The damsite No. 1 abuts on massive slopes, according to the 1/50,000 topographic map. Geological map in scale of 1/250,000 (Ref. 31) shows a north-south trending belt of the Temburong Formation in the damsite. This means that the dam foundation is in shales and siltstones of Upper Oligocene to Lower Miocene. Accordingly, the suitable type is fill dam. As the Crocker Formation is developed in the upstream and downstream areas near the damsite, the hard sandstones can be available for rock material. Residual soil for earth material is wide spread in this area. The sand and gravels in the Padas river channel will be usable for concrete aggregates.

The damsite No. 2 is in the province of the Crocker Formation, but the Temburong Formation is very close on the left bank. A fill type dam would be preferable. Topographically, the left abutment is situated on a rather thin protruding ridge with saddles. Possibility of fault running north to south is envisaged.

In view of the above conditions, the site No. 1 is probably more favorable than No. 2.

There is a couple of unvisited alternative damsites on the Telekosang river, a tributary of the Padas. One of the alternatives is located 7.5 km east-southeast of Tomani and the other is about 8.5 km upstream along the river channel from the former. The both damsites have massive slopes to abut and are situated in the Crocker Formation province. Probably the foundation engineering conditions are not essentially different from other damsites in the Crocker Formation.

3.2 The Pensiangan River Basin

3.2.1 General

The Pensiangan river basin in southern Sabah has approximately 6×10^3 km^2 of catchment area. It shares most part of its watershed with the Kinabatangan basin and the Padas river basin. Collecting the major tributaries of the Sapulut, the Talankai, the Tagul et al, the river flows southward across the Indonesian border into Kalimantan.

The basin is divided into four geological provinces. The western zone of the basin is covered by the Crocker Formation, of which accounts has been given in the former chapter. The middle zone is widely occupied by the Upper Cretaceous to Eocene Sapulut Formation, consisting of mudstones, sandstones, greywackes, conglomerates and locally limestones. The eastern zone is the province of mudstones and sandstones of the Oligocene to Lower Miocene Labang Formation and the Upper Miocene Tanjong Formation.

A long stretched Witti fault which makes the boundary between the Sapulut Formation and the Crocker Formation in the west runs in the north-northeasterly direction through Punan Batu, about 35 km west of Sapulut village. Southern extension of Pinangah fault in the upper

Kinabatangan basin passes from north to south through Labang at 12 km east of Sapulut.

Strikes of the strata are consistently oriented north-northeast in the Crocker Formation. In the other formations, they are intensively varied, reflecting complex distortions of strata, though showing general tendency of north-south to northwest-southeast.

3.2.2 Damsites

There are five contemplated damsites in the Pensiangan river basin, as follows:

(1) Pensiangan damsite: on the Pensiangan main stream, about 4 km upstream from the Indonesian border (Catchment area: 5.1×10^3 km^2),

(2) Sapulut damsite: on the Sapulut river, about 6.5 km downstream from Sapulut (Catchment area: 2.6×10^3 km^2),

(3) Sibungo damsite: on the Sibungo river, 8 km northwest from Pensiangan (Catchment area: 530 km^2),

(4) Tagul damsite: on the Tagul river, 6 km west-southwest from Pensiangan (Catchment area: 449 km^2), and

(5) Sumatalun damsite: on the Sumatalun river, 2 km upstream from the confluence to the Pensiangan river (Catchment area: 384 km^2).

None of these damsites could be visited for inspection, hindered by damage of the road under heavy rainfall.

According to geological map in scale of 1/250,000 (Ref. 26), all the damsites are situated in the province of the Sapulut Formation of Upper Cretaceous to Eocene ages, which is composed of mudstones, sandstones, greywackes, conglomerates and some limestones. So far as observed in the north of Sapulut, the general geological feature is irregular alternation of sandstones, mudstones and shales. The sandstones comprise fine to medium grained brownish grey hard rocks and fine to medium grained bluish grey very hard ones. The mudstones are grey to yellowish grey coloured and moderately hard, sometimes with thin black bands of carbon. The shales are grey, bluish grey and chocolate brown coloured moderately hard rocks, and sometimes phyllitic. Thickness of each layer ranges from a few centimeter to around 2 m. The feature has remarkable resemblance with the Crocker Formation.

It seems that there is no substantial difference between the Sapulut Formation and the Crocker Formation from foundation engineering viewpoint, except that the mudstones and shales rather predominate as against sandstones in the Sapulut Formation. Probably, there are no essential problems for construction of high fill type dams, if the dam abutments are located on topographically massive slopes. In this respect, the Pensiangan damsite is in good condition.

Weathering appears several meters to 10 m in depth. Residual soil in the upper part of the weathered zone can be a big source of earth material. Hard sandstones are good for rock material. Bluish grey very hard sandstones can be utilized for concrete aggregates. Investigation should be made for river deposits in the vicinity of damsites.

3.3 The Kinabatangan River Basin

3.3.1 General

The Kinabatangan river basin covers 16.8 x 10^3 km^2 of area in Eastern Sabah. Two major tributaries, the Milian and Kuamut rivers, originate in the western watershed of the basin which runs through Trusmadi range, Maitland range and the mountainous zone with 900 to 1,700 m of ground height in the southern part of central Sabah. These two rivers join with each other to become the Kinabatangan river in approximately 250 km of length from Kuamut to the river mouth in the northern coast of Dent peninsula. All the area around the Kinabatangan river and the most part of the surroundings of the Milian river are low land and flat hills. Mountainous area of high relief is developed only in the western margin and the southwestern part of the basin.

The basin geology is a complicated mosaic of the Crystalline Basement, Palaeogene geosynclinal flysch sediments, marine shelf sediments, basic and intermediate intrusive rocks, volcanic rocks and alluvium. The outcrop of igneous and metamorphic rocks of the Crystalline Basement which is not younger than Lower Triassic is located only in a limited part of the southern watershed. Also, the intrusive rocks, ranging from peridotite to granodiorite, are scattered only in a narrow belt which crosses the basin in its central part from south to north. Miocene spilite and basalt lava occurs in the upper reaches of the Tongod river, a tributary of the Milian, in the vicinity of the northern watershed. Most parts of the basin is occupied by the geosynclinal flysch consisting of cherts with spilites, limestones, greywackes, mudstones, conglomerates, sandstones and shales of the Chert-Spilite Formation, the Sapulut Formation, the Crocker Formation and the Kulapis Formation. Areno-argillaceous rocks of the late Tertiary marine shelf sediments, with limestones and lignites, are wide-spread in the south-western mountains and the downstream low hills. The alluvial plain is developed only in a narrow zone along the Kinabatangan and in a 15-km wide belt along the coast.

3.3.2 Damsites

Three alternative dam plans were proposed and are studied in the pre-feasibility study of Kinabatangan River Basin Development Project (Ref. 34). Those dam plans are:

(1) Balat dam, located at Balat village on the Kinabatangan river, with 10.7×10^3 km^2 of catchment area,

(2) Deramakot dam, located about 10 km upstream of the Balat damsite, with 10.4×10^3 km^2 of catchment area, and

(3) A combination of Milian dam and Kuamut dam; the former is located on the Milian river at 30 km upstream from the confluence with the Kuamut river, having 6.65×10^3 km^2 of catchment area. The latter is on the Kuamut river at 15 km upstream of the confluence and has 3.1×10^3 km^2 of catchment area.

Each contemplated dam is 50 to 60 m high, partly depending on the depth of foundation excavation.

The damsites are situated in the geological provinces of Tanjong and Labang Formation, which are composed of alternating areno-argillaceous rocks, that is, sandstones, shales and mudstones, of the Oligocene to Miocene marine shelf deposits. In the Milian damsite, the geosynclinal Kulapis Formation is also expected to occur according to a geological map, but there seems to be little difference in the appearance of the actually exposed rocks from those in the other sites. According to the Report (Ref. 34), the bedrocks are relatively soft rocks, but the weathering is not deep. In the Balat damsite, weathered soil is about 5 m thick at the top of the hills and 2 to 3 m on the slopes.

In the draft interim report (March, 1981), it seems that the Balat damsite is favored by the engineers, after holding in abeyance the Deramakot damsite because of predominance of less resistant shales and the Milian-Kuamut damsites because of the longest dam axis and faults.

For the dam type, the Report recommends earthfill dam, considering that:

(1) strength of the bedrocks is questionable for foundation of concrete gravity dam,

(2) hard rock materials for concrete aggregates and rockfill is not sufficiently available within a reasonable distance, and

(3) as the damsites are located in valleys of gentle slopes, large scale earth moving works can be easily carried out.

The project is now under further study by a study team from JICA.

3.4 Tawau Area

3.4.1 General

Several damsites are contemplated on small rivers in the northern vicinity of Tawau. The rivers are the Balung, Kinabutan, Tawau and Merotai.

The contemplated project area is situated in an extensive foothills of a group of Tertiary and Quaternary volcanoes centered on Mt. Magdalena (El. 1,311 m). Central spines of the marginal old volcanoes remain in the form of local peaks in the foothill area.

The hills are composed of volcanic rocks of various ages, such as Tertiary andesites, dacites, pyroclastic flows and breccias, and Quaternary dacites, olivine basalts, etc., originating from Magdalena, Lucia, Maria, Andrassy and Kinabutan volcanoes. Intrusive diorite porphyries form the isolated hills of Mt. Gemok, Middle Hill and Kukusan Hill in the northwestern part of Tawau.

Sedimentary rocks of the Miocene Kalumpang Formation consisting of sandstones, conglomerates, shales and mudstones are developed in the middle to upper reaches of the Merotai river, in the northwest of Tawau.

Alluvial plain and low hills of unconsolidated sand, gravels, clay and tuffaceous sand of Quaternary are developed up to 10 km or more inland from the coast in the east and west of Tawau. In the vicinity of Tawau, the older volcanic facies are stretched close to the sea and the alluvials are limited in narrow area near the coast (Refs. 28 and 38).

3.4.2 Tawau damsite

The Tawau river arises on the southern slope of Mt. Lucia (El. 1,202 m), 24 km north of Tawau, and runs southward through Tawau to pour into Sibuko bay.

The Tawau damsite is located about 11 km north from Tawau and 2 km southeast of Bombalai Hill. The river channel shows general trend of north to south, with weak incised meander. The river bed, approximately 15 m wide, is at about El. 145 m in ground height, according to the 1/50,000 topographic map. The slope on the left bank, which is on the concave side of meander, is steep with 1/1 or more gradient. The right bank slope shows averagely 1/1.4 of inclination up to about El. 220 m, above which develops a flat terrain of an oil palm estate. There is a narrow terrace and mild slope of talus on the right river bank. The gradient of the riverbed is noticeably steep.

The bedrock is Tertiary volcanic breccia, of which matric is moderately consolidated coarse acidic tuff. Rock blocks and fragments contained in the volcanic breccia are predominantly andesitic and ranges from a few centimeter to more than 1 m in size. In the damsite, however, they are generally small sized and sparsely contained. Pumice tuff, including a little rock fragments, also occurs. Bedding planes show N60°W/30°SW of strike and dip. A joint set right angle to the bedding plane is observed. The bedrock cropping out on the river brinks appears massive.

The flat terrain on the top of the right bank slope is composed of Quaternary basalt lava flow. The boundary between the basalt and the volcanic breccia on the right bank has to be confirmed by core drilling in the future investigation.

Weathering reaches to several meters of depth on the right bank. It could be thinnner on the left bank.

The foundation rocks are not sufficiently hard for concrete gravity dam. A fill dam is the only suitable type of dam.

Decomposed rock zone or residual soil is an abundant source for earth material. Rock material may be obtained from basalt and spilite beds in Bombalai Hill, 2 km from the damsite. The other possible quarry for rock material is Mt. Gemok, 7 km south-southwest from the damsite, which is composed of diorite porphyries. Concrete aggregates, both fine and coarse, can be extracted from the downstream riverbed. Core drilling of Bombalai Hill to check its possibility for quarry site is recommendable for the early stage of the investigation.

3.4.3 Kinabutan damsite

The Kinabutan Besar river, originating in the south of Mt. Maria, flows southward through the foot of Mt. Andrassy and Mt. Kinabutan Besar.

The Kinabutan damsite on the Kinabutan Besar river is located at west-southwestern foot of Mt. Andrassy (El. 2,150 m) and about 11 km northeast from Tawau. The riverbed, at approximately El. 130 m, is 3 to 10 m wide. The river flows southward in the damsite. The slopes on both banks are inclined at 1/2 or milder, except for the parts of steep inclination within 10 m of height from the riverbed. A flat terrace is formed at about 40 m of height on the right bank.

Outcrops, well exposed in the river channel, consist of hard dacite-andesite rocks, with outstanding joint sets of N20° to 40°W/50° to 60°NE and N15°E/65°SE. The rocks are rarely exposed on the slopes. If the same kind of rock is prevalent in the whole abutment area, a concrete gravity dam is technically feasible. According to geological map (Ref. 38), however, pyroclastic rocks which are probably softer could be encountered. A fill type dam would be a sound choice. Weathering seems to be within several meters of thickness.

The dacite-andesite rocks in the vicinity can be good rock material for fill dam. Residual soil for earth material is obtained in the downstream hilly area. The nearby river deposits seem insufficient in quantity for concrete aggregates. Their source should be found in the downstream river channel.

There seem to be some discrepancies between the topographic map in scale of 1/50,000 and the actual topography. It is essential at first to confirm the topographic condition by survey.

In view of rather steep gradient of the riverbed, the present damsite may not be very advantageous to take good reservoir capacity. An alternative may need to be examined at some 1.5 km upstream. There is no big differences in geological conditions within 2 km of distance upstream.

The extent of the hard dacite-andesite rocks and occurrence of pyroclastic rocks, if any, should be confirmed in the first stage of the future investigation by means of detailed geological mapping and core drilling.

3.4.4 Balung damsites

The Balung river arises on the southeastern slope of Mt. Lucia, and flows down southeastward to pour into Sibuko bay at Indarasabak village, 33 km east from Tawau.

The Balung damsite No. 1 is located at the northern foot of Quoin Hill, approximately 25 km northeast of Tawau. The Balung river flows eastward with strong incised meander. The slopes on both banks show 1/1.7 to 1/1.2 of inclination. Some 60-m wide flood terrace is formed on the left side of the river, that is, in the convex side of meander. The riverbed is at ground height of El. 160 to 170 m, according to the 1/50,000 topographic map. The slope on the right abutment reaches to a mildly inclined flat at about 30 m of height from the riverbed, whereas the left abutment is on a dissected narrow ridge.

The bedrock cropping out on the right bank is hard andesite. Reddish brown residual soil covers the surface of the slope with about 2 m of thickness and is underlain by a few or several meter thick weathered rock zone. There could be andesitic pyroclastic rocks on the left bank, which was not confirmed for the difficulty of crossing the river.

One of the problems is the thinness of the left bank ridge. Detailed topographic check is required first of all when investigation is performed.

It seems that the other site, about 400 m upstream, may be a better alternative, where the ridge on the left bank is relatively, but not very promissingly, thicker and the 1/1.2 slope descends to the river brink from the right bank side.

There is possibility that soft pyroclastic rocks are involved in parts of the foundation. Fill type dam is deemed appropriate for this site.

Andesites and basalts for rock material are obtained in the vicinity. Residual soil and weathered rocks for earth material are unlimited in quantity in the downstream low hills. Concrete aggregates are to be searched in the downstream river channel.

The Balung damsite No. 2 is located on a left side tributary of the Balung river, which joins the main stream at 3.5 km south of Mt. Pyramid. The damsite is contemplated at about 4 km upstream from the confluence. Topography of the surrounding area is mildly undulating terrain with sporadically outstanding small hills. The valley is wide open. While the slope on the left bank with 1/1.2 of inclination is close to the river channel, the right abutment is nearly 1 km distant, and an isolated hill, about 60 m high, is located between the river channel and the right abutment. In consequence, the dam will be divided into two parts.

The bedrock consists of dacites, apparently autobrecciated. Volcanic breccia with acidic tuffaceous matrix crops out downstream. A fill type dam is deemed suitable because of flat and wide topographic feature and possibility of soft rocks intermingled in the foundation.

The dacites can be used for rock material. Also, andesite is abundantly available in Muul Hill, 3 km south from the damsite. Earth material can be found in the vicinity.

3.4.5 Merotai damsites

The Merotai Besar river originates in the south of Mt. Binuang, about 34 km north from the river mouth, and flowing southward pours into Cowie Harbour at 17 km northwest of Tawau. The Merotai Kanan, a tributary, flows down from the western slope of Mt. Magdalena toward southwest and joins to the Merotai Besar in Merotai village. The contemplated Merotai damsite No. 1 is located about 4.5 km north of Merotai village, or 26 km north-northwest from Tawau, on the Merotai Besar main stream. The damsite No. 2 is located on the Merotai Kanan river and 6 km north from Bukil village or 23 km north-northwest from Tawau.

In the Merotai damsite No. 1, the riverbed at El. 15 m or lower shows about 15 m wide southerly flow. The surroundings are undulating hilly region of low relief. Slopes on the both banks show mild gradients of nearly 1/3.

The bedrocks of the damsite No. 1 are shales, sandy shales and sandstones of Miocene Kelumpang Formation and Umas Umas Formation. Bedding planes, well developed, strikes northeast in general and dips eastward at 40° or lower angle. Many irregular joints are developed. Geological maps (Refs. 28 and 38) show an inferred fault running northwestward across the river, which, however could not be confirmed. Weathering appears to be about 10 m or thicker.

Because of the moderate hardness of bedrocks and relatively large volume of dam in the wide valley as well as unavailability of hard rock material in the nearby areas, an earthfill dam is recommended.

Residual soil for earth material is abundant in the surroundings of the damsite. Possible source of rock material is Quaternary basalts around Mt. Tiger in the southeast, from which the haul distance will be more than 15 km. Source of concrete aggregates will be the river deposits of the Merotai Kecil river more than 10 km distant along the road and, if it is insufficient, the Tawau river with about 30 km of haul distance.

The Merotai damsite No. 2 on the Merotai Kanan river is situated at approximate ground height of El. 40 m. The slope on the left bank, which is developed on the margin of a basalt plateau, is rather steep, but the topography on the right bank is flat. The valley is widely open. The river channel in the damsite could not be inspected, hindered by extensive thick bush.

The bedrock seems to be the shales of the Kalumpang Formation for the most part of the dam foundation. Basalts on the upper parts of the left bank slope are decomposed into residual soil or very soft rock in a few meter of thickness in the surface. The weathered rock zone is deemed to extend deeper. Conceivable type of dam is a fill dam.

For the damsite No. 2, basalts may be available for rock material within a small distance from the site. The occurrence and quality should be examined by core drillings on the left bank plateau, where is an extensive oil palm plantation. Earth material source is almost unlimited in the vicinity, as the other damsites. Sources of concrete aggregates are the Merotai Kecil and the Tawau river or production from the quarried basalts.

4. GEOLOGY OF THE PROJECTS IN SARAWAK

4.1 Kuching Area

4.1.1 General

There are several contemplated damsites in the hilly area in the upper reaches of the Sarawak and Sadong rivers, which are located south of Kuching and near the Indonesian border. A couple of alternative damsites are also contemplated in the Batang Kayan river basin to the west of Kuching.

The area west from the Lupar river is situated in so-called Kuching Zone as defined in the aspect of geological structure of Borneo. The main parts of sediments in the Kuching Zone had been formed by the end of Mesozoic period or the beginning of Tertiary, and in Tertiary period when thick deposition of the Northwest Borneo Geosyncline took place in its northern adjacent zone it was a subsiding shallow sedimentary basin where post-geosynclinal marine shelf or deltaic sedimentation continued. These Tertiary facies, consisting of sandstones, conglomerates, mudstones shales, limestones and marls, occur mainly in the southern parts of the Lupar river basin, the extreme upper reaches of the Sarawak river and the hills in the Batang Kayan basin. The other areas are covered by the pre-Tertiary areno-argillaceous rocks and the Quaternary deposits. Phyllites and schists of pre-Triassic basement crop out in Kuching.

Upper Triassic volcanic facies consisting of basalts, andesites and pyroclastic rocks is developed in the vicinity of Serian. Intrusive igneous rocks, comprising from granite to gabbro, are scattered in the south of the Lupar river and the area west from Kuching.

4.1.2 Tebia damsite

The Tebia river is a tributary of the Semadang river, which is approximately 10 km long from the head on the southern slope of Mt. Menoeng to the confluence with the Semadang river at Pang Ampat village.

The Tebia damsite is located at the part of gorge where the river breaks through a continuous ridge from west to east. The location is about 3 km north-northwest of Padawan village. The ridge is higher than El. 300 m in the peaks. Downstream from the ridge, the Tebia valley opens wide through undulating peneplain.

The Tebia river is 10 to 20 m wide at the damsite and the approximate ground height of the riverbed is El. 50 m according to the 1/50,000 topographic map. Inclination of the slopes on both abutments is steeper than 1/1.7. Within 20 m of height from the riverbed, the slope gradient is almost 1/1 in the steepest part. For a 90 m high dam, the crest length would be around 400 m. The right abutment is relatively thin.

The ridges on both banks are composed of white siliceous coarse sandstones and grey grits which are hard to moderately hard, with well developed bedding planes trending N25°E/40° - 65°NW and joints at N35° - 65°NW and joints at N35°E/40° - 65°W/90°. Directions of the river channel appear to be strongly controlled by this pair of trends. Pebbly conglomerates with 10 to 20 cm of thickness are occasionally intercalated. Fresh and slightly weathered bedrocks are exposed continuously on the river banks and sporadically on the slopes. A minor fractured zone is observed to run in the direction of crossing the river immediately downstream of the damsite. The rocks on the slopes are weathered and softened in general. Covering of top soil is not thicker than 1 m. Depth of the fresh rock interface is possibly within several meters of depth from the slope surface. No evidence of extraordinarily high permeability was observed. The minor fractured zone as mentioned above can be treated by ordinary grouting procedure.

Rock mechanical test to evaluate the shear strength of the moderately hard sandstone will be required if a concrete gravity dam is contemplated. No serious problems are seen for a fill type dam.

Earth material for the fill type dam is abundantly available in the residual soil and weathered rock zones in the downstream hills. Rock material source will be found in the hard grits in the extension of the damsite ridge. Fine aggregate for concrete or filter material for rockfill dam can be taken from the downstream river deposit within 10 km of distance. For coarse aggregate of concrete, however, the river gravels seem to be not suitable because of probably high content of soft rocks. The coarse concrete aggregate will have to be produced from quarry rocks. Detailed geological mapping and laboratory tests are necessary to determine the quarry site and to evaluate the quality of earth material and concrete aggregates.

4.1.3 Semadang damsite

The Semadang river, one of the upstream tributaries of the Sarawak Kiri river, arises on the mountain slope near Semuti village, which is located within 4 km from the Indonesian border. The river flows northward forming intensive meander and joins with the Bengoh river in the vicinity of Bengoh village. Downstream from the confluence is the Sarawak Kiri river.

The Semadang damsite is located at 2 km south from Padawan village. Ground height of the riverbed is around El. 45 m in the damsite. The river channel, about 15 m in width, runs north-northeast almost straightly across a east-southeasterly trending ridge. The slopes on both banks are inclined at around 1/1.2 of gradient.

The bedrocks seem to be moderately hard tuffaceous sandstones and hard grits. Outcrops are rather limited. The bedding planes show northwesterly strikes and southwesterly steep dips. The riverbed is filled by sand and gravels including many angular blocks of hard grits.

Some of the round gravels are of soft weathered grit. The slopes are thickly covered by residual soil and scree.

Depth of fresh rock interface and the subsurface distribution of softer or moderately hard rock beds should be, first of all, confirmed by core drillings in the future.

The situation for the availability of construction materials is nearly similar to that in the Tebia dam. Hard grits for rock material will be obtained on the slope of Mt. Mrobung on the upstream left bank.

4.1.4 Bengoh damsite

The Bengoh river is a tributary of the Sarawak Kiri river which flows down eastward and joins with the Semadang river in the vicinity of Bengoh village to become the Sarawak Kiri in the downstream reaches. Numerous small tributaries originating inside the arc of Bengoh range and the Indonesian border range are the source of the river.

The Bengoh damsite is located about 6.5 km south-southwest as the crow flies and 10 km upstream along the river course from Puruh Semadang village. The site is in narrow gorge formed at the break of the eastern part of warped Bungoh range. The riverbed, at around El. 45 m, has about 30 m of width, with ragged outcrops protruding above the water and seemingly thin sand and gravel deposits. The slopes on both banks are steep, with some 1/1.2 to 1/1 of inclination.

The bedrocks consist largely of white siliceous coarse grits and medium grained sandstones, intercalated by conglomerates and dark grey shales, which are hard to moderately hard. The conglomerates are composed of chert pebbles and gravels and siliceous gritty matrix. Shales are sufficiently hard but sheared, with irregular discontinuity often reddish brown stained in the surfacial zone.

The most strongly developed discontinuity is the bedding plane, striking N30° - 50°W and dipping 45° to 65°SW, which crosses the river at acute angle or is almost parallel to the river dipping toward the right bank. As the dip of the bedding planes is steeper than the slope of the left bank, the above condition does not appear to result in any instability of the slope. The other set of strong cleavages is joints, striking northeast and dipping northward at 50° to sub-vertical. These joints are relatively long stretched but not very frequent, and rarely open up to 1 mm.

Weathering appears deep in the upper parts of the slopes. Probably about 10 m deep foundation excavation will have to be considered to expose the fresh rock zone.

Essentially, no serious technical difficulties are envisaged. The bedrocks are good for foundation of a fill type dam. Concrete gravity dam may be also feasible, though confirmation of the rock mechanical strength is required.

For rock material, the grits and sandstones may be utilized, if possible low yield of sufficiently hard rocks is tolerated. Otherwise, hard limestones are available within 3 km of distance downstream from the damsite. Earth material will be obtained from residual soil and weathered rock zones in the downstream hilly region. Sand for fine aggregate of concrete and filter material of fill dam can be taken from the river deposits in the downstream river channel. Coarse concrete aggregate should be produced by crushing the quarry rocks, because the river gravels appear to include high proportion of soft rocks. The sole source for the coarse aggregate would be the limestone.

4.1.5 Kedup damsite

The Kedup river arises in the north of Mt. Rawan on the Indonesian border and flows eastward at first through Terbat Bazaar and Mentu Pundok village. Then turning to north-northeast and again to north-northwest, finally it joints to the Sadong river at 7.5 km southwest of Serian. The damsite is located at 2 km upstream from Terbat Bazaar on the initial easterly course.

The river channel, at about El. 50 m according to the topographic map, is 10 m wide and forms a strong meander in the damsite. The left abutment is situated on a mild slope of Entama Hill, whereas the right abutment is on the slope of a ridge which extends to northwest from Ramungan Hill. Approximately 250 m wide flood terrace and 300 m wide low hills are formed between the both slopes. The wide open valley is the topographic feature of the damsite.

The bedrock is composed of coarse arkose sandstones of the Upper Triassic Sadong Formation. Thin coal layers intercalate occasionally. The sandstones are moderately hard. The bedding planes are observed to strike in northwest and dip steeply to southwest. Trends of joints are northwesterly, northeasterly and east-northeasterly.

Weathering is deep on the right bank slope, seemingly more than 10 m. The left abutment was not inspected.

For the lack of sufficient hardness of the bedrock for foundation of concrete gravity dam, the suitable type of dam is a fill dam. An earth dam seems to be an economical choice as the earth material can be easily obtained from the decomposed rock zones wide-spread in the vicinity. The quality should be checked in the future investigation.

Diorites on Ramungan Hill, 2 to 3 km southeast, is to be investigated for rockfill material and concrete aggregates. The river deposit contains hard gravels from the Serian Volcanic Formation. Proportion of soft rocks should be examined to determine its applicability for coarse aggregate of concrete. The river sand appears to be good for fine aggregate and filter material, though its quantity may be questionable.

Extensive investigations and tests of construction material are necessitated, and confirmation of depth of the fresh rock interface by means of seismic exploration and core drilling is required in the first stage of the future investigations.

4.1.6 Batang Kayan damsite

The Batang Kayan river, arising in the mountainous zone, about 20 km west from Kuching, runs through the hills of the Upper Cretaceous to Eocene Plateau Sandstone Formation in its upper reaches and then through the alluvial plain to pour into South China Sea at Kuala Lundu, 8 km east-northeast of Lundu.

The damsite No. 1 is located at 11 km northeast from the bridge of the Bau - Lundu highway as the crow flies, and 1.6 km upstream from the confluence of the Kukoh river to the Batang Kayan. The surroundings are mildly sloped hilly areas where the highest part is not higher than El. 150 m. The river channel, running southward, is about 30 m wide and a little higher than El. 15 m according to the 1/50,000 topographic map. The slopes on both banks show low inclinations and the valley is wide open. The length of a dam crest would be more than 10 times the height of the dam.

It seems that a low watershed in the northern part of the reservoir area set limit to the reservoir high water level at around El. 45 m, under the condition that saddle dykes are to be constructed at five locations. Accordingly, the maximum height of the dam would be 30 m above the riverbed.

The bedrocks are mostly sandstones which are white, siliceous, medium to coarse grained, massive and moderately hard. A vast outcrop of the slightly weathered sandstones form a rapid in the riverbed on the dam axis. Bedding planes trend around N85°W/10°SW. Joints strike at N20°W, N85°W, N40°E, etc., and dip sub-vertical.

The slopes on both banks are covered by sandy-clayey residual soil. Thickness of weathering on the slopes should be confirmed by core drilling.

In view of the insufficient hardness of the bedrocks and the lack of hard rock material in the vicinity, an earthfill dam will be the only appropriate type of dam. The residual soil is for earth material. The river sand is usable for fine aggregate of concrete. Coarse aggregate for concrete will have to be searched in the mountains of intrusive adamellites near Lundu, which will require about 40 km of haul distance.

The Batang Kayan damsite No. 2 is contemplated about 30 km upstream along the river channel from the site No. 1. This site was not visited for inspection. It is situated in the province of the Plateau Sandstone Formation as well. Condition of the foundation rocks could be similar to that in the damsite No. 1 (Refs. 6 and 9).

4.2 The Kemana River Basin

4.2.1 General

The Kemana river basin, 6.0×10^3 km^2, is developed between Bintulu and the mountain chain through Tinggili Hill (El. 230 m), Lumut Hill (El. 900 m), Sekalap Hill (El. 1,235 m) and Sekiwa Hill (El. 695 m) which is the western watershed of the upper Rajang basin. The basin is widely covered by sandstones, shales, siltstones and marls, with limestones and coal seams, of Miocene Belait Group and Setap Group. The formations are strongly folded. The bedding planes show general trend of northeasterly strikes, but local disturbances and distortions are wide-spread. Quaternary deposits are also well developed in wide valleys up to the far inland area near the watershed (Refs. 23 and 27).

4.2.2 Damsites

There are several contemplated damsites located on the tributaries in the upper reaches of the basin. Some of these damsites were inspected only from an air-born helicopter.

In Pesu damsite No. 1 on the Pesu river at 3 km downstream from the Matalum river confluence, the abutment is on rather thin ridge with thick covering of residual soil as seen on a cut slope of timber road. The Pesu damsite No. 2 on the Matalum river at about 4 km upstream along the river channel has more stable abutments.

The Tubau damsite on the Tubau river at 4.3 km north-northwest from the confluence of the Tingang river is situated in the valley with wide bottom. The both abutments are on massive and seemingly stable slopes.

The Pandan damsite on the Pandan river is located at 3.3 km south-west of the confluence of the Kalo river, where the Pandan river breaks through a low ridge elongated in the east-northeasterly direction. Cut slopes of timber road show orange coloured residual soil, apparently thick. The site appears to be suitable for rather low fill dam.

The Miocene sandstones and shales in the Kemana river basin are probably moderately hard or soft rocks, which are good for foundation of fill type dams but not usable for rock material and coarse aggregate for concrete. Earthfill dam is deemed the only appropriate dam type in this basin. Concrete aggregate will have to be carried from the Rajang river basin which is 10 to 20 km distant on the straight from the damsites.

4.3 The Rajang River Basin

4.3.1 General

The Rajang river basin covers 51.1×10^3 km^2 of area in central Sarawak, ranging from the border with Indonesian Kalimantan in the east to the coast of South China Sea in the west.

The basin is situated almost totally in the geological province of the Upper cretaceous to Upper Eocene flysch deposits of the Northwest Borneo Geosyncline. Those flysch deposits which are identified as Rajang Group consist of hard siliceous and feldspar-bearing sandstones, greywackes, philites, slates, shales and siltstones. The formations are strongly folded with roughly east-west trending folding axes and show steep dips either northward or southward. Following the east-west trend of the folding and, accordingly, the strikes of bedding planes, each stratigraphic member of the Rajang Group is exposed in belt elongated in the same direction, with older members to the south and younger to the north in order.

In the upper reaches of the basin located are several masses of Tertiary and Quaternary volcanic products, such as, basalt-spilitic lavas, tuffs and breccias of Eocene in Linau Balui Plateau, Kajang Hill, etc. and rhyo-dacitic lavas and pyroclastic rocks of late Tertiary to Quaternary in Hose Mountains and Usun Apau Plateau.

Geomorphology of the basin is closely related with the geological structure of intensively folded areno-argillaceous alternations. The east-west trending long ridges are developed along thick hard sandstones or greywackes, and the long valleys parallel to the ridges are formed presumably with softer argillaceous rockbeds as cores. The ridges are broken through by rivers at places, probably along joints anf faults which develop right angle to the bedding planes.

Linearment of those fold mountain ridges shows a couple of warps concave to the north; one in the area west of Linau-Balui Plateau and the other around Usun Apau Plateau. This structural trend controls the shape of the northern watershed of the basin. This geomorphological linearment is rather vague in the southern watershed. The eastern watershed, which is the border line to Kalimantan, comprises a chain of mountains from El. 1,000 to 1,800 m.

Coastal alluvial plain is developed in a 60 km wide belt downstream from Sibu, consisting of loose sand, silt, clay and peat. There, the river branches into complicated network of channels through the flat land of soft deposits which pour into the sea. In a narrow zone around the Rajang river, the alluvial plain stretches up to Kanowit, 100 km from the coast.

No major structural faults are recorded in the Rajang basin (Refs. 23 and 25).

4.3.2 Damsites

The Master Plan for Power System Development of Sarawak (Ref. 33) studied 11 hydro-electric projects in the upper Rajang river basin. The proposed damsites and contemplated dam types are as follows:

(1) Raja 284 on the Rajang river, 58 m high concrete gravity dam;

(2) Balu 037 on the Balui river, 206 m high concrete arch dam;

(3) Bela 010 on the Belaga river, 140 m high rockfill dam with a central asphaltic concrete core; and

(4) Muru 040 on the Murum river, 145 m high concrete arch dam.

Geological mapping and core drilling in a scale of preliminary study were performed for the damsites in (1) and (2). According to the Report, there is much resemblance in geological conditions amont these damsites, and it even seems that the conditions from engineering geologic viewpoint are essentially similar for them all. The above determination of dam type is based on a cost comparison, after a procedure which rules out rockfill and arch dams in case that the river diversion during construction cannot be solved by means of tunnels or that powerhouse must be integrated into the dam body.

In all those damsites, the foundation rockbeds consist of alternations of hard and massive quartzitic sandstones or silicified greywackes and less hard silty or slaty rocks. Generally, the hard arenaceous rocks are predominant. Discontinuity in the rocks is the bedding plane striking E-W or NE-SW with steep dips and two or three sets of joint, one of which is of horizontal or mildly dipping joints and the others are of sub-vertical ones perpendicular to the bedding plane.

Depth of overburden and weathered rock zone is various for the sites and the parts of slopes. The deepest examples are 15 to 20 m in Raja 284. It is within several to 10 m in the other sites. Fresh rocks or slightly weathered rocks are often exposed widely in the riverbeds. The bedrocks seem to be sufficiently solid and good for concrete gravity dams and fill-type dams. The Report states necessity of rock mechanic tests for foundation of arch dams, especially for the interbedding slates.

As for construction materials, the Report proposes the following sources:

(1) Rock material: Quartzitic sandstones from excavation for waterways in the damsites or from a quarry. Haul distance can be within a reasonable range.

(2) Earth core material: Residual soils and decomposed rocks in siltstone and slate zone. Great quantity is expectable within a short distance from every damsite.

(3) Concrete aggregates and filter zone material: Sand and gravels may be sufficiently available from the river deposits in the vicinity for Raja 284 and Bela 010. For the other damsites, quantity of the river deposits is limited, and the sand and gravels will have to be produced from quarry rocks.

Feasibility study and detailed design of each project will require a detailed geological mapping of damsite in scale of 1/1,000 or 1/500, core drillings with permeability tests for more than 2,000 m in total length and geophysical (seismic) explorations of approximately 5,000 m in length of the exploration lines. Furthermore, test aditting on both abutments and in-situ rock tests will be recommended for a large dam with height more than 100 m. Though all rockfill dams in the master plan were conceived to have central asphaltic concrete cores, the feasibility of central earth core would be examined based on a soil mechanical study of the available earth materials.

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FIGURES

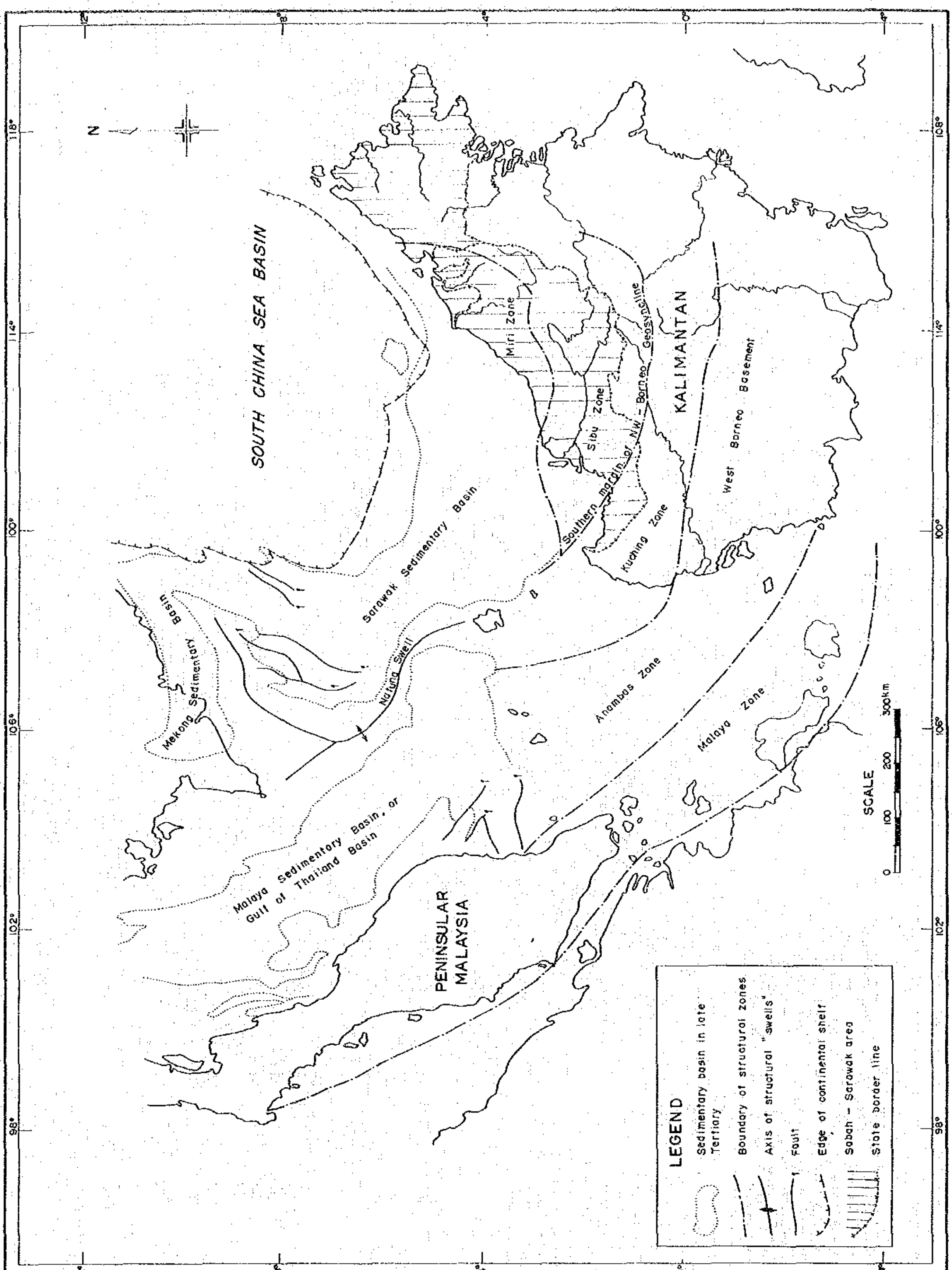

Fig. 1 Structural Zones of Borneo

Based on Ref. SQ 1 and SQ 2

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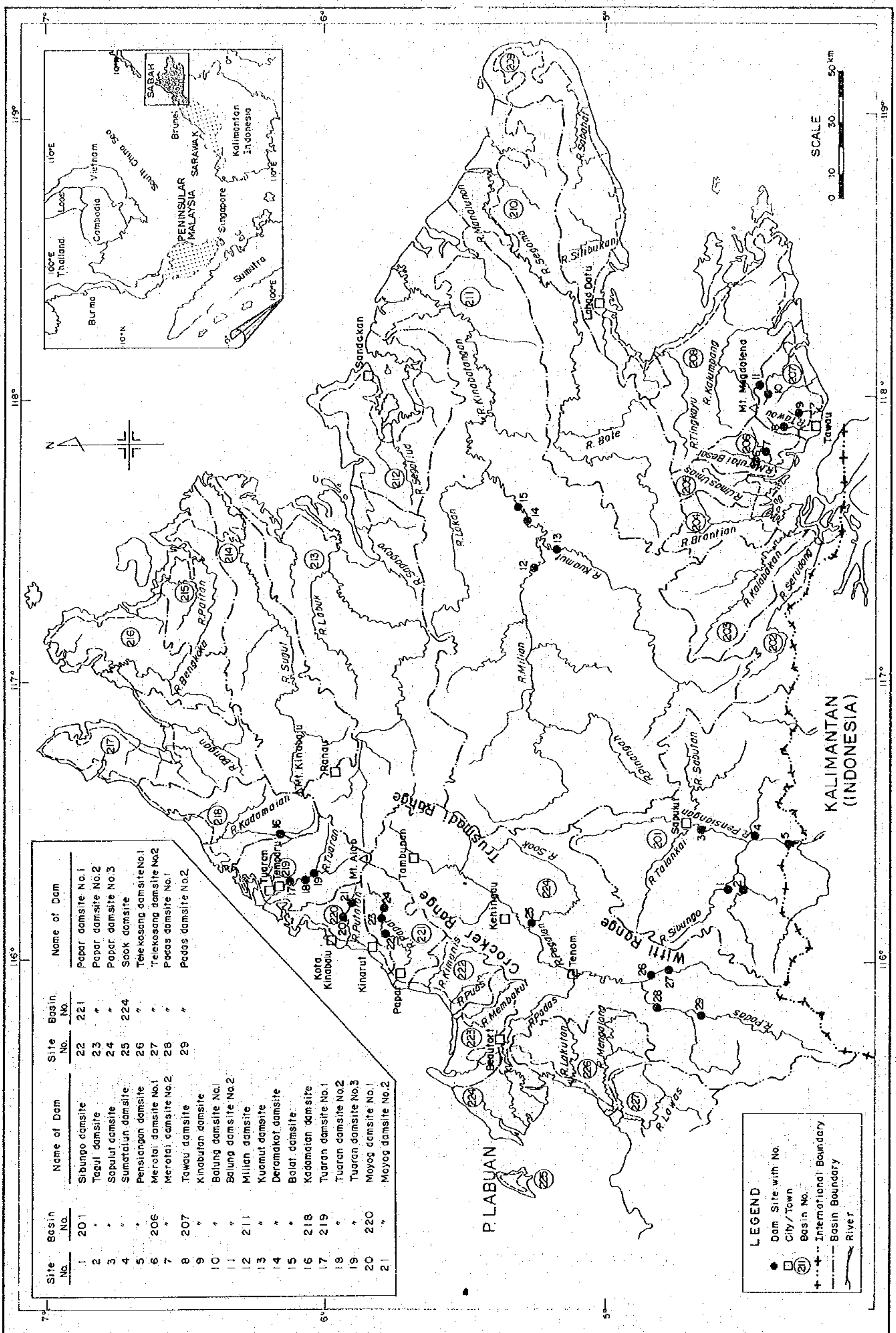

Site No.	Basin No.	Name of Dam
1	201	Sibungo damsite
2	〃	Tagul damsite
3	〃	Sapulut damsite
4	〃	Sumatalun damsite
5	〃	Pensiangan damsite
6	206	Merotai damsite No.1
7	〃	Merotai damsite No.2
8	207	Tawau damsite
9	〃	Kinabutan damsite
10	〃	Balung damsite No.1
11	〃	Balung damsite No.2
12	211	Milian damsite
13	〃	Kuamut damsite
14	〃	Deramakot damsite
15	〃	Bolat damsite
16	218	Kadamaian damsite
17	219	Tuaran damsite No.1
18	〃	Tuaran damsite No.2
19	〃	Tuaran damsite No.3
20	220	Moyog damsite No.1
21	〃	Moyog damsite No.2
22	221	Papar damsite No.1
23	〃	Papar damsite No.2
24	〃	Papar damsite No.3
25	224	Sook damsite
26	〃	Telekosang damsite No.1
27	〃	Telekosang damsite No.2
28	〃	Padas damsite No.1
29	〃	Padas damsite No.2

Fig. 2 Location of Dam Site in Sabah

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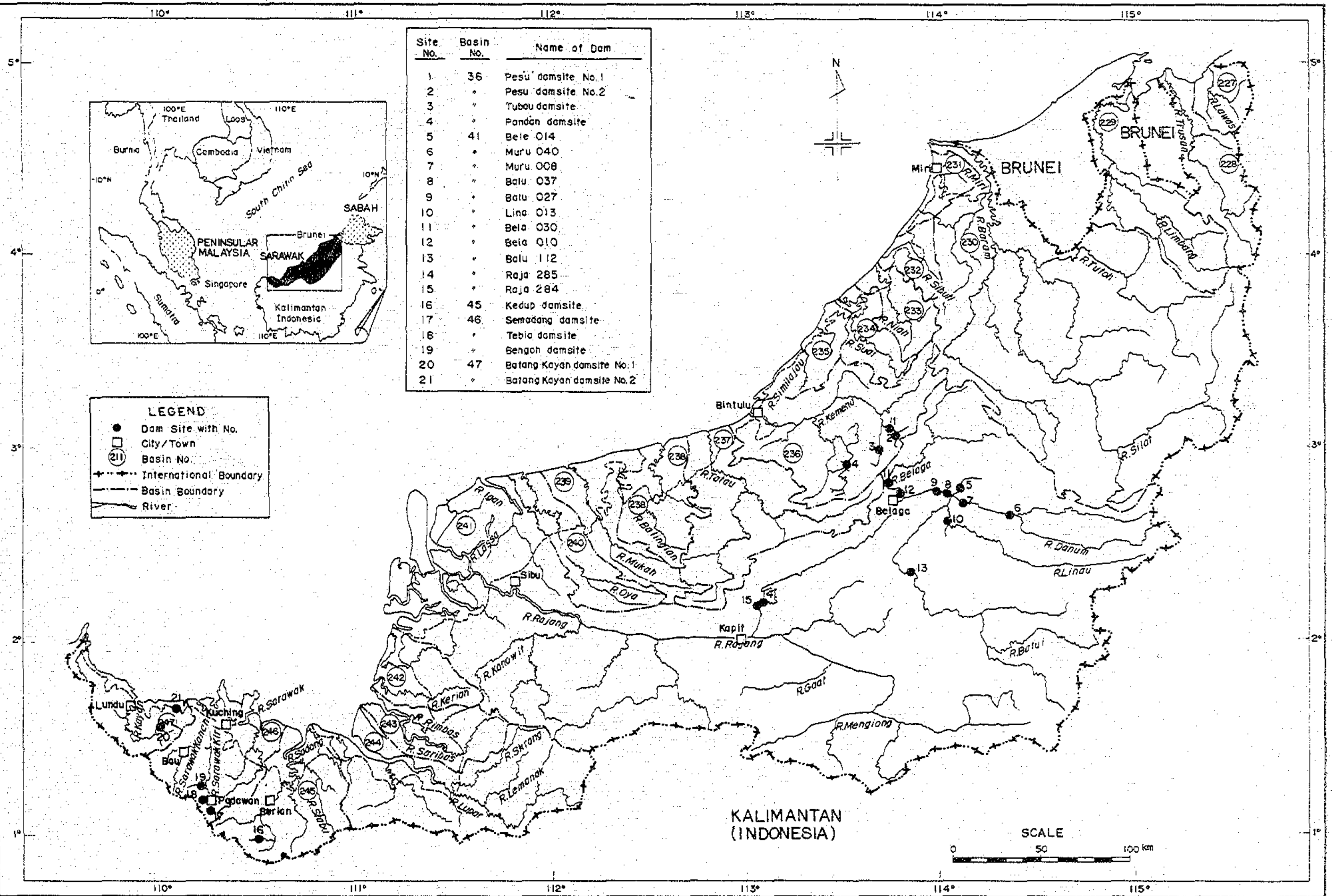

Site No.	Basin No.	Name of Dam
1	36	Pesu' damsite No.1
2	"	Pesu damsite No.2
3	"	Tubau damsite
4	"	Pandan damsite
5	41	Bele 014
6	"	Muru 040
7	"	Muru 008
8	"	Balu 037
9	"	Balu 027
10	"	Lina 013
11	"	Bela 030
12	"	Bela 010
13	"	Balu 112
14	"	Raja 285
15	"	Raja 284
16	45	Kedup damsite
17	46	Semadang damsite
18	"	Tebia damsite
19	"	Bengoh damsite
20	47	Batang Kayan damsite No.1
21	"	Batang Kayan damsite No.2

Fig. 3 Location of Dam Site in Sarawak

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