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Musa River Hydro-Electric Scheme, Eastern Papua: Conclusions and Recommendations from 1970 Geological and Geophysical Investigations

by

E.K. Carter

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MUSA RIVER HYDRO-ELECTRIC SCHEME, EASTERN PAPUA : CONCLUSIONS AND RECOMMENDATIONS FROM 1970 GEOLOGICAL AND GEOPHYSICAL INVESTIGATIONS

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PREFACE

This Record sets out the conclusions drawn from two geological studies and one geophysical study of the site for the proposed development of the Musa River for hydro-electric power by damming the Musa Gorge in the Didana Range, Eastern Papua (see Plates 1 and 2). The field work was carried out in 1970. Recommendations are also made for further geological and geophysical investigations of the preferred damsites and for other necessary studies relating to the feasibility and design of the scheme and the impact of the scheme on the region.

The studies referred to above are reported in:

"The geology of the proposed Musa River hydro-electric project area, Eastern Papua", by G.P. Robinson, PNG Geological Survey Note on Investigation 71-007. This report deals with the regional geology of the scheme, including the storage area, and refers briefly to two possible alternative schemes on the Adau River (Boroboro Gorge) and the Awala River (Awala Gorge).

"Geology of the Musa Gorge damsite area, Eastern Papua" by L.F. Macias, PNG Geological Survey Note on Investigation 71-008. This report deals with the five prospective damsites and associated structures selected for investigation in the Musa Gorge.

"Musa River hydro-electric scheme, geophysical investigation, 1970", by F.J. Taylor, Bureau of Mineral Resources Record 1971/121. This report covers the geophysical investigations carried out in the Musa Gorge area and a single seismic traverse near Safia airstrip.

This Record has been written, at the request of investigating engineers of the Commonwealth Department of Works, in order to bring together in one report the results of the three investigations and to present an integrated set of conclusions and recommendations. The author provided senior technical supervision of the geological investigations of the scheme and collaborated in the planning and interpretation of the geophysical work. He visited the site on two occasions.

The conclusions and recommendations were agreed to by all concerned with the investigations, and represent the Bureau's view. They are essentially based on geological considerations (as determined by the geological and geophysical observations) and do not fully take into account the implications, in terms of cost, of other, non-geological, considerations. For example, no calculation has been made of the volume of fill that would be needed for a fill dam at each site; therefore in recommending one site in preference to another, factors such as depth of weathering, rock types present, and known geological structures have been given greatest weight, although crest length has been considered.

CONCLUSIONS

RESERVOIR

1. Provided levels around the reservoir are as indicated on existing maps, there is no risk of leakage from the reservoir as the shortest leakage path is about 8 km. Any leakage would be wholly or largely through rocks, which, where fresh, have only fracture permeability - and this is expected to be slight.

2. Slopes within the main reservoir area (i.e. other than the Musa Gorge, for which see 3 below) are generally gentle, but some are composed of soft material which may fail if saturated. Robinson (1971, p.71) refers to three localities where debris avalanches and debris flows could occur:

(a) around the northwestern margin of the proposed reservoir, where poorly consolidated sandstone and conglomerate of the Domara River Beds occur;

(b) in the southeast, resulting from failure of the poorly consolidated Boroboro Conglomerate;

(c) east of Boroboro Gorge, where the proposed reservoir would cover the lower part of the Ibinambo alluvial fan.

Any failures within the main reservoir area would not affect the operation or capacity of the scheme.

3. Slopes within the gorge are steep and of strong rock, but joints, shears, and faults could produce areas of instability. Numerous old slides have been recognized (see Maffi, in Cumming & Carter, 1969), and one, apparently geologically very recent, slide between damsites 2 and 3, indicates that slope stability within the gorge should be carefully studied.

4. The size of the proposed reservoir for full development of the river system (with full supply level at about 250 m - 800 feet - above sealevel) is such that, even in a stable area, measurable depression of the land surface about the reservoir, and significant increase in seismicity, could be expected as the reservoir fills. As the scheme is sited in a tectonically active area the geodetic and seismic effects of filling may be greater than in a stable area. Both parameters should be fully documented and measured.

DAMSITES

1. A very large landslide mass, possibly containing 5,000,000 m^3 of rock and debris, is present on the left side of the river to the east of control point 'Lollo'. The stability of the mass and the condition of the constituent mass have not been established. However, until proven otherwise it must be assumed that the mass is potentially unstable as

the toe has been eroded away; immersion in the waters of a reservoir would increase the likelihood of further movement. The slide lies between the axes of prospective damsites 2 and 3 (Macias, Plate 8) and a fill dam at either site 2 or 3 would extend into the area of the existing slide mass. The stability and useability of the rock of the slide mass need to be considered in the selection of the most economical damsite. The determination of the configuration, stability, and condition of the rock forming the slide mass should therefore be an early objective in the further investigation of the scheme. Up to 30%, by volume, of the upper part of the slide mass appears to consist of sediments and volcanics of the Domara River Beds and scree which are of dubious value for use as fill. The remainder of the slide mass consists of ultramafic rocks, the condition of which has not been determined. The exposed rock in the left bank of the river in the slide area is generally sound; if it forms part of the slide mass, most of the ultramafic rocks in the slide could probably be sound enough for use as rock fill. Relatively low seismic velocities in ultramafic rock which is presumably below this slide surface suggest possible 'damage' to the bedrock near the slide.

2. All the five prospective damsites are in ultramafic or mafic rocks of the Didana Ultramafic Complex. The rocks are all igneous rocks but they show a fair range of mineral composition, due to variations in original composition and subjection to various type of alteration (other than weathering). The main types of alteration are serpentinization, uralitization, and carbonatization (described by Macias, 1971, p.16), which have altered the rock fabric to some extent and produced new minerals, including serpentines, talc, and carbonates. Serpentine and talc are soft and 'greasy' and where present probably reduce the compressive and shear strength of the rock mass. The presence of carbonates would also tend to weaken the rock. The rocks present in the five damsites therefore probably have a fairly wide range of mechanical properties, but where fresh should be amply strong for any type of dam structure of the height under consideration. Seismic velocities obtained for the highest velocity refractors on the various traverses below R.L. 250 m (820 feet), range from 2,600 m/s (8,500 ft/sec) to 4,570 m/s (15,000 ft/sec). Most are 3,000 m/s (10,000 ft/sec) or higher. The lower velocities occur well above river level and are probably due to slight to moderate weathering and, or, close-spaced and slightly open joints. Consolidation grouting would possibly substantially improve the mechanical properties of the rock mass. Values for Poisson's Ratio of from 0.14 to 0.31 and of modulus of elasticity of 0.80 X 10^{-5} to 4.80 X 10^{-5} kg/cm^2 have been obtained from the seismic work (for qualifications see Taylor, 1971, p.6). The distribution of serpentine, talc, and carbonates in rock specimens whose mineral content has been determined suggests that they are less abundant upstream of damsite 3 than downstream (see Macias, 1971, Plate 5), but it is not known how representative the specimens are. The mechanical properties of a range of rock types collected for the purpose should be determined at an early stage.

3. Exposed rock at, or near, river level is generally fresh to slightly weathered, but some moderately weathered rock has been observed. Higher up the slopes exposures, except in cliffs (which could not be

examined), are sparse; most of those examined were moderately to completely weathered. The seismic work shows that the depth to the highest velocity refractors (measured normal to the natural slope) ranges from 5 to 42 m; in general depth of weathering increases with height above river level*. Many sections of the prospective dam axes were not covered by seismic traverses. Low seismic velocities may be due to the presence of soil and scree, weathered bedrock, or jointed or sheared bedrock. The material giving velocities of 300 to 1700 m/s should readily be removed by mechanical means. The thickness of weathered rock for damsites 1 to 3 given by Macias (1971, Plate 9) can be taken, for purposes of comparison between sites, as the amount of stripping needed for either a concrete or a fill dam. Few data were obtained for damsites 4 and 5 as access was only possible to elevations well above crest level.

No direct evidence was obtained as to the depth to sound rock below the river. Rapids in a number of plans could indicate that the river is shallow; however, rapids could also be caused by accumulations of large blocks or boulders of rock, such as the remnants of large rock falls from the gorge walls. In situ rock in the river bed is almost certainly at least as fresh as that in the banks at river level; the level at which fresh rock occurs is probably not higher than those indicated in seismic traverses A7-A10.

4. Both banded and massive mafic and ultramafic rocks occur but the banding does not constitute planes of weakness. The bedrock is extensively jointed. Data on frequency, openness, and orientation of joints are given by Macias (1971, pp. 12 and 13, figures 10-13, 15-19 and various photographs). Joints in exposed rock are closely to moderately spaced, and are tight to 10 cm open. A few are filled with serpentine or carbonates. No strongly preferred orientation was noted. Joints parallel to the slopes of the gorge, on both sides of the river, were recorded. The orientation of joints and of intersections of joint planes will have an important bearing on the stability of the gorge walls and of excavated surfaces.

A total of 76 shear zones were observed in the area mapped (see Plate 1); the zones mapped range in width generally from 15 to 60 cm but up to 4 m. Some irregularities in seismic profiles are interpreted by Taylor as due to shear zones. Only one possible fault was observed, but in view of the tectonic history of the area, extensive shearing and faulting should, at this stage, be assumed to occur in any foundations, tunnels, or other excavations. Weathering is expected to be deeper in shear and fault zones than elsewhere. Further detailed investigation of the selected site or sites will be needed to confirm that there are no rock defects present that would seriously impair the suitability of the site.

* Seismic traverses A7-A10 were, it is considered, carried out on accumulations of scree and alluvium - all except A10 are on the inside of a river bend, and A10 is below a large accumulation of scree - consequently the thicknesses of low velocity material indicated are considered not to be representative of the lower slopes. Many slopes display extensive exposed rock in which sound rock at a depth of a few metres could be expected.

5. The rocks, being of igneous origin, have no significant intergranular permeability, but the presence of joints, shears, and faults creates local zones of slight to high permeability. Normal excavation for the cut-off would remove most of the material with high potential for leakage, and normal grouting procedures, if properly designed, would provide a zone below the dam with satisfactorily low permeability.

6. Because of the jointing and suspected presence of shears and faults, stripping of unsound rock to expose rock of adequate bearing strength is expected to leave a fairly irregular surface. The surface will require dental treatment, blasting, or line drilling to remove protuberances, or build-up of batters with concrete, to produce an acceptable profile. Where planar defects are unfavourably oriented some rock bolting may be needed for safety and to avoid the need to remove slabs and wedges of rock. The possibility of joints parallel to the stripped surface which might provide unstable conditions should be fully investigated at the design or construction stage.

7. As slopes are generally extremely steep, stripping of foundations, will create unstable conditions above the excavation; allowance must therefore be made for stripping and stabilization of slopes well above the crest level of any dam.

<u>Comments on Each Damsite</u> (see also Macias, 1971, pp. 17-21)

<u>Site 1</u>:

(a) Has the greatest crest length of any of the five sites, measured between natural slopes at R.L. 250 m.

(b) Is upstream of the major landslide and far enough from it to not be directly affected by any movement on the slide.

(c) Apparently has rock at least as sound as other sites, but stripping depth overall may be greater than elsewhere.

(d) A photo-lineament in the right bank could represent a significant structural defect. Joints parallel to the slopes on both sides, and shears up to 4 m wide, have been noted.

<u>Site 2</u>:

(a) Has the shortest crest length (measured at R.L. 250 m between natural slopes).

(b) The axis, as shown by Macias (1971, Plate 8), is upstream of the major landslide, but the downstream toe of a fill dam would extend onto the slide mass. The left-hand end of the axis could probably be moved slightly upstream to reduce, but not eliminate, this problem. The possibility of 'damage' to the bedrock adjoining the slide mass should be borne in mind.

(c) Rock which would form foundations is generally of adequate strength (it includes a gabbro intrusion on the left bank, near the slide). However, the rock above the right abutment has a seismic velocity of only 2,600 m/s (8,500 ft/sec); should rock of this quality extent into the abutment area it may prove unsatisfactory, without extensive remedial action, for the abutment of a concrete structure. A photo-lineament (probably a continuation of that at damsite 1) has been recognized in the right bank (see also Fig. A2-1 in BMR Record 1969/76), and two in the right slope. Exposed rock, particularly in the left abutment, is broken and sheared in many places.

(d) The area between the right abutment and 'Rebel' survey control point probably lends itself to an open-cut spillway more readily than the other damsites do.

Site 3: (a) Has a crest length about 30 m longer than Site 2 and 10 m longer than site 4; however, the volume of fill required for a fill dam at site 3 would probably not be greater than for site 4.

(b) Is downstream of the major slide, but the upstream toe of any fill dam would extend onto the slide. Until proved otherwise, it must be assumed that a dam should not be constructed at Site 3 unless the slide mass is removed or stabilized.

(c) Rock at the site is possibly slightly more altered and weathered than at other sites, possibly due to proximity to the major slide. Seismic velocity near crest level in both abutments is only 2,750 m/s (9,000 ft/sec), which may not be satisfactory for a concrete dam.

(d) Depth of weathering appears to be less than on most, or all, of the other sites. However, the left downstream part of any fill dam would rest against a narrow spur which may prove to be deeply weathered. The fill could block the mouth of 'Old Village Gully'.

(e) A scarp occurs above the left abutment. Its origin is not known but the area should be closely examined for evidence of further landsliding behind the existing major landslide.

(f) Photo-lineaments have been recognized in the left bank near river level and above crest level; another may extend into the damsite area on the right slope.

Site 4: (a) Has the second shortest crest length of the five damsites. It is downstream of the large landslide.

(b) There is no direct seismic evidence of depth of weathering and open-jointing except near river level, on the right bank (seismic traverse A9), where the highest velocity refractor is at a depth of about 9 m (30 feet). Exposed rock at this point is slightly to moderately weathered.

(c) A photo-lineament occurs in the left abutment and a feature a short distance downstream (and possibly intersecting the axis below the river) has been identified both on air - photographs and in seismic traverse B5. It may be a fault or a dyke; the seismic data strongly suggests mechanically strong material. The lineament was not inspected on the ground.

<u>Site 5</u>: (a) The axis as shown by Macias (Plate 8) is at an angle to the river flow. The right abutment could possibly be moved upstream a short distance. The crest length, without stripping, is the second longest of the five sites; in addition, the dam would have to be nearly 10 m higher than a dam at site 1 to impound water to the same R.L. as a dam at site 1.

(b) The site is about 900 m downstream of the large landslide and therefore might not be so seriously affected by reactivation of the slide as the reservoir filled as site 4 would be. However, extensive investigation would be needed to assess the effect of reactivation of the slide.

(c) Upstream of the axis, on the right side, is a large accumulation of scree of unknown thickness. The thickness and condition of the scree, its affect on the design of a dam at site 5, and the performance of the mass if saturated by reservoir waters, would have to be determined.

<u>POWER STATION SITES</u>

1. Most of the flat or gently sloping ground, suitably placed for a power station in respect to the various damsites, is probably of unconsolidated scree and alluvium. Seismic traverses A7 to A9 reveal material which gives velocities of 1,520 to 1,920 m/s (5,000 to 6,300 ft/sec) and is from 4 to 28 m thick over strong bedrock. Traverse A9 passed over exposed rock, but in view of the seismic results, the exposed rock may form large boulders. Traverse A10 (1,525 m/s; 5,000 ft/sec) shows a most irregular profile for the highest refractor, suggesting either a most irregular bedrock surface, non-uniform conditions in the bedrock (the velocity of the bedrock is lower than for traverses A7 to A9, but still indicative of fairly strong rock), or possibly extremely large blocks of sound rock resting on the bedrock.

Other flat, or gently sloping, areas occur on the left bank between damsites 1 and 2, and at the mouth of Old Village Gully on the right bank near the mouth of the gully between damsites 1 and 2 (east of seismic traverse A7); and on both sides of the river below damsite 5.

The first two areas could not be used with fill dams, but only with concrete structures at damsites 1 and 3 respectively. Bedrock is exposed or may occur at shallow depth in all of these areas except possibly at the mouth of Old Village Gully.

2. The areas of suspected scree and alluvium may provide inadequate foundations without piling to bedrock for parts, at least, of the station structure unless the power station design requires excavation down to the level of the highest velocity seismic refractor. Any scree and alluvium is probably largely made up of boulders, and testing of the foundations may prove difficult.

3. As any surface power station will be at the foot of a steep slope or a cliff, it will be necessary to establish that the area above the station site is stable and that the site is not likely to be subjected to rock falls. The presence of an extensive mantle of bare rock scree, at angle of rest, on the slopes above the area covered by seismic traverse A10, indicates the need for careful investigation of the safety of the seismic traverse A10 area before it is adopted for the site of a power station.

4. Should it prove impossible to find a satisfactory surface power station site, a site for an underground station could doubtless be found. The behaviour of the rock mass, particularly the friction on joints, could be of great importance for an underground station; this would require detailed in situ and laboratory testing. Any site selected would doubtless be affected by some shear zones but it should prove possible to locate a site free from major defects.

<u>DIVERSION AND OUTLET WORKS</u>

1. Assuming that any diversion tunnel or tunnels would later serve as outlet tunnels from the reservoir to the power station and as outlets for flood waters, the location of the tunnels would be largely dictated by the dam and power station sites selected. However, the area of the major landslide should be avoided.

2. Fresh ultramafic rock, which should be encountered throughout any section of tunnel more than 50 m (and perhaps as little as 10m) beneath (or in from) the nearest land surface, would be amply strong for even large diameter tunnels, with appropriate support and lining. While some differences in engineering properties can be expected in the various rock types which could be encountered, the differences are not likely to be of crucial importance. The differences should, none-the-less, be ascertained as early as possible.

3. In a region of such highly strained rock, significant faults, shears, and joints would undoubtedly be encountered in any tunnels but the available evidence is inadequate to indicate the best location on geological grounds, for a tunnel or tunnels. Studies to date do not indicate any strongly preferred orientation of shears, faults, and joints (though it has proved possible to analyse the distribution of attitudes of joints and shears and to interpret the result in terms of the tectonic

stress field that existed when the elements were formed). No general conclusion can therefore be drawn at present about suitable and unsuitable orientations for any tunnels.

4. The portals of tunnels will probably have to be established in overburden and weathered rock. Because of the steep slopes and the risk of slides and rock falls, portals should be established with as little disturbance to the natural slopes as is possible. Tentative sites for tunnels and portals should be selected on engineering considerations, and geological conditions at the selected sites should then be evaluated.

5. As river bed conditions are unknown, no conclusions can be drawn about the difficulties likely to be encountered in constructing coffer dams. Material suitable for the construction of coffer dams should be available locally. However, the closeness of joints in the mafic and ultramafic rocks will limit the size of blocks available (see under 'Construction Materials').

SADDLE AREA

The topographic saddle to the east of survey control point 'Rebel', along which seismic traverse A6 was run, was considered during early studies of the gorge area to be possibly suitable for a spillway, the excavation of which would yield substantial volumes of construction materials for a fill dam.

1. Seismic traverse A6 (which was not supplemented by seismic cross-traverses) indicates that the saddle area has 4 to 5.2 m (13 to 17 ft) of soil, underlain by a layer with seismic velocities of 1,050 to 1,300 m/s (3,500 to 4,200 ft/sec) which is 19 m (60 ft) thick at the lowest point of the saddle and 30 m (100 ft) thick at the eastern end of the traverse (see Taylor, 1971, Plate 3). The 1,050 to 1,300 m/s layer, which is presumably decomposed bedrock, should be readily removed by earth-moving equipment. Its suitability as impermeable core material is referred to under 'Construction Materials'.

2. The highest velocity refractor, with velocities of 2,450 to 3,700 m/s (8,000-12,500 ft/sec), is probably slightly to moderately weathered and/or open-jointed ultramafic rock. The lowest elevation for the top of this seismic zone is R.L. 296 m (970 ft) - about 52 m above full supply level for the reservoir. At this stage it can be assumed that a large proportion of the high velocity material would be suitable for rock fill; the assumption will, however, need to be tested.

CONSTRUCTION MATERIALS

1. Rock-fill (see Macias, pp.23, 24)

(a) Fresh mafic and ultramafic rock of the Didana Ultramafic Complex should provide rock-fill suitable for use in any part of a 150 m high dam; it is strong, durable, tough, and difficult to break with a geological hammer. Slightly weathered material could probably be used in selected parts of the dam. There is, however, a considerable range in the mineral content and fabric of the rocks present. Some contain high percentages of serpentines, talc, and carbonates which may significantly reduce the strength (particularly shear strength) and hardness of the rock in which they occur (see pp. 4-6). The mechanical properties, including performance under impact and blasting, should be determined for a representative collection of rock types.

(b) Fresh to slightly weathered bedrock is widely exposed at and near river level and in cliffs, and would be encountered at various depths in any excavation for engineering purposes, e.g. the saddle east of 'Rebel', in tunnels and in spillway excavations.

(c) The major landslide on the left side of the river between damsites 2 and 3 may contain useable fill material but extensive investigation would be needed to check the possibility.

(d) Joint blocks in exposures generally range in maximum dimensions from 0.3 to 1.5 m and most quarry product would probably not exceed these dimensions. Joint spacing will therefore impose a limit on the size of blocks for rip-rap, but larger blocks may possibly be obtained at depth.

2. Filter material (see Macias, p.24) could be obtained by using either fine or crushed and sized material from the rock-fill or concrete aggregate quarry or from river gravels, which occur abundantly in the river beds and banks in the Musa basin and less abundantly in the Musa Gorge (see Pounder - Appendix 1 of Robinson, 1971). Fine quarry product from the Didana Ultramafic Complex may, however, contain an unacceptable proportion of soft material.

3. Impervious earth material (see Macias, p.25, and Pounder). Large volumes of earth materials occur as the weathered mantle of the ultramafic and mafic rocks (see, for example, seismic traverse A6 - Taylor, Plate 3) and as alluvium in the Musa basin. However, the suitability of these materials for earth core material has not been established; the alluvium may prove to be unsuitable. The weathered mafic and ultramafic rocks should be systematically tested in the first place.

4. Coarse concrete aggregate (see Macias, p.24). Fresh ultramafic and mafic rock should provide satisfactory concrete aggregate. However, the effect of the various soft and 'greasy' minerals which are likely to be present will need to be established by thorough testing. Present information suggests that it would not be possible to locate a block of ultramafic or mafic rocks, suitable for a quarry for concrete aggregate, which would be entirely devoid of serpentines, talc, or carbonates, but it should be possible to find an area where the percentage of all or most, of these minerals is small.

The river gravels in the rivers of the Musa basin (see Pounder, Plate 1) and in the Musa Gorge (see Macias, Plate 7) would probably provide suitable material for aggregates but they have not been tested or systematically investigated.

5. Fine concrete aggregate. Fine sand occurs in large quantities, generally associated with gravel deposits, in the Musa basin, and probably also in the Musa Gorge. Subject to tests proving satisfactory, these sources should provide ample supplies of fine aggregate.

Fines from any quarry operation in the Didana Ultramafic Complex are likely to contain an unacceptable proportion of soft, and perhaps flaky, material. However, coarse quarry product could possibly be crushed to obtain satisfactory fine aggregate.

OTHER CONSIDERATIONS

1. Of the two gorges inspected as possible sites of comparatively small first-stage power generation schemes, the Boroboro Gorge is cut into poorly cemented and permeable Pleistocene sediments which would not provide durable and watertight abutments or stable reservoir sides, and is not suitable. The downstream end of the Awala Gorge is composed of strong volcanics, which form part of the Urere Metamorphics; the metamorphics are intruded by large dykes and are prominently jointed. On geological grounds, the site appears suitable for a damsite, but no systemmatic study of the site has been undertaken.

2. The region is one of moderate seismicity, though less severe than most parts of New Guinea (as distinct from Papua). Allowance for seismicity should be made in the design of engineering structures (including a surge of reservoir water), particularly as filling of the reservoir could lead to a significant increase in seismicity (see under 'Reservoir').

3. No volcanic centres closer than 45 km from the damsite area and 35 km from the reservoir are known; therefore the scheme is not considered to be subject to the risk of damage by volcanic activity.

4. Nickel, copper, and chromium have been recorded in the Musa River basin area, either in ultramafic rocks or in soil overlying ultramafic rocks and breccia (see Smith & Green, 1961, pp. 37 and 38). All recorded occurrences appear to be above top water level of the proposed reservoir. A number of areas are currently held under prospecting authorities but no economic deposits of these elements have been reported publicly.

Smith & Green also record a small production of alluvial gold from the headwaters area of the Adau River, and showings of gold elsewhere in the Musa basin.

5. Access within the scheme area is generally difficult. Within the Musa Gorge slopes of 35°-45° are common; there are many cliffs. Vehicular movement along the river banks within the gorge would generally require extensive roadmaking, using explosives. Within the main reservoir area movement is restricted by numerous difficult creek and river crossings and areas of swamp; elsewhere in the interfluves roadmaking would be fairly easy.

RECOMMENDATIONS

In the recommendations which follow no account has been taken of the possibility of the development of the Musa River system by stages as no information is available to the Bureau of the likely height of dam and other engineering requirements for the first, and any intermediate, stage. The recommendations are therefore in respect of the full development of the scheme, but most, if not all, should be implemented at the time of the Stage 1 investigation.

SITE SELECTION

Geologically, it is considered desirable to site the dam as far upstream as possible in order to minimize problems arising from instability of the gorge walls. It is therefore recommended that Site 1 be investigated as the preferred site, with Site 2 as the alternative site. Both Sites 1 and 2 may possibly have significant structural defects in the right abutment, and Site 2 may not be as suitable for a concrete dam as other sites, but has other advantages over sites 3 to 5.

An effort should be made to find a secure surface power station site, preferably on in situ rock rather than scree and alluvium, before considering an underground site. No particular site can be recommended at present.

SITE INVESTIGATIONS

1. It is recommended that the configuration and quality of material in the large landslide between damsites 2 and 3 be ascertained by geophysical methods at an early stage of the investigation in order to evaluate its stability and useability as rock fill material. If damsite 1 is selected, however, the landslide need not be investigated, provided no elements of the scheme could be affected by reactivation of the slide and that no construction activity takes place near the slide; the toe of the slide, in particular, should not be disturbed. If damsites 3, 4, or 5 are selected a rigorous evaluation of the stability of the slide mass, particularly when saturated, would be necessary.

2. The selected damsite should initially be investigated to establish feasibility. Methods of investigation should include -

(a) detailed seismic traverses, with weathering spreads, on both abutments and the slopes above the abutments. To achieve this, and for geological mapping, substantial support, including the provision of climbing ropes and ladders, and the clearing of vegetation, will be needed;

(b) seismic or other geophysical methods to determine the depth to sound bedrock below the river. If geophysical methods cannot be used, drilling platforms, for shallow vertical drillholes, will need to be erected in the river;

(c) detailed geological mapping of outcrops in both abutments. As plane tabling will not be possible, the cost of photographing both abutments and producing a contoured outcrop map using a photo-theodolite and automatic plotter should be investigated. Failing the use of a photo-theodolite, a close-spaced reference grid should be laid out over both abutments with numbered pegs;

(d) at the next stage of investigation only a little costeaning may prove practicable, but provision should be made for some costeaning supplemented by pitting to a depth which will reveal mappable structure and enable samples of the weathered material to be obtained for testing as fill material;

(e) to determine subsurface conditions both abutments should be diamond drilled. Oriented drill core should be obtained and holes should be water-pressure tested. Holes should be designed both to ascertain rock quality and to investigate the presence and nature of suspected structural defects;

(f) depending on the results of investigations of the river section, inclined drilling beneath the river from one, or both, banks may be necessary;

(g) in view of the height of the proposed dam, the diversity of rock types present, and the possibility of prominent joints parallel to the abutments, adits or tunnels should be driven into both abutments a distance of 30-40 feet into fresh or slightly weathered rock. The adits would provide material for laboratory testing, a site for in situ determination of the mechanical properties of the rocks forming the abutments (jacking tests, etc.) and for measurements of the stress field would permit a much better evaluation of geological conditions than surface mapping and drilling can provide, and would give a sound idea of the tunnelling characteristics of the rock.

3. Similar surface investigations, probably with some diamond drilling, should be undertaken at the site selected for any spillway.

4. Preliminary investigations of possible surface power station sites should be undertaken, to evaluate foundation and slope stability conditions. The preferred site should then be subjected to detailed geophysical and geological investigation, supported as required by clearing, pitting, and diamond drilling.

5. Tunnel portals and alignments should be selected on engineering considerations. The portals should then be geologically mapped and investigated by geophysical methods. The stability of the slope or cliff above should be assessed. Appropriate methods of subsurface examination will probably depend on site conditions.

6. In order to evaluate what are safe attitudes of joints, i.e. at what angle a block of rock might fail along a joint plane or intersecting joint planes, and to check the general stability of the gorge walls, the occurrence of rock defects (joints, faults, shears) in the gorge walls should be studied systemmatically. Particular attention should be given to the recording of the attitudes of joint planes and intersections of joint planes along which failure has occurred.

7. Resources and properties of potential construction materials should be evaluated both in the field and in the laboratory. Attention should first be given to the possible sources of material of various types in the gorge area, such as weathered bedrock for core material, fresh rock for fill and aggregate, and river gravel and sand. Possible locations are dealt with under 'Conclusions'. The evaluation will require seismic work (if practicable), drilling and augering, and probably some stripping and excavation (or pitting) to obtain bulk samples.

LABORATORY INVESTIGATIONS

1. The suite of specimens already collected, if suitable, should be subjected to a comprehensive range of tests to determine mechanical properties, including the effect of the various minerals present, and their suitability as aggregate.

2. Standard tests for suitability of the various soil, sand, and gravel materials investigated in the field for construction purposes should be carried out.

3. Consideration should be given to the conduct of research into the friction of joints in mafic and ultramafic rocks, to aid evaluation of angles at which slippage occurs. This information is needed to assist in the study of the stability of gorge walls and of blocks of rock in excavated surfaces, (e.g. dam abutments, spillway and road cuts, tunnels). It may be possible to interest a research group (e.g. Professor J.C. Jaeger, Australian National University) in this study.

OTHER

1. Strong motion accelerographs should be installed at the two sites selected, as soon as possible, and arrangements made for records to be changed and interpreted. In addition, it is considered that a strong motion accelerograph should be set up, probably near Safia airstrip. Knowledge of the behaviour of the sediments of the Musa basin, and hence of the floor of the reservoir, during an earthquake would aid evaluation of the likely behaviour of the reservoir waters in such an event.

2. A network of at least three seismographs should be set up in the region as soon as possible to permit knowledge of the seismicity of the area to be built up, for comparison with the seismicity after the reservoir starts to fill. This information is essential for the assessment of any claims for damage arising from local earthquakes which occur after the reservoir starts to fill.

3. Before the reservoir starts to fill a network of permanent, precisely levelled survey marks should be set up in and around the reservoir area to permit the settlement of the land surface resulting from the filling of the reservoir to be measured. The survey marks should be installed as soon as a firm decision is taken to construct the scheme so that three readings, at 2 to 3 year intervals, can be made before filling starts. Information would thereby be obtained on changes in the land surface of tectonic origin. The information obtained on pre-filling and subsequent settlement would be of great scientific value and may have considerable value for the project.

REFERENCES

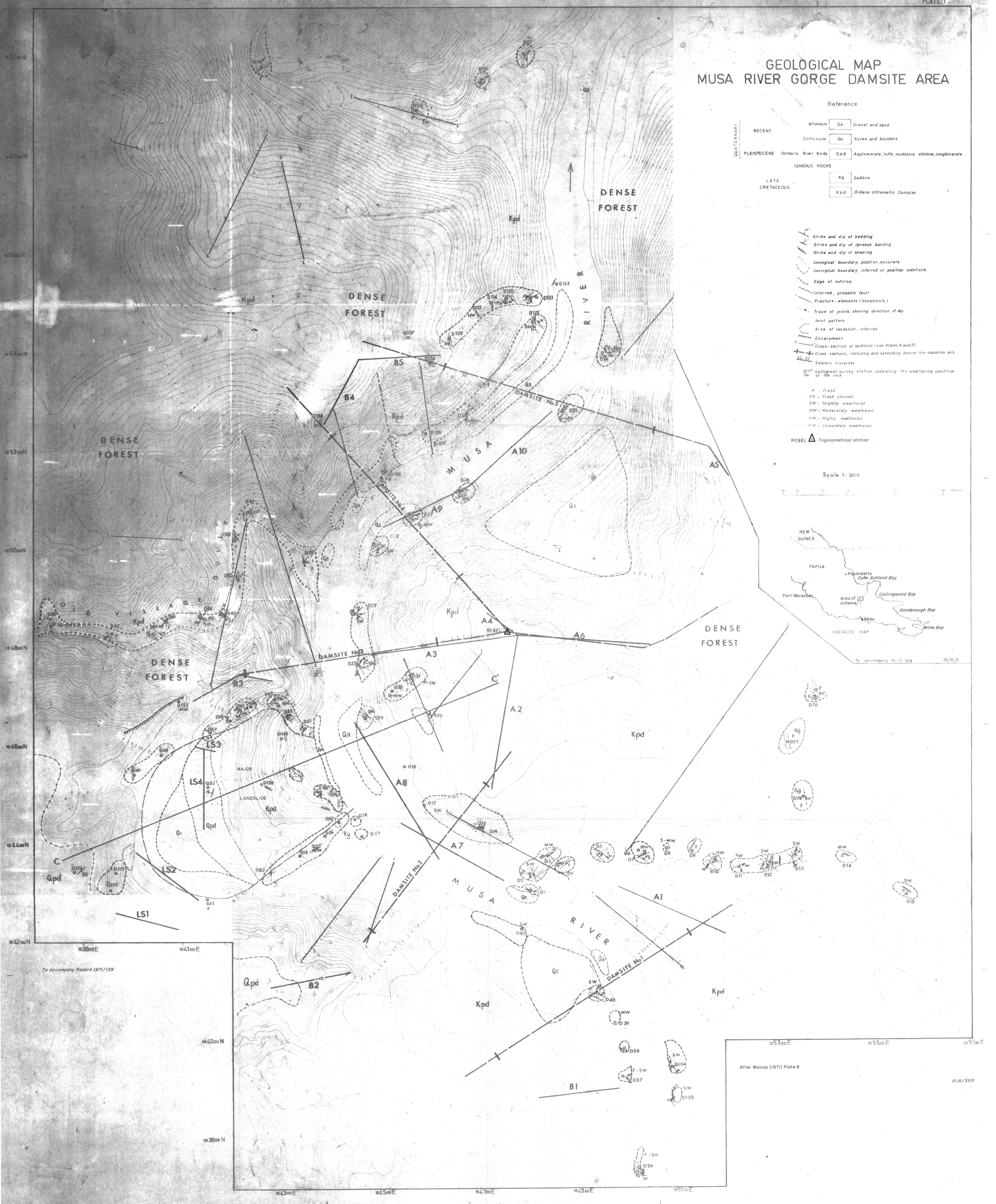
CUMMING, I.S., and CARTER, E.K., 1969 - Appraisal of the geology of the Musa River hydro-electric scheme. Bur. Min. Resour. Aust. Rec. 1969/76 (unpubl.).

MACIAS, L.F., 1971 - Geology of the Musa Gorge damsite area, Eastern Papua. PNG Geol. Surv. Note on Investigation 71-008 (unpubl.).

ROBINSON, G.P., 1971 - The geology of the proposed Musa River hydro-electric project area, Eastern Papua. PNG Geol. Surv. Note on Investigation 71-007 (unpubl.).

SMITH, J.W., and GREEN, D.H., 1961 - The geology of the Musa River area, Papua. Bur. Min. Resour. Aust. Rep. 52.

TAYLOR, F.J., 1971 - Musa River hydro-electric scheme, geophysical investigation, 1970. Bur. Min. Resour. Aust. Rec. 1971/121 (unpubl.).


GEOLOGICAL MAP
MUSA RIVER GORGE DAMSITE AREA
Reference
QUATERNARY
RECENT
Alluvium Qa Gravel and sand
Colluvium Qc Scree and boulders
PLEISTOCENE Domara River Beds Qpd Agglomerate, tuffs, mudstone siltstone, conglomerate
IGNEOUS ROCKS
LATE CRETACEOUS
Kg Gabbro
Kpd Didana Ultramafic Complex
Strike and dip of bedding
Strike and dip of igneous banding
Strike and dip of shearing
Geological boundary, position accurate
Geological boundary, inferred or position indefinite
Edge of outcrop
Inferred, probable fault
Fracture-elements (lineaments)
Trace of joints, showing direction of dip
Joint pattern
Area of landslide, inferred
Escarpment
Cross-section of landslide (see Plates 6 and 7)
Cross sections, including and extending beyond the damsites axis
A2, B2 Seismic traverses
Geological survey station, indicating the weathering condition of the rock
F = Fresh
FS = Fresh stained
SW = Slightly weathered
MW = Moderately weathered
HW = Highly weathered
CW = Completely weathered
REBEL Trigonometrical station
Scale 1: 3000
metres
NEW GUINEA
PAPUA
Popondetta
Dyke Ackland Bay
Collingwood Bay
Port Moresby
Area of scheme
Goodenough Bay
Abau
Milne Bay
LOCALITY MAP
To accompany N1 71 008
DENSE FOREST
MUSA RIVER
DAMSITE No 1
DAMSITE No 2
DAMSITE No 3
DAMSITE No 5
MAJOR LANDSLIDE
REBEL
Kpd
Qa
Qc
Qpd
Kg
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
B1
B2
B3
B4
B5
LS1
LS2
LS3
LS4
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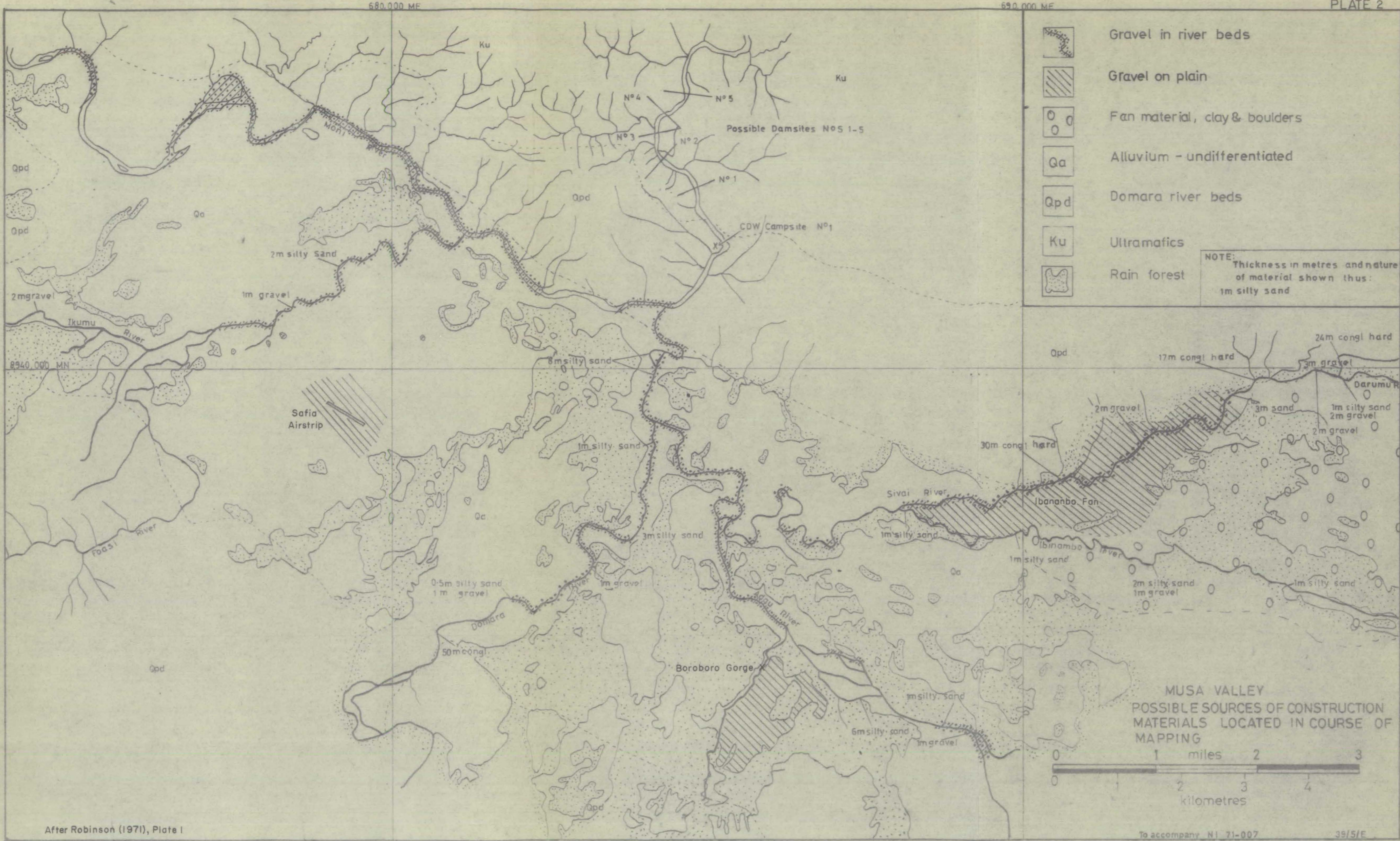
To accompany Record 1971/139
After Macias (1971) Plate 8
P/A/359



To accompany Record 1971/139

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