COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD No. 1962/95

DETAILED GEOLOGICAL INVESTIGATION
UPPER RAMU HYDRO-ELECTRIC PROJECT, NEW GUINEA 1961

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SUMMARY

The site of the project is the gorge of the Upper Ramu River approximately 75 miles north-west of Lae in the Territory of New Guinea. Access to the area is obtained by means of a bypass from the Highlands developmental road connecting Lae and Kainantu. Foot tracks lead from the bypass to various parts of the scheme, usually along the crests of "razor back" ridges.

It is proposed to construct a low dam across the river at the head of the gorge to divert water through a 7-foot diameter low pressure tunnel approximately 7000 feet long. The water will then descend through two surface steel penstocks to an outdoor power station near the river's edge: the gross head available is 660 feet, and the flow available for power generation for 100 per cent of the time is 110 cusecs. The first stage development of the scheme involves the installation of two 5,000 kilowatt turbo-alternator sets, one to act as a spare. The main purpose of the scheme is to supply power to Lae in the first instance, but it is recognised that the potential exists for considerable further development of power.

Horizontal and vertical control for geological mapping was obtained from a preliminary survey by the Commonwealth Department of Works, Port Moresby. Mapping of geological detail at the weir site, intake site, and power house site was carried out at a scale of 40 feet to one inch by plane table tacheometry. Mapping of outcrops along the tunnel line, penstock route and adjacent stream beds was controlled by tape and compass traverses and was carried out at a scale of 200 feet to one inch. Because of a paucity of outcrops it was necessary in many places to obtain information by costeaning. Aerial photographs were only used occasionally.

The topography of the area is rugged, particularly in the gorge where cliffs and slopes of 50 degrees are common. The configuration of the river is such that it falls 680 feet over a straight line distance of 1.4 miles, although the distance by river is 2.8 miles, thus providing very favourable conditions for a hydro-electric scheme.

Previous regional geological investigations suggest that the Kainantu Beds, which overlie the basement metamorphic rocks at the project, are Pleistocene in age, while the basement rocks are assigned to the Palaeozoic. The Kainantu Beds are between 100 to 200 feet thick and consist of sub-horizontal beds and lenses of clay, silt, sand, gravel and boulders. The underlying low-grade metamorphic rocks are moderately folded and faulted, and consist of silicified greywacke, sandstone, siltstone, shale and slate. Areas of porphyritic hornfels are found adjacent to numerous altered basic or intermediate dykes and sills.

Observations made during the survey show that earthquakes of intensity VI on the Modified Mercalli Scale may be expected to occur occasionally and that it would be wise to allow for earthquakes of intensity VIII in designs.

Mapping at the weir and tunnel intake sites shows that both structures would be founded on laminated beds of silicified greywacke, sandstone, and siltstone with thin interbeds of shale and slate, dipping at 35 degrees. It is expected that these rocks will provide good foundations, although certain measures will be required at the tunnel intake to prevent earth and rock slides occurring. Three diamond drill holes to test the weir site and three to test the funnel intake have been planned. Water pressure testing will be necessary to test the foundation rocks for water tightness. Maximum total drilling footage proposed for the two sites is 620 feet.

Surface mapping indicates that the tunnel line lies in metamorphic rocks cut by basic to intermediate dykes for its entire length. There is a possibility that thin beds of marble will be encountered in the tunnel, but they are not expected to be cavernous. Proposed diamond drill holes to investigate rocks along the tunnel line total a maximum of 1,830 feet. Depending on the results of these holes, further examination of the floor of the Kainantu Beds may be necessary, to ensure that no deep ravines filled with unconsolidated sediments exist in the basement rocks.

The surge tank and penstocks, if placed in the proposed position, will be exposed to risk of damage by rocks from cliffs above. Alternative layouts are suggested, and in addition, it is strongly recommended that the penstock anchor blocks be founded on firm bedrock because of the instability of the overburden. Details of suitable diamond drill holes to investigate foundation conditions are given.

Geological mapping at the power house site indicates that no serious foundation problems will be encountered. However, it is recommended that the power station and ancilliary equipment be constructed away from the edge of the river, or underground, to avoid the possibility of damage by floods. Only two 50-foot holes will be required to test a surface power station site, but if it is decided to adopt an underground layout a much more extensive diamond drilling and water pressure testing programme will be necessary.*

For each part of the project, geological features likely to affect engineering installations are emphasised and recommendations are made concerning treatment for them. Suggestions are made about the collection of rock samples for mechanical testing, and broad indications are given of further engineering geological work which may be necessary during construction of the project.

No deposits of gravel or sand suitable for concrete aggregate were found during the survey, but ample supplies of rock for crushed aggregate are available within a short distance of any part of the planned engineering works. The suitability of the more important rock types for concrete aggregate is discussed.

Detailed specifications for diamond drilling and water pressure testing to investigate the rock at depth are given in an appendix. Other appendices describe procedures to be used in the logging of drill cores; water pressure testing methods; and thin section examinations of rocks from the locality.

*The maximum total footage planned for the whole scheme at this stage is 3,170 feet, together with 1,000 feet of water pressure testing.

INTRODUCTION

GENERAL

In June 1961, at the request of the Commonwealth Department of Works, a geological survey was commenced of a proposed hydro-electric scheme to be situated on the Upper Ramu River, Territory of New Guinea. The scheme involves the construction of:-a low diversion dam or weir across the Ramu River at the head of a gorge approximately 75 miles north-west of Lae and 7 miles east-north-east of Kainantu; (see Plate 1.); a 7-foot diameter low pressure tunnel approximately 7,000 feet long; and two 4-foot diameter surface steel penstocks with a head of 650 feet.

Average annual rainfall is about 85 inches and hydrological information at present available indicates that the minimum flow in the river is about 110 cusecs. On this figure, the first stage development would allow for the installation of two 5,000 kilowatt turbo-alternator sets, one set to act as a spare. Ultimately, the power station would house a further three similar sets, giving a total capacity of 25,000 kW, or an effective capacity of 20,000 kW with one set acting as a spare. This would require an effective river storage of about 32,000 acre feet to be provided by a dam above the head of the gorge, where the river has a gentler gradient and suitable sites are likely to be available.

The geological survey was executed by J.K. Hill over a period of three months. He was assisted during the first two weeks by E.K. Carter. Field inspections of all sections of the scheme were made with Mr. J.R. Brett, Commonwealth Department of Works, Port Moresby.

The objects of the geological survey were:-

1) To select a weir site and to determine likely foundation conditions.

2) To examine all outcrops in the vicinity of the intake portal, tunnel line, and outlet portal, likely to yield information bearing on the nature of ground to be penetrated by the tunnel.

3) To determine the depth of overburden and nature of foundation rock at the proposed surge tank site and along the penstock route.

4) To examine the foundation rock at the proposed power house site.

5) To provide information on which to base a diamond drilling programme for further testing of the rock at depth.

LOCATION AND ACCESS

The proposed scheme is about 100 miles by road from Lae (see Plate 1), and is at the head of a gorge where the Ramu River falls nearly 3,000 feet in 10 miles from the edge of the Eastern Highlands down to the central depression of the Lower Ramu Valley. The nearest township, Kainantu, is 10 miles by road from the proposed weir site. The existing Highlands developmental road connecting the Lae-Markham Valley road to Kainantu passes 2½ miles to the south-east. The road in the immediate vicinity of the scheme is a by-pass suitable for light vehicles only, (not more than 30 hundredweight). When the developmental road is dry and all bridges are open it is possible for heavy trucks to be driven from Lae to Kainantu with full loads in one day. In wet periods most roads in the Highlands can be negotiated with care in four-wheel drive vehicles.

The proposed weir site is situated within a quarter of a mile of the Yonki by-pass road at an elevation of 3,870 feet. Access to the penstock route and power house site is best gained by a road through the grounds of the Swiss Mission, about 1½ miles from the weir site, and thence on foot along a rough track to a saddle above the slopes that lead down to the gorge. From this point can be seen white survey pegs and beacons marking the line of the tunnel and penstock. Points on the tunnel line between intake and surge tank site are reached by following prominent "razor back" ridges, most of which have foot tracks along their crests.

METHOD OF MAPPING

Horizontal and vertical control was obtained from an excellent preliminary survey executed by Mr. D. Thiedecke, Department of Works, Port Moresby. All bench marks are permanently marked by black and white tripods 8 feet high; traverse pegs are marked by 4-foot white stakes with the horizontal chainages indicated on them.

Mapping of geological detail at the weir site, intake site and power house site was carried out at a scale of 40 feet to one inch by plane table tacheometry.

Mapping of outcrops along the tunnel line, penstock route and adjacent stream beds was controlled by tape and compass traverses tied to Department of Works' survey pegs. The scale used was 200 feet to one inch. Where possible all traverses were closed, the closing errors calculated, and adjustments made to distribute the error, both horizontally and vertically. It was possible to complete traverses with a horizontal misclosure of not more than 14 feet per 1,000 feet traversed horizontally and a vertical misclosure of 1 foot per 100 vertical feet. In view of the steepness of the slopes and stream beds (vertical angles of more than 40° were not uncommon) and the thickness of the vegetation, closures of this order are considered to be satisfactory. A few traverses were not closed as the extra time required to do so was not warranted by the order of accuracy of the geological mapping.

Outcrops are almost entirely lacking along the tunnel line and in many places it was necessary to obtain information by costeaning. Some of the costeans were between 10 and 14 feet deep; not all exposed bedrock. Twenty three costeans were dug during the survey.

Aerial photographs were used to locate positions on a traverse down the Ramu Gorge from intake to power station site, and to plan other traverses. The lacustrine sediments were accurately delineated in most places by photogrammetry followed by field checks in doubtful areas.

TOPOGRAPHY

The Ramu River rises 14 miles south-west of Kainantu, in a mountainous area between the Kratke and Bismarck Ranges, at about 7,000 feet above sea level (see Plate 1). It flows eastwards across the Highlands to Arona and thence turns northwards through a steep gorge, from which it emerges onto the main valley floor. Near the head of the gorge the configuration of the river is such that it falls 680 feet over a straight line distance of 1.4 miles, although the distance by river is about 2.8 miles (see Plate 2). Above its junction with Yonki Creek the gradient of the Ramu is relatively shallow.

The slopes leading down to the river in the gorge are steep and are covered with a thick growth of Kunai grass, shrubs and timber. In general the spurs and ridges have convex profiles, the gradient increasing from about 10 to 20 degrees near the top to about 40 to 50 degrees at the bottom. This is in contrast to ridges in the overlying lacustrine sediments, which are distinctively razor back in shape, with concave profiles in both transverse and longitudinal directions; the intervening valleys have well-developed U-shaped cross sections.

Over most of the country between intake and power station sites a prominent flat or gently sloping shelf can be seen, both from the ground and by stereoscopic inspection of aerial photographs. This shelf or bench is the physical expression of the top of the resistant metamorphic rocks. The overlying unconsolidated lacustrine sediments are less resistant to erosion than the metamorphic rocks and remain only as residuals with horn-shaped promontories, sharp ridges and a gently sloping bench at the foot.

The inter-connecting promontories and ridges form a distinctive pattern on aerial photographs. Bands of more resistant material are expressed as rounded discontinuous ledges along the sides of ridges, revealing the horizontal bedding of the lake sediments.

No outcrops are found above the shelf marking the bottom of the lake sediments except in the beds of streams which have cut through the sediments to the underlying metamorphic rocks. Outcrops are plentiful along the steep sides of the gorge.

Four or five sink-holes have developed in marble or crystalline limestone immediately to the north-east of the Swiss Mission Settlement. Run-off from a small catchment flows underground at one of the sink-holes and emerges from a cave in marble at an altitude of 3650 feet in a small creek which joins the Ramu River 50 yards downstream from the power station site. This is the only evidence of extensive underground drainage found in the marble and is believed to be an isolated case. The sub-surface movement of water appears to take place along slightly enlarged joints, fractures, and bedding planes, and, apart from the one stream, probably involves small quantities.

Because of numerous impervious beds of clay, the lacustrine sediments are saturated with water. No trees are found growing on the sediments, and the bush line in each stream coincides with the boundary between metamorphic rocks and lacustrine sediments.

An impressive feature of the Ramu River Gorge is the degree to which the bed of the river is choked with enormous boulders of granodiorite. Many of these were estimated to weigh more than 200 tons. Nearly all the tributary streams are filled with smaller granodiorite boulders, some of which may weigh up to 60 tons. The possible origin of these boulders is discussed on page 14.

GENERAL GEOLOGY

PREVIOUS INVESTIGATIONS

Mackay (1955) carried out a regional reconnaissance geological survey of the area between Kainantu in the north-west and Wau in the south, i.e. the main drainage systems of the Markham and Ramu Rivers, with the object of adding to existing maps compiled by other geologists, (chiefly N.H. Fisher, L.C. Noakes and G.A.V. Stanley). Mackay describes the Kainantu Beds, which occur in the open basins near Kainantu, as sub-horizontal clay, silt, sand, gravel, and boulder beds deposited in large lakes which were subsequently drained. The beds were then dissected by the present drainage system of the Ramu River. He considers the Kainantu Beds to be Pleistocene in age and to have a maximum thickness of about 100 feet.

The basement rocks of the area are described by Mackay as a Palaeozoic metamorphic complex consisting of quartz-mica schist and gneiss, white quartzite, grey quartzite, blue slate, grey phyllite and grey sericite schist. These highly metamorphosed rocks had been strongly folded during regional tectonism and intruded by plutonic rocks, which are dominantly granitic, although more acidic and basic differentiates formed locally.

McMillan and Malone (1960) mapped the eastern portion of the Highlands of New Guinea with the object of assessing the economic potential of the area. They recognised two formations in the Palaeozoic metamorphic complex - the Goroka and Bena Bena Formations. The basement rocks in the vicinity of the proposed Upper Ramu hydro-electric scheme were mapped as belonging to the Bena Bena Formation. The most common rock types in the formation are stated to be green actinolite-chlorite schist; quartz-muscovite schist with small garnets; knotted hornblende-feldspar-gneiss; granite gneiss; garnet quartzite; mica schist; and hornfels. Many rocks in the formation are noted as being considerably less highly metamorphosed. They include metamorphosed siltstone, greywacke, feldspathic siltstone and arkose. Presumably it is to this latter class that the rocks occurring in the hydro-electric scheme area belong.

The numerous basic dykes and sills that intrude the metamorphic rocks are probably associated with a composite intrusion called the Yonki Stock which adjoins the area mapped in the present survey. McMillan and Malone describe it as consisting of hornblende gabbro, in places metasomatised to monzonite and granodiorite. A more basic phase, consisting of olivine gabbro and verging on pyroxenite in some specimens, is also present. The associated minor intrusives are noted as consisting mainly of olivine micro-gabbro. An alternative evolution of the different rock types is suggested, involving successive intrusions of gabbro followed by more acid intrusions.

Noakes and Gardner (1959) completed a geological reconnaissance survey of the Upper Ramu Gorge with a view to selecting sites for a hydro-electric scheme. With regard to weir sites, they found that the walls of the gorge are in solid rock and that the profile near water level is narrow and symmetrical. At that time it was proposed that a pipeline be installed on the western side of the gorge. Steep slopes and gullies between the intake site and the power station site were partly examined in order to assess slope stability and the total length of bridging required. It was concluded that the relationship between the dip of the metamorphic rocks and the slope of the ground is not likely to be critical because the dip of the beds normally exceeds the inclination of the slopes in which the bench would be cut.

A tentative site for the power station was selected at the foot of a long spur by inspection of aerial photographs, but was not examined on the ground. The reconnaissance provided sufficient geological information to warrant the preliminary design of a scheme and its pegging out on the ground.

SEISMIC ACTIVITY

Noakes and Gardner (1959) conclude from the few records available that infrequent tremors of low intensity only, perhaps II to III on the Modified Mercalli Scale, can be expected in the Upper Ramu region. They also suggest that intermediate-depth earthquakes of fair intensity occurring at either of two prolific sources some hundred miles distant to the north, might give rise to an earthquake of intensity VI on the Modified Mercalli Scale in the Upper Ramu area.

Observations made during the present survey show that earthquakes of intensity V-VI occur, and that it would therefore be wise to allow for earthquakes of about intensity VIII in engineering designs. A qualitative record was kept of tremors felt during the three months duration of the survey. The results are set out below. It should be noted that the majority of tremors were recorded at night when the writer was seated or in bed. Doubtless many more passed unnoticed during the daytime when he was driving a vehicle or engaged in mapping.

EARTH TREMORS RECORDED AT KAINANTU BETWEEN JUNE AND SEPTEMBER, 1961

Date	Time	Description	Estimated Modified Mercalli Intensity
21. 6.61	P.M.	Slight tremor	II
25. 6.61	01^{20} or 02^{20} hrs	2 to 3 sharp jolts, total duration 5 secs. Sufficient to awaken people. Articles fell from shelves. Water in 2000 gallon tank oscillated for 20 secs.	IV - V
3. 7.61	19^{20} hrs	Slight tremor	II - III
5. 7.61	03^{15} hrs	Slight tremor	II - III
7. 7.61	00^{15} hrs	Slight tremor	II - III
8. 7.61	08^{00} hrs	Slight tremor	II - III
13. 7.61	21^{15} hrs	Slight tremor	II - III
18. 8.61	18^{37} hrs	Slight tremor	II - III
13. 9.61	13^{10} hrs	Severe shake lasting 30 secs. Water slopped out of kettles on stove, books and vases fell from shelves, objects fell from shelves in storeroom. People started to run outside*	V - VI

*This description was supplied by Mr. R. Teale of Experimental Station, Onamuga, via Kainantu, New Guinea, who has continued to keep records of tremors experienced since the author left Kainantu.

ENGINEERING GEOLOGY

WEIR SITE

Geology

The metamorphic rocks at the weir site consist of silicified greywacke, sandstone, and siltstone, with interbeds of shale and slate. Porphyroblastic hornfels is found adjacent to altered basic to intermediate dykes and minor sills. Most of the rocks are laminated or thinly bedded, but in a few places are thickly bedded. The silicified greywacke, sandstone and siltstone beds are hard and strong, but the shale and slate beds, having strongly developed foliation and at least two cleavage systems, though hard are only moderately strong to weak. The hornfels is both hard and strong. The beds are very uniform, with little or no lensing, but have numerous rolls, warps, and minor fault displacements. They strike between 030° and 070°* and dip 30° to 40° south-east.

The metamorphic rocks at the site are intruded by a set of closely spaced basic to intermediate dykes (up to 35 feet thick but generally no more than 5 feet thick) and minor associated sills, (see Plate 4). The dyke rocks consist of altered porphyritic dolerite and gabbro (see Appendix V) which, above the water table, are weathered soft, and friable to a depth of 12 feet in places. Other phases of the intruded rocks are richer in quartz and have not weathered to the same extent. Most of the dykes have augen of hard, strong rock in the weathered matrix, and also inclusions of country rock.

The dykes have been emplaced along a strongly developed joint system that strikes east and dips 60° to 80° north. A second joint system with steep to vertical dips strikes approximately north. These two joint systems are present, with minor variations, throughout the whole area of the scheme. In places near the weir and intake sites the joints are very closely spaced and constitute sheeted zones. The two intersecting sheet systems have produced a rectangular pattern in the rock, and the joints, together with the thin bedding, have dissected the rock into rough cubes with 3 to 6 inch sides. The effect on the engineering excavations and diamond drilling is discussed on pages 11 and 12 and in Appendix II.

In places the shale and slate have two or more strongly developed cleavages, which impart a shattered appearance to the rock. Such an area is found in the vicinity of drill hole DD1 (see Plate 4). Elsewhere, the incompetent beds are generally thin (4 to 6 inches) and constitute only minor interbeds between the stronger greywacke and sandstone.

Upstream from the bend in the river the banks are composed of large broken rock masses which have been slightly displaced by unloading, faulting, settling and root-wedging, resulting in an open network of joints. It is expected that some open joints will continue below the water table.

Downstream from the bend in the river the banks are composed of sounder less disturbed rock, except for the area of shattered or cleaved shale and slate previously described. At the right abutment of the proposed weir the rock is strong and consists of medium to coarse grained metamorphic rocks, with numerous patches of gabbro and hornfels - presumably associated

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* All bearings are based on magnetic north.

with an irregular intrusion which is thought to extend down the river bed from a point near peg 200R. The north bank consists of large blocks of hard strong silicified greywacke, sandstone, and siltstone, with occasional shale and slate interbeds, transected by a long harrow dyke, which is soft and weathered at the surface but hard and fresh near river level. Part of the left abutment of the weir will be founded on this dyke.

Minor movements have occurred along faults, as evidenced by bedding displacements of up to 6 inches, small amounts of silty gouge (1 to 2 inches) and local shattering. A steep reverse fault at the southern boundary of the area has a displacement of 3½ feet. Movement has also taken place along some of the dykes, evidence being:-

(a) small amounts of gouge at the contacts;

(b) polished or striated rock at the contacts;

(c) conversion of the gabbro to a breccia, gabbro schist, or possibly tremolite schist;

(d) displacement and tipping of rock masses between dykes.

There is a larger fault zone (3 to 4 feet wide) near traverse peg 300R (see Plate 4). The fault strikes 080° and dips 80° north, and the fault zone is filled with blue-gray gouge and fragments of brecciated country rock. The gouge consists of tough, plastic, platy clay with numerous polished surfaces, and no difficulty was experienced in excavating this material with pick and bar to a depth of 6 feet. The walls of the fault zone are corrugated and extensively polished and striated. The corrugations and striae plunge 41° on a bearing of 057°. The gouge is unstable in water; when a sample was placed in still water decrepitation commenced immediately and was complete within two hours.

No trace of the fault could be found on the opposite (east) bank of the river despite the digging of three overlapping costeans to locate it. Possibly the fault continues downstream, along the bed of the river, and passes through the weir site; the presence of an area of shattered rock on the south bank supports this theory. However, it is also possible that the fault curves away from the river to the south. The fault was not recognised in a costean to the west, probably because the fault zone narrows abruptly in this direction and continues only as a thin band of gouge an inch or so wide. The part excavated appears to be a lens or pod in the fault zone. It will be difficult to locate the fault should it be present in the vicinity of the weir if it is only one or two inches wide, because of the ease with which the small amount of gouge will wash away under the action of circulating drill water. The displacement across the fault could not be determined.

A weir placed near the bend in the river (i.e. within about 250 feet upstream or downstream) would be unfavourably oriented with respect to one or other of the two main joint systems. Joints striking north would be transverse to an upstream weir, and joints striking east would be transverse to a downstream weir. In each case the possibility of a direct leakage path exists. Similarly, the bedding strikes obliquely to possible weir axes in either position with the additional unfavourable factor that the beds dip downstream below the bend in the river.

A weir constructed downstream in the position proposed would be transverse to any dykes intruded along the east-striking joint system and therefore transverse to any fault zones along the dyke contacts. Should such zones be present they should be regarded as possible leakage paths.

There are very few positions in which an upstream weir could be constructed other than oblique to the numerous gabbro dykes and their possible faulted contacts.

Overburden

The metamorphic rocks have not weathered deeply near the river and the average depth of soil and rock overburden is about 5 feet. In places up to 10 feet of overburden may be present due to accumulation of debris by movement down the steep slopes. Above the water table the gabbro dykes have weathered to a greater depth than has the country rock. One dyke just above the river's edge was excavated to a depth of 12 feet, at which point the material was still soft and weak. Crushing of the gabbro by faulting has resulted in an even deeper weathered zone.

Diamond Drilling

Specifications and objectives of three diamond drill holes to test the weir site are set out in Appendix II. Maximum footage is 300 feet. Vertical sections are given in Plates 5 and 6. Briefly the main objectives of the holes are:-

(a) to sample the metamorphic rocks and gabbro dykes at depth and to provide specimens for mechanical strength determinations;

(b) to determine if the fault previously described passes through the site;

(c) to determine the proportion of incompetent shale and slate;

(d) to test the water tightness of the foundation rocks;

(e) to examine dyke contacts for signs of faulting;

(f) to determine the depth of weathering in the long narrow dykes on the north bank.

The proposed position of drill hole DD1 is not the optimum position from a geological point of view. Plans to drill the hole from the most suitable point 120 feet farther downstream on the south bank had to be abandoned when an inspection made evident the impracticability of the site.

Conclusions and Recommendations

The position of the proposed weir (see Plate 4) was chosen mainly on engineering grounds. On the evidence available and without further information from diamond drilling, the geology of this site appears to be slightly more favourable than that for any site above the bend in the river. A vertical section across the proposed site is given in Plate 5. With the exception of one or two thin slate and shale beds, the metamorphic and igneous rocks will provide strong foundations for a weir 20 to 30 feet high where not affected by faulting. Abutment foundations for a dam higher than this will be less satisfactory and will require further investigation by drilling and costeaning.

The presence of minor faults elsewhere in the area suggests that they may be found at the weir site, but no serious difficulties should occur during treatment of foundations because extensive crushing and shattering are not associated with most of the faults. However, if the large fault previously described continues downstream and passes through the weir site, then foundation conditions will be much less favourable. Should a gouge-filled pod as wide as that excavated near peg 300R occur in the fault zone near the proposed axis, then the site is unsuitable and should be rejected in favour of one upstream from the bend in the river.

The gabbro dykes will provide strong foundations for a weir except where they have weathered in the abutments above the water table and at faulted contacts. The gabbro is expected to be fresh and strong in the bed of the river.

Much of the rock exposed along the bank of the river has well developed open joint networks, and it is expected that some open joints will continue below the water table. Normal grouting methods should be capable of controlling leakage from the pond.

INTAKE SITE

Geology

The tunnel intake will be situated in thinly bedded or laminated metamorphic rocks similar to those described on page 8. Sheet jointing is well developed in two directions (east and north), dissecting the rock into rough cubes. The joints are tight with the exception of three or four large open joints (1 to 2 inches wide) which cut diagonally across the face. These joints probably close up within 5 or 6 feet as it is thought they are due to movements of slabs of rock into the river. It is expected that zones of sheet jointing will be encountered throughout the length of the tunnel.

The vertical section given in Plate 7 shows four dykes cutting the tunnel line within the first 280 feet from the entrance. The position of the dyke nearest the entrance is accurate, but the positions of the remaining three are approximate only, having been extrapolated from outcrops some 500 feet to the east. It is possible that these dykes may have converged, diverged or terminated within this distance.

Overburden

The tunnel entrance, as at present proposed, will be located at the foot of a smooth rock face, dipping at 35°. At the top of the face 20 to 30 feet above the river, the overburden is unstable, as it is unsupported on the downhill side. It is evident that the rock face or dip slope has been cleared by soil and loose rock sliding into the river, and that such slides will continue in the future. To stop further falls taking place during construction, preventive measures should be taken, and some suggestions are given on page 12.

NOTE: Since this was written (21st August, 1961) several debris slides have occurred in the vicinity of the intake; one down the rock face in question. These falls took place after heavy rain in the last week in August.

Diamond Drilling

Three holes are proposed to test the soundness and water tightness of the rock near the tunnel intake. Maximum footage is 320 feet. The specifications and objectives of these holes are set out in Appendix II. Briefly the main objectives of the holes are:-

(a) To test the first 200 feet of strata, through which the tunnel will pass, for soundness and water-tightness.

(b) To determine the nature of the rock above the tunnel portal and the proportion of incompetent shale and slate.

(c) To examine the gabbro dyke contacts for gouge and other evidence of faulting, and to determine the freshness of the rock in the dyke itself.

(d) To provide specimens for mechanical strength determinations.

Recommendations

The following recommendations are submitted:

(a) In order to prevent debris sliding into the tunnel mouth during and after construction it is recommended that either the overburden be stripped off for a width of 25 to 30 feet on either side of the tunnel line to at least R.L. 3940 feet, or that a low concrete protection wall, anchored and buttressed to sound rock, be constructed at about R.L. 3910 feet. The latter alternative may be preferable if it appears that, even after stripping back, debris slides are still likely to come down from above. An additional measure would be to excavate a 10-feet wide berm at the top of the cleared area or immediately above the concrete protection wall.

(b) In view of the sheeted nature of the rock jointing over the proposed tunnel entrance, the thin to laminated bedding, and the similar inclinations of bedding and ground surface, it is recommended that rock bolting be carried out to a systematic pattern up to about R.L. 3890 feet before excavation commences. Immediately above the entrance the bolts should be at 3 feet centres and have the maximum length possible without interfering with excavations. Spacing could be increased to 4-feet centres and bolt length to 10 feet higher up the face. Bolts on either side of the entrance should be 10 feet long. All bolts should be placed normal to the rock surface, and tensions should be checked regularly during the initial stages of driving the tunnel. Unless the rock above the tunnel proves to be very weak, it should not be necessary to use groutable rock bolts.

(c) In the early stages of excavation of the tunnel entrance it is suggested that only small charges of explosive be used in each round until the behaviour of the rock is established.

(d) In view of the sheeted nature of the rock at the surface it is considered likely that rock bolting inside the tunnel entrance will be necessary but this can be decided by inspection.

(e) The first gabbro dyke cutting the tunnel line will be encountered within 50 to 60 feet from the entrance, and the precautions outlined on page 16 should be taken.

(f) A slight increase in rock cover above the tunnel would be obtained if the tunnel entrance were relocated 50 to 60 feet farther west. In this position minor groundwater seepage from the small creek east of B.M.I. would be reduced, and the tunnel would be removed from any joints that developed as a result of unloading in the depression of the stream. If the entrance is relocated, geological conditions will be the same as those outlined above except that the first gabbro dyke would be encountered further from the portal.

TUNNEL LINE

Geology

Surface mapping indicates that the proposed tunnel line lies in metamorphic rocks cut by basic to intermediate dykes for its entire length (see Plate 8). Rock types similar to those at the weir and intake sites occur, together with very hard black hornfels, fine-grained quartzite, fine-grained basic to intermediate volcanics (probably flows) and siliceous marble. The marble is exposed only in one, or possibly two, outcrops in Loop Creek, and one outcrop to the northwest of B.M.VI. In each place the beds are no more than 15 feet thick, and are composed of sound tight rock. If encountered in the tunnel the marble is not expected to be cavernous.

Traverses down the Ramu Gorge from intake site to power house site, and up other creeks, showed that the metamorphic rocks form a broad asymmetrical anticline whose axis strikes approximately east and crosses the tunnel line between B.M.III and B.M.IV, (see Plate 8). The north and south limbs of the anticline converge to form a "nose" at the eastern extremity of the area. Superimposed on this major east-plunging structure are other smaller folds, rolls, warps and faults; the rocks penetrated by the tunnel may therefore change their attitude many times within a short distance. At the northern end of the tunnel line the strike of the bedding swings from north-west to north, producing an apparent syncline in the longitudinal section.

In some parts of the tunnel massive thickly bedded rocks will be encountered but on the whole thinly bedded or laminated rocks will predominate. Where the rocks are thinly bedded or laminated or where one or more sets of sheet jointing exist, good rock breakage should be achieved with economical use of explosives. The main joint system noted at the weirsite (strike east, dip 60° to 80° north) appears to persist throughout the area with the accompanying dyke sets. The latter are abundant between B.M.II and B.M.III, (i.e. between Dyke Creek and Corner Creek); at least one dyke is 100 feet thick. It is very likely that dykes will be encountered throughout the tunnel line.

The basement metamorphic rocks are overlain at about R.L. 4,100 to 4,200 feet by unconsolidated lacustrine gravel, sand, silt, and clay. Considerable attention was given to determining whether or not the floor of the sediments is level. The altitude of the top of the metamorphic rock was determined in ten places either by costeans or by traverses up creek beds. The maximum relief was found to be 170 feet, the lowest point being

R.L. 4,080 feet near the confluence of Yonki Creek and the Ramu River, and the highest point R.L. 4,250 feet, near B.M.V at the northern end of the tunnel line. The floor of the lake sediments appears to undulate gently and to rise steadily from south to north; no major depressions or ravines were found either in the field or by stereoscopic inspection of aerial photographs (on which the boundary between metamorphics and sediments stands out clearly). It is concluded that the minimum thickness of metamorphic rock between the proposed tunnel and the lake sediments will be 250 to 300 feet at the intake end, increasing to a maximum of 400 at B.M.V. Results of diamond drilling along the tunnel line may indicate that further testing of the boundary is necessary.

A puzzling feature was the abundance of large, rounded boulders of diorite or granodiorite in the Ramu River and in nearly all the creeks in the area. Even small creek beds 2 to 3 yards wide are choked with the granodiorite boulders ranging from a few pounds in weight to 60 or 70 tons. No outcrops of granodiorite have been found. It was concluded at an early stage that the source of the boulders was either a granodiorite intrusion in the metamorphic rocks now hidden by lake sediments or deep weathering, or the lake sediments themselves. A costean 200 feet long was dug at the head of a creek near B.M.V in which granodiorite boulders were found. The costean was commenced in lake sediments and continued down-slope until metamorphic rocks were encountered. Immediately above the metamorphic rocks a layer approximately 40 feet thick was found, in which granodiorite boulders were mixed with gravel, sand, and silt, together with water-worn fragments of sandstone, quartzite and shale. This indicates that a basal boulder bed in the lake sediments is a source of some, if not all, of the granodiorite boulders. It is therefore unlikely that a large granodiorite intrusion will be encountered in the tunnel, although a large igneous mass has been emplaced some miles to the north and west of the area covered by the project. It is not known whether the granodiorite boulder bed extends throughout the whole area or whether it is confined to the central and northern portions. No traces of boulders in situ were found at the intake end of the tunnel, although adjacent creeks contain granodiorite boulders.*

Noakes and Gardner (1959) suggest that detritus on the bench marking the top of the metamorphic rocks and on the slopes below has been derived from andesitic lava flows over-lying the metamorphic rocks but under-lying the lake sediments. They further note that this andesite is not a constituent of the metamorphic rocks seen in the gorge below. Mapping and costeaning of the area during the present survey have not disclosed any evidence pointing to the existence of andesite lava flows capping the metamorphic basement. Most of the detritus on the slopes was found to be laminated metamorphic rock, hornfels, and fine-grained dolerite or andesitefrom dykes and sills. Verification of the presence or otherwise of andesite lavas will therefore depend on

* McMillan and Malone (1960) regard Quaternary boulder beds in the Goroka valley as piedmont fans at the mouths of steep valleys of the Bismarck and Asaro Ranges. "The unstratified piedmont material was distributed across the floor of the valley by the Asaro River and its tributaries, being sorted and bedded in the process. Near the margins of the valley, flat-lying bedded deposits inter-finger with the unstratified piedmont material which was laid down on a surface sloping gently basinwards .... Close to the Bismarck Range, north of Asaro, the piedmont fans consist of large rounded boulders, of all sizes in a clay and sand matrix. No bedding is present, and the boulders are commonly not in contact."

the results of diamond drilling.

Diamond Drilling

The proposed diamond drilling programme is shown in the longitudinal section (Plate 8), and the specifications and objectives are set out in Appendix II. The main objectives of the holes are:-

(a) to provide a continuous sample of the rock types, from the surface to 50 feet below the tunnel line, which will enable the proportion of incompetent beds to be determined, together with such other features as intensity of jointing at depth;

(b) to provide tenderers with an opportunity to examine rock specimens from the vicinity of the proposed tunnel line, and to enable them to be supplied with geological logs of drill cores;

(c) to determine the altitude of the top of the metamorphic rocks and the thickness of the underlying weathered zone.

(d) to determine the presence or otherwise of andesite lava flows overlying the metamorphic rocks.

(e) to determine the presence or otherwise of a granodiorite intrusion in the metamorphic rocks.

(f) to permit the rocks in the vicinity of the tunnel line to be tested for water tightness.

(g) to determine the water table level.

(h) to sample the dyke contacts for possible fault zones and to determine the nature and frequency of these zones at depth.

(i) to provide specimens for mechanical strength tests.

The drill holes are inclined to the south in order to avoid the possibility that long sections of hole will be entirely in dyke material, and to ensure that as many dyke contact zones as possible will be penetrated to give an indication of the extent of faulting. Maximum footage at present proposed is 1,830 feet, including 320 feet for the intake site.

Specifications are also given in Appendix II for a contingent set of shallow holes or "prickings" which may be necessary to provide further information about the altitude of the top of the metamorphic rocks, (i.e. whether deep ravines filled with lake sediments are present). These holes could be extended slightly to investigate the depth of weathering in the metamorphic rocks if necessary. The drill used should be capable of coring through a possible granodiorite boulder bed 40 feet thick at a depth of 50 to 100 feet. The overlying lake sediments are unconsolidated and contain pebble and cobble bands which may cause loss of diamonds. Results of DD4, DD5, and DD6 will affect the number of prickings required, if any, and determine their final positions. The estimated footage for 6 holes is 710 feet, the deepest hole being 250 feet.

Recommendations

The following recommendations are submitted:-

(a) Further investigation of the floor of the lake sediments by seismic survey or by "prickings" with a small drill may be necessary if DD4, DD5, and DD6 show a very uneven floor to the sediments.

(b) Where the tunnel cuts through gabbro dykes, the soundness of the country rock in contact with the dyke should be determined as soon as possible. The strength of the country rock at these points will depend on the nature of the contact, (which may be faulted and consist of gouge), the attitude of the bedding, the thickness of the beds or laminations, the presence or absence of weak shale and slate bands, the direction and intensity of jointing, and the presence or absence of clay or other material on bedding or joint planes. Rock bolting or lining of the tunnel at such points may be necessary. If unsound ground is penetrated, rock bolts should be placed after each round is fired, so that the roof is supported up to the face at all times.

(c) The tunnel may pierce several beds of marble. These should be examined for signs of solution networks which might allow water leakage from an unlined tunnel under unfavourable hydraulic conditions. Radial drilling and water pressure testing will be necessary if such networks are present, to determine the potential water loss and the length of tunnel to be lined. (It should be pointed out that although most of the proposed tunnel will be below the water table, it is quite possible that aquifers of high pressure water may be encountered whose pressure is unrelated to depth. Similarly, zones of low pressure water may be encountered at quite great depths below the water table. These phenomena are known to occur elsewhere in the world in fissured non-porous rocks).

(d) Disposal of rubble excavated from the tunnel at the intake end may present problems, and it is suggested that consideration be given to driving the tunnel from the surge tank end, where disposal of excavated material would not be difficult. This method would also have the advantage that drainage of the tunnel would be by gravity.

(e) If water pressure test results along the tunnel line from surface diamond drilling are unfavourable, further testing should be carried out by radial drilling from the tunnel itself at regular intervals.

(f) Regular geological inspections and mapping of the tunnel should be made as excavation proceeds to record the nature of the rock and to enable estimates of rock bolting or tunnel lining to be prepared.

(g) Representative samples of selected rock types encountered in the tunnel should be tested for durability when exposed to alternate wetting and drying. This will simulate the conditions in an unlined free flow tunnel and will indicate which rock types require protection. In sections of the tunnel where durable rocks occur, but where other weaknesses such as close jointing are present, adequate tunnel support should be obtained by mesh and gunite with grouted rock bolts.

(h) Rock samples from diamond drill holes intersecting the tunnel should be tested for compressive strength, etc.

Maximum cover over the tunnel is about 500 feet, and it is not likely that rock stresses in excess of the strength of the rock will exist. However, it will probably be necessary to line the tunnel with steel sets and reinforced concrete near the intake and exit portals because of the deficiency of cover.

(i) Representative rock samples from the tunnel should be tested for alkali reaction. This is discussed in more detail on page .

(j) In view of the seismic activity of the area and the possibility that the rock mass is under tectonic stress, strain indicators should be placed in the tunnel to study the tectonic loading.

PENSTOCK AND SURGE TANK

Geology

The first 900 feet of the penstock will be anchored in metamorphic rock on a slope of 25 to 30 degrees. Thin beds of marble may occur. The lowest 400 feet of the penstock will be anchored in marble. Information from eight costeans along the penstock line is summarised in Appendix I. Most of the costeans are located at or near the proposed positions of anchor blocks. The deepest costean revealed 14 feet of soil and rock debris without reaching firm bedrock; this was at Peg 849.19 near the marble contact, where debris has accumulated by downslope movement. It is probable that 20 feet or more of soil and rock will have to be excavated before firm foundation rock is reached in some places. In other places bedrock will be encountered at between 10 to 15 feet.

Both the metamorphic rock and the marble are likely to have a dip component downslope along the penstock route. The metamorphic rocks and dykes have the same physical characteristics as those previously described. The marble is described on page 19.

The tunnel portal and surge tank will be located in a slight hollow in the hillside where soil and rock litter have accumulated. The depth of the overburden at this point could not be determined by costeaning because of the size of the blocks encountered. The presence of this material and the configuration of the adjacent slopes suggests that the proposed surge tank site is a natural debris trap or couloir, the material gravitating from the slopes and cliffs above. Low cliffs of metamorphic rock are situated some 350 feet horizontally overlooking the surge tank site. Large blocks scattered over the slopes below indicate that rock falls are of frequent occurrence. Recommendations concerning protection of installations are made on page 18.

The summit of the hill above the cliffs should provide suitable foundations for gantry or tramway installations. Access to the slopes below will be possible through a gap in the cliffs.

Diamond drilling

In view of the fact that only the costeans above the marble encountered sound bedrock and that elsewhere along the penstock route the depth to sound bedrock is uncertain, it is recommended that shallow holes be drilled at the surge tank site and at each anchor block site to determine the thickness of overburden and the soundness of foundations. It may be possible to save time and cost by drilling these holes with a small semi-portable drill instead of a less easily handled larger rig. The maximum total footage is 230 feet. Details of the holes are set out in Appendix II. Consideration should be given to testing the anchor sites by excavation instead of drilling.

Recommendations

The following recommendations are submitted:-

(a) In view of the unstable nature of the overburden, the possibility of soil and overburden creep, the steepness of slope (25 to 50 degrees), and the down-slope dip component of the underlying rock, it is recommended that the penstock anchor blocks be founded on sound bedrock. Excavation of about 20 feet at each anchor site should be allowed for in designs, and checked by drilling at actual sites. (There is a high risk that foundations of the floating type will move.)

(b) To avoid the possibility of damage to outlet portal, surge tank installations and vulnerable sections of the penstock, one of the following proposals should be adopted(see Plate 12):-

A. The surge tank should be placed underground if it is decided to retain the present location; or

B. The surge tank should be placed 230 feet south-east of the present site; or

C. The surge tank should be placed 120 feet north-west of the present site.

The penstock would have to be realigned. A berm and concrete protection wall could be constructed at the site chosen as an additional measure if necessary.

(c) Before construction commences on this section of the project it is recommended that the cliffs above be inspected and barred down. Rock bolting may be necessary in places.

(d) The lower part of the penstock deviates from the crown of the spur leading to the river. It is recommended that the pipeline be re-located to the crown where protection from rock falls will be increased, as falling rock tends to move down the steep slopes on either side of the spur. Further, overburden may be shallower along the crown of the spur. The power house would still be in approximately the same position as at present proposed. The suggested realignment of the penstock is shown in Plate 12.

(e) If anchor site excavations show that cut slopes are unstable or that downslope movement of over-burden is likely to occur, it would be wise to design the anchor blocks so that minimum resist-ance is offered to encroaching material. Ellipsoidal blocks, with the long axis parallel to the direction of steepest ground slope, or 'V'-shaped blocks with the apex of the 'V' pointing uphill, are two suitable forms.

(f) As a result of mapping in adjacent creeks, it appears likely that strata underlying the penstock will have a dip component down the slope. Should diamond drilling or excavations for anchor blocks reveal a high proportion of thinly bedded or laminated rock, mechanical tests should be carried out to determine the shear strength of the rock parallel to bedding planes. The results should be examined in the light of the downhill thrusts to be imposed on the foundations by the anchor blocks. If an insufficient margin of safety exists, anchor bars or rock bolts extending further into bedrock may be necessary.

POWER HOUSE SITE

Geology

The power house will be situated on a gently sloping to flat bench, 80 feet wide, cut by the river in coarse to fine-grained white marble. The marble conformably underlies the metamorphic rocks, and relict bedding and a possible secondary foliation are present. Two well developed joint systems strike east and north, and minor basic or intermediate intrusions occur along some joints and bedding planes. The rock is moderately hard and strong but fresh surfaces have a tendency to disintegrate by granulation or "sugaring".

Near the river, solution networks are moderately developed along joints, and ground water circulation is probably slight to moderately free. The stream entering the Ramu immediately north of B.M.VII emerges from a cave in the marble at R.L. 3650 feet; this was the only evidence found of major underground drainage. The cave is situated 1,400 feet horizontally from the power house site.

The rock bench is covered with a thin layer (6 inches to 2 feet) of soil, river sand and gravel, indicating that floods have risen above the level of the bench. There is a possibility that large debris slides from the slopes of the gorge may block the river above or below the power house site. In the former case there is a danger that water will be impounded behind the natural dam thus formed, later to be released when the dam bursts in a wave which might damage the power house, transformer yard or switch-yard. Should the river be blocked immediately below the power house, the temporary rise in water level might interfere with discharge from the tailrace tunnel.

Heavy rain during the present survey has shown that some slopes above the river are unstable and prone to movement by debris slides. Scars produced by large slides in the past can be seen on aerial photographs of the region. It is impossible to estimate accurately the probability of a river blockage occurring, but it represents a definite hazard to the power house and other installations should they be constructed on the rock bench described above.

As described on page 17 there is evidence that blocks of rock occasionally roll down the slopes above the power house. During unusually wet periods rock falls are more numerous than at other times. A surface power station, transformer yard and switch-yard at the foot of the slope would be less exposed than structures higher up the slope, provided they were sited to avoid the natural path of falling rocks down either side of the spur.

The possibility of rock falls occurring from the cliffs on the opposite side of the river should not be overlooked. Several large vertical joints cut the cliff obliquely, forming semi-detached slabs of rock which may be unstable. An inspection should be made after vegetation is cleared.

Diamond Drilling

Two 50-foot holes should be sufficient to test the foundations at the power house site. Water pressure testing will be necessary to help determine the degree of development of solution cavities and channels. The specifications are set out in Appendix II.

Recommendations.

The following recommendations are submitted:-

(a) As floods have risen above the rock bench, consideration should be given to placing the power house and transformers underground or higher up the slope. It is expected that when detailed hydrological data become available this course of action will be endorsed. Because of the steepness of the slope overlooking the rock bench, excavations for a power house site, transformer yard and switchyard higher up will be difficult. Problems likely to be met with farther up the slope are:-

variations in material to be excavated - jointed marble bedrock, loose blocks, scree and soil; downhill creep of overburden; and instability of cut slopes. Therefore, placing the installations underground is considered to be the best method of protection available. It would have the additional advantage of eliminating risk of damage by rock falls from higher up the slope.

(b) Should it be decided to house the power station and associated equipment underground, one of several layouts could be adopted, and a more detailed geological appraisal would be necessary than is given here. The diamond drilling programme would have to be revised and expanded to provide adequate information on which to base choice of site and preliminary engineering designs. No holes have been planned for this purpose at this stage.

(c) Representative samples of marble should be taken from drill cores and the various significant properties of the rock determined, e.g. modulus of elasticity, ultimate compressive strength, Poisson's ratio, absorption, thermal expansion, deformation by creep, strength and nature of bond with cement.

An investigation of the differential thermal expansion of calcite may be necessary; it was noticed that freshly exposed faces of marble tend to deteriorate by granulation or "sugaring". This effect could be due to destruction of weak intergranular bonds by exposure to air, or to a small increase in volume of the surface layers produced by differential thermal expansion of interlocking calcite crystals or granules. Elsewhere, up to 1 per cent increase in volume of marble due to differential thermal expansion has been observed, (Birch, 1942). Granulation of the surface of marble in this manner may affect the strength of the cement bound.

(d) If diamond drilling and water pressure testing results indicate the existence of solution cavities and channels beneath the site, foundations should be consolidated by grouting.

(e) An inspection should be made of the marble cliffs on the east side of the river opposite the rock bench. If unsound blocks are present, they should be removed or secured by rock-bolting.

SOURCES OF AGGREGATE

River gravel and sand

No deposits of gravel or sand suitable for concrete aggregate were found during the survey. Most of the gravel and sand used for road metal in the area is dug by hand from thin lenses and bands found in the lake sediments. These are not generally more than 2 to 3 feet thick and contain a large proportion of silt and clay. In most places, large volumes of overlying material would have to be removed to expose the gravel lens, which might be of small extent. However, lake sediments elsewhere in the basin may contain more suitable deposits.

A possible source of aggregate exists at the confluence of Yonki Creek and the Ramu River, where the river is somewhat wider than normal, and where sand, gravel and boulders have accumulated. The reaches of the Ramu River near Arona should be examined for similar deposits.

The river gravel and sand in the Ramu River are composed of a variety of rock types, viz. silicified greywacke, sandstone, siltstone, shale, slate, marble, hornfels, diorite, granodiorite, dolerite, gabbro, basalt and andesite. The sand contains abundant minute flakes of various micaceous minerals. Both gravel and sand intended for use as aggregate should be examined petrographically to determine the proportions of deleterious rocks and minerals present. An examination should also be made of any exterior coatings of reactive minerals.

Crushed aggregate

Because of the variety of rocks present within a short distance of any part of the planned engineering works, a wide selection of rocks for crushed aggregate is available. A detailed discussion as to their suitability would be out of place at this stage, but a few suggestions are submitted concerning a preliminary choice.

A possible source of rock for crushed aggregate will be the material excavated from the weir site, tunnel, and power house site.

At the weir site and over much of the tunnel line, the metamorphic rocks are thinly bedded and are cut by numerous altered gabbro or dolerite dykes, so it will be difficult to ensure that uniform material is supplied for crushing. Of the rock types present only the shale and slate are expected to possess undesirable physical properties, where not weathered. Some of the gabbro and dolerite may be crushed and altered due to faulting, but it is unlikely that much of this material will be encountered. With the exception of chert, none of these rocks is expected to provide serious difficulties from the point of view of reactive aggregate, although the presence of a sodium zeolite in minor quantities was noted in a specimen of greywacke, (see Appendix V). All of these rock types should be examined petrographically for minerals likely to cause alkali-aggregate reaction, viz. volcanic glass, opal, chalcedony, tridymite, zeolites, sulphides.

Noakes and Gardner (1959) reported the presence of cherts and tuffs in the metamorphic sequence in the Ramu Gorge. The former is one of the most troublesome rocks the engineer has to handle. Although it is very hard and strong, it frequently shows a marked increase in volume upon absorption of water. Cherts often contain alkali-reactive forms of silica (tridymite) and are suitable for use in concrete only with adequate safeguards against the alkali-aggregate reaction. Unweathered chert has a smooth, almost glassy surface and a good bond with cement may not be obtained. Attention is called to the extreme range in quality shown by chert; some cherts may be found of suitable quality for use in concrete, but it would be best to consider all as suspect until found otherwise.

Tuffs should be examined petrographically to determine the nature of any volcanic glass present and its reaction with alkalies.

If the proportion of deleterious rocks or minerals in the excavation material from the tunnel is too high to permit its use as aggregate, or if it is found that adequate sorting of desirable from undesirable rocks cannot readily be achieved, then consideration might be given to the use of crushed diorite or granodiorite from a large intrusion about 2 miles towards Kainantu from Yonki Creek bridge. Both diorite and granodiorite are deeply weathered in situ, but fresh rock is durable, hard, tough to a reasonable degree, and should crush to fragments of good shape. The fragments would have a good bond with cement and should be chemically stable.

Another rock type which may have deleterious properties in concrete, and found in the vicinity of the project, is andesite. The main undesirable minerals found in andesite are volcanic glass and devitrified glass.

ACCESS ROADS

It is expected that access roads to drill sites along the tunnel line will be constructed without difficulty. A network of ridges extends over most of the area, and one or two sweeps with a bulldozer blade should be sufficient to form a dry weather road in most places. When a road line deviates from a ridge, additional formation work will be necessary because of the steep slopes. Care should be taken over drainage, as the lake sediments are permanently water-logged and probably unstable because of this. Roads along ridge tops would require less attention to drainage.

Access to the saddle at the head of the slopes leading down to the power house site can be obtained from the narrow road through the grounds of the Swiss Mission. This road ends some 300 yards from the saddle, but intervening grades are gentle.

If the drilling rig is sledged along the tunnel line from hole to hole, grades encountered will be reasonable for the most part except for slopes above the intake. A few short steep slopes elsewhere may necessitate detours being made.

ACKNOWLEDGEMENTS

I wish to thank Mr. John Brett of the Commonwealth Department of Works, Port Moresby, for his ready and efficient co-operation in all matters connected with this survey, and the Assistant District Officer at Kainantu for his assistance in providing native labour and rations. The Lae Office of the Commonwealth Department of Works supplied tools and vehicle parts from time to time. The excellent preliminary survey carried out by Mr. D. Thiedecke of the Department of Works greatly expedited the establishment of survey control for geological mapping.

REFERENCES

BIRCH, F., 1942 - Handbook of physical constants. Geol.Soc.Amer.Spec.Paper, 36

MACKAY, N.J., 1955 - Geological report and reconnaissance of the Markham and Upper Ramu drainage systems, New Guinea. Bur.Min.Resour.Aust.Record 1955/25. (unpubl.)

McMILLAN, N.J. & MALONE, E.J., 1960 - The geology of the Eastern Central Highlands of New Guinea. Bur.Min.Resour.Aust.Report 48

NOAKES, L.C. & GARDNER, D.E., 1959 - Lae hydro-electric projects, New Guinea,- Reconnaissance geological investigation of the Upper Ramu scheme. Bur.Min.Resour.Aust.Record 1959/23 (unpubl.)

APPENDIX I

RESULTS OF COSTEANING

Tunnel line chainage (Feet)	Penstock line chainage (Feet)	Depth of over-burden (Feet)	Bedrock	Remarks
478.05	-	9	Metamorphics	Soft, clayey.
Near 1016.12	-	4	Metamorphics	Soft, clayey.
3207.31	-	7 +	Lacustrine sediments.	Soft, weathered granodiorite, sand, clay.
4400.37	-	10 +	Lacustrine sediment	Clay, sand, cemented bands.
Near 5464.06	-	2	Lacustrine sediments overlying granodioritic boulder bed and metamorphics.	Soft and weathered.
R/S 608	-	13	Lacustrine sediments	Clay, sand, gravel
6276.35	-	6	Metamorphics and gabbro	Broken and friable.
7004.21	0	3 +	Metamorphics?	Not determined.
7004.21	0	10	Metamorphics and gabbro	Broken and friable.
-	249.15	10	Metamorphics	Broken rock.
-	550.51	7 +	Metamorphics?	Not determined.
-	849.19	14 +	Metamorphics?	Not determined.
-	899.83	7	Marble	Firm, strong.
-	979.01	4	Marble	Firm, strong.
-	1070 approx	5	Marble	Firm, strong.
-	1120 to 1170 approx	2	Marble	Firm, strong.

APPENDIX II

SUMMARY OF DIAMOND DRILLING SPECIFICATIONS FOR WEIR SITE, INTAKE AND TUNNEL

HOLE NO.	LOCATION	INCLINATION FROM HORIZONTAL	MAGNETIC BEARING	LENGTH	CORE SIZE	CORING	WATER PRESSURE TEST
D.D.1	South bank of river at weir site	-40°	045°M	200'	NX	0 ft.- 200 ft	0 ft.-200 ft
D.D.1.A.	North bank of river at weir site	-80°	196°M	50'	AX	0' - 50'	0' - 50'
D.D.1.B.	South bank of river at weir site	-60°	196°M	50'	AX	0' - 50'	0' - 50'
		TOTAL FOR WEIR		200' 300'	Minimum Maximum	Total 200' 300'	Total 200' 300'
D.D.2.	To intersect proposed tunnel 60 ft. from intake, (horizontal distance)	-80°	158°M	80'	NX	0' - 80'	40' - 80'
D.D.2.A.	To intersect proposed tunnel 130 ft. from intake	-45°	338°M	100'	NX	0' - 100'	60' -100'
D.D.3.	To intersect proposed tunnel 200 ft. from intake.	-45°	338°M	140'	NX	0' - 140'	100' -140'
D.D.4.	To intersect proposed tunnel 1530 ft. from intake	-80°	158°M	370'	NX,BX	30' - 370'	270' -370'
D.D.5	To intersect proposed tunnel 3350 ft. from outlet, (surge tank end)	-80°	158°M	400'	NX,BX	30' - 400'	300' -400'
D.D.6.	To intersect proposed tunnel 900 ft. from outlet	-80°	158°M	390'	NX,BX	30' - 390'	290' -390'
D.D.7.	To intersect proposed tunnel 80 ft. from outlet	-60°	338°M	100'	NX	0' - 100'	40' -100'
D.D.8.	To intersect proposed tunnel 200 ft from outlet	-90°	-	120'	NX	0' - 120'	60' -120'
D.D.8.A	To intersect proposed tunnel 150 ft from outlet	-60°	338°	130'	NX	0' - 130'	70' -130'
		TOTAL FOR TUNNEL LINE		1600' 1830'	Minimum Maximum	TOTAL 1510 1740	TOTAL 500' 600'

APPENDIX II

SUMMARY OF DIAMOND DRILLING SPECIFICATIONS

FOR SURGE TANK SITE, PENSTOCK AND POWER HOUSE SITE

HOLE NO.	LOCATION	CHAINAGE	R.L.OF COLLAR	INCLINATION FROM HORIZONTAL	LENGTH	HOLE SIZE	CORING	WATER PRESSURE TEST
		Feet	Feet		Feet		Feet	
D.D. 9	Surge tank	0	3847	-90°	50	NX	0 -50	-
D.D.10	Anchor A	103.65	3804	-90°	20 -30	AX	10 in bedrock	-
D.D.11	Anchor B	199.73+25	3765	-90°	20 -30	AX	"	-
D.D.12	Anchor C	449.18+40	3610	-90°	20 -30	AX	"	-
D.D.13	Anchor D	700.62+17	3485	-90°	20 -30	AX	"	-
D.D.14	Anchor E	849.19.+38	3410	-90°	20 -30	AX	"	-
D.D.15	Anchor F	979.01+12	3300	-90°	20 -30	AX	"	-
D.D.16	)Power house)site	1102.04+60	3195	-90°	50	AX	0 -50	0'-50'
D.D.17	)	1102.04+60	3195	-90°	50	AX	0 -50	0'-50'
			TOTALS	Maximum	330'		210'	100'
				Minimum	270'			

APPENDIX II

SUMMARY OF DIAMOND DRILLING SPECIFICATIONS

SECONDARY PRICKINGS ALONG TUNNEL LINE

HOLE NO.	LOCATION (HORIZONTAL DISTANCES)	R.L.	INCLINATION FROM HORIZONTAL	ESTIMATED LENGTH	HOLE SIZE	CORING	WATER PRESSURE TEST
	Feet	Feet		Feet			
P.1.	700' from Intake	4215	-90°	100	AX	All hard rock	-
P.2.	1100' " "	4195	-90°	80	AX	" " "	-
P.3.	2300' " "	4195	-90°	80	AX	" " "	-
P.4	3270' " "	4240	-90°	110	AX	" " "	-
P.5	2800 " Outlet	4330	-90°	170	AX	" " "	-
P.6	1940' " "	4355	-90°	170	AX	" " "	-
		Approximate total		710 ft			

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SPECIFICATIONS FOR DRILLING

PROJECT: Upper Ramu Hydroelectric Project.

DRILL HOLE NO. TEMPORARY D.D.1 FINAL

TYPE OF DRILLING: Diamond drilling with stationary split inner-tube core barrel.

LOCATION: South bank of Ramu River at proposed weir site.

OBJECTIVES OF DRILLING: To test soundness & water tightness of rock and possible faulting below river.

SITE INDICATED BY: Wooden peg near tree stump.

DRILL SITE PEG, CO-ORDINATES: E N Not surveyed.

METHOD OBTAINED: ———

DRILL SITE PEG, R.L. OF GROUND SURFACE: 3877 ft.

METHOD OBTAINED: Telescopic alidade & tape, Abney level and compass.

DIRECTION OF HOLE: 045° magnetic INDICATED BY: Not indicated.

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) -40°

REQUIRED SIZE: NMLC.

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) To extend 30 ft. (horizontal distance) beyond north edge of river.

ANTICIPATED DEPTH: 200 ft.

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES): Hard strong greywacke, sandstone and siltstone with weaker interbeds of shale and slate. Laminated or thinly bedded. Also hornfels and gabbro, hard and strong. Well developed zones of sheet jointing and cleavage may cause caving and jamming of drill rod in 40° hole. Plan of hole is almost parallel to strike of bedding, may cause deflection.

WATER PRESSURE TESTING REQUIRED: Every 20 ft throughout hole.

SPECIAL REQUIREMENTS: Maximum core recovery particularly important. Core to be laid out as little disturbed as possible and protected from weather until photographed and logged by geologist. If possible core to be photographed in barrel by driller. Any signs of blue clay in circulating water or core barrel to be recorded by driller. Core to be carefully stored. Direction and inclination of hole to be accurately marked for driller. Collar to be surveyed, marked and sealed on completion.

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SPECIFICATIONS FOR DRILLING

PROJECT: Upper Ramu Hydroelectric Project.

DRILL HOLE NO. TEMPORARY D.D.1A FINAL

TYPE OF DRILLING: Diamond drilling with stationary split inner-tube core barrel.

LOCATION: North abutment of proposed weir site.

OBJECTIVES OF DRILLING: If D.D.1 is in unsound rock with high water loss, D.D.1A should be drilled to test abutment rock on north bank.

SITE INDICATED BY: Not marked.

DRILL SITE PEG, CO-ORDINATES: E N Not surveyed.

METHOD OBTAINED: ————

DRILL SITE PEG, R.L. OF GROUND SURFACE: 3870 ft. approx.

METHOD OBTAINED: From topographic map.

DIRECTION OF HOLE: 196° magnetic INDICATED BY: Not indicated but along proposed axis of weir.

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) -80°

REQUIRED SIZE: AX ?

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) To test soundness and water tightness of rock in zone affected by loading and head of weir.

ANTICIPATED DEPTH: 50 ft.

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES): Hard strong silicified greywacke, sandstone and siltstone, with weaker interbeds of shale and slate. Laminated or thinly bedded. Also hard strong hornfels and gabbro. Well developed zones of sheet jointing and cleavage in sandstone and shale respectively.

WATER PRESSURE TESTING REQUIRED: Every 10 ft. throughout hole.

SPECIAL REQUIREMENTS: Maximum core recovery. Requirements as for D.D.1.

SITE SET OUT BY: DATE: 13/9/61

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SPECIFICATIONS FOR DRILLING

PROJECT: Upper Ramu Hydroelectric Project.

DRILL HOLE NO. TEMPORARY D.D.1B FINAL

TYPE OF DRILLING: Diamond drilling with stationary split inner-tube core barrel.

LOCATION: South abutment of proposed weir site.

OBJECTIVES OF DRILLING: If D.D.1 is in unsound rock with high water loss D.D.1B should be drilled to test abutment rock on south bank.

SITE INDICATED BY: Not marked.

DRILL SITE PEG, CO-ORDINATES: E N Not surveyed.

METHOD OBTAINED ——————

DRILL SITE PEG, R.L. OF GROUND SURFACE: 3,864 ft. approx.

METHOD OBTAINED: From topographic map.

DIRECTION OF HOLE: 196° magnetic INDICATED BY: Not indicated but along proposed axis of weir.

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) -60°

REQUIRED SIZE: AX ?

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) To test soundness & water tightness of rock in zone affected by loading and head of weir.

ANTICIPATED DEPTH: 50 ft.

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES): As for D.D.1A

WATER PRESSURE TESTING REQUIRED: Every 10 ft throughout hole.

SPECIAL REQUIREMENTS: Maximum core recovery. Requirements as for D.D.1.

SITE SET OUT BY:

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SPECIFICATIONS FOR DRILLING

PROJECT: Upper Ramu Hydroelectric Project.

DRILL HOLE NO. TEMPORARY D.D.2 FINAL

TYPE OF DRILLING: Diamond drilling with stationary split inner-tube core barrel.

LOCATION: Collar 10 ft. north of B.M.I. on tunnel line, (horizontal distance)

OBJECTIVES OF DRILLING: To intersect proposed tunnel 60 ft. from intake, and to test rock above portal.

SITE INDICATED BY: Not marked.

DRILL SITE PEG, CO-ORDINATES: E N Not surveyed.

METHOD OBTAINED: ————

DRILL SITE PEG, R.L. OF GROUND SURFACE: 3,920 ft. approx.

METHOD OBTAINED: From topographic map.

DIRECTION OF HOLE: 158° magnetic. INDICATED BY: Not indicated but along tunnel line towards intake.

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) -80°

REQUIRED SIZE: NMLC

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) To test soundness of rock and water tightness in vicinity of tunnel, and to penetrate gabbro dyke approx. 60 ft. from intake along tunnel line. To test dyke contacts for faulting.

ANTICIPATED DEPTH: 80 ft.

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES) Hard strong silicified greywacke, sandstone and siltstone with weaker beds of shale and slate. Beds thin or laminated, dipping in same direction as hole. Well developed zones of sheet jointing and cleavage. Also hard strong porphyritic gabbro dykes.

WATER PRESSURE TESTING REQUIRED: Every 10 ft from 40-80 ft.

SPECIAL REQUIREMENTS: Maximum core recovery. Core to be photographed and stored as for D.D.l. Driller to note any traces of blue clay in circulating water or core barrel. Direction and inclination of hole to be accurately marked for driller. Collar to be surveyed, marked and sealed on completion.

DATE: 13/9/61

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SPECIFICATIONS FOR DRILLING

PROJECT: Upper Ramu Hydroelectric Project.

DRILL HOLE NO. TEMPORARY D.D.2A FINAL

TYPE OF DRILLING: Diamond drilling with stationary split inner-tube core barrel.

LOCATION: Collar as for D.D.2.

OBJECTIVES OF DRILLING: If D.D.2 is in unsound rock, then D.D.2A should be drilled to intersect proposed tunnel 130 ft. from intake.

SITE INDICATED BY: Not marked.

DRILL SITE PEG, CO-ORDINATES: E N Not surveyed.

METHOD OBTAINED: ————

DRILL SITE PEG, R.L. OF GROUND SURFACE: 3,920 ft approx.

METHOD OBTAINED: From topographic map.

DIRECTION OF HOLE: 338° magnetic INDICATED BY: Not indicated but along tunnel line away from intake.

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) -45°

REQUIRED SIZE: NMLC

REQUIRED DEPTH: (IN TERMS OF OBJECTIVES) To test soundness of rock and water tightness in vicinity of tunnel between D.D.2 and D.D.3

ANTICIPATED DEPTH; 100 ft

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES) As for D.D.2

WATER PRESSURE TESTING REQUIRED: Every 10 ft from 60-100 ft.

SPECIAL REQUIREMENTS: As for D.D.2

SITE SET OUT BY:

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SPECIFICATIONS FOR DRILLING

PROJECT: Upper Ramu Hydroelectric Project.

DRILL HOLE NO. TEMPORARY D.D.3 FINAL

TYPE OF DRILLING: Diamond drilling with stationary split inner-tube core barrel.

LOCATION: Collar 60 ft (horizontal distance) north of B.M.I. on tunnel line.

OBJECTIVES OF DRILLING: To intersect proposed tunnel 200 ft from intake.

SITE INDICATED BY: Not marked.

DRILL SITE PEG, CO-ORDINATES: E N Not surveyed.

METHOD OBTAINED ————

DRILL SITE PEG, R.L. OF GROUND SURFACE: 3,948 ft approx.

METHOD OBTAINED: From topographic map.

DIRECTION OF HOLE: 338° magnetic INDICATED BY: Not indicated but along tunnel line.

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) -45°

REQUIRED SIZE: NMLC.

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) To test soundness of rock and water tightness in vicinity of tunnel, and to test dyke contacts for faulting.

ANTICIPATED DEPTH: 140 ft.

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES): As for D.D.2.

WATER PRESSURE TESTING REQUIRED: Every 10 ft from 100-140 ft.

SPECIAL REQUIREMENTS: As for D.D.2

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SPECIFICATIONS FOR DRILLING

PROJECT: Upper Ramu Hydroelectric Project.

DRILL HOLE NO. TEMPORARY D.D.4 FINAL

TYPE OF DRILLING: Diamond drilling with stationary split inner-tube core barrel.

LOCATION: Collar 40 ft north of peg 1508°57 on tunnel line.

OBJECTIVES OF DRILLING: To intersect proposed tunnel 1,530 ft approx. from intake.

SITE INDICATED BY: Not marked.

DRILL SITE PEG, CO-ORDINATES: E N Not surveyed.

METHOD OBTAINED: ———

DRILL SITE PEG, R.L. OF GROUND SURFACE: 4,165 ft approx.

METHOD OBTAINED: From topographic map.

DIRECTION OF HOLE: 158° magnetic INDICATED BY: Not indicated but along tunnel line towards intake.

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) -80°

REQUIRED SIZE: NMLC as deep as possible.

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) To extend 50 ft below the proposed tunnel to test soundness of rock and water tightness in vicinity of tunnel. Also to determine R.L. of bottom of lake sediments and presence or otherwise of andesitic volcanics overlying metamorphic basement. To determine the presence and extent of any beds of marble and the water table level.

ANTICIPATED DEPTH: 370 ft.

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES): As for D.D.2. It is expected that up to 70% of hole will be in gabbro or hornfels, - hard rock. Unconsolidated sands and clays with gravel or boulder beds in first 30-50 ft. Dip of bedding 30-45° south-east.

WATER PRESSURE TESTING REQUIRED: Every 20 ft from 270-370 ft.

SPECIAL REQUIREMENTS: As for D.D.2.

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SPECIFICATIONS FOR DRILLING

PROJECT: Upper Ramu Hydroelectric Project.

DRILL HOLE NO. TEMPORARY D.D.5 FINAL

TYPE OF DRILLING: Diamond drilling with stationary split inner-tube core barrel

LOCATION: Collar 10 ft north of peg 3705.50 on tunnel line.

OBJECTIVES OF DRILLING: To intersect proposed tunnel 3,350 ft from outlet.

SITE INDICATED BY: Not marked.

DRILL SITE PEG, CO-ORDINATES: E N Not surveyed.

METHOD OBTAINED: ———

DRILL SITE PEG, R.L. OF GROUND SURFACE: 4,200 ft approx.

METHOD OBTAINED: From topographic map.

DIRECTION OF HOLE: 158° magnetic INDICATED BY: Not indicated but along tunnel line towards intake.

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) -80°

REQUIRED SIZE: NMLC as deep as possible.

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) To extend 50 ft below tunnel and to test soundness of rock and water tightness in vicinity of tunnel. Also to determine R.L. of bottom of lake sediments and presence or otherwise of andesitic volcanic rocks overlying the metamorphic basement.
To determine presence and extent of any beds of marble and the water table level.

ANTICIPATED DEPTH: 400 ft.

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES) Unconsolidated sands and clays with gravel or boulder beds, in the first 30-50 ft. Thereafter as for D.D.2. Attitude of bedding variable, dip 10-30°. Hard gabbro dykes present.

WATER PRESSURE TESTING REQUIRED: Every 20 ft from 300-400 ft.

SPECIAL REQUIREMENTS: As for D.D.2

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SPECIFICATIONS FOR DRILLING

PROJECT: Upper Ramu Hydroelectric Project.

DRILL HOLE NO. TEMPORARY D.D.6 FINAL

TYPE OF DRILLING: Diamond drilling with stationary split inner-tube core barrel.

LOCATION: Collar 50 ft north of peg 6180.90 on tunnel line.

OBJECTIVES OF DRILLING: To intersect proposed tunnel 900 ft from outlet.

SITE INDICATED BY: Not marked.

DRILL SITE PEG, CO-ORDINATES: $\frac{E}{N}$ Not surveyed.

METHOD OBTAINED: ———

DRILL SITE PEG, R.L. of GROUND SURFACE: 4,175 ft approx.

METHOD OBTAINED: From topographic map.

DIRECTION OF HOLE: 158° magnetic. INDICATED BY: Not indicated but along tunnel line towards intake.

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) -80°

REQUIRED SIZE: NMLC as deep as possible.

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) To extend 50 ft below tunnel to test soundness of rock and water tightness in vicinity of tunnel. Also to determine the presence or otherwise of andesitic volcanic rocks overlying the metamorphic basement. To determine the presence and extent of any beds of marble, and the water table level.

ANTICIPATED DEPTH: 390 ft.

ANTICIPATED DRILLING CONDITIONS (STRATA,STRUCTURES): 10-15 ft of soil and rock debris. Thereafter as for D.D.2. Dip of bedding 15-30° east.

WATER PRESSURE TESTING REQUIRED: Every 20 ft. from 290-390 ft.

SPECIAL REQUIREMENTS: As for D.D.2.

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SPECIFICATIONS FOR DRILLING

PROJECT: Upper Ramu Hydroelectric Project.

DRILL HOLE NO. TEMPORARY D.D.7 FINAL

TYPE OF DRILLING: Diamond drilling with stationary split inner-tube core barrel.

LOCATION: Collar 35 ft south of peg 6922.26 on tunnel line.

OBJECTIVES OF DRILLING: To intersect proposed tunnel 80 ft. from outlet and to test rock above portal.

SITE INDICATED BY: Not marked.

DRILL SITE PEG, CO-ORDINATES: E N Not surveyed.

METHOD OBTAINED: ————

DRILL SITE PEG, R.L. OF GROUND SURFACE: 3,900 ft approx.

METHOD OBTAINED: From topographic map.

DIRECTION OF HOLE: 338° mag. INDICATED BY: Not indicated but along tunnel towards outlet.

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) -60°

REQUIRED SIZE: NMLC.

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) To extend 30 ft below tunnel to test soundness of rock and water tightness in vicinity of tunnel, and to test rock back above portal.

ANTICIPATED DEPTH: 100 ft.

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES): 10-20 ft of soil and rock debris; thereafter as for D.D.2. Dip of bedding 20-40° east

WATER PRESSURE TESTING REQUIRED: Every 20 ft from 40-100 ft.

SPECIAL REQUIREMENTS: As for D.D.2.

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SPECIFICATIONS FOR DRILLING

PROJECT: Upper Ramu Hydroelectric Project.

DRILL HOLE NO. TEMPORARY D.D.8 FINAL

TYPE OF DRILLING: Diamond drilling with stationary split inner-tube core barrel.

LOCATION: Collar 30 ft south of peg 6830.67 along tunnel line.

OBJECTIVES OF DRILLING: To intersect proposed tunnel 200 ft from outlet.

SITE INDICATED BY: Not marked.

DRILL SITE PEG, CO-ORDINATES: E N Not surveyed.

METHOD OBTAINED: ———

DRILL SITE PEG, R.L. OF GROUND SURFACE: 3,935 ft approx.

METHOD OBTAINED: From topographic map.

DIRECTION OF HOLE: ——— INDICATED BY: ———

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) - 90°

REQUIRED SIZE: NMLC.

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) To extend 30 ft below tunnel to test soundness of rock and water tightness in vicinity of tunnel.

ANTICIPATED DEPTH: 120 ft.

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES): 10-20 ft of soil and rock debris, thereafter as for D.D.2. Dip of bedding 20-40° east.

WATER PRESSURE TESTING REQUIRED: Every 20 ft from 60-120 ft.

SPECIAL REQUIREMENTS: As for D.D.2

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SPECIFICATIONS FOR DRILLING

PROJECT: Upper Ramu Hydroelectric Project.

DRILL HOLE NO. TEMPORARY D.D.8A FINAL

TYPE OF DRILLING: Diamond drilling with stationary split inner-tube core barrel.

LOCATION: As for D.D.8

OBJECTIVES OF DRILLING: If D.D.7 is in sound rock and D.D.8 in unsound rock or vice versa, then D.D.8A should be drilled to intersect the proposed tunnel 150 ft from the outlet. If D.D.7 and D.D.8 are both in sound rock, then D.D.8A is not required.

SITE INDICATED BY: Not marked.

DRILL SITE PEG, CO-ORDINATES: Not surveyed.

METHOD OBTAINED: ———

DRILL SITE PEG, R.L. OF GROUND SURFACE: 3,935 ft approx.

METHOD OBTAINED: From topographic map.

DIRECTION OF HOLE: 338° mag. INDICATED BY: Not indicated but along tunnel towards outlet.

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) -60°

REQUIRED SIZE: NMLC.

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) To extend 30 ft below tunnel to test soundness of rock and water tightness.

ANTICIPATED DEPTH: 130 ft.

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES) 10-20 ft of Soil and rock debris, thereafter as for D.D.2. Dip of bedding 20°-40° east.

WATER PRESSURE TESTING REQUIRED: Every 20 ft from 70-130 ft.

SPECIAL REQUIREMENTS: As for D.D.2

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SPECIFICATIONS FOR DRILLING

PROJECT: Upper Ramu Hydroelectric Project.

DRILL HOLE NO. TEMPORARY D.D.9 FINAL

TYPE OF DRILLING: Diamond drilling with stationary split inner-tube core barrel.

LOCATION: At proposed site of surge tank.

OBJECTIVES OF DRILLING: To test soundness of foundation rock.

SITE INDICATED BY: B.M.VI

DRILL SITE PEG, CO-ORDINATES: E——— N —

METHOD OBTAINED: ———

DRILL SITE PEG, R.L. OF GROUND SURFACE: 3,847 ft.

METHOD OBTAINED: Preliminary survey.

DIRECTION OF HOLE: ——— INDICATED BY: ———

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) -90°

REQUIRED SIZE: NMLC

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) To determine soundness of foundation rock in zone affected by loading of surge tank.

ANTICIPATED DEPTH: 50 ft.

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES): 10-20 ft of soil and rock debris, thereafter hard strong silicified greywacke, sandstone and siltstone with weaker interbeds of shale and slate. Also porphyritic gabbro dykes. Well developed jointing and cleavage. Dip of bedding $20-40^{\circ}$ east.

WATER PRESSURE TESTING REQUIRED: ———

SPECIAL REQUIREMENTS: Maximum core recovery. Core to be laid out as little disturbed as possible until photographed and logged by geologist. Any signs of blue clay to be noted by driller. Core to be carefully stored. Collar to be surveyed, marked and sealed on completion.

DATE: 13/9/61

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SPECIFICATIONS FOR DRILLING

PROJECT: Upper Ramu Hydroelectric Project.

DRILL HOLE NO. TEMPORARY D.D.10-15 FINAL

TYPE OF DRILLING: Diamond drilling with stationary split inner-tube core barrel.

LOCATION: Anchor A 103.65, B.199.73+25, C 449.18+40, D.700.62 +17, E. 849.19+38, F 979.01+12 (Horizontal chainages down penstock from BM VI).

OBJECTIVES OF DRILLING: To determine depth of overburden and soundness of foundation rock at each proposed anchor block site.

SITE INDICATED BY: ———

DRILL SITE PEG, CO-ORDINATES: E N ———

METHOD OBTAIHED: ———

DRILL SITE PEG, R.L. OF GROUND SURFACE: A3804 ft, B 3765 ft, C 3610 ft, D 3485 ft, E 3410 ft, F 3300 ft.

METHOD OBTAINED: Preliminary survey.

DIRECTION OF HOLE: ——— INDICATED BY: ———

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) All holes -90°

REQUIRED SIZE: AX ?

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) To establish depth to, and soundness of, foundation rock in zone affected by thrust of each anchor.

ANTICIPATED DEPTH: 20-30 ft.

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES): As for D.D.9.
Marble may be encountered near bottom of D.D.14 & 15.

WATER PRESSURE TESTING REQUIRED: ———

SPECIAL REQUIREMENTS: 5 ft core to be taken in bedrock. Other requirements as for D.D.9

SITE SET OUT BY:

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SPECIFICATIONS FOR DRILLING

PROJECT: Upper Ramu Hydroelectric Project.

DRILL HOLE NO. TEMPORARY D.D.16-17 FINAL

TYPE OF DRILLING: Diamond drilling with stationary split inner-tube core barrel.

LOCATION: Proposed powerhouse site at selected points near chainage 1102.04+60 on penstock line.

OBJECTIVES OF DRILLING: To test soundness of foundation rock.

SITE INDICATED BY: ———

DRILL SITE PEG, CO-ORDINATES: E ——— N

METHOD OBTAINED: ———

DRILL SITE PEG, R.L. OF GROUND SURFACE: 3,195 ft.

METHOD OBTAINED: Preliminary survey.

DIRECTION OF HOLE: ——— INDICATED BY: ———

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) Both holes -90°

REQUIRED SIZE: AX ?

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) To determine soundness of foundation rock and development of solution cavities and joints.

ANTICIPATED DEPTH: 50 ft.

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES): Soft, moderately strong marble with two well developed joint systems. Minor gabbro intrusions. Dip of bedding 15-30° east.

WATER PRESSURE TESTING REQUIRED: Every 10 ft throughout holes.

SPECIAL REQUIREMENTS: Driller to note any loss in circulation while drilling. Other requirements as for D.D.9.

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SPECIFICATIONS FOR DRILLING

PROJECT: Upper Ramu Hydroelectric Project.
(Secondary prickings along tunnel line)

DRILL HOLE NO: TEMPORARY: P.1-P.6 FINAL

TYPE OF DRILLING: Diamond drilling with small drill.

LOCATION: P1 - 700 ft from intake; P2 - 1100 ft from intake; P3 -2300 ft from intake; P4 - 3270 ft from intake; P5 -2800 ft from outlet; P6 - 1940 ft from outlet. (Horizontal distances)

OBJECTIVES OF DRILLING: Shallow drilling to delineate floor of unconsolidated lake sediments, following results of D.D.4, 5 and 6.

SITE INDICATED BY: ———

DRILL SITE PEG, CO-ORDINATES: E———
N

METHOD OBTAINED: ———

DRILL SITE PEG, R.L. OF GROUND SURFACE: P1 - 4215 ft, P2 - 4195 ft, P3- 4195 ft, P4 - 4240 ft, P.5 - 4330 ft, P6 - 4355 ft,

METHOD OBTAINED: From topographic map.

DIRECTION OF HOLE: ——— INDICATED BY:———

REQUIRED SLOPE (ANGLE FROM HORIZINTAL) All holes -90°.

REQUIRED SIZE: AX ?

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) To determine R.L. of bottom of unconsolidated lake sediments and presence or otherwise of andesitic volcanic rocks overlying the metamorphic basement.

ANTICIPATED DEPTH: P1 - 100 ft, P2 - 80 ft, P3 - 80 ft, P4 - 110 ft, P5 - 170 ft, P6 - 170 ft.

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES): Initially in soft, water-logged sand, silt and clay with gravel bands and granodiorite boulder bed in places. Finally in weathered thinly bedded metamorphic rocks.

WATER PRESSURE TESTING REQUIRED: ———

SPECIAL REQUIREMENTS: Core in hard rock only. Core 10-20 ft in metamorphic basement.

SITE SET OUT BY:

DATE: 13/9/61

J.K. HILL
ENGINEERING GEOLOGIST

APPENDIX III

LOGGING OF DRILL CORES

I. GENERAL PROCEDURE

The following notes are intended as a guide in logging features of diamond drill cores. In a "Report on an Inspection of the Proposed No.2 Hydro-electric Station, Port Moresby, Papua" by D.G. Moye and J.A.S. McLeod, a description is given of general procedures in diamond drilling of the Snowy Mountains Authority. The most important points are:-

(a) All holes are NM-LC.

(b) Particular attention is given to complete core recovery and avoidance of grinding. Such performance is obtainable with NM-LC core barrels, hydraulic feed drills, and skilled drillers.

(c) Core boxes are labelled in advance with depths at regular intervals - 5, 10, 15, 20 feet etc., and core put in the boxes correspondingly; i.e. the length of core box = depth of drilling. Core losses are allowed for as blank spaces. Depth of the bottom of the lift is marked in paint on the core and on the box immediately after drilling. Where any core is lost, square section spacer blocks are inserted in the space. These blocks are the same length as the core loss and are painted red. Where core is removed for testing, spacer blocks painted white are inserted and marked with the reason for removal.

(d) Drill holes are preserved and permanently marked by cementing a 10 to 20 foot length of large diameter water pipe in the top of the hole and placing a cast-iron S.V. cover over it.

(e) Cores are photographed in a standard manner.

(f) All cores are carefully preserved for inspection not only by geologists and engineers but also by tenderers.

Logging can be done directly onto field log sheets and later traced onto transparent log sheets (sample attached), from which prints can be taken. Field log sheets usually become too dirty to allow inking in and direct printing. An alternative method is to construct a slotted templet from thin cellulose or perspex to cover the field sheet. Plotting can then be done through the appropriate slots and inked in later if the sheet is sufficiently clean.

The graphic logs and descriptions, and adjusted water pressure test results should be kept up to date at all times. One copy should be supplied to Geological Branch, Canberra, and two to Commonwealth Department of Works, Port Moresby, as soon as a hole is completed. A complete list of abbreviations for use in log descriptions is given on page 473 of "Geologic Field Methods" by Julian W. Low.

The core should be photographed in a standard manner at regular intervals so that a complete coverage is obtained. If

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

GEOLOGICAL LOG OF DRILL HOLE

PROJECT ______ HOLE NO. ______ R.L. ______

LOCATION ______ ANGLE FROM HORIZONTAL ______ DIRECTION ______

ROCK TYPE & DEGREE OF WEATHERING	DESCRIPTION	DEPTH & SIZE OF CORE	LOG	LIFT & CORE RECOVERY	STRUCTURES JOINTS, VEINS, SEAMS, FAULTS, CRUSHED ZONES	
A	B	C	D	E	F	G

DRILL NO. ______
TYPE ______

DRILLER ______
COMMENCED ______
COMPLETED ______

LOGGED ______

VERTICAL SCALE ______

at all possible, the core should be photographed in black and white, (on rare occasions in colour), as soon as the core barrel is opened. Otherwise a satisfactory method is to lay the core out in sequence on a sheet of corrugated iron with a clearly marked linen tape to show footage. A shallow core tray is equally suitable. Attention should be paid to lighting conditions whilst photographing to ensure that flat lighting does not reduce detail. Filters can be used to increase contrast when black and white film is being used. A useful method to bring up the colour of the rock and to increase definition is to soak the core with water shortly before photography commences. The axis of the camera lens should be perpendicular to the core tray to avoid perspective effects.

If he is unable to attend continuously throughout drilling operations, it is the responsibility of the geologist to see that the driller observes instructions regarding photographing, marking, and storing of core. In some cases it will be the geologist's responsibility to ensure that the proposed water pressure testing programme is carried out satisfactorily.

II. RECORDING OF OBSERVATIONS

The hole number, elevation of collar, location of hole (preferably by coordinates), inclination from horizontal, and direction (state whether magnetic or true bearing), should be entered at the head of the log sheet. Daily readings of water table elevation should be taken and recorded separately for use in water pressure testing computations. This should be done before drilling commences each day.

Cores should be logged in considerable detail until the main rock types are established. When various rock types begin to be repeated in the core, the number of features logged should be reduced, only those having significance in engineering geology being retained. It is often difficult to decide which features will prove to be the most important from the engineering point of view in the early stages of logging. In such cases it is better to err in having too full a log rather than in having a paucity of recorded information. Features whihh have been shown by past experience to be important in the interpretation of rock soundness and engineering suitability are listed below as a guide; the most critical features differ according to the object of the investigation.

If it is desired to correlate strata penetrated by the hole with strata in adjacent areas, then more attention should be given to recording lithological features of the core as opposed to its engineering characteristics. Conversely, for isolated holes greater attention should be paid to the recording of those features of the rock most likely to affect its suitability for foundations.

Some of the physical features which can be logged from diamond drill cores are as follows:-

1. <u>MINERAL CONTENT</u> - essential minerals; accessory minerals; rock fragments; metallic minerals such as pyrite, marcasite, or other sulphides which may react with cement;

2. <u>TEXTURE</u> - dominant crystal or grain size and range; crystallinity; roundness; sphericity; sorting; arrangement of grains or crystals - graded bedding, cross bedding, sedimentary structures, massive or uniform, flow patterns, lineations, schistosity, foliation.

3. <u>COLOUR OR COLOUR PATTERN</u> - banding, spotting, mottling etc., preferably using the standard terms and colour indices in the Munsell Rock Colour Chart. Distinguish between the overall colour and the colours of fresh and weathered rock.

4. <u>CEMENT OR MATRIX</u> - siliceous, calcareous, ferruginous, dolomitic, glauconitic, phosphatic, pyritic, micaceous-chloritic, clay.

5. <u>VEINS</u> - composition, (as for cement or matrix but with igneous types in addition); thickness; attitude to core axis; spacing; particular note should be made of minerals likely to react with cement, e.g. zeolites, pyrite, marcasite, etc.

6. <u>WEATHERING</u> - depth of surface weathering; degree of decomposition (chemically and in terms of hardness and strength - friable, flaky, etc.); penetration of weathering along joints or cleavage planes; proportion of weathered material in core; presence ofvugs or pockets of weathered rock; colour; staining - limonite, manganese oxides;

7. <u>UNCONSOLIDATED MATERIALS</u> - note whether soil, scree, clay, sand, silt, gravel, boulder bed, etc., and proportions present. Note lithology of gravel etc., and suitability for aggregate; also other features such as colour, cemented bands, water content, compaction (ease of drilling).

8. <u>HARDNESS</u> - some sort of semi-quantitative scale should be devised to enable rapid objective determinations to be made, e.g.

Hard to very hard	- impossible to scratch with point of knife blade
Moderately hard	- shallow scratches can be made with knife blade.
Soft	- deep scratches can be made with knife blade.

9. <u>STRENGTH</u> - there are many ways of measuring the strength of a rock; one method applicable to field work is to make a semi-quantitative estimate of its percussive strength, e.g.

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

Care should be taken to avoid unnecessary mutilation of core when this method is employed. Any similar objective method is preferable to simply stating that the rock is "very hard" or "quite strong". Whatever method is used, the basis of measurement should be clearly stated.

Features in groups 1, 2, 3, 4, 7, 8, 9, should be noted in column "B" on the log sheet, (sample attached). Descriptions of veins should go in column "F", and notes on weathering should be made in column "A". The name of the rock is also listed in column "A".

Grain size determinations should be based on the Wentworth Grade Scale. Sizes down to ¼mm. can be estimated by comparison with a pocket scale, viz.

very coarse grained	-	2 to 1mm.
coarse grained	-	1 to ½mm.
medium grained	-	⅛ to ¼mm.

A rough guide for sizes below this is:-

Grains clearly visible to naked eye (fine grained)	-	¼ to ⅛mm.
Grains only just visible individually to naked eye, (very fine grained)	-	⅛ to 1/16mm.
Grains just visible under lens	-	coarse silt.

10. <u>BEDDING</u> - thickness; attitude to core axis; uniformity (graded, massive, etc.); nature of bedding planes - mud covered, shale parting, clay seam; bedding plane features - ripples, sun cracks, rain prints, etc.;

A scale should be fixed for terms used in describing stratification, e.g.

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

11. <u>JOINTS, FAULTS, CRUSH ZONES, SHEAR ZONES, ETC</u>.

This section constitutes an important part of core logging for engineering projects and the features listed should be recorded in somewhat greater detail than in other sections.

JOINTS - attitude to core axis; spacing; uniformity (curved or straight); nature of intersection with other joint systems; tightness; fillings - clay, gouge, silt; nature of joint surfaces - presence of slickensides, polishing, irregular striations, and their orientation; off-setting of bedding planes or other joints;

Natural joints should be distinguished from drilling fractures if possible.

FAULTS AND CRUSH ZONES - thickness; attitude to core axis if measurable; nature of material - gouge, fine or coarse breccia, platy clay; polished "schistosity" planes in clay or gouge; stability of clay or gouge in water; orientation of slickensides; hardness and strength of fault material; degree of weathering; tightness; presence and continuity of voids; nature of secondary fillings in interstices;

SHEAR ZONES - thickness of sheared material; attitude of shear planes to core axis; hardness and strength of sheared rock; presence of secondary minerals; tightness; degree of weathering;

CLEAVAGES - attitude of various systems; fissility of rock;

The features listed in groups 10 and 11 should be included in column "F" on the log sheet and shown diagrammatrically in column "D". When joints are so closely spaced that they cannot be logged individually, e.g. sheeted zones, a note should be made o f the density of jointing and the average unbroken core length. In very broken sections of core a size range should be given, e.g. "minute to 100mm." Arbitrary limits should be established to separate the various intensities of natural fractures in the rock, e.g.

Cleavage -	10mm. to infinitely close spacing
Sheet jointing -	10 to 100mm.
Closely spaced joints	100 to 300mm.
Medium spaced joints	300mm, to 1m.
Widely spaced joints	more than 1m.

The choice of arbitrary limits for bedding, jointing, or other features will largely depend on the nature of the rock being logged. Where possible figures should be chosen that emphasise natural groupings or spreads of the feature being recorded, e.g. it would not be sensible to choose a parameter of 100mm. to separate the two classes of "sheet jointing" and closely spaced joints if it was found that a large number of joints were occurring with spacings from 50 to 200mm. The classification might then be adjusted as follows:-

Cleavage -	10mm. or less.
Sheet jointing -	10 to 50mm.
Closely spaced joints	50 to 200mm.
Medium spaced joints	200mm. to 1m.
Widely spaced joints -	more than 1m.

Whatever classification is decided upon after a cursory examination of the core, the parameters used should be stated in a note attached to the log.

In the initial stages of drilling, the core logged before the geologist has become fully conversant with the rock types being penetrated, the features deserving close attention, and the classifications to be used, may require re-logging if inconsistencies occur. Once the main rock types and classifications are established, a reduction in the number of observations can be made and the core logged more rapidly.

12. <u>MISCELLANEOUS OBSERVATIONS</u> - The depth and size of core are noted in column "C" on the log sheet. Scales of 10 or 20 feet to the inch are satisfactory for graphic plotting in most cases unless a very detailed log is being made. The various stages in which the core is lifted are shown by

horizontal lines in column "E" with the percentage recovery for each lift in the corresponding space.

Other observations which should be made and recorded in column "G" are:-

Evidence of grinding by the bit.

Reasons for loss of core.

Loss of water circulation and depth.

R.L. of bottom of casing if any.

R.L. of standing water table with date.

APPENDIX IV

NOTES ON WATER PRESSURE TESTING

The following notes have been extracted from a memorandum by T.P. Ahrens (1951), U.S. Department of the Interior, Bureau of Reclamation, on equipment and methods of conducting permeability tests in drill holes:-

Length of Test Section

The length of the test section is governed by the character of the rock, but in general a length of 10 to 20 feet is desirable. Some rock tends to cave if a 20 foot section is used. In such material a shorter test section may result in greater stability of the side of the hole and should be used. At times, due to caving or fractures in the rock, a good seal cannot be obtained for the packer at the planned elevation. Under these circumstances the test section length should be increased or decreased or test sections overlapped to assure that the test is made with well-seated packers. On some tests a 10 or 20 foot section will take more water than the pump can deliver, and no back pressure can be developed. When this occurs, the length of the test section should be shortened until back pressure can be developed; sufficient tests using the shorter length should then be made to cover the length of hole in which this difficulty is present. Under no circumstances should a packer be set inside the casing when making a test. The annular space between the casing and the wall of the hole, even when the fit is relatively tight, nearly always offers an easy path of escape of water from the test section around the bottom of the casing. This results in a permeability determination greater than is actually present in the rock. Except under adverse conditions, the use of test sections greater than 20 feet in length is inadvisable. Longer test sections do not permit sufficient localization of permeable zones and complicate computations.

Methods of Testing

Drilling 10 or 20 feet of hole and then pressure testing is the most common practice in the Bureau of Reclamation. In rock that tends to cave into the hole and which must be cemented to permit continuation of drilling, it is the only practical method. Where the rock is firm and does not require cementing, the hole is drilled to the total depth without testing. Two packers are mounted near the end of the rod or pipe used for making the test. The bottom of the rod is sealed and the section between the packers is perforated. The perforations should be at least one-fourth inch in diameter, and the total area of all perforations should be greater than twice the inside cross-sectional area of the rod. Tests are made beginning at the bottom of the hole. When a large drilling programme is under way, this method offers the advantage that the drilling rig may be moved and drilling on another hole started while the pressure testing is done using a tripod at the completed hole.

Cleaning of Test Sections before Testing

Before each test, the test section should be surged with clear water and bailed out to remove cuttings. If the test section is above the water table and will not hold water, water should be poured into the hole during surging, then bailed out as rapidly as possible. When a completed hole is tested using two packers, the entire hole can be cleaned in one operation. Cleaning the hole is frequently omitted from testing procedures, resulting in a permeable rock appearing to be tight because the openings are partly sealed by cuttings.

Size of Rod or Pipe to Use in Tests.

Drill rods are used to make pressure tests on many projects. NX rods can be used for this purpose without seriously affecting the reliability of the data if the intake of the test section does not exceed 12 to 15 g.p.m., and the depth to the top of the test section does not exceed about 50 feet, but for general use a 1¼ inch pipe is more satisfactory. The reason is that pressure losses in NX rod tend to become excessive at depths greater than 50 feet or flows greater than 15 g.p.m. EX rod might be considered as an alternative to 1¼ inch pipe.

Pumping Equipment

Many tests are run using the circulation pump on the drill for pumping the water. Such pumps are generally the multiple cylinder type with a uniform fluctuation in pressure. They have a maximum capacity of about 25 g.p.m. and if not in good condition may have capacities as small as 17 to 18 g.p.m. Many tests are failures because such pumps do not have sufficient capacity to develop back pressure in the length of hole being tested. When this happens, the tests are generally reported "took capacity of pump, no pressure developed". This result does not permit determination of permeability of the material tested, when in such materials good approximations are most desirable. In addition, the fluctuating pressures of multiple cylinder pumps, even when an air chamber is used, are often difficult to read accurately.

It is recommended that all permeability tests be performed with centrifugal pumps of 250 to 350 g.p.m.capacity against a total dynamic head of 140 to 160 feet. Such pumps will furnish sufficient water of adequate uniform pressure for most tests.

Swivels for Use in Tests

Swivels used on most drill rigs have a narrow constriction which causes a considerable loss of pressure as water passes through the swivel. A swivel with uniform inside diameter is recommended.

Location of Pressure Gauges in Tests

In most tests the pressure gauge is located between the pump and the water meter, or between the water meter and the swivel. Both locations are undesirable because the actual pressure on the test section will always be less by an unknown amount than that shown on the pressure gauge. The ideal location for the pressure gauge is near the top of the pipe or rod; i.e. between the packer and the swivel. The hole for the gauge should be located below the bottom of the swivel at a distance of at least 10 times the diameter of the pipe or rod.

Recommended Types of Water Meters

Water deliveries in pressure tests may range from less than 1 g.p.m. to as much as 400 g.p.m. No one meter is sufficiently accurate at all ranges to be used. Therefore,two meters for each drilling rig are recommended: a 4 inch impeller type meter to measure flows between 50 and 350 g.p.m., and a 1 inch disc-type meter for flows between 1 and 50 g.p.m. When possible, water meters should be tested at least once a month.

Adapters should be available for each meter. They should be at least 10 times as long as the diameter of the rated size of the meter. This length of adapter permits the water flow to become steady and eliminates the turbulence due to a change in pipe diameter. The accuracy of most meters is influenced adversely by turbulent flow.

Length of Time for Tests

The minimum length of time to run a test depends on the nature of the material tested. Tests should be run until stabilisation occurs; that is, until three or more readings of water intake and pressure taken at 5 minute intervals are essentially equal. In tests above the water table, pumping water into the test section for 10 to 20 minutes is a desirable practice. Stability is obtained much more rapidly below the water table. When multiple pressure tests are made, general practice is to maintain each pressure for 20 minutes with intake and pressure readings made at 5 minute intervals both as the pressure is increased and decreased.

Pressures to be Used in Testing

Where subsurface conditions for proposed reservoirs or other water impounding or storage facilities are being investigated, the minimum effective pressure used in the test section should equal the theoretical head that would be effective at the depth of the test below the maximum level of the reservoir. When tests are made in locations where the ground surface is below the maximum pool level, the use of such test pressure is sometimes impractical because of the dangers of blow-outs or heaving. Under these conditions a safe pressure in all rock is 1 pound per foot of depth from the ground surface to the top of the test section.

Water Table

Continuous daily records should be kept of the water table level in the hole throughout drilling operations and at weekly or monthly intervals thereafter for as long as geologist, engineer or hydrologist considers necessary. The best time to make the daily reading is immediately prior to starting drilling operations for the day, assuming that only one daylight shift is being worked. There are numerous devices available for recording water levels in drill holes. The depth below collar should be recorded, together with time and date. If no water table is found this should be clearly stated.

APPENDIX V

THIN SECTION DETERMINATIONS OF SELECTED ROCKS

by

Robert Bryan

R.8813 T.S.7170 Field No.6
Altered gabbro or dolerite

This rock now consists of augite, tremolite-actinolite, andesine-labradorite, black iron oxide and sparse biotite. The rock consists of anhedra of augite up to 3.0 mm. across set in a fibrous aggregate of tremolite-actinolite. Amphibole also commonly surrounds the pyroxene crystals. Some elongate twinned laths of plagioclase are present, and probably are relics from the original rock.

There can be little doubt that the rock was originally a feldspar-poor gabbro or dolerite that has been subjected to either late magmatic deuteric alteration, or low grade regional metamorphism.

No sign of shearing could be seen, nor any minerals that would be likely to cause any trouble, but as a precaution the rock should be tested for any reaction with high-alkali cement, if it is to be used as concrete aggregate.

R.8814 T.S.7171 Field No.24
Slightly metamorphosed greywacke

Approximately half the rock consists of fine matrix material now converted to epidote, sericite and fine feldspar. Of the remaining half of the rock, 2/3 is albite and 1/3 quartz. Some iron oxide also is present. No bedding is apparent, but the rock has been sheared quite strongly, and the planes of movement have been filled by veins of analcime - a sodium zeolite. These zeolites very readily exchange ions - especially sodium or calcium - so this change could be expected if used as concrete aggregate. I have no knowledge of the implications of this exchange on strength and permeability.

The original greywacke, apart from being sheared, has suffered low grade regional metamorphism, but apart from the veins, no unsuitable minerals were seen.

This rock should be used with caution, as the infilling of the shears may be only local, and elsewhere the shears may be unfilled.

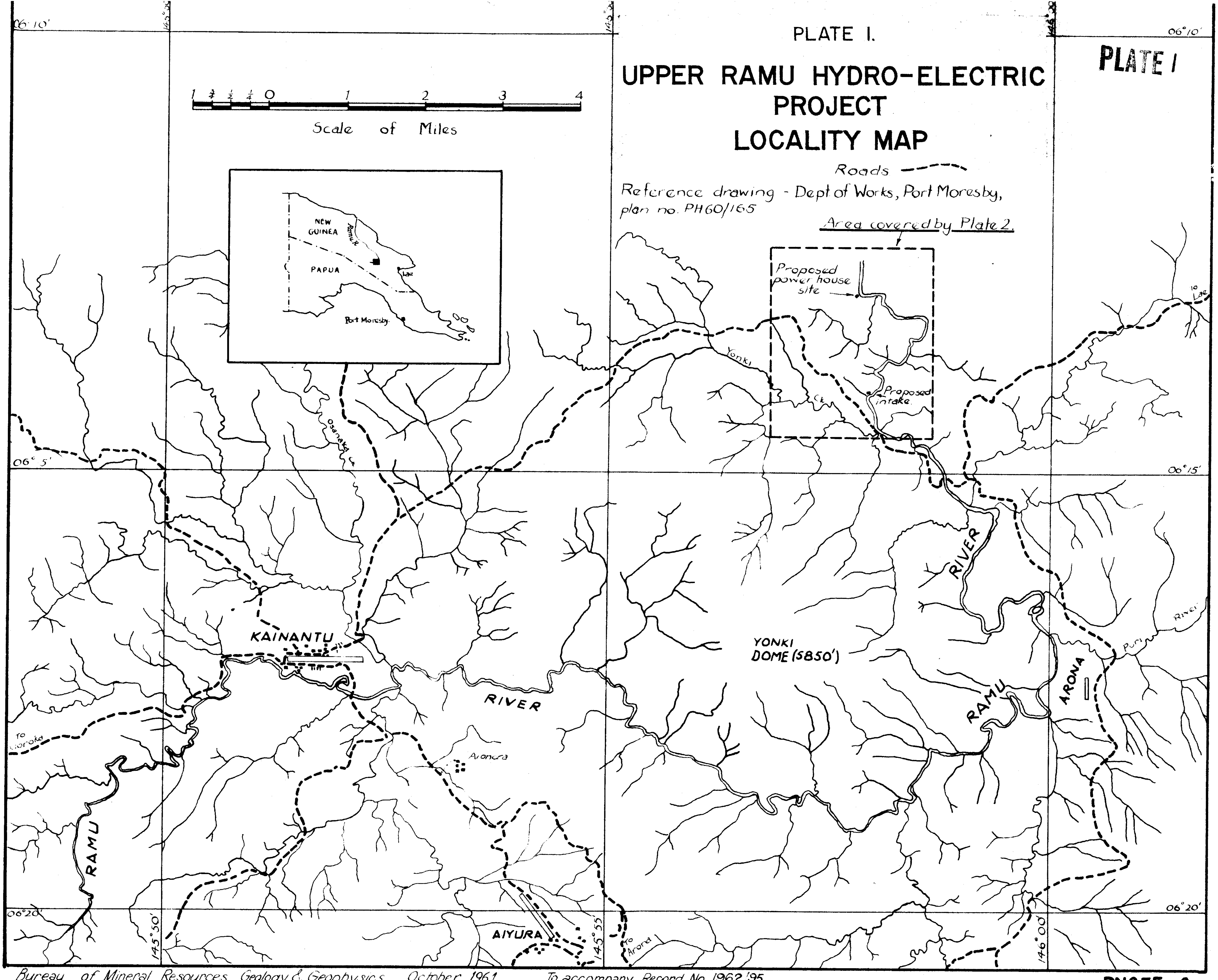
If used, the rock should be tested with high alkali cement.

R.8815 T.S.7122 Field No. 26
Hornblende-biotite granodiorite

The specimen consists predominantly of oligoclase, with some orthoclase and much less quartz. The mafic minerals are biotite and smaller amounts of hornblende. Iron oxide, prehnite and apatite occur in accessory amounts. The texture is typically granitic.

The rock has been slightly altered; the biotite has been chloritised, some plagioclase saussuritized slightly, and some secondary amphibole produced. The orthoclase has been moderately kaolinized.

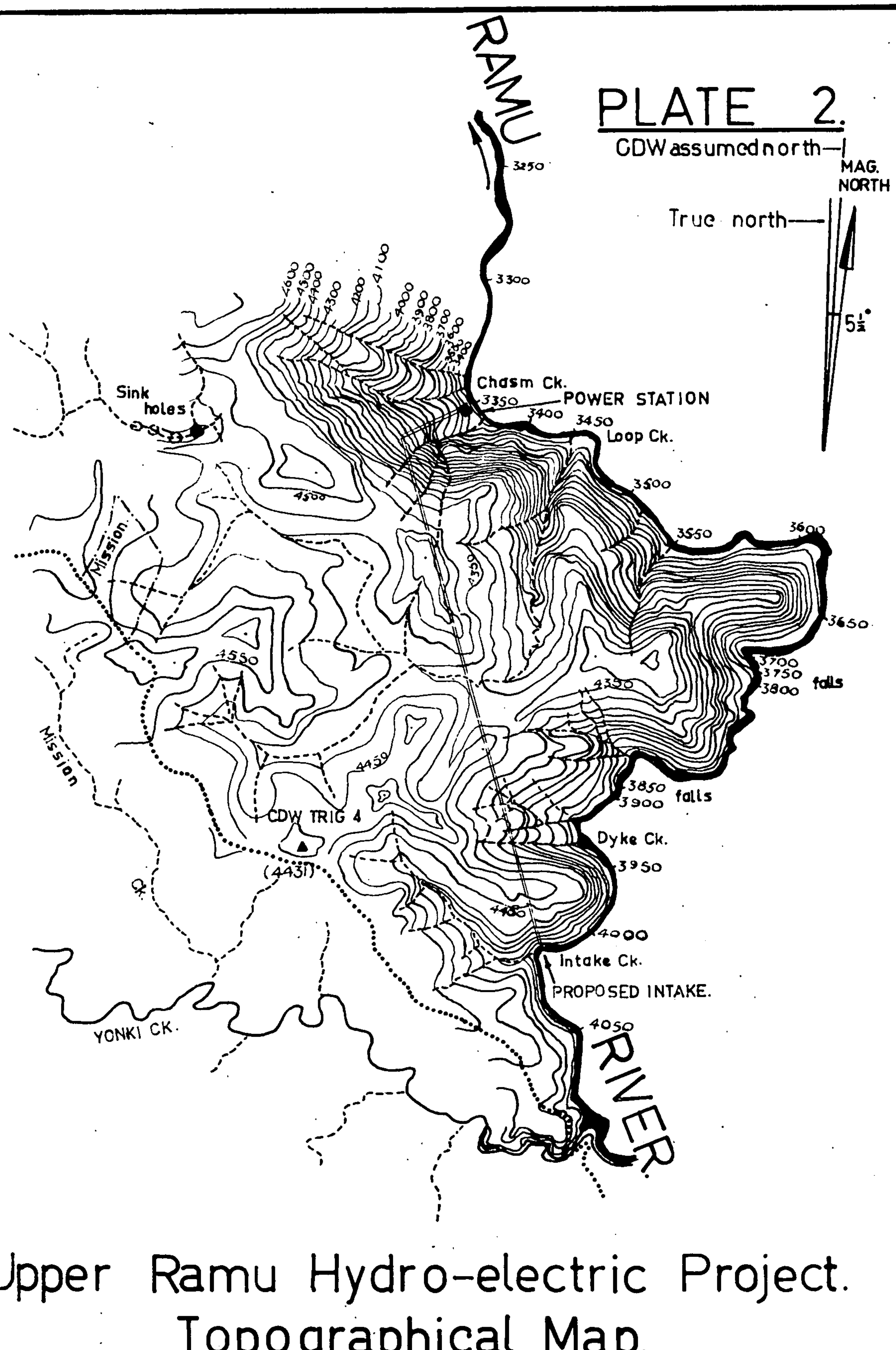
No shearing was apparent, nor any soluble minerals detected; but the rock should be tested with high alkali cement in case some amorphous silica is present.



Bureau of Mineral Resources, Geology & Geophysics. October, 1961. To accompany Record No. 1962/95

PNG7E-8

PLATE 2.



Upper Ramu Hydro-electric Project.

Topographical Map.

Scale: 1 inch: 2000 feet (approximately).

Existing road.

Creek.

PROPOSED TUNNEL LINE

Reference drawing-CDW PLAN NO. PH 60/270.

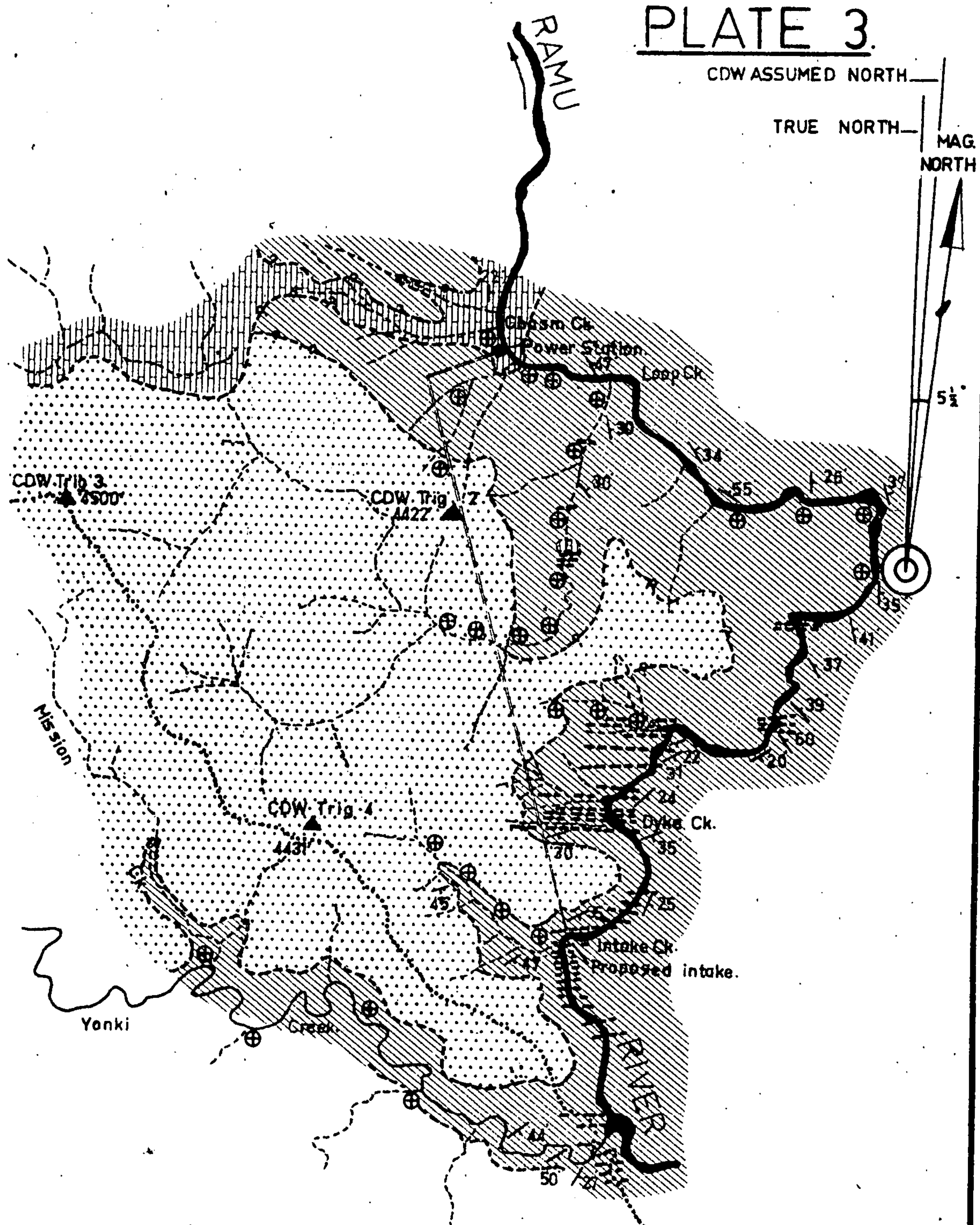
NOTE :- 1) Elevations should be reduced by 120 feet approx. to comply with new CDW datum, (Trig 4 4431').

2) Contours calculated from aerial photographs using barometric survey as ground control.

To accompany Record No. 1962/95

Bureau of Mineral Resources, Geology & Geophysics. October, 1961. PNG 7E-6.

PLATE 3.



Upper Ramu Hydro-electric Project.
General Geological Map

Scale: 2000 feet : 1 inch (approximately).

Existing road.
Creek.
Proposed tunnel line.
Geological boundary mapped in field or interpreted from aerial photographs.
Geological boundary inferred.
Strike and dip of bedding.

Horizontally bedded lacustrine sediments.
Bedded marble.
Basic or intermediate dyke sets.
Metamorphic rocks.
Diorite or granodiorite boulders.

Bureau of Mineral Resources, Geology & Geophysics, October, 1961. *To accompany Record No. 1962/95* PNG7E-4

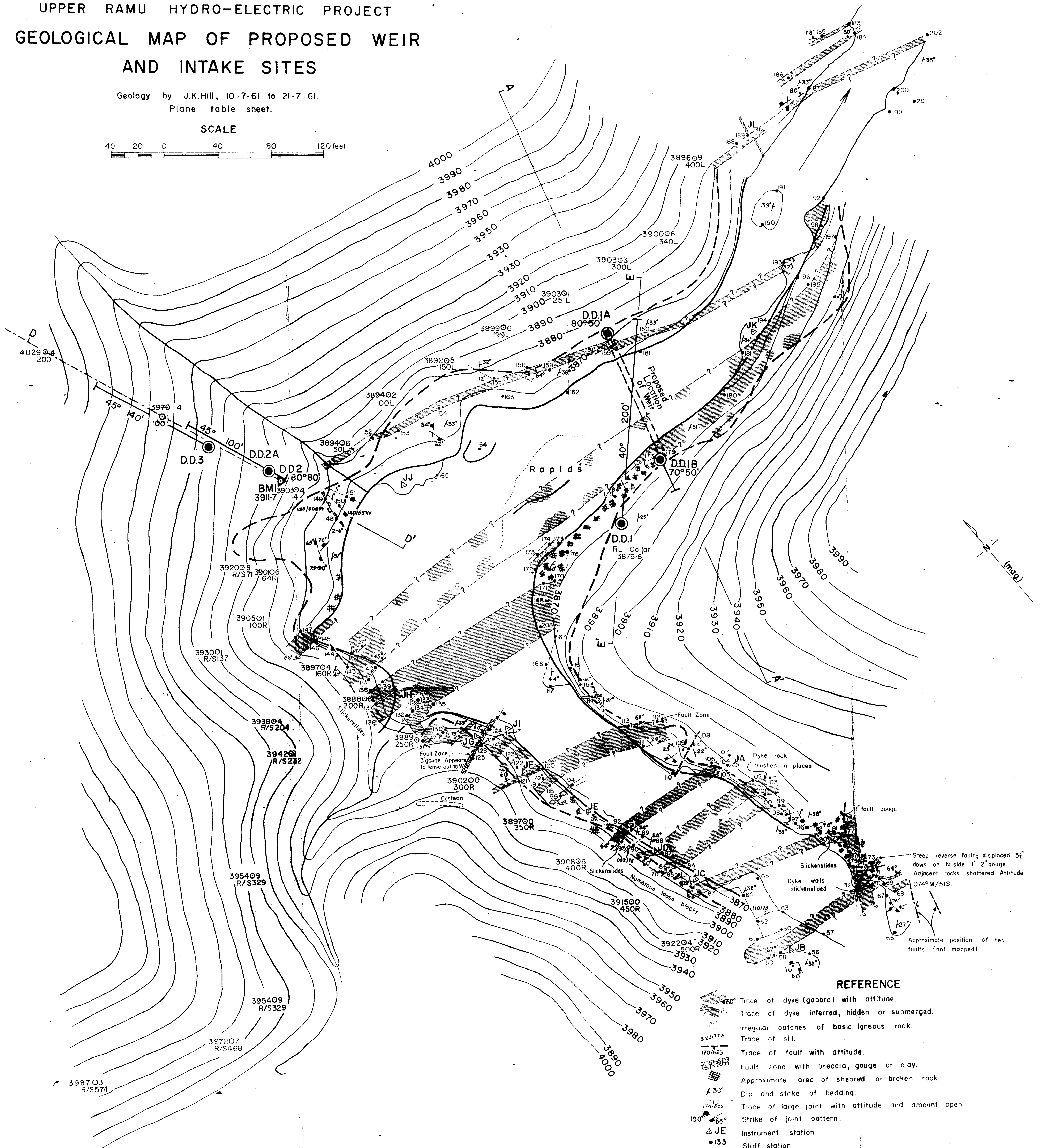
UPPER RAMU HYDRO-ELECTRIC PROJECT

GEOLOGICAL MAP OF PROPOSED WEIR AND INTAKE SITES

Geology by J.K.Hill, 10-7-61 to 21-7-61.
Plane table sheet.

SCALE

40 20 0 40 80 120 feet



REFERENCE

- Trace of dyke (gabbro) with attitude.
- Trace of dyke inferred, hidden or submerged.
- Irregular patches of basic igneous rock.
- Trace of sill.
- Trace of fault with attitude.
- Fault zone with breccia, gouge or clay.
- Approximate area of sheared or broken rock.
- Dip and strike of bedding.
- Trace of large joint with attitude and amount open
- Strike of joint pattern.
- △JE Instrument station.
- •133 Staff station.
- Surveyed line of proposed tunnel.
- 392008 Topographic survey pegs with R.L.
- Upper limit of exposed rock.
- Collar and plan of proposed diamond drill hole, with length and inclination from horizontal.
- Datum is Trig. Stn 3, 4500' (C.D.W. plan no. PH61/114).
- Contours traced from C.D.W. plan no. PH61/116.
- Line of vertical cross section.
- Trace of weak shale or slate interbed.

NOTE: All rocks other than dykes are thin bedded metamorphic rocks.

PLATE 5

INTERPRETATIVE VERTICAL CROSS-SECTION ALONG AXIS OF WEIR, LOOKING DOWNSTREAM

SHOWING PROPOSED DIAMOND DRILL HOLES
(For location, see Plate 4)

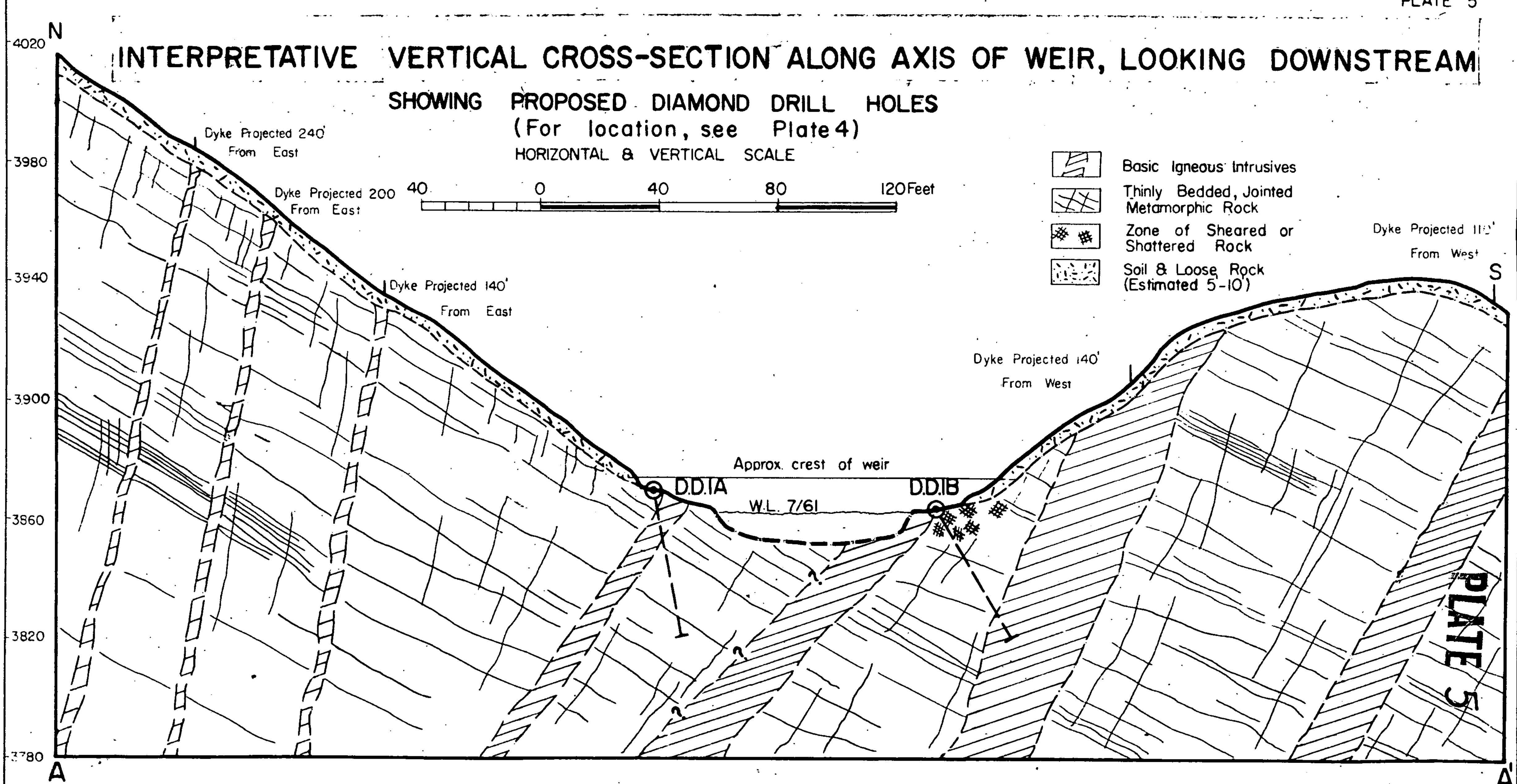
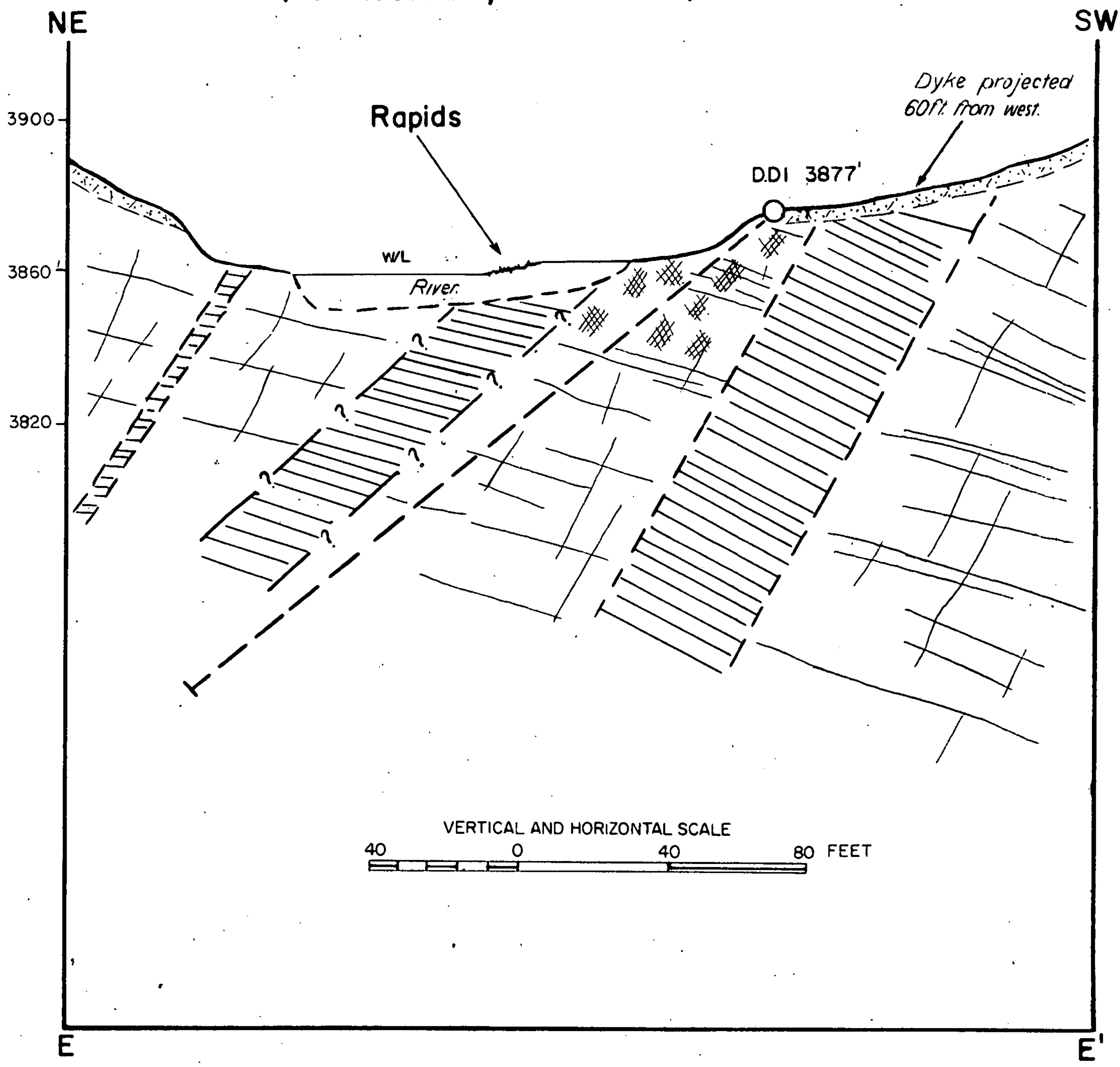


PLATE 6

UPPER RAMU HYDRO-ELECTRIC PROJECT

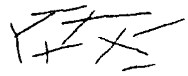
INTERPRETATIVE LONGITUDINAL SECTION THROUGH D.D.I

(For location, see Plate 4)



REFERENCE

Soil and rock debris 5'–10' (estimated)



Thinly bedded jointed metamorphic rock

Basic igneous intrusives

Area of sheared or broken rock

Bureau of Mineral Resources, Geology and Geophysics Nov.1961 For Records No 1962/95 PNG7E/12

UPPER RAMU HYDRO-ELECTRIC PROJECT

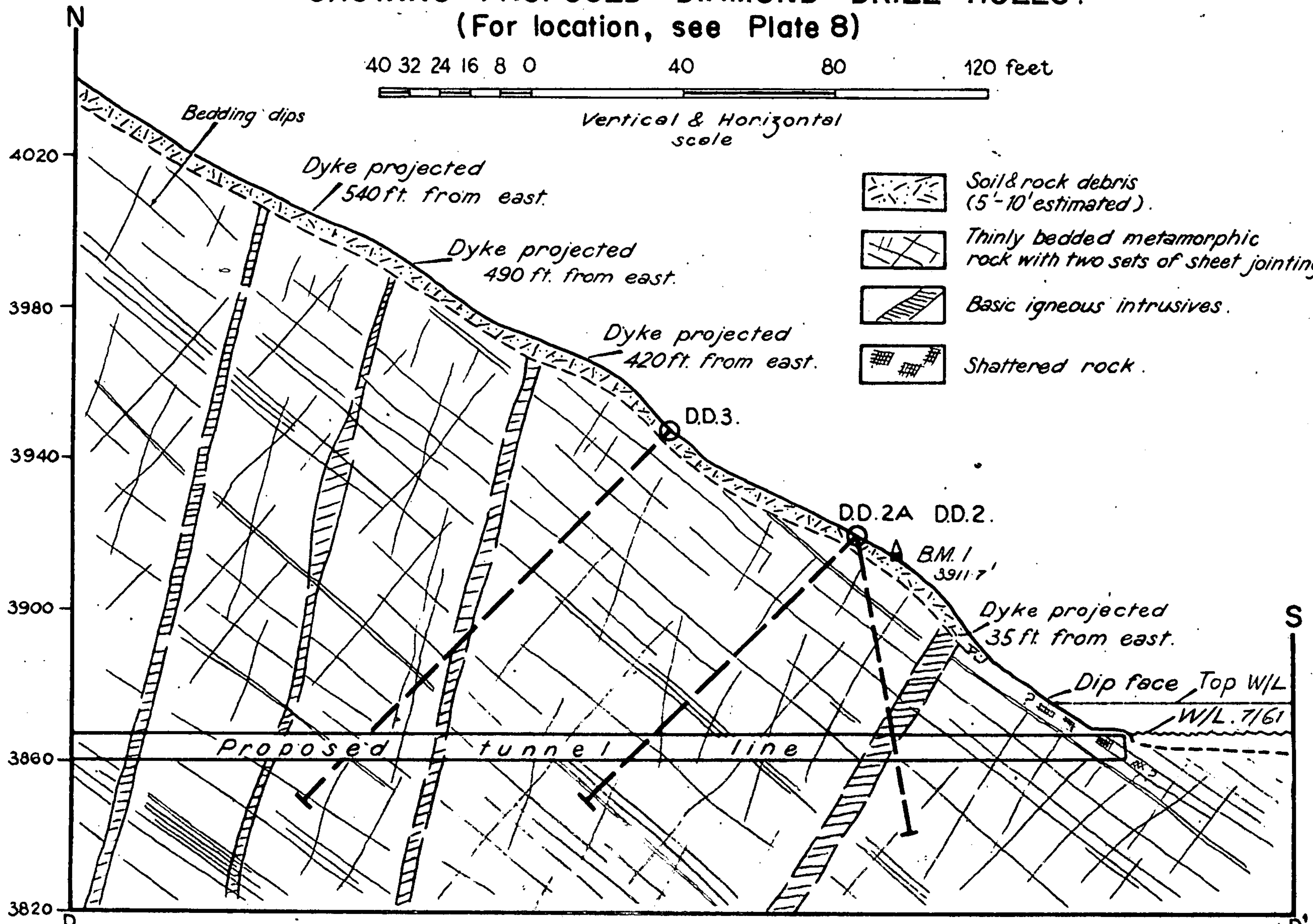
N S

PLATE 7.

INTERPRETATIVE LONGITUDINAL SECTION AT INTAKE.

SHOWING PROPOSED DIAMOND DRILL HOLES.

(For location, see Plate 8)



Bureau of Mineral Resources, Geology & Geophysics Nov. 1961 To accompany Record No. 1962/95 PNG 7E-13

PLATE 7

PLATE 8

UPPER RAMU HYDRO-ELECTRIC PROJECT
NEW GUINEA

GEOLOGICAL MAP AND LONGITUDINAL SECTION OF PROPOSED TUNNEL LINE

NOTE: 1. Positions of dykes diagrammatic, except X–X, but dips approximately correct. 2. Trace of bedding of metamorphic rocks diagrammatic.

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To accompany Record No. 1961/95

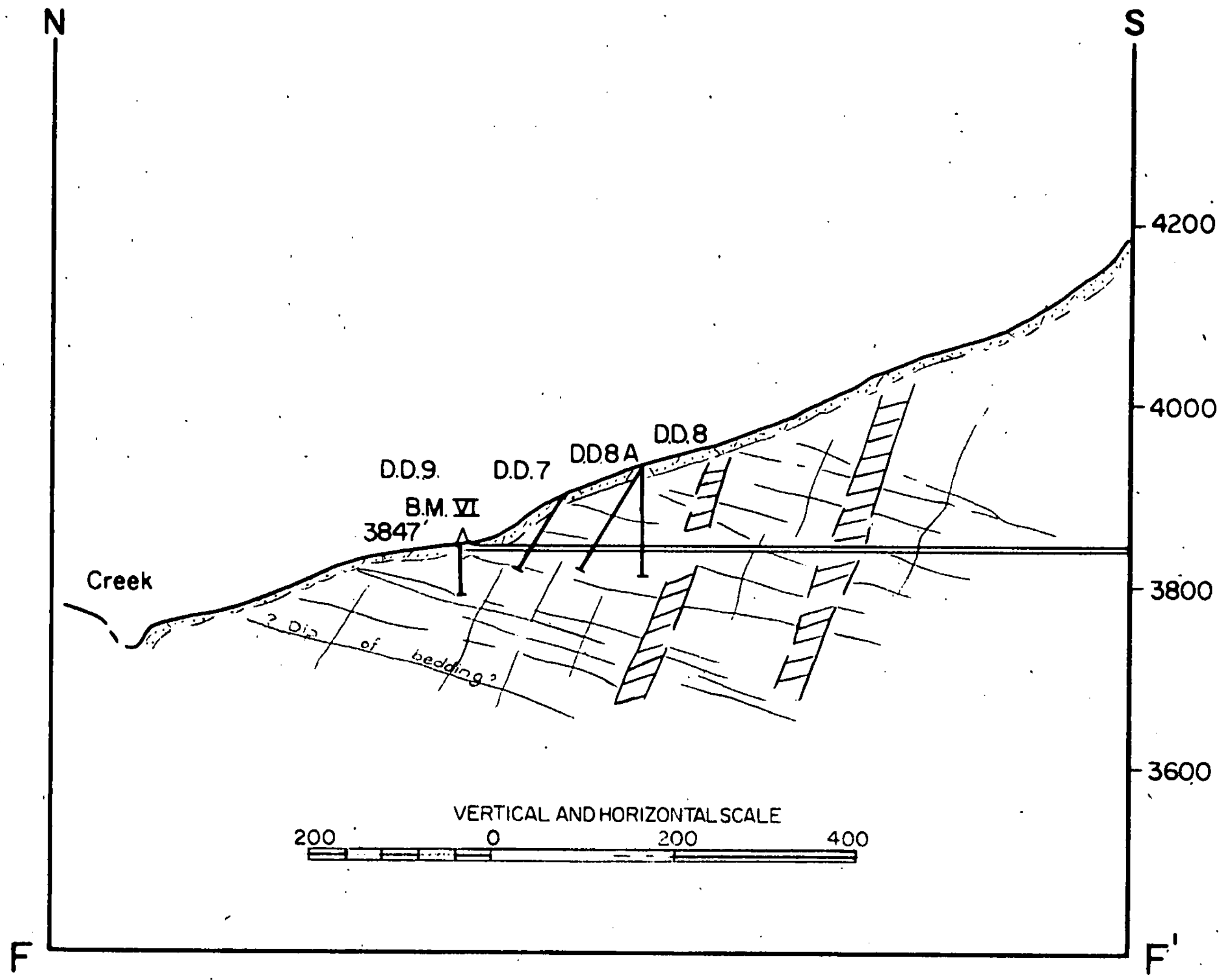
PNG7E-10

PLATE 9

UPPER RAMU HYDRO-ELECTRIC PROJECT

INTERPRETATIVE LONGITUDINAL SECTION AT OUTLET PORTAL AND SURGE TANK SITE SHOWING PROPOSED DIAMOND DRILL HOLES

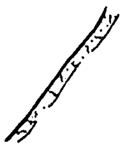
(See Plate 8)



REFERENCE

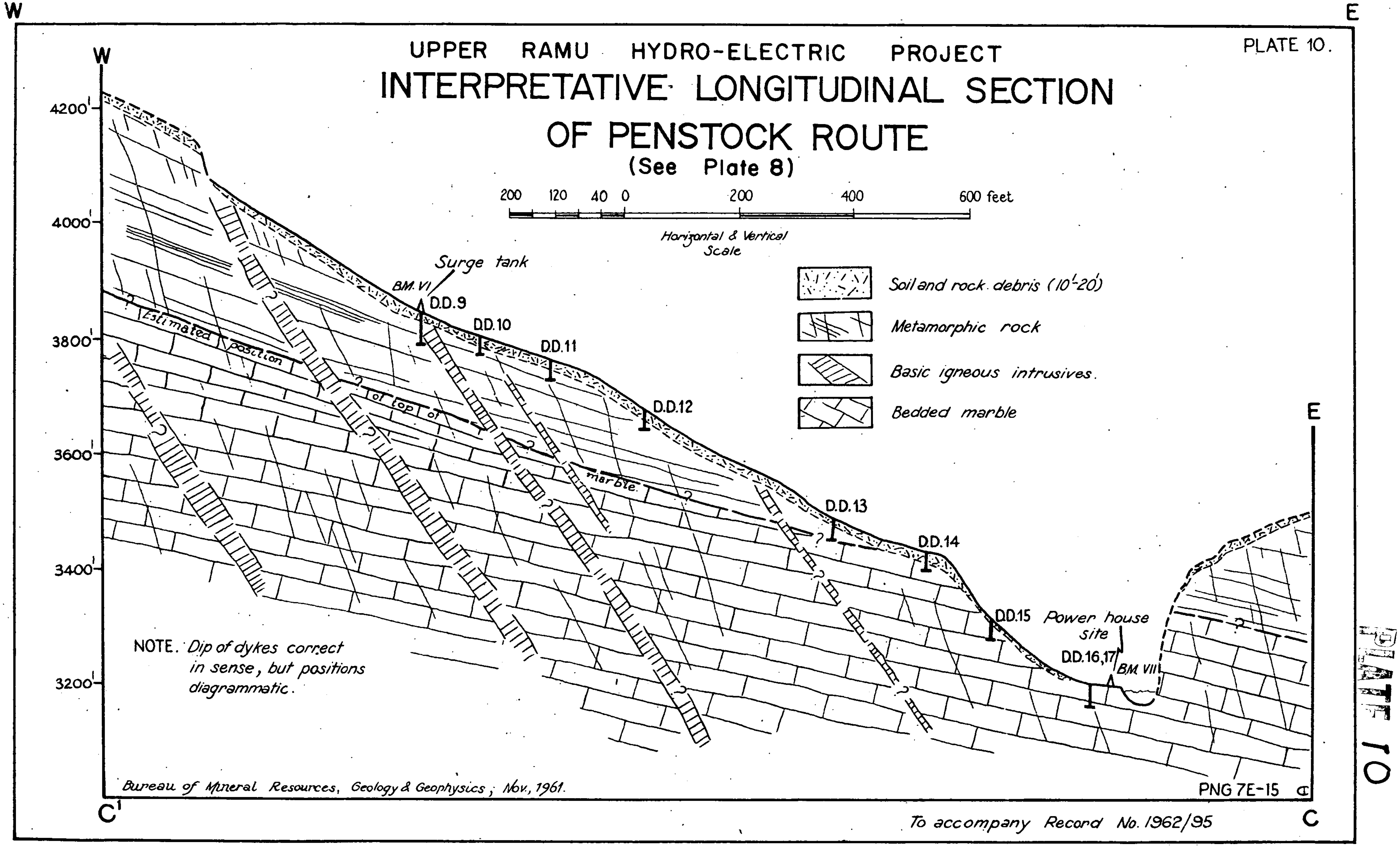
Thinly bedded jointed metamorphic rocks

Basic igneous intrusions



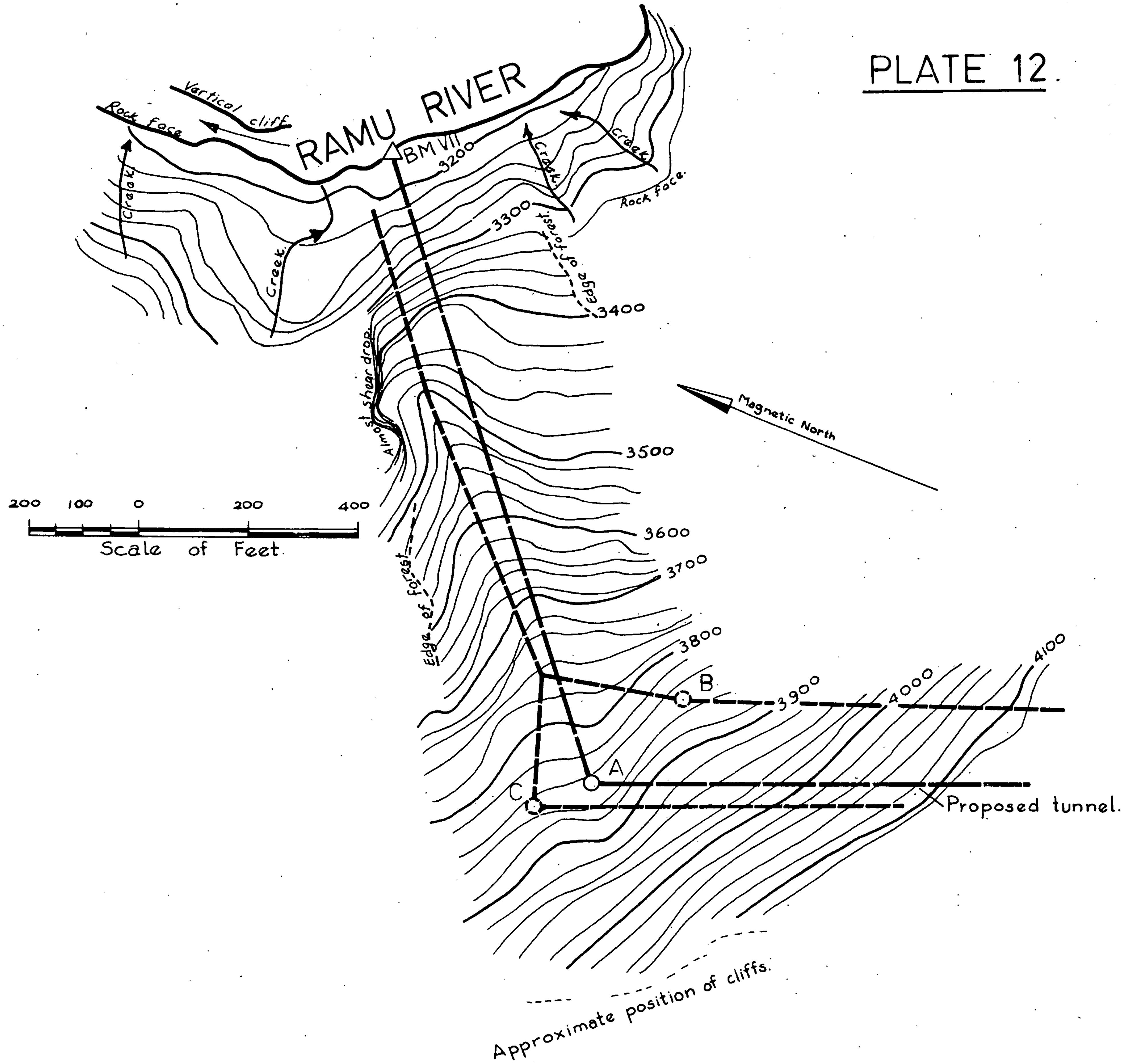
Soil and rock debris (10'—20')

NOTE: Dip of dykes in correct sense but positions diagrammatic


W
E
PLATE 10.
UPPER RAMU HYDRO-ELECTRIC PROJECT
INTERPRETATIVE LONGITUDINAL SECTION
OF PENSTOCK ROUTE
(See Plate 8)
200 120 40 0 200 400 600 feet
Horizontal & Vertical Scale
W
4200'
4000'
3800'
3600'
3400'
3200'
Surge tank
BM. VI
D.D.9
D.D.10
D.D.11
D.D.12
D.D.13
D.D.14
D.D.15
Power house site
D.D.16,17
BM. VII
Estimated position of top of marble
Soil and rock debris (10'-20')
Metamorphic rock
Basic igneous intrusives.
Bedded marble
E
NOTE. Dip of dykes correct in sense, but positions diagrammatic.
Bureau of Mineral Resources, Geology & Geophysics; Nov., 1961.
PNG 7E-15
C'
C
To accompany Record No. 1962/95
PLATE 10

UPPER RAMU HYDRO-ELECTRIC PROJECT
GEOLOGICAL PLAN OF PROPOSED
POWER HOUSE SITE
PLANE TABLE SHEET.
40 20 0 40 80 FEET.
MN
PLATE II
REFERENCE
Dip and strike of bedding
Trace of top of marble (inferred)
Trace of joint pattern
Strike of joint pattern
Cliff or near vertical slope
Costean
Proposed diamond drill hole with length
Instrument station
Staff station
Topographic survey peg with R.L.
Structure contour with altitude
Metamorphic rock.
Contours traced from CDW plan PH61/17
Geology by J.K.Hill 14-15/8/61
Approx. position of east wall of gorge
Rock face
Solution joint 12"-3"
Few large granite boulders
Joint
BM VII
NV
50' DD16
50' DD17
Costean 6"-2' o/burden o/lying marble
Shallow soil and river Seria cover
Water level recorder
Large boulders of granite, gabbro, and metamorphic rocks
Boulder
Boulder fan
Inferred position of marble boundary
Costean 5' o/burden marble
50' DD15
Costean 4' o/burden marble.
Costean 7' o/burden marble
50' DD14
Costean 14'+ o/burden.
Boundary of top of marble. All outcrops south of this boundary are metamorphosed sandstones, siltstones, quartzites etc. with basic intrusions.
NOTE. attitude of top bedding plane of marble deduced from 5 exposures as being 015°M/20°E. Structure contours at 10' vertical intervals.
Bureau of Mineral Resources, Geology and Geophysics. October 1961.
To accompany Records 1961/95
G.D.125
PNG 7e/9
A.F.

PLATE 12.



UPPER RAMU HYDRO-ELECTRIC PROJECT.

A —o— Proposed tunnel line, surge tank and penstock positions.

B.C --o-- Alternative positions.

Reference drawing - CDW plan no. PH61/114.

Bureau of Mineral Resources, Geology & Geophysics October, 1961.

To accompany Record No. 1962/95

PNG-7E-5