[redacted]

COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

006042

RECORD No. 1966/133

GEOLOGICAL FEASIBILITY INVESTIGATION OF THE TOWANOKOKO-PONDO HYDRO-ELECTRIC SCHEME,

NEW BRITAIN, T.P.N.G., 1962

by

E.J. BEST

GEOLOGICAL FEASIBILITY INVESTIGATION OF THE TOWANOKOKO-PONDO HYDRO-ELECTRIC SCHEME, NEW BRITAIN, T.P.N.G., 1962.

by

E. J. Best

Record: 1966/133

CONTENTS

	Page No.
SUMMARY	1
INTRODUCTION	2
Location and access	2
Climate and vegetation	3
Topography and drainage	3
Outline of the scheme	4
Mapping	4
Geophysical investigations	5
Seismic method	5
Electrical resistivity methods	5
REGIONAL GEOLOGY	5
Lithology	5
Stratigraphy	6
Structure	6
Folding	6
Faulting	7
Jointing	8
ENGINEERING GEOLOGY	8
Scheme A	8
Towanokoko weir site	8
Alternative Towanokoko weir site	9
Pondo weir site	9
Tunnel line	10
Low pressure pipeline	11
High pressure pipeline	11
Power station site	12
Scheme B	12
Towanokoko weir site	12
Alternative Towanokoko weir site	13
Pondo weir site (as for Scheme A)	14
Tunnel line	14
Low pressure pipeline (as for Scheme A)	16
High pressure pipelines (one as for Scheme A)	16
Power station sites (one as for Scheme A)	16
Pondo second stage weir site	16
Evaluation of alternative schemes	17
Water circulation and leakage	18
Landslides	18
Seismicity	19
Construction Materials	19

	Page No.
POSSIBLE ALTERNATIVE LOCATIONS FOR A HYDRO-ELECTRIC SCHEME	20
Warangoi River	20
Toriu River	20
CONCLUSIONS	20
RECOMMENDATIONS	22
ACKNOWLEDGEMENTS	22
REFERENCES	23

FIGURES

		Facing Page
1.	Stereoscopic pair of photographs showing the proposed layout of the scheme and the recent landslide on the Towanokoko River.	4
2.	Contoured joint plane stereogram.	8

PLATES

1.	Locality map	2 miles : 1 inch
2.	Proposed layout of the scheme and stadia survey data of the area.	1000 feet : 1 inch
3.	Map of Pondo and Towanokoko Rivers showing bedding measurements and sample localities.	2000 feet : 1 inch
4.	Geological sections along Pondo and Towanokoko Rivers showing interpretation of structure.	2000 feet : 1 inch
5.	Geological observations along Pondo River in area of the scheme.	400 feet : 1 inch
6.	Geological observations along Towanokoko River in area of the scheme.	400 feet : 1 inch
7.	Towanokoko weir site, Scheme A	40 feet : 1 inch
8.	Towanokoko alternative weir site, Scheme A	40 feet : 1 inch
9.	Pondo weir site, Schemes A and B	40 feet : 1 inch
10.	Pondo power station site, Schemes A and B, and second stage weir site.	40 feet : 1 inch
11.	Towanokoko weir site, Scheme B	40 feet : 1 inch
12.	Towanokoko alternative weir site, Scheme B	40 feet : 1 inch

FEASIBILITY INVESTIGATION OF THE TOWANOKOKO-PONDO HYDRO-ELECTRIC SCHEME, NEW BRITAIN, T.P.N.G., 1962.

by

E.J. Best

Record: 1966/133

SUMMARY

The middle reaches of the Towanokoko and Pondo Rivers have been selected as the location of a possible hydro-electric scheme to supply power for Rabaul, New Britain. Two alternative scheme layouts, each with an output of about 5,000 kilowatts, were planned from inspection of air photographs and other available information, and a combined geological and geophysical feasibility investigation was carried out from September to December, 1962.

The scheme is sited in steep limestone terrain about 6 miles from the west coast of the Gazelle Peninsula. Present access from the coast and the east is by foot only.

The geological succession in the area of the scheme consists of gently dipping Tertiary limestone with many interbeds of marl and mudstone. Two major faults have been located in the area; others are undoubtedly present. The limestone is hard and strong, but the mudstone interbeds are soft, weak, and plastic when wet. The presence of mudstone has restricted underground water circulation considerably, but the resultant saturation at the interfaces with overlying limestone or marl has resulted in many landslides in the area of the scheme.

The geological and geophysical investigation has indicated the most suitable scheme layout of the proposed alternatives. Considerable engineering difficulties are to be expected even in this layout, however, particularly in the tunnel and portals. Difficulties would also be encountered in obtaining suitable construction materials; sand would have to be imported, and suitable aggregate would probably have to be hauled at least 6 air miles to the scheme area.

In considering the feasibility of the scheme, a major factor is the extreme instability of the area, both topographically and seismically; the former is well illustrated by the large landslide on the Towanokoko River, just downstream of the proposed scheme, which occurred in recent years. It would be extremely difficult to guard against the destructive effect of such a landslide on any engineering structures, and it would be impossible to predict, with certainty, future landslides.

It is concluded that there would be considerable difficulties in the design and construction of the proposed scheme, and that it would be very costly. Even if construction is an economic proposition, there is doubt that the scheme could be maintained as a permanent public facility, owing to the extreme instability of the area.

It is recommended that alternative schemes, previously rejected in favour of the Towanokoko-Pondo scheme, be reconsidered in the light of this investigation; the Warangoi and Toriu schemes in particular warrant further investigation.

INTRODUCTION

At the present time, diesel generators are the only source of electrical energy in Rabaul and the nearby plantations. However, the power requirements of this area are increasing at such a rate that hydro-electric power will soon be economically competitive with diesel power. Several nearby river systems have been investigated during the past few years (see Plate 1 inset) but no suitable sites for hydro-electric schemes of sufficient economic power potential have been found within 30 miles of Rabaul. The combined waters of the middle reaches of the Pondo and Towanokoko river systems have sufficient potential to generate the required 5,000 kilowatts, however, and this area was selected for detailed investigations.

The area of the proposed scheme was first inspected in 1958, after which a fluviometer was installed by the Commonwealth Department of Works at Wilanbengau village. Sporadic gauging of the two rivers was carried out, and when it became apparent that the rivers had the necessary power potential three automatic river level recorders were installed (two on the Pondo and one on the Towanokoko). Tacheometric traverses were made of portions of the Pondo and Towanokoko Rivers in mid-1961, and subsequent stadia surveying continued until the area of the scheme had been covered (see Plate 2). Geological investigations carried out so far consist of a brief reconnaissance made by Fisher (1959), and 2½ weeks mapping of the Pondo and Towanokoko Rivers by Carter (1962). A reconnaissance was also made by Carter of the area through which any power transmission line to Rabaul must pass.

The hydrological and geological data obtained during these investigations indicated that a hydro-electric scheme was practicable, and when air photographs of the area became available, two alternative layouts for the scheme were selected for geological and geophysical investigation. The geophysical survey was carried out between 25th September and 17th December, 1962 by the Compagnie Generale de Geophysique. All elements of the alternative schemes were tested by the seismic refraction method; the total length of seismic traverses was 18,125 feet. Some components of the scheme were also tested by electrical resistivity methods.

The author spent the period 25th September to 27th November in the area. The components of the schemes were mapped geologically and topographically, and geological mapping along the Pondo and Towanokoko rivers was extended both upstream and downstream to provide more information on the regional geology. The author was also available to provide geological information to the geophysicists, particularly while the geophysical results were being interpreted.

LOCATION AND ACCESS

The Pondo and Towanokoko Rivers are situated on the west coast of the Gazelle Peninsula of New Britain and enter the sea, one mile apart, 25 miles south of Cape Lambert (see Plate 1). The rivers are roughly parallel to each other, and flow in a south-westerly direction. The proposed scheme, which covers the middle reaches of the two rivers, is 5 to 6 miles direct distance from the coast and 38 miles from Rabaul.

The area of the proposed scheme is accessible, by native tracks only, from the south-west via Pondo Plantation, and from the east via Vudal Bridge and Maleseit. At Pondo Plantation, there is an open anchorage useable by small craft for most of the year; this is approximately 14 hours from Rabaul by small boat. From the harbour, a foot track crosses the coastal plain for three miles and then climbs steeply onto the ridge between the two rivers. The track, which is clearly defined, follows the ridge with numerous short steep rises, and crosses the Pondo River about 11 miles by track from the coast. The base camp is situated 300 feet west of this crossing.

Vudal Bridge marks the western limit of the road network radiating from Rabaul. From here, a well-defined native track climbs in a south-westerly direction to 2,000 feet above sea level and continues over the divide into the Toriu River valley. On the descent to the river, the track passes through the native village of Maleseit. The Toriu River crossing, which is not fordable after heavy rain, is at an elevation of 820 feet; from here the track follows the southern side of the upper Toriu valley, climbing steadily to the divide between the Toriu and Pondo Rivers at an elevation of 3,700 feet. The track finally descends to the Pondo River crossing, passing through the native village of Wilanbengau one mile east of the river. The distance from Vudal Bridge to the base camp is about 28 miles.

CLIMATE AND VEGETATION

Although the area receives much of its rainfall during the north-west monsoon season (December to April), rainstorms occur throughout the rest of the year, and rain-free days are infrequent. Rain gauges have only recently been installed in the area, but the average annual rainfall would be more than 200 inches. During the author's stay in the area (during the dry season), three inches of rain fell in one day, and two inches was exceeded on several other occasions. The general daily weather pattern is a sunny morning with cloud cover increasing from about 11 o'clock onwards, heavy rain falling during the early or middle afternoon.

Although the humidity is high, working conditions are not uncomfortable owing to moderate day temperatures and extensive cloud and vegetation cover. Nights are cool, blankets being necessary to sleep comfortably.

Tropical forest covers the whole area, forming a continuous canopy broken only by rivers. Ground cover is generally sparse, except along river banks, and a bush knife is not necessary for cross country traverses. Along river banks and in areas of recent landslide activity, however, the ground cover is commonly very dense and difficult to penetrate.

TOPOGRAPHY AND DRAINAGE

The scheme is situated in very broken limestone country which extends for several miles in all directions. Karst topography is well developed in the surrounding areas, and the terrain rises to at least 4,000 feet at the heads of the Pondo and Towanokoko valleys. In the area of the proposed scheme, the Pondo and Towanokoko Rivers are separated by a pronounced ridge, up to 750 feet high, which has steep sides with occasional cliff faces. Between B.M.2 and B.M.11 (see Plate 2) the ridge is generally between 5 and 40 feet wide, though in the region of B.M.9 it widens to 200 feet. Sinkholes occur extensively but are generally quite shallow; they are probably not connected to an integrated sub-surface drainage system because of the numerous impermeable mudstone bands interbedded in the limestone.

A common feature of both rivers and their tributaries is the extensive deposition of travertine on boulders and bedrock of the stream courses. In some places (e.g. the East Towanokoko River downstream of the main falls) this has resulted in the formation of a series of calcareous terraces with intervening deep pools. The travertine in stream beds undoubtedly seals many joints in bedrock, and probably is an important factor in stabilising water flow in the main rivers. It may also conceal near-surface movement of water through joints and crevices.

OUTLINE OF THE SCHEME

At the time of the geological investigation of the area by Carter, it was proposed that water from the Towanokoko River at an elevation of about 1940 feet above sea level should be diverted into the Pondo River by a low pressure tunnel and penstock, the power station being located in the vicinity of the junction of the East and North Pondo Rivers. Additional capacity was to be obtained by diverting water from the Pondo River, at the same intake level as that on the Towanokoko River, into the low pressure tunnel from the Towanokoko River.

When it was decided that the scheme was feasible, two alternative schemes were designed, mainly on the basis of hydraulic and power output considerations. It was proposed that an evaluation of the relative merits of each scheme be made on the basis of geophysical and geological investigations of the various components of the schemes. In the first scheme (Scheme A) the water from the Towanokoko River at an elevation of 1730 feet would be diverted into a low pressure pipeline on the Pondo side of the dividing ridge via a tunnel, and water from the Pondo River would be collected at a similar elevation and fed into the pipeline. Power would be generated at a power station sited in the vicinity of Pondo stream gauging station G.S. 63 at an elevation of about 1060 feet, the output being 2800 kilowatts (kW) with run of river flow and 4350 kW with diurnal pondage. In Scheme B, a weir on the Towanokoko River at an elevation of 1940 feet is proposed to divert water from the Towanokoko River, via a tunnel through the dividing ridge, to a power station on the Pondo River at an elevation of approximately 1590 feet. A weir is also proposed on the Pondo River just downstream from this power station, and the combined waters of the Pondo and Towanokoko Rivers would be used to generate more power at a station in the region of G.S.63. Using this layout, 3350 kW of power would be available with run of river flow and 5150 kW with diurnal pondage.

The proposed layout of the alternative schemes investigated geophysically is shown in Fig. 1 and Plate 2. It differs from the original proposal in that the scheme B weir site on the Pondo River has been moved upstream to the site of the proposed weir to serve scheme A, the scheme B power station and high pressure pipeline having been relocated accordingly. The original scheme B weir site close to stadia station 48 was rejected because of adverse geological conditions affecting both the weir site and the low pressure pipeline.

The two alternative weir sites on the Towanokoko River were selected and investigated after geophysical investigation of the original weir sites had indicated the presence of suspect abutments at both sites.

MAPPING

A total of six weir sites were mapped by plane table tacheometry at a scale of 40 feet to 1 inch (see Plate 2 for locations). Control for the survey at each site was provided by bench marks which had been established during a previous dumpy level survey by the Commonwealth Department of Works. At the Scheme B weir sites on the Towanokoko River, some topographic information was available from an earlier stadia survey, but at all other sites both geology and topography were plotted by plane table survey.

Geological observations along the rivers in the area of the scheme were plotted directly on a base map prepared by a stadia survey (see Plates 5 and 6). Control for all other mapping along the Pondo and Towanokoko Rivers was provided by air photographs. The scale of the prints used in the field is about 4000 feet to 1 inch; for plotting purposes, the scale has been enlarged to 2000 feet to 1 inch (Plate 3).

Fig. 1: Stereoscopic pair of photographs showing the proposed layout of the scheme (refer to Plate 2 for details). The recent extensive landslide in the Towanokoko valley is clearly visible downstream of the scheme area.

GEOPHYSICAL INVESTIGATIONS

Seismic method

Seismic refraction traverses by the Compagnie Generale de Geophysique were conducted with twelve-geophone spreads. Three different lengths of spread were used (220, 440 and 880 feet), depending upon the depth of investigation required - the corresponding geophone spacings were 20, 40 and 80 feet. Generally, five shots were used for each 220-foot spread, nine shots for the 440-foot spreads, and three shots for the 880-foot spreads. The seismic results were interpreted using the intercept time method.

All components of the scheme were tested by seismic traverses, but lack of time precluded the testing of parts of the proposed low pressure pipeline (see Plate 2). In addition, 375 feet of the Scheme A tunnel line could not be tested owing to inaccessibility of proposed geophone stations. A total of 81 220-foot spreads, 5 440-foot spreads, and 3 880-foot spreads were shot during the survey, the total horizontal distance traversed being 18,125 feet.

Electrical resistivity methods

The Schlumberger quadripole arrangement was used, in which the potential electrodes are placed a short distance apart relative to the spacing of the outer current electrodes. Three variations of the basic method were used during the survey:

1. Electrical sounding. The spacing of the two current electrodes is gradually increased so that a deeper penetration of the electrical field occurs. The potential electrodes remain fixed, and the actual resistivity of the layers directly below the centre of the arrangement may be calculated from the measured apparent resistivities.

2. AB profiling. The current electrodes remain fixed, while a series of measurements are made with several adjacent positions of the potential electrodes. The current electrodes are then moved along the traverse, and another set of readings taken with adjacent positions of the potential electrodes; these overlap with the previous series of readings to provide a continuous profile. This method is particularly suitable for rugged terrain.

3. AMONB profiling. The spacing of the current and potential electrodes remains constant, and the whole arrangment is moved along the traverse. Each shift of the spread is equal to half the spacing of the potential electrodes. This method is effective in locating superficial vertical discontinuities.

The total horizontal distance traversed by resistivity profiling methods was 6,329 feet. In addition, twelve locations were selected for electrical soundings.

REGIONAL GEOLOGY

LITHOLOGY

The scheme is set in a thick sequence of Miocene limestone, marl and mudstone which crops out over much of the Western Gazelle Peninsula. In the area of the scheme, the dominant rock type is limestone, but numerous interbeds of marl and mudstone occur.

The limestone is a cream to light buff thickly-bedded fine-grained rock which is hard and strong where fresh. It has a uniform composition, and bedding planes are seldom evident. Beds of limestone breccia and coralline limestone crop out in many places along the river valleys; they are characterised by honeycomb weathering.

The mudstone is a soft weak blue-grey rock. It generally occurs as interbeds ranging in thickness between a few inches and 10 feet, though some interbeds are at least 40 feet thick. Many of the mudstone beds contain fossils, and a few are extremely fossiliferous.

Where they are exposed in the river valleys, the mudstone beds are very soft, wet and plastic. They therefore have a very low strength, and their inability to support overlying rock has resulted in the development of numerous landslips along the river courses.

Marl is commonly associated with the mudstone, usually forming a transition zone between the mudstone and limestone. Its composition ranges from clayey limestone to calcareous mudstone, and the physical properties range correspondingly between those of limestone and mudstone.

Traverses from the area of the scheme to the coast were made down both the Pondo and Towanokoko Rivers to determine the regional distribution of rock types and their attitudes. The interbedded limestone, marl and mudstone which crops out in the area of the scheme was mapped downstream to within four miles of the coast. From here to the coastal flats, the rivers flow over a sequence of very thickly-bedded, apparently pure, limestone. The absence of mudstone interbeds has resulted in extensive underground drainage, and the rivers flow in narrow, steep-sided gorges. In one section, the Pondo flows underground intermittently over a distance of almost a mile. Unfortunately this section of the river valley was inaccessible in the time available, so it was not possible to determine whether the underground flow is due to natural underground drainage, or to the formation of a roof over very narrow sections of the gorge as a result of rock falls and subsequent deposition of travertine. The limestone in this downstream area is similar in composition and physical properties to the limestone in the area of the scheme.

STRATIGRAPHY

The geological observations of the traverses down the Pondo and Towanokoko Rivers are plotted on Plate 3, from which geological sections along both rivers have been constructed (Plate 4). The base of the thickly bedded pure limestone has not been located in the field, but the presence of andesitic volcanic rocks at the Pondo Plantation homestead enables the base of the limestone succession to be located approximately on the geological section.

Assuming that there are no major displacements by faulting of the succession mapped along the rivers, the thickly-bedded pure limestone directly overlying the basement volcanics is estimated to be 6000 feet thick. This sequence is in turn overlain by interbedded limestone, marl and mudstone with a total thickness of at least 2000 feet; no stratigraphic subdivision of this interbedded sequence is possible, owing to the paucity of in-situ outcrops along the rivers.

Samples of limestone from scattered localities (see Plate 3) along both rivers have been submitted for palaeontological investigation; the results are the subject of a separate Record (Lloyd, 1963). Samples from the base of the limestone succession were determined as being of Lower Miocene age, as were samples from the overlying succession of interbedded limestone and mudstone.

STRUCTURE

Folding

The Miocene limestone appears to form a fairly flat blanket over much of the Western Gazelle Peninsula, and the dips observed along the Pondo and Towanokoko Rivers in few places exceed 25°. The geological sections constructed from the dips measured along the rivers (Plate 4) show that the limestone sequence is very gently folded to form a broad syncline, with some minor gentle folding in the trough. Correlation of the folds shown in the two sections indicates that the fold axes trend east-west.

The area where the succession of interbedded limestone, marl and mudstone crops out is characterised by comparatively subdued topography, in contrast to well-developed karst topography of the areas of pure limestone. The aerial photographs show that the interbedded succession crops out over a roughly circular area, 4 miles across, which is entirely surrounded by pure limestone country with masses of pinnacles and sinkholes and no evident surface drainage. It would therefore appear that the broad syncline inferred from Plate 4 is part of a basin structure.

Faulting

Three faults only have been mapped along the river courses, although others are undoubtedly present in the area. One of the faults mapped crops out in the Towanokoko River 2½ miles downstream of the proposed hydro-electric scheme; it is a normal fault dipping at 45° to the south. The other two faults crop out in the area of the scheme, and both have direct bearing on the feasibility of the proposed alternative layouts of the scheme.

One of the faults crops out in the Pondo River between stations 49 and 50 (see Plate 5). It is a high angle fault which strikes roughly at 030° magnetic*, and it is marked by a zone, several feet thick, of brecciation in the limestone; adjacent mudstone bands are severely contorted and irregularly weathered. The interpolated downstream extension of the fault crosses the river at station 47 and continues along the right bank. The fault is not exposed in this area, but its presence is reflected in an unstable slope on the right bank for a considerable distance downstream of station 47; in addition, there is an old landslip on the left bank between stations 47 and 49. It was originally proposed that the Scheme B weir site on the Pondo be located between stations 48 and 49, but an inspection of the river valley in this area indicated that topographically suitable weir sites were impracticable on geological grounds. Even if a weir site with adequate foundations could be located, the route for the low pressure pipeline would have to traverse the steep, unstable slope downstream of station 47. The original Scheme B weir site on the Pondo was therefore rejected and the layout of the scheme rearranged as shown in Plate 2.

The third fault was mapped in the Towanokoko River between stations 28 and 29 (see Plate 6). Sheared and contorted mudstone occurs extensively in the river bank in this area; the shear zone strikes roughly at 105°. Geological discontinuities and minor folding are also evident along the Towanokoko in the gorge between stations 23 and 25. This fault appears to be a major regional feature as the shear zone is in line with the cliff face behind the large landslide just upstream; in addition, the fault can be traced to the west of the Towanokoko, and to the east of the landslide area, as a distinct lineament on air photographs. The interpreted eastern extension of this fault is particularly important, as it crosses the proposed tunnel lines of the alternative schemes.

* All bearings and directions in this report are magnetic.

Jointing

Jointing in the limestone and marl is obscured in many outcrops by the deposition of travertine. The altitudes of 136 joints were measured during the mapping of the elements of the scheme and the river courses; they were plotted on an equal area stereographic net, and the distribution emphasized by contouring the plot (see Fig. 2). It can be seen that there are three main concentrations of joint attitudes. All joint sets are vertical. One set strikes at 090° which corresponds with the axial plane of the broad fold described earlier. The other sets of joints strike at 045° and 132°, and presumably represent a set of shear joints developed at about 45° to the direction of the compressive forces that produced the folding.

ENGINEERING GEOLOGY

SCHEME A

Towanokoko Weir Site

The originally proposed weir site is located just upstream of the natural lake formed by the damming of the Towanokoko River by landslide material. Plate 7 is the plane table map of the area showing the proposed axis of the weir; it can be seen that it is not a particularly good site topographically, being rather wide.

Little geological information was obtained from surface mapping because of the paucity of exposures. The 60-foot high cliff on the south bank of the river is entirely covered by travertine, which is up to 1 foot thick; the only exposure on which measurements could be taken occurs just downstream of the small tributary stream. This exposure revealed weathered, massive limestone dipping 14° west. Joint planes are mostly obscured by the thin layer of travertine which covers the limestone. On the north bank, massive limestone with a thin cover of travertine is exposed in two places, but no bedding planes were evident. The exposure on the side of the knoll forming the right abutment of the proposed weir is very irregular, particularly at the foot of the cliff, where large disjointed blocks of limestone occur. It is suspected that the knoll may be composed of landslide material which would not form an acceptable abutment.

The pebble banks in the river at the weir site consist of pebbles, cobbles and occasional boulders of limestone and marl which have been deposited by the river on entering the lake immediately downstream. The width of the river and the steepness of the banks at river level indicate that the original river bed may be some distance below the present bed, in which case a considerable volume of pebbles and cobbles would have to be removed if the weir were constructed. The geophysical traverse along the axis has located a layer beneath the river with a seismic velocity of 5000 ft/sec. which may represent saturated gravels or alluvium. The base of this layer is 18 feet below the surface at the proposed axis, but the longitudinal geophysical traverse shows that it increases in depth in a downstream direction as one would expect where gravels are deposited on an old river bed.

The geophysical traverse along the proposed axis indicates very poor abutments, particularly on the south bank where much of the 30-foot high bench between the river and the limestone cliff is composed of loose soil and scree with a seismic velocity of only 1,100 ft/sec. The northern abutment is composed mainly of 4,000 ft/sec material, representing weathered and jointed limestone, overlain by up to 20 feet of soil and scree (1,100 ft/sec).

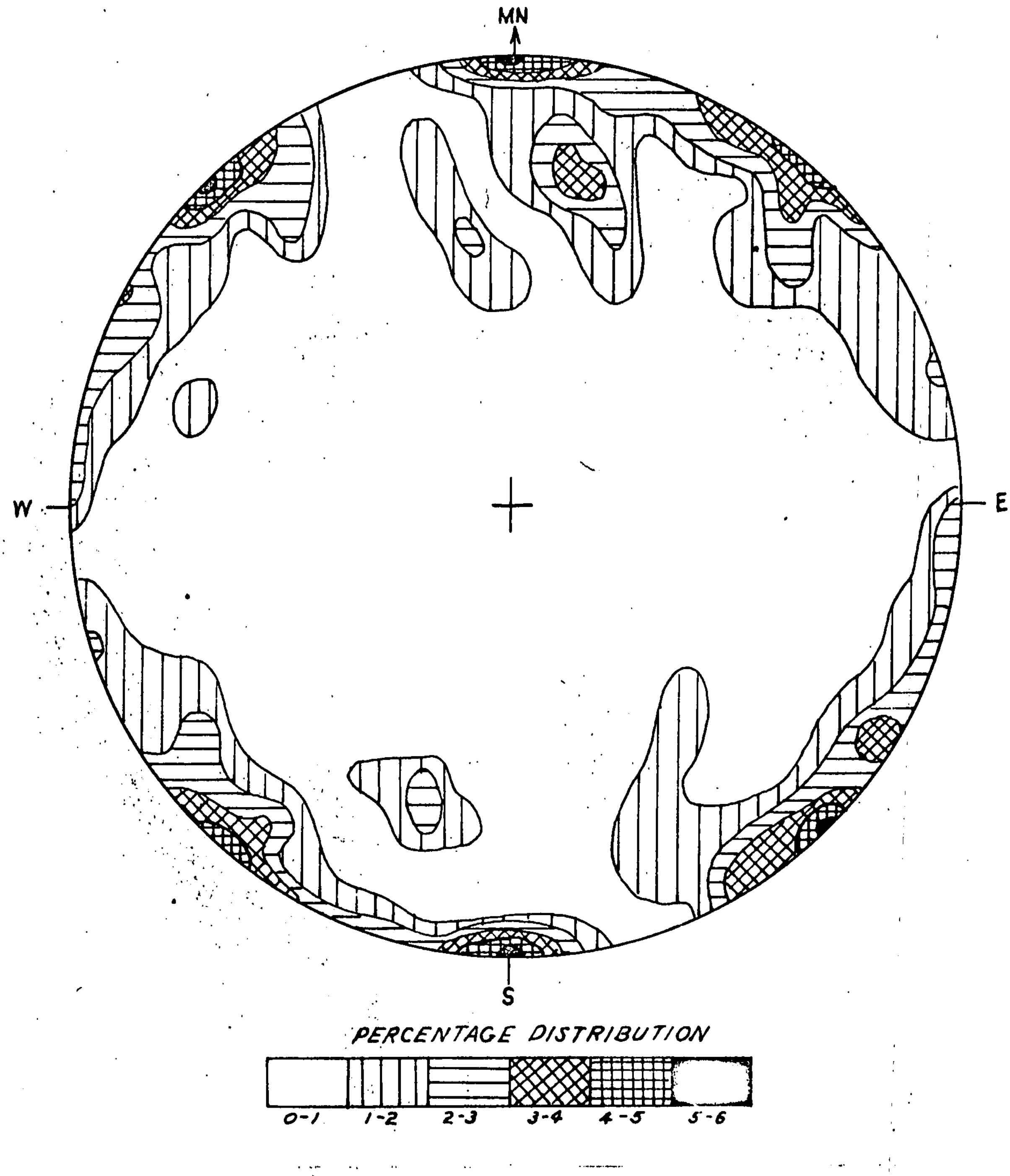


Fig. 2: Contoured joint plane stereogram. Poles of 136 joint measurements are projected onto the lower hemisphere, using an equal area net.

Alternative Towanokoko Weir Site

Because of the adverse conditions prevailing at the weir site described above, it was decided to select an alternative site for investigation. Between B.M.3 and station j the river is too wide for a weir, and upstream of station h there are extensive landslips and outcrops of mudstone in the river banks. A site was therefore selected between stations j and h where the valley sides are relatively steep and where the presence of mudstone is restricted to a band 4 feet thick at river level.

The only true outcrop at the site occurs on the lower slopes of the west bank and continues down to river level (see Plate 8). This exposure consists of a cliff of massive, weathered limestone, the face of which is a major joint dipping at 85° east. A thin layer of travertine has obscured any other joint or bedding planes. A bed of soft, grey, fossiliferous mudstone, 4 feet thick and dipping 4° south, is exposed at river level, and is underlain by marly limestone which is exposed in the river bed. The west bank is quite steep and weathered bedrock is therefore close to the surface; a pit excavated close to geophone station 2 encountered at a depth of 3 feet a large limestone mass which may have been in place. The slope of the east bank is much gentler and consequently there is a considerable thickness of soil and scree overlying weathered bedrock. A pit excavated between geophone stations 15 and 16 to a depth of 9 feet encountered clay soil and limestone scree throughout.

With regard to the foundation conditions, there were no traces of mudstone bands found at the site apart from the 4 foot bed at river level. The abutments probably consist of limestone which is weathered, though quite strong - this is reflected in the higher seismic velocity (5,000 ft/sec) than is usual for weathered bedrock. However, the rather low velocity for bedrock (7,500 ft/sec), combined with evidence of a conductive sub-stratum in the electrical sounding carried out on the east bank (E.S.8) indicates that other mudstone interbeds occur in the limestone below the weir site; these are probably the same mudstone beds that crop out in the river upstream. No indication is given in the geophysical report of the depth and thickness of the conductive layer located, so drilling will be necessary to obtain this information if further investigation of the scheme is undertaken.

Pondo Weir Site

This site was selected because of the steep abutments, the widening of the valley upstream which gives a moderately good storage capacity, and because the outcrop in the river banks, though sparse, indicates the presence of strong massive limestone.

Massive limestone crops out in both banks of the river just downstream from the proposed axis (see Plate 9), the cliff on the north bank being 15 feet high. The limestone is openly jointed, particularly on the south bank where surface movement has probably occurred. No bedding planes were observed in either outcrop. Upstream of the proposed axis, massive limestone crops out on the north bank of the river. Bedding planes are clearly evident here; they form two continuous benches 3 feet wide along the river bank. The dip ranges between 16 and 19 degrees south. A few widely spaced joints, most of them vertical, are also present. The series of small waterfalls along the river are probably formed by similar limestone benches, but the extensive deposition of travertine prevents detailed examination.

Two pits 8 feet deep were excavated at the site, one in each abutment. The pit on the south bank encountered soil and scree only, but the one on the north bank was excavated mostly in very weathered limestone and marl. One distinct limestone band was evident, but an accurate measurement of bedding was unobtainable owing to surface creep. Numerous open cracks perpendicular to the ground surface provide further evidence of surface creep. Many slickensided planar surfaces, probably bedding planes, dipping gently (less than 20°) towards the river were noted. Some blue-grey mudstone is exposed, but it was not possible to determine whether it was in place.

The seismic traverse across the site revealed good quality limestone bedrock with a velocity of 9,000 ft/sec., overlain by considerable thicknesses of low velocity material on both abutments. The weathered limestone exposed in the pit on the north bank corresponds to the 2,500 ft/sec. material, the rather low velocity presumably being due to the opening of joints and cracks by surface creep. It is possible, therefore, that the 2,500 ft/sec material would form adequate foundations for a low weir if the open joints were grouted. However, drilling would be necessary for the correlation of seismic velocity and geology and for the location of any mudstone beds, particularly as the electrical sounding on the south bank (E.S.12) indicated that the strong limestone is not very thick compared with the more conductive strata both above and below it. This conductive material may be clayey limestone, or even mudstone, and drill core is required before a reliable opinion on the suitability of the weir site can be given.

Tunnel Line (Plate 2)

The only outcrop along the tunnel line is the cliff on the Pondo side of the ridge between 2,100 and 2,300 feet above sea level. Parts of the cliff face are obscured by scree material, but it can be seen that numerous mudstone bands occur interbedded with limestone and marl. As the regional dip is very shallow and the elevation of the tunnel line is only 1750 feet, the base of the exposed succession is at least 300 feet above the proposed tunnel line. Thus the only information obtainable on the rock conditions at tunnel line level is derived from the seismic traverse.

In the seismic profile three velocity layers are delineated. The topmost layer consists of material with a seismic velocity of 2,500 ft/sec. or less and represents soil, scree, and possibly very weathered and jointed bedrock. The thickness of this layer ranges from 10 feet to 50 feet, and is generally between 20 feet and 30 feet.

Weathered and jointed bedrock is generally represented by a velocity layer of 4,000 ft/sec. On the Towanokoko side of the ridge, the thickness of this layer ranges from 40 feet to 80 feet. Close to the Towanokoko weir site the velocity of the weathered zone is 5000 ft/sec. and the zone is 40 feet thick. On the Pondo side of the ridge, the weathered zone is exceptionally thick at the foot of the cliff face; it reaches a maximum of 120 feet, and strongly suggests the presence of a fault of shear zone. Inspection of the air photographs reveals two very strong lineaments which intersect in the area, one of which is associated with shearing in the Towanokoko valley; this evidence tends to confirm the view that a major shear or fault zone would be encountered along the tunnel line. The condition of the rock in this area is quite critical as the Pondo portal of the tunnel would be located in the weathered zone.

The unweathered bedrock is shown on the profile as a layer with a uniform velocity of 8,000 ft/sec. throughout the tunnel line, suggesting a succession of impure limestone beds. From the geological observations in the cliff on the Pondo side of the ridge and also in the 400-foot cliff behind the large landslide to the west of the tunnel line, it is evident that there are several thick mudstone interbeds towards the top of the ridge which do not show up in the bedrock profile. It is therefore possible that mudstone beds occur lower in the succession (i.e. closer to the tunnel elevation) which have not been located by the geophysical traverses. The field interpretation of the seismic results did, in fact, include two thick interbeds of low velocity material in the bedrock profile; one was a 5,900 ft/sec. layer between 1890 feet and 1930 feet elevation, the other a 5,600 ft/sec. layer between 2050 feet and 2120 feet. The possibility of mudstone beds occurring along the tunnel line is also indicated by tracing the extensive mudstone outcrops in the East Pondo River along the regional dip and strike; this extrapolation indicates that the same mudstone beds should occur between 1800 feet and 2000 feet in the area of the tunnel line.

As the alignment of the tunnel is approximately parallel to the regional strike of the rocks, the tunnel would be excavated in a very narrow portion of the geological succession. Thus, if good tunnelling rock is found at the Towanokoko portal, it will probably continue along the tunnel line as far as the shear zone on the Pondo side of the ridge. Conversely, if the mudstone is found to occur between 1750 feet and 1800 feet at the Towanokoko portal, the tunnel would have to be excavated for most of its length in the mudstone. It is therefore important that the geological succession in the region of the Towanokoko portal be investigated by diamond drilling at an early stage of any future investigation.

Low Pressure Pipeline (Plate 2)

There are no rock exposures along the proposed route of the low pressure pipeline; seismic traverses form the only basis for determining rock conditions. Only part of the pipeline route was surveyed geophysically, but the results are quite uniform and give an indication of the foundation conditions to be expected along the entire route.

The interpreted depth to fresh bedrock along the main pipeline ranges between 60 and 100 feet. However, the weathered bedrock, represented by the 4,000 ft/sec. layer, would probably be sufficiently strong to support anchor blocks for the pipeline; the depth to this layer is everywhere less than 40 feet. Along the pipeline from the Pondo portal to the main pipeline, the fresh bedrock is shallower but the depth to weathered bedrock is generally between 25 and 40 feet.

High Pressure Pipeline (Plate 2)

As for the low pressure pipeline there are no outcrops along the high pressure pipeline and the only information available is the seismic survey. The seismic profile indicates that the depth to bedrock ranges from 40 to 80 feet: generally about 60 feet. The bedrock has a uniform velocity of 8000 ft/sec. except towards the Pondo River where it increases to 9000 ft/sec., indicating a succession of limestone and marl beds. From the evidence of the geological mapping up the North and East Pondo Rivers, however, it is likely that mudstone bands occur along the pipeline route.

The weathered bedrock has a velocity of 4,000 ft/sec. except towards the Pondo River where it increases to 5,000 ft/sec. The depth to the weathered zone is generally less than 30 feet.

There are two areas along the pipeline route where a change in the surface gradient and the dip of the seismic layers may indicate a shear zone or some other discontinuity. Should any drilling be undertaken to correlate the seismic results with geology along the pipeline, one of these areas should be selected as a drilling target.

Power Station Site.

The power station site was investigated geophysically by three 220-foot long seismic traverses set out in the shape of a Z to cover the area of the proposed site (see Plate 10). Bedrock was found to consist of good quality limestone (9,500 to 11,000 ft/sec. material); the bedrock surface is flat and between 45 and 55 feet below the ground surface.

The zone of weathered bedrock is represented by a 5,000 ft/sec. layer, the top of which is everywhere less than 20 feet deep. This material may provide adequate foundations for a power station, providing there are no thick mudstone bands present. An adversely dipping lubricated mudstone-limestone contact beneath the proposed site, which is on a ledge 60 feet above the river, could initiate a major landslip under an increased load.

SCHEME B

Towanokoko Weir Site

This weir site was selected by Carter during the preliminary investigation as being the best site available on the Towanokoko River for a low weir; it has steep abutments which are close together, the valley immediately upstream being wide and providing a good storage capacity. However, an examination by Carter of the few outcrops that occur revealed some abnormally high bedding dips which could be due to faulting or to displacement by landslides. A saddle on the west bank was also noted which could provide a leakage path through the spur on which the saddle occurs; the difference in elevation of river level on either side of the spur is 50 feet and the leakage path is only 350 feet long. In spite of these features, it was considered that a detailed examination of the site by geophysics was warranted, and both seismic and resistivity traverses were conducted along the proposed axis: in addition, a deep electrical sounding was made at geophone station 6. Before the geophysical survey was carried out, the reservoir area was accurately surveyed, and that part of the survey close to the proposed weir site was extended downstream for 150 feet by plane table mapping; all rock outcrops were plotted onto this map (Plate 11).

On the east bank, the spur forming the abutment of the proposed weir was seen to consist dominantly of large, loosely packed boulders of limestone which are not in place. A pit on the top of the spur revealed rounded limestone boulders which are overlain by up to 6 feet of river sand and gravel with some silt. These river deposits consist mainly of rounded grains of limestone, but many rounded mudstone pebbles occur. Such porous, unsaturated alluvium should be characterised by high resistivity, and electrical soundings E.S.7 and E.S.9. (Plate 11) did, in fact, locate a superficial resistive layer which is approximately 40 feet thick at E.S.7 and 14 feet thick at E.S.9. The seismic profile obtained along the axis also indicates the presence of loose, unconsolidated, and unsaturated material with a velocity of 1,100 ft/sec. over much of the eastern abutment. The interface between this material and the underlying weathered bedrock (4,000 ft/sec.) rises gently up-slope from the present river level at an angle of 15°. The depths of this interface at E.S.7 and E.S.9 are 27 feet and 18 feet respectively which agree well with the interpretation of the electrical soundings. It is therefore concluded that the eastern abutment is not suitable for the construction of a weir without considerable excavation and the consequent widening of the river valley.

Two other rock exposures occur on the east bank in the vicinity of the proposed axis. One, an outcrop, situated close to the river and 40 feet downstream of the axis, is almost certainly in place and consists of weathered fossiliferous limestone. Two bedding planes, with a dip of 28° east-south-east, were noted. The other exposure forms a cliff 25 feet high and 40 feet long, and consists of angular to subrounded limestone boulders intermixed with marl and clayey material. Along the tunnel line traverse, the seismic velocity obtained for this material was only 1,100 ft/sec. so it is almost certainly landslide debris. A pit excavated on the tunnel line just downstream of this outcrop revealed mostly clay and mudstone with some limestone boulders up to 1 foot across; this also indicates landslide material.

The limestone outcrop on the western abutment is more uniform and massive, and is possibly in place; rounded and undercut limestone at the base of the outcrop was probably shaped by erosion at times of flood. A pit excavated on top of the knoll forming the abutment revealed weathered and jointed clayey limestone at a depth of 5 feet; above this there is a gradation through very weathered clayey limestone to brown soil at the surface. The seismic profile indicates a velocity of 1,100 ft/sec. for this weathered limestone which considering the condition of the exposed rock, is much too low. The limestone exposed is of the quality to be expected for the 5,000 ft/sec. layer which was interpreted as being at least 14 feet below the surface. No bedding dips were obtainable from the outcrop or from the limestone exposed in the pit; however, from all the evidence available it is concluded that the abutment is probably composed of limestone which is in place.

The saddle on the west bank, adjacent to the knoll which would form the west abutment, was also investigated geophysically in order to determine the possibility of leakage. Both seismic and resistivity traverses were run along the axis of the saddle. In the seismic profile, four layers were located with velocities of 1,100 ft/sec., 2,500 ft/sec., 5,000 ft/sec. and 8,000 ft/sec. respectively. The boundaries between these layers are all roughly parallel to the ground surface; the saddle, therefore, apparently does not occupy an old infilled river course. At the crest of the saddle, the ground surface is at an elevation of 2028 feet, the base of the 1,100 ft/sec. layer is at 1993 feet, the base of the 2,500 ft/sec. layer is at 1984 feet, and the top of the 8,000 ft/sec. layer is at 1937 feet. Therefore, if the two upper layers are at all permeable, the saddle would provide a leakage path around a weir with a crest higher than 1984 feet, i.e.30 feet or more above river level. The 5,000 ft/sec. layer, which is probably weathered limestone, may also be permeable enough to cause significant leakage around the proposed weir. The resistivity traverse indicated a sharp increase in resistivity at the crest of the saddle, and two smaller anomalies were located below geophone stations 17 and 8 of the saddle traverse. However, no interpretation of these anomalies has been suggested by the geophysicists, except that they may be due to deep electrical discontinuities. An electrical sounding (E.S. 10) was carried out close to geophone station 8, but the resulting resistivity curve was featureless and gave no indication of the nature of the anomaly at this point on the resistivity profile.

In view of the weak abutments, particularly on the east bank, and the possibility of leakage through the saddle, this weir site need not be considered further.

<u>Alternative Towanokoko Weir Site</u>

This weir site was selected for investigation when it was realised that the original weir site was unsuitable; it is situated 600 feet upstream of the original weir site. Plate 12 shows the geology of the site, which was plotted by compass, tape and Abney level traverses on to the contour map already prepared by the surveyors; the positions of the seismic and resistivity traverses are also plotted.

The east bank is steep and consequently weathered bedrock is very close to the surface. A large outcrop of limestone occurs just beyond the eastern end of the axial geophysical traverse and weathering out of a softer band of marl has revealed a bedding plane dipping at 12° to the north-east. The limestone is massive with a few vertical joints striking 045°. One of the shot points for the seismic survey was located just below this outcrop and the resultant hole exposed weathered marl below 6 inches of soil cover. The marl is irregularly jointed, probably due to the explosive charge, and a bedding plane dipping 16° to the north-north-east was observed. Another extensive outcrop occurs 60 feet upstream; it consists of massive limestone, with no trace of bedding or jointing because of a thin covering of travertine.

The west bank has a gentle slope for the first 40 feet above river level, and consists of large blocks of calcite-covered limestone scattered among soil and scree. Farther up-slope, the gradient increases towards the foot of a vertical cliff 20 to 40 feet high which extends for 200 feet upstream from the axis. The cliff is composed of massive limestone which is almost entirely coated by a layer of calcite up to 2 inches thick. Several major open joints up to 1 foot wide are present, the faces of which are also covered with calcite; it is likely that the cliff face itself is a major joint plane. The large blocks of limestone down-slope must have fallen from this large outcrop; the fall would have beenfacilitated by the open jointing. Upstream, the outcrop is terminated by a large landslip, composed mainly of limestone rubble, which extends for a vertical distance of at least 200 feet up the hillside, and down to river level. No traces of mudstone were found anywhere on the landslip, indicating that it may be a large rock fall of openly jointed limestone, probably triggered off by an earth tremor. Whatever the cause of the landslip, the stability of the west bank must be carefully evaluated before it is decided to build a weir at this site.

The seismic traverse along the axis of the weir indicated a velocity of only 5,000 ft/sec. for the limestone exposed on both banks. Such a relatively low seismic velocity would be expected for the weathered limestone of the east bank, but a higher velocity would seem more appropriate for the massive limestone in the cliff on the west bank. The low seismic velocity is probably due to the major open joints; these must persist to a considerable depth as the 5,000 ft/sec. layer is 90 feet thick below geophone station 23.

The fresh bedrock has a velocity of 8,000 ft/sec. indicating impure limestone or marl interbeds, whereas the resistivity profile shows a high resistivity for bedrock on both abutments which suggests the presence of pure limestone. The electrical sounding E.S.11 shows a fall in resistivity for the deepest measurement, however; this would be due to a deep conductive stratum such as mudstone or marl.

The overburden on the west bank is at least 20 feet thick according to the seismic profile, and a considerable volume would have to be removed if a weir were constructed; this would make an already wide weir site even wider. On the east bank, there is little overburden except close to the river. E.S. 11, sited on the east bank of the river, has located a superficial resistive layer 6 feet thick which is probably unsaturated alluvium.

Pondo Weir Site

As for Scheme A (see p. 9).

Tunnel Line (Plate 2)

There is a complete lack of outcrop along the tunnel line, and the overburden is everywhere too thick for pits or costeans to be of any practical use. Consequently the only information available on rock conditions has been deduced from seismic and resistivity traverses which were conducted along the proposed tunnel line.

The tunnel alignment selected for investigation is unsatisfactory, as the tunnel level is too close to the ground surface for some two thirds of its length. The topography of the dividing ridge between the Pondo and Towanokoko Rivers is such that a tunnel must make a detour towards the south-east from the Towanokoko portal in order to obtain sufficient rock cover; this would increase the length of tunnel required. However, the geophysical results obtained give a general picture of the rock conditions to be expected along any re-alignment close to the investigated route.

The seismic profile shows three velocity layers only, namely 2,500 ft/sec. or less, 4,000 ft/sec. and 8,000 ft/sec. The 8,000 ft/sec. layer, representing unweathered bedrock, is between 100 and 150 feet below ground surface throughout most of the tunnel line. The absence of any velocity variations, particularly in bedrock velocity, and the smoothness of the interfaces indicates that only a generalised picture of sub-surface conditions has been obtained; the seismic results have not revealed any of the details of structure and lithology which would be required for the location of a satisfactory tunnel line.

The main part of the tunnel line (from the top of the dividing ridge to the Towanokoko portal) was tested by resistivity profiling and the general picture obtained was that a regular resistive layer, probably limestone, is overlain by a conductive overburden, the thickness of which varies with the topographic relief. Four resistivity anomalies of at least 60 ohm/metre, were located; these anomalies cannot be correlated with the generalised seismic results obtained. Additional data, in the form of a deep electrical sounding, are available for one anomaly (E.S.3 at geophone station 22), and the results obtained are similar to those of three other electrical soundings along the tunnel line (E.S. 1, 2 and 4). They have been interpreted as indicating the presence of a resistive layer, up to 150 feet thick and at a depth of 150 to 200 feet, underlain by conductive material which is probably mudstone. However, the anomaly at E.S.3 and the one below geophone station 56 could be due to fault zones, particularly as there are marked depressions in the ground surface above these anomalies. A pit was excavated at geophone station 24 in an effort to expose material which could indicate faulting. Brown clay was present to a depth of 3½ feet and was underlain by 2½ feet of alternating bands of very wet, brown and grey clay. This indicates that the bedrock is probably mudstone; because the material exposed was saturated with water, it was not possible to detect any evidence of faulting such as cleavage or shearing. The pit had to be abandoned at 6 feet as the daily rainfall kept it permanently flooded.

The other two resistivity anomalies, which occur below geophone stations 188 and 208, do not have any surface expression which could indicate their origin. A pit was excavated close to geophone station 208, but revealed only large, calcite-coated limestone blocks.

On examining the seismic profile along the high pressure pipeline route on the Pondo side of the divide, a sharp change in dip of the seismic layers below geophone station 44 is evident, together with comparatively thick overburden. These features probably represent the extension of the fault or shear zone which was interpreted from the seismic traverse along the Scheme A tunnel line (p. 10). In both schemes this postulated fault zone coincides with the Pondo portal areas; therefore similar engineering problems would be encountered at the Pondo end of each tunnel line.

Low Pressure Pipeline

As for Scheme A (see p. 11 and Plate 2).

High Pressure Pipelines (Plate 2)

The high pressure pipeline to serve a power station at stream gauging station G.S.63 has already been considered in Scheme A (see p. 11).

The first stage power station of Scheme B would be served by a high pressure pipeline from the Pondo portal of the tunnel. As for the tunnel line, the pipeline route investigated geophysically would be re-aligned should the scheme be considered for further investigation. The seismic profile indicates that the 4,000 ft/sec. material, which would probably provide adequate foundations for the anchor blocks, is at depths ranging from 20 to 40 feet; this order of depth of foundations would probably apply along the re-aligned pipeline.

Power Station Sites

The power station site near stream gauging station G.S.63 has been dealt with under Scheme A (see p. 12).

The first stage power station is situated in the valley of a tributary of the Pondo River near the base camp. There are no rock outcrops at the site, and the only information obtained was three seismic profiles arranged in a pattern similar to that at the other power station site. These indicate that weathered bedrock (4,000 ft/sec.) is generally 25 feet below the surface and is nowhere deeper than 30 feet. The fresh bedrock, which has a seismic velocity of 9,000 ft/sec., is generally 50 feet deep. The regular seismic profiles and the comparatively shallow depth of bedrock indicate that the site is suitable for the construction of a power station.

PONDO SECOND STAGE WEIR SITE

Although this weir site is not included in the initial 5,000 kilowatt scheme, it is hoped that future development of the power potential of the Pondo and Towanokoko Rivers will be possible if one of the schemes at present under consideration is constructed. The first stage in any further development would be the diversion of the Pondo River and the water from the tailrace of the power station; this diversion would be as close to the power station as possible to avoid loss of potential head. The river valley at gauging station G.S.63 is topographically suitable for a low weir (see Plate 10) and as there is strong, massive limestone exposed at river level it was decided to test the site at the same time as the power station on the north bank.

The site is suitable for the construction of a low weir only, because of the gentle gradient of the south abutment and a wide bench at an elevation of 1040 feet (i.e. 40 feet above the river); the north bank also flattens at 1060 feet. The river gradient immediately upstream is low, and though the valley is not particularly wide, storage would probably be adequate.

Very hard and strong, massive limestone is exposed in the river banks (see Plate 10), and would provide excellent foundations for a weir. The surface of the large outcrop on the south bank is a bedding plane which dips at 12° in a northerly direction. Farther up-slope the limestone is overlain by much weaker material, probably soil and scree. Fragments of mudstone were found in the rock debris around B.M.12 and in the scree immediately overlying the limestone outcrop; Carter has also noted an outcrop of mudstone 300 feet upstream of the axis with bedding dipping at 10° to the north, i.e. the same attitude as the limestone. It is therefore concluded that a mudstone band overlies the massive limestone exposed in the river banks. This would account for the low gradient of the south bank, the average slope of which is the same as the dip of bedding, as a mudstone band overlying the massive limestone would provide a plane of failure for any overlying beds. The north bank would be more stable, as the mudstone dips away from the river.

Apart from a few major joints, which stand out clearly as small cliffs on the river banks, the limestone is massive and unbroken - this is reflected in the comparatively high seismic velocity of 11,000 ft/sec. No other geological observations could be made at the site because of the lack of outcrop and the travertine deposits in the bed of the tributary 150 feet upstream.

The seismic traverse along the axis shows that the massive limestone is close to the surface on the south bank and dips gently to the north. However, the profile shows that the dip of the 11,000 ft/sec. material is reversed beneath the north bank. This indicates that either the limestone is folded into a gentle syncline, or the mudstone band is thin and is overlain by another bed of massive limestone on the north bank.

The zone of weathered bedrock on the north bank is up to 40 feet thick, but as the velocity is comparatively high (5,000 ft/sec.) it should form adequate foundations for a low weir, providing that extensive mudstone bands do not occur. The weathered zone is overlain by up to 25 feet of soil and scree material.

EVALUATION OF ALTERNATIVE SCHEMES

A study of the topography, geology and geophysical data for all elements of the alternative schemes has been made, on the basis of which the following conclusions have been drawn:

1. The alternative Towanokoko weir site for Scheme A is preferred to the original weir site.

2. The alternative Towanokoko weir site for Scheme B is recommended in place of the original weir site; in fact the latter is so highly suspect, both from the point of view of foundation strength and leakage, that it should not be considered further.

3. The alternative Towanokoko weir site for Scheme B is rather wide and a considerable volume of material would have to be removed before a weir could be constructed. Further, the western abutment is composed of very openly jointed limestone which is liable to slide. The alternative Towanokoko weir site for Scheme A is therefore considered to be the most favourable of the Towanokoko weir sites.

4. The Pondo weir site which will serve both Schemes A and B may not be feasible, and requires further investigation of the abutments; an alternative site may be necessary.

5. The Scheme B tunnel line needs to be re-aligned, as it is too close to the surface for half of its length; even then it would be much longer than the Scheme A tunnel line, and for this reason the Scheme A alignment is considered the more favourable. A fault zone is postulated to exist at the Pondo portal of both alignments investigated, and it would almost certainly intersect any re-alignment of the Scheme B tunnel line.

6. From the geophysical evidence available, it is considered that the site of the upstream power station for Scheme B is probably satisfactory.

7. The power station site common to both schemes is probably underlain by at least one mudstone band of unknown thickness. The evidence available indicates that the beds dip away from the river; consequently there is little danger of unstable power station foundations. Drilling would be necessary to verify foundation conditions, including the thickness of any mudstone interbeds.

8. It follows from the conclusions drawn above that the most favourable layout for a hydro-electric scheme would be the Scheme A arrangement using the alternative weir site on the Towanokoko River. The tunnel line and part of the low pressure pipeline may need re-aligning.

WATER CIRCULATION AND LEAKAGE

An important factor in determining the feasibility of a hydro-electric scheme in limestone country is the evaluation of underground water circulation and leakage. Both the Pondo and Towanokoko Rivers flow fairly constantly throughout the year, indicating that there is sufficient percolation of rainwater to keep the water table well above the level of the main river valleys and some of the larger tributaries. The impermeable mudstone interbeds, which occur through the dominantly limestone succession, restrict the groundwater flow and are mainly responsible for the high water table levels. The extensive deposition of travertine on the bedrock of the river courses must also be an important factor in stabilising water flow, as it seals the beds of the rivers and many tributaries.

Although it is expected that the river water is in general in contact with the groundwater, it is likely that fluctuations in flow, owing to irregularities in the water table, occur along the river courses according to whether the rivers are losing water to or gaining it from the formation. Such irregularities of the water table would be due partly to the alternate permeable and impermeable beds traversed by the rivers, and partly to the irregular topography.

The position of the water table relative to river level at the proposed weir sites will determine whether it will be possible to dam the rivers without excessive water loss due to percolation underground. Theoretically it is possible that the water table has only a very gentle gradient towards the river (or even away from the river) at one or more of the proposed weir sites; in such a case, leakage from any reservoir could be excessive. It is therefore important that regular water level observations be made in any subsequent investigation of weir sites.

LANDSLIDES

Many landslides and landslips, of very diverse extent and magnitude, have been noted along the valleys of the Pondo and Towanokoko Rivers, and their tributaries. Some of the more obvious slips are noted on Plates 5 and 6, but there are probably many older landslips which have been obscured by the subsequent growth of vegetation and modification by erosion. Most landslides are associated with mudstone interbeds in the marl and limestone sequence, and failure is invariably due to lubrication by water of the boundaries between mudstone and limestone or marl. The high seismicity of the area, the steep terrain, and the regular rainfall undoubtedly accelerate the development of landslides.

Numerous landslides are also present along the river courses for 1½ miles downstream of the scheme area. Problems resulting from unstable river banks will therefore occur in any proposed second stage development downstream of the present scheme area.

On a much larger scale, the Towanokoko River has been completely blocked in recent years (since 1958) by a gigantic landslide (for location and extent, see Plates 2 and 5 and Fig. 1). The plane of failure was a vertical fault which can be traced along strike for over two miles as a lineament on the air photographs. The near-vertical cliff face behind the landslide is 4,000 feet long and ranges in height between 200 and 400 feet. The landslide debris covers an area of almost a quarter of a square mile, and includes a block of country 1,000 feet long, 200 feet wide and about 150 feet high which broke away from the opposite side of the river valley under the impact of the landslide material. The river now flows between this block and the cliff face from which it broke away. A natural lake, 1,000 feet long and up to 250 feet wide, has formed upstream of the landslide, and the river gravels mapped at the Scheme A weir site are accumulating where the river enters the lake.

The landslide debris is completely chaotic, and no trees were left standing. The area is now covered by a dense undergrowth, generally less than 10 feet high, and unburied trunks of the original trees are not greatly decayed; the landslide must therefore have occurred only a matter of years ago.

Inspection of the air photographs reveals a probable landslide of similar dimensions one mile downstream and on the right bank of the Towanokoko River. The suspected landslide debris is covered by tall trees similar to the surrounding country, but the presence of a high cliff and the change in river course strongly suggest an old, very large landslide.

Construction of the proposed scheme would not be seriously jeopardised by the minor landslides along the river banks, but the necessary slope stabilisation and treatment near engineering structures would add considerably to the overall cost. Further, it would be impossible to prevent a landslide of similar proportions to the recent one in the Towanokoko valley if unstable conditions are present, or to guard against the destructive effect of such a failure. It would be equally impossible to predict, with any degree of certainty, the liklihood or otherwise of a similar landslide developing in the near future without very expensive and continuing studies. For these reasons alone, the Towanokoko-Pondo area is considered unsuitable for the construction of a hydro-electric scheme.

SEISMICITY

The Gazelle peninsula is a very highly seismic area, and the loci for most of the major earthquakes are sufficiently deep for them to affect wide areas. A summary of all recorded seismic data in the area is given in Brooks, 1963. Brooks predicts that, statistically, an earthquake of intensity 9 on the Modified Mercalli scale could be expected once every 25 to 50 years, and an earthquake of intensity 10 once every 100 years. These in themselves are most severe conditions, and in a geologically unstable area it raises doubts whether it is possible to design for a safe and permanent structure.

CONSTRUCTION MATERIALS

The only source of aggregate in the area is the limestone, which is probably not suitable for high-strength concrete. The volcanic rocks which crop out at the Pondo homestead would probably make good aggregate - this would be the nearest source of suitable rock. To the east, suitable aggregate could probably be obtained by crushing basement rocks which crop out in the Toriu valley close to Galavit. Access to the site would be very difficult and costly, however.

No suitable natural sand deposits have been located within an economic radius of the scheme. Suitable sand may be obtainable from the Tongaliekanei River 16 miles north of Pondo, or from the Toriu River 11 miles south - both rivers drain areas that contain rocks other than limestone. Alternatively, if concrete aggregate is obtained by crushing suitable rock, sand could be economically produced by the same method.

POSSIBLE ALTERNATIVE LOCATIONS FOR A HYDRO-ELECTRIC SCHEME

WARANGOI RIVER

A possible scheme located on the lower reaches of the Warangoi River was considered several years ago, along with two other schemes, but it was rejected on the basis of relative cost. It is now evident that the Towanokoko-Pondo scheme would cost far more than the estimate of £1,750,000 made in 1960, even if it were considered a practical proposition. It has therefore been necessary to re-appraise the alternative schemes, and the Warangoi scheme has been selected for a more thorough investigation. It has the advantage of being close to the main consumption area, which would substantially reduce the cost of transmission and access. The proposed damsite and part of the proposed reservoir rim has been geologically mapped, and drilling is in progress.

TORIU RIVER

During the present investigation, several reconnaissance traverses were made along the upper reaches of the Toriu River to determine the suitability of the river for the development of a hydro-electric scheme. Barometric readings along the river showed that the river gradient is quite steep, and geological observations revealed hard, strong, sparsely jointed igneous rocks cropping out in the river valley from Galavit to the Galavit-Maleseit track crossing. The area is therefore well-suited to the development of hydro-electric power, provided there is an adequate steady flow of water in the river. Only sporadic gaugings of river flow have been taken up to the present, and it is considered that regular gaugings over a period of time should be taken so that the hydro-electric potential can be accurately assessed. The presence of good foundation rocks should enable a sufficiently large dam to be constructed that would provide more than diurnal pondage. Construction materials would be readily available, and access from Maleseit should not prove very difficult.

Information obtained during the reconnaissance traverses along the Toriu River forms the subject of a separate Record.

CONCLUSIONS

1. The geological succession in the area of the scheme consists of interbedded limestone, marl and mudstone. The overall dip of the strata is approximately 10° to the south-west; mapping along the river valleys indicates some gentle folding.

2. Two major faults have been located in the area of the scheme, one of which can be traced on air photographs for at least two miles. Several other strong lineaments which could represent other fault zones have been noted on air photographs.

3. The strength of the foundation rocks depends mainly upon the clay content: pure limestone is hard and strong, clayey limestone and marl is moderately strong, and the grey mudstone is soft, weak, and deforms plastically under load.

4. Saturation of mudstone at the interface with overlying limestone results in failure of the mudstone; this is the major cause of the many landslides in the area of the scheme. Therefore mudstone beds in the foundations of proposed structures should be avoided as much as possible.

5. There are numerous landslides along the banks of both river valleys; engineering works must be located away from active or potential landslips.

6. Insufficient information is available to enable the problem of leakage to be evaluated. Although the mudstone and marl bands have restricted the development of karst topography considerably, underground water circulation undoubtedly occurs and could possibly affect the feasibility of the scheme.

7. The geological and geophysical investigation of the components of the alternative layouts has indicated that the most favourable layout is the Scheme A arrangement using the alternative weir site on the Towanokoko River.

8. The storage of the alternative Towanokoko weir site for Scheme A is poor and it may not be possible to construct a weir high enough to provide diurnal pondage; if this is the case, only run-of-river capacity would be available. Diurnal pondage would be provided by a weir 30 feet above river level at either of the originally proposed weir sites on the Towanokoko River, but in both cases construction of such a weir would be very costly owing to the amount of stripping, length of weir, and permeability control needed; further slides may occur into the storage area of the Scheme B weir sites.

9. The seismicity of the area is high and it is expected that earthquakes of intensity 8 to 9 on the Modified Mercalli scale will be experienced from time to time. Brooks (1963) predicts that, statistically, an earthquake of intensity 10 can be expected once every 100 years.

10. Construction materials may be difficult to obtain. Some of the pure limestone may possibly be suitable for use as concrete aggregate, but thorough testing would be necessary. Sand would certainly have to be imported into the area of the scheme.

11. The lower parts of the valley walls of both the Pondo and Towanokoko Rivers consist largely of landslide material for 1½ miles downstream of the proposed scheme and consequently a second stage development in this area would be difficult. The Towanokoko valley particularly is unsuitable for the construction of any permanent structures and there are only two or three locations on the Pondo River which might be suitable for the construction of a weir. Farther downstream, again, the limestone is dominantly massive and pure, and the rivers flow in narrow gorges. Foundations would be better in this area, but the problem of leakage is likely to be more serious than in the area at present under consideration.

12. The large landslide in the Towanokoko valley just downstream from the Scheme A weir site is an indication of the instability of the limestone sequence in the area. This landslide was controlled by a major fault zone and was probably triggered by an earthquake. Air photos indicate several lineaments which may represent major faults and joints along which major landslides could take place. Many other planes of weakness may be present but would be very difficult to locate.

13. The seismic traverses indicate that the overburden is generally thick; soil and scree (seismic velocity of 2,500 ft/sec. or less) ranges in thickness from 20 to 50 feet, while weathered, jointed bedrock (4,000 to 5,000 ft/sec.) ranges in thickness from 20 to 100 feet.

14. Consideration of the factors set out above leads to the conclusion that there would be considerable difficulties in the design and construction of the scheme, and that it would be very costly. Even if it is an economic proposition, there is doubt whether the scheme could be maintained as a permanent public facility, owing to the extreme instability of the area, both geologically and seismically.

RECOMMENDATIONS

1. As the Towanokoko-Pondo Scheme is such a doubtful proposition, regardless of expenditure, further investigation of the scheme cannot be justified, at least until the alternative schemes have been examined more closely. Both the Warangoi and Toriu schemes warrant additional investigation (at the time of writing, detailed mapping of the Warangoi damsite and reservoir has been completed, and a diamond drilling programme is being carried out).

2. The hydro-electric potential of the Toriu scheme should be evaluated before any detailed work is undertaken. Continuous records of rainfall and stream flow will be necessary, and some surveying along the river will be required to determine the head available for any proposed hydro-electric scheme layouts.

ACKNOWLEDGEMENTS

The Commonwealth Department of Works made the necessary arrangements for transport, messing and labour force, and the assistance of all concerned is gratefully acknowledged. Particular thanks are due to Mr. R. Jensen who was responsible for all arrangments at the base camp, in addition to his duties as surveyor. His ready co-operation in allocating both native and European assistantsas and when required, particularly for the traverses down to the coast and in the Toriu area, was greatly appreciated.

Thanks are also due to the manager of Pondo Plantation, Mr. J. Cooper, for his hospitality which was particularly welcome after completing the traverse down the Towanokoko River.

REFERENCES

BEST, E.J., 1962 - Geological investigation of part of the Toriu River, New Britain. Unpublished report, B.M.R. File 65-6678

BROOKS, J.A., 1963 - Earthquake activity and seismic risk in Papua and New Guinea. Bur. Min. Resour. Aust. Record 1963/162 (unpubl.)

CARTER, E.K., 1962 - Geological investigation of the Towanokoko-Pondo hydro-electric scheme, New Britain, T.P.N.G. Bur. Min. Resour. Aust. Record 1962/120 (unpubl.)

COMPAGNIE GENERALE DE GEOPHYSIQUE, 1963 - Geophysical survey, Towanokoko-Pondo hydro-electric scheme, New Britain. Report H 6506 (unpubl.)

FISHER, N.H., 1959 - Geological reconnaissance of the Towanokoko River hydro-electric scheme. Bur. Min. Resour. Aust. Record 1959/120 (unpubl.)

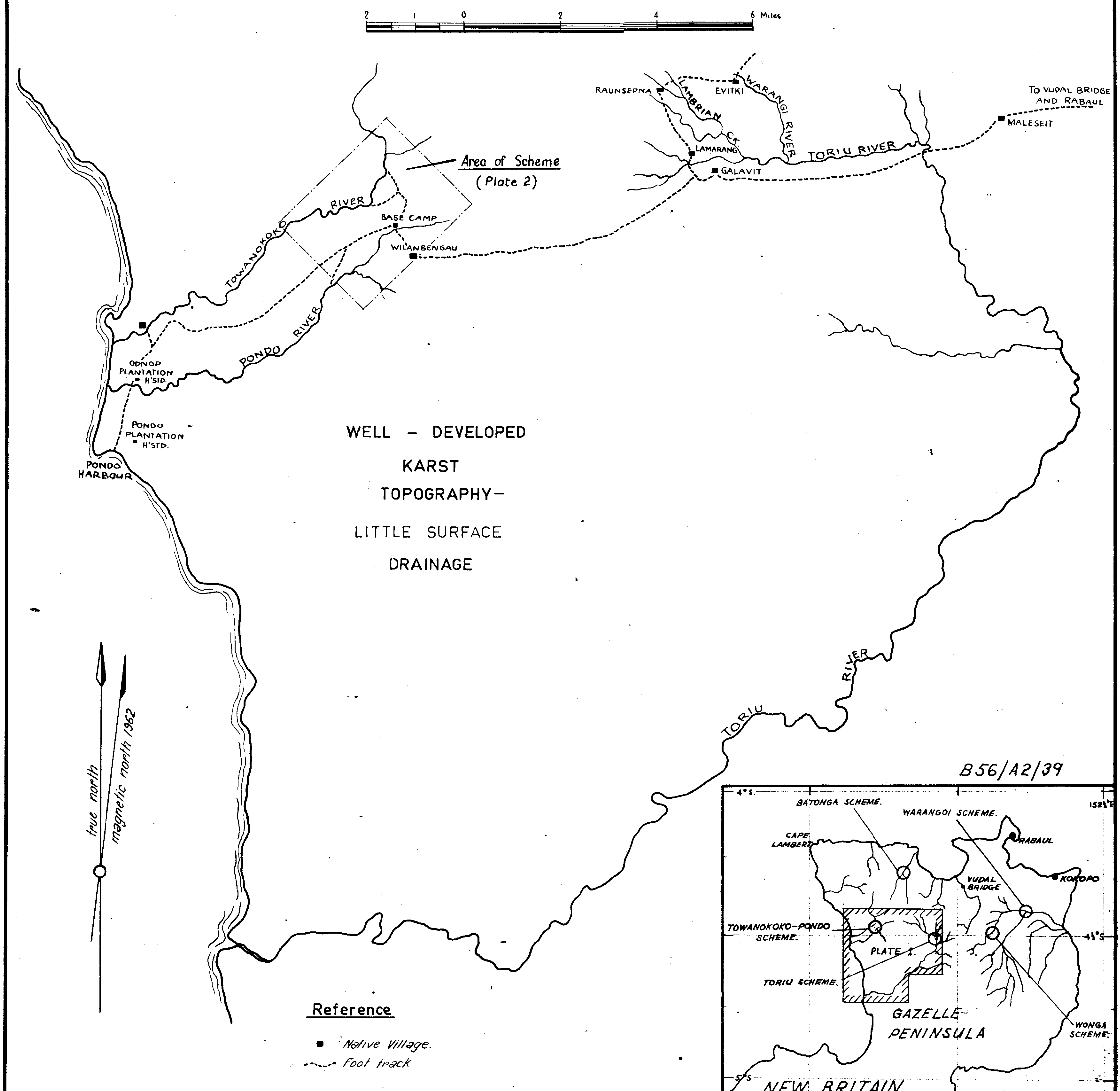
FRASER, J.B., 1964 - Investigation of Towanokoko-Pondo hydro-electric scheme. Unpublished Com. Dep. Works report for Papua and New Guinea Electricity Commission.

LLOYD, A.R., 1963 - Foraminifers and other fossils from the Tertiary of the Gazelle Peninsula. Bur. Min. Resour. Aust. Record 1963/91 (unpubl.)

NOAKES, L.C., 1942 - Geological report on the Island of New Britain. Terr. N. Guin. Geol. Bull. 3.

PLATE I

LOCALITY MAP



Bureau of Mineral Resources, Canberra, May 1963.

To accompany Record 1966/133

TOWANOKOKO — PONDO HYDRO — ELECTRIC SCHEME

SHOWING PROPOSED LAYOUT OF THE SCHEME AND STADIA SURVEY DATA OF THE AREA

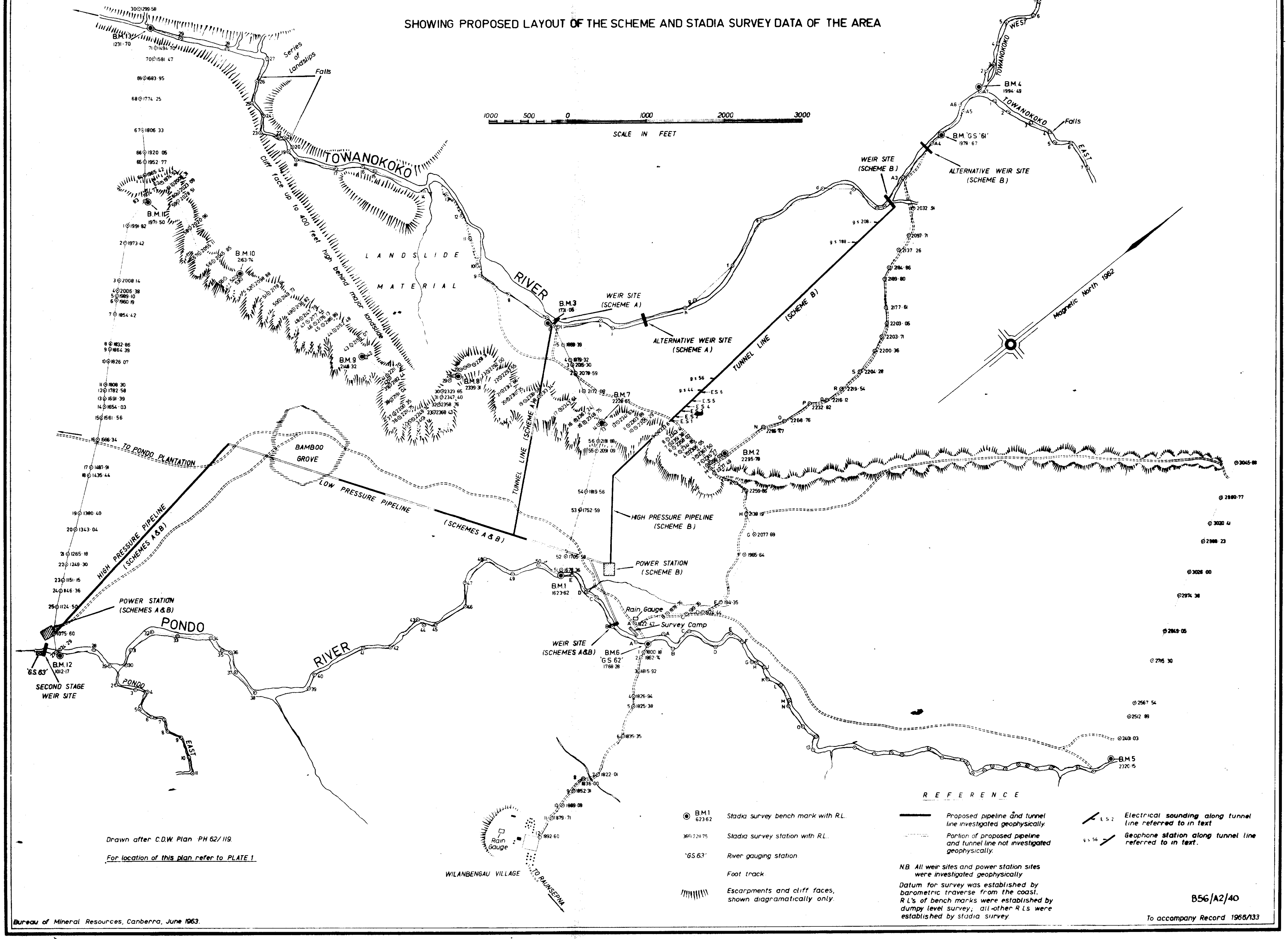


PLATE 3

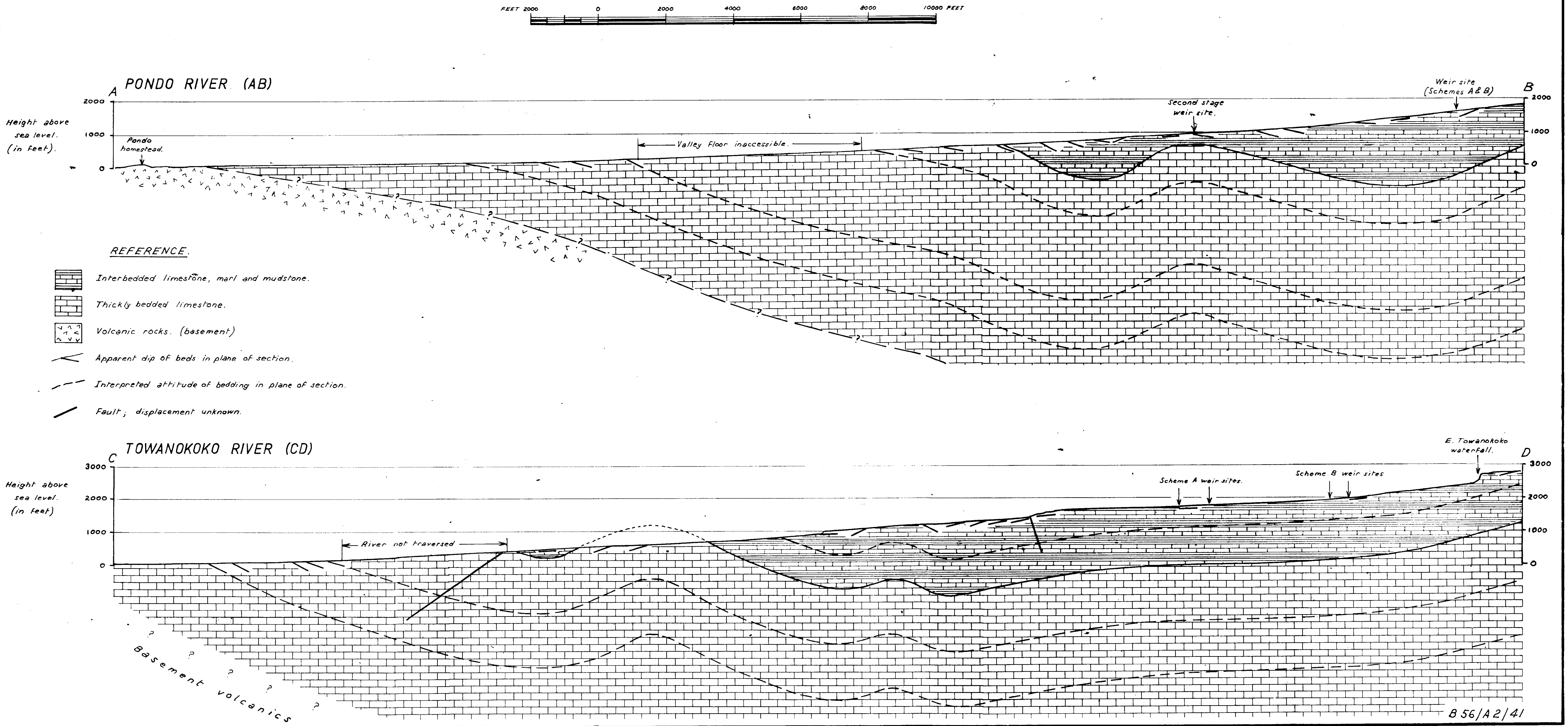
Bureau of Mineral Resources, May 1963.

To accompany Record No. 1966/133

B56/2/15

GEOLOGICAL SECTIONS ALONG PONDO AND TOWANOKOKO RIVERS SHOWING INTERPRETATION OF STRUCTURE

FOR LOCATION SEE PLATE 3



Bureau of Mineral Resources, Geology and Geophysics, January 1966.

To accompany Record 1966/133

PLATE 5

GEOLOGICAL OBSERVATIONS ALONG PONDO RIVER IN AREA OF SCHEME

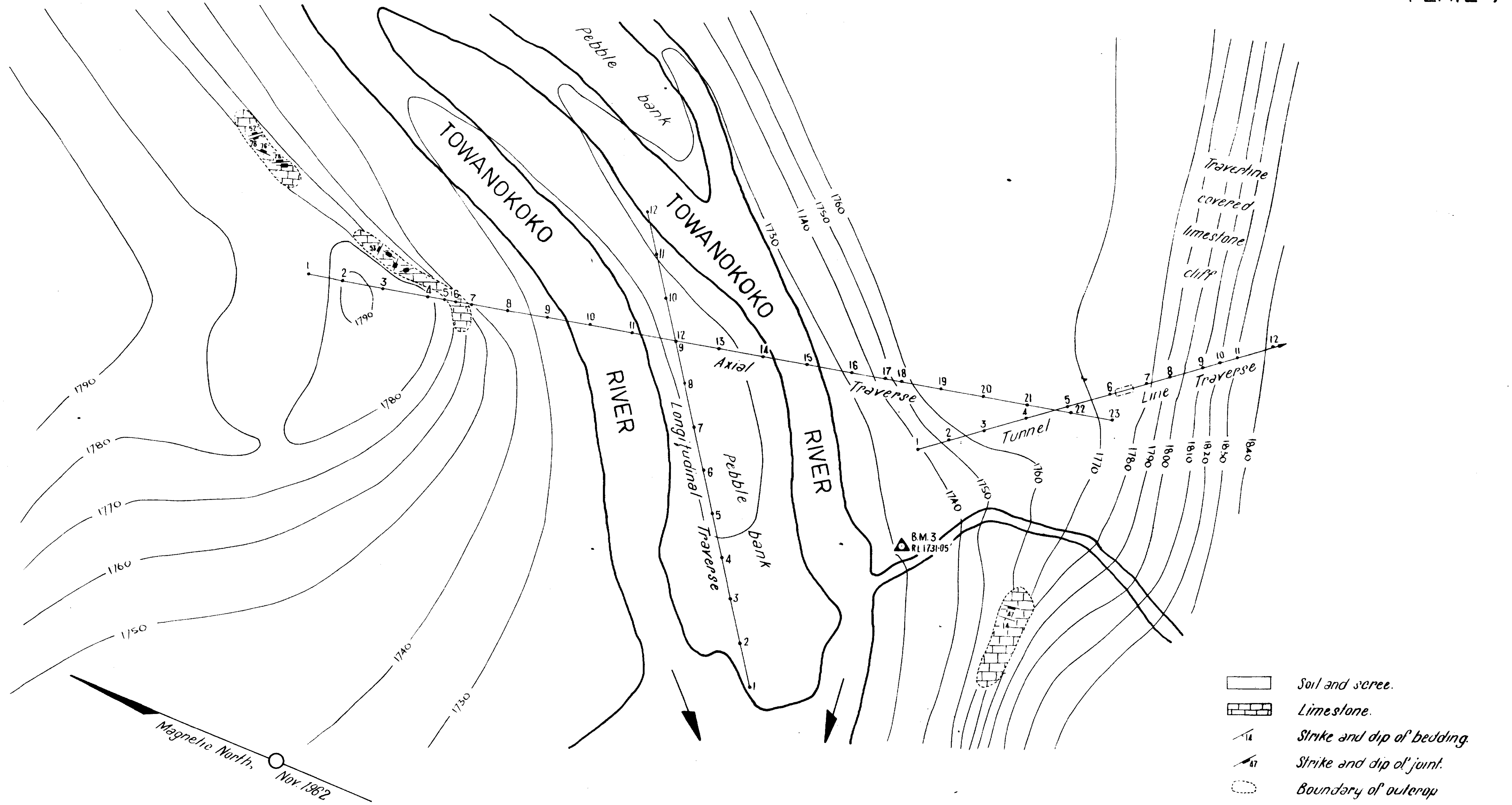
PLATE 6

GEOLOGICAL OBSERVATIONS ALONG TOWANOKOKO RIVER IN AREA OF SCHEME

Bureau of Mineral Resources, Canberra, June 1963

To accompany Record No 1966/133

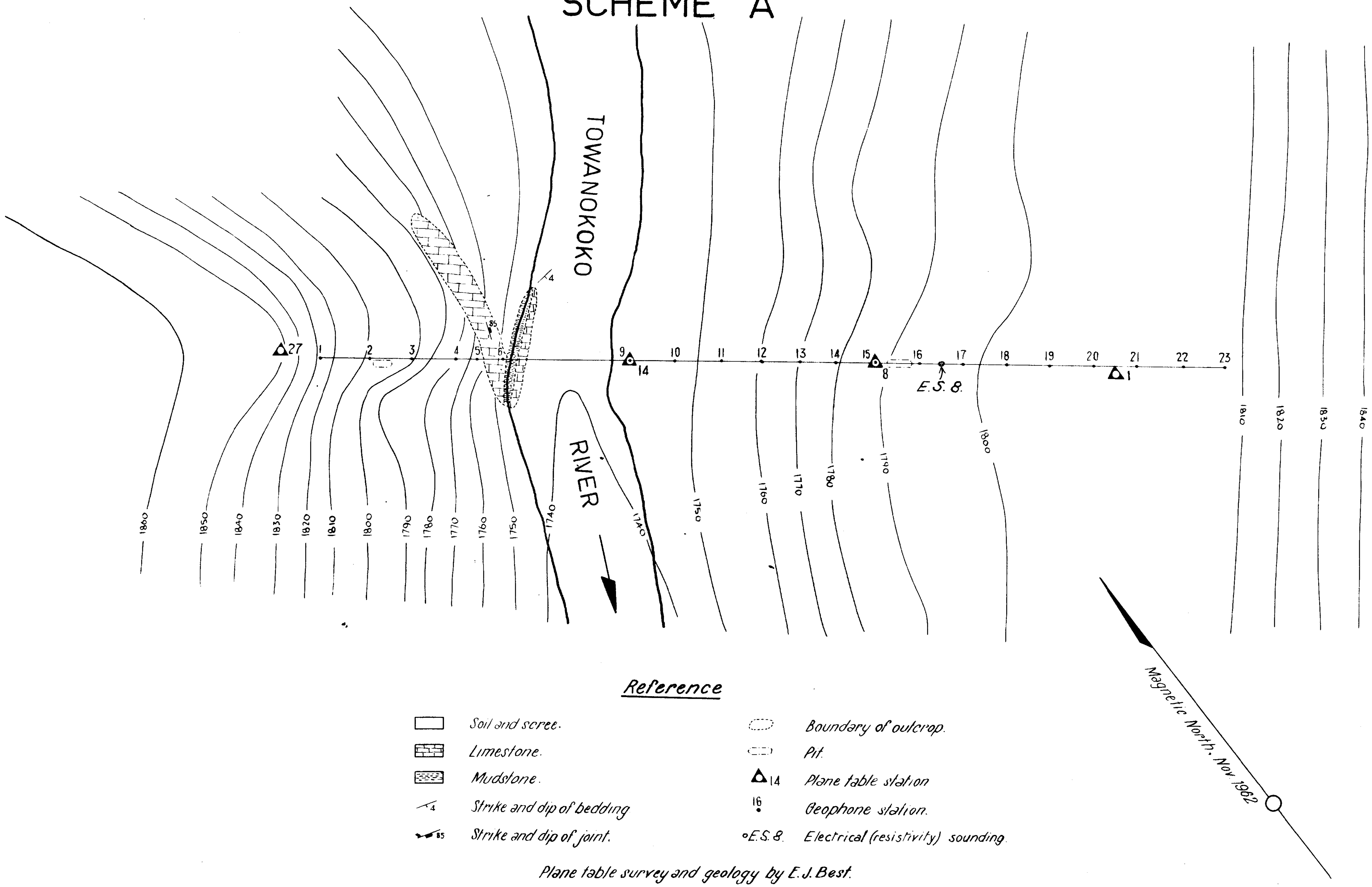
B 56/A2/43



TOWANOKOKO WEIR SITE
SCHEME 'A'

Plane table survey and geology by E.J. Best.
Stadia survey of geophysical traverses by R.Jensen.

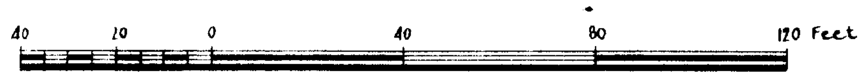
TOWANOKOKO ALTERNATIVE WEIR SITE
SCHEME 'A'



Reference

▭	*Soil and scree.*	⬭	*Boundary of outcrop.*
▦	*Limestone.*	▭	*Pit.*
▤	*Mudstone.*	△14	*Plane table station*
⟋4	*Strike and dip of bedding*	16 •	*Geophone station.*
⟿85	*Strike and dip of joint.*	∘E.S. 8.	*Electrical (resistivity) sounding.*

Plane table survey and geology by E.J. Best.
Stadia survey of geophysical traverse by R. Jensen.



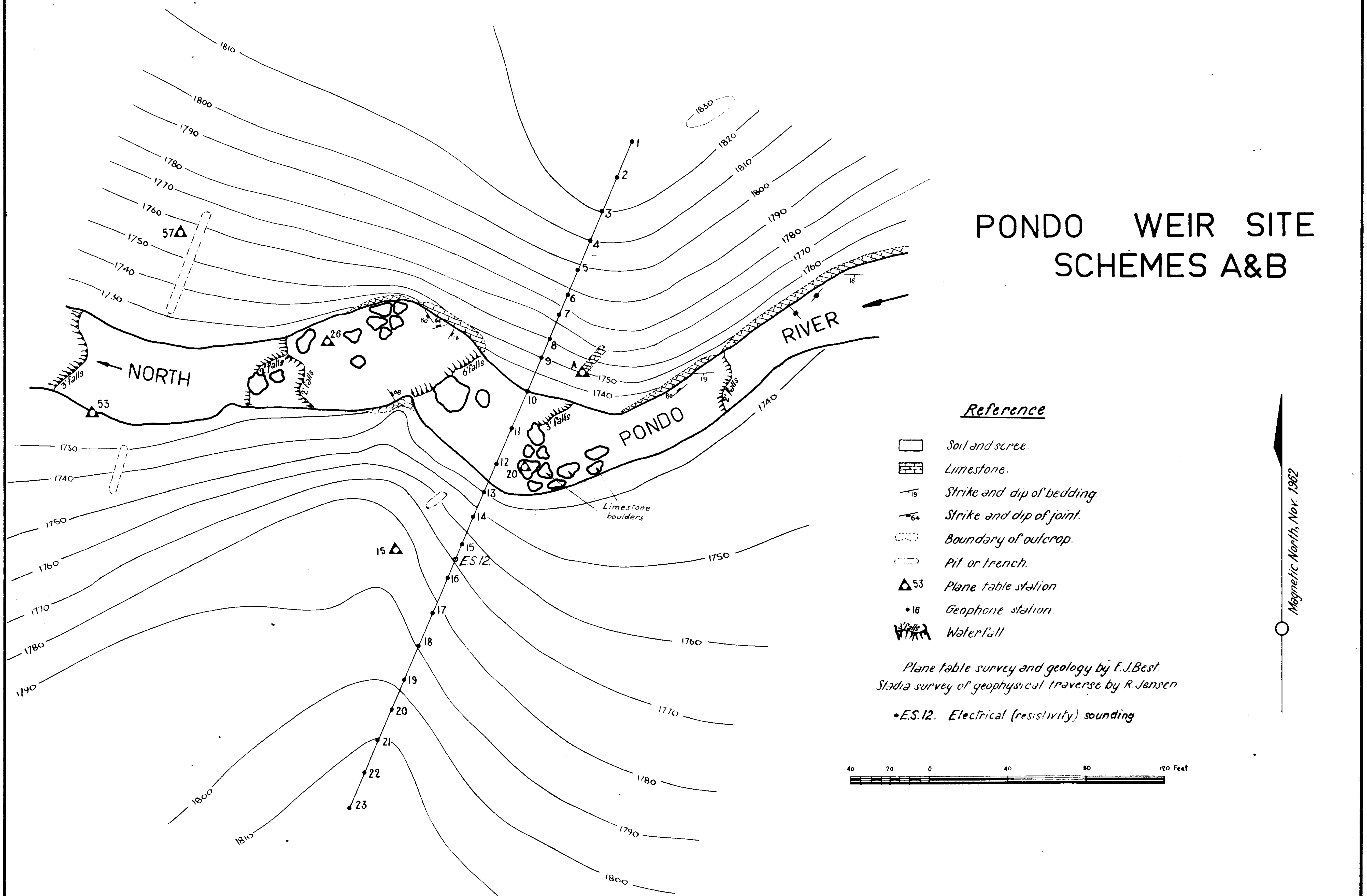
Bureau of Mineral Resources, May 1963.

To accompany Record Nº 1966/133

B 56/A2/45

PAS

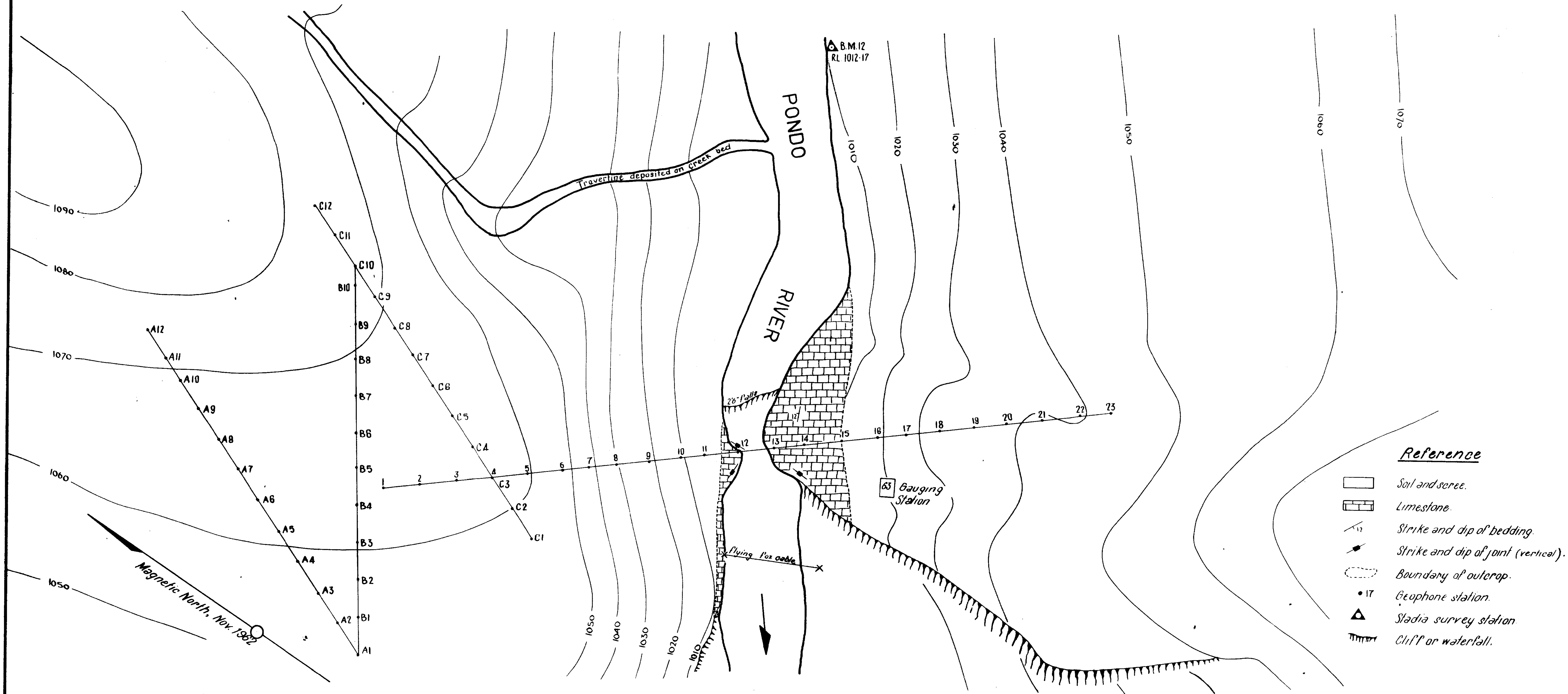
PONDO WEIR SITE SCHEMES A&B



Bureau of Mineral Resources, May 1963.

To accompany Record Nº 1966/133

B 56/A2/46



Plane table survey and geology by E.J. Best.
Stadia survey of geophysical traverses by R. Jensen.

PONDO POWER STATION SITE
SCHEMES A&B AND SECOND STAGE WEIR SITE

Bureau of Mineral Resources, May 1963.

To accompany Record Nº 1963/133

B 56/A2/47

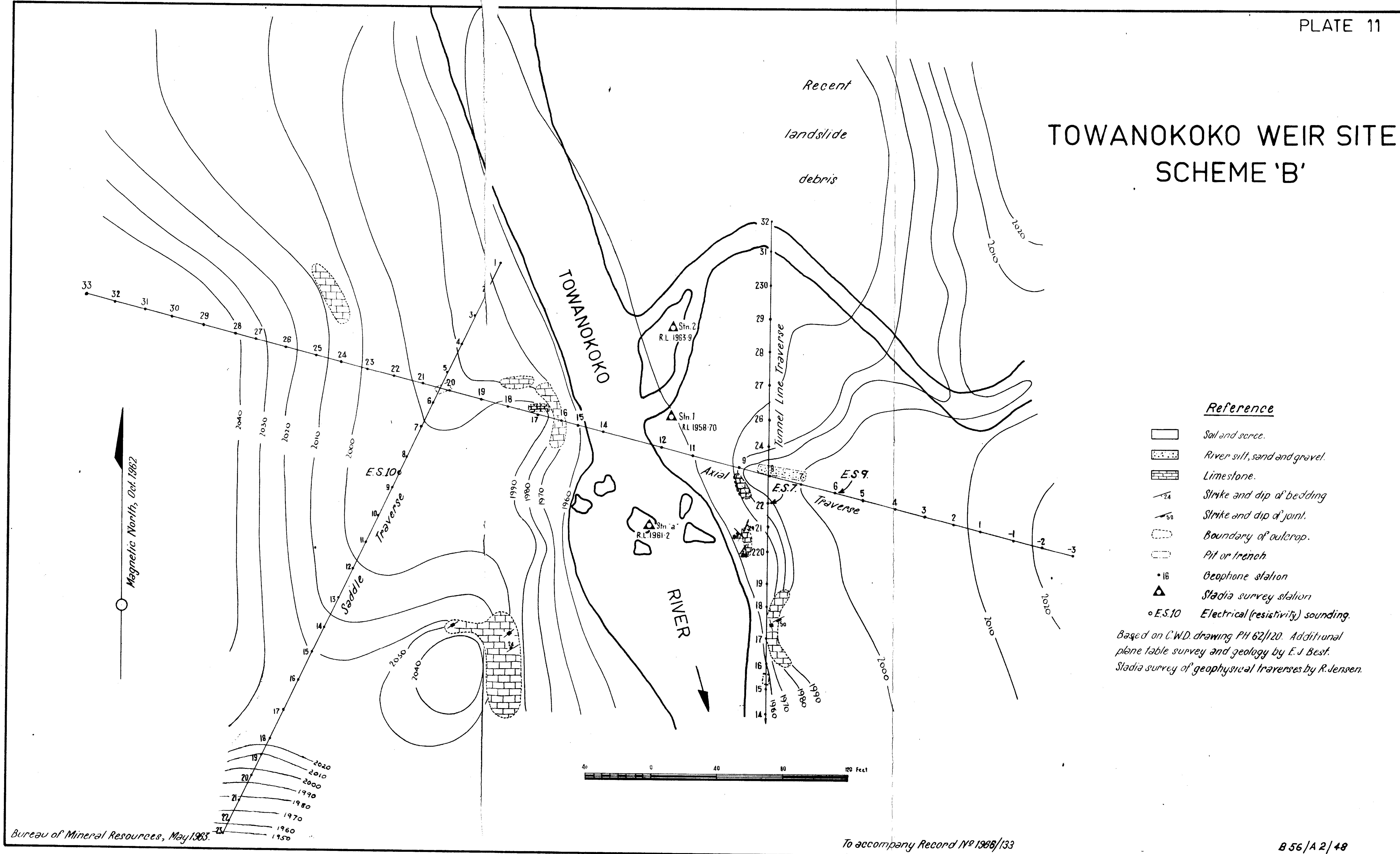
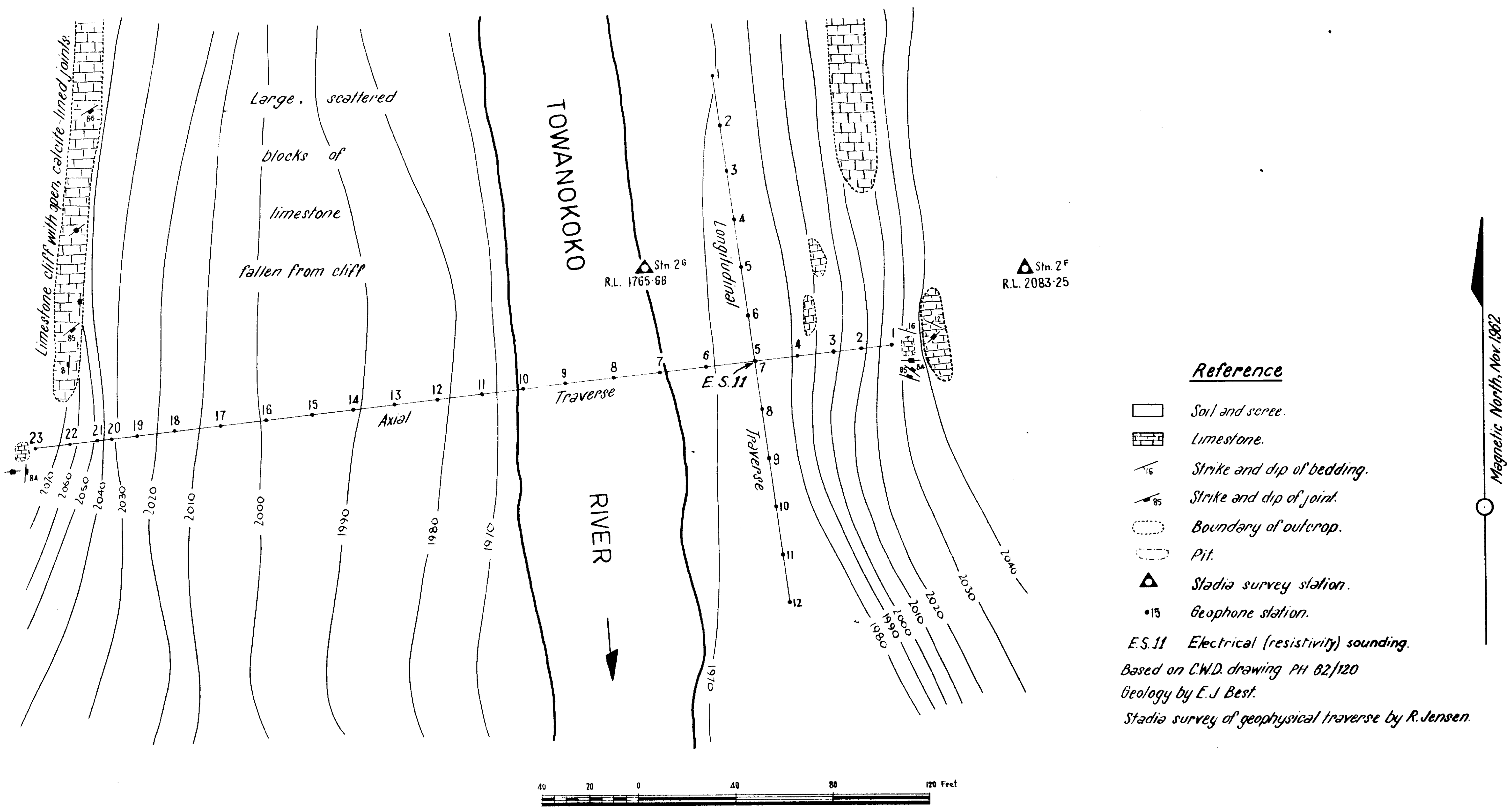


PLATE 11
TOWANOKOKO WEIR SITE
SCHEME 'B'
Recent
landslide
debris
TOWANOKOKO
RIVER
Saddle Traverse
Tunnel Line Traverse
Axial
Traverse
E.S.10
E.S.9.
E.S.7.
Stn. 2 R.L. 1963·9
Stn. 1 R.L. 1958·70
Stn 'a' R.L. 1961·2
Magnetic North, Oct. 1962
Reference
Soil and scree.
River silt, sand and gravel.
Limestone.
Strike and dip of bedding
Strike and dip of joint.
Boundary of outcrop.
Pit or trench.
Geophone station
Stadia survey station
Electrical (resistivity) sounding.
Based on C.W.D. drawing PH 62/120. Additional plane table survey and geology by E.J Best.
Stadia survey of geophysical traverses by R. Jensen.
40 0 40 80 120 Feet
Bureau of Mineral Resources, May 1963.
To accompany Record Nº 1966/133
B 56/A 2/48

TOWANOKOKO ALTERNATIVE WEIR SITE
SCHEME 'B'



Bureau of Mineral Resources, May 1963.

To accompany Record Nº 1966/133