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BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

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Upper Ramu Hydro-electric Scheme: Investigation of the Possibility of Leakage from No. 1 (Yonki) Reservoir, T.P.N.G.

by

J.C. Braybrooke and E.K. Carter

UPPER RAMU HYDRO-ELECTRIC SCHEME: INVESTIGATION OF THE POSSIBILITY OF LEAKAGE FROM No.1 (YONKI) RESERVOIR, T.P.N.G.

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SUMMARY

Results of the geological and geophysical work carried out in the Arona Basin in 1968 are briefly described and the various possible leakage paths from the proposed reservoir are discussed.

It is concluded that, from the available evidence, the risk of leakage from the reservoir is extremely slight. Three possible courses of action are suggested.

INTRODUCTION

In the draft of the Snowy Mountains Hydro-Electric Authority's report on the feasibility of developing the Ramu Gorge for hydro-electric power*, attention is drawn to the possibility of leakage from the proposed No.1 Reservoir through beds of marble adjoining Yonki Dome. At the request of Dr. E.K. Carter, Supervising Geologist, Bureau of Mineral Resources (B.M.R.), 8½ geologist days were spent in mapping outcrops in the Upper Ramu No.1 reservoir area. This work was carried out by J.C. Braybrooke and R.J. Tingey during the first week of April, 1968 (Braybrooke, 1968).

Two areas, that at the head of the proposed storage basin and that extending south from Little Yonki Creek (the main southern tributary of Yonki Creek) were examined in detail to ascertain the distribution, structure, and likely permeability of marble in the proposed storage area and to define accurately the eastern limit of Yonki Dome. In addition, mapping of the basal, or near-basalt conglomerates of the Lake Beds was carried out in tributaries to the east of the proposed damsite.

Following the mapping, geophysical work was undertaken, both in the storage area and on an alternative site for the storage dam, by W. McDevitt of the Commonwealth Department of Works, Central Testing and Research Laboratories (CTRL), in the latter half of 1968 (McDevitt, 1969). The objectives were to provide, if possible, information on the following points:-

(a) thickness of lake sediments in the reservoir area,

(b) location and shape (both near-surface and at depth) of the eastern margin of the body of Akuna Dolerite that forms Yonki Dome,

(c) distribution of the Omaura Greywacke beneath the lake sediments in, and west of, the reservoir area,

(d) distribution of marble in the Omaura Greywacke in, and west of, the reservoir area,

(e) if present, whether the marble is sound or cavernous, and

(f) whether dolerite dykes intrude the Omaura Greywacke in the area of interest, below the lake sediments; and if so, the abundance of such dykes.

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* For location and proposed layout of the No.1 Scheme see earlier reports, e.g. C.D.W. (1966) or MacGregor (1967).

The results of the geological mapping and the geophysical work in the storage area were discussed at a conference held at the Commonwealth Department of Works, Central Testing and Research Laboratories, Port Melbourne, on 4th June, 1969. The conference was attended by Messrs G. Browning and W. McDevitt for C.D.W. and Dr. E.K. Carter for B.M.R. A slightly revised form of the conclusions reached are presented in this report.

To check the geophysical interpretation of the data obtained from the right bank of the proposed damsite, a costean was dug, and some further mapping of the basal conglomerate was carried out by I.S. Cumming, at the end of May, 1969.

Logs of four holes drilled in 1965 at the two alternative storage damsites are included as Appendix 1.

GEOLOGY

Omaura Greywacke

The formation of Lower Miocene age consists of discontinuous lenses of marble overlain by a thick succession of fine-grained greywacke, siltstone and shale. In places, the siltstone has been metamorphosed to a hornfels.

The contact zone between siltstone of the Omaura Greywacke, and Akuna Dolerite is exposed in road cuttings on Yonki Dome. Although severe weathering hinders interpretation, the contact appears to be gradational with numerous basic intrusions cutting through the partially assimilated nearby sediments.

Marble

The marble is generally white, with black laminae along bedding planes, at half-inch to eight-inch spacings. A few zones have thinly interbedded silty layers. Numerous coarse-grained, basic dykes cut the marble. At least some of these dykes have been metamorphosed (see, for example, specimen 1519*). Outcrops of marble are strongly fractured with fracture spacings averaging one to two feet. At, or near, the surface, solution of calcium carbonate has rounded the joint margins, pitted the marble surfaces and formed solution cavities up to three inches wide. Underground tunnels and sink-holes occur.

Marble crops out about half-way up Little Yonki Creek; it strikes north-north-east and dips to the east. Where Little Yonki Creek branches at position 41,650E, 69,450N, a solution tunnel, three feet by five feet in cross-section, passes beneath a low ridge (see Plate 2a). Downstream of the tunnel, springs occur in marble in the right bank.

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* All specimen numbers refer to specimens held in the Geological Office, Port Moresby.

In the tributary of the Ramu River immediately to the south-east of Little Yonki Creek only Lake Beds (see below) are present below maximum flood level (R.L. 4,135 feet) * Farther up the tributary, hornfels and dolerite crop out but marble is absent.

Marble crops out between co-ordinates 46,000E to 50,000E and 49,000N to 54,000N, at the head of the proposed reservoir area (see Plate 2b). The bedding measurements obtained indicate that the sequence is folded into some form of a basin. Numerous sink holes occur along the trend of the marble and a side stream runs underground for a distance of 900 feet before emerging to flow into the Ramu River. Outcrops are present in the Ramu River to as far downstream as 49,600E, 53,950N. Lake Beds and recent alluvium hide any further extension of the unit.

Hornfels and Siltstone:

Grey-green and black, siliceous, hornfelsed siltstone is normally fresh and hard, often showing finely crenulated bedding. Minor pyrite veining is associated with these rocks in places especially near Yonki Dome. Elsewhere, especially where overlain by lake beds, shale, siltstone and minor amounts of sandstone are completely weathered, soft and weak. Numerous basic dykes cut the unit. No leakage paths are expected within it. However, the contact between this unit and the lake beds may have a singificant permeability.

Lake Beds

Conglomerate and clay bands occur in approximately equal proportions towards the base of the lake beds, which are believed to be Recent in age. Higher in the stratigraphic sequence, silty clay predominates. Bedding is nearly horizontal.

The near-basal or basal conglomerate cropping out below the Bailey Bridge at R.L. (reduced level) 4,000 feet in the Ramu River bed, in the first side creek on the right bank below the bridge, in the trench along line B - B_1 (from river level to R.L. 4,047) and at R.L. 3,970 to 4,070 feet in the second creek on the right bank (see Plate 2c), are moderately well indurated. Rounded boulders, generally less than ten inches in diameter, and more rarely up to 6 feet in diameter, of dolerite, diorite, silicified hornfels, and other rock types, are set in a firm to weak, sandy-clay matrix which can be dug with crowbars. Since deposition, the conglomerate has undergone chemical weathering to such a degree that many of the smaller boulders, less than 12 inches in diameter, are now completely weathered. Larger boulders have an outer skin of completely weathered material four to six inches thick. It is probable that volume change, resulting from the weathering, has increased the compaction of the matrix.

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* R.L. 4,135 was the maximum flood level adopted for planning purposes at the time of the investigation. The presently adopted figure is R.L. 4,136, with full supply level at R.L. 4,120, but no change from the earlier figures have been made in the drawings and text of this report.

Owing to the clayey nature of the matrix, the conglomerate has a low to very low primary permeability. However, seepage is apparent in places, especially from the sides of the second creek, though no seepage was observed in the costean, B - B_1, even after heavy rain. Results of earlier mechanical and permeability tests (both in plan and in the field) are given in CTRL (1965).

In the costean B - B_1, the conglomerate is overlain by gravel with only scattered boulders from R.L. 4,024 feet to R.L. 4,047 feet. From R.Ls 4,047 to 4,060 feet there is a yellow-white, stiff, silty micaceous clay with thin layers of compacted organic matter.

Outcrops of similar, moderately indurated, conglomerate occur at 50,200E, 73,300N in the first tributary on the right bank, 2,900 feet up-river of the bridge (Plate 2c). This conglomerate crops out at R.L. 4,005 to 4,010 feet over a distance of 600 feet. At R.L. 4,010 feet the conglomerate overlies a large boulder of highly weathered basic rock, at least 150 square feet in area. Farther up the same creek, thin bands of similar conglomerate are interbedded with grey, micaceous clay.

MacGregor (1965, p.3) observed that coarse conglomerate and sand at the base of the lake sediments is exposed in a cliff half a mile downstream from the damsite. Further exposures of basal sediments overlying Omaura Greywacke occur at positions 72,600E, 43,100N; 73,150E; 43,250N and 45,000E, 65,400N (Plate 2a). At the first two positions, friable sandy conglomerate overlies highly weathered siltstone intruded by dykes, at R.L. 4,060 feet and 4,050 feet respectively. In the third position, micaceous sand overlies possibly-completely-weathered, columnar-jointed siltstone at R.L. 4,180 feet.

In 1965, four holes were drilled through the lake beds at, and downstream of, the Bailey bridge (see Appendix 1 for drill logs and Plate 2c for locations). The logs, summarised below, indicate an undulating lake floor.

Hole No.	R.L. Collar (feet)	Thickness of lake beds drilled (feet)	R.L. lake floor (feet)
RDS 1.	4008.6	58	3950.6
RDS 2.	3990	11	3979
RDS 3.	4101.5	166.5	3935.5
RDS 4.	4011.9	63.5	3948.4

Seepage is noticeable from above the more clay-rich portions of the lake beds. The silty and clayey beds have little cohesion and tend to slump and creep when saturated, forming shallow gravity slumps about 10 to 15 feet in depth. The slumps leave residual slopes of 15 degrees or less. Serious slumping appears to be restricted to several horizons of highly plastic clay (Read, 1966).

When the reservoir fills, extensive local slumping of the silty and clayey lake beds is expected to occur, particularly in the banks of deeply incised gullies. However, as the valley slopes below R.L. 4135 are generally less than 13° and long slopes greater than 15° occur only in a few of the tributary gullies, the total volume of silt contributed to the reservoir floor is not expected to be large. Extensive testing will be necessary to enable a quantitative evaluation to be made of the effect of silt on outlet works. Some slopes at the downstream end of the reservoir may have to be stabilized and protected by rip-rap.

GEOPHYSICS

Field Work

Five seismic refraction and magnetometer traverses were made in the reservoir area. Another series of traverses were made in the vicinity of the proposed storage damsite.

In the reservoir area, traverse A was along a straight water course draining east, south of the Lae - Kainantu road, from 42,550E, 59,600N, to 51,000E, 58,200N. Traverse B, near the head of the proposed reservoir, ran from 44,400E, 55,400N, along a small tributary, crossing the Ramu River, finishing near 50,000E, 53,200N. Traverse C ran from 43,700E, 63,250N, across the highway to 51,000E, 61,300N. Traverses D and E ran along the bed of the northern-most watercourse in the western part of the reservoir; D ran approximately from 44,850E, 63,800N, to 44,950E, 64,400, while E ran from 44,550E, 67,350N to 44,550E, 67,950N (see Plate 1).

Significance of Results

(a) The thickness and low permeability of the lake sediments are such that the only possible points of entry into any existing solution cavities in marble from the proposed reservoir, assuming maximum flood water level as 4,135 feet are -

(i) Near the head of the proposed reservoir, along the Ramu River between approximate co-ordinates 47,400E, 54,400N and 50,500E, 53,400N.

(ii) (From observation in the field of near-basal lake sediments and one bedrock exposure in the gully - see Plate 2a) through the floor of the gully that passes through co-ordinates 44,500E, 67,500N; only that part of the gully that occurs below R.L. 4,147 feet and has a shallow cover of lake sediments could provide a point of entry. The seismic traverse along part of the gully (Traverse E) indicated strata of 5000 - 5500 feet/second velocity to a depth of about 180 feet. With these velocities the strata cannot be unequivocally identified as either lake sediments or decomposed bedrock; seismic tests showed that near surface marble has a velocity of about 8000 feet/second; further, an exposure of dolerite was mapped in a nearby tributary of the gully (see Plate 2a). It is therefore concluded on two grounds that there is little danger of the gully providing a point of entry underground for water of the reservoir. The grounds are: the probable absence of marble and the presence of dolerite that would inhibit the development of widespread cavities in any marble present.

(b) Traverse B (near the head of the proposed reservoir) indicates that the cover of lake sediments along the traverse line and south of the Ramu River is less than 30 feet, and generally less than 20 feet. The traverse results can be interpreted to indicate widespread occurrence of marble (of unknown thickness) east of chainage 4200 (which is 300 feet west, along the traverse line, from the Ramu River). Marble is also exposed at chainages 2900 - 3250 and at 3400 - 3700. Dolerite crops out in these areas and would probably have effectively prevented the development of a sub-surface drainage system north of the river in this part of the traverse.

(c) The thickness of weathered bedrock with velocities 5,000 - 6,500 feet/second along traverses A and C in those sections below the proposed reservoir area ranges from 120 - 200 feet. Velocities of these magnitudes are not characteristic of marble, it is therefore probable that no marble beds of greater horizontal thickness than, say, 100 feet are present. The possible presence of thinner marble bands cannot be excluded.

(d) Velocities of 8,000 feet/second in the eastern 1,000 feet of traverse C could be interpreted as indicating the presence of marble (under at least 60 feet of lake sediments). However, the magnetometer readings are more in keeping with weathered siltstone or greywacke than with marble.

(e) The location of the eastern margin of the gabbro was not established but it was found that the gabbro on Yonki Dome was very deeply weathered. If this is the general condition, it is unlikely that gabbro overlies the greywacke at the western limits of traverses A and B since the depths to fresh rock are 150 and 70 feet respectively.

DISCUSSION OF POSSIBILITY OF LEAKAGE FROM RESERVOIR

Two situations need to be considered:

Case A: An integrated drainage system in the marble of the area, formed before the lake sediments were deposited.

Case B: An integrated drainage system formed after the lake was drained, i.e. in the present erosional cycle.

Considering Case A: It is unlikely that the ancestral Ramu River had an outlet from the Arona basin at an elevation equal to, or lower than the present one. There is no geomorphological evidence for such an outlet, and the greatest known thickness of lake beds occurs near the head of the Ramu Gorge. However, should there have been such an outlet, an associated subterranean outlet through marble could only have led eastwards into the Markham Valley, as the large body of granodiorite exposed in the Ramu Gorge would have blocked any passage to the north. Available evidence suggests that intrusives extend continuously from the granodiorite of the Ramu Gorge to east of Kassam Pass; further, any drainage system would have been severely disrupted by the movements which formed the lake in which the lake sediments accumulated to a depth of at least 350 feet.

It is therefore concluded that any drainage system formed within the marble would have been confined to the Arona basin. It has not been conclusively proved that there is no integrated buried drainage system connecting possible intake beds near the head of the proposed reservoir with an outlet outside of the reservoir and at a level lower than R.L. 4,135 feet. It is believed, however, that leakage from the proposed reservoir by such a drainage system is most unlikely to occur for the following reasons:

(a) The marble beds of the area tend to be lenticular,

(b) The strata are complexly folded,

(c) Wherever exposed in the area the Omaura Greywacke, in which marble occurs, is cut by steep-dipping dolerite dykes which would inhibit underground drainage.

(d) The Omaura Greywacke is extensively faulted. Some of the faults probably relate to the time of intrusion of the granodiorite, gabbro and dolerite (these would have interrupted the continuity of the marble). Other ~~faults~~ may be related to the later movements which formed the lake and would have further disrupted both the strata and any solution channels in the marble.

(e) As the lake sediments accumulated they would have penetrated any openings in marble in the lake floor and effectively plugged them. Any cavities below R.L. 4135 probably had a load of at least 200 feet of sediment on them.

Considering Case B: For the reasons given for Case A, it is considered that no subterranean outlet from the Arona Valley has developed since the lake was formed within the valley. The time available for such a lengthy and tortuous system to develop is very short (probably less than 60,000 years). Further, had such a system developed before the lake was drained by downcutting of the barrier, the lake water, because of the head available, would probably have enlarged the system to the point that the lake would have drained through the subterranean passage rather than cutting through the barrier.

The only possible leakage path from the proposed reservoir is therefore within the Arona Valley. Marble is known in the valley floor (i.e. below, say R.L. 4,200) outside the reservoir in the following places: -

1. South of the Ramu River, near the head of the proposed reservoir.
2. Little Yonki Creek.
3. Yonki Creek.
4. Chasm Creek
5. In drillholes for the investigation of the machine hall and tailrace tunnel sites.
6. In the Ramu River in the general area of the tailrace tunnel portal.

Subterranean drainage systems have developed in Chasm Creek (4 above) and south of the Ramu River (1 above). In each case a substantial hydraulic gradient is involved, but there is no evidence for a more deepseated and widespread drainage system than the obvious one. Further, during the extensive drilling programme in the area, no large voids were found though a few rounded joint surfaces were observed indicating solution by groundwater.

Considering the possibility of leakage from the proposed reservoir to each of the six points listed above:

1. The area south of the Ramu River, near the head of the proposed reservoir is within the catchment of the proposed reservoir and therefore cannot, in itself, provide a possible outlet from the reservoir.

2. In Little Yonki Creek, exposures of marble lie at elevations ranging from R.L. 4,200 to 4,100 feet. They are therefore at a higher level than the possible intake beds exposed in the head of the proposed reservoir (R.L. 4,080) and no unfavourable gradient exists. The distance between the two points is about 3½ miles; in the same (straight line) distance the river falls about 100 feet. Even between maximum flood water level, R.L. 4,135 (<u>not</u> full supply level), and the marble in Little Yonki Creek the gradient is only 1 : 530. Further, dolerite crops out in Little Yonki Creek, and the only known exposures of bedrock between the marble in Little Yonki Creek and the head of the reservoir are of hornfelsed siltstone and dolerite. It is therefore concluded that there is no risk of leakage to Little Yonki Creek.

3. In Yonki Creek, marble occurs down to R.L. 3,960, giving a gradient from the intake beds near the head of the proposed reservoir at full supply level (R.L. 4,115 feet) of about 1 : 150; the distance is about 4½ miles. Dolerite is also exposed in Yonki Creek. However, for reasons (a) to (d), given under Case A, leakage into Yonki Creek is considered extremely unlikely.

4, 5, and 6. The geology between the confluence of Yonki Creek and Ramu River is better known than farther upstream because of larger exposures of bedrock along the Ramu River and because of the extensive drilling associated with the site investigation for the proposed underground works. Most holes drilled into bedrock intersected dolerite. Dolerite also occurs extensively in the Ramu River, both upstream and downstream of the proposed headworks for the power station; most dykes strike roughly east-west and dip steeply. For this reason alone leakage north from the reservoir as far as the underground elements of the scheme is considered impossible. Leakage from Yonki Creek into the machine hall is also not considered a serious risk for the same reason.

It is therefore concluded that the risk of leakage from the reservoir is extremely slight.

Possible action to be taken:

As the final conclusion reached must be regarded as a matter of judgment rather than a proven matter, the Department of Works may wish to carry out further work to verify it. It is suggested that three courses are possible:-

(a) To accept the judgment that leakage is most unlikely to occur from the reservoir:

(b) To carry out diamond drilling to (i) determine the thickness of the marble in the upper reservoir area; (ii) check for the presence of cavities in the marble; (iii) ascertain the significance of the geophysical results:

(c) To assess the feasibility and cost of blanketing exposures of marble within the proposed reservoir area.

At the design investigation stage for No.1 dam it will also be necessary to establish more accurately the permeability and distribution of sand and conglomerate in the abutments of the dam, and elsewhere where leakage paths are short, as recommended by MacGregor (1965).

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APPENDIX I

Logs of Diamond Drill Holes
RDS 1, 2, 3, and 4.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER RAMU HYDRO-ELECTRIC SCHEME

LOCATION Near proposed dam site, 16' from northern corner of bridge on bearing 358°, Drawing N° P.C. 65/29, Sheet 1.

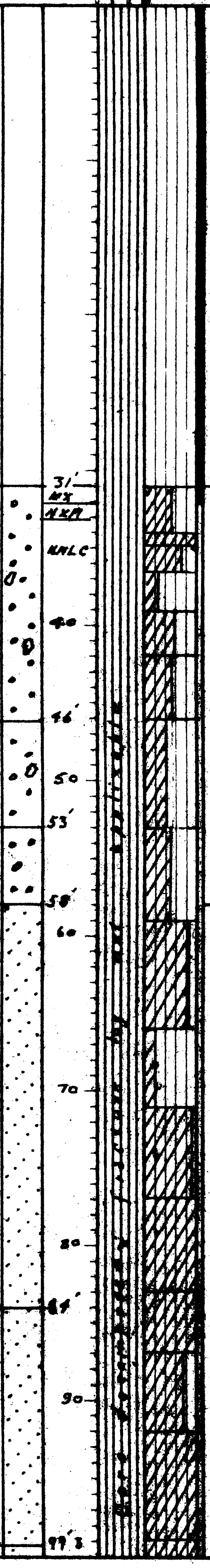
ANGLE FROM HORIZONTAL -90° DIRECTION —

COORDINATES 48040E 72795N R.L. 4008·6'

HOLE No. RDS 1

SHEET 1 OF 2

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION LITHOLOGY, COLOUR, STRENGTH, HARDNESS, ETC	DEPTH & SIZE OF CORE	STRUCTURES JOINTS, VEINS, SEAMS, FAULTS, CRUSHED ZONES
	Percussion drilled		
Alluvium	Broken coarse alluvium, and core lengths to 7"; pebbles and large cobbles of greywacke, siltstone and dolerite. Between 31' and 33' a few inches of matrix, clay and sandy clay	31' NX HXM NMLC 40	
Alluvium	Sand, pebbles, and small cobbles. Matrix consists of clay and sandy clay	46' 50	
Alluvium	Pebbles, one cobble. Traces of clayey matrix	53'	
? — ?	? — ?	58'	
Decomposed greywacke	Decomposed, fine to medium grained fragments. Clayey; soft	60 70 80	Joints not examined in detail; obscured by decomposition. Joints are planar, some slickensided, coated with iron oxides, and decomposed micaceous or chloritic minerals.
Siltstone Decomposed	Very fine grained Clayey; soft Core lengths 1½-5" below 97'; firm but not hard	84' 90	
Greywacke		97'3"	



DRILL TYPE MINDRILL E12A
FEED Hydraulic
CORE BARREL TYPE Triple tube
DRILLED W. Adams
COMMENCED 8-3-65
COMPLETED 10-3-65
LOGGED BY D.E. Gardner
VERTICAL SCALE 1 inch : 10 feet

NOTES

FRACTURE LOG – Number of fractures per foot of core. Zones of core loss are blacked in.
BEDDING AND JOINT PLANES – Angles are measured relative to a plane normal to the core axis.

WATER PRESSURE TESTS
PACKER TYPE
SUPPLY LINE
VERTICAL SCALE
Figures given are gauge pressures. Test sections are indicated graphically by stippled in strip.

PHOTOGRAPH REFERENCE SYSTEM
BLACK AND WHITE
COLOUR

BUREAU OF MINERAL RESOURCES,
GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER RAMU HYDRO-ELECTRIC SCHEME
LOCATION Near proposed dam site, 14' from northern corner of bridge on bearing 358°, Drawing N° P.C.65/29, Sheet 1
ANGLE FROM HORIZONTAL -90° DIRECTION —
COORDINATES 46040E 72795N R.L. 4008·6'

HOLE NO. RDS 1

SHEET 2 OF 2

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION LITHOLOGY, COLOUR, STRENGTH, HARDNESS, ETC	GRAPHIC LOG	DEPTH & SIZE OF CORE	FRACTURE LOG	FT & % CORE RECOVERY	CASING	STRUCTURES JOINTS, VEINS, SEAMS, FAULTS, CRUSHED ZONES	WATER LEVEL	WATER PRESSURE TEST Loss in gallons per minute per foot	PHOTO REF. NO. CORE BOX	CORE BARREL
Greywacke Decomposed	Core lengths 2-4" from 105-106'2 and 107'8-108'; firm but not hard. Original rock fine to medium grn.		100 NMLC 108'	Not applicable			As above				
END	OF HOLE										

Mindrill F62B
Hydraulic
CORE BARREL TYPE
Triple tube
DRILLER W. Adams
COMMENCED 4-3-65
COMPLETED 10-3-65
LOGGED BY D.E. Gardner
VERTICAL SCALE 1 inch : 10 feet

NOTES

FRACTURE LOG — Number of fractures per foot of core. Zones of core loss are blocked in

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WATER PRESSURE TESTS
PACKER TYPE
SUPPLY GAUGE
VERTICAL SCALE
Figures are gauge pressures
Test sections are indicated graphically by blocked in strips

PHOTOGRAPH REFERENCE SYSTEM
BLACK AND WHITE
COLOUR

BUREAU OF MINERAL RESOURCES,
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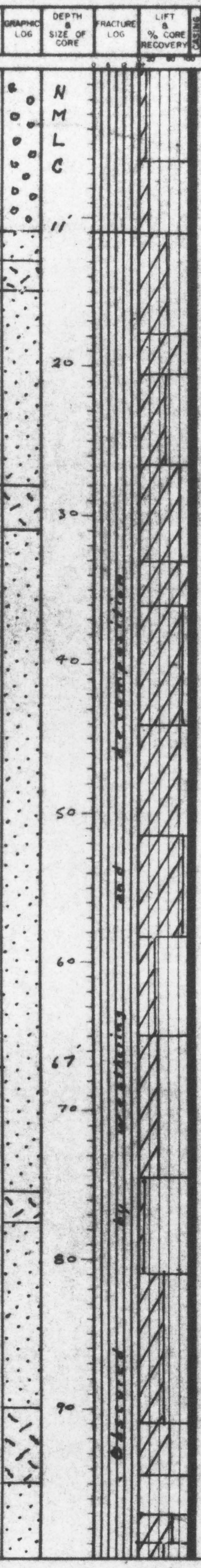
GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER RAMU HYDRO-ELECTRIC SCHEME
LOCATION Near left abutment, alternative site for storage dam.
ANGLE FROM HORIZONTAL 90° DIRECTION —
COORDINATES 47550 E 73900 N R.L. 3990'

RDS 2

SHEET 1 OF 2

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION LITHOLOGY, COLOUR, STRENGTH, HARDNESS, ETC.	STRUCTURES JOINTS, VEINS, SEAMS, FAULTS, CRUSHED ZONES
Alluvium Fines lost in drilling water	Broken core fragments dolerite and sillicified greywacke & siltstone; pebbles, micaceous med. grained sand.	
Greywacke and Siltstone decomposed to clay and silty clay. Probable decomposed dolerite from about 13' - 15' and 28' - 31'	Fine to medium grained. greywacke (green - grey clay) Probable dolerite, medium grained (cream - yellow clay) Siltstone (green-grey and brown grey clay) Bedrock soft and friable; collapses into hole below casing: Washed up in drilling water as clay and fragments of sand size, fine to coarse, and granules.	Obscured by weathering and decomposition
Greywacke and Siltstone decomposed to clay and weathered to small firm fragments. A few core lengths 2" - 4" Decomposed dolerite from 76'6 - 77'6 and about 90' - 95'	As above; fragments in drilling water to size of small pebbles tend to jam casing.	



WATER LEVEL

WATER PRESSURE TEST
Loss in gallons per minute per foot

PHOTO REF. NO.
CORE BOX
CORE

DRILL TYPE MINDRILL E1000
FEED Hydraulic
CORE BARREL TYPE NMLC Triple tube
DRILLER T. J. Condon
COMMENCED 19-8-65
COMPLETED 31-8-65
LOGGED BY D.E. Gardner
VERTICAL SCALE 1 inch : 10 feet

NOTES

FRACTURE LOG - Number of fractures per foot of core. Zones of core loss are blacked in.
BEDDING AND JOINT PLANES - Angles are measured relative to a plane normal to the core axis

WATER PRESSURE TESTS
PACKER TYPE
SUPPLY LINE
VERTICAL SCALE
Figures given are gauge pressures
Test sections are indicated graphically by blocked in strips

PHOTOGRAPH REFERENCE SYSTEM
BLACK AND WHITE
COLOUR

BUREAU OF MINERAL RESOURCES,
GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER RAMU HYDRO-ELECTRIC SCHEME
LOCATION Near left abutment, alternative site for storage dam
ANGLE FROM HORIZONTAL 90° DIRECTION –
COORDINATES 47550E 73900N R.L. 3990'

HOLE NO. RDS 2
SHEET 2 OF 2

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION LITHOLOGY, COLOUR, STRENGTH, HARDNESS, ETC	GRAPHIC LOG	DEPTH & SIZE OF CORE	FRACTURE LOG	LIFT & % CORE RECOVERY	CASING	STRUCTURES JOINTS, VEINS, SEAMS, FAULTS, CRUSHED ZONES	WATER LEVEL	WATER PRESSURE TEST Loss in gallons per minute per foot	PHOTO REF NO. CORE BOX	CORE SAMPLE
			100'	0 5 8	20 60 100						
Siltstone and grey-wacke; dolerite about 103'-105' Weathered and decomposed	Coarse porphyritic dolerite About 50% of firm to hard fragments of bedrock.		N M L C 110 117'	See under Structures			Obscured by Weathering and decomposition				
End	of hole										

DRILL TYPE MINRILL E1000
FEED Hydraulic
CORE BARREL TYPE NMLC
Triple tube
DRILLER T.J. Condon
COMMENCED 19-8-65
COMPLETED 31-8-65
LOGGED BY D.E. Gardner
VERTICAL SCALE 1 inch : 10 feet

NOTES

FRACTURE LOG – Number of fractures per foot of core. Zones of core loss are blacked in
BEDDING AND JOINT PLANES – Angles are measured relative to a plane normal to the core axis

WATER PRESSURE TESTS

PACKER TYPE
SUPPLY LINE
VERTICAL SCALE
Figures given are gauge pressures.
Test sections are indicated graphically by blacked-in strips

PHOTOGRAPH REFERENCE SYSTEM

BLACK AND WHITE
COLOUR

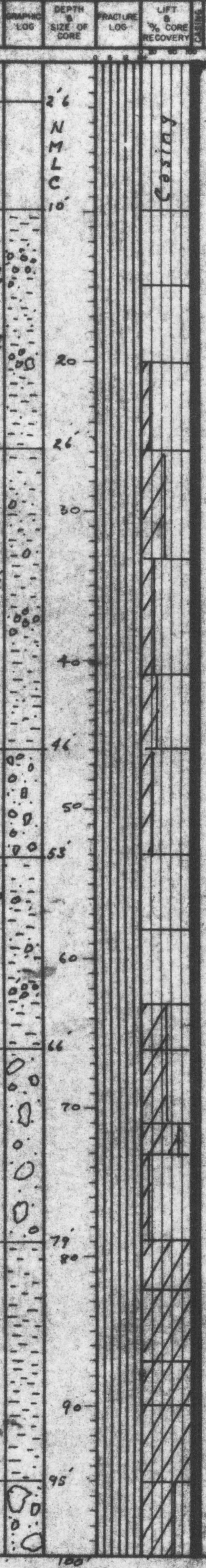
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER RAMU HYDRO-ELECTRIC SCHEME
LOCATION PROPOSED SITE FOR STORAGE DAM, right abutment, near top water level
ANGLE FROM HORIZONTAL -90°
DIRECTION
COORDINATES 72925 N 48345 E
R.L. 4101·5'

HOLE NO. RDS 3
SHEET 1 OF 3

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION LITHOLOGY, COLOUR, STRENGTH, HARDNESS, ETC.	DEPTH & SIZE OF CORE
Black and red soil	●	0 – 2'6
	Fine to medium grained sand recovered as sludge in drilling water.	2'6 – 10' NMLC
Alluvium or lake sediments. Driller's remarks: Clay and stones.	In core box: Fine to medium sand (sludge) 10' - 14'10, 15-18'9, and 21'8 - 25'; Pebbles and broken cobbles 14'10 - 15, 18'9-21'8; Cream-yellow clay (cored 25' - 26')	10' – 26'
Driller: Stones and clay	Sludge, fine to medium sand, 29'3 - 30', 35 - 40'6, 45' - 46'; Pebbles and broken and partly cored cobbles 26' - 27'1, 33'3 - 35, 35'8 - 36, 43'3 - 44'10; Cored cream-yellow clay 27' - 29'3	26' – 46'
Driller: Stones with sand and gravel.	Sludge, fine to coarse sand, minor granules and small pebbles 47'6 - 53; broken and partly cored cobbles, 46' - 47'6	46' – 53'
Driller: Clay and stones.	Sludge, fine to coarse sand 53' - 57'5; 57'10 - 63'10 broken and partly cored pebbles and cobbles 57'5 - 57'10, 63'10 - 66'	53' – 66'
Driller: Broken stones.	Sludge, fine sand 69' - 71', 77'4 - 77'6; broken and partly cored pebbles and cobbles 66' - 69', 71' - 73', 77'10 - 79'	66' – 79'
Driller: Hard grey-green clay.	Buff and pale brown clay and silty clay.	79' – 95'
Driller: Broken Stones	Broken and partly cored cobbles, pebbles, granules, sand, and feebly cemented clayey matrix	95' – 100'



STRUCTURES JOINTS, VEINS, SEAMS, FAULTS, CRUSHED ZONES
WATER LEVEL
WATER PRESSURE TEST Loss in gallons per minute per foot
PHOTO REF. NO. CORE BOX CORE BARREL

DRILL TYPE MINDRILL E1000
FEED Hydraulic
CORE BARREL TYPE Triple tube
DRILLER T. I. Condon
COMMENCED 9-9-65
COMPLETED 15-9-65
LOGGED BY D.E. Gardner
VERTICAL SCALE 1 inch : 10 feet

NOTES

FRACTURE LOG – Number of fractures per foot of core. Zones of core loss are blocked in.
BEDDING AND JOINT PLANES – Angles are measured relative to a plane normal to the core axis.

WATER PRESSURE TESTS
PACKER TYPE
SUPPLY LINE
VERTICAL SCALE
Figures given are gauge pressures
Test sections are indicated graphically by blocked-in strips

PHOTOGRAPH REFERENCE SYSTEM
BLACK AND WHITE
COLOUR

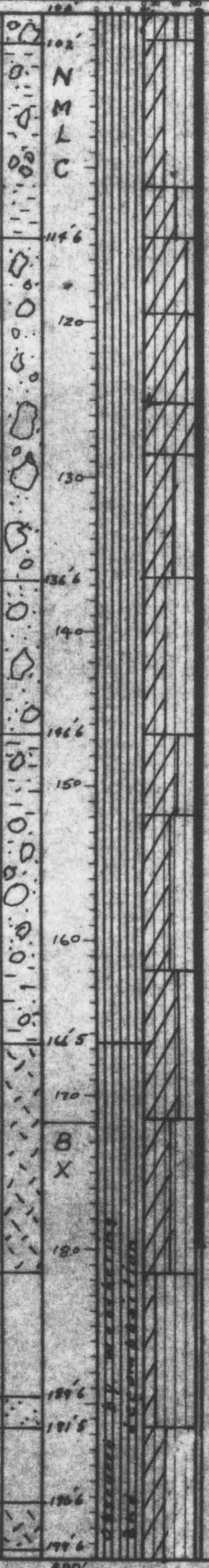
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER RAMU HYDRO-ELECTRIC SCHEME
LOCATION Proposed site for storage dam, right abutment, near top water level.
ANGLE FROM HORIZONTAL -90° DIRECTION —
COORDINATES 72925 N 48345 E R.L. 4101.5'

HOLE NO. RDS 3
SHEET 2 OF 3

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION LITHOLOGY, COLOUR, STRENGTH, HARDNESS, ETC.	DEPTH & SIZE OF CORE
Alluvium	Driller: Broken stones and clay. Core Box: Sludge, medium sand 109'6-111'2; pebbles and broken and partly cored cobbles 111'6-114'6	100' 102' NMLC
Weathered alluvium, and feebly cemented matrix between 114'6 - 161'6	Driller: Broken Stones Core Box: Sludge: Fine and medium sand 115' - 115'4, 119'8 - 120' 135 - 136'6 Pebbles, broken and partly cored cobbles and boulders, traces of clayey sand matrix 114'6 - 115', 115'4 - 119'8, 121' - 128'6, 131' - 135'	114'6 120 130
	Driller: Broken stones and sand Core Box: Sludge, medium sand 140 - 141'4, 145 - 146'6 Broken, partly cored pebbles and cobbles, matrix clayey sand 136'6 - 140'	136'6 140
	Drillers log: 152' - 162' Broken stones Remainder: Broken stones & clay Core Box: Sludge, fine and medium sand 146'6 - 148'4, 152' - 162' Pebbles, broken cobbles and boulders, in part weathered, 148'4 - 152' 157' - 161'6, 166' - 166'5	146'6 150 160
Dolerite	Decomposed	166'5 170 BX 180
	Not cored	
Siltstone Greywacke	Weathered Decomposed	189'6
	No core	191'5
Dolerite	Weathered and decomposed	196'6 199'6 200'



STRUCTURES JOINTS, VEINS, SEAMS, FAULTS, CRUSHED ZONES

WATER LEVEL

WATER PRESSURE TEST Loss in gallons per minute per foot

PHOTO REF. NO. CORE BOX CORE BARREL

DRILL TYPE MINDRILL E1000
FEED Hydraulic
CORE BARREL TYPE Triple tube
DRILLER T. J. Condon
COMMENCED 9-9-65
COMPLETED 15-9-65
LOGGED BY D.C. Gardner
VERTICAL SCALE 1 inch : 10 feet

NOTES

FRACTURE LOG — Number of fractures per foot of core. Zones of core loss are blocked in.

BEDDING AND JOINT PLANES :— Angles are measured relative to a plane normal to the core axis

WATER PRESSURE TESTS

PACKER TYPE

SUPPLY LINE

VERTICAL SCALE;

Figures given are gauge pressures
Test sections are indicated graphically by blocked-in strips

PHOTOGRAPH REFERENCE SYSTEM

BLACK AND WHITE

COLOUR

BUREAU OF MINERAL RESOURCES,
GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER RAMU HYDRO-ELECTRIC SCHEME
LOCATION Proposed site for storage dam, right abutment, near top water level
ANGLE FROM HORIZONTAL -90°
DIRECTION
COORDINATES 72925N 48345E
R.L. 4101·5'

HOLE NO.
RDS 3
SHEET 3 OF 3

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION LITHOLOGY, COLOUR, STRENGTH, HARDNESS, ETC.	GRAPHIC LOG	DEPTH & SIZE OF CORE	FRACTURE LOG	LIFT & % CORE RECOVERY	CASING	STRUCTURES JOINTS, VEINS, SEAMS, FAULTS, CRUSHED ZONES	WATER LEVEL	WATER PRESSURE TEST Loss in gallons per minute per foot	PHOTO REF. NO. CORE BOX	PHOTO REF. NO. CORE SAMPLE
			200'	0 4 8	20 60 100						
Dolerite Weathered	Fragments ½"–2"		BX 202'								
	END OF HOLE										
			210								
			220								
			230								
			240								
			250								
			260								
			270								
			280								
			290								
			300								

DRILL TYPE MINDRILL E1000
FEED Hydraulic
CORE BARREL TYPE
Triple tube
DRILLER T. J. Condon
COMMENCED 9-9-65
COMPLETED 15-9-65
LOGGED BY D. E. Gardner
VERTICAL SCALE 1 inch : 10 feet

NOTES

FRACTURE LOG – Number of fractures per foot of core. Zones of core loss are blacked in

BEDDING AND JOINT PLANES – Angles are measured relative to a plane normal to the core axis

WATER PRESSURE TESTS

PACKER TYPE
SUPPLY LINE
VERTICAL SCALE

Figures given are gauge pressures
Test sections are indicated graphically by blacked-in strip

PHOTOGRAPH REFERENCE SYSTEM

BLACK AND WHITE

COLOUR

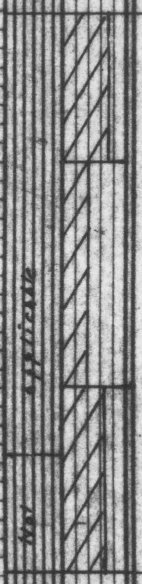
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT UPPER RAMU HYDRO-ELECTRIC SCHEME
LOCATION ~~P~~Near proposed storage dam, at bottom of Shaft, right bank of river
ANGLE FROM HORIZONTAL -90°
DIRECTION Vertical
COORDINATES 73070 N 48170 E
R.L. Shaft collar 4011·9'

HOLE NO. RDS4
SHEET 1 OF 1

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION LITHOLOGY, COLOUR, STRENGTH, HARDNESS, ETC.	GRAPHIC LOG	DEPTH & SIZE OF CORE	FRACTURE LOG	LIFT & % CORE RECOVERY	CASING	STRUCTURES JOINTS, VEINS, SEAMS, FAULTS, CRUSHED ZONES	WATER LEVEL	WATER PRESSURE TEST Loss in gallons per minute per foot	PHOTO REF. NO. CORE BOX	CORE BARREL
Alluvium in walls of Shaft	Not drilled		5 10 20 30								
Conglomerate	Boulders, cobbles, pebbles, granules and sand in coherent clayey matrix. Matrix intact and conglomerate cored from 40'-45', and 56' 10 - 58'6		40' N M L C 50 60	Not applicable							
Greywacke Siltstone Dolerite	Dolerite 64'4-65'3 Decomposed, clayey		63'6								
Dolerite	Decomposed, clayey		67'8 70'								
END	OF HOLE		80 90 100								



DRILL TYPE MINDRILL E1000
FEED Hydraulic
CORE BARREL TYPE
Triple tube
DRILLER T. J. Condon
COMMENCED 17-9-65
COMPLETED 18-9-65
LOGGED BY D.E. Gardner
VERTICAL SCALE 1 inch: 10 feet

NOTES

FRACTURE LOG — Number of fractures per foot of core. Zones of core loss are blocked in

BEDDING AND JOINT PLANES — Angles are measured relative to a plane normal to the core axis

WATER PRESSURE TESTS

PACKER TYPE
SUPPLY LINE
VERTICAL SCALE
Figures given are gauge pressures
Test sections are indicated graphically by blocked-in strips

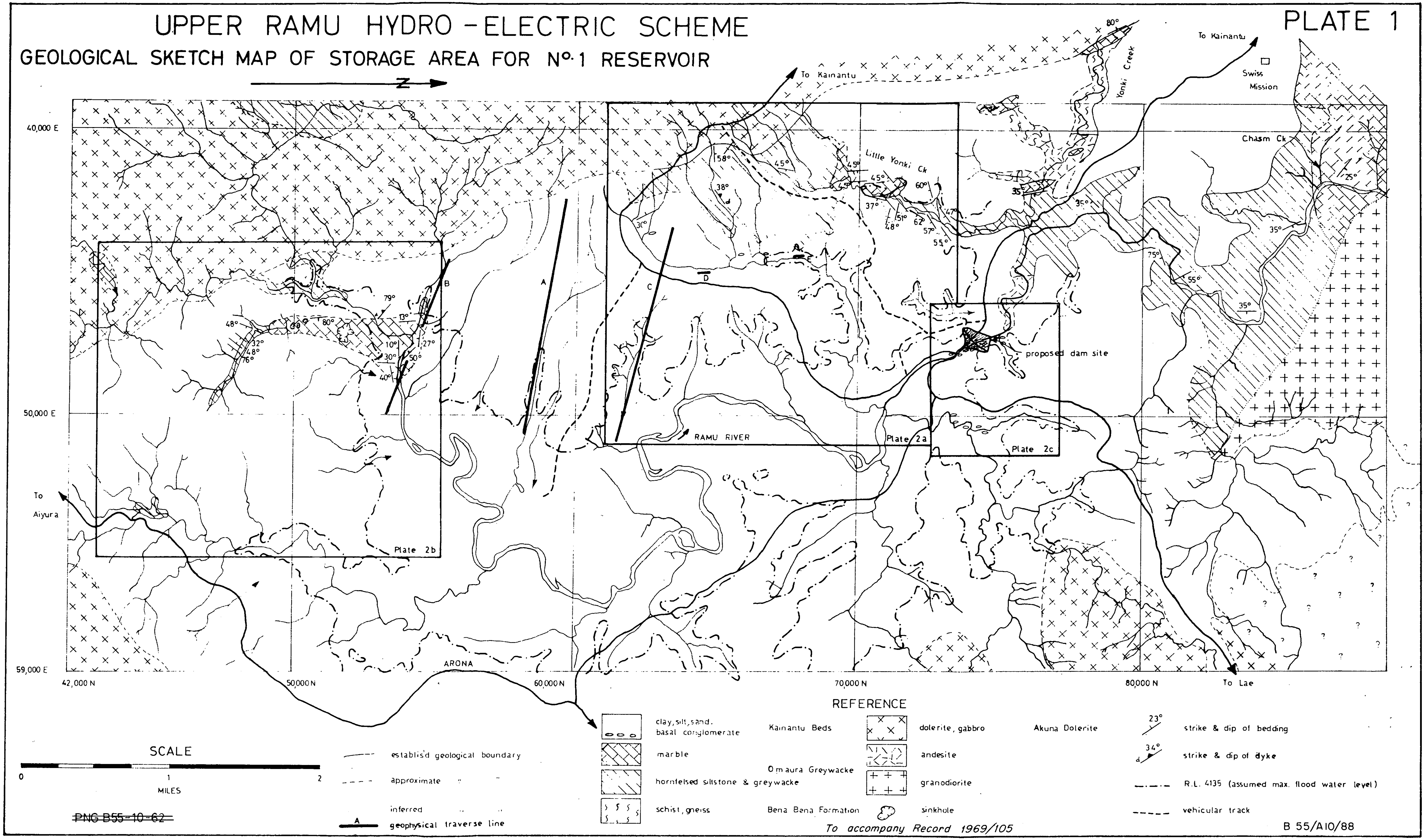
PHOTOGRAPH REFERENCE SYSTEM

BLACK AND WHITE
COLOUR

UPPER RAMU HYDRO-ELECTRIC SCHEME

GEOLOGICAL SKETCH MAP OF STORAGE AREA FOR N° 1 RESERVOIR

PLATE 1



~~PNG B55-10-62~~

To accompany Record 1969/105

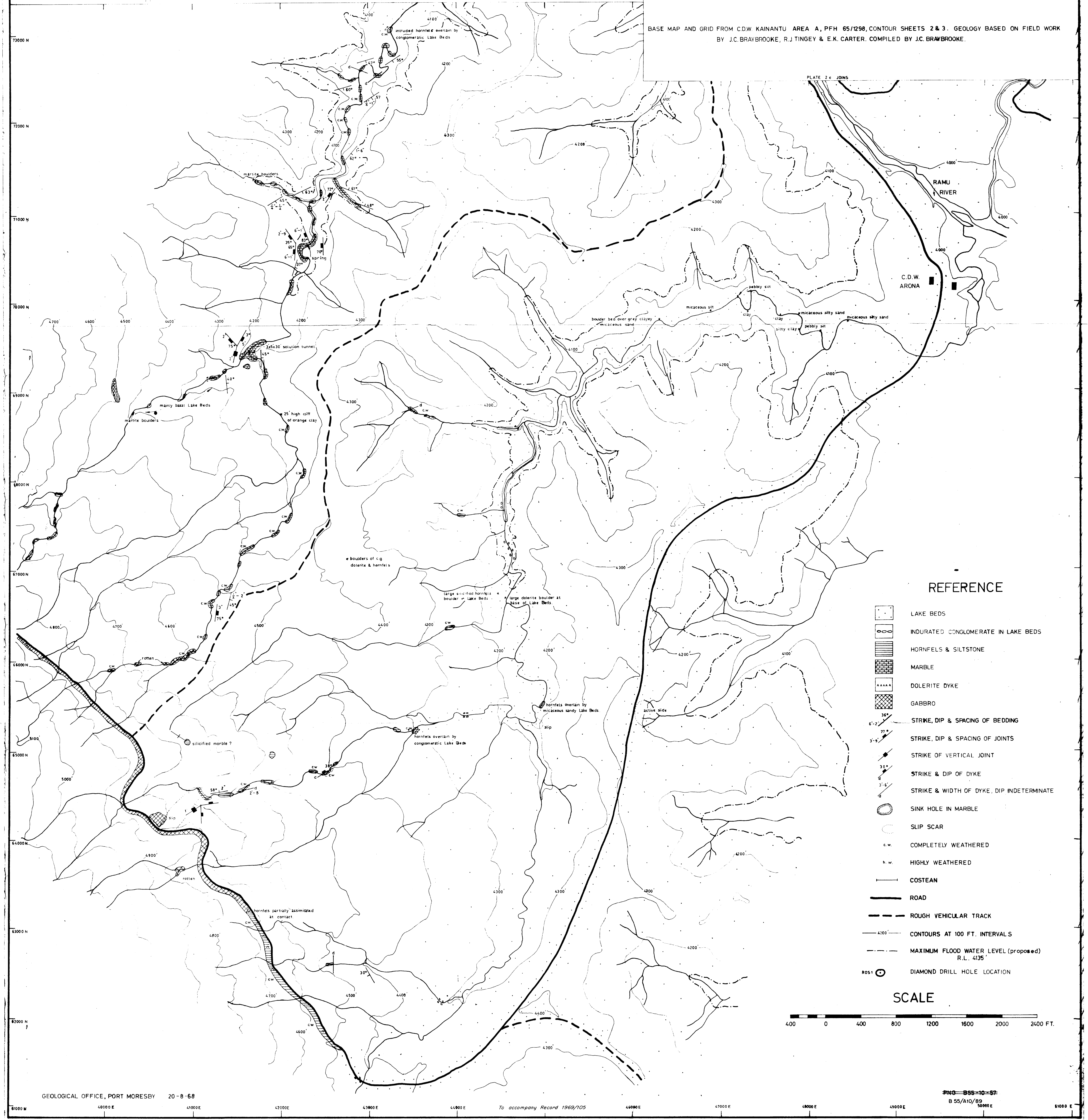
B 55/A10/88

UPPER RAMU HYDRO-ELECTRIC SCHEME

PLATE 2a

GEOLOGICAL OUTCROP MAP OF STORAGE AREA FOR NO1 RESERVOIR

BASE MAP AND GRID FROM C.D.W. KAINANTU AREA A, PFH 65/1298, CONTOUR SHEETS 2 & 3. GEOLOGY BASED ON FIELD WORK BY J.C. BRAYBROOKE, R.J. TINGEY & E.K. CARTER. COMPILED BY J.C. BRAYBROOKE.



REFERENCE

⁙	LAKE BEDS
⬭	INDURATED CONGLOMERATE IN LAKE BEDS
☰	HORNFELS & SILTSTONE
▦	MARBLE
∧∧∧∧∧	DOLERITE DYKE
▩	GABBRO
36° 6"-2'	STRIKE, DIP & SPACING OF BEDDING
77° 3'-9'	STRIKE, DIP & SPACING OF JOINTS
	STRIKE OF VERTICAL JOINT
30° d	STRIKE & DIP OF DYKE
3'-6' d	STRIKE & WIDTH OF DYKE, DIP INDETERMINATE
	SINK HOLE IN MARBLE
	SLIP SCAR
c.w.	COMPLETELY WEATHERED
h.w.	HIGHLY WEATHERED
├─┤	COSTEAN
━━	ROAD
━ ━ ━	ROUGH VEHICULAR TRACK
—4200'—	CONTOURS AT 100 FT. INTERVALS
—·—·—	MAXIMUM FLOOD WATER LEVEL (proposed) R.L. 4135'
RDS1 ⊙	DIAMOND DRILL HOLE LOCATION

SCALE

400 0 400 800 1200 1600 2000 2400 FT.

GEOLOGICAL OFFICE, PORT MORESBY 20-8-68

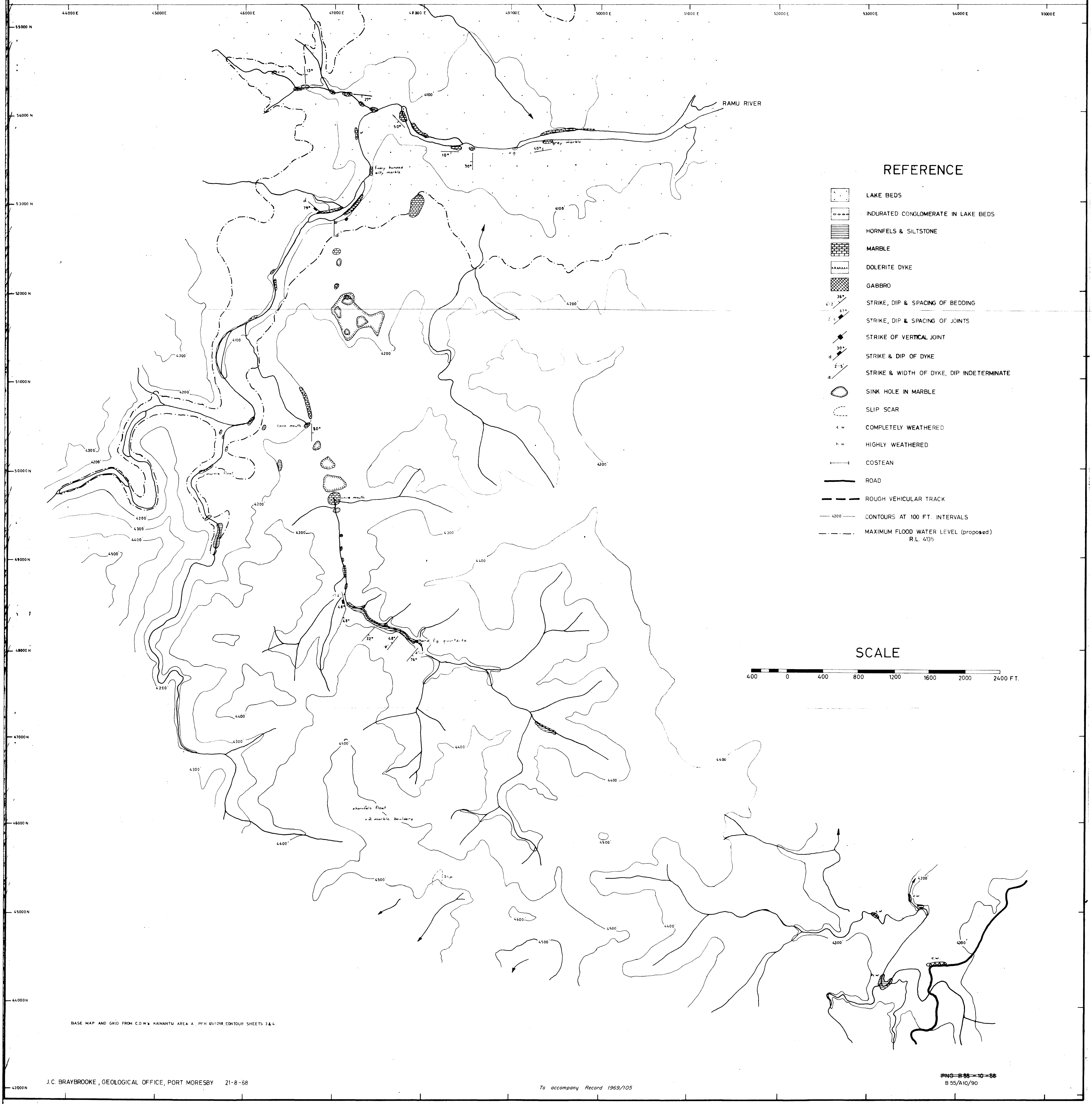
To accompany Record 1969/105

~~PNG B55-10-57~~
B 55/A10/89

UPPER RAMU HYDRO – ELECTRIC SCHEME

GEOLOGICAL OUTCROP MAP OF STORAGE AREA FOR NO. 1 RESERVOIR

PLATE 2b



REFERENCE

- LAKE BEDS
- INDURATED CONGLOMERATE IN LAKE BEDS
- HORNFELS & SILTSTONE
- MARBLE
- DOLERITE DYKE
- GABBRO
- 36° 6'-2' STRIKE, DIP & SPACING OF BEDDING
- 67° 2'-6' STRIKE, DIP & SPACING OF JOINTS
- STRIKE OF VERTICAL JOINT
- 30° d STRIKE & DIP OF DYKE
- 2'-5' d STRIKE & WIDTH OF DYKE, DIP INDETERMINATE
- SINK HOLE IN MARBLE
- SLIP SCAR
- c w COMPLETELY WEATHERED
- h w HIGHLY WEATHERED
- COSTEAN
- ROAD
- ROUGH VEHICULAR TRACK
- 4200' CONTOURS AT 100 FT. INTERVALS
- MAXIMUM FLOOD WATER LEVEL (proposed) R.L. 4135

SCALE

400 0 400 800 1200 1600 2000 2400 FT.

BASE MAP AND GRID FROM C.D.W's KAINANTU AREA A, PFH 65/1298, CONTOUR SHEETS 3 & 4

J.C. BRAYBROOKE, GEOLOGICAL OFFICE, PORT MORESBY 21-8-68

To accompany Record 1969/105

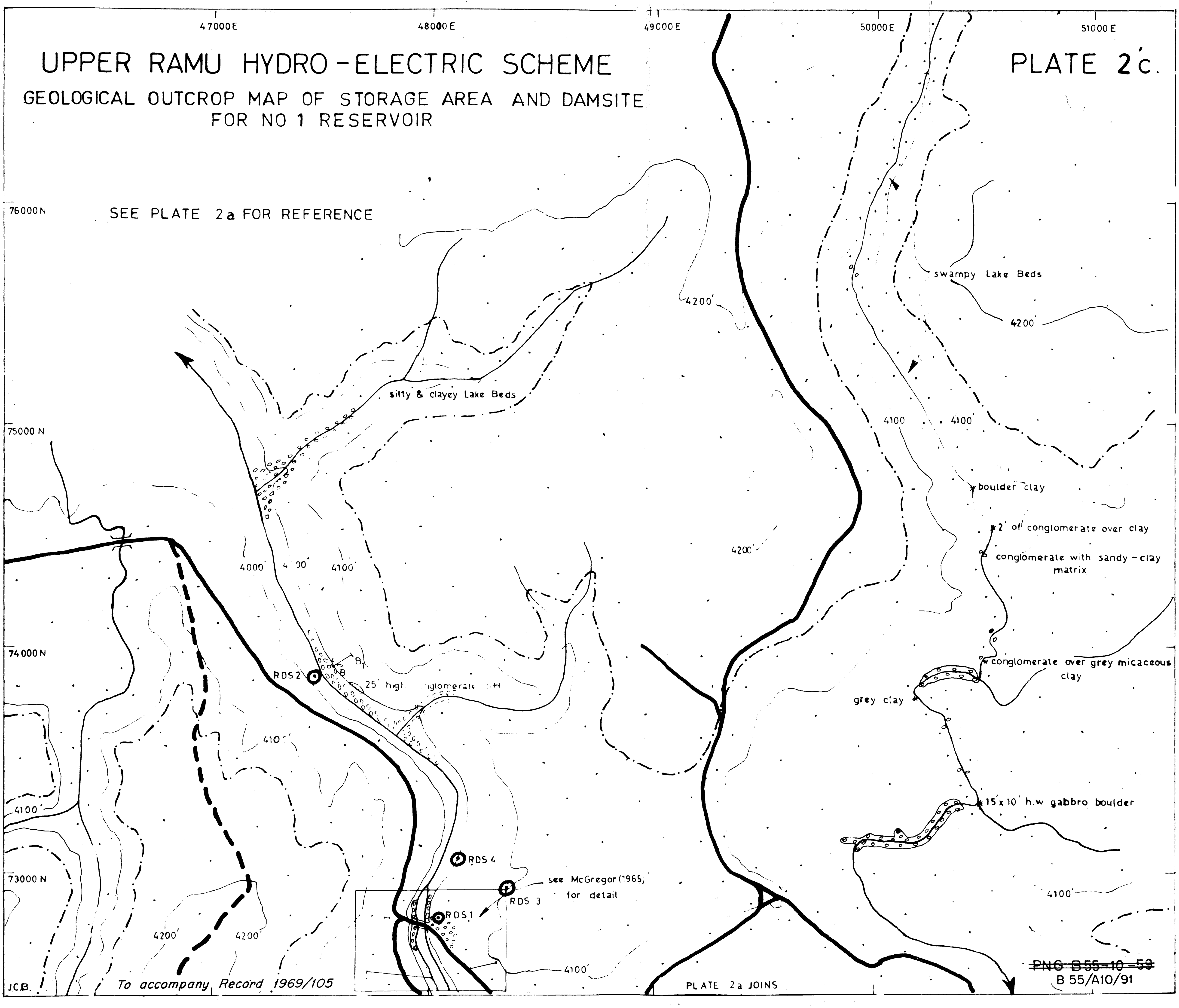
~~PNG B55 – 10 – 58~~
B 55/A10/90

UPPER RAMU HYDRO-ELECTRIC SCHEME

PLATE 2c.

GEOLOGICAL OUTCROP MAP OF STORAGE AREA AND DAMSITE FOR NO 1 RESERVOIR

SEE PLATE 2a FOR REFERENCE



To accompany Record 1969/105

~~PNG B55-10-59~~
B 55/A10/91