Records 1959/22

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SUMMARY

A reconnaissance has been made of a hydro-electric scheme on the Sankwep River, on the southern flanks of the Rawlinson Range, 15 miles north of Lae.

The rocks of the area consist of a sequence of Miocene greywacke and conglomerate with some interbeds of claystone and limestone; basic igneous rocks intrude the sediments in the northern portion of the area.

In the southern part, the sequence is little disturbed and dips gently northwards; deformation increases in severity, toward the Rawlinson Range, through a zone of faulting and folding in the centre of the area to an easterly trending belt of strong deformation toward the northern end in which the sediments have been folded and faulted, and intruded by basic igneous rocks.

The area is situated in an active earthquake belt; present data suggest that 3-4 comparatively minor shocks may be expected each year with infrequent fairly major earthquakes. The most recent of these apparently occurred in 1935 when intensity seems to have been in the vicinity of 8-9 on the modified Mercalli scale.

The diversion weir and tunnel are situated in the basic belt where the effects of an earthquake are likely to be at their maximum. Due to the complexities of this belt, it is not possible to predict the distribution of rock types along a tunnel with any confidence but a preponderance of shattered basic rock, with ribs of greywacke, is expected; the tunnel would need support and both support and lining should be as flexible as possible to counter earthquake hazard.

Penstocks anchor and power station would overlie greywacke or limestone where deformation is less severe than in the basic belt; adequate foundations should be available for these installations but detailed investigation will be required.

Nothing less than a full scale detailed investigation, including a major drilling campaign, is likely to provide more precise information on the cost and practicability of the scheme.

INTRODUCTION

A possible scheme to provide hydro-electric power for Lae uses the fall of the Sankwep River which rises in the Rawlinson Range and flows southward into Huon Gulf a few miles east of Lae. The scheme involves diversion of water from the Sankwep River about 15 miles north of Lae, into a tunnel through the ridge between the Sankwep and Musom Valleys and thence through penstocks to a power station near the Musom River itself (see Plate 2).

Access to the area is at present by foot; a vehicle track extends from Lae to the Busu River, a distance of about 8 miles, and a foot track leads up the Busu and Musom Rivers to the village of Gawan which is situated on the divide between the Sankwep and Musom River systems; the journey from the Busu to Gawan takes four to five hours.

GEOLOGY

INTRODUCTION

Traverses were made along the access route to the area from the confluence of the Sankwep and Busu Rivers, along the main ridge between the Sankwep and Musom Rivers, and along the beds of these rivers and of Bumsa Creek. Good but not continuous outcrops occur along the rivers; elsewhere outcrops are sporadic, weathered, and, in many places, disturbed by soil creep. The entire area is covered by rain forest.

The distribution of rock types observed in the field is shown on Plate 2 by closely spaced symbols; extensions made by photo interpretation to provide a first reconnaissance map are indicated by the more widely spaced symbols.

In summary, the area is underlain for the most part by a sedimentary sequence consisting of greywacke,* and greywacke-conglomerate, with interbeds of siltstone and claystone, and in places, of limestone. At the southern end of the area, these sediments dip gently northward at 5 to 10 degrees; the dips gradually increase in a northerly direction until deformation by faulting and folding becomes severe in the foothills of the Rawlinson Range. Basic igneous rocks, although absent in the south, are widely distributed in this belt of deformation and become the dominent rock near the northern end of the area. The basic rocks, as well as the greywackes, are fractured and sheared in this belt in which the structure is most complex.

The writers can throw little light on the age of the rocks of this area nor on the sequence of tectonic events from the information collected during the reconnaissance; discussion of these aspects has, in any case, little bearing on this preliminary investigation. From information on the geology of the Saruwageds to the west and north-west of the area, gleaned from

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* Greywacke: A sedimentary rock with the same grainsize as a sandstone (0.06-4.0 mm.) consisting of angular to rounded grains of a number of minerals, including rock fragments set in a matrix of fine-grained material. It is distinguished from sandstone or quartz-sandstone which has little or no matrix and is a "cleaner" rock.

unpublished reports of the Island Exploration Co.Pty.Ltd.[ø], and from Mr.J. Best,[*] Bureau of Mineral Resources, the greywacke sequence is probably equivalent to the Mebu Series of Lower Miocene age, established farther west, where intrusive basic igneous rocks have also been recorded.

Structural information from these sources indicates that major deformation is the result of compression from the north, producing overfolding and thrusting, and of subsequent uplifts, involving warping and faulting. There is indubitable evidence in the occurrence of earthquakes, of recent marine terraces along the coast of Huon Peninsula and of fault scarps along the northern edge of the Markham Valley, that the Saruwaged block is still active and tending to rise or tilt to the south.

LITHOLOGY

The country rocks along the Busu and Musom Rivers up to Bumsa Creek are greywacke and greywacke-conglomerate. A thick limestone member outcrops in the Musom about two miles south of Bumsa Creek. At about one mile south of the mouth of this creek the greywacke is intruded by basic igneous rock. Greywacke occupies the crest of the main ridge between Sankwep River on the east and Bumsa Creek and Musom River in the west. In the bed of Bumsa Creek and of Sankwep River for at least about half a mile north and a mile south of Gawan village the country rock is basic igneous rock containing relatively small masses of greywacke some of which are clearly intruded by basic rock. In addition to the main limestone body, about half way between Gobadik and Gawan villages, a limestone bed perhaps ten feet thick occurs in the bed of Bumsa Creek about a mile north-west of Gawan and another on the ridge about a mile and a half south-east of Gawan. Large loose blocks of limestone up to 30 feet by 20 feet on the bed of the Sankwep, east of Gawan, indicate that at least one fairly thick limestone band occurs in this locality.

The greywacke appears to be derived largely from basic igneous rocks. In the southern part of the area, downstream from the limestone member, the greywacke sequence is predominantly coatse-grained; it includes many pebble-conglomerates and in places cobble- conglomerates, but few interbeds of siltstone or claystone. In the northern part of the area in the ridge between the two stream systems, the greywacke is mainly medium-grained and has fine interbeds of siltstone and claystone. Carbonaceous films are locally abundant and some of them form thin beds of anthracitic coal. At a locality in the bed of the Sankwep about one-third of a mile south of Gawan village, large loose blocks of greywacke contain unbroken coralline fossils. The greywacke is consolidated and where it occurs in coarse-grained and massive beds it forms a hard and compact rock. The fine-grained interbeds in the northern part of the area are conspicuously lacking in strength and when exposed are susceptible to rapid weathering and slaking. Landslips are common where these beds occur on steep slopes.

ø Unpublished reports of Island Exploration Co.Pty.Ltd. -
Quigley, M., 1939 - Review of the Geology of the Central and South-eastern Part of Permit 2.
Mott, W.D., 1939 - Report on Trans-Finisterre Reconnaissance.

* Personal communication.

The basic rocks are mainly fine-grained, altered dolerites. ~~Thin section descriptions are given in Appendix I.~~ They are nearly all chloritized; some are cut by reticulate veins of zeolites and a little calcite. One specimen, collected 1½ miles south-east of Gawan village, consists of basaltic glass. Much of the basic rock has been highly stressed; it is intersected by innumerable joints and as a result breaks down into small greasy-faced rhombic fragments. Landslips are common on slopes underlain by stressed basic rock. Some bodies of less-altered basic rock appear to be massive and tough, and form very steep or vertical cliffs at constrictions in the Sankwep River.

The limestone is dense and compact, mostly white, and seems relatively pure. The greywacke is covered by a thick crust of travertine adjacent to the main body of limestone cropping out in the bed of the Musom. Travertine dissolved from the limestone forms conspicuous deposits in creek beds. Much of this limestone is strongly fractured and jointed and is likely to contain solution cavities.

STRUCTURE

FIELD DATA

The structure is relatively simple along the valleys of the Busu and Musom Rivers as far upstream as the thick limestone member. The greywacke beds strike a little south of east and have a northward dip that ranges from about 5° to 10° near the Busu River up to 40° at about one-quarter of a mile from the limestone. Higher, anomalous dips three-quarters of a mile south of Gobadik village are probably the result of minor block faulting. At a few hundred feet from the limestone the dip of the greywacke has increased to 75°. The attitude of the limestone itself is not apparent. In the greywacke immediately north of it the dip is reversed to 70° southwards and strikes trend north-east. Continuing upstream, before Bumsa Creek is reached, the strike swings back to south of east, as prevails in the country south of the limestone. The reversal of dip at the limestone member indicates folding and/or faulting; one or more southward-dipping faults probably occur here; the basic igneous rocks lie in the region of anomalous dips and are likely to have been intruded along fault zones.

The structural picture between Bumsa Creek and Sankwep River is not clear. The area is underlain by basic igneous rocks of which some at least are intrusive; these are capped by greywacke whose orientation in some outcrops appears to have been disturbed by the intrusives. The greywacke seemingly occurs as "roof pendants" over, or as screens or wedges within, bodies of basic intrusive rock. Severe crushing of much of the basic rock suggests that a good deal of faulting may have taken place during and after the intrusion; dislocation by faulting and intrusion could account for the apparently random orientations of the greywacke.

It is possible that some of the basics in the valleys of the Sankwep River and Bumsa Creek could be flows interbedded with the greywackes, but no volcanic material was found in the sediments southwards from the belt of deformation to support this idea. The basaltic glass on the ridge 1½ miles south-east of Gawan could be a remnant of a basalt flow that is younger than, and resting on greywacke; remnants of younger flows have been observed by J.G. Best, Bureau of Mineral Resources, farther west along the ranges. On the other hand, fine-grained glassy rocks, occurring in chilled margins to basic intrusives, were noted in 1939 by geologists of the Island Exploration Company working farther west.

PHOTO INTERPRETATION

The area is almost completely covered by rain forest and geology is indicated only indirectly by topography and patterns in the vegetation. These appear to delineate joints or fractures in many places, but the attitude of bedding, where shown at all, cannot be reliably interpreted. For example, in the area south of the main limestone and east of the Musom, where field work shows northerly dips, the lineation in the photos has the appropriate strike but a southerly dip. In other places the lineation appears to strike at right angles to the bedding. In Bumsa Creek a lineation in basic igneous rock appears in the photo to be well developed bedding. However, traverse information has been extended by photo-interpretation to provide a reconnaissance geological map in which mistakes are not likely to have vital bearing on engineering problems.

The most obvious structure in the photos is an apparent fault which trends south-east through the junction between Bumsa Creek and the Musom River. The structure dips steeply to the north-east in some places and may be vertical in others. The area on the north-eastern side contains the basic rocks of Sankwep River and Bumsa Creek and the disturbed greywackes that cap the ridge between them. They are cut by numerous major joints or fractures, and probable faults that strike parallel to the main fault and dip fairly steeply to the south-west. A second obvious structure, a probable fault, crosses the Musom River at the upstream boundary of the thick limestone member, runs north-east and dips steeply south-east. The greywacke on the upstream side strikes parallel to the fault and has the anomalous southerly dip noted during the field traverse up the Musom.

Southwards from the limestone member the strike of the greywackes, based on field traverses, appears to be uniformly eastward. The dips become gentler and the beds appear relatively undisturbed.

ENGINEERING GEOLOGY

Strength and Stability of Rocks

The Sankwep region may be divided into four 'area' (A, B, C, and D on Plate 2), in each of which the rocks have somewhat different characteristics as regards foundations; the blocks are mainly delineated by major structures, probably faults; changes in strength and stability are related to the severity of deformation as well as to the distribution of rock types.

Area A, where the sediments have been least disturbed, consists mainly of greywacke and conglomerate with little jointing or fracturing. Foundation conditions are very good.

Areas B and C lie in the central part of the area where faulting and folding is apparent. They consist of greywacke and conglomerate with some limestone and intrusive basic rock; basic rocks outcrop in Area C but only boulders were noted in Area B. Many subsidiary faults or fractures would be expected in these areas, particularly in the limestone and in the basic rocks.

Both the greywacke and the limestone are competent rocks but sites of foundations and excavations would need careful investigation for excessive jointing, fracturing and faulting. The limestone is liable to contain solution cavities. The shattered basic rock is relatively unstable; it is largely chloritized and numerous joints and minor (?)thrust-surfaces are faced by "greasy" chloritic materials; excavations would need support.

In Area D, which contains the main "basic belt", much of the exposed basic rock and greywacke tend to expand, crack, and scale off. The basic rocks are intersected by numerous closely-spaced joints, lubricated by chloritic alteration products, and deteriorate rapidly. Suitable foundations could be prepared for a structure such as a weir, taking precautions against deterioration of exposed surfaces. Tunnels would present greater difficulties and would probably need complete support in the basics and a fair amount of support in the greywacke.

Seismic Hazard

The Saruwaged Mountains and Huon Peninsula lie within one of the most seismically active areas in New Guinea and are subject to fairly frequent earthquakes but the earthquake hazard in the Sankwep area can only be determined within broad limits.

There are a number of lines of evidence bearing on likely seismic intensity. A fairly prolific source of earthquakes occurs some 25 miles to the south, between Lae and Salamaua ø (epicentre group 1, in Table 1) and even more prolific ones occur 70 miles east-south-east (epicentre 2) and about 200 miles east of the Sankwep area (epicentre 3). The two epicentres east of Sankwep are probably the most important ones because they appear to lie on the eastward continuation of the Saruwaged tectonic trend; the more distant of these epicentres, situated in the 'deep' off the southern coast coast of New Britain, is a source of major earthquakes. Two additional epicentres, from which one earthquake has been recorded, are situated some 65 miles east (epicentre 4) and about 40 miles north of the Sankwep area (epicentre 5).

Some details of earthquakes recorded from these five epicentres in the period 1913 - 1937 are shown in Table 1. In all, 24 shocks were recorded by instrument during this 24 year period of which one was a major earthquake (1920) and another, a shock of considerable magnitude (1936); these two shocks and two additional ones (in 1931 and 1936) probably produced earthquakes in the Sankwep area of intensity approximating M.M.8 ☆. Earthquakes in 1925, 1927 and 1930 probably produced intensities of about M.M.7 in the same area. This evidence would indicate therefore that in a period of eleven years (1925 - 1936) the Sankwep area was subjected to seven earthquakes of intensities ranging say between M.M.6 and M.M.8. According to a graph produced by Newmann☆☆(1945), and assuming a ground period of close to one second in the basic belt at Sankwep, these intensities would suggest accelerations ranging from .05g to .15g. These figures are, of course, approximations; the figures for intensities in the Sankwep area have been deduced and, in addition,

ø For convenience, these are termed 'epicentres, Nos.1, 2, and 3 are epicentre groups.

☆ Measurement on the modified Mercalli Scale; this scale of earthquake intensity is detailed in Appendix 1.

☆☆ Newmann F. (1945). 'Earthquake Intensity and Related Ground Motion'. University of Washington Press.

there is apparently no close agreement among seismologists on the relationship between the intensity and acceleration scales.

The only accounts available to the writers of earthquakes in the Sankwep area itself came from a native in the area, now a fairly well educated medical assistant. He estimates that some three or four minor, but noticeable, earthquakes occur each year; the intensity of these shocks probably ranges between 2 and 5 on the modified Mercalli Scale.

The most recent major earthquake felt in the area was confidently dated as 1935 by this man; his memory of the damage is vague except for cracks in the ground, and the terror of the natives; landslides seemed to have followed the earthquake, presumably when rain saturated ground disturbed by the vibration. The intensity may have been as high as M.M.8, with a probable maximum acceleration exceeding .1g.

This earthquake is readily identified as that which occurred on 20/9/35; it was a major earthquake coming from one of the three centres of major earthquakes in the Sepik area, some 300 to 400 miles north-west of the Sankwep area. It was strongly felt along the entire coastal belt, and along the Markham Valley.

This earthquake is additional to those already noted between 1925 - 1936 and brings the total of fairly strong shocks in the Sankwep area during that period to 8. No details are readily available of seismic activity in this area since 1937; it may well have been less pronounced, as activity tends to be episodic, but the record of 1925 - 1936 could obviously be repeated in the future; this suggests a maximum seismic intensity of about M.M.8 in the basic belt, with maximum accelerations of .1g to .2g.

This assessment assumes that the broad seismic pattern is not likely to change in the near future; seismic intensity at Sankwep would rise steeply if a major earthquake were produced from any of the four epicentres within a hundred miles, from which, in the past, no major earthquake has been recorded.

It is considered reasonable, at this stage, therefore, to assess seismic hazard at Sankwep in terms of maximum accelerations of .1 to .2g. This suggests that installations at Sankwep should be designed to take .2g; however, because of the probable high cost, it may be more practicable to design for .1g and accept some element of risk. Sound foundations in the least fractured rock should be sought for weirs, power stations and anchor blocks for penstocks, and allowances made for vibration and differential movements in penstocks.

The main hazard appears to be in damage to the tunnel and to the lining, because the tunnel would lie mainly in the shattered basic belt in which earth movements are likely to reach their maximum in this area; moreover, actual movement could presumably take place on some of the faults within this belt during an earthquake.

A rough assessment of possible damage to a tunnel in the basic belt can be attempted in terms of maximum accelerations of .1 to .2g. Extensive wrecking of the tunnel and its lining, as happened to railway tunnels in granite and weathered granite near Bakersfield, California, in 1952, would be very unlikely with maximum accelerations of this order. Damage to the tunnel itself is likely to be restricted to caving and falling of blocks;

the portal sections are the most likely ones to be affected, but since the "backs" along the tunnel would average little more than 250 feet, badly fractured sections anywhere along the tunnel tend to cave or to contribute detritus. The tunnel lining would be subjected to additional stresses in weak sections and a fairly rigid lining like un-reinforced concrete would tend to crack. The emphasis falls, therefore, on strong but flexible support, particularly in portal sections and weak zones, and on a flexible lining, such as steel.

Innumerable landslips, both old and new, are no doubt partly the result of earthquakes; a tremor in recent years actually changed the pattern of underground water circulation, and affected surface drainage to a lesser degree, in the hills bordering the Markham valley, some 30miles west of Sankwep. ☆ A large tributary of the Leron River was completely dammed by landslip in 1958, resulting in a major flood of silt-laden water when the dam was breached. ☆☆

Damming by landslip, in which earthquakes probably play some part, is possible in any of the rivers flowing southward from the Saruwageds; the damage to hydro-electric installations in such an event might well be limited to interruption of power generation but there remains the possibility of reduction of pondage by siltation or of damage to a weir or power station; siltation would become a major hazard if installations included a dam of high trap-efficiency in contrast to a diversion weir.

ENGINEERING PROJECTS

Weirs

Possible weir sites were not examined in any detail but weirs to divert water to either of the possible tunnels would be founded on basic rocks. Constrictions in the Sankwep valley in this area are formed in the most massive basic rocks and should obviously be favoured for weir sites.

Sites with narrow cross-sections are available for Tunnel A, and although the basic rock is jointed, fractured and chloritized, foundations adequate for a low diversion weir should present little real difficulty. In the case of Tunnel B, a shift of half a mile upstream or .4 mile downstream from the present tentative location would provide a narrower cross-section and stronger foundations for a weir.

Rapid weathering and deterioration of exposed surfaces in foundations might have to be countered by protective spraying during construction but these and other problems would be clarified by detailed investigation and diamond drilling.

Weirs would need to be designed to withstand a fairly major earthquake.

☆ Personal communication - J.G. Best, Bureau of Mineral Resources.

☆☆ Personal communication - Patrol Officer, Kaiapit, December, 1958.

Tunnels

Two possible tunnel routes have been suggested (Plate 2). Tunnel 1 is about a mile long; tunnel 2 is nearly two miles long. Both tunnels would lie almost entirely in the basic belt; tunnel 1 is much shorter, but would provide some 750 feet of head against approximately 900 feet available from tunnel 2. Any tunnel line in the present scheme would have to cross the main (?) fault along the south-western margin of the basic belt.

The downstream portal of both possible tunnels lies close to two faults, if the present interpretation is correct, and would need to be shifted probably to the north-east.

Where the structure is relatively simple, geological reconnaissance can indicate the distribution of rock types along a proposed tunnel with fair accuracy; this cannot be done in this case, because outcrop detail is meagre and because surface rocks, particularly if they are sediments, cannot be projected to the level of the tunnel with any confidence. Greywackes on Gawan ridge appear to be pendants on intrusive basic rocks, so that any tunnel from the Sankwep south-westward to the main fault would probably lie mainly in basic rocks with some bands of greywacke occurring as screens, wedges or fragments within and between basic rocks. The basic rocks would presumably show the same wide variations in type, hardness and degree of fracturing and weathering as they show in the Bumsa and Sankwep sections.

On the south-western side of the main fault, in Block B, tunnels should traverse fractured and steeply inclined greywacke with little or no intrusive basic rock. The backs in either of the tunnels would not exceed a maximum of 450 - 500 feet and should average about 250 feet; for the most part the tunnels would lie close to or below the watertable.

It should be noted that even detailed investigation, including fairly close diamond drilling, in the basic belt would not be likely to provide a complete forecast of rock conditions along a tunnel crossing the strike of the belt.

The main difficulties in constructing a tunnel and the main sources of expense over and above that estimated for construction under favourable rock conditions, would lie in driving in bad ground, in support and in lining.

At this stage it would seem wise to allow for some support for the whole length of tunnel traversing the basic belt. The type of support necessary would presumably depend partly on the strength of the lining used, but might range from steel ribs and lagging in the worst sections to rock bolts in more massive rock. Used in the normal way, rock bolts are not efficient in closely fractured rocks but recent experiments by the S.M.H.E.A. in consolidating fragments or gravels by mesh and rock bolt might well have an application in a circular tunnel in basic rocks and would provide a suitably flexible support. Sections of the tunnels in greywacke should need less support but this would depend on the degree of fracturing in the greywacke and the number of fine-grained interbeds present. Considering that the greywacke section of either tunnel has a main fault at one end and a portal at the other, both likely to need close support, it would be wise to budget for support in at least half of the greywacke section.

Tunnels would need lining, apart from hydraulic considerations, to control small rock falls and to safeguard the turbines from rock fragments, scaling off the basic rocks. The earthquake hazard would presumably rule out ordinary concrete in favour of a more flexible lining such as steel.

Penstocks

The penstocks would be founded on greywacke and limestone in Block B, where fracturing is less intense than in the basic belt. Boulders of basic rocks found on the track to Gawan indicate that some of these rocks occur in Block B, but probably to only a minor extent. A penstock line with anchors placed in firm greywacke or limestone seems quite practicable but since outcrops are poor on this slope, a very detailed investigation, including costeaning and diamond drilling would be needed to determine the most practicable route and lay out; it may not be practicable to follow the most direct route from tunnel to power station.

To minimize earthquake damage, anchor blocks should be installed in the firmest foundation available and allowance made in design for differential movement in the penstocks.

Power Stations

No real difficulties are expected in siting a power station in the vicinity of its tentative location, which is close to the contact of limestone and greywacke in Block B. On present indications, the greywacke is likely to provide the better foundations. Further investigation would be combined with the examination of routes for the penstocks.

FURTHER INVESTIGATIONS

Although the information yielded by this short reconnaissance is very incomplete, the writers feel that if the scheme is to be proceeded with, nothing less than a full scale investigation is likely to provide more precise data for the engineers; much more geological work needs to be done but, without costeaning and drilling, this is unlikely to throw much more light on rock conditions along tunnel and penstock lines.

Further investigation would require, therefore, construction of a jeep road into the Gawan area to give access to drills and to supply vehicles. Surveying, drilling, costeaning geological and geophysical work might then be carried out concurrently. Investigation should begin on the tunnel because this appears to be the most difficult part of the scheme. The following is a tentative programme for investigation which at least shows the scope of the work to be done.

1. Relocation of tunnel line or lines on data now available.
2. Surveying and clearing of tunnel line; regional and detailed geological, and probable geophysical work commences.
3. Drilling of tunnel line, starting in the basic belt, with vertical holes at initial intervals of 500 feet. Except for regional work, effort concentrated on the tunnel line; no estimate of possible footage can be given because drilling results may necessitate closer drilling interval or require exploratory drilling to guide relocation of the tunnel.

Possible weir sites would be examined in detail and costeaned late in this phase.

4. With a practicable tunnel assured, weir sites would be drilled; surveying and geological examination of the penstock-power house area completed.

5. Drilling to confirm foundations for penstock anchors and power station.

No reliable estimate of drilling footage can be given but the complete programme would probably involve drilling of the order of 7,000 feet, which would be likely to take a number of years if only one drilling plant were available.

CONCLUSIONS

The Sankwep is not an attractive site for a hydro-electric scheme for a number of reasons; rocks and structures present difficulties, earthquakes provide some hazard, detailed investigation will be expensive, the cost of the tunnel will be difficult to assess and maintenance is likely to be heavier than on a scheme constructed in more suitable terrain.

Doubtless, the scheme could be constructed, but the writers feel that the estimated initial cost of the Sankwep scheme would need to be very significantly lower than that of alternative schemes, such as that on the Upper Ramu River, to warrant its selection.

It is hoped that the information provided in this report will prove sufficient for preliminary costing and for a decision to be made without incurring the expense of additional investigations.

TABLE 1

EARTHQUAKES IN THE REGION OF HUON GULF, NEW GUINEA.

1913 - 1937

(Records from Riverview College Observatory, Sydney)

EPICENTRE GROUPS (Approximate Position)	Date of Recorded shock	Relative movement ☆	Information on Intensity ✻	Writers' Remarks
1 25 miles south of Sankwep Area	31.10.27	?	M.M.6 at Morobe	Likely M.M.7 at Sankwep.
	28. 8.28	2	?	?
	18. 5.30	6	M.M.7 Markham Valley and Morobe	Likely M.M.7 at Sankwep
	29.12.36 ø	88	M.M.5 Rabaul and Duke of York Island.	Strongest shock from this epicentre, likely M.M.8 Sankwep.
2 70 miles east-south-east of Sankwep Area	11.10.13	35	?	
	21.10.19	3	?	
	25. 8.20	16	M.M.5 at Morobe	Likely M.M. 5-6 at Sankwep
	6. 1.21	3	?	
	4. 2.25	2	?	
	21. 3.25	1	?	
	10. 9.25	4	M.M.5 at Rabaul.	Likely M.M.7 at Sankwep.
3 200 miles east of Sankwep Area	1. 2.20	2	?	
	2. 2.20	165	Major earthquake. M.M.9-10 Gasmata - much damage. M.M.6 Losuia, 5-6 Cape Nelson.	Likely M.M.8 at Sankwep.
	3. 2.20	5		
	7. 2.20	3		
	9. 2.20	5		
	5. 1.23	5		
	8. 7.25 ø	3	M.M.4 at Gasmata	Minor at Sankwep
	14. 8.25	1		
	22. 3.26	6		
	3. 5.27	3		
	3. 7.29	1	M.M.1 - 2 at Kieta	Minor at Sankwep
4. 65 miles east of Sankwep Area	5. 5.36 ø	7	?	Likely M.M.7-8 at Sankwep.
5 40 miles north of Sankwep Area	17. 6.31	7	M.M.7 Markham Valley and Morobe.	Likely M.M.7-8 at Sankwep.

ø Provisional epicentre.

☆ Relative movement at Riverview - may be taken as a guide to relative strength of these shocks.

✻ Intensities in the records are given in terms of the Rossi-Forrel Scale (1 - 10); for purpose of informity in this report, these are converted to modified Mercalli (1 - 12) by adding one to the R.F. reading.

APPENDIX 1

MODIFIED MERCALLI INTENSITY SCALE

1. Not felt except by a few under specially favourable circumstances.

2. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

3. Felt quite noticeably indoors, especially on upper floors of buildings but many people do not recognise it as an earthquake. Standing motor cars may rock slightly. Vibrations like passing of lorry. Duration estimated.

4. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors, disturbed ; walls make cracking sound; sensation like heavy lorry striking building. Standing motor cars rocked noticeably.

5. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.

6. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

7. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; some chimneys broken. Noticed by persons driving motor cars.

8. Damage slight in especially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbs persons driving motor cars.

9. Damage considerable in especially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

10. Some well-built wooden structures destroyed; masonry and frame structures and their foundations destroyed; ground badly cracked. Rails bent. Landslips considerable from river banks and steep slopes. Shifted sand and mud. Water splashed over banks of rivers, etc.

11. Few, if any, masonry structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and landslips in soft ground. Rails bent greatly.

12. Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown upward in the air.

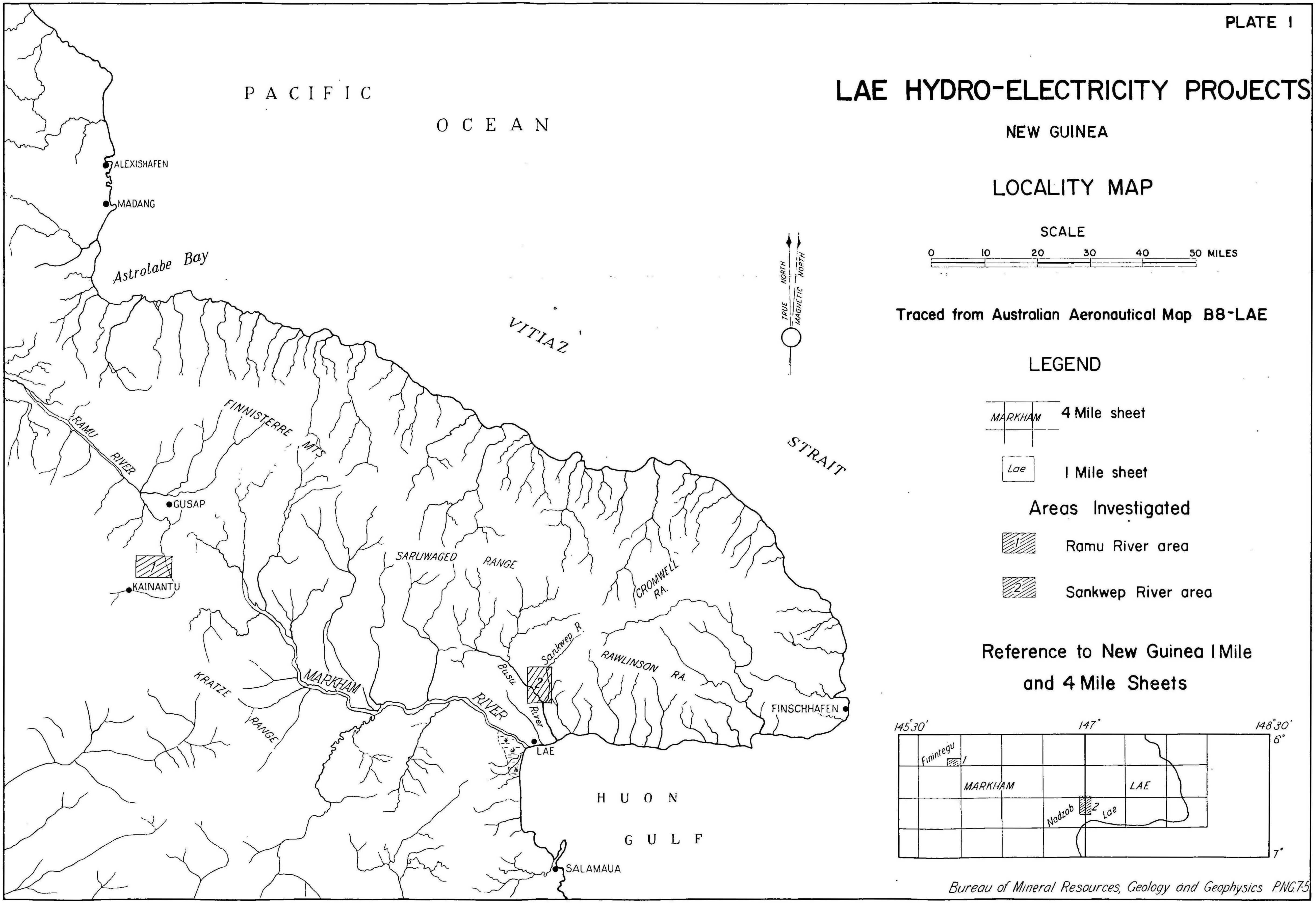


PLATE I
LAE HYDRO-ELECTRICITY PROJECTS
NEW GUINEA
LOCALITY MAP
SCALE
0 10 20 30 40 50 MILES
Traced from Australian Aeronautical Map B8-LAE
LEGEND
MARKHAM 4 Mile sheet
Lae 1 Mile sheet
Areas Investigated
1 Ramu River area
2 Sankwep River area
Reference to New Guinea 1 Mile and 4 Mile Sheets
145°30′
147°
148°30′
6°
7°
Finintegu
MARKHAM
LAE
Nadzab
Lae
TRUE NORTH
MAGNETIC NORTH
PACIFIC
OCEAN
ALEXISHAFEN
MADANG
Astrolabe Bay
VITIAZ
STRAIT
FINNISTERRE MTS
RAMU RIVER
GUSAP
KAINANTU
SARUWAGED RANGE
CROMWELL RA.
RAWLINSON RA.
Sankwep R.
Busu River
MARKHAM RIVER
KRATZE RANGE
LAE
FINSCHHAFEN
HUON
GULF
SALAMAUA
Bureau of Mineral Resources, Geology and Geophysics P.N.G.7-5

PLATE 2

LAE HYDRO-ELECTRICITY PROJECTS

NEW GUINEA

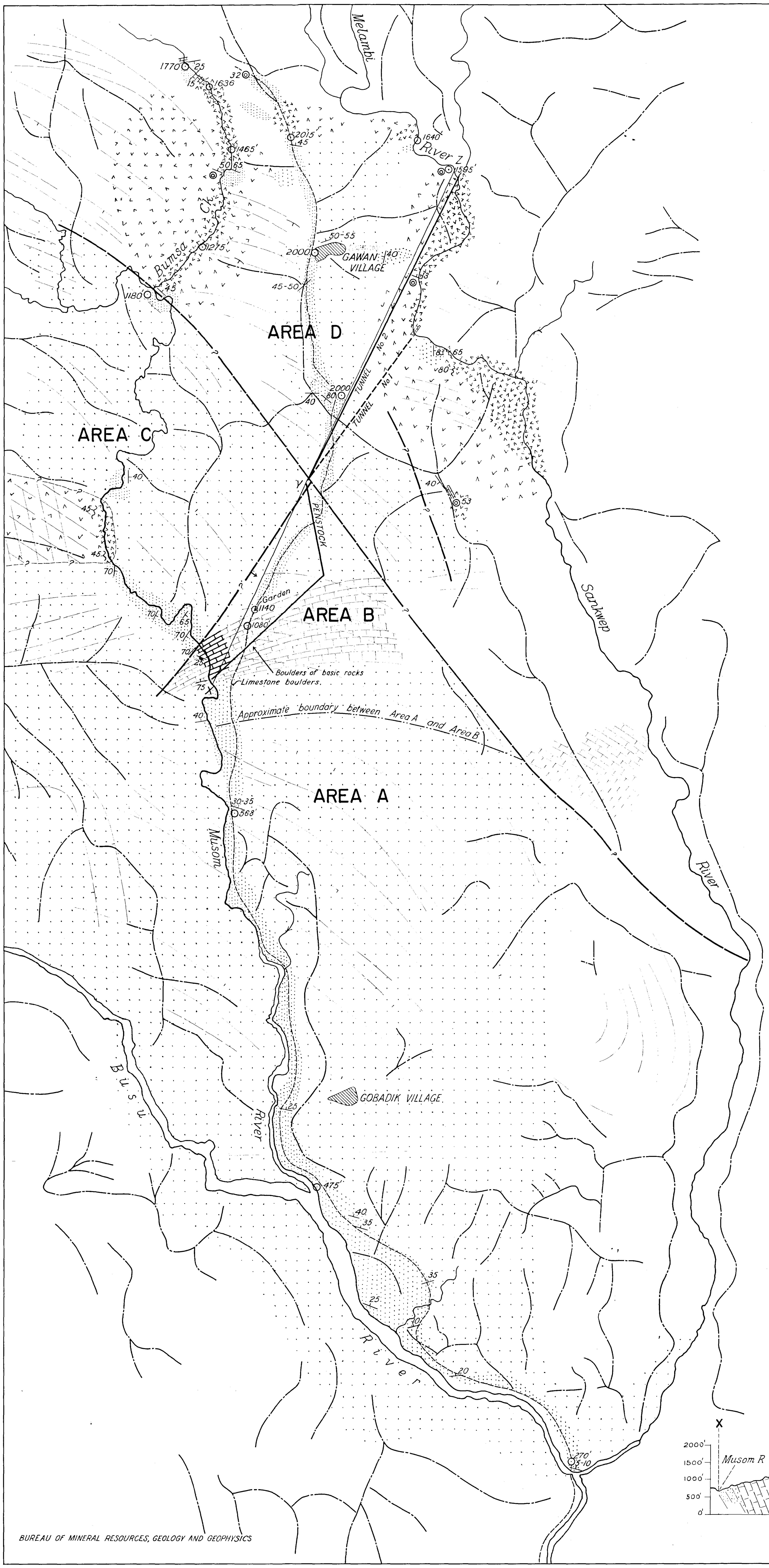
GEOLOGICAL RECONNAISSANCE OF THE SANKWEP RIVER SCHEME

APPROXIMATE SCALE

Based on Reconnaissance Traverses and Photo-Interpretation

by L. C. Noakes & D. E. Gardner

February 1959



Legend

Field Mapping

- *Greywacke and greywacke-conglomerate*
- *Limestone*
- *Basic igneous rocks*
- *Strike and dip of bedding*
- *Strike and dip of lineation or banding in basic igneous rocks*

Photo-interpretation

- *Greywacke and greywacke-conglomerate*
- *Limestone*
- *Basic igneous rocks*

Trend of dominant lineations from Air Photos (Probably joints or fractures)

- *Vertical*
- *Steeply inclined*
- *Steeply inclined, but direction of dip indeterminate*
- *Linear structure interpreted as probable fault*
- *Ridge*
- *Gully*
- *Spot height (aneroid)*
- *Foot track*
- *Specimen collected*

Section X-Y-Z

Along the longer of the two possible tunnels

Natural Scale