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PRELIMINARY GEOLOGICAL INVESTIGATION OF LOWER WARANGOI RIVER HYDRO-ELECTRIC SCHEME, NEW BRITAIN, T.P.N.G. AUGUST-NOVEMBER, 1964

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SUMMARY

A three-month preliminary geological investigation of a proposed hydro-electric scheme 32 miles south of Rabaul, on the Lower Warangoi River, Gazelle Peninsula, New Britain, was carried out by the Bureau of Mineral Resources from 7th August to 5th November, 1964.

The site for the proposed dam to provide storage and head for a power station is at a narrow constriction of the river through a major ridge. The ridge extends for several miles to the southwest of the damsite and forms a divide between the Warangoi and Sigule River systems. Upstream from the damsite the river flows for about 2 miles across a broad valley situated below the confluence of its two major tributaries, the Kavavas and Upper Warangoi Rivers.

At the damsite the ridge is formed of hard, strong and apparently impermeable basaltic agglomerate, over and around which is draped Upper Miocene coral limestone. The storage basin, and the southern ridge south-west of the agglomerate, consists entirely of flat-lying to gently east-dipping, soft, moderately compacted sediments of Upper Miocene and Pliocene age.

The abutments appear suitable for the construction of a 120 foot high dam; at the present stage of investigation, however, nothing is known about the rocks or structures beneath river level at the damsite.

Gravels and sand which appear to be suitable for use as concrete construction materials are abundant, particularly at the damsite. No systematic search for, or investigation of, earth materials suitable for dam construction was undertaken.

With a 120 foot high dam the storage area would extend for about 8 miles upstream from the damsite. Two possible leakage areas occur around the reservoir area. The most critical is the southern ridge between the Sigule and Warangoi Rivers, which in places is only 500 feet wide at a height of about 100 feet above river level, and which consists in part of soft, porous sediments. Conditions at the north end of the left abutment ridge are unknown and, until proved sound, must be regarded with caution. The agglomerate is thought to be impermeable but will require normal water pressure testing, especially where faulted.

The conclusions and recommendations, particularly those concerned with siltation and seismic risks, submitted by Carter and MacGregor (1964), are re-affirmed. A full programme of investigation is recommended to prive the soundness of the damsite, and the strength and watertightness of the sediments which form the southern dividing ridge.

Specifications of the initial programme of diamond drilling and water pressure testing are given in Appendix I.

INTRODUCTION

In March, 1964, at the request of the Commonwealth Department of Works (C.D.W.), a four-day geological inspection of two possible sites for an hydro-electric scheme on the Lower Warangoi River, Gazelle Peninsula, New Britain, was carried out by E.K. Carter and J.P. MacGregor.

The report on that inspection (Carter and MacGregor, 1964) was submitted for distribution to C.D.W. on 24th September, 1964.

Of the two sites inspected by Carter and MacGregor only one, Damsite A, was found to be suitable for the development of a hydro-electric scheme. Therefore, at the beginning of August, 1964, a preliminary geological survey of that site was commenced by J.R.L. Read (party leader) and D.F. Maggs (geologist), of the Bureau of Mineral Resources (B.M.R.). The survey was carried out, in association with J.P. MacGregor, by Read and Maggs from 7th August to 2nd October and by Read from 2nd October to 5th November, 1964.

This report is a study of the geological conditions affecting the feasibility of the proposed scheme; it contains a description of the geology at the site, together with conclusions and recommendations for further investigations.

A description of the vegetation, climate, hydrology and previous investigations carried out in the Warangoi area are contained in Carter and MacGregor (1964), pages 1-3.

Location

The proposed scheme is 32 miles by road from Rabaul (Fig. 1). The nearest township, Kokope, is 13 miles by road from the damsite, the last 5 miles of which are along privately maintained plantation roads.

The damsite is located about 13 river miles, or about 8 air miles, from the mouth of the Lower Warangoi River, and approximately 2½ river miles downstream of the confluence of the tributary Kavavas and Upper Warangoi Rivers.

Public roads are serviceable at most times but after heavy rain plantation roads and some sections of the Kokope road are suitable for four-wheel drive vehicles only.

Outline of Scheme

The Lower Warangoi hydro-electric scheme has been proposed to fulfil the future electricity requirements for Rabaul, New Britain.

The proposal for a hydro-electric scheme to be located on the Lower Warangoi River follows the decision to discard, for geologic reasons, the previously investigated hydro-electric scheme on the Towanokoke-Pondo River system (Fisher, 1959; Carter 1962 and Best, in prep.).

A 120 foot high dam at the site under investigation will provide the necessary storage and head for a power station on the Lower Warangoi River.

Method of Mapping

Horizontal and vertical control at the damsite were obtained from a damsite survey grid pegged at 50 foot intervals by R. Jensen of C.D.W. Survey Section, Port Moresby.

Mapping of geological detail on the abutments was carried out by plane table and theodolite tachiemetry.

Mapping of outcrop in the area of the southern (right), abutment ridge and divide between the Warangoi and Sigule River systems (the southern ridge), was carried out by tape, compass and abney level traverses. All traverses were tied to a survey line run by the C.D.W. survey party along the crest of the southern ridge; the traverses have subsequently been accurately surveyed by the C.D.W. survey party.

Aerial photographs, of approximate scale 4000 feet to one inch, were used to locate positions on traverses run along the Kavavae and Upper Warangoi Rivers, from approximate top storage level to the damsite.

Topography

River level at the damsite is approximately 100 feet above mean sea level.* The minimum width of the river channel between the abutments is 305 feet. The river at this point is only 2-3 feet deep during periods of low flow but is up to 15 feet deep in places nearby. The river is subject to rapid fluctuations in level after periods of heavy rain in the watershed; it would be inadvisable to attempt a river crossing by wading during the wet season.

The abutments of the proposed damsite are formed by two steeply terminated spurs, the axes of which strike north-east. (See Plate 1, Fig. 1 and Plate 6). The left abutment spur and ridge is flanked by steep gullies, more or less parallel to the crest, and continues for only a short distance northwards, where it leads onto an extensive plateau which stands about 350 feet above river level. This plateau is extensively planted with cocoa and coconut.

The right abutment spur is located at the northern end of the southern ridge. The ridge (Plate 5), extends for about 4 miles to the south-west from the abutment and forms the divide between the Warangoi and Sigule River drainage systems. Very narrow-crested over much of its length, the ridge has been dissected by numerous steeply descending creeks and gullies. Headward erosion in some of these creeks has formed several low saddles across the ridge, the lowest of which stands only 190 feet above the level of the river at the damsite.

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* All elevations in this report are heights above mean sea level.

The Warangoi River valley is about 2 miles wide between the damsite and the confluence of the Kavavas and Upper Warangoi Rivers. Its fall in this section is slight, being only about 25 feet in 2½ river miles.

The Kavavas and Upper Warangoi Rivers are separated by a topographic high which would divide the porposed reservoir into two areas (Plate 5), both of which would extend upstream from their confluence for a distance of about 5 miles; both areas of the reservoir would be confined to the present river channels.

Beyond the head of the proposed storage the river gradients rise rapidly into the steep, deeply dissected terrain of the upper part of the catchment area.

REGIONAL GEOLOGY

The oldest rock found about the damsite are basic, fragmental volcanics (agglomerate), which are probably of Lower Tertiary age. The base of the agglomerate is not exposed at the damsite, but a stream section approximately ½ mile downstream of the left abutment reveals a thickness of about 40 feet of agglomerate conformably underlain by medium-grained, indurated, silty sandstone. The contact between the agglomerate and sandstone is slightly above river level at this point.

The agglomerate near the damsite is overlain by coral limestone of Upper Miocene age (Carter and MacGregor, 1964, Appendix 2). Reworked material abounds at the base of the coral, which is draped around and over the agglomerate, and grown as a coral reef.

The remainder of the stratigraphic sequence is entirely sedimentary, and includes beds of claystone, siltstone, sandstone, and conglomerate. A sample taken from the base of the sedimentary sequence exposed in the southern ridge has been determined to be of Pliocene age. (Appendix 2).

The strata are essentially flat-lying to gently dipping, east and west. As the coral exposed on both sides of the agglomerate that forms the left abutment dips easterly, it is considered that at least local tilting of the sequence took place after formation of the coral.

The sharp deflection of the Warangoi River along the southern ridge (Plate 5), and the passage through the ridge at the damsite are considered to have been caused by geological factors, the main feature of which probably were :

(1) The presence of coral along the upstream face of the ridge. The coral is much more susceptible to erosion by running water than the hard, strong agglomerate, and so provided a line of least resistance to the direction of river flow.

(2) A line of structural weakness across the ridge at the damsite, probably created by faulting, dislocated both the agglomerate and the coral.

The catchment area above the limits of the proposed storage was not inspected. The rocks are inferred, from the abundant pebbles and cobbles of quartzite and igneous rocks in the river course near the damsite, to consist mainly of volcanics, acid and basic intrusive rocks, and metasediments. They probably belong to the Baining 'Series', and to a volcanic sequence probably of Lower Tertiary age (Noakes, 1942). The Baining 'Series' is believed, from evidence elsewhere, to unconformably underlie the Upper Tertiary sediments. The relationship between the volcanics of the catchment area and the agglomerate at the damsite is unknown.

The Blanch Bay volcanic complex occurs about 14 miles north of the damsite. Tuffaceous material ejected during the 1937 eruptions is preserved in several localities near the proposed damsite.

DAMSITE GEOLOGY

Left Abutment

Plates 1, 2 and 3 are photographs of the damsite and of the left abutment. Plate 6 is a geological map of the damsite. An interpretative cross-section through the damsite along a possible axis of the proposed dam is included on Plate 6.

Rock exposed in the left abutment is of two types; volcanic agglomerate and coral limestone.

The agglomerate consists of coarse, angular to subrounded fragments of basaltic rock (Carter and MacGregor, 1964, Appendix 1), set in a hard, fine-grained, tuffaceous matrix. Numerous dykes and irregular bodies of basalt intrude the agglomerate and one 10 foot thick basalt flow is located slightly above river level on the upstream face of the abutment. Small interbeds of hard, tuffaceous sandstone also occur within the agglomerate.

The base of the agglomerate cannot be observed at the damsite and nothing is known of the rock types or structures beneath either the left or right abutments, or beneath the river channel. A tuffaceous sandstone interbed which dips 30°east at river level on the upstream face of the abutment may mark the base of the sequence, but this can only be verified by subsurface investigation.

The agglomerate forms a very massive sequence of hard, strong rock. Outcrop is superficially weathered only; weathered rock normally disintegrates to form a course rubble scree. On steep slopes, where fractures have been induced by root-wedging or the opening of joints, the agglomerate tends to spoil off the outcrop in large slab-like blocks. Soil forms a very thin veneer over the surface and is readily washed away by heavy rains. The maximum soil depth is perhaps no more than 5 feet on the moderate slopes across the crest of the abutment ridge.

The altitude of the agglomerate can only be measured at the few interbeds of tuffaceous sandstone, which all dip from 10° to 40° to the east and south-east. No regularly oriented joint system is apparent; most joints are closed.

Coral is draped over the agglomerate along the crest of the abutment ridge and also crops out on the downstream side of the abutment spur. The contact between agglomerate and coral is exposed between grid references * G+1/374NE and H+20/346NE, along the base of the 60 feet high.

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* The damsite survey grid base line is indicated by survey pegs A00 to W00. Grid references are given in terms of (1) distance along base line in part, i.e. I+20 or M+35 and (2) distance in feet north-east or south-west from the base line; i.e. I+20/300NE or M+35/300SW.

almost vertical cliff of coral occurring on the upstream face of the abutment spur; it was also located in two trenches excavated at R.L. 290 feet (grid reference K+16/308NEO) and R.L. 215 feet (grid reference N+30/309NE) on the downstream face of the spur.

The coral is a hard, pale buff limestone containing very many small (½-2 inches), open cavities. In fresh coral the cavities are generally infilled by calcareous debris.

The coral has a distinct bedding which dips from 5° to 35° to the east and south-east. Numerous irregularly spaced, open joints and fractures occur at the surface, but it is not known to what extent these persist at depth.

Three known faults intersect the abutment. Two of the faults, F_1 and F_2, occur on the upstream side of the abutment and the third, F_3, is located on the downstream side (Plate 6).

Faults F_1 and F_2 are normal faults. Both offset the same sequence of tuffaceous sandstone interbed, basalt flow and agglomerate (Plate 3). Fault F_1, with a displacement of 20 feet, strikes at 056° magnetic and dips about 85° NW : fault F_2 has a displacement of at least 6 feet, strikes at 100°M and dips 70°N.

The scouring action of the river when in flood has created a small cave in the abutment along the plane of fault F_2. (Plate 3). This cave extends 12 feet into the abutment, is 3 feet wide, and has a maximum roof height of 12 feet. Fault zone material exposed in the cave consists of shattered, angular fragments of agglomerate, set in clay. The exposed hanging wall of the fault, in the cave, which consists of agglomerate, is quite hard and has not collapsed at any point.

Fault F_3 strikes 065° magnetic across the downstream of the abutment and probably extends across the river to form the steep north face of the right abutment. The fault is considered to be a normal fault upthrown to the south-east; coral which conformably overlies agglomerate on the western side of the fault does not occur on the elevated eastern block, which consists entirely of agglomerate.

Right Abutment

Plate 4, Figs. 1, 2 and 3, are photographs of the right abutment.

With the exception of outcrops of coral which conformably overlie agglomerate on the downstream side of the abutment (Plate 4, Fig. 1), rock exposed in the right abutment is entirely agglomerate. No interbeds of tuffaceous sandstone were observed; the agglomerate is otherwise identical with that in the left abutment. The exposures are particularly massive and the only indication of bedding was obtained from the outcrops of coral, which dip 35° to the south-east.

Soil cover is very shallow and is thickest across the crest of the abutment ridge.

Scree deposits of agglomerate occur at the base of the north face of the abutment; most of the detritus has been supplied by the spalling of large blocks of agglomerate from the face, which is very steep and clean-cuts. (Plate 4, Figs. 2 and 3).

It is thought that the steep north face may be the exposed footwall of fault F_3 but further investigation will be required to prove this possibility.

The depth of gravels in the river channel between the abutments is not known but is considered unlikely to be much less than 20 feet.

GEOLOGY OF THE STORAGE AREA

Southern Ridge

Plate 7 is a geological outcrop map of the damsite and southern ridge, and shows the location of all traverses made by both geological and C.D.W. survey parties.

Plate 8 includes interpretative cross-sections through the ridge and Plate 9 is a longitudinal profile section along the ridge.

Volcanic agglomerate forms the main body of the southern ridge over a total crest length of about 2600 feet. (Plate 7; Plate 9). Only slightly weathered, strong, hard agglomerate is exposed continuously along the upstream (west) face of the ridge between the right abutment and survey peg C.D.W. ∩ 64

Coral limestone is exposed on the downstream (east) face of the ridge to about 1900 feet south of the right abutment (Plate 7). It may be continuous under the soil and scree with exposures of coral along traverses T and T1, on the west side of the ridge (Plate 7).

The coral both on the east side of the ridge and along traverses T and T1 is overlain by moderately indurated silty clay and fine-grained silty sandstone, and is underlain by moderately indurated silty claystone and siltstone. (Plate 8, cross-sections CD and EF). Thin interbeds of conglomerate and medium-grained uncemented sand occur within the silty claystone and siltstone. These beds continue laterally at the same stratigraphic level throughout the remainder of the ridge.

The coral and agglomerate are replaced laterally by beds of soft, moderately indurated, blue-grey siltstone, with interbeds of claystone, uncemented, medium-grained sandstone and conglomerate. (Plate 7; Plate 8, cross sections GH, IJ, KL and MN; Plate 9).

Three sets of beds have been used as marker beds in the sedimentary sequence of the ridge. These are :

(1) Shell bed; a grey, medium to fine-grained, moderately indurated silty sandstone which contains an abundant Pliocene fauna (Appendix 2). Although nowhere more than about 10 feet thick this bed was located in most traverses between survey pegs C.D.W. ∩ 20 (Traverse T_7) and C.D.W. △ 51 (Traverse T_{22}).

(2) Sand beds; yellow-brown, medium-grained, uncemented sands. Although moderately well compacted in situ, where it sometimes forms near-vertical cliffs up to 15 feet high, the sand is very soft and lacks cohesion; in hand specimen it readily crumbles to loose sand. The sand has an open, porous texture, and is expected to be highly permeable.

(3) Conglomerate beds; the conglomerate consists of well-rounded pebbles of sedimentary and igneous composition set in a sandy matrix. The maximum length of the long axis of the pebbles is about 4 inches, the average about one inch. The sandy matrix is poorly cemented and has the same texture as the uncemented sand beds described above. Unlike the sand beds the matrix contains large amounts of clay; consequently the conglomerate has a lower permeability than the sand.

Two sets of sand and conglomerate beds occur above the shell bed throughout the sequence, and one set between survey pegs C.D.W. △ 27 and C.D.W. △ 51 is exposed below (Plate 9). The sand beds normally overlie the conglomerate beds, but in several places the two merge to form a single unit. Small lenses of sand also occur in numerous siltstones and fine-grained sandstones which form the remainder of the sediments in the southern ridge.

The sediments and the coral in the southern ridge are essentially flat-lying or gently east-dipping. Local variations have been noted. Foreset bedding can be observed in the fine-grained sediments, and cross-bedding, microbedding and graded bedding occur in the sand beds.

The sediments are predominantly massive and poorly jointed. Well-developed joints are largely confined to the silty claystone; they are tight.

Two faults were mapped in the agglomerate of the ridge. Both strike east across the ridge and have vertical fault planes. One is exposed on the west side of the ridge below survey peg C.D.W. △ 13 (Plate 7). A small waterfall has formed at the exposure, where two separate basaltic lava flows have been offset by at least 4 feet. The fault plane exhibits a 3 feet wide zone of shattered agglomerate, and some clay. The extent of the fault through the ridge is unknown.

The second fault has created a vertical-sided, 10 feet wide, open slot which extends into the ridge along traverse F_x (Plate 7) for about 65 feet. The vertical walls of the slot are up to 70 feet high and are formed by hard, sound agglomerate.

A third fault is located in the sediments of the ridge along traverse T_9 (Plate 7). It is only a minor fault; it strikes east, has a vertical face and shows a maximum displacement of 2 feet.

Reservoir

Reconnaissance traverses were made along the Kavavas and Upper Warangoi Rivers, where there are several exposures in the predominantly steeply-cliffed side of the river channels. No investigation was made of the very many rapidly ascending and deeply incised tributary streams of the two rivers.

All exposures examined revealed an entirely sedimentary sequence of flat-lying, soft and moderately indurated, silty claystone, siltstone, fine-grained sandstone and rare conglomerate. Minor occurrences of pumice were noted, not as part of the sequence, but as a surface covering over the sediments. Extensive gravel banks and cliffs of gravel up to 100 feet thick were also found in, or bounding, the Kavavas river bed.

No major faults were identified, either from the ground survey or from a study of aerial photographs.

ENGINEERING GEOLOGY

No investigation of a power station site was carried out. It would probably be best if the power station were constucted on agglomerate, if possible, to reduce seismic hazard to the station.

Damsite

The base of the limestone on the left abutment of the damsite stands 200 feet above river level at the most likely location of the axis of the proposed dam. Thus, as no limestone occurs on the right abutment, a dam with a crest height of 120 feet would have its abutments founded entirely in volcanic agglomerate.

The agglomerate appears to be a sound, hard rock. Weathering at the surface of the exposures is superficial only, and very little stripping should be required to uncover fresh rock.

Excessive leakage through the abutments is unlikely. The agglomerate has a hard, fine-grained matrix, which does not appear to be permeable. Open joints, which would facilitate leakage, occur only in the basaltic dyke rocks which appear to be isolated bodies within the agglomerate, and not to be interconnected through the ridge. However the abutment ridges are very narrow and should further investigation prove the agglomerate to be permeable considerable leakage through the abutments may be expected.

Other possible leakage paths which require investigation are :

(1) Fault zone F_2 in the left abutment and fault F_3 in the right abutment.

(2) Beneath the damsite. The rocks beneath the abutments and the river channel are not known. It is possible that a permeable sedimentary stratum may occur underneath the agglomerate. Such a layer, together with any possible faults which may occur beneath the river channel, could create a zone of leakage underneath the damsite.

(3) North of the left abutment. The extent and relationship of coral limestone and agglomerate in this direction is unknown. Any continuation through the ridge of the coral which crops out below top storage level in the gullies upstream of the left abutment could, if the coral is permeable, result in leakage.

The volcanic agglomerate forms a particularly cohesive mass which is expected to show a high strength throughout. Possible areas of structural weakness are :

(1) Fault F_2. This fault strikes east from the upstream face of the left abutment in the direction normal to the axis of the proposed dam. An investigation of the effect of the fault on the overall strength and behaviour of the abutment during an earthquake should be carried out, particularly if the construction of a thin arch structure is considered.

(2) Fault F_3. This fault is located sufficiently far downstream to have little, if any, effect on the strength of the left abutment. However if the steep north face of the right abutment is formed by the foot-wall of the fault, it will be necessary during construction to ensure that the abutment, and that part of the foundation situated over the fault, is located in sound rock.

(3) Any weak sedimentary stratum that may be present beneath the agglomerate or of fault zones in the rock underneath the river channel.

It is not known whether the cleft in the left abutment between grid lines H/100-200NE and I/100-200NE, where rock is not exposed, is structurally controlled. The cleft could be exposed for further examination by exposing by sluicing. Drillhole WD2, if drilled, may also give some information.

Storage Area

The southern ridge, which runs south-west from the right abutment to form the divide between the Warangoi and Sigule River systems is regarded as one of the most critical features affecting the feasibility of the scheme.

For most of its length the ridge, although narrow, stands at least 250 feet above river level at the damsite, and at no place would be overtopped by a reservoir with a top storage level of R.L. 220 feet (i.e. 120 feet above river level at the damsite). However, the ridge has some low saddles, the lowest of which (between survey pegs C.D.W. △ 8 and C.D.W. △ 9), has an R.L. of 291 feet, which allows for only 70 feet of clearance from top storage level.

The saddles, created by headward erosion of the creeks incised into the slopes of the ridge, are not only topographically low but are also steep-sided and narrow-crested.

The narrowness of the ridge at such locations, together with the likely high permeability of the uncemented sand beds exposed in the ridge, may combine to form a serious problem of leakage from the reservoir, through the ridge into the Sigule watershed.

The uncemented sand beds are very porous and are expected to be extremely permeable. The sand bed below the marker shell bed (see p. 7) is continuously exposed along the base of the ridge between survey pegs C.D.W. △ 51 and C.D.W. △ 27 (Plate 9), at an elevation ranging from 200 to 220 feet. It probably also extends, though not exposed, along the ridge at least as far west as survey peg C.D.W. △ 8. Two narrow saddles occur in this section of the ridge. One, as already described, occurs between survey pegs C.D.W. △ 8 and C.D.W. △ 9 and the other is located between survey pegs C.D.W. △ 41 and C.D.W. △ 48. The minimum leakage path through the ridge, at R.L. 220 feet, is only 500 feet (Plate 8, cross section K.L.).

The sand beds above top storage level (i.e. above the marker shell bed, Plate 9), would not cause problems of leakage, and in fact may provide a natural system of drainage from within the ridge. The remaining sediments - claystone, siltstone, fine-grained sandstone and conglomerate - contain considerable amounts of clay, and are probably not highly permeable. Extensive field testing and laboratory testing of all the sediments in the ridge will be required to evaluate thoroughly the risk of unacceptable leakage through the ridge.

In addition to permeability testing a detailed programme of investigation of the strength and stability of the ridge will be needed. The sand and conglomerate beds, although apparently possessing reasonable confined strength in situ, have little shear strength. The lack of cement between the grains in some of the beds renders these sediments particularly susceptible to failure if any pore pressure develops. Nearly all the sections of sand and conglomerate form vertical exposures which are readily undercut by waterfall and stream action. The claystone, siltstone and fine-grained sandstone, although moderately strong, are very soft; they are easily dissected by flowing water and a sample will readily disintegrate when worked in the hand under water.

Any failure of the sediments after the reservoir has been filled could disrupt the reservoir. Slope failure, induced, for example, by erosive wave action, would not only reduce the length of the leakage path through the ridge but once started could, by a process of continuing slope collapse and erosion, lead to the eventual overtopping of the storage into the Sigule drainage system. The desirability of providing adequate slope protection either by use of rip-rap or other suitable means should form an integral part of the investigation.

Few problems are expected in that section of the ridge composed of agglomerate (Plates 7 and 9). The agglomerate appears to be both hard and strong and is apparently permeable. However, potential leakage paths which will require investigation are :

(1) The two known faults in the agglomerate located along traverse F and beneath survey peg C.D.W. △ 13 (Plate 7).

(2) The possible subsurface continuation of the coral that is exposed on the east face of the ridge to connect with the coral exposed along traverses T and T_1 (Plate 7). If these exposures are connected leakage along solution joints could occur.

Leakage from the remainder of the storage is considered unlikely (but see "Damsite Geology"). The major problem which may be encountered is the failure of the soft sediments in the steep slopes, both in the reservoir and the catchment area, which could produce excessive siltation of the storage.

Siltation

The Warangoi River and the tributary Kavavas and Upper Warangoi Rivers have a heavy bed load and suspended sediment lead at times of high flow. A rapid increase in the lead was observed even after periods of only moderate rainfall in the catchment area, and it is considered that a high rate of siltation can be expected during the wet season. Any large-scale slope failure would appreciably increase the expected high rate of siltation.

Therefore, attention is again drawn to the recommendation of Carter and MacGregor (1964 p. 10) for the immediate implementation of a regular stream-sediment sampling programme so that an evaluation of the normal siltation hazard for the reservoir can be carried out.

As a greater hazard of siltation arises from the likely high incidence of earthquakes in the storage area (Carter and MacGregor, 1964 p. 10), it is also again stressed that, in the event of a substantial earthquake shock causing disruption of the land surface in the area, sampling should be augmented promptly to record the added silt load. Any other measures, such as aerial photography of the catchment area, that would aid in the evaluation of earthquake-induced siltation should also be taken promptly.

The results of stream sediment sampling, even for a short period, and any sampling following earthquakes, would provide some rough guide to the probable effectual life of the storage. The reservoir would need to be sufficiently large to accommodate, over its working life, estimated normal siltation plus a generous contingency for additional sedimentation arising from seismic activity.

Construction Materials

As reported by Carter and MacGregor (1964 p. 8), there is an ample supply of material, apparently suitable for use as concrete aggregate, in the extensive gravel banks above and below the damsite. The apparent lack of sand as compared to gravel reported by Carter and MacGregor was found to be over-estimated. Test pits and auger holes sunk in the gravel bank immediately above the damsite (Plate 7) revealed that extensive quantities of fine material occur between the larger pebbles beneath the surface. Areas consisting almost entirely of sand can be observed in many of the gravel banks. Also inspection of an aggregate screening plant located in the river bed near the recently constructed Upper Warangoi River bridge showed abundant sand in the screened material.

Apart from the river gravels and the volcanic agglomerate in the abutments and southern ridge, extensive deposits of material suitable for use as rock-fill were not observed near the damsite or in the storage area. Sufficient quantities of earth materials suitable for dam construction were not seen near the damsite or in the storage area. No systematic search for, or investigation of, these materials was undertaken.

Access Roads

More adequate access than that already available, both at the damsite and along the southern ridge, will be required before further investigation, particularly drilling, is commenced. At present a formed vehicle track exists through the plantations north of the damsite only as far as the left abutment ridge. Regrading and extension of this track along the ridge would provide excellent access to the top of the left abutment.

Access to the river bed between the abutments will have to be made either by:

(1) extending the track to the left abutment down the gully on the downstream side of the abutment, or by

(2) regrading and improving an existing pathway which branches from the track to the left abutment and leads through the plantation to the river bed about ½ mile below the damsite. At present this pathway is suitable for 4-wheel drive vehicles in dry weather only, but could very easily be formed into an all weather track.

Some form of roadway will be required along the crest of the southern ridge. Access to the ridge will be difficult. At present, the most suitable route appears to be along the survey line from peg C.D.W. Ω 74 to C.D.W. Ω 48.

As safe fording of the river is possible only at times of low flow, a secure means of transport across the river will also be required.

SEISMICITY

The proposed hydro-electric scheme is located in one of the most seismically active regions of New Guinea (Brooks 1963; Plates 5, 6, 7 and 8).

The relevant details of the intensity and frequency of earthquakes which can be expected in the area have been outlined by Carter and MacGregor (1964, p. 9) and by Brooks (1963).

Between 9th August and 4th November 1964, 14 earthquakes were recorded at the Vulcanological Observatory in Rabaul. Of these, only four were felt by the field party at the damsite.

They were :

Date	Time (local)	Epicentre (Lat. & Long)	Intensity (Modified Mercalli)	Magnitude (Richter)
24.9.64	1915	?	VI	?
25.9.64	0915	5.5°S/151.5°E	IV	5.0
27.9.64	0855	4.9°S/153.5°E	III	5.5
19.10.64	2029	?	III	?

Since then two strong earthquakes, neither of which caused any damage, have been recorded by the C.D.W. survey party at the damsite. In both cases the shock was prolonged (60 seconds and 45 seconds), and was estimated to have an intensity of VI on the modified Mercalli scale.

As well as allowing for high accelerations in the design of the hydro-electric scheme, it will be necessary to give full consideration to the effects of regular, moderate to high seismic activity in the storage area. Any tendence to unstability of the steep slopes, especially during the wet season, may be exaggerated not only by the direct impact of vibration on the sediments but also by the erosive action of earthquake-induced waves in the reservoir.

The serious consequences of any failure of the sediments which form the southern ridge has previously been discussed (p. 11). It has already been recommended (Carter and MacGregor p. 9) that instruments to measure the ground response to earthquakes of the coral, agglomerate and other rocks be installed at the damsite; it is further recommended that the installation of these instruments be extended to include the sediments that form the southern ridge.

CONCLUSIONS

It is concluded that :

(1) Subject to the limitations contained in the report (see particularly (5) and (7) below), the damsite and storage area appear to be suitable for development of the proposed hydro-electric scheme.

(2) The abutments of a 120 feet high dam would be located entirely in one formation, volcanic agglomerate, which appears to be both hard and strong; and should provide good foundation conditions. Although the agglomerate appears impermeable, diamond drilling and water pressure testing will be required to determine the permeability of the formation.

(3) Rock types and structures beneath the abutments and the river channel are not known. It is possible that a weak, permeable, sedimentary stratum may occur beneath the agglomerate. It is also possible that faulted rock occurs between the abutments beneath the river channel. Diamond drilling, water pressure testing and geophysical surveys will be necessary to prove the soundness of the damsite below river level.

(4) Neither the subsurface extent nor the permeability of the coral limestone around the ends of the agglomerate north of the damsite, in the left abutment ridge, and in the southern ridge are known. Geophysical surveys, probably with subsequent drilling and water pressure testing, will be required to locate these boundaries and enable an evaluation to be made of the likelihood of leakage through the coral.

(5) A potential leakage path from the reservoir through the southern ridge into the Sigule drainage system is in places only 500 feet long and 100 feet above river level. In addition, the sediments are very soft and only moderately compacted. It will be necessary to prove very thoroughly the strength and watertightness of the sediments that form the southern ridge, and also the watertightness of the two known faults which occur in the agglomerate of the ridge. Should the sandstone bed (see p. 10) prove highly permeable and not amenable to economic sealing, the maximum height of storage will be limited to slightly less than 100 feet above present river level. If highly permeable or weak beds occur below the sandstone and cannot be effectively treated, economically the scheme will not be practicable.

(6) The proposed scheme is located in an area of extremely high seismicity. Any structures will have to be designed to withstand high accelerations. In addition it will be desirable to undertake a very thorough investigation of the likely effect of earthquakes, and of earthquake-induced waves in the reservoirs on the sediments which bound the storage area, particularly those which form the southern ridge.

(7) The Warangoi River carries a heavy silt load at times of high flow. The load increases rapidly even after periods of moderate rainfall in the catchment area and it is expected that the reservoir will be subject to a high rate of siltation during the wet season. An extra, extreme, hazard of siltation exists from the likely disruption of the land surface by a major earthquake.

(8) The abundance of river gravels apparently suitable for use as concrete aggregate provide an economic factor that favours the construction of a concrete dam. Other than the river gravels and volcanic agglomerate, materials suitable for an earth or rock-fill structure were not observed in quantity in the area. The supply of suitable earth materials was, however, not specifically investigated.

RECOMMENDATIONS

The following recommendations are submitted.

1) The further investigation of the damsite should include :

(A) The implementation of a programme of diamond drilling and water pressure testing to prove the strength and permeability of the abutments. Specifications for initial diamond drilling are contained in Appendix 1. The drill holes proposed, WD1 to WD4 and WD8, have been so located that it will be possible to operate during the wet season. Drill holes WD1 and WD2 are located in positions which may be difficult to occupy with a rig, but every effort should be made to do so; WD1A and WD2A are provided as alternatives to WD1 and WD2 out should only be drilled if it is impossible to occupy positions WD1 and WD2.

The objectives of the drilling are :

(a) To determine the properties of, structures in, and permeability of, the agglomerate which forms the left and right abutments.

(b) To prove the location, properties and permeability of fault zones F_2 in the left abutment and F_3 in the right abutment.

(c) To determine the lithology and permeability of, and the structures in, the rock below river level.

One drill hole, WD2, has been planned to extend to a depth of 200 feet below river level; this is to establish the nature of rocks at depth, since, should the agglomerate not extend deeply below river level, the presence of any weak or permeable sedimentary stratum could seriously affect the usefulness of the site.

Additional drilling will be necessary in the dry season to complete the proving of conditions below the river channel.

(B) Geophysical survey. A seismic survey should be carried out along the axis of the proposed dam. The survey will provide further information about the properties of the volcanic agglomerate and the known or suspected faults in the abutments and beneath the river channel; it should also lead to the identification of any structurally weak zones which have not been identified from the surface investigation.

A seismic survey will be required to determine the depth and extent of unconsolidated material in the river channel; the results obtained from this survey should be supplemented by percussion drilling.

Additional seismic profiles may be used to locate the subsurface boundaries of agglomerate and coral in the left abutment ridge, north of the damsite.

Tests carried out with a portable magnetometer by Mr. J. Dooley, Geophysical Branch, B.M.R., have shown that the agglomerate possesses pronounced magnetic properties. A magnetic survey, in addition to the seismic survey, is recommended to assist in the exact location of the agglomerate and coral in the left abutment ridge north of the damsite. Drilling of the area may subsequently be necessary.

(2) As already stressed, it is of vital importance to prove very thoroughly the strength and watertightness of the sediments which form the southern ridge. The programme of investigation should include :

(A) Diamond drilling. The specifications for initial diamond drilling and water pressure testing on, or near, the southern ridge are contained in Appendix 1.

Drill holes WD6 and WD7 have been sited at the two lowest and narrowest saddles in the ridge where the direct leakage path is shortest. Drill hole WD5 has been sited at the base of the ridge to check the continuation of the sedimentary sequence beneath the exposures along the base of the ridge.

The objectives of the drill holes are to determine the lithology, mechanical properties and permeability of the sediments forming the southern ridge and in particular to ascertain the precise location, thickness and permeability of the uncemented sand and poorly-cemented conglomerate beds in the sequence.

Further drilling will be required to prove the soundness of the two known faults in the agglomerate of the ridge.

(B) A comprehensive programme of sampling and laboratory and field testing of the sediments in the ridge, particularly the sand and conglomerate beds, will be needed. The testing should be designed to determine the strength and permeability of the sediments under all foreseeable conditions, including the hazard of frequent intense seismic activity.

(C) Seismic and magnetic surveys to locate the boundaries of the agglomerate and coral limestone in the ridge. If the coral, exposed on both the east side of the ridge and along traverses T and T_1 on the west side of the ridge, is continuous below the top level of storage, diamond drilling to determine the permeability of the coral will be required.

The seismic and magnetic profiles may also be extended to trace the extent of the two faults in the agglomerate.

Electric logging, including resistivity measurements of the drill holes, may prove useful for correlation and determination of physical properties of the rocks.

(D) Regular measurements of water level should be made in at least one of the drill holes in the ridge. The hole would probably need to be kept open by the placing of perforated casing.

(3) Close attention must be given at an early stage of the investigation to an analysis of the most suitable methods of preventing :

(a) leakage from the reservoir through the southern ridge into the Sigule River system, and

(b) failure of the sediments in the ridge after the reservoir has been filled.

It is recommended that a full examination be made of the economic feasibility of reducing top storage level to 100 feet above river level at the damsite. The reduction of top storage to this level would lower the reservoir below the known outcrops of uncemented sand beds in the ridge and thus considerably decrease the likelihood of leakage through the ridge; it would also remove the reservoir from the steeper slopes of the ridge, thus lessening the need for slope protection.

(4) If not already in progress, a programme for gauging the amount of sediment transport in the river should be initiated immediately. In the event of a severe earthquake before the dam is built, ~~magnetic~~ energetic measures should be taken urgently to build up as complete knowledge as possible of the transport of sediment induced by the earthquake.

(5) The installation of suitable instruments to measure ground response to earthquakes has been recommended by Carter and MacGregor (1964, p. 11). It is further recommended that the installation of these instruments should be extended to include not only the volcanics, limestone and other rocks at the damsite, but also the sediments which form the southern ridge.

(6) Samples of the river gravel and sand should be submitted for size analysis and normal reactivity tests to determine their suitability for use as concrete aggregate. If an earth or rock-fill structure is to be considered systematic investigation and sampling of the earth materials available in the area should be undertaken.

ACKNOWLEDGEMENTS

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Particular thanks are due to Messrs. R. Jensen and A. Tidy of the Commonwealth Department of Works Survey Section, Port Moresby, whose friendly and always helpful co-operation facilitated the investigation.

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APPENDIX 1 - DRILLING SPECIFICATIONS

PROJECT : Lower Warangoi hydro-electric scheme, New Britain.

DRILL HOLE No. : WD1 TEMPORARY

TYPE OF DRILLING : Diamond, NMLC barrel, triple split stationary inner tube

LOCATION : Left abutment of damsite

OBJECTIVES OF DRILLING : To determine properties of, structures in, and permeability of, agglomerate forming left abutment, and to ascertain the location, proparties and permeability of fault located at river level.

SITE INDICATED BY : White survey peg, marked WD1.

DRILL SITE PEG, CO-ORDINATES : E+23 353NE) based on C.D.W. damsite survey grid.

METHOD OBTAINED : Chained from C.D.W. survey pegs.

DRILL SITE PEG, R.L. OF GROUND SURFACE : 320' above M.S.L.

METHOD OBTAINED : Stadia survey by C.D.W.

DIRECTION OF HOLE : 178° Magnetic INDICATED BY: -

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) - 70°

REQUIRED SIZE : NMLC

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) : To prove strata to 65 feet below river level and to prove fault at river level.

ANTICIPATED DEPTH : 300 feet

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES) : Hard strong agglomerate. Some possible joints and weathered material. Fault intersection is approximately 230 feet; may have bad ground and result in water loss.

WATER PRESSURE TESTING REQUIRED : Every 20 feet and at fault zone. Special test lengths at discretion of Geologist.

SPECIAL REQUIREMENTS : Core to be photographed in box, and if possible in barrel. To be stored in sound boxes in 5 feet lengths. Lifts to be indicated and core loss marked by wooden spacers of appropriate length. Boxes to be adequately labelled and stored in dry conditions. Drillers to note special drilling conditions, such as loss of drilling water, mud, soft drilling etc. This hole may be difficult to occupy with rig. Every effort is to be made to occupy it, but if it is not possible to operate at this point alternative position W.D. 1A is to be drilled.

SITE SET OUT BY : E.K. Carter & J.R.L. Read DATE : 24th October, 1964.

PROJECT : Lower Warangoi hydro-electric scheme, New Britain.

DRILL HOLE No. : WD1A TEMPORARY

TYPE OF DRILLING : Diamond, NMLC barrel, triple split stationary inner tube.

LOCATION : Left abutment of damsite.

OBJECTIVES OF DRILLING : To determine properties of, structures in, and permeability of, limestone and agglomerate forming left abutment, and to ascertain the location, properties, and permeability of fault zone located at approximate R.L. 280'.

SITE INDICATED BY : White survey peg, marked WD1A

DRILL SITE PEG, CO-ORDINATES : H+24 419NE } Based on C.D.W. damsite survey grid.

METHOD OBTAINED : Chained from C.D.W. survey pegs.

DRILL SITE PEG, R.L. OF GROUND SURFACE : 430' above M.S.L.

METHOD OBTAINED : Stadia survey by C.D.W.

DIRECTION OF HOLE : 178° Magnetic INDICATED BY : -

REQUIRED SLOPE (ANGLE FROM HORIZONTAL): - 80°

REQUIRED SIZE : NMLC

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) : To prove strata to R.L. 210' and to prove fault located at approximate R.L. 280'.

ANTICIPATED DEPTH : 220 feet

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES) : Hard, strong, coralline limestone for 115 feet, agglomerate for remainder. Some possible open joints and weathered material. Fault intersection after approximately 150 feet of drilling.

WATER PRESSURE TESTING REQUIRED : Every 20 feet, also at limestone-agglomerate contact and at fault zone. Special test lengths at discretion of geologist.

SPECIAL REQUIREMENTS : As for WD1.
This hole is an alternative to WD1 and should only be drilled if it is impossible to occupy position WD1.

SITE SET OUT BY : E.K. Carter & J.R.L. Read DATE : 24th October, 1964.

PROJECT : Lower Warangoi hydro-electric scheme, New Britain.

DRILL HOLE No. : WD2 TEMPORARY

TYPE OF DRILLING : Diamond, NMLC barrel, triple split stationary inner tube

LOCATION : Left abutment of damsite.

OBJECTIVES OF DRILLING : To determine properties of, structures in, and permeability of, agglomerate forming left abutment, and to ascertain lithology and proportion of rock below river level.

SITE INDICATED BY : White survey peg, marked WD2.

DRILL SITE PEG, CO-ORDINATES : H+0) Based on C.D.W. damsite
245NE) survey grid.

METHOD OBTAINED : Chained from survey pegs.

DRILL SITE PEG, R.L. OF GROUND SURFACE : 270' above M.S.L.

METHOD OBTAINED : Stadia survey by C.D.W.

DIRECTION OF HOLE : Vertical INDICATED BY : /-

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) : -90°

REQUIRED SIZE : NMLC

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) : To prove strata to 200 feet below river level.

ANTICIPATED DEPTH : 370 feet

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES) : Hard strong agglomerate, some possible joints and weathered material. Conditions below river level unknown.

WATER PRESSURE TESTING REQUIRED : Every 20 feet. Special test lengths at discretion of geologist.

SPECIAL REQUIREMENTS : As for WD1.
This hole is in a position which may be difficult to occupy with the rig. Every effort is to be made to occupy it but if it is not possible to operate at this point alternative hole position WD2A is to be drilled.

SITE SET OUT BY : E.K. CARTER & J.R.L. READ DATE : 24th October, 1964.

PROJECT : Lower Warangoi hydro-electric scheme, New Britain.

DRILL HOLE No. : WD2A TEMPORARY

TYPE OF DRILLING : Diamond, NMLC barrel, triple split stationary inner tube.

LOCATION : Left abutment of damsite.

OBJECTIVES OF DRILLING : To determine properties of, structures in, and permeability of agglomerate forming left abutment and to ascertain lithology and properties of rock below river level.

SITE INDICATED BY : White survey peg marked WD2A

DRILL SITE PEG, CO-ORDINATES : I+34) Based on C.D.W. survey
317NE) grid

METHOD OBTAINED : Chained from C.D.W. survey pegs.

DRILL SITE PEG, R.L. OF GROUND SURFACE : 358' above M.S.L.

METHOD OBTAINED : Stadia survey by C.D.W.

DIRECTION OF HOLE : Vertical INDICATED BY : -

REQUIRED SLOPE (ANGLE FROM HORIZONTAL): -90°

REQUIRED SIZE : NMLC

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) : To prove strata to 50 feet below river level.

ANTICIPATED DEPTH : 310 feet

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES) : First 40 feet in weathered limestone, remainder in hard, strong agglomerate; some possible joints and weathered zones. Conditions below river level unknown.

WATER PRESSURE TESTING REQUIRED : Every 20 feet, and at limestone-agglomerate contact. Special test lengths at discretion of geologist.

SPECIAL REQUIREMENTS : As for WD1.
This hole is provided as an alternative to WD2 and should only be drilled if it is impossible to occupy hole position WD2.

SITE SET OUT BY : E.K. Carter & J.R.L. Read DATE : 24th October, 1964.

PROJECT : Lower Warangoi hydro-electric scheme, New Britain.

DRILL HOLE NO. : WD3 TEMPORARY

TYPE OF DRILLING : Diamond, NMLC barrel, triple split stationary inner tube

LOCATION : Right abutment of damsite.

OBJECTIVES OF DRILLING : To determine properties of, structures in, and permeability of agglomerate forming right abutment, and to ascertain the lithology and properties of rock below river level.

SITE INDICATED BY : White survey peg, marked WD3+4

DRILL SITE PEG, CO-ORDINATES : K+25 257SW) Based on C.D.W. damsite survey grid

METHOD OBTAINED : Chained from C.D.W. survey pegs.

DRILL SITE PEG, R.L. of GROUND SURFACE : 130 feet above M.S.L.

METHOD OBTAINED : Stadia survey by C.D.W.

DIRECTION OF HOLE : 153° Magnetic INDICATED BY : -

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) : - 30°

REQUIRED SIZE : NMLC

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) : To prove strata through the abutment and to 100 feet below river level.

ANTICIPATED DEPTH : 260 feet

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES) : Initially in agglomerate scree with possible weathered fault zone after 30 feet of drilling. Remainder probably in hard, strong agglomerate; conditions below river level not known.

WATER PRESSURE TESTING REQUIRED : Every 20 feet in agglomerate, and at fault zone. Special test lengths at discretion of geologist.

SPECIAL REQUIREMENTS : As for WD1.

SITE SET OUT BY : J.R.L. Read DATE : 26th October, 1964.

PROJECT : Lower Warangoi hydro-electric scheme, New Britain.

DRILL HOLE No. : WD4 TEMPORARY

TYPE OF DRILLING : Diamond, NMLC barrel, triple split stationary inner tube

LOCATION : Right abutment of damsite.

OBJECTIVES OF DRILLING : To determine the lithology, properties, and permeability of rock below river channel.

SITE INDICATED BY : White survey peg marked WD3+4

DRILL SITE PEG, CO-ORDINATES : K+25 257SW) Based on C.D.W. survey grid.

METHOD OBTAINED : Chained from C.D.W. survey pegs.

DRILL SITE PEG, R.L. OF GROUND SURFACE : 130 feet above M.S.L.

METHOD OBTAINED : Stadia survey by C.D.W.

DIRECTION OF HOLE : 012° Magnetic INDICATED BY : -

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) : - 45°

REQUIRED SIZE : NMLC

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) : To prove strata to a depth of 130 feet below river level.

ANTICIPATED DEPTH : 220 feet

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES) : Initially in agglomerate scree and possibly river gravel. Conditions under river channel unknown but expected to be hard, strong agglomerate; some joints and weathered material.

WATER PRESSURE TESTING REQUIRED : Every 20 feet in rock strata. Special test lengths at discretion of geologist.

SPECIAL REQUIREMENTS : As for WD1.

SITE SET OUT BY : J.R.L. Read DATE : 26th October, 1964.

PROJECT : Lower Warangoi hydro-electric scheme, New Britain.

DRILL HOLE : WD5 TEMPORARY

TYPE OF DRILLING : Diamond, NMLC barrol, triple split stationary inner tube.

LOCATION : 640 feet north of C.D.W. survey peg △ 20 on southern ridge.

OBJECTIVES OF DRILLING : To determine the lithology, properties and permeability of sediments beneath base of southern ridge and to ascertain the location, thickness and permeability of any uncemented sand or conglomerate beds.

SITE INDICATED BY : White survey peg, marked WD5.

DRILL SITE PEG, CO-ORDINATES :

METHOD OBTAINED : Chained from C.D.W. survey peg.

DRILL SITE PEG, R.L. OF GROUND SURFACE : 180 feet above M.S.L.

METHOD OBTAINED : Abney levelling from C.D.W. survey peg.

DIRECTION OF HOLE : Vertical INDICATED BY : -

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) : - 90°

REQUIRED SIZE : NMLC

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) : To prove strata to 100 feet below river level.

ANTICIPATED DEPTH : 180 feet

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES) : Soft sediments, prodominantly clays and siltstone. Beds of uncemented sand and conglomerate may be encountered in first 50 feet of drilling. Caving ofdrill hole expected and will probably require casing.

WATER PRESSURE TESTING REQUIRED : Every 20 feet, and at all changes in lithology as drilling proceeds. Special test lengths at discretion of geologist.

SPECIAL REQUIREMENTS : As for WD1.

SITE SET OUT BY : J.R.L. Read Date : 26th October, 1964.

PROJECT : Lower Warangoi hydro-electric scheme, New Britain.

DRILL HOLE No. : WD6 TEMPORARY

TYPE OF DRILLING : Diamond, NMLC barrel, triple split stationary inner tube

LOCATION : Southern ridge saddle between C.D.W. survey pegs △ 8 and △ 9.

OBJECTIVES OF DRILLING : To determine the lithology, properties and permeability of sediments beneath crest of southern ridge and to ascertain location, thickness, and permeability of any uncemented sand and conglomerate beds.

SITE INDICATED BY : White survey peg marked WD6.

DRILL SITE PEG, CO-ORDINATES :

METHOD OBTAINED : Chained from C.D.W. survey pegs.

DRILL SITE PEG, R.L. OF GROUND SURFACE : 291 feet above M.S.L.

METHOD OBTAINED : Stadia survey by C.D.W.

DIRECTION OF HOLE : Vertical INDICATED BY : -

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) : - 90°

REQUIRED SIZE : NMLC

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) : To prove strata to 50 feet below river level.

ANTICIPATED DEPTH : 245 feet

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES) : Soft sediments, predominantly clays and siltstones. Beds of uncemented sand and of conglomerate expected at R.L. 244'. Caving of drill holes expected; hole will probably require casing.

WATER PRESSURE TESTING REQUIRED : Every 20 feet and at all changes in lithology as drilling proceeds. Special test lengths at discretion of geologist.

SPECIAL REQUIREMENTS : As for WD1.

SITE SET OUT BY : J.R.L. Read DATE : 26th October, 1964.

PROJECT : Lower Warangoi hydro-electric scheme, New Britain.

DRILL HOLE : WD7 TEMPORARY

TYPE OF DRILLING : Diamond, NMLC barrel, triple split stationary inner tube

LOCATION : Southern ridge at C.D.W. survey peg △ 43.

OBJECTIVES OF DRILLING : To determine the lithology, properties and permeability of sediments beneath crest of southern ridge and to ascertain location, thickness and permeability of any uncemented sand or conglomerate beds.

SITE INDICATED BY : White survey peg marked WD7.

DRILL SITE PEG, CO-ORDINATES :

METHOD OBTAINED : Stadia survey by C.D.W.

DRILL SITE PEG, R.L. OF GROUND SURFACE : 364 feet above M.S.L.

METHOD OBTAINED : Stadia survey by C.D.W.

DIRECTION OF HOLE : Vertical INDICATED BY : -

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) : - 90°

REQUIRED SIZE : NMLC

REQUIRED DEPTH (IN TERMS OF OBJECTIVES) : To prove strata to 50 feet below river level.

ANTICIPATED DEPTH : 315 feet

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES) : Soft sediments, predominantly clays and siltstones. Beds of uncemented sand and conglomerate expected at R.L. 310'; 255'; 220'. Caving of drill hole expected; hole will probably require casing.

WATER PRESSURE TESTING REQUIRED : Every 20 feet and at all changes in lithology as drilling progresses. Special test lengths at discretion of geologist.

SPECIAL REQUIREMENTS : As for WD1.

SITE SET OUT BY : J.R.L. Read DATE : 26th October, 1964.

PROJECT : Lower Warangoi hydro-electric scheme, New Britain.

DRILL HOLE NO. : WD8 TEMPORARY

TYPE OF DRILLING : Diamond, NMLC barrel, triple split stationary inner tube.

LOCATION : Right abutment of damsite.

OBJECTIVES OF DRILLING : To ascertain location, properties and permeability of possible fault zone at approximate R.L. 89 feet.

SITE INDICATED BY : White survey peg marked WD3+4.

DRILL SITE PEG, CO-ORDINATES : K+25) Based on C.D.W. survey
257SW) grid.

METHOD OBTAINED : Chained from C.D.W. survey pegs.

DRILL SITE PEG, R.L. OF GROUND SURFACE : 130 feet above M.S.L.

METHOD OBTAINED : Stadia survey by C.D.W.

DIRECTION OF HOLE : 153° Magnetic INDICATED BY : -

REQUIRED SLOPE (ANGLE FROM HORIZONTAL) : - 70°

REQUIRED SIZE : NMLC

REQUIRED DEPTH (IN TERMS OF OBJECTITES) : To prove possible fault zone at approximate R.L. 89'.

ANTICIPATED DEPTH : 80 feet

ANTICIPATED DRILLING CONDITIONS (STRATA, STRUCTURES) : Initially in agglomerate scree. Possible fault zone at 45 feet depth.

WATER PRESSURE TESTING REQUIRED : Every 20 feet in agglomerate and at fault zone. Special test lengths at discretion of geologist.

SPECIAL REQUIREMENTS : As for WD1.

SITE SET OUT BY : J.R.L. Read DATE : 26th October, 1964.

APPENDIX 2

SAMPLE FROM THE LOWER WARANGOI RIVER, NEW BRITAIN

by

D.J. Belford

A sample collected by J.R.L. Read during geological investigation of the Lower Warangoi hydro-electric scheme, Gazelle Peninsula, New Britain, has been received for palaeontological examination. The sample, which is from the base of the stratigraphic sequence in the ridge forming the divide between the Warangoi and Sigule River systems, contains abundant foraminifera, ostracoda and mollusca.

Foraminifera identified are:

Globigerinoides quadrilobatus (d'Orbigny) *immaturus* LeRoy
G.bollii Blow
G.ruber (d'Orbigny)
Globigerina bulloides d'Orbigny
Globorotalia cultrata (d'Orbigny)
Pulleniatina obliquiloculata (Parker & Jones)
Geminospira bradyi Bermudez
Florilus elongatus (d'Orbigny)
Siphoninoides echinatus (Brady)
Brizalina patula Belford (MS)
B.vescistriata Belford (MS)
*B.*sp.
Rectobolivina limbata (Brady)
R.fasciata Belford (MS)
Siphogenerina sp.cf. *S.costata* Schlumberger
Sigmavirgulina tortuosa (Brady)
Amphistegina sp.cf. *A.lessonii* d'Orbigny
*A.*sp.
Operculina ammonoides Gronovius
O.gaimardi d'Orbigny?
Elphidium craticulatum (Fichtel & Moll)
E.advenum (Cushman)
*E.*spp.
Ammonia maculosa Belford (MS)
Asterorotalia ? sp.
Neoeponides parantillarum (Galloway & Heminway)
Cancris auriculus (Fichtel & Moll)
"Eponides" subhaidingeri (Parr)
"E". praecinctus (Karrer)
Sphaerogypsina globulus (Reuss)
Pseudorotalia schroeteriana (Parker & Jones)
P.gaimardi (d'Orbigny)
*P.*sp.cf.*P.catilliformis* (Thalmann)
Discorbinella bertheloti (d'Orbigny)
Cancris bodjongensis (LeRoy)
Triloculina tricarinata d'Orbigny
Quinqueloculina bicostata (d'Orbigny)
Spiroloculina eximia (Cushman)
Pyrgo sp.cf.*P.elongata* (d'Orbigny)
Cymbaloporetta bradyi (Cushman)
Reussella aculeata Cushman
Textularia conica d'Orbigny
*T.*spp.

This sample is regarded as Pliocene in age.

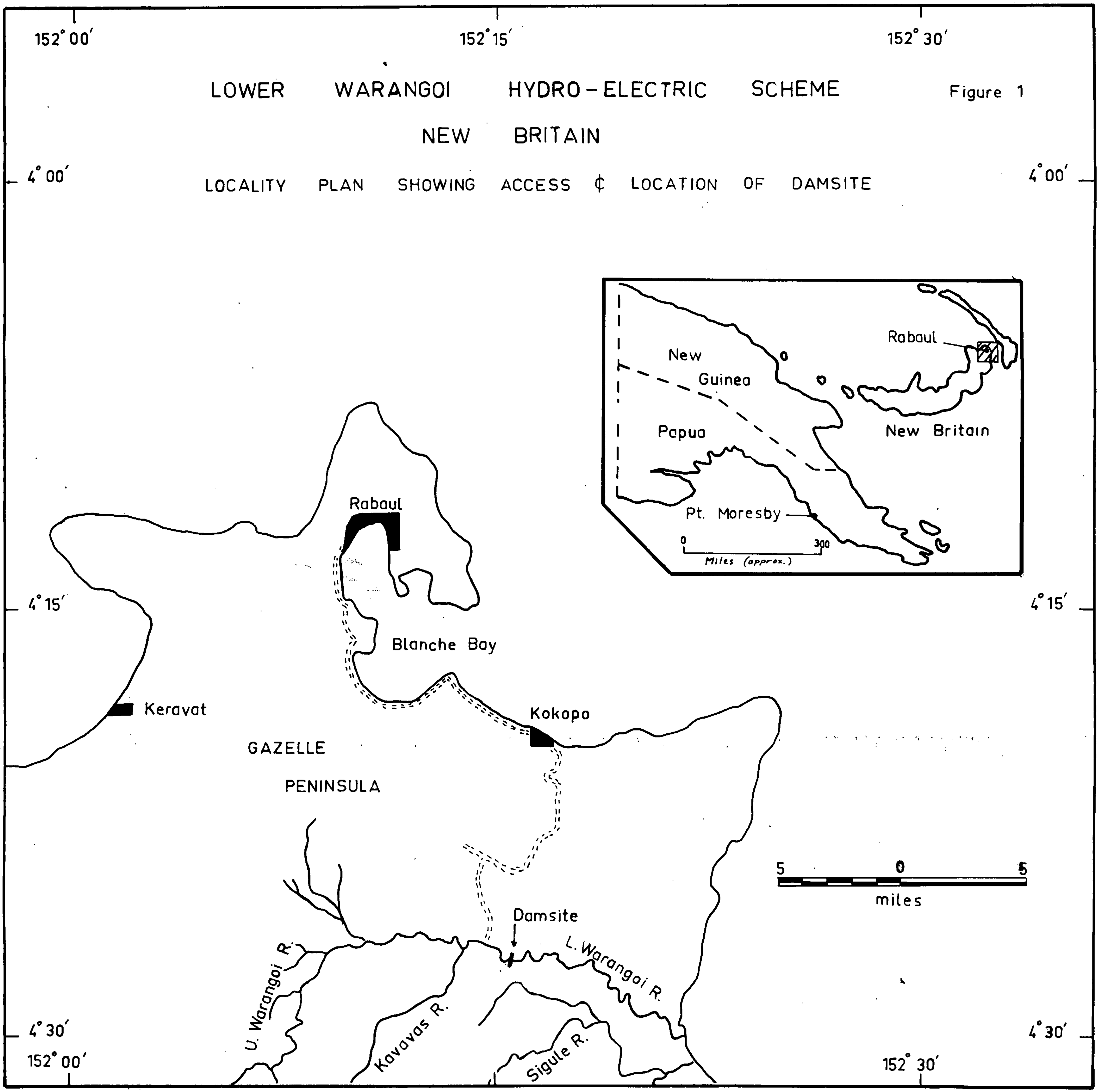

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PLATE 1

Fig. 1: Warangoi damsite, view looking downstream, October, 1964. The distance between the abutments at river level is about 300 feet and the top of the ridge at the left of the photograph is about 400 feet above river level.

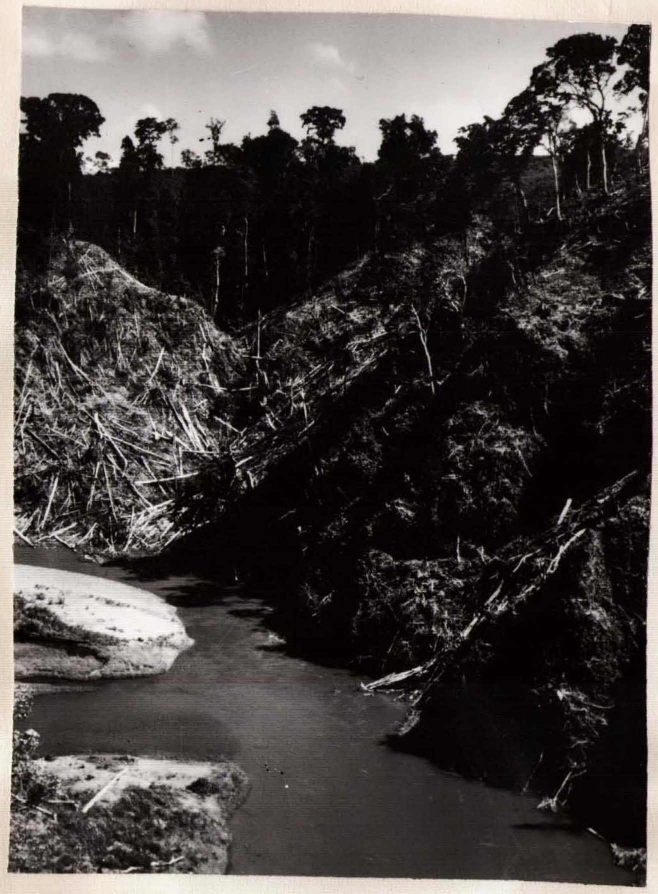


Fig. 2: Upstream from left abutment viewed from the right abutment, October, 1964.

Fig. 3: Upstream face of left abutment, viewed from right abutment, October 1964.

PLATE 2

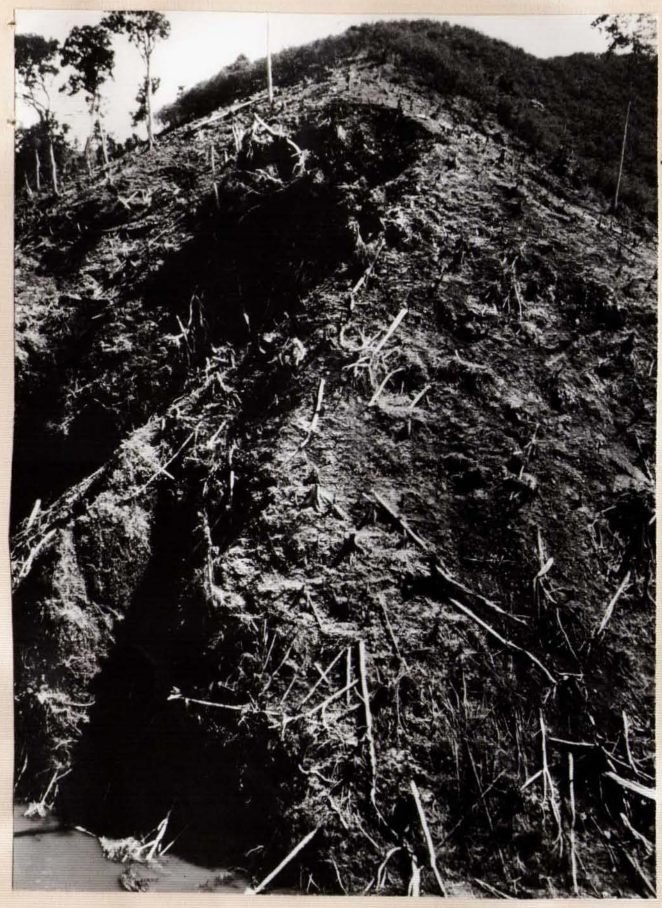


Fig. 1: Axis of left abutment viewed from right abutment, October, 1964.

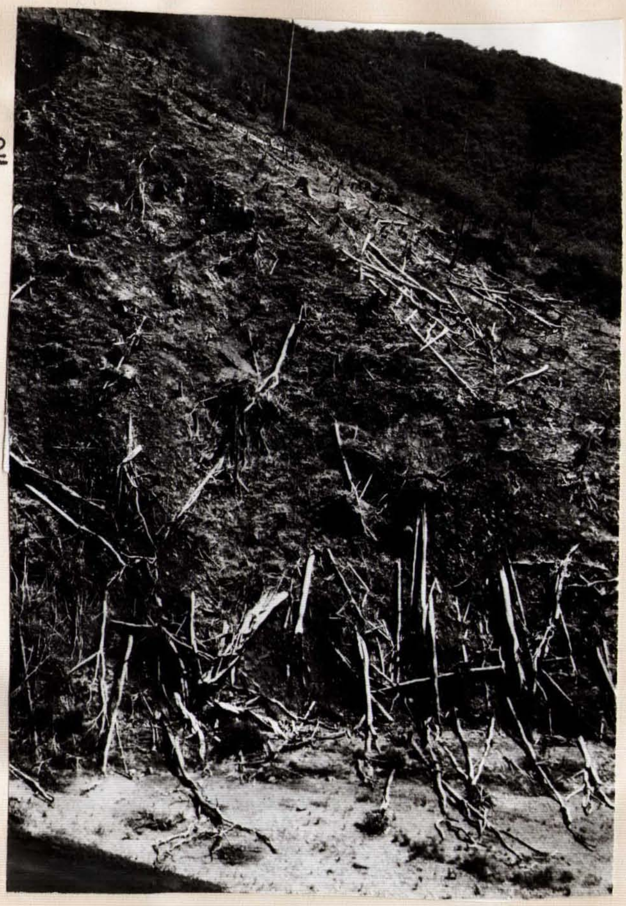


Fig. 2: Downstream face of left abutment, viewed from the right abutment, October, 1964.

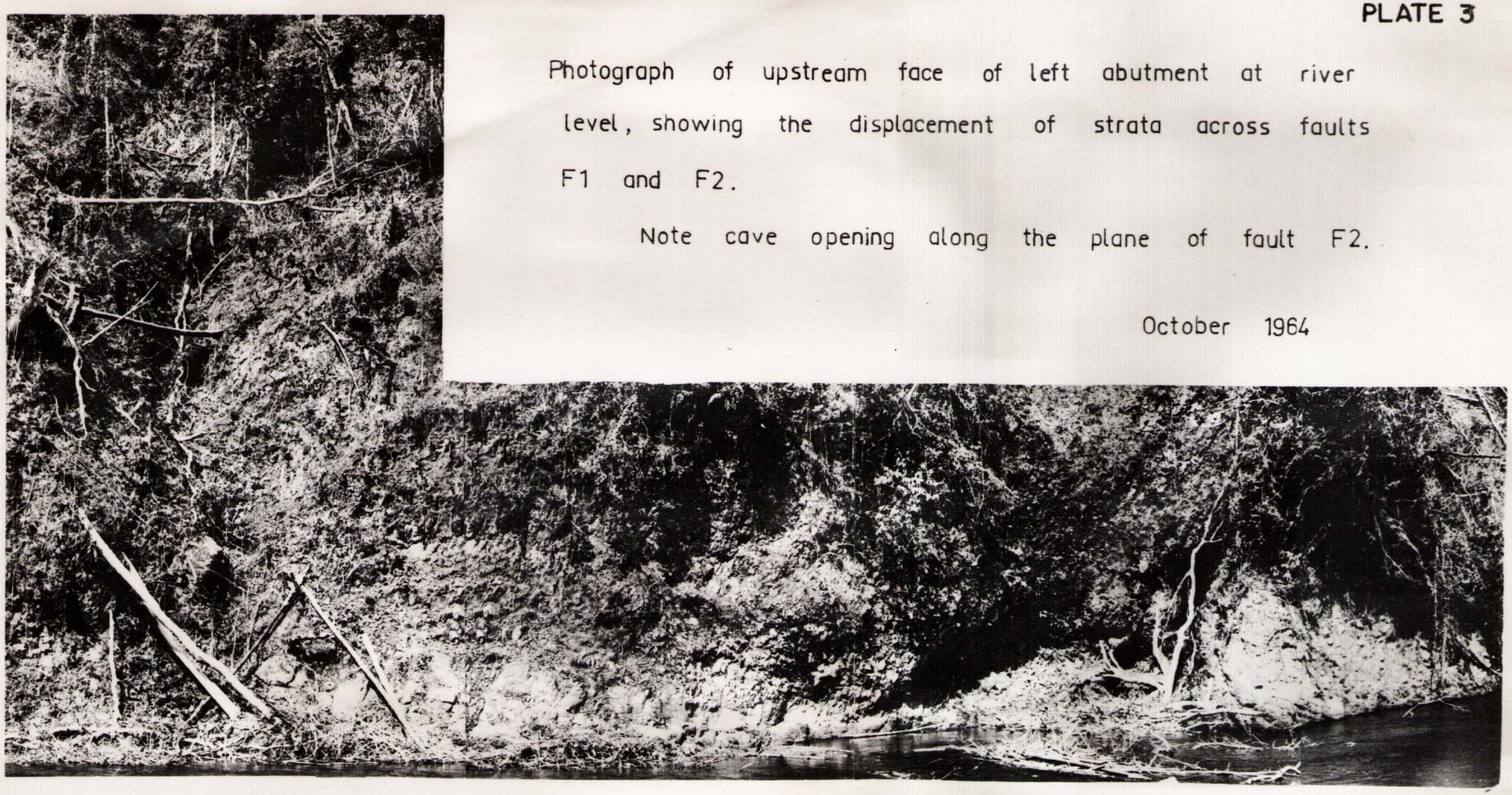
Fig. 3: Downstream from left abutment, viewed from right abutment, October, 1964.

PLATE 3

Photograph of upstream face of left abutment at river level, showing the displacement of strata across faults F1 and F2.

Note cave opening along the plane of fault F2.

October 1964



Overlay to accompany Plate 3

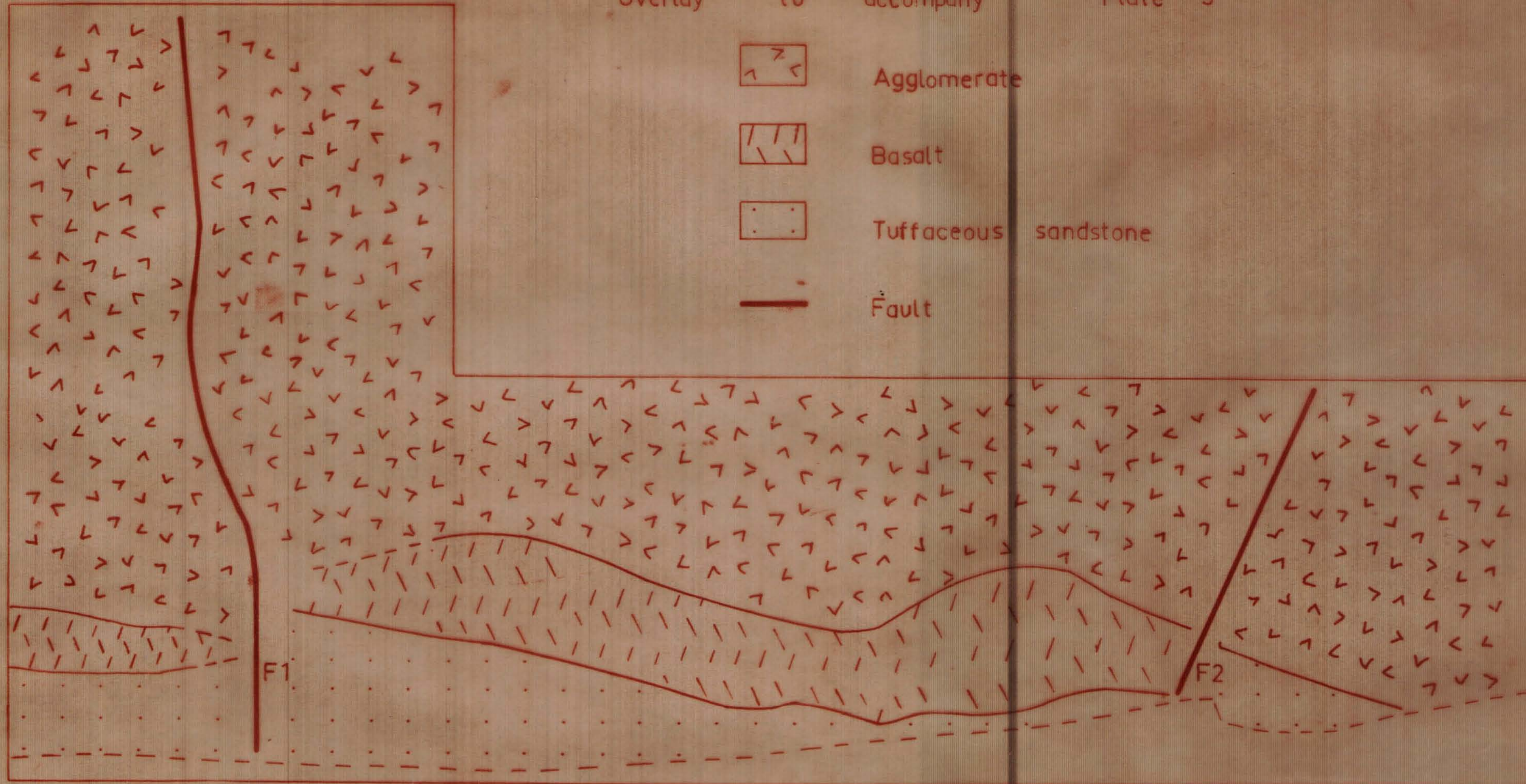


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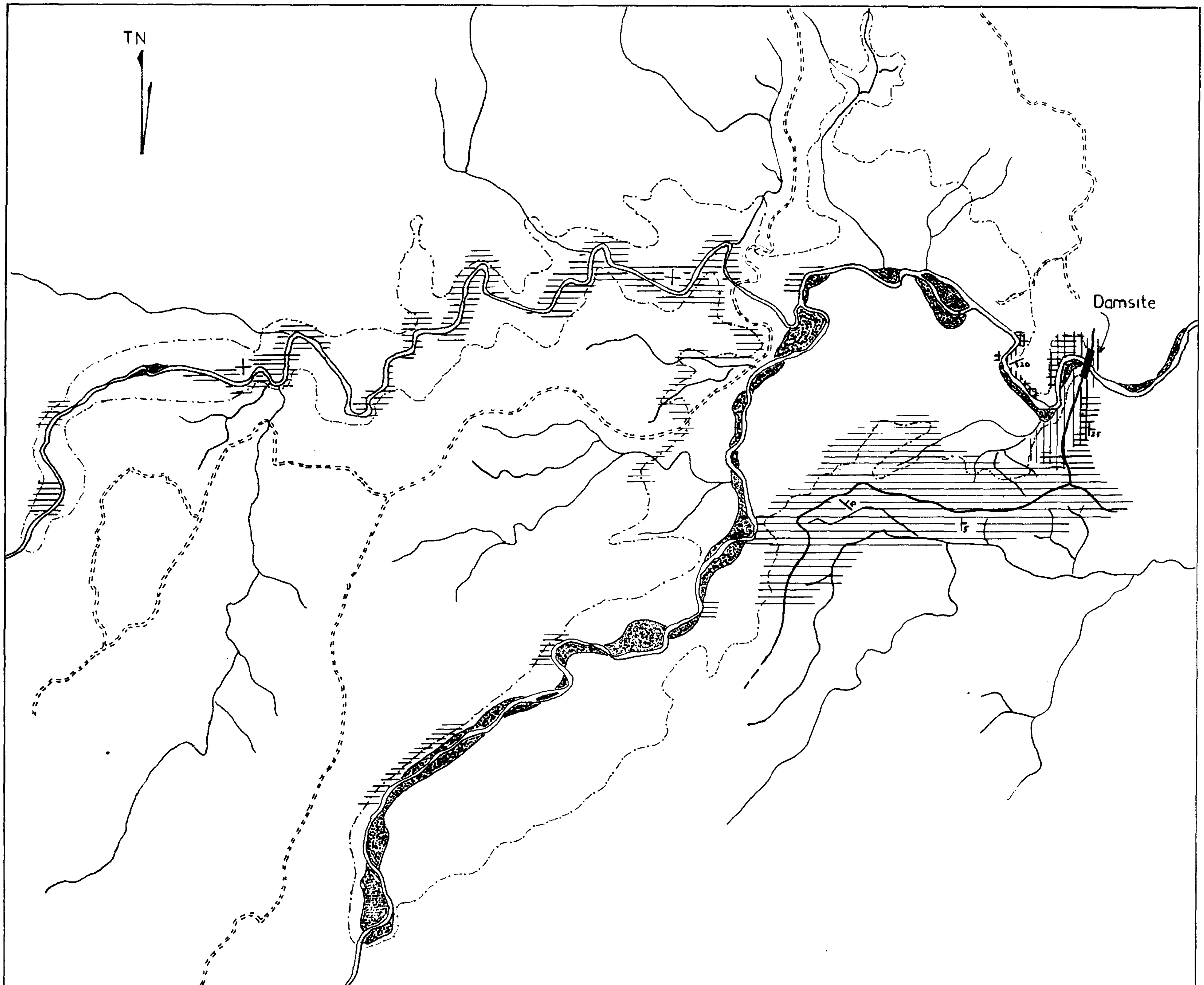
PLATE 4

Fig. 1: Downstream face of right abutment, viewed from left abutment, October, 1964. Coral crops out slightly left of centre of photograph.

Fig. 2: Right abutment, viewed from left abutment, October, 1964.

Fig. 3: Upstream face of right abutment viewed from left abutment, October, 1964.

PLATE 5



LOWER WARANGOI HYDRO-ELECTRIC SCHEME

PLAN SHOWING GEOLOGY OF DAMSITE & STORAGE AREA (traced from air photgraphs)

Gravel & sand bank.		Approximate top storage level (R.L. 220 feet)		Bedding	
Sediments, (clays, siltstones, sandstones)		Southern ridge		Horizontal bedding	0 5,000 10,000 feet
Coral limestone.		Vehicle access			
Volcanic agglomerate.					

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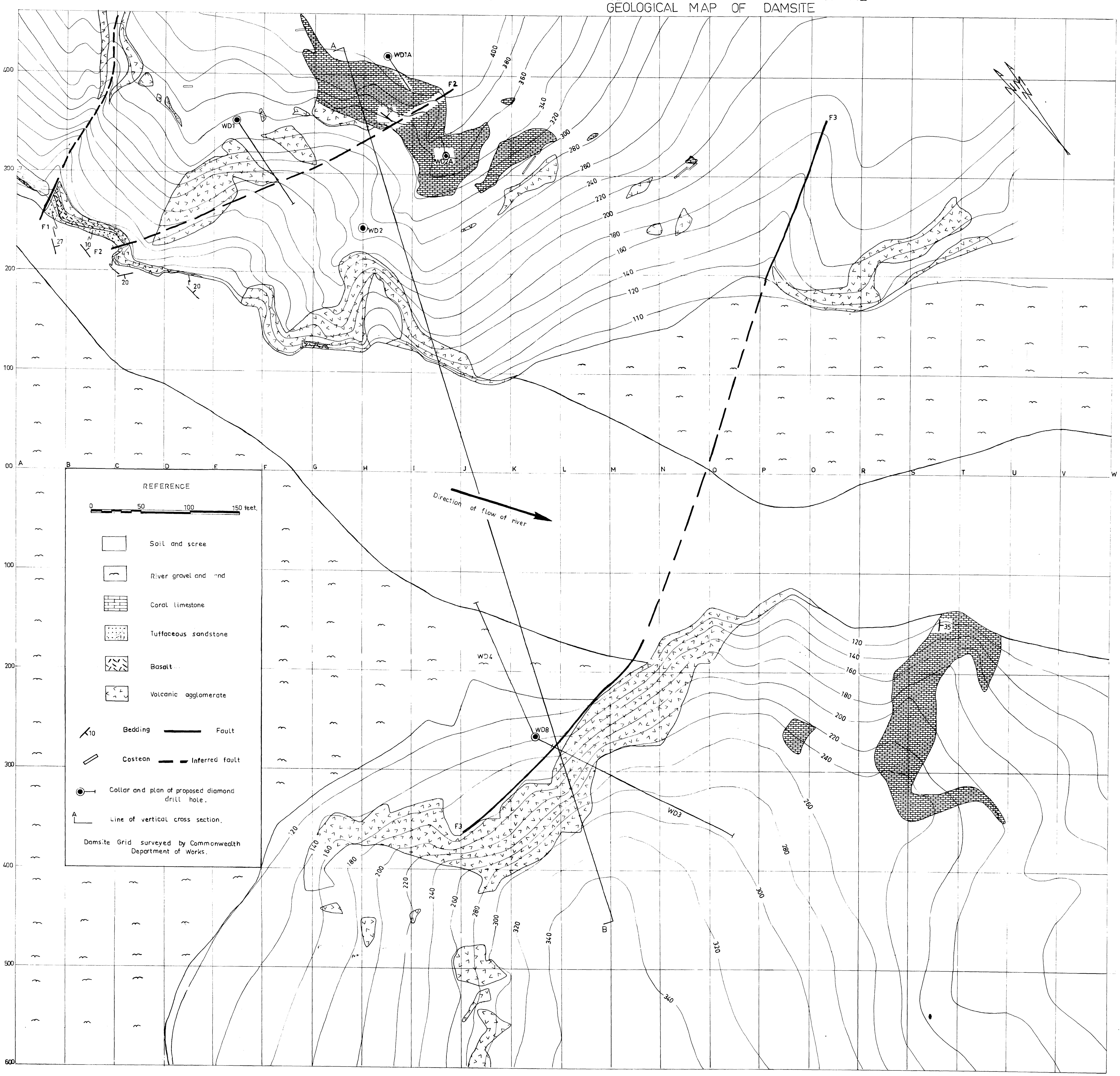
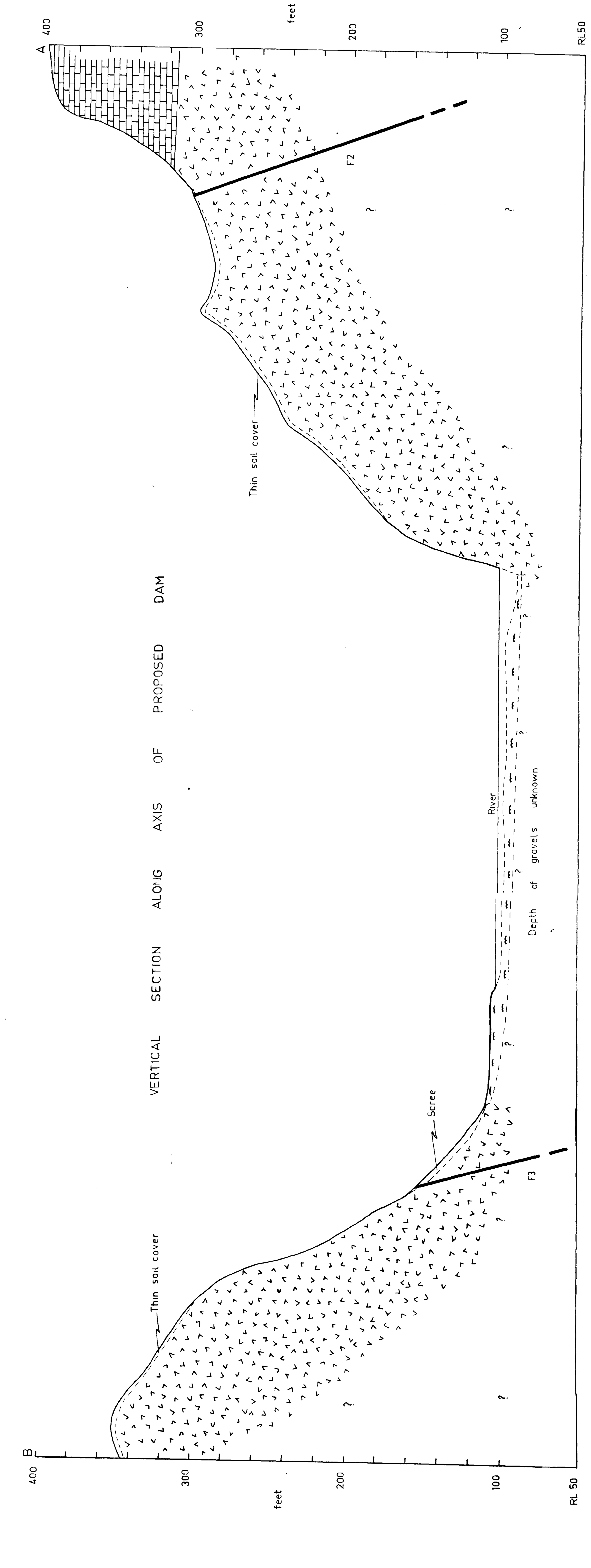
PLATE 6

LOWER WARANGOI HYDRO-ELECTRIC SCHEME

GEOLOGICAL MAP OF DAMSITE





LOWER WARANGOI HYDRO - ELECTRIC SCHEME

GEOLOGICAL MAP OF SOUTHERN RIDGE ¢ DAMSITE AREA

0 400 800 1600
feet

Sand ¢ gravel

Calcareous sandstone

Silty clay ¢ fine-grained silty sandstone

Conglomerate

Uncemented medium-grained sandstone

Blue-grey siltstone with interbeds of claystone

Shell bed

Coral limestone

Silty claystone ¢ siltstone

Agglomerate

Bedding

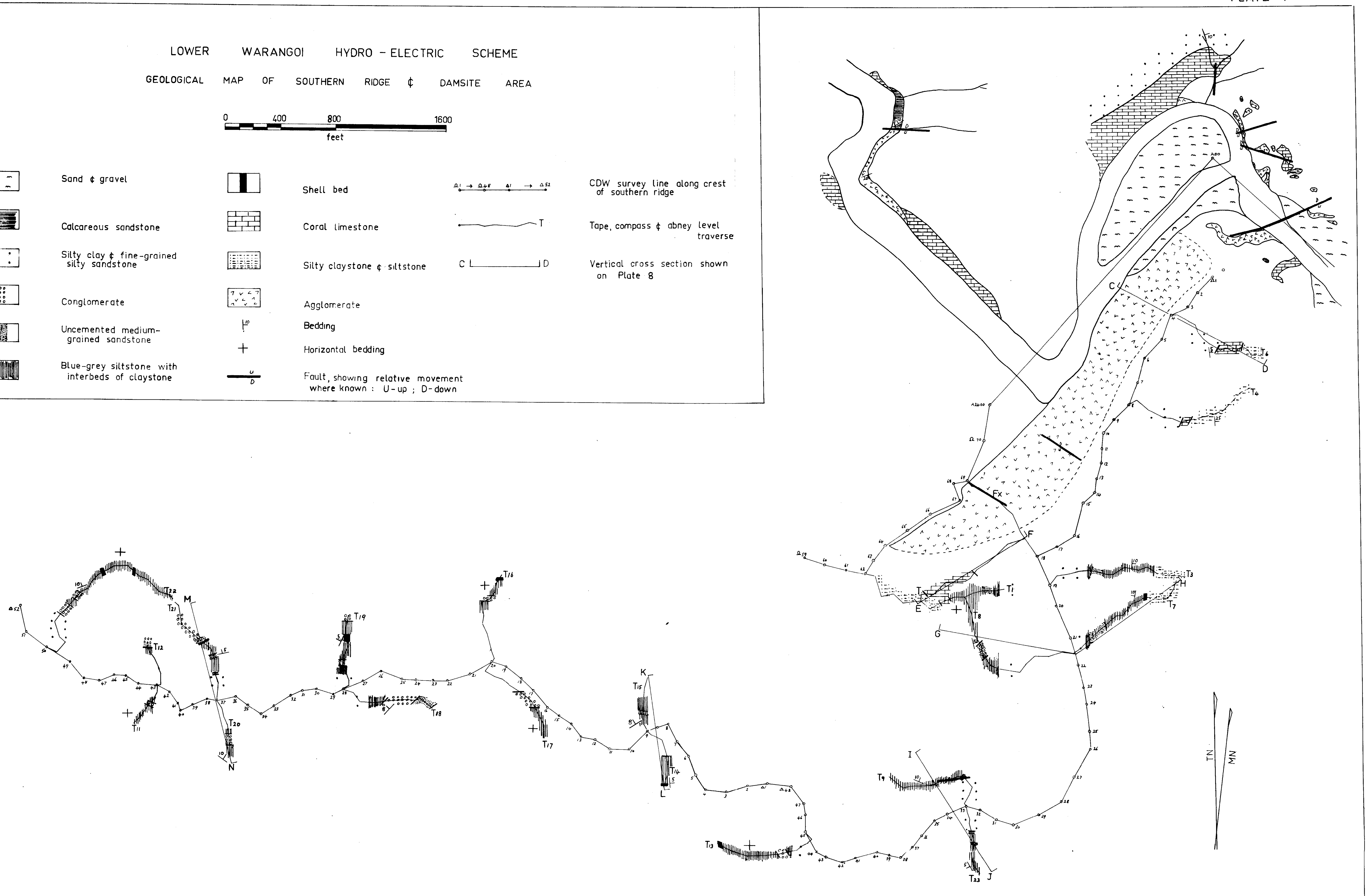
Horizontal bedding

Fault, showing relative movement where known : U-up ; D-down

CDW survey line along crest of southern ridge

Tape, compass ¢ abney level traverse

Vertical cross section shown on Plate 8



LOWER WARANGOI HYDRO - ELECTRIC SCHEME

PLATE 8

INTERPRETATIVE CROSS SECTIONS THROUGH SOUTHERN RIDGE

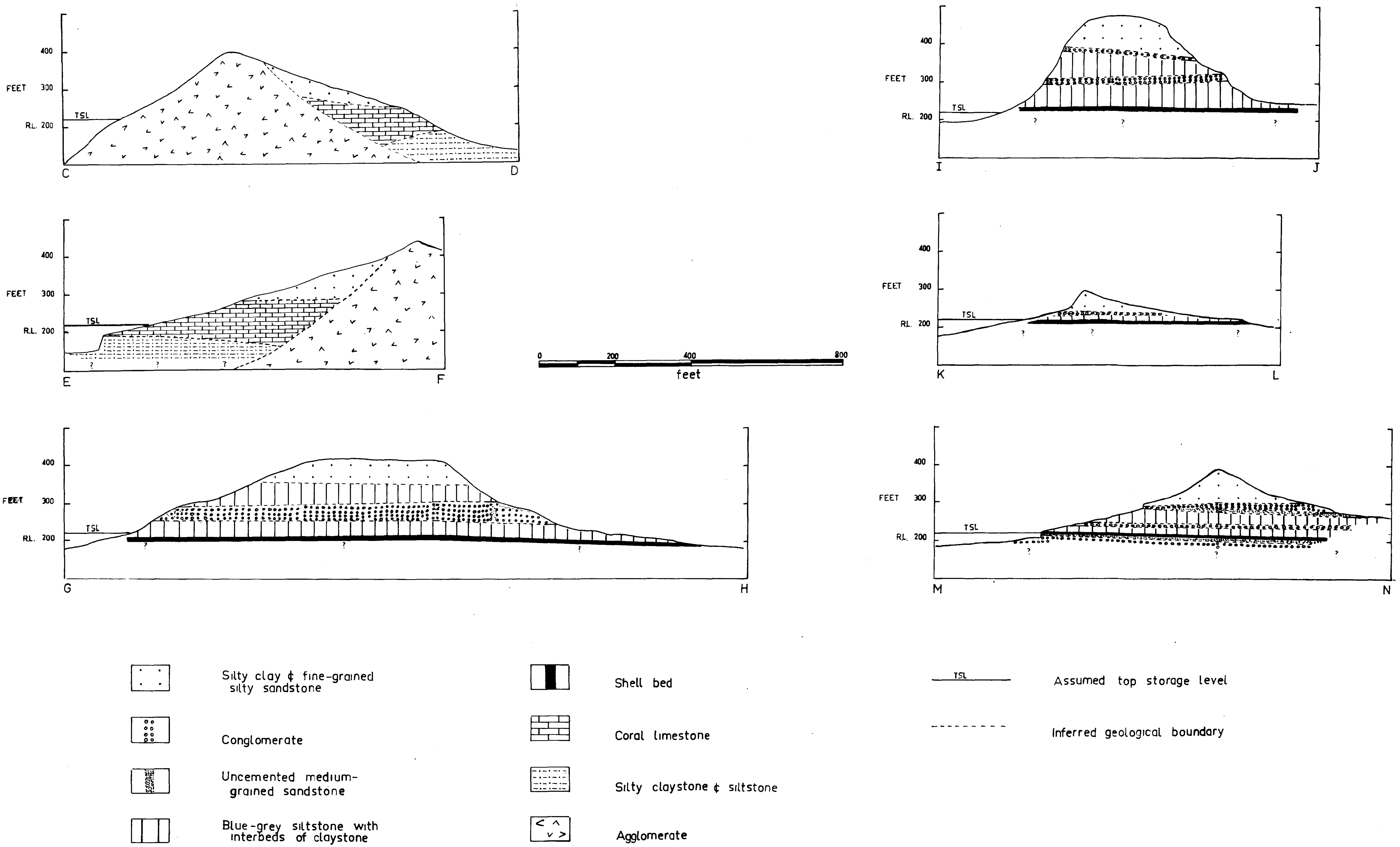


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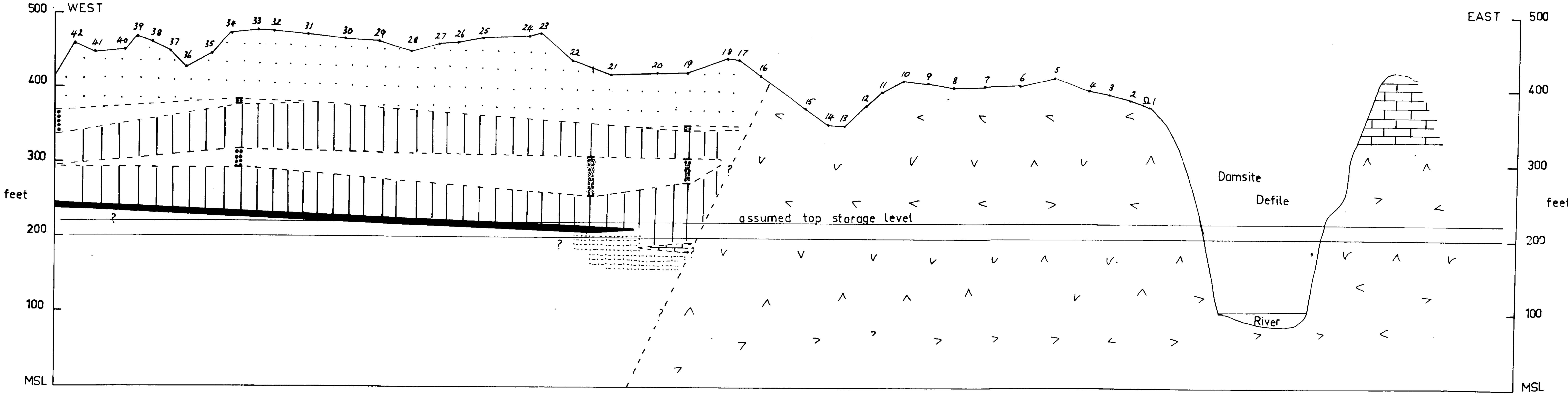
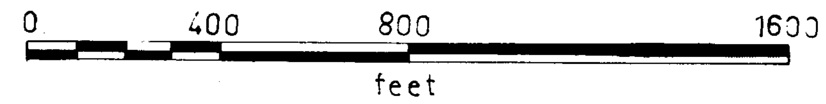
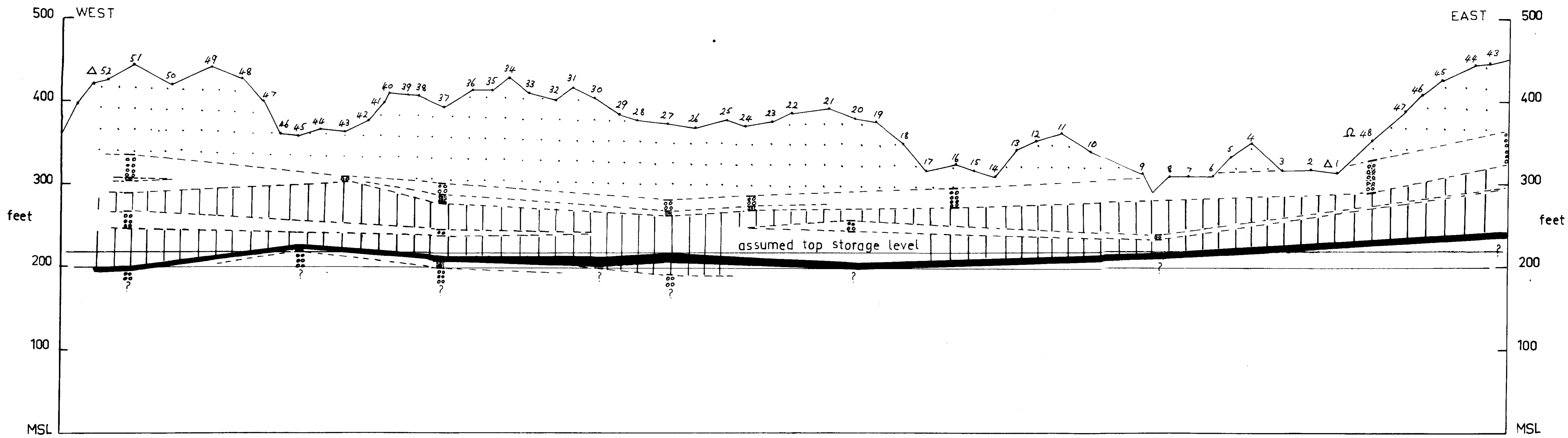
PLATE 9







LOWER WARANGOI HYDRO - ELECTRIC SCHEME

PLATE 9 — INTERPRETATIVE SECTION ALONG CREST OF SOUTHERN RIDGE (projected from ridge centre line to plane of section)

Silty clay & fine-grained silty sandstone

Conglomerate

Uncemented medium-grained sandstone

Blue-grey siltstone with interbeds of claystone

Shell bed

Coral limestone

Silty claystone & siltstone

Agglomerate

Inferred geological boundary

Ω1 to △52 — CDW survey line along crest of southern ridge

LOWER WARANGOI HYDRO - ELECTRIC SCHEME

INTERPRETATIVE GEOLOGY OF SOUTHERN RIDGE & DAMSITE AREA