quartzite in which the dip of jointing is vertical or very steep to the north-east, and so a steep face should form a stable spillway wall in this location also.

LEAKAGE

In an area where competent sandstones and quartzites with a well developed joint system (and consequently a low water table) form the main foundation rocks, leakage is one of the main engineering problems, and can only be controlled by thorough grouting. The water pressure test results shown in Plate 5 indicate that leakage rates are high and are controlled by fractures in the competent rock. Water losses are particularly high in the downfaulted block north of the proposed axis (see results from P-3) and are moderate in the adjacent areas.

The highest recorded leakage rates, 2½ to 3½ gallons per minute (g.p.m.) per foot of NX hole, occur adjacent to the main east-west fault on the east bank. These results were obtained using 5 foot test sections, however, and comparable results would probably have been obtained if 5-foot sections instead of 20-foot sections were used in other holes, particularly P-3. The recorded leakage through the downfaulted block was 1 g.p.m. per foot at pressures ranging from 20 to 36 pounds per square inch (p.s.i.). These pressures were due only to the weight of the water column in the drill rods, however, and in these tests no back pressures were developed, even with the water pump running at full capacity. Tests in the same drill hole gave much higher pressures in the rocks outside the downfaulted block, and water losses were only moderate (½ g.p.m. per foot at 30-50 p.s.i.).

Below the river, water losses were high, even though little pressure could be built up by the pump during the tests. These high losses tend to confirm the presence of a fault zone along the river, and are particularly serious as the assumed leakage path is normal to the proposed wall.

On the west bank, water losses have only been measured in the core of the anticline and in the vicinity of the Cotter Fault. In the anticline, water losses were moderate to high in the fractured and folded sandstone, but where the drill hole penetrated laminated siltstones, the leakage was only 0.4 g.p.m. per foot, even at a pressure of 70 p.s.i.. Leakage through the west bank foundations generally can be expected to be moderate in view of the prevalence of moderately jointed quartz sandstone and quartzite.

Although the Cotter Fault has no bearing upon the foundations of the dam structure, the upstream extension of the fault zone passes through the reservoir area for a considerable distance. Therefore, it could provide an excellent leakage path around the dam structure, and the object of the drill hole P-2, in addition to locating the fault zone, was to determine the possibility of serious leakage along the fault. Although the drill hole did not penetrate right through the fault zone, the results obtained indicate that leakage would not be as serious as expected. Losses were moderate in the quartz sandstone above the water table, but below this high pressures were obtained with low water losses. In fact, it was possible to increase the length of test sections from 5 feet to 20 feet and still obtain pressures as high as 115 p.s.i., with consequent water losses of only 0.3-0.4 g.p.m. per foot. Even from 165 feet to 185 feet where the core recovery was only 50%, the water losses were very low. The drill hole did not penetrate right through to the phyllite on the western side of the fault, however, and further testing will be necessary before the fault zone can be eliminated as a possible leakage path.

Summarising, to prevent serious leakage beneath a dam structure at Site E, an effective grout curtain will be necessary and will have to extend at least down to the present water table in the abutments. From the water pressure tests in P-1 and P-1B, grouting will be necessary to at least 50 feet below the river, and possibly deeper, depending upon the extent of the fault zone below the river. Grout takes can be expected to be high in most of the foundations, particularly in the downfaulted block at the eastern end of the wall. Depending upon the exact location and width of the grout curtain, however, it may be possible to avoid grouting this particularly bad area. Compared with the Bendora Dam, grout takes will be much greater, as the highest water loss recorded during water pressure testing at Site C was 1½ g.p.m. per foot at 50 p.s.i., compared with 3½ g.p.m. per foot at 58 p.s.i. at Site E. At least half of the water pressure tests at Site E recorded a loss greater than 1 g.p.m. per foot, and most of these were at low pressures.

Another possible leakage path from the reservoir exists through the ridge which forms the extension of the eastern abutment. This ridge is drained to the south by Kangaroo Creek and to the north by White Sands Creek, the latter being only 20 or 30 feet lower in elevation than Kangaroo Creek. The top water level of the reservoir will be at least 160 feet above the bed of Kangaroo Creek in its lower reaches, and so there will be a considerable leakage head available over the distance between Kangaroo Creek and White Sands Creek (about ½ mile). Further investigations will be necessary to investigate this possible leakage path.

SEISMIC RESULTS

Three seismic traverses were performed at the damsite with the object of estimating the depth to sound bedrock and obtaining, if possible, quantitative data on the quality of the bedrock. This geophysical survey will be the object of a separate Record, and only the provisional results are given here.

Bedrock profiles

The main seismic traverse was run across the damsite along the proposed dam axis. Four longitudinal seismic velocity ranges were distinguished, namely 1,000 feet per second (ft/sec.), 2,200 to 2,300 ft/sec., 6,000 to 9,000 ft/sec./ and 10,000 to 11,500 ft/sec.; these were correlated respectively with soil, scree and eluvium, very weathered and fractured bedrock, and slightly weathered and fractured bedrock. However, the lack of drill hole data at the time of interpretation - hole P-2 had not been drilled - resulted in emphasis being placed upon the degree of weathering rather than upon the open jointing. Hence, according to the seismic profile, the very weathered zone extends to a constant depth of 60 feet over the west bank, and the layer below this is denoted as slightly weathered. Drill hole P-2 shows, on the other hand, that below 15 feet from the surface, the bedrock is only slightly weathered, except for a 30-foot wide fracture zone where weathering is moderate. It seems quite likely therefore, that the comparatively low seismic velocities obtained are due to fracturing and jointing rather than weathering.

On the west bank, the seismic profile is very regular, and is parallel to the surface practically all the way down the hillside. There is no depression in the profile where the traverse crosses the anticline, indicating the absence of deep weathering and jointing in the core of the fold.

The seismic profile was not obtained directly beneath the river unfortunately, and so the magnitude and extent of the fault zone below the river is still unknown.

On the east bank, the seismic profile shows two distinct depressions which coincide respectively with the cleaved shale in the core of the anticline, and the shear zone farther up-slope. As these features do not show open jointing, the depressions in the profile appear to reflect deeper weathering along the shear zone and in the core of the anticline.

The second seismic traverse was run along the strike of the cleaved shale outcrop on the east bank, the primary object being to obtain an indication of the mechanical properties of the shale. However, in addition to this, a profile was obtained of the boundary between 8,000 ft/sec. and 11,000 ft/sec. layers, and this shows that the depth of weathering decreases in a northerly direction along the shale outcrop.

The third traverse was run along the east bank of the river, but did not reveal any discontinuities in the seismic profile.

The thickness of soil and scree was determined by the seismic method at several seismic stations, and varied between 7 feet and 15 feet.

Rock quality

From measured values of both longitudinal and transverse wave velocities, Poisson's Ratio and Young's Modulus were calculated by the geophysicists assuming a specific gravity for bedrock of 2.55. For the purpose of these calculations, the traverse across the west bank was divided into two sections, and the values of Poisson's Ratio obtained for the upper and lower slopes were 0.30 and 0.26 respectively. For the east bank traverses along the dam axis and the shale outcrop, a value of 0.34 was obtained in each case. Respective values obtained for Young's Modulus in these areas were 2.3×10^6, 3.5×10^6, 2.2×10^6, and 2.7×10^6 p.s.i., but it must be remembered that values obtained by this method are 10-20 % higher than corresponding values determined with static methods. On the other hand, owing to inhomogeneities in the rock (joints, etc.) the figures obtained are not true measures of Young's Modulus and Poisson's Ratio, but are good indications of rock quality.

CONSTRUCTION MATERIALS.

Geological investigations at the damsite indicate that a rock-fill dam will probably be the most suitable type of structure, and the emphasis in the search for construction materials has been on the location of adequate rockfill material, and also material suitable for use as an impermeable core. For a 200-foot high dam with an impermeable core, 1,350,000 cubic yards of rock-fill material would be required, together with 170,000 cubic yards of impermeable core material and 220,000 cubic yards of graded material for use as filters. If a concrete or steel lining on the upstream face is used instead of an impermeable core, only 1,000,000 cubic yards of rockfill would be required (advice from Department of Works officers, Canberra). In the latter case, however, the mechanical properties of the rockfill material are more important as/uneven settlement, with consequent deformation or fracture of the impermeable membrane, must be avoided.

Rockfill.

In the course of a reconnaissance of the ridge which forms the extension of the right abutment of the damsite, several steeply dipping bands of hard,massive quartzite were located; the quartzite would be suitable as rockfill. One bed was mapped by tape, compass and Abney level traverses. It is estimated to be 100 to 150 feet thick, dips steeply to the west, and extends south from White Sands Creek towards Kangaroo Creek. It is exposed on the intervening ridge, but is terminated by a fault between the summit of the ridge and Kangaroo Creek. The probable extension of the bed to the south of the fault has been located 750 feet to the south-east, where it extends down the hillside and across Kangaroo Creek. Sections were drawn across the main outcrop between White Sands Creek and the fault, and 3,750,000 cubic yards of rock was estimated to be obtainable from free-draining quarries. Additional material is available in the outcrop south of the fault.

The outcrop of Tidbinbilla Quartzite on the right abutment of the damsite would also provide a source of rockfill for the dam, though mapping indicates that there is only about 150,000 cubic yards of material available. Suitable material would also probably be available from the spillway excavation, though the volume obtained would only be about 350,000 cubic yards. If McConnell and Hosking's suggestion to locate the spillway on the east bank is adopted, the construction material available from the spillway excavation would include the 150,000 cubic yards of Tidbinbilla Quartzite previously mentioned.

Massive granodiorite porphyry crops out on the right hand side of the Cotter valley between 1 and 1½ miles upstream from the damsite. Outcrops occur from 100 feet above river level almost down to the river, and the fresh rock exposed appears to be suitable for use as rockfill. No estimate has yet been made of the volume of suitable rock available.

In their unweathered condition, both the quartzite and the granodiorite porphyry would produce excellent rock-fill material with good particle shape and grading; the granodiorite porphyry would be easier and less costly to drill than the quartzite. Both areas will require detailed exploration by costeans and diamond drilling to examine uniformity, weathering and overburden conditions, on the basis of which a definite quarry site can be selected in either rock formation.

Impervious material.

The only rock type suitable for use as impervious core material in the Cotter valley is weathered granite; two possible sites for borrow pits have been located, but only one has been examined in detail. The main area under consideration is 3 miles upstream from the damsite on the left hand side of the Cotter valley; it extends from just above river level for a considerable distance up the gently sloping hillside. Scattered fresh or partly weathered granite boulders up to 2 feet across may make excavation slow and expensive, if not impracticable. Exploration by systemmatic pitting, augering and trenching will be required to establish whether this is correct or not. Also, representative samples will have to be tested in the laboratory to ensure the suitability of the weathered granite as impervious core material.

Similar material has been located in the Kangaroo Creek valley about 2½ miles, in a direct line, from the damsite. Benches of decomposed granite occur between the tributaries of Kangaroo Creek; one, without outcropping granite, occurs 1,000 feet upstream from the tributary that marks the boundary between the Ordovician arenaceous rocks and granite. It is estimated that the area of this bench is large enough to yield adequate quantities of material, even if the depth of weathering is no more than 10 feet. Detailed pitting, trenching and laboratory testing will be necessary to prove the suitability of the material. Probably any access road for construction purposes would pass close by the deposit and make its exploitation economical.

Filters

Gravels for use as filters should be obtainable from the extensive river flats upstream from the damsite. These deposits have not been examined, so grid sampling and sizing of the material will be necessary to prove the presence of adequate supplies. It would also be advisable that samples of the gravels be examined megascopically, and possibly microscopically, to ensure their suitability for use in the dam.

CONCLUSIONS

1. The rocks at the damsite are steeply dipping quartzite, silicified quartz sandstone, siltstone, shale and slate, with arenaceous rocks predominating over shale and slate.

2. The metasediments are strongly folded, particularly on the east bank. The plunge of the folds is very shallow and in a south-easterly direction.

3. Faulting and jointing is prominent and is associated mainly with the compressive forces which caused the folding. Joints are open in places to the greatest depth of drilling and would provide ready leakage paths for impounded water; they will require considerable grouting.

4. Present indications are that the Cotter Fault will not cause serious leakage from the reservoir. Further investigations will be necessary to confirm this, however.

5. The soil and scree cover at the damsite is generally only a few feet thick and will not seriously affect the cost of a dam. Depths of up to 15 feet have been recorded near the river, but the cover on the hillsides is considerably thinner.

6. Weathering is generally quite shallow, except in the vicinity of faults and very openly jointed rocks. Much of the quartzite and silicified quartz sandstone is fresh at the surface, but locally weathering extends to considerable depths along joints and broken zones. Weathering is also deeper in the cores of the folds on the east bank.

7. The compressive strengths of the unweathered rocks are high; the foundation rocks are therefore quite strong.

8. A thin arch dam is not feasible, because of the open jointing and consequent weakness of the abutments, particularly on the east bank.

9. The site is suitable for either a concrete gravity dam or a rock-fill dam, though the amount of foundation excavation necessary would be greater for a concrete structure.

10. If a rock-fill dam is constructed, it must be decided whether to use an impermeable earth core or an impermeable membrane of concrete or steel on the upstream face. From the point of view of cost, the latter would be preferable as less rock fill would be required, and graded materials for the core and filters would be unnecessary. Also, if the dam is to be built in two stages, which is quite possible, the use of a concrete or steel membrane would be much more convenient.

11. Adequate supplies of suitable construction materials are almost certainly present within an economical radius from the damsite.

12. Present proposals are for the spillway of a rock-fill dam to be excavated out of massive, silicified quartz sandstone at the western extremity of the dam, though McConnell and Hosking (see list of References), in a report on field inspections of construction materials sources, have suggested excavating the spillway out of the Tidbinbilla Quartzite at the eastern end of the dam, thus avoiding proximity to the Cotter Fault. Excessive excavation to remove the danger of rockfalls in the spillway would not be necessary in either case.

RECOMMENDATIONS

Should it be decided to construct a dam at Site E, additional geological information will be needed on which to base the design of the dam. At this stage of the project, quite large sections of the foundation rocks have not been investigated by diamond drilling, water pressure testing, or costeaning, and while sufficient information has been gained from elsewhere at the site to show that the construction of a dam is feasible from a geological point of view, the remainder of the investigations should be completed in order to provide the fullest possible understanding of the foundation conditions and leakage paths, and an adequate knowledge of the location, volume and properties of available construction materials. The preliminary geological investigation has indicated that a rock-fill structure is best suited to the site, and the following recommendations are directed to obtaining information for the design of a rock-fill dam. The final planning of a design investigation programme can only be done after a decision has been made as to the type of impermeable membrane to be used, though the recommendations apply to both types.

The following design investigations are recommended:

1. The probable fault zone beneath the river should be further examined by drilling and water pressure testing, using a pump of sufficient capacity to develop in the rock at depth a pressure differential equivalent to the pressure which will be exerted when the reservoir is full; the pump must also have the capacity to maintain this pressure, in spite of high water losses, for the duration of the test. (The United States Bureau of Reclamation strongly recommends the use of a centrifugal pump of 250 to 350 gallons per minute capacity against a total dynamic head of 140 to 160 feet. The Bureau of Reclamation does not consider multiple cylinder drill circulation pumps to be satisfactory for water pressure tests because of their low capacity and fluctuating pressures.) Reliable water pressure test results for the zone under the river would materially assist in determining its true nature and importance, likely grout and excavation requirements, and the required depth of the group curtain. Probably one inclined hole 150 feet long would be sufficient for this investigation.

2. Further diamond drilling and water pressure testing should be undertaken between the river and the 3,200-foot contour on the east bank to provide a complete section of the foundation rock sequence. Three inclined or vertical holes, total length 600 to 700 feet, would be required to cover this section. The holes would provide valuable information on the degree of weathering in the core of the anticline, and water pressure testing would show the amount of leakage along the faults already located.

3. The possible east - west fault zone high up on the east bank which passes close to station A36 should be investigated by a costean, and if proved, should be traced along its strike by further costeaning.

4. The overburden in the area around station J on the east bank should be stripped off to facilitate detailed mapping and interpretation of the complex structure of that area.

5. At least one hole must be drilled through the entire width of the Cotter Fault and be thoroughly water pressure tested. The first hole would need to be about 300 feet long, and is considered to be an essential part of the investigations.

6. In order to obtain a complete section of the anticlinal sequence between the river and the 3,200-foot contour on the west bank, the axial costean on the west bank should be extended from its present point of termination at 3,080 feet to an elevation of about 3,160 feet, where the rocky quartzite rib will be encountered. This area should also be tested by diamond drilling and water pressure testing, particularly as no quantitative figures of leakage have yet been obtained for the quartzite on the west bank; this would probably require two inclined holes, each about 150 feet long.

7. An examination should be made of any potential leakage paths that might exist through the ridge which forms the extension of the eastern abutment. The top water level of the reservoir will be more than 150 feet above the bed of Kangaroo Creek to the south of this ridge, whilst White Sands Creek, which flows roughly parallel to the lower reaches of Kangaroo Creek, is only ½ mile to the north and slightly lower. Thus there will be a leakage head of about 150 feet available over a distance of only ½ mile. Surface geological mapping of the ridge must be undertaken, and if any areas are found where leakage is possible, drilling and water pressure testing should be carried out to establish the permeability of the rock. If a strong possibility of leakage exists, two or three holes up to 200 feet deep might be required; these could later be used to make regular measurements of the water table.

8. When the reservoir is full, there will be a possibility of leakage around the edge of the dam high up on the abutments. This will be overcome by extending the grout curtain beyond the ends of the dam. To provide an estimate of the potential leakage (and thus the amount of grouting required), at least one vertical hole should be drilled in each abutment and water pressure tested. The collars of the holes should be between 50 and 100 feet above the proposed top water level of the reservoir, and the holes will need to be about 200 feet deep.

These holes could be used for regular measurements of the depth of the water table after the filling of the reservoir.

9. A programme of seismic work, in conjunction with pattern drilling, is considered necessary to determine the thickness of overburden and the amount of excavation required to provide adequate foundations for the dam. A programme of seismic traverses, totalling 1,500 feet, has already been planned, and will probably be carried out by geophysicists from the Bureau late in 1962.

A series of diamond drill holes set out on a 200-foot grid is recommended for determining the probable foundation level necessary for the dam; the total length of drilling necessary will be about 750 feet.

10. Stripping and costeaning, totalling about 1,000 feet, will be necessary to determine rock conditions in the area of the impermeable membrane, whether it be on the upstream face or in the core of the dam. In the case of an impermeable core, less costeaning will be required as the axial costean already excavated will provide the necessary information on part of the west bank.

11. Pitting, trenching, drilling and laboratory testing will be necessary at the sites of possible borrow pits and quarries in sources of construction materials; details are given in the text of the section on Construction Materials. Seismic traverses have already been planned in the areas of granodiorite porphyry and weathered granite in the Cotter valley.

ACKNOWLEDGEMENTS

The assistance of officers of the Department of Works in arranging the construction and maintenance of the access track from the Forestry road is gratefully acknowledged. They were also responsible for the provision of labourers at the damsite to carry out the programme of costeaning and pitting.

In the course of the investigations, the site was visited on one occasion by Messrs. D.G. Moye and I.L. Pinkerton of the Snowy Mountains Hydro-Electric Authority, and on another occasion by Mr. R. Rhoades, a consultant engineering geologist, late of the United States Bureau of Reclamation. Their appraisals of the site were very valuable and are used extensively in this report.

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APPENDIX 1.

DEFINITIONS OF SEMI-QUANTITATIVE DESCRIPTIVE TERMS.

The following semi-quantitative descriptive terms have been used as much as possible in this report.

Grade Scale.

Very coarse grained - 1mm. to 2mm. in diameter.
Coarse grained - $\frac{1}{2}$mm. to 1mm. in diameter.
Medium grained - $\frac{1}{4}$mm. to $\frac{1}{2}$mm. in diameter.
Fine grained - $\frac{1}{8}$mm. to $\frac{1}{4}$mm. in diameter.
Very fine grained - $\frac{1}{16}$mm. to $\frac{1}{8}$mm. in diameter.

Bedding.

Laminated - less than 10 mm. thick.
Thinly bedded - 10mm. to 100 mm. thick.
Thickly bedded - More than 100 mm. thick.

Hardness

Hard to very hard - impossible to scratch with knife blade.
Moderately hard - shallow scratches with knife blade.
Soft - deep scratches with knife blade.

Percussive strength.

Strong to very strong - cannot be broken after repeated blows with a hammer.
Moderately strong - rock breaks after 3 or 4 heavy blows with a hammer.
Weak - rock breaks after one blow (includes brittle, fissile, friable, plastic and flaky rocks).

APPENDIX 2

PETROGRAPHY OF SPECIMENS FROM UPPER COTTER DAM SITE "E"

by

L.V. Bastian

INTRODUCTION

Five specimens from the Upper Cotter Dam Site "E" were submitted by E.J. Best for petrological examination, as representing a range of interbedded shales, siltstones, and sandstones at that locality. Three of these have the common feature of containing pyrite, both disseminated and in concentrations, and an opinion on the origin of the pyrite was sought.

PETROGRAPHY

R9394 (T.S.7434) is a light grey medium-grained sandstone containing numerous fragments of grey shale and small amounts of disseminated pyrite. Parts of the rock show a patchy colour change to a pale brownish shade. The sample was obtained from D.D.H. P - 1B, at a depth of 92'9".

The thin-section examination shows the sand to be made up of well-rounded quartz grains - a high maturity sand - around 0.3 mm. in size, with scattered grains of shale and silty shale. Feldspars and micas are absent. The quartz is of a wide variety, suggesting a mixed parentage, and the grains have prominent authigenic outgrowths which now occupy all voids and interlock closely. Much of the quartz is heavily strained, and this strain continues into the authigenic material, showing that it took place after lithification, probably as the result of tectonism. The detrital shale fragments have been impacted by the quartz grains, producing contortions in the orientation of their clay particles, and giving a misleading appearance of being patches of matrix; but the impaction, and hence their real nature, is well displayed in the largest fragment: an undoubted pebble of silty shale about 5mm. by 2,5mm. in size.

Pyrite occurs as isolated cubes and clumps of cubes, concentrated mainly within the shale fragments and also within patches of cherty void filling and cherty quartz grains. The brownish parts of the rock are patches in which the pyrite has been oxidised, and occasional partly dissolved or replaced pyrite grains can be seen.

This rock shows the curious paradox of having a very mature and well-rounded quartz sand, indicative of a lengthy transport, associated with unrounded shale and silty shale fragments, whose weakness is well seen by their considerable impaction. Because the unstable fraction is made up of only a single rock type, it probably was derived from very close by - perhaps from a slightly earlier formation in the same sequence.

R9485 (T.S.7800) is a massive, light-grey, medium-grained (6.4 mm.) quartzitic sandstone, which contains angular fragments of dark grey shale aligned in the bedding plane.

It was collected from the surface, whereas R9394 is from a bore core, but in thin-section the two appear to be essentially the same rock type. It is made up largely of moderately to well-rounded grains of quartz and quartzite (about 75%), numerous detrital shale fragments (about 20%), a few grains of fine microcrystalline quartz, and little, if any, genuine clay matrix. The shale is made up of intergrowths of sericite and finely divided quartz, with a few cubes of hydrated iron oxide pseudomorphing pyrite. This rock thus shows the same two obvious phases, and is not properly a greywacke. It can best be called a lithic quartz sandstone or protoquartzite (Pettijohn 1957, p.205), and a similar name would also fit specimen R9394.

<u>R9395 (T.S. 7435)</u> is a tough, pale grey protoquartzite with a granular sugary appearance. It contains numerous clots of pyrite crystals ranging from about 1 to 5 mm. in diameter. This sample was obtained from D.D.H. P - 1, at a depth of 113'4".

The main constituent is again a well-rounded mature quartz sand which has developed authigenically so as to interlock closely. A few well-rounded grains of zircon are present, but feldspars and micas are, as before, absent. Many of the interstices are filled with a chlorite (very low birefringence, positive relief, length-fast, non-pleochroic), probably clinochlore. In addition to this void filling, some patches of this mineral take instead the form of detrital grains, and suggest the same conclusions as for the previous specimens, viz: that these were sand-sized particles of shale which have been incorporated into the sediment and have then been squeezed out to fill adjacent voids, giving the erroneous appearance of being a clay matrix. However, whereas in the previous specimens this material was represented by common shale minerals, it is here represented by chlorite. This may indicate that the rock had here been subjected to a low grade of pressure metamorphism, and the presence of occasional grains of epidote within the chlorite patches supports this idea. However, an addition of Mg to the rock must also be envisaged, and so a better explanation may be simply that the chlorite was primary; derived from a different source to the lithic material seen in the other specimens.

Pyrite cubes are concentrated into several clumps, and their euhedral form has been exerted at the expense of other minerals. Several well-defined thin sinuous lines of pyrite are also developed, running in between grain contacts among the quartz. These appear to represent channelways for sulphide solutions, and at least one of the clumps is located at the node of a tightly looping seam. This suggests a control for the initiation of the clumps. It seems that clumps started to develop at points along these channels, after which the continued growth of pyrite progressed as a matter of course from those centres, by virtue of its strong power of crystallisation.

<u>R9393 (T.S. 7433)</u> was obtained from D.D.H. P - 1B, at a depth of 28'4". It is a buff-grey massive mudstone, without any distinct cleavage, which contains irregular patches of white material having a bleached appearance. These patches show a marked zonation, from a central zone laden with small pyrite crystals to outer zones of mauve and brick-red colours.

There may be one or two secondary red rings, and then the colour drops off rapidly to the background buff colour.

The thin-section examination shows that the major part of the material is a fine mesh of well oriented kaolinite crystals; presumably this was recrystallised from originally finer mud. Minor amounts of silt-sized particles of quartz and sericite are also present. The pyrite is located entirely within the white zone, and takes the form of a scattering of perfect cubes, each rimmed with a diamond-shaped growth of small muscovite flakes, suggesting a "pressure-shadow" effect. The kaolinite here is quite colourless. Then follows a narrow zone just within the red zone, in which the pyrite has been completely dissolved away, leaving mainly cubic cavities; some of these have been subsequently filled by quartz. Enrichment with hydrated ferric oxide begins sharply, and in this zone the pyrite cavities are occupied by pseudomorphing iron oxide, possibly goethite. Outwards from the most heavily oxidised zone, the iron oxide impregnation decreases rapidly and is paralleled by a steady decrease in the numbers of cubical pseudomorphs, indicating that there was here a definite patch of pyrite. The background buff rock is seen as a mildly ferruginised kaolinite intergrowth (slightly pleochroic due to iron impurities) without any pyrite pseudomorphs. It is noted that the muscovite "pressure-shadows" were developed around the pyrite under the pressure of the mild metamorphism seen here, they indicate that pyrite enrichment preceded the metamorphism. The oxidation was a much later weathering process which had begun to advance into the strongly reduced pyrite zone, in the course of which, because of the higher percentage of iron in that zone, increasing amounts of ferric oxide were produced.

R9486 (T.S. 7801) is a light grey, massive, fine siltstone, with a marked banding caused by numerous compositional changes. It is heavily faulted on a small scale, but the fractures are closed and firm, and associated with this is small-scale folding of incompetent type.

In thin-section the rock is seen to be made up of a fine "flour" of detrital grains with a mean grain-size averaging about 0.01 mm. Quartz makes up 65-70% of the sediment, but fine flakes of muscovite and golden brown montmorillonite are abundant, and form a distinctive lattice-like texture. The darker bands are made up of the same sized material, but contain higher proportions of montmorillonite. There are also numerous patches of opaque iron oxides and leucoxene, and some unidentifiable material. The fracturing, folding and mineral assemblage suggests that this rock has, like the others, suffered a mild degree of regional metamorphism.

General Comments

The rocks examined here are of high maturity, and are not by any means typical of the geosynclinal environment, although they were presumably laid down in some part of a geosyncline. The particular feature to be noted here is the inclusion of incompetent shale fragments in sand which had undergone lengthy transport; this suggests a paralic environment lacking a heavy supply of immature sediment from nearby highlands.

This evident paucity of supply is further supported by marked changes of sediment type, and contrasts with the characteristic thickness and homogeneity of formations laid down under conditions of heavy supply.

The pyrite channelways and the occurrence of pyrite as distinct concentrations, show that it entered these rocks from elsewhere. The bright colour banding in specimen R 9393 is the product of oxidation of pyrite under normal weathering conditions.

APPENDIX 3.

GEOLOGICAL LOGS OF DIAMOND DRILL HOLES AT SITE E.

In the following drill core logs, the term greywacke is used quite frequently. Petrographic examination of selected specimens, however, has shown that rocks with the field name of greywacke are not true greywackes, but are impure sandstones, or sandstone with much impacted shaly material in the matrix. Therefore, the term has not been used in the report, though it persists in these drill core logs, most of which were drafted before the results of the petrography were available.

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GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER COTTER DAM SITE "E"   HOLE NO P 4   R L 2995'

LOCATION W. BANK OF RIVER, 33' AT 259° M. FROM PEG C.   ANGLE FROM HORIZONTAL 30°   DIRECTION 86° M.

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION	DEPTH & SIZE OF CORE	LOG	LIFT & CORE RECOVERY	STRUCTURES JOINTS VEINS SEAMS FAULTS CRUSHED ZONES	
Colluvium	Sand, gravel and scree.	NX 8' 6"				NX casing
Clayey sand.	Red-brown sand and clay with occasional fragments of quartzite.	20' 0"				
Sandy clay & silt	Red-brown, grading to grey	21' 0"				
Sand and pebbles.	Coarse sand and pebbles with some clay.	23' 1"				
Gravel.		29' 10"				NX core barrel.
Fine grained quartz greywacke.	Greenish colour, yellow when weathered. Bedding at 25°-30° to core. Numerous joints coated with black iron oxide - irregular and along bedding. Core lengths up to 5".	30' 7"				Full water return.
		31' 10"			Fairly broken rock.	
		33' 9"				
		34' 2"			Fairly broken rock.	
		35' 0"				
	Weathered greywacke-broken	36' 4"		6"	Clayey zone	
Coarse grained qtz. greywacke.	Massive; core lengths up to 8". Joints stained with black iron oxide.	39' 1"			Joints at 20°-35° to core. Irregular quartz veins up to 6 mm. wide.	
Fine quartz greywacke.	Fragments of silt and clayey material present.	40' 10"		45%	Clayey zone washed out for 1 foot.	
Fine quartz greywacke and siltstone.	Shows sedimentary structures.	42' 2"			Graded bedding at 45°-50°	
	2 core lengths 2" long. Remainder very broken and weathered — in part clayey.	44' 0"			Numerous joints at 45°-60° and 90° to core.	
		44' 4"			Shale band.	
		45' 0"			Fine qtz. veining present.	
	Core lengths to 4". Graded bedding at 60°. Bands at 45' 9" & 46' 3" showing coarser qtz. - 1mm.	46' 9"			Joints at 45°-60° and 90°. - stained black, red and yellow.	
Fine quartz greywacke?	Broken fragments only.	49' 5"		6" 5"	Sheared and decomposed with some clay.	
						No water return.

DRILL NO 6 - A - 17
TYPE BOYLES.

DRILLER L. TOMIC
COMMENCED 22 - 7 - 61
COMPLETED 15 - 8 - 61

Core recovery 100% except where indicated as % recovery.

LOGGED E. J. BEST.

VERTICAL SCALE 5' = 1"

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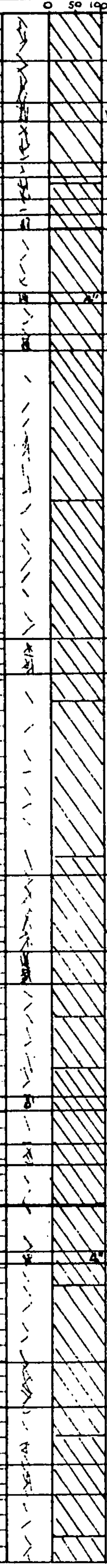
GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER COTTER DAM SITE "E"
HOLE NO. P. 1.
R.L. 2995'
LOCATION W. BANK OF RIVER, 33' AT 259° M. FROM PEG C.
ANGLE FROM HORIZONTAL 30°
DIRECTION 86° M.



ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION	DEPTH & SIZE OF CORE	LOG	LIFT & CORE RECOVERY 0 50 100%	STRUCTURES JOINTS VEINS SEAMS FAULTS CRUSHED ZONES	
Fine to medium grained quartz greywacke.	Core lengths up to 4". Bedding at 50° - 60°.	51' 6"			Joints commonly at 60°.	No water return for rest of hole.
	Broken with occasional fragments up to 2" long.	52' 10"			Joints at 60°.	
		53' 6"			Very broken & decomposed rock.	
		54' 10"				
		55' 4"				
	Core lengths up to 6".	56' 0"			Broken fragments.	
		56' 6"				
		57' 0"				
		59' 0"		4"	Broken and partly decomposed.	
		60' 4"				
		60' 10"			Sheared & decomposed rock.	
Medium grained quartzite.	Massive, hard rock with core lengths up to 16". Spots and fragments of shale occur throughout, though they are more frequent from 72' downwards. These spots are irregular and up to 1" in lengths Spots of pyrite also occur throughout. They tend to be equi-dimensional, and up to 1" in diameter. They consist of clusters of minute crystals Quartz veins are also present being up to ¼" wide. Some contain disseminated pyrite.	70' 2"			Joint at 45°. Joint at 45°. Black stained joints at 60°, and at 65° in opposite direction. Joints at 40° and 50°.	
		71' 4"			Zone of broken fragments.	
		77' 10"			Joint at 60°. Joint at 45°.	
	From this point downwards, joints appear to be fairly open, quartz crystals often being present in open joints.	80' 4"			Crushed and weathered fragments. Jointing is prominent and irregular.	
		81' 4"			Crushed, sheared & decomposed zone with shale fragments.	
		85' 0"			Joints at 40° and 60° in opposite directions.	
		85' 5"			Zone of broken rock.	
		86' 6"			Joint at 65°.	
		87' 2"			Zone of broken rock.	
		88' 5"			Small broken zone along joint plane at 65°. (1" wide)	
		90' 0"			Joints at 60° and 70°.	
				4"	Crushed, clayey zone.	
		93' 6"			Joint at 55°. Joint at 25°. Joint at 55°.	
		95' 0"			Broken core, fragments stained red-brown.	
		96' 10"			Joint at 90°. Joint at 15°.	
		97' 10"			Broken pieces from 1" to 3" long.	
					Joint at 55°. Joint at 65°.	

DRILL NO. 6 - A - 17
TYPE BOYLES
DRILLER L. TOMIC
COMMENCED 22 - 7 - 61
COMPLETED 15 - 8 - 61

LOGGED E. J. BEST
VERTICAL SCALE 5' = 1"

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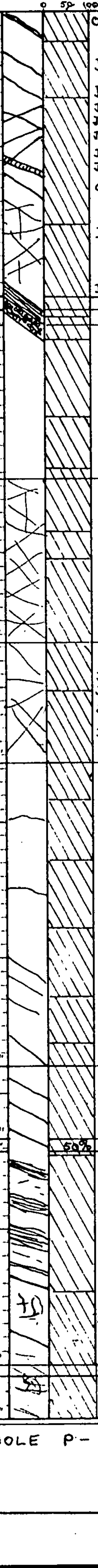
GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER COTTER DAM SITE "E"
HOLE NO P1.
R L 2995'

LOCATION W. BANK OF RIVER, 33' AT 259° M. FROM PEG C.
ANGLE FROM HORIZONTAL 30°.
DIRECTION 86° M.



ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION	DEPTH & SIZE OF CORE	LOG	LIFT & CORE RECOVERY	STRUCTURES JOINTS VEINS SEAMS FAULTS CRUSHED ZONES
Medium grained quartzite - slightly weathered.		110' 6"			Open, clay-filled joint at 30°. Joint at 30°. Joint at 30°. Joint at 45°. Joint at 45° with thin shale band. Joint at 45°. Joint at 60°. Joint at 45 with clay seam ¼" wide. Clayey joint at 60°. Irregular joints. Joint along silty band at 45°
Shale bands	Thin alternating bands at 35°.	111' 0"			
Clayey material	Very decomposed and crumbly.	111' 7"			
Fresh Medium grained quartzite.	Very hard, almost pure quartzite. Core lengths up to 16". Pyritic spots present in abundance down to 115'. A few shale inclusions occur at about 116'.	117' 2"			
Highly silicified greywacke.	Moderately broken along irregular joints. Core lengths up to 4".	123' 4"			
	Core lengths upto 7".	127' 9"			Joint at 15°. Joint at 40°. Joint at 45°. Joint at 70°.
Fresh medium grained quartzite.	Very hard, almost pure quartzite. Core lengths from 4" to 16", mostly 12"-16". No pyrite or shale spots.	138' 10"			Very little jointing. 40° joints. Joint at 45°.
	Same hard quartzite, but with occasional pyrite and shale inclusions.	141' 7"			Joint at 40°. Joint at 60°.
Clay.	Soft, decomposed clay.	142' 2"		50%	
Compact siltstone, fresh.	Dark grey — black in colour. Bedding at 30° - quite regular. Jointing and shearing prominent parallel to bedding and irregular. Planes of shear shiny and slickensided. Pyrite is disseminated throughout, occasional clusters being present. Pyrite in shear zones is flattened and sheared by movement.	150' 0"			Shear zone. Shear zone. Shear zone. Shear planes. Quartz veining. Zone of re-cemented breccia. Bedding and joint at 25°.
		152' 0"			Quartz veins

END OF HOLE P-1.

DRILL NO 6-A-17
TYPE BOYLES

DRILLER L. TOMIC
COMMENCED 22-7-61
COMPLETED 15-8-61

LOGGED E.J. BEST.

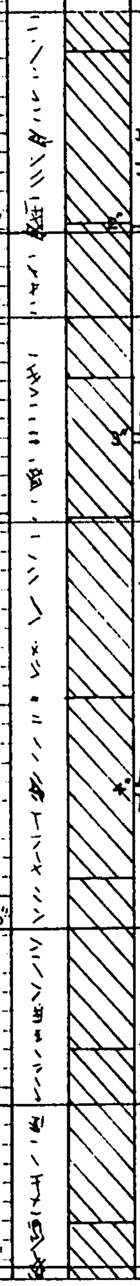
VERTICAL SCALE 5' = 1"

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER COTTER DAM SITE "E" HOLE NO. P-18. R.L. 2995'

LOCATION 37·5' FROM D IN DIRECTION 23° M. ANGLE FROM HORIZONTAL 50° DIRECTION 265° M.



ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION	DEPTH & SIZE OF CORE	LOG	LIFT & CORE RECOVERY 0 50 100%	STRUCTURES JOINTS VEINS SEAMS FAULTS CRUSHED ZONES	
Soil		NX 7' 0"				NX casing
Coarse sand.		10' 7"				
Boulders and gravel	Deposited by the river.	16' 9"				
Compact fine greywacke and siltstone. Weathered irregularly in patches.	Grey-green when fresh, brown-yellow when weathered. Joints are at 30°, 45° and irregular, and are stained brown and/or black.	22' 7"			Bedding at 75°. Joints at 45°. Joints at 45°. Sheared & decomposed zone	NX core barrel. Full water return.
Medium grained quartz greywacke - weathered.	Compact rock. Pieces of core up to 4" long.	24' 10"			Joint at 45°. Parallel bands of weathering or possibly bedding at 90°.	
Fine grained greywacke to siltstone. Weathered in irregular patches.	Core lengths up to 5".				Thin joints at 80°-90° containing a little pyrite. Irregular cherty zone with much disseminated pyrite. Broken zone. Bedding at 60°-70°.	
	Irregular coarse patches and bands occur from here to 41'. These have curved boundaries, shown up by weathering — probably occur due to slump folding. Silicification increases from 35' downward.	40' 10"			Bedding ? at 60°. Joints at 45°. Bedding at 60° } strikes parallel, Joint at 30° } opposite dips. Shear zone with decomposed rock. Coarse zone at 80° - bedding? Joint at 50°. Joints at 30°. Joint at 60°.	
Fine to medium grained quartz greywacke. Irregular weathered patches.	Bedding at 60°-70°.	45' 5"			45° joint. Joints at 30° and 60°. Joints at 60° and 70°. Joint at 40°.	
Fine grained greywacke and siltstone. Weathered in irregular patches.		49' 7"			Broken zone. Joint at 70°. Joint at 65°. Broken zone. Joints at 60° and 20°.	

DRILL NO. 6-A-17
TYPE BOYLES
DRILLER L. TOMIC
COMMENCED 18-8-61
COMPLETED 1-9-61

LOGGED E. J. BEST

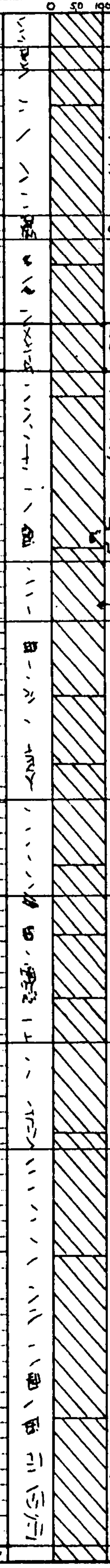
VERTICAL SCALE 5' = 1"

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER COTTER DAM SITE "E" HOLE NO P-1B R L 2995'.

LOCATION EAST BANK OF RIVER, 37·5' FROM D IN DIRECTION 23°M. ANGLE FROM HORIZONTAL 50°. DIRECTION 265°M.



ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION	DEPTH & SIZE OF CORE	LOG	LIFT & CORE RECOVERY	STRUCTURES JOINTS, VEINS, SEAMS FAULTS CRUSHED ZONES	
				0 50 100%		
Fine to medium quartz greywacke.	Irregularly weathered.	51' 1"				
Siliceous siltstone.	Broken and crushed.	51' 10"				
Hard, fresh, medium quartz greywacke. Weathered along joints. Occasional silty interbeds.	Core lengths up to 12". Bedding at 50°. Contains dark fragments up to 6 mm. in size scattered irregularly throughout zone. Pyrite inclusions from 55' 6" to 56' 6".	56' 6"			Joint at 50°. Joints at 45° and 40°.	
	Sheared and crushed siltstone.	57' 3"			Clay at junction with greywacke.	
	Siltstone grading gradually back to medium quartz greywacke at 59' 8".	60' 0"			Joint at 50°. Joint at 75°.	
		61' 7"			Moderately broken zone - fragments 1" to 4" core lengths weathered to orange-brown.	
	Fresh rock with dark fragments.	67' 8"			Joint at 30°. Joint at 60°. Joint at 90°. Original silty band sheared and decomposed.	Water lost at 64' 2". No water return.
Fine qtz. greywacke and siltstone.	Graded bedding at 60°. Core lengths up to 10".	69' 7"			8mm. pyrite inclusion.	
Medium grained, massive, fresh quartzite.	Core lengths up to 8". A few angular dark spots are present.	75' 5"			Broken zone - silty interbed. Irregular open jointing. Broken zone. Joint at 60°.	Caving at 74'.
Fine to medium grained quartzite	Thinly bedded with occasional dark fragments present. Thin cherty bands interspersed throughout.	78' 6"			One or two pyrite inclusions present.	
Siltstone.	Graded bedding, some interbeds containing quartz.	83' 3"			Quartz vein 1½ cm. wide. Crushed zone. Crushed and broken zone. Bedding at 65°.	
Medium grained quartzite.	Graded bedding to 84', massive thereafter.	86' 8"			Bedding at 70°. Moderate jointing - core from 1" to 4" long.	Could not get rods past 74' because of caving.
Medium to fine grained quartz greywacke and quartzite. Weathered adjacent to joint planes.	Hard, massive rock. Core lengths from 3" to 8". Blue grey when fresh, weathering to brown. Clusters of pyrite occur scattered throughout - also pyrite occurs disseminated throughout the rock. Irregular, dark, angular fragments occur from 92' downwards.	BX 99' 6" 100' 0"			Irregular quartz veining occurs. Joint at 30°. Joint at 30°. Joint at 25°. Joint at 30°. Broken zone. Joint at 40°. Broken zone. Irregular open jointing - approx. 30° and 90°. Joint at 35°. Broken & weathered zone.	Reduced to BX. Full water return. Slump folding in medium quartz greywacke which contains a 2" band of more felspathic material - dips at 60°. Angular, dark fragments occur adjacent to slumping features.

DRILL NO 6-A-17

TYPE BOYLES

DRILLER L. TOMIC

COMMENCED 18-8-61

COMPLETED 1-9-61

LOGGED E. J. BEST

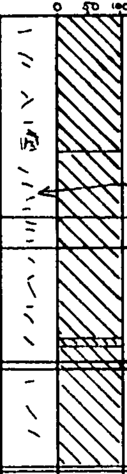
VERTICAL SCALE 5' = 1"

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER COTTER DAM SITE "E" HOLE NO P-1B R L 2995'

LOCATION EAST BANK OF RIVER, 37·5' AT 23°M FROM PEG D. ANGLE FROM HORIZONTAL 50° DIRECTION 265°M.

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION	DEPTH & SIZE OF CORE	LOG	LIFT & CORE RECOVERY 0 50 100%	STRUCTURES JOINTS, VEINS, SEAMS, FAULTS, CRUSHED ZONES	
Medium to fine grained quartzite and quartz greywacke	Continuation of bed from 86' 8".	105' 4" 106' 1" 109' 1" 111' 10"			Numerous dark fragments. Bands of siltstone from ¼mm. to 2½cm. thick. Graded bedding at 45°. Joints at 30°. Silty and argillaceous bands 1-10mm. thick. Dip at 35°. Thin crushed clay band at 109' 3". Zone ½" thick Joint at 30°.	Full water return.
	END OF HOLE. P-1B					

DRILL NO 6-A-17
TYPE BOYLES.

DRILLER L. TOMIC
COMMENCED 18-8-61
COMPLETED 1-9-61

LOGGED E. J. BEST

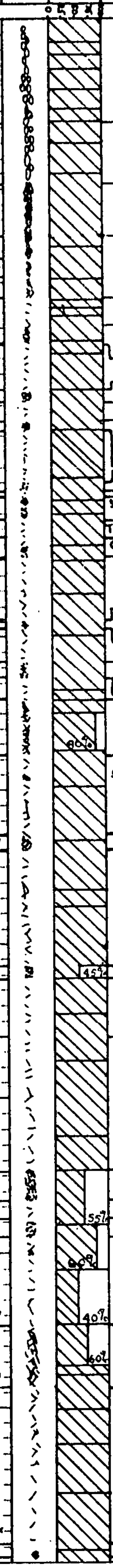
VERTICAL SCALE 5' = 1"

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER COTTER DAM SITE 'E'
HOLE NO P-2
R.L. 3329'
LOCATION 17' FROM A 46 ON BEARING 206°M.
ANGLE FROM HORIZONTAL 45°
DIRECTION 270°M.

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION	DEPTH & SIZE OF CORE	STRUCTURES JOINTS VEINS, SEAMS FAULTS CRUSHED ZONES	
Fine grained quartz greywacke	Fragments of boulders and scree material, intermixed with clayey soil.	NX 6' 9"		
	Fragments of scree material.	10' 7"		NX casing to 10'.
Very weathered, fine grained, silicified q'tz. greywacke.	Brown clay intermixed with small (< 1") fragments of quartz greywacke.	14' 0"		
Weathered, fine grained, silicified quartz graywacke.	Fragments of quartz greywacke up to 1½" long with some inter-mixed clayey material. Mainly clayey material	15' 5" 16' 8" 18' 0"		
Slightly weathered, medium to coarse grained, silicified, quartz greywacke.	Very hard rock with irregular quartz veining scattered throughout. Jointing at 45°, 60° and irregular. Joints stained brown and black. Occasional shale fragments are contained in the greywacke.	20' 0" 21' 1" 24' 0" 24' 10" 26' 0" 30' 0" 32' 5" 33' 6" 34' 10"	Broken zone – ¼" to 3" fragments. Broken zone – 1" fragments. Crushed zone – clay to ¼" fragments. Originally fine grained silty material. Broken – clay to 1" fragments ⅛" fragments to 2" core lengths Thin silty band at 80° to core. Clay to 1½" fragments	No water return from 18' 10" to 32' 0". Much caving in this zone – resulted in having to cement hole down to 31' 1", in an effort to prevent caving. Intermittent water loss.
Slightly weathered fine grained, silicified, quartz greywacke.	Occasional thin medium grained bands occur. Shale fragments occur throughout. Joints are irregular and stained brown and black. Irregular quartz stringers occur scattered throughout. Core lengths are generally between 2" and 4". – maximum of 5".	38' 11" 41' 8" 42' 7" 44' 0" BX 47' 8" 52' 11" 53' 10" 61' 4" 62' 2" 66' 0"	Shear zone 5" wide. – clay to ½" fragments. Moderately broken zone – clay to 1½" core lengths. Broken zone – clay to 1" core lengths. Small shear zone 3" wide. Broken zone – clay to 1" fragments. Shear zone – clay to ¼" fragments. Thin shaly bands at 35° to core.	Hole caved badly between 41' and 44'. Resulted in reducing hole size to BX from 44' 1" downwards. 70% water return.
Moderately weathered, silicified, fine grained quartz greywacke to siltstone.	Some patches of fresher rock occur, green in colour, though weathered yellow for up to ¼" from joints and quartz veins. In weathered rock, joints and veins weathered even more to a reddish colour. Core lengths generally 1"–3", with maximum of 5". Jointing and quartz veining irregular. Joints stained red, brown and black.	74' 8" 76' 8" 77' 9" 79' 0" 84' 8"	Sheared and decomposed fragments with clay 3" shear zone. Some clayey material recovered.	No water return from 66' 1" to 74' 8". Full water return.
Slightly weathered, fine grained, silicified quartz greywacke.	Mainly fairly broken up to 93' 6", after which core lengths up to 13" occur. Jointing at 45°, 60° and irregular. Irregular quartz veins and stringers occur throughout. Rock is weathered yellow adjacent to joints and veins up to 95', after which very little weathering occurs. Joints stained yellow, brown and black.	88' 8" 98' 10" 99' 7"	Broken zone – ½" to 2" fragments with some clay. Broken zone with some clay.	



DRILL NO 6 – A – 16
TYPE BOYLES
DRILLER L. TOMIC & J. GRECH
COMMENCED 7 – 10 – 61
COMPLETED 7 – 11 – 61
LOGGED E. J. BEST
VERTICAL SCALE 10' = 1"

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER COTTER DAM SITE 'E' HOLE NO P-2 R.L. 3329'

LOCATION 17' FROM A 46 ON BEARING 206° M. ANGLE FROM HORIZONTAL 45° DIRECTION 270° M.

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION	DEPTH & SIZE OF CORE	LOG	LIFT & CORE RECOVERY 0 25 50 75 100	STRUCTURES JOINTS VEINS SEAMS FAULTS CRUSHED ZONES	
		108' 0"			Quartz veins up to ¼" wide.	Full water return.
Slightly weathered, silicified, very fine quartz greywacke to siltstone.	Grey-green in colour. Irregular quartz veining, some of which re-cements brecciated rock. Core lengths 1" to 6", commonly 4" to 6".	122' 6"			Banding at 20°.	
		123' 6"		50%	Shear zone with fragments up to 1".	
		134' 6"			Banding at 80°. Banding at 50°.	
		135' 0"			Sheared fragments partly decomposed to a white clay.	
		137' 9"				
		139' 10"			Shear zone — clay to 1" fragments.	
		145' 5"			Banding at 40°.	
		147' 4"		15%	Crushed zone - most of clay washed away.	
		149' 0"			Banding at 60°.	
Almost fresh, fine grained quartz greywacke.	Grey-green in colour. Irregular quartz veining	151' 0"				
Almost fresh, very fine grained quartz greywacke to siltstone. Silicified.	Irregular quartz veining. Core lengths 1" to 6" - commonly 4".	170' 6"		30%	Moderately broken core pieces.	
		171' 10"			Crushed and decomposed zone - clay to ½" fragments.	
				35% 40% 50%	Siltstone with cleavage at 65°. Crushed and clayey material. Core recovered is moderately broken with joints commonly at 90° and 40° to core. Banding at 45°. Banding at 45°.	80% water return. Full water return. No water return. 50% water return.
	END OF HOLE	P-2			198' 0".	

DRILL NO 6 - A - 16

TYPE BOYLES

DRILLER L. TOMIC & J. GRECH

COMMENCED 7-10-61

COMPLETED 7-11-61

LOGGED E. J. BEST

VERTICAL SCALE 10' = 1"

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER COTTER DAM SITE 'E' HOLE NO P-3 R.L. 3220'

LOCATION 53' FROM PEG A.7 ON BEARING 161° (EAST BANK) ANGLE FROM HORIZONTAL 45° DIRECTION 010° M.

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION	DEPTH & SIZE OF CORE	LOG	LIFT & CORE RECOVERY	STRUCTURES JOINTS VEINS SEAMS FAULTS CRUSHED ZONES	
				0 50 100%		
Soil	Dark brown in colour.	0' 11"				NX casing.
Sandy clay with fragments of scree	Scree fragments of weathered quartz greywacke.	NX 3' 10"				
Medium grained quartz greywacke. Weathered to light brown colour	Massive with core lengths up to 12". Contains small fragments of mica.	27' 11"			Irregular quartz veins up to $\frac{1}{2}$" wide for first 2'. 60° joint showing slickensides. Bedding at 40°. 90° joint. 60° joint. 40° joint. Blebs of pyrite present. 3" of soft decomposed rock. 4" of broken rock. 8" of broken rock. 3" clay zone 3" decomposed zone. Irregular quartz veins up to $\frac{1}{4}$" wide from 22' 8" 60° joint.	NX core barrel.
Fine to medium qtz. greywacke.	Weathered. Contains thin silty bands which are not so weathered.	30' 3"			Graded bedding at 45°.	
Fine to medium quartz sandstone. Weathered except for a few almost fresh patches.	Core lengths up to 14".	47' 4"			Occasional irregular quartz veins up to $\frac{1}{8}$" wide. Jointing prominent at 50° and irregular. 70° joint. 40° joint. 70° joint.	Drilling water lost at 32' 6" and throughout the remainder of the drill hole.
Medium to coarse grained greywacke. Moderately weathered with occasional patches of almost fresh rock.		73' 0"			Occasional small blebs of pyrite. Open cavity containing terminated quartz crystals up to $\frac{1}{8}$" long. Quartz vein $\frac{1}{4}$" wide in moderately broken zone. 60° joint. 65° joint. 55° joints. 6" decomposed zone - originally a silty band. 60° joint. 50° joints. 65° joint.	
Fine to medium quartz sandstone. Moderately weathered.	Core lengths up to 10". Irregular quartz veining throughout the zone. Jointing irregular.	88' 0"			Very broken zone - was a silty band. 3" siltstone band. Decomposed silt band (2" wide) 1' of massive quartz veining Broken zone. 2" silty band. 2" silty band - bedding at 53°.	4" of core lost.
Weathered siltstone.	Graded bedding at 40°.	90' 0"			3" decomposed zone. 5" decomposed zone.	
Fine to medium quartz sandstone.	Weathered.	91' 11"			Irregular quartz veins up to $\frac{1}{2}$" wide.	
Fine qtz sandstone	Weathered.	93' 4"			Quartz veining.	
Laminated siltstone - weathered.	Bedding at 45°.	95' 1"			Moderately broken. Decomposed along joint planes.	
Fine to medium quartz sandstone	Weathered.	97' 0"			Occasional quartz stringers. 5" laminated silt band - 45° bedding	
Fresh fine grained quartz sandstone.	Contains disseminated pyrite.					

DRILL NO 6-A-17

TYPE BOYLES.

DRILLER L. TOMIC.

COMMENCED 7-9-61.

COMPLETED 20-9-61

LOGGED E.J. BEST.

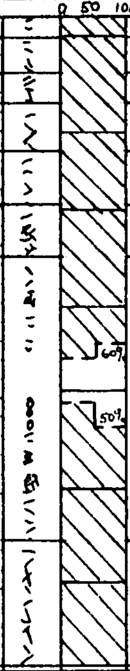
VERTICAL SCALE 10' = 1"

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER COTTER DAM SITE 'E' HOLE NO P-3. R.L. 3220'

LOCATION 53' FROM PEG A 7 ON BEARING 161° M (EAST BANK) ANGLE FROM HORIZONTAL 46° DIRECTION 010° M.



ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION	DEPTH & SIZE OF CORE	LOG	LIFT & CORE RECOVERY	STRUCTURES JOINTS, VEINS, SEAMS, FAULTS, CRUSHED ZONES	
		101' 1"				
Medium-coase quartz greywacke.	Slightly weathered	102' 11"			Veined by quartz. Contains disseminated pyrite.	
Siltstone.	Moderately weathered.	104' 4"			Brecciated.	
Medium grained quartz sandstone.	Moderately weathored.	107' 0"			5" of massive quartz veining.	
Fine to medium quartz greywacke.	Contains bands of laminated siltstone. Slight weathoring.	110' 0"				
Medium grained qtz. sandstone.	Slight to moderate weathering.	112' 8"			Thin silty bands in broken zone. Quartz vein 3/4" wide.	
Laminated siltstone and fine quartz greywacke. Moderately weathered.	Graded bedding at 45°.	127' 4"			3" decomposed shear zone. Zone of brecciated siltstone recemented by quartz. 5" broken zone. Bedding at 45°.	117' 0" to 117' 9" — 60% core recovery. 117' 9" to 120' 0" - no core. 120' 0" to 121' 3" - 50% core recovery.
Fine to medium quartz greywacke. Fresh except adjacent to joints.		134' 0"			Occasional quartz stringers. 70° joint. 50° joint. 45° joint.	
	END OF HOLE P-3.					

DRILL NO 6-A-17

TYPE BOYLES.

DRILLER L. TOMIC

COMMENCED 7-9-61

COMPLETED 20-9-61

LOGGED E. J. BEST

VERTICAL SCALE 10' = 1"

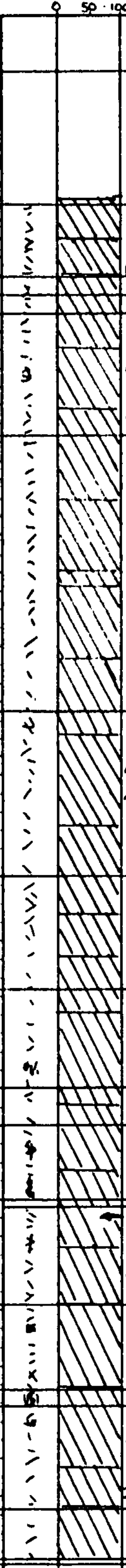
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER COTTER DAM SITE 'E' HOLE NO P-4 R L 3013'.

LOCATION 33' FROM PEG E IN DIRECTION 312°M (WEST BANK) ANGLE FROM HORIZONTAL 30° DIRECTION 227°M.

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION	DEPTH & SIZE OF CORE	LOG	LIFT & CORE RECOVERY	STRUCTURES JOINTS VEINS SEAMS FAULTS CRUSHED ZONES	
				0 50 100%		
Soil.		NX 3' 0"				NX casing.
Quartz greywacke and siltstone boulders.		10' 3"				NX core barrel.
Laminated siltstone. weathered along bedding planes	Shows graded bedding at 75° and sedimentary structures.	14' 0"			Moderately broken. - core lengths up to 2". 6" zone of decomposed rock.	
Massive siltstone.	Irregular cherty patches.	15' 0"			Pyrite cubes present.	
Laminated siltstone.	Graded bedding at 25°. Fresh.	16' 0"				
Fresh fine to medium grained quartz greywacke.	Core lengths up to 10". Small cherty patches present.	22' 9"			45° joint. 20° joint. 9" broken silt layer. Pyrite cubes present in cherty patches.	
Fresh fine quartz greywacke to siltstone.	Graded bedding indicating slumping and folding throughout the zone. Core lengths to 8". No badly broken zones.	37' 6"			30° joint. 30° joint. 60° joint. 30° joint. 55° joint. 60° joint. Bedding at 75°. Small shear zone.	
Fine to medium fresh quartz greywacke and quartzite.	Massive with core lengths up to 11".	46' 6"			45° joints. 45° joints. 45° joints. 2" silty band.	
Fresh fine greywacke to siltstone	Graded bedding at 60°. Core lengths up to 14".	52' 7"			Moderately broken to 49' 0". 50° joint. 3" shear zone. Small shear zone.	
Laminated siltstone moderate weathering.	Bedding at 55°. Core lengths up to 8".	58' 0"			Irregular jointing - tendency to part along bedding planes. 3" shear zone.	
Fresh siltstone.	Bedding at 60°.	60' 0"			Indefinite parting along bedding.	
weathered siltstone	Bedding at 60°. Tendency to part along bedding planes.	64' 0"			Irregular jointing 4" zone of very broken rock. 10" zone of sheared siltstone.	
Fresh laminated siltstone.	Core lengths from 1" to 7". Bedding planes are wavy, possibly due to slumping. Bedding varies from +30° to -10°.	69' 9"			Quartz veins. 90° with massive quartz. 40° joint.	Large joint infilled with massive quartz containing small open cavities. Shows slickensiding well.
Slightly weathered siltstone and fine greywacke	Graded bedding at 55°. Core lengths from 1" to 8", mainly 2".	74' 3"			Fissile zone. Quartz veins ¼" and ½" wide.	
Sheared siltstone.		75' 2"			Some massive qtz. present.	
Weathered bedded siltstone.		80' 8"			Bedding at 65°. Tendency to break along bedding planes. Irregular bedding - slumping?	
Fresh siltstone	Graded bedding at 70°. Core lengths to 12".	84' 4"				
	END OF HOLE P-4.					Water lost during most of the drilling. Water pressure tests unsuccessful.



DRILL NO 6-A-16

TYPE BOYLES.

DRILLER J. GRECH

COMMENCED 14-9-61

COMPLETED 22-9-61

LOGGED E. J. BEST

VERTICAL SCALE 10' = 1"

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER COTTER DAM SITE 'E' HOLE NO P-5 R.L. 3155'

LOCATION 19' FROM PEG A16 IN DIRECTION 85°M. ANGLE FROM HORIZONTAL 55° DIRECTION 165°M

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION	DEPTH & SIZE OF CORE	LO	% CORE RECOVERY 0 50 100	STRUCTURES JOINTS VEINS SEAMS FAULTS CRUSHES	
Weathered medium grained quartz greywacke, shale, and siltstone.	Fragments of boulders — scree material.	NX 5' 0"		100 100 100		NX casing.
Fresh, fine grained quartz greywacke.	Massive.	6' 4"		100	Thin quartz stringers at 70° and 80° 40° joint.	NX core barrel.
Fine quartz greywacke to siltstone. Slightly weathered, particularly along joint planes.	Core lengths up to 9". Contains irregular cherty patches — no pyrite though there are red-brown specks which may be after pyrite. Medium grained zone from 7'4" to 7'9". Shely zone from 8'9" to 9'2".	10' 6"		100	40° joint. 45° joint. Two quartz veins ¼" wide at 70°.	
Laminated siltstone — moderately weathered	Fairly compact — core lengths up to 10". Angle of bedding varies throughout the zone and is very contorted in places.	20' 11"		100 100	Bedding at 50°. Very contorted bedding. Bedding at 0° to ±5°. 80° joint. Bedding at 30° — shows sedimentary faulting. Bedding very contorted. 50° joint. Bedding wavy but not so contorted as previously — approx. at 20°. 80° joint with slickensides. Sheared and decomposed zone. Bedding at 60°.	60% water return during drilling.
Laminated shaly siltstone with moderate to strong weathering.	Minutely jointed and sheared, though rock is still quite compact.	23' 6"			Quartz vein at 80°. Bedding at 55°.	
Very fine quartz greywacke to siltstone. Slight to moderate weathering	Quite compact and massive with occasional faint traces of bedding which are wavy - probably slumping. Core lengths up to 11". Occasional cherty zones.	27' 8"		100	Jointing is irregular. Quartz veining at 70°. Broken zone. Irregular quartz veining.	70% water return. 80% water return.
Siltstone.	Sheared and decomposed to clay	28' 8"		91		4" of core washed away.
Siltstone, irregularly weathered along joints.	Moderately broken — 1" fragments to 4" core lengths. Some mica present in the rock.	37' 6"		100 100	Irregularly jointed. Quartz veining scattered throughout. Crushed and decomposed zone — clayey material Banding at 35°.	60% water return.
Siltstone and very fine sandstone. Slightly to moderately weathered.	Banded in places. Bedding at 35°.	41' 10"		100		20% water return.
Fresh fine grained quartz greywacke.	Massive with core lengths up to 8". Blue-grey in colour.	45' 6"		100	Irregular quartz stringers. Irregularly jointed zone.	No water return
Weathered siltstone	Banded in places, showing probable slumping. Zone of medium grained quartz greywacke from 48' 5" to 48' 10".			100 100	Clayey zone. (3") Crushed zone (5")	20% water return. 60% water return.

DRILL NO 6-A-17

TYPE BOYLES

DRILLER L. TOMIC

COMMENCED 27-9-61

COMPLETED 12-10-61

LOGGED E. J. BEST

VERTICAL SCALE 5' = 1"

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER COTTER DAM SITE 'E'   HOLE NO P-5   R.L. 3155'

LOCATION 19' FROM PEG A 16 IN DIRECTION 85°M   ANGLE FROM HORIZONTAL 55°   DIRECTION 165°M

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION	[illegible]		0 50 100%	STRUCTURES JOINTS VEINS SEAMS FAULTS [illegible]	
Weathered siltstone (cont.)		55' 0"		100	Broken and decomposed zone (1') Bedding at 40°. Crushed zone (8") Irregular banding - probably due to slumping.	60% water return
Fine grained, almost fresh quartz greywacke.	Irregularly fractured and silicified up to 55' 10". From 55' 10", irregular quartz stringers occur.	57' 2"				
Siltstone	Sheared and decomposed.	57' 7"		100		80% water return
Fine quartz greywacke with thinly bedded siltstone bands.	Slightly weathered - siltstone bands slightly to moderately weathered.	59' 10"			Bedding at 40°.	
Medium grained quartz greywacke Slight to moderate weathering.	Core lengths from 4" to 18".	62' 3"		100	40° joint	70% water return
Laminated mudstone	8" core length and fragments	63' 0"			Cleaved parallel to core.	
NO CORE	RECOVERY	64' 4"				Very soft drilling.
Slaty material	Very broken.					
Medium grained quartz greywacke moderately weathered.		66' 10"		75	Irregularly jointed and broken.	
Fine grained quartz greywacke. Slight to moderate weathering.	Fresh blue grey rock from 69' 0" to 70' 6". Core lengths from 5" to 18".	72' 6"		100	Banding at 45° to core - probably bedding.	No water return for rest of hole.
Siltstone	Brecciated and silicified.	73' 2"			Irregular quartz veining.	
Fine qtz. greywacke	Broken and stained.	73' 8"			Veined by quartz.	
Medium qtz. greywacke	Moderately weathered.	74' 7'				
Silty mudstone		75' 0"			Cleaved.	
Medium quartz greywacke. Moderately weathered to cream-yellow colour.	Core lengths from 2" - 7".	77' 10"		100 100	Stained black along joints. 50° joint.	
Fine grained quartz greywacke. Strongly weathered.	Core lengths up to 4".	80' 0"			Silty laminae at 70°.	
Vein qtz. and clay.	4" of core lost.	80' 8"		80		
Siltstone	Strongly weathered.				Partly silicified.	
Medium grained quartz greywacke strongly weathered.	Strongly jointed.	83' 9"		100	7" broken zone with some shale laminae.	
NO CORE RECOVERY.		85' 9"			Open cavity or a wide washed-out joint.	Driller reported no pressure on bit. Water pressure dropped to zero.
Fine grained quartz greywacke Moderately weathered.	Core lengths from 2" to 16". Patches of only slightly weathered rock from 90' 0". Fresh rock from 91' 9" to 93' 3".	97' 9"		52 100 100 100	Broken zone (6"). Irregular quartz veining. 8" broken zone. Bedding at 35°. 40° joint. 80° joint.	
Medium grained quartz greywacke Moderate weathering.		99' 4"			1" shale band at 20°.	
Siltstone & Shale	Banded and weathered.	100' 0"				

DRILL NO 6 - A - 17

TYPE BOYLES.

DRILLER L. TOMIC

COMMENCED 27 - 9 - 61

COMPLETED 12 - 10 - 61

E.J. BEST

5' = 1"

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER COTTER DAM SITE 'E' HOLE NO P-5 R.L. 3155'

LOCATION 19' FROM PEG A 16 IN DIRECTION 86° M. ANGLE FROM HORIZONTAL 55° DIRECTION 165° M.

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION	DEPTH & SIZE OF CORE		CORE RECOVERY 0 50 100%	STRUCTURES JOINTS VEINS SEAMS FAULTS CRUSHED ZONES	
Fine grained quartz greywacke.	Moderately weathered up to 104', slightly weathered from 104'. Core lengths 2" to 11".	106'4"		100 100 100	Broken and stained zone (9") Shaly band.	
Moderately weathered, laminated siltstone.	Banding at 60° to core	112'3"		95	3" of core washed away.	
Fresh fine grained quartz greywacke.	Blue grey in colour.	114'4"		100		
Fine qtz greywacke	Moderately weathered, though hard.	114'10"				
Laminated siltstone. Moderately weathered	Bedding at 20°.	116'0"				
Very fine grained quartz greywacke.	Moderately weathered. Hard.	117'2"		100		
Laminated siltstone	1" fragments to 5" core lengths.	121'0"		100	Zones of close irregular jointing from 117'2" - 118'1" and 119'5" to 119'9". Brecciated and recemented from 118'1" to 119'2", probably by silica.	
	HOLE COMPLETED AT 121'0".					

DRILL NO 6-A-17

TYPE BOYLES

DRILLER L. TOMIC

COMMENCED 27-9-61

COMPLETED 12-10-61

LOGGED E. J. BEST.

VERTICAL SCALE 5' = 1"

APPENDIX 4.

WATER PRESSURE TEST RESULTS

The key to the symbols in the column headings of the water pressure test result sheets is as follows :-

* measured along the inclination of the hole.

‡ use (1) when water table is below the test section.
use (2) when water table is above the test section.

† factor e for head loss is read from standard graphs.

\+ factor n for conversion to NX hole is read from a standard table;

N.B. because of insufficient data in this table, this correction was ignored in all results from Damsite E.

o calculated from graph of P against L for each test section.

BUREAU OF MINERAL RESOURCES

PROJECT: **UPPER COTTER DAMSITE 'E'.** HOLE Nº: P-1

WATER PRESSURE TESTING RESULTS

SIZE OF HOLE: **NX**

INCLINATION TO HORIZ.(θ): 30°

Section tested (feet) From	Section tested (feet) To	Length of section (feet)	Depth* to standing water (feet)	Height* of gauge above hole (feet)	Water column pressure (p.s.i.)	Friction head loss (p.s.i.)	Gauge pressure (p.s.i.)	Effective test pressure (p.s.i.)	Metered water loss (g.p.m.)	Standardised water loss (g.m.p./foot of NX hole	REDUCED RESULTS Standard effective pressure (p.s.i.)	Equivalent° water loss (g.p.m.)
a	b	b-a=c	d	h	‡ 0·44×Sineθ(a+h)=w (1) ‡ 0·44×Sineθ(d+h)=w (2)	$\frac{(a+h)e^{\dagger}}{10}$ = f	p	p+w−f = P	l	$\frac{l\times n^{+}}{c}$ = L		
32·0	55·5	23·5	20·0	2·5	4·4	0·4	4·0	8·0	8·0	0·34		
45·5	55·5	10·0	20·0	2·0	4·4	0·6	5·0	8·8	8·0	0·80		
55·5	70·2	14·7	20·0	2·0	4·4	0·9	2·0	5·5	9·0	0·64		
70·2	82·3	12·1	20·0	1·3	4·4	1·4	6·0	9·0	10·0	0·83		
82·3	95·8	13·5	20·0	1·9	4·4	1·9	3·0	5·5	11·0	0·84		
95·8	107·8	12·0	20·0	1·8	4·4	2·0	7·0	9·4	10·6	0·88		
107·8	116·8	9·0	20·0	0·9	4·4	1·1	5·0	8·3	6·4	0·72	10·0	0·89
					4·4	2·2	10·0	12·2	10·2	1·19		
					4·4	2·6	14·5	16·3	11·2	1·26		
115·1	125·1	10·0	20·0	1·9	4·4	0·4	10·0	14·1	1·5	0·15	10·0	0·10
					4·4	0·5	25·0	28·9	3·0	0·30	25·0	0·25
					4·4	0·7	50·0	53·7	4·0	0·40	50·0	0·40
					4·4	0·9	75·0	78·5	5·0	0·50		
125·1	138·0	12·9	20·0	2·0	4·4	0·4	10·0	14·0	0·5	0·04	10·0	0·04
					4·4	0·4	25·0	29·0	0·7	0·05	25·0	0·05
					4·4	0·4	50·0	54·0	1·1	0·08	50·0	0·08
					4·4	0·4	75·0	79·0	1·6	0·12		
138·0	152·0	14·0	20·0	3·0	4·4	0·4	10·0	14·0	0·0	0·00	10·0	0·00
					4·4	0·4	25·0	29·0	0·0	0·00	25·0	0·00
					4·4	0·4	50·0	64·0	0·2	0·01	50·0	0·01
					4·4	0·4	75·0	79·0	0·3	0·02		
					4·4	0·4	100·0	104·0	0·4	0·03		

BUREAU OF MINERAL RESOURCES

PROJECT: UPPER COTTER DAMSITE 'E' HOLE Nº: P-1B

WATER PRESSURE TESTING RESULTS

SIZE OF HOLE: NX to 87', BX thereafter. INCLINATION TO HORIZ.(θ): 50°

Section tested (feet)		Length of section (feet)	Depth* to standing water (feet)	Height* of gauge above hole (feet)	Water column pressure (p.s.i.)	Friction head loss (p.s.i.)	Gauge pressure (p.s.i.)	Effective test pressure (p.s.i.)	Metered water loss (g.p.m.)	Standardised water loss (g.m.p./foot of NX hole	REDUCED RESULTS	
From	To										Standard effective pressure (p.s.i.)	Equivalent water loss (g.p.m.)
a	b	b-a=c	d	h	‡ $0{\cdot}44 \times \text{Sine}\,\theta(a+h) = w$ (1) ‡ $0{\cdot}44 \times \text{Sine}\,\theta(d+h) = w$ (2)	$\frac{(a+h)e^{\dagger}}{10} = f$	p	$p + w - f = P$	l	$\frac{l \times n^{+}}{c} = L$		
20·0	34·7	14·7	7·0	1·2	2·2	0·2	5	7·0	6·0	0·40	10	0·57
					2·2	0·4	11	12·8	9·8	0·69		
34·7	43·8	9·1	7·0	0·8	2·2	0·2	10	12·0	3·9	0·43	10	0·33
					2·2	0·4	20	21·8	6·9	0·75	25	0·87
					2·2	0·7	30	31·5	10·3	1·12		
43·8	53·1	9·3	7·0	1·6	2·2	0·9	10	11·3	10·0	1·03		
53·1	62·4	9·3	7·0	2·1	2·2	1·0	13	14·2	9·7	1·03		
62·4	72·0	9·6	7·0	1·4	2·2	1·3	11	11·9	10·3	1·07		
72·0	81·8	9·8	7·0	1·8	2·2	1·2	16	17·1	8·8	0·90		
87·0	100·0	13·0	7·0	2·4	2·2	1·6	10	10·6	3·2	0·25	10	0·23
					2·2	3·7	25	23·5	5·6	0·43	25	0·45
					2·2	8·4	50	43·8	8·8	0·68		
100·0	111·8	11·8	7·0	1·3	2·2	0·5	10	11·7	1·3	0·11	10	0·09
					2·2	1·2	25	26·0	2·6	0·22	25	0·22
					2·2	2·7	50	49·5	4·2	0·36	50	0·36
					2·2	4·2	75	73·0	5·6	0·47		
					2·2	5·8	100	96·4	6·7	0·56		

BUREAU OF MINERAL RESOURCES

PROJECT: UPPER COTTER DAMSITE 'E'. HOLE Nº: P-2

WATER PRESSURE TESTING RESULTS

SIZE OF HOLE: NX to 44', BX thereafter. INCLINATION TO HORIZ.[θ]: 45°

Section tested (feet)		Length of section (feet)	Depth* to standing water (feet)	Height* of gauge above hole (feet)	Water column pressure (p.s.i.)	Friction head loss (p.s.i.)	Gauge pressure (p.s.i.)	Effective test pressure (p.s.i.)	Metered water loss (g.p.m.)	Standardised water loss (g.m.p./foot of NX hole	REDUCED RESULTS	
From	To										Standard effective pressure (p.s.i.)	Equivalent° water loss (g.p.m.)
a	b	b−a=c	d	h	‡ 0·44×Sineθ(a+h)=w (1) ‡ 0·44×Sineθ(d+h)=w (2)	$\frac{(a+h)e^{\dagger}}{10}$ = f	p	p+w−f = P	l	$\frac{l \times n^{+}}{c}$ = L		
56·0	61·0	5·0	79·0	1·2	17·7	0·6	5	22·1	1·8	0·36	10	0·10
					17·7	1·5	10	26·2	3·4	0·68	25	0·52
					17·7	3·6	25	39·1	6·8	1·16		
					17·7	10·8	42	48·9	10·4	2·08		
61·0	66·0	5·0	79·0	1·4	19·5	7·1	5	17·4	8·0	1·60		
					19·5	13·6	8	13·9	11·0	2·20		
66·0	71·0	5·0	79·0	0·8	20·8	4·7	5	21·1	6·2	1·24		
					20·8	8·7	10	22·1	8·6	1·72		
					20·8	14·4	17	23·4	11·0	2·20		
71·0	76·0	5·0	79·0	2·3	22·7	6·6	5	21·1	7·0	1·40	10	0·88
					22·7	10·2	10	22·5	8·8	1·76	25	1·41
					22·7	13·4	20	29·3	10·2	2·04		
76·0	81·0	5·0	79·0	1·8	23·9	0·2	5	28·7	0·0	0·00	10	0·00
					23·9	0·2	10	33·7	0·0	0·00	25	0·00
					23·9	0·5	25	48·4	1·2	0·24	50	0·24
					23·9	0·7	50	73·2	1·6	0·32		
81·0	86·0	5·0	79·0	1·2	24·8	0·2	5	29·6	0·0	0·00	10	0·00
					24·8	0·2	10	34·6	0·0	0·00	25	0·00
					24·8	0·4	25	49·4	1·0	0·20	50	0·20
					24·8	0·8	50	74·0	2·0	0·40		

BUREAU OF MINERAL RESOURCES

PROJECT: UPPER COTTER DAMSITE 'E'. HOLE №: P-2

WATER PRESSURE TESTING RESULTS

SIZE OF HOLE: NX to 44', BX thereafter. INCLINATION TO HORIZ.[θ]: 45°

Section tested (feet)		Length of section (feet).	Depth* to standing water (feet)	Height* of gauge above hole (feet)	Water column pressure (p.s.i.)	Friction head loss (p.s.i.)	Gauge pressure (p.s.i.)	Effective test pressure (p.s.i.)	Metered water loss (g.p.m.)	Standardised water loss (g.m.p./foot of NX hole	REDUCED RESULTS	
From	To										Standard effective pressure (p.s.i.)	Equivalent° water loss (g.p.m.)
a	b	b-a=c	d	h	‡ $0{\cdot}44 \times \mathrm{Sine}\,\theta(a+h) = w$ (1) ‡ $0{\cdot}44 \times \mathrm{Sine}\,\theta(d+h) = w$ (2)	$\frac{(a+h)e^{\dagger}}{10} = f$	p	$p + w - f = P$	l	$\frac{l \times n^{+}}{c} = L$		
86·0	90·2	4·2	79·0	1·4	24·8	1·7	10	33·1	3·0	0·70	25	0·45
					24·8	2·6	20	42·2	3·8	0·91	50	0·98
					24·8	3·4	50	71·4	4·4	1·05		
90·2	95·4	5·2	79·0	0·9	24·8	11·8	10	23·0	8·6	1·60		
					24·8	22·8	20	22·0	11·8	2·16		
95·4	100·1	4·7	79·0	2·2	24·8	0·6	10	34·2	1·2	0·25	25	0·00
					24·8	1·4	25	48·4	2·4	0·50	50	0·52
					24·8	2·2	50	72·6	3·2	0·68		
100·1	105·2	5·1	79·0	1·7	24·8	0·4	10	34·4	1·0	0·20	25	0·14
					24·8	0·8	30	54·0	1·8	0·36	50	0·31
					24·8	1·2	50	73·6	2·6	0·52		
105·2	110·2	5·0	79·0	2·3	24·8	0·4	10	34·4	0·8	0·16	25	0·08
					24·8	0·6	30	54·2	1·4	0·28	50	0·26
					24·8	1·1	50	73·7	2·4	0·48		
107·3	115·3	8·0	79·0	1·4	24·8	0·3	15	39·5	0·0	0·00	25	0·00
					24·8	0·4	25	49·4	0·5	0·06	50	0·06
					24·8	0·5	50	74·3	1·2	0·15		
					24·8	1·4	75	98·4	2·8	0·35		
112·3	125·3	13·0	79·0	2·0	24·8	0·3	25	49·5	0·0	0·00	50	0·00
					24·8	0·3	50	74·5	0·3	0·03		
					24·8	0·4	75	99·4	0·6	0·05		

BUREAU OF MINERAL RESOURCES

PROJECT: **UPPER COTTER DAMSITE 'E'.** HOLE №: **P-2**

WATER PRESSURE TESTING RESULTS

SIZE OF HOLE: **NX to 44', BX thereafter.** INCLINATION TO HORIZ.(θ): **45°**

Section tested (feet)		Length of section (feet)	Depth* to standing water (feet)	Height* of gauge above hole (feet)	Water column pressure (p.s.i.)	Friction head loss (p.s.i.)	Gauge pressure (p.s.i.)	Effective test pressure (p.s.i.)	Metered water loss (g.p.m.)	Standardised water loss (g.m.p./foot of NX hole	REDUCED RESULTS	
From	To										Standard effective pressure (p.s.i.)	Equivalant° water loss (g.p.m.)
a	b	b-a=c	d	h	‡ $0{\cdot}44 \times \text{Sine}\,\theta(a+h)=w$ (1) ‡ $0{\cdot}44 \times \text{Sine}\,\theta(d+h)=w$ (2)	$\frac{(a+h)e^{\dagger}}{10} = f$	p	$p+w-f = P$	l	$\frac{l \times n^{+}}{c} = L$		
117·3	145·3	28·0	79·0	1·9	24·8	0·3	10	34·5	0·0	0·00	25	0·00
					24·8	0·7	25	49·1	1·2	0·04	50	0·04
					24·8	2·0	50	72·8	3·1	0·11		
					24·8	5·6	75	94·2	6·0	0·21		
					24·8	9·5	100	115·3	8·0	0·29		
145·3	165·0	19·7	79·0	2·6	24·8	0·7	10	34·1	1·0	0·05	10	0·00
					24·8	1·3	25	48·5	2·0	0·10	25	0·02
					24·8	2·8	50	72·0	3·4	0·17	50	0·10
					24·8	4·8	75	95·0	4·8	0·24		
					24·8	7·4	100	117·4	6·2	0·31		
165·0	183·2	18·2	79·0	1·7	24·8	0·8	10	34·0	0·8	0·04	25	0·00
					24·8	1·5	25	48·3	2·0	0·11	50	0·12
					24·8	4·4	50	70·4	4·2	0·23		
					24·8	7·0	75	92·8	5·6	0·31		
					24·8	9·9	100	114·9	6·8	0·38		
178·0	198·0	20·0	79·0	1·4	24·8	6·4	5	23·4	5·0	0·25		
					24·8	16·3	15	23·5	8·6	0·43		
					24·8	29·5	24	19·3	11·6	0·58		

BUREAU OF MINERAL RESOURCES

PROJECT: **UPPER COTTER DAMSITE 'E'.** HOLE Nº: **P-3**

WATER PRESSURE TESTING RESULTS

SIZE OF HOLE: **NX** INCLINATION TO HORIZ.[θ]: **45°**

Section tested (feet) From	Section tested (feet) To	Length of section (feet)	Depth* to standing water (feet)	Height* of gauge above hole (feet)	Water column pressure (p.s.i.)	Friction head loss (p.s.i.)	Gauge pressure (p.s.i.)	Effective test pressure (p.s.i.)	Metered water loss (g.p.m.)	Standardised water loss (g.m.p./foot of NX hole	REDUCED RESULTS Standard effective pressure (p.s.i.)	REDUCED RESULTS Equivalant° water loss (g.p.m.)
a	b	b−a=c	d	h	‡ 0·44×Sineθ(a+h)=w (1) 0·44×Sineθ(d+h)=w (2)	$\frac{(a+h)e^{\dagger}}{10} = f$	p	p+w−f = P	l	$\frac{l \times n^{+}}{c} = L$		
8·0	19·4	11·4	> 134	1·6	2·5	0·0	5	7·5	0·8	0·07	10	0·09
					2·5	0·0	10	12·5	1·4	0·12		
					2·5	0·0	15	17·5	2·4	0·21		
19·4	31·5	12·1	> 134	0·9	6·1	0·1	10	16·0	1·6	0·13	10	0·07
					6·1	0·1	20	26·0	2·8	0·23	25	0·22
33·1	48·3	15·2	> 134	1·3	10·3	0·1	10	20·2	2·8	0·18	10	0·08
					10·3	0·2	25	35·1	4·2	0·28	25	0·23
					10·3	0·4	50	59·9	7·8	0·51	50	0·42
48·3	57·2	8·8	> 134	2·4	15·0	07	6	20·3	8·4	0·95		
57·2	67·0	9·8	> 134	2·0	17·8	1·1	4	20·7	9·6	0·98		
67·0	76·5	9·5	> 134	1·7	20·4	1·3	3	23·1	9·8	1·03		
76·5	86·4	9·9	> 134	1·3	23·8	1·5	2	24·3	10·0	1·01		
86·4	96·0	9·6	> 134	2·2	27·0	1·4	5	30·6	9·0	0·94		
96·0	105·8	9·8	> 134	1·1	30·0	1·3	6	34·7	8·4	0·86		
105·8	115·0	9·2	> 134	0·9	33·8	2·1	1	31·9	10·0	1·09		
115·0	124·5	9·5	> 134	2·7	35·8	2·4	0	33·4	10·2	1·07		
124·5	134·0	9·5	> 134	1·6	38·8	2·6	0	36·2	10·2	1·07		

BUREAU OF MINERAL RESOURCES

PROJECT: UPPER COTTER DAMSITE 'E'. HOLE Nº: P-4

WATER PRESSURE TESTING RESULTS

SIZE OF HOLE: NX. INCLINATION TO HORIZ.[θ]: 30°

Section tested (feet)		Length of section (feet)	Depth* to standing water (feet)	Height* of gauge above hole (feet)	Water column pressure (p.s.i.)	Friction head loss (p.s.i.)	Gauge pressure (p.s.i.)	Effective test pressure (p.s.i.)	Metered water loss (g.p.m.)	Standardised water loss (g.m.p./foot of NX hole	REDUCED RESULTS Standard effective pressure (p.s.i.)	REDUCED RESULTS Equivalent° water loss (g.p.m.)
From	To											
a	b	b−a=c	d	h	‡ 0·44×Sineθ(a+h)=w (1) ‡ 0·44×Sineθ(d+h)=w (2)	$\frac{(a+h)e^{\dagger}}{10} = f$	p	p+w−f = P	l	$\frac{l \times n^{+}}{c} = L$		
12·0	34·4	22·4	> 83	1·4	2·6	0·2	0	2·4	9·6	0·43		
19·4	34·4	15·0	> 83	0·9	4·3	0·4	0	3·9	9·6	0·64		
24·4	34·4	10·0	> 83	2·1	5·4	0·5	0	4·9	9·6	0·96		
34·4	48·7	14·3	> 83	1·7	7·6	0·7	0	6·9	9·6	0·68		
48·7	58·5	9·8	> 83	1·1	10·7	0·2	10	20·5	2·4	0·24	10	0·15
					10·7	0·2	30	40·5	3·2	0·33	25	0·26
					10·7	0·2	60	70·5	3·8	0·39	60	0·36
58·5	69·7	11·2	> 83	2·3	12·9	1·1	5	16·8	9·6	0·86		
69·7	83·3	13·6	> 83	2·5	15·3	1·3	5	19·0	9·6	0·70		

BUREAU OF MINERAL RESOURCES

PROJECT: **UPPER COTTER DAMSITE 'E'.** HOLE Nº: **P-5**

WATER PRESSURE TESTING RESULTS

SIZE OF HOLE: **NX** INCLINATION TO HORIZ.[θ]: **55°**

Section tested (feet) From	To	Length of section (feet)	Depth* to standing water (feet)	Height* of gauge above hole (feet)	Water column pressure (p.s.i.)	Friction head loss (p.s.i.)	Gauge pressure (p.s.i.)	Effective test pressure (p.s.i.)	Metered water loss (g.p.m.)	Standardised water loss (g.m.p./foot of NX hole)	REDUCED RESULTS Standard effective pressure (p.s.i.)	Equivalent° water loss (g.p.m.)
a	b	b−a=c	d	h	‡ $0{\cdot}44\times\text{Sine}\,\theta(a+h)=w$ (1) ‡ $0{\cdot}44\times\text{Sine}\,\theta(d+h)=w$ (2)	$\frac{(a+h)e^{\dagger}}{10} = f$	p	$p+w-f = P$	l	$\frac{l\times n^{+}}{c} = L$		
10·0	20·3	10·3	>121	1·4	3·6	0·1	5	8·5	4·0	0·39		
19·0	29·0	10·0	>121	0·8	6·9	0·3	3	9·6	8·7	0·87		
29·0	34·6	5·6	>121	1·1	10·4	0·4	6	16·0	8·3	1·51		
34·6	39·0	4·4	>121	2·3	12·4	0·3	10	22·1	5·6	1·25	10	1·15
					12·4	0·3	20	32·1	5·9	1·32	25	1·27
39·0	43·8	4·8	>121	1·7	14·0	0·1	10	23·9	1·8	0·38	10	0·08
					14·0	0·2	20	33·8	2·9	0·61	25	0·40
					14·0	0·2	30	43·8	4·2	0·88	50	1·08
					14·0	0·3	40	53·7	5·7	1·20		
43·8	50·0	6·2	>121	0·9	15·8	0·1	10	25·7	2·3	0·36	10	0·00
					15·8	0·4	25	40·4	6·5	1·03	25	0·32
					15·8	0·5	29	44·3	7·7	1·23		
50·0	57·6	7·6	>121	1·4	18·0	0·2	10	27·8	1·6	0·21	10	0·07
					18·0	0·2	25	42·8	3·4	0·45	25	0·17
					18·0	0·6	40	57·4	7·5	0·99	50	0·71
57·6	62·6	5·0	>121	2·9	20·8	0·2	10	30·6	1·2	0·24		
					20·8	0·4	25	45·4	4·9	0·98		
					20·8	1·0	20	39·8	9·4	1·88		
62·6	67·2	4·6	>121	2·3	22·6	0·3	10	32·4	3·4	0·74		
					22·6	0·7	25	46·9	7·5	1·63		
					22·6	1·2	22	43·4	9·6	2·09		
67·2	71·9	4·7	>121	1·7	24·2	0·2	10	34·0	0·4	0·08	10	0·01
					24·2	0·2	25	49·0	0·6	0·13	25	0·07
					24·2	0·2	50	74·0	1·0	0·21	50	0·14
71·9	77·8	5·9	>121	1·8	25·9	0·2	10	35·7	1·0	0·17		
					25·9	0·2	25	50·7	1·6	0·27		
					25·9	0·6	50	75·3	5·2	0·88		
					25·9	1·3	40	64·6	9·2	1·56		

BUREAU OF MINERAL RESOURCES

PROJECT: UPPER COTTER DAMSITE 'E'. HOLE Nº: P-5

SIZE OF HOLE: NX INCLINATION TO HORIZ.[θ]: 55°

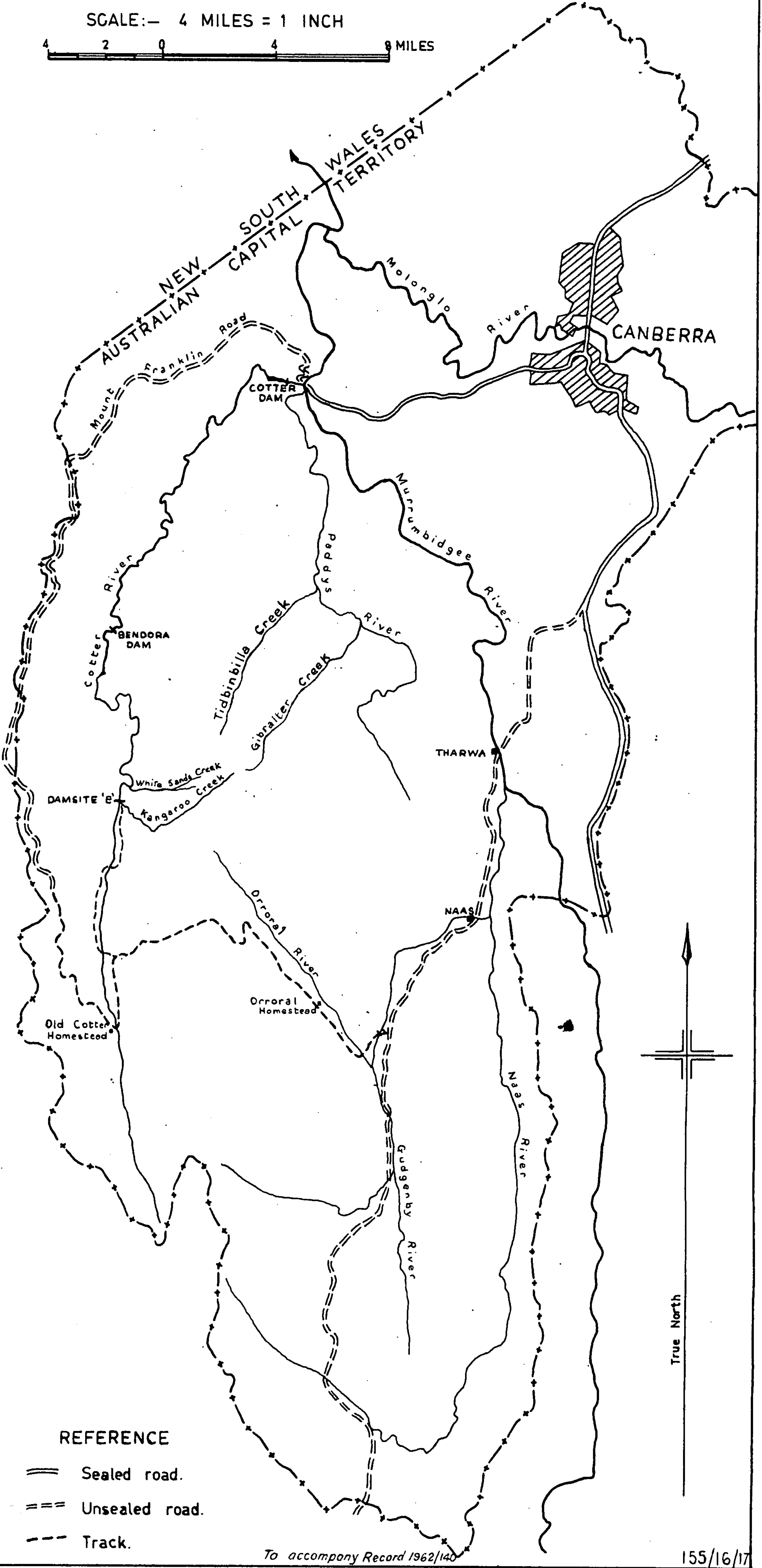
WATER PRESSURE TESTING RESULTS

Section tested (feet)		Length of section (feet)	Depth to standing water (feet)	Height of gauge above hole (feet)	Water column pressure (p.s.i.)	Friction head loss (p.s.i.)	Gauge pressure (p.s.i.)	Effective test pressure (p.s.i.)	Metered water loss (g.p.m.)	Standardised water loss (g.m.p./foot of NX hole	REDUCED RESULTS Standard effective pressure (p.s.i.)	 Equivalant° water loss (g.p.m.)
From	To											
a	b	b-a=c	d	h	‡ $0{\cdot}44 \times \text{Sine}\,\theta(a+h) = w$ (1) ‡ $0{\cdot}44 \times \text{Sine}\,\theta(d+h) = w$ (2)	$\frac{(a+h)e^{\dagger}}{10} = f$	p	$p + w \mp f = P$	l	$\frac{l \times n^{+}}{c} = L$		
77·8	83·3	5·5	>121	1·4	28·0	1·6	0	26·4	9·8	1·81		
83·3	87·3	4·0	>121	2·9	30·0	1·6	0	28·4	9·6	2·35		
87·3	93·7	6·4	>121	0·9	31·4	1·7	0	29·7	9·8	1·55		
					31·4	4·5	0	26·9	16·6	2·62		
93·7	100·3	6·6	>121	1·8	33·8	0·7	5	38·1	5·0	0·76		
					33·8	2·0	13	44·8	10·4	1·58		
100·3	106·3	6·0	>121	1·0	36·1	1·9	0	34·2	9·6	1·58	25	1·25
					36·1	3·4	17	49·7	13·4	2·20	50	2·21
106·3	111·1	4·8	>121	2·1	38·3	2·6	5	40·7	11·0	2·32	25	1·38
					38·3	4·0	15	49·3	14·2	2·99	50	3·04
111·1	117·2	6·1	>121	2·4	40·0	0·9	5	44·1	5·6	0·92	50	1·15
					40·0	2·3	25	62·7	10·4	1·72		
					40·0	4·4	45	80·6	14·6	2·40		
117·2	121·0	3·8	>121	3·1	42·2	1·0	5	46·2	5·0	1·30	50	1·76
					42·2	1·4	10	50·8	7·4	1·95		
					42·2	3·9	20	58·3	13·2	3·50		

PLATE 1

LOCALITY MAP

AUSTRALIAN CAPITAL TERRITORY



To accompany Record 1962/140

155/16/17

Bureau of Mineral Resources, Geology and Geophysics. December, 1961.

PLATE 2

GEOLOGICAL PLAN
- OF -
PORTION OF UPPER COTTER VALLEY

(BASED ON AERIAL PHOTOGRAPHS)

To accompany Record No. 1962/140

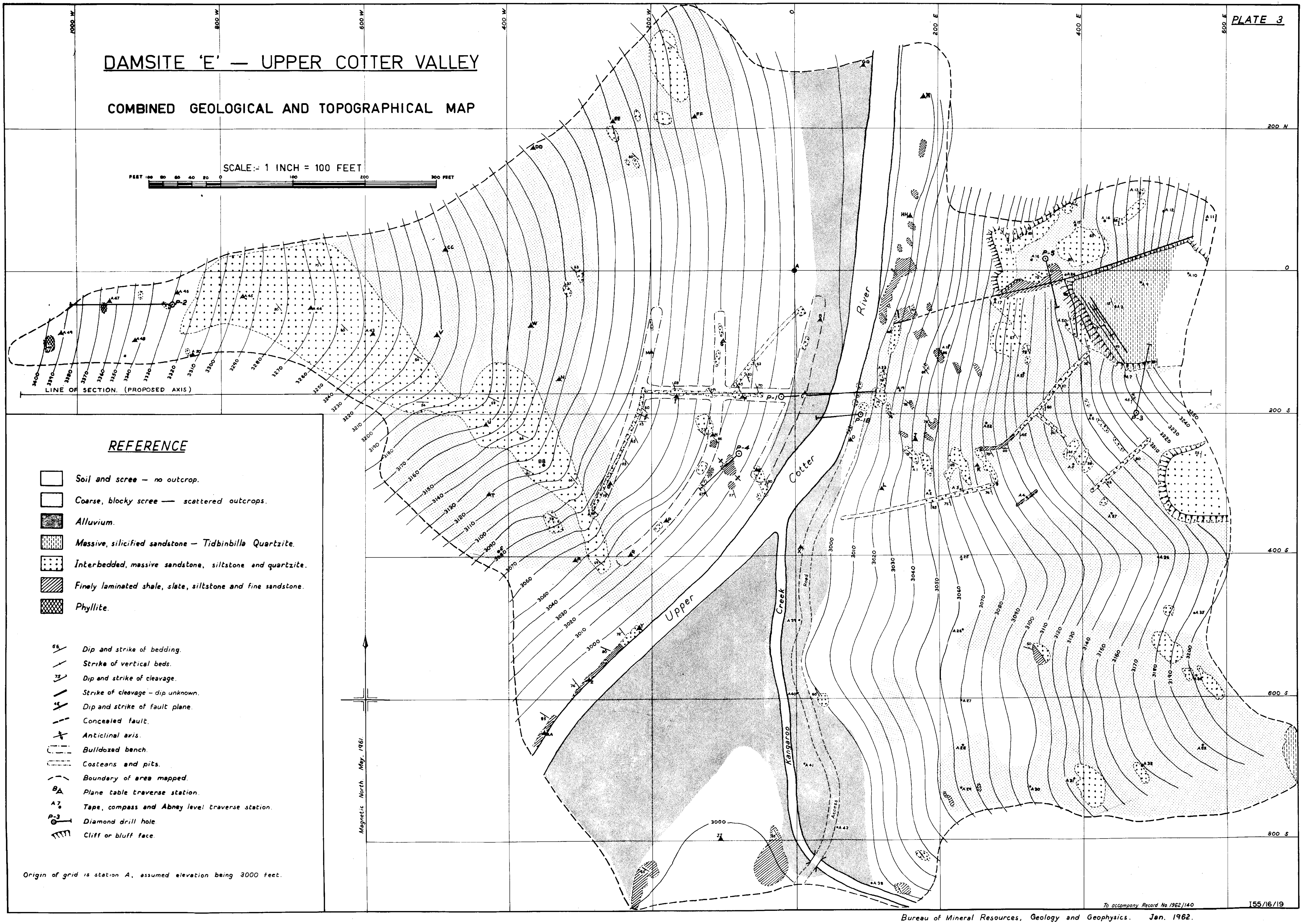
155/16/18

PLATE 3

DAMSITE 'E' — UPPER COTTER VALLEY

COMBINED GEOLOGICAL AND TOPOGRAPHICAL MAP

SCALE:- 1 INCH = 100 FEET



REFERENCE

▢ Soil and scree — no outcrop.

▢ Coarse, blocky scree — scattered outcrops.

▩ Alluvium.

▥ Massive, silicified sandstone — Tidbinbilla Quartzite.

⁘ Interbedded, massive sandstone, siltstone and quartzite.

▨ Finely laminated shale, slate, siltstone and fine sandstone.

▦ Phyllite.

66 Dip and strike of bedding.

Strike of vertical beds.

75 Dip and strike of cleavage.

Strike of cleavage — dip unknown.

45 Dip and strike of fault plane.

Concealed fault.

Anticlinal axis.

Bulldozed bench.

Costeans and pits.

Boundary of area mapped.

B ▲ Plane table traverse station.

A 7 ● Tape, compass and Abney level traverse station.

P-3 Diamond drill hole.

Cliff or bluff face.

Origin of grid is station A, assumed elevation being 3000 feet.

To accompany Record No. 1962/140

I55/16/19

Bureau of Mineral Resources, Geology and Geophysics. Jan. 1962.

PLATE 4

DAMSITE E — UPPER COTTER VALLEY

DETAILED GEOLOGICAL MAP OF OUTCROPS AND COSTEANS

REFERENCE

Quartz sandstone and quartzite.
- ⁘ Coarse grained.
- ⁘ Medium grained.
- ⁘ Fine grained.
- ⁘ Interbedded fine to coarse grained — not mapped in detail.

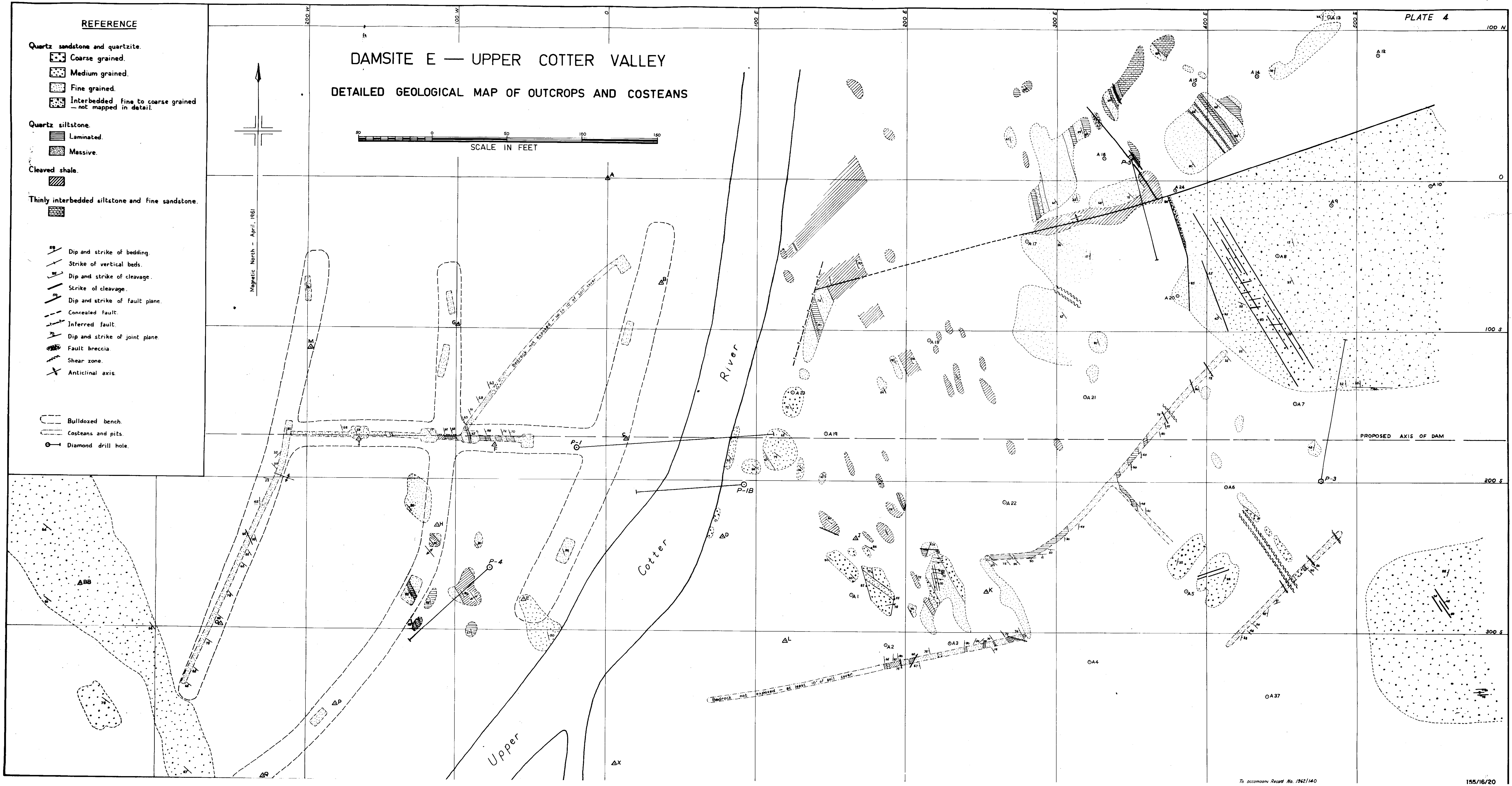
Quartz siltstone.
- ▤ Laminated.
- ▨ Massive.

Cleaved shale.
- ▨

Thinly interbedded siltstone and fine sandstone.
- ▤

- Dip and strike of bedding.
- Strike of vertical beds.
- Dip and strike of cleavage.
- Strike of cleavage.
- Dip and strike of fault plane.
- Concealed fault.
- Inferred fault.
- Dip and strike of joint plane.
- Fault breccia.
- Shear zone.
- Anticlinal axis.

- Bulldozed bench.
- Costeans and pits.
- Diamond drill hole.

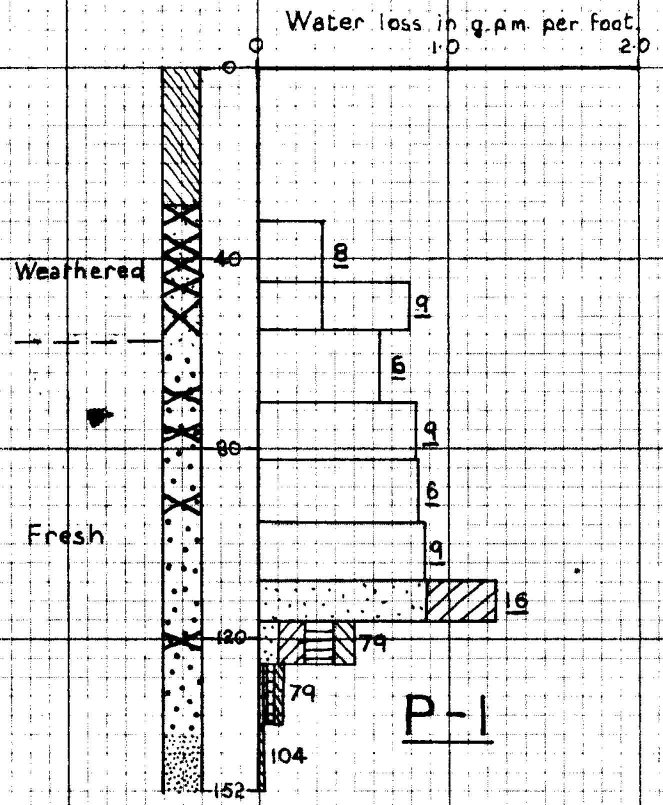


To accompany Record No. 1962/140

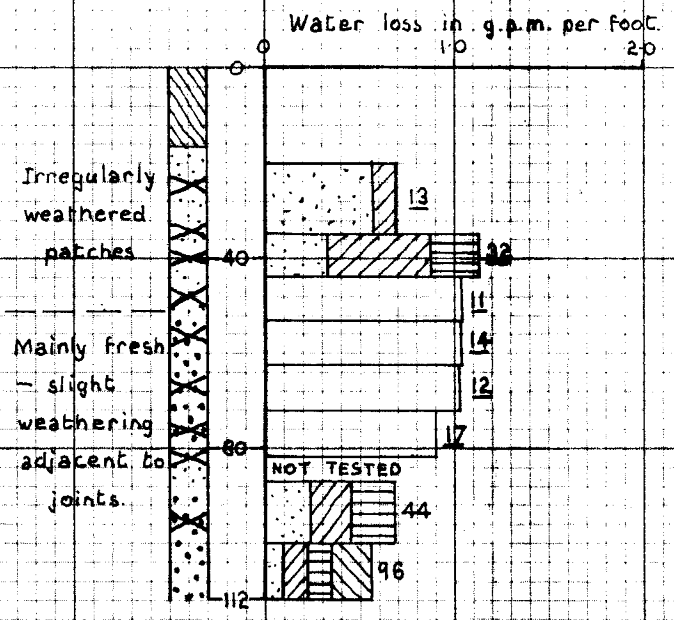
155/16/20

UPPER COTTER DAMSITE E

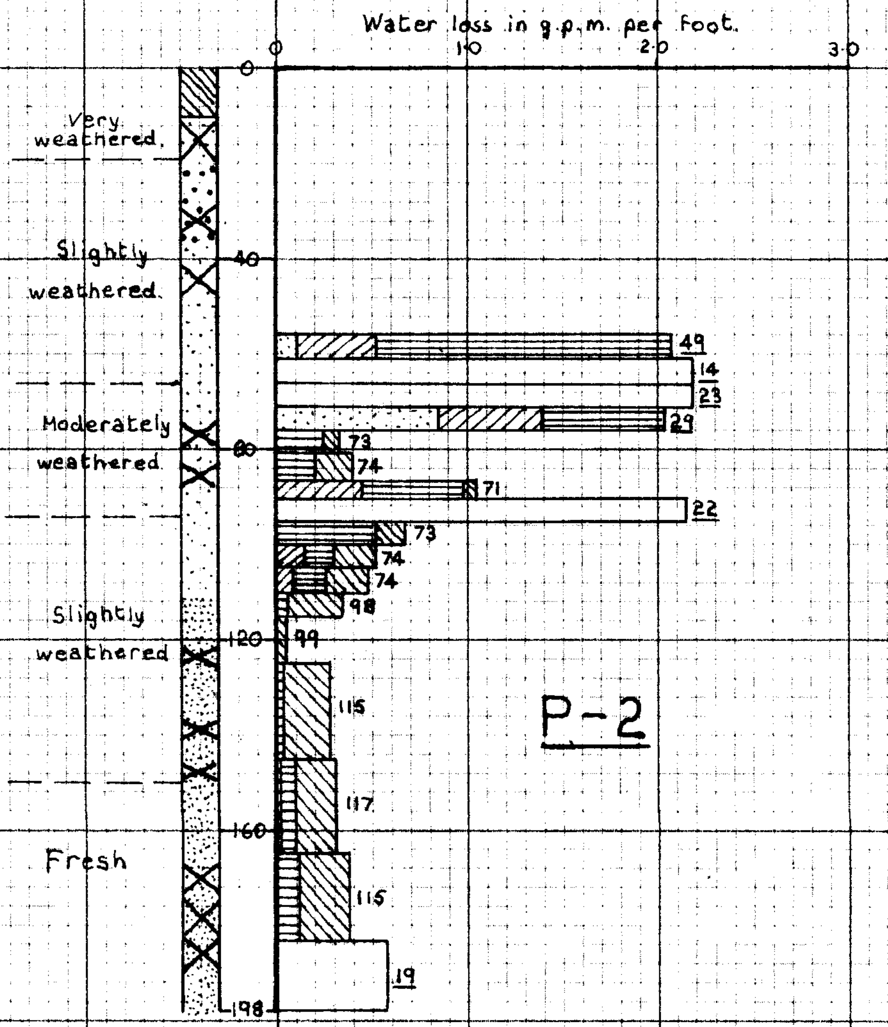
DRILL CORE LOGS AND WATER PRESSURE TEST RESULTS



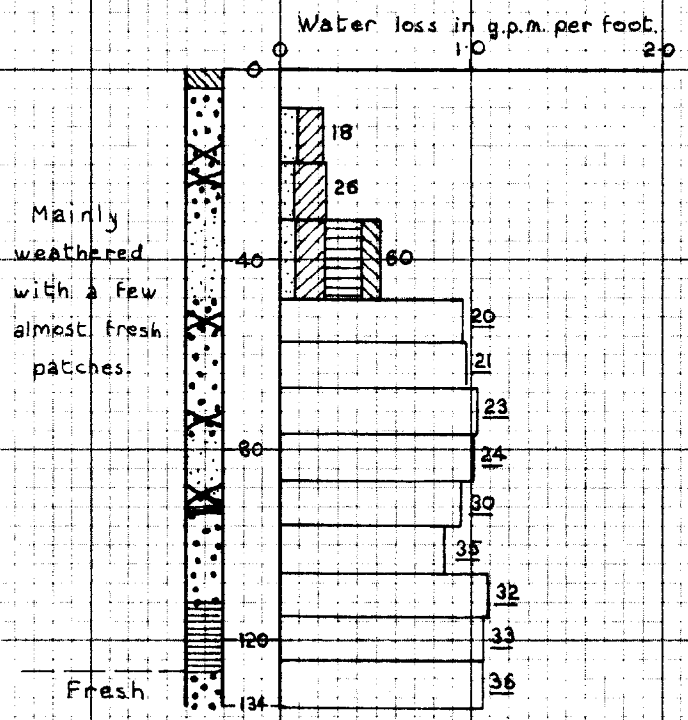
P-1



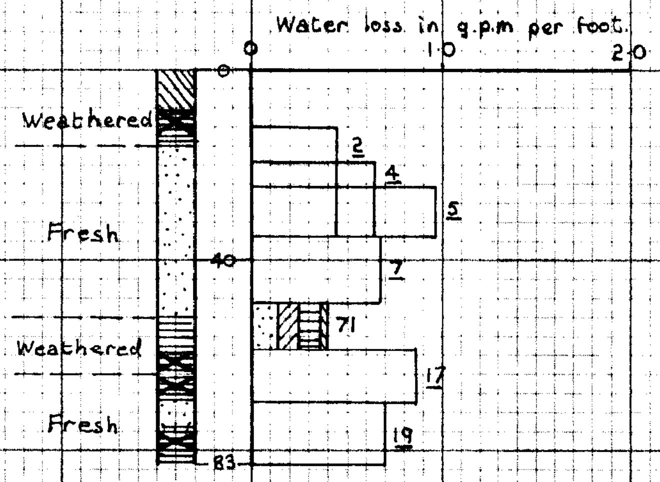
P-1B



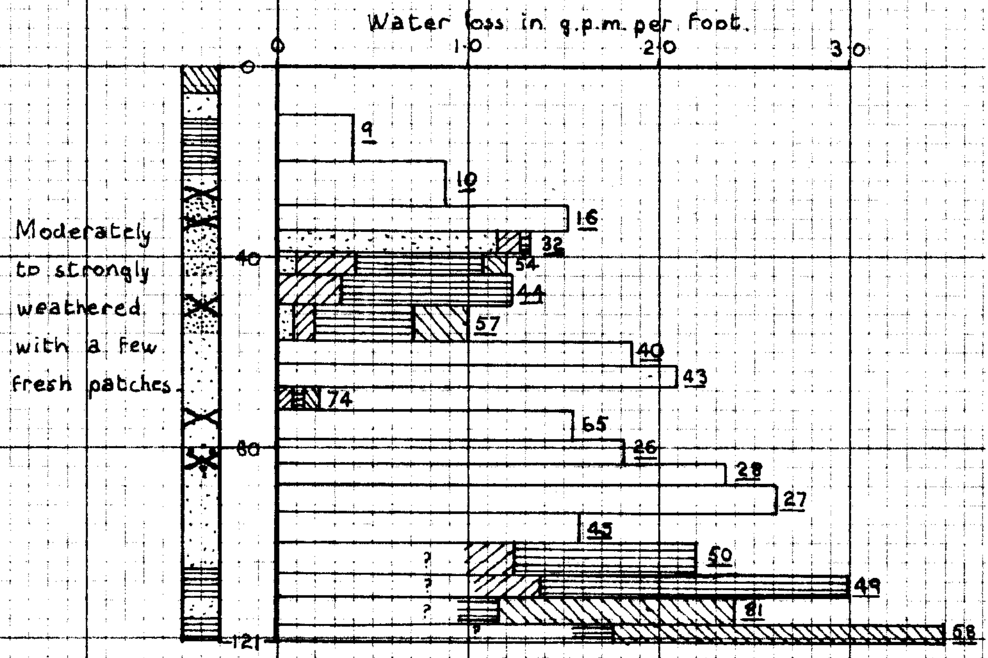
P-2



P-3

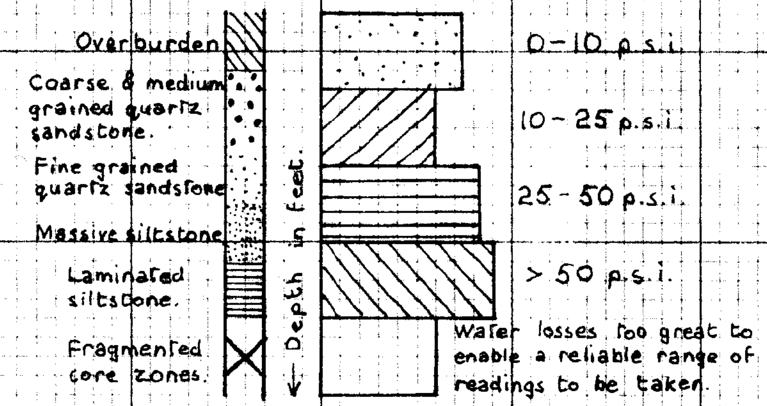


P-4



P-5

REFERENCE



74 Maximum pressure obtained (higher readings possible). } in p.s.i.
12 Maximum possible pressure with equipment used.

NOTE:- Pressures are corrected for friction loss and weight of column of water in drill rods above the water table.

Bureau of Mineral Resources, Geology and Geophysics. Dec 1961

To accompany Record No 1962/140

PLATE 6

DAMSITE E — SECTION ALONG PROPOSED AXIS

To accompany Record No 1962/140

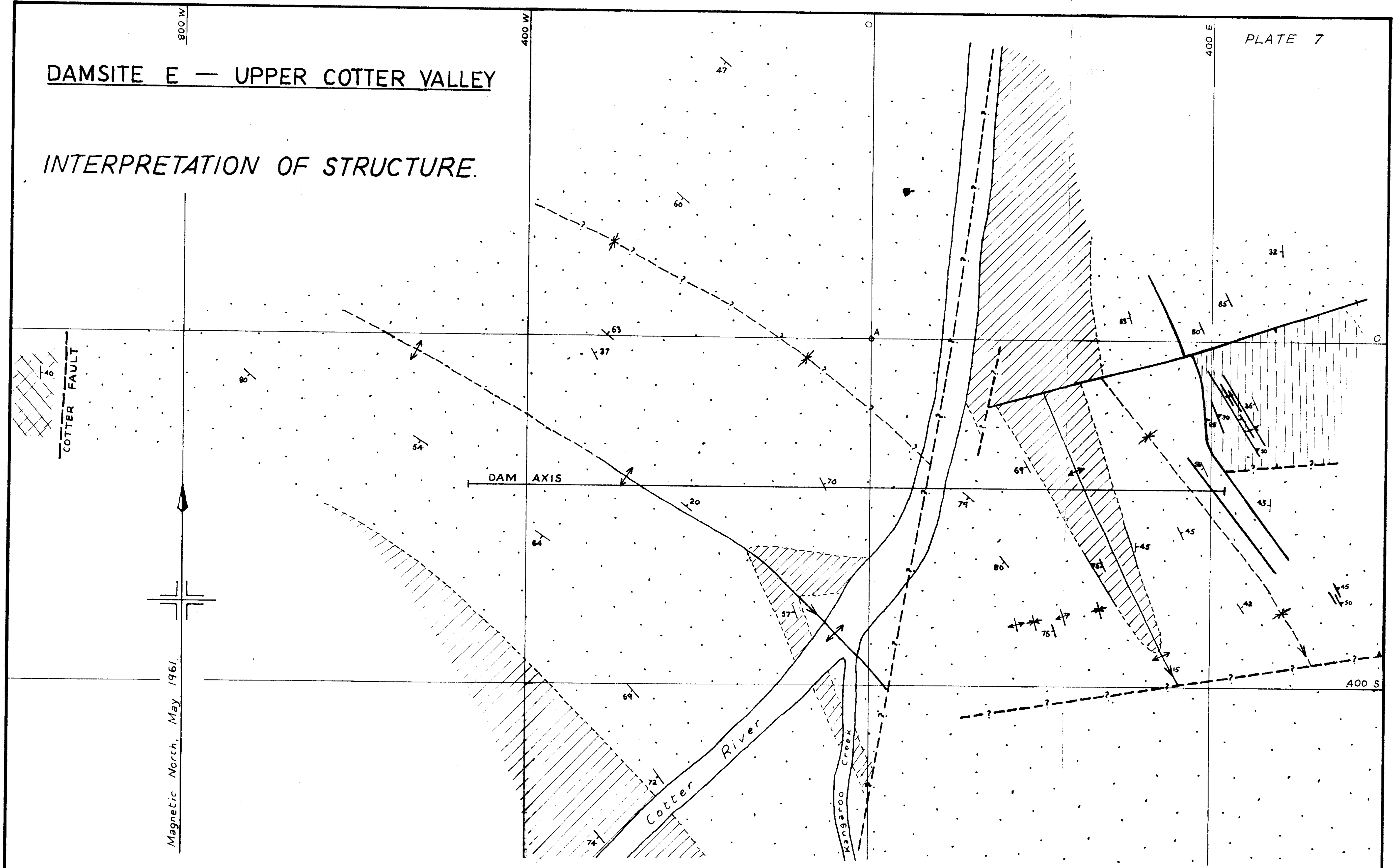
155/16/22

Bureau of Mineral Resources, Geology and Geophysics. January, 1962.

PLATE 7.

DAMSITE E — UPPER COTTER VALLEY

INTERPRETATION OF STRUCTURE.



SCALE:- 1 INCH = 100 FEET

FEET 100 0 100 200 300 400 500 FEET

Tidbinbilla Quartzite.

▥

Franklin beds.

- ⬚ *Interbedded massive sandstones and siltstones.*
- ▨ *Finely laminated shale, siltstone and sandstone.*
- ▩ *Phyllite.*

45	*Dip and strike of bedding.*
15 ↔	*Anticline, position accurate, showing plunge.*
--↕--	*Anticline, position approximate.*
←✳--	*Syncline, position approximate, showing plunge.*
-?-✳-?	*Syncline, inferred.*
⁀	*Accurate geological boundary.*
┄	*Approximate geological boundary.*
━	*Fault, position accurate.*
╍	*Fault, position approximate.*
--?--	*Fault, inferred.*
30 ▲	*Normal fault with dip.*

To accompany Record No. 1962/140

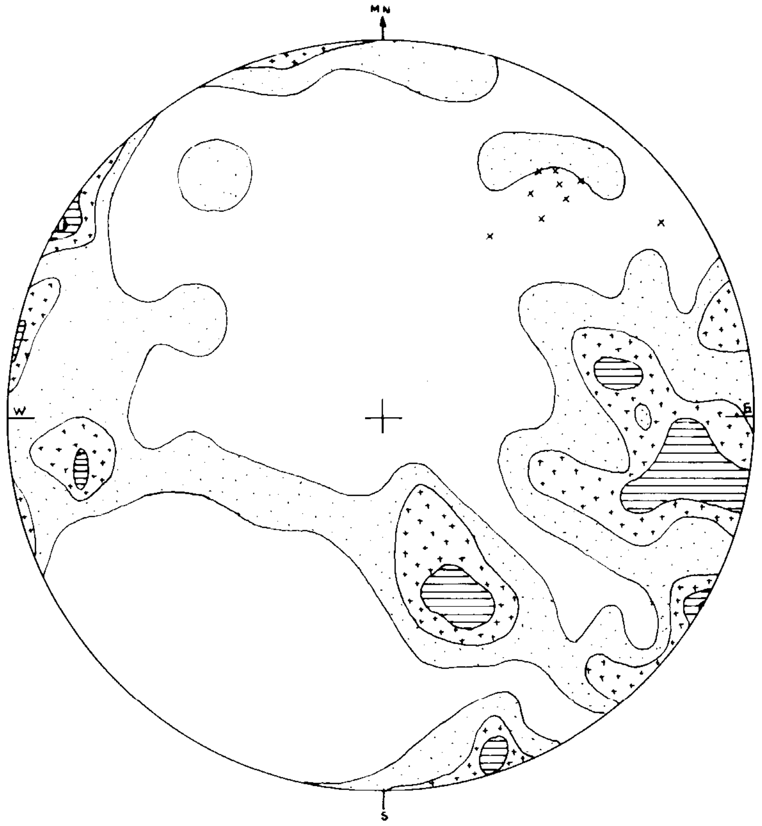
I55/16/23

Bureau of Mineral Resources, Geology and Geophysics, Jan, 1962.

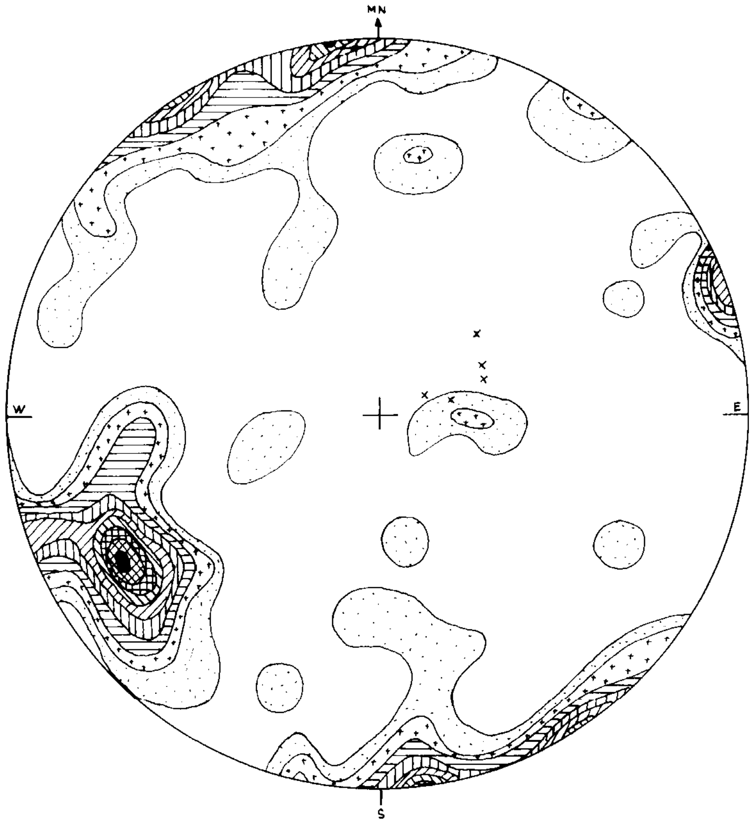
PLATE 8

CONTOUR MAPS OF JOINT PATTERN STEREOGRAMS

1 200 MEASUREMENTS FROM THE PROMINENT QUARTZ SANDSTONE OUTCROP NEAR STATION U



2. 100 MEASUREMENTS FROM TIDBINBILLA QUARTZITE BLUFFS NEAR A 8 & A 9.



POLES OF THE JOINT PLANES WERE PROJECTED IN TO THE LOWER HEMISPHERE AND THEN BY POLAR PROJECTION ON TO THE EQUATORIAL PLANE.

THE PERCENTAGE DISTRIBUTION OF THE POLES OVER THE NET IS REPRESENTED BY CONTOURS.

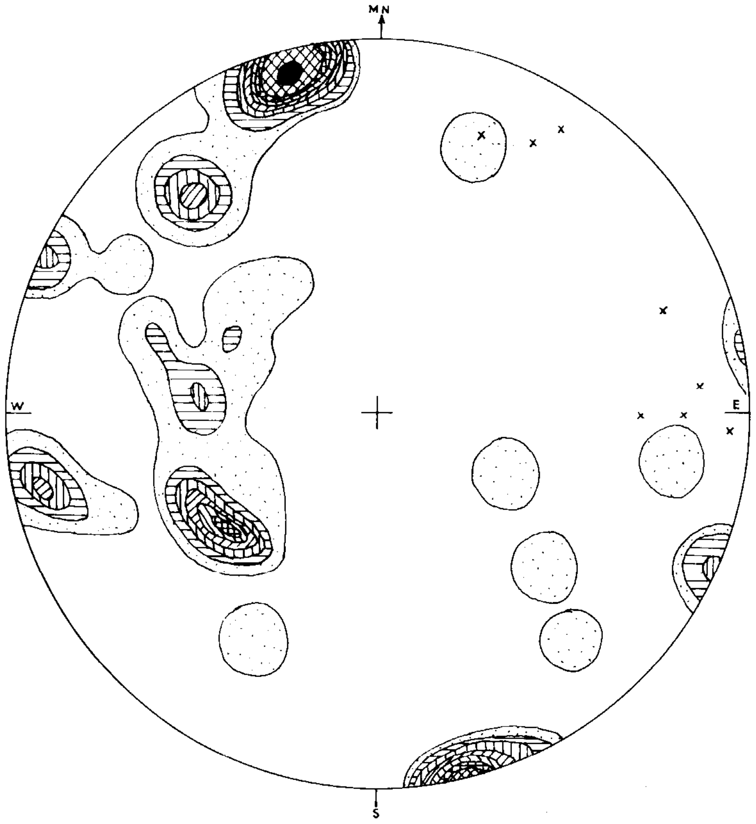
AN EQUAL AREA NET WAS USED THROUGHOUT.

× REPRESENTS POLE OF BEDDING PLANE.

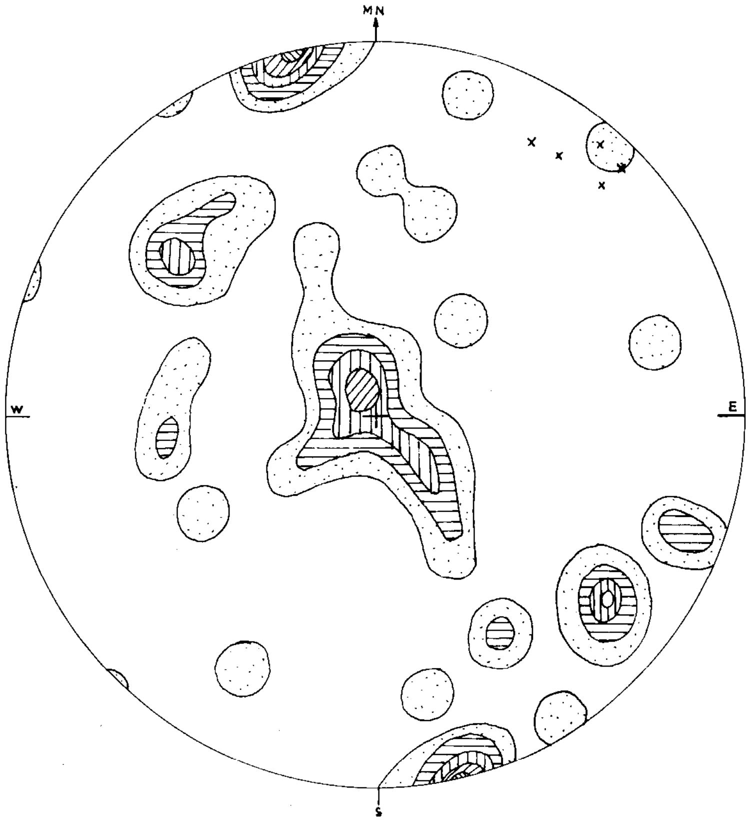
PERCENTAGE DISTRIBUTION

☐	⋯	⁘	▤	▥	▨	▧	▦	▩	■
0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10

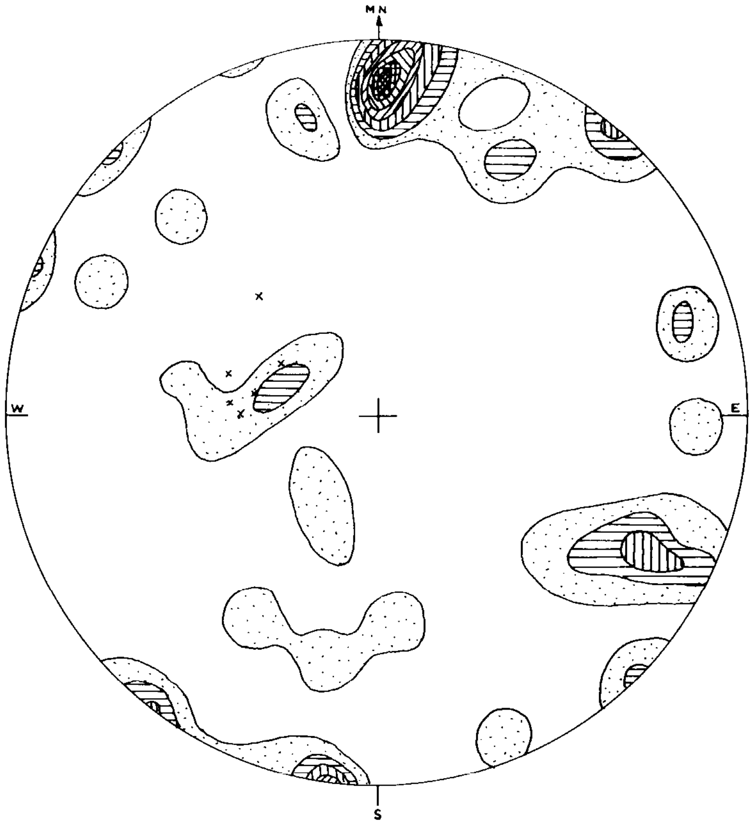
3. 48 MEASUREMENTS FROM QUARTZ SANDSTONE OUTCROPS NEAR STATION K.



4. 50 MEASUREMENTS FROM QUARTZ SANDSTONE OUTCROPS NEAR STATIONS J & A 3.



5. 46 MEASUREMENTS FROM COARSE QUARTZ SANDSTONE OUTCROPS NEAR A 5.



PERCENTAGE DISTRIBUTION

☐	⋯	▤	▥	▨	▧	▦	▩	■
0-2	2-4	4-6	6-8	8-10	10-12	12-14	14-20	20-25

To accompany Record No 1962/140

155/16/24

Bureau of Mineral Resources, Geology and Geophysics: Dec. 1961.