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Relationship of gabbro and pillow lavas in the Lupar Formation, West Sarawak: Implications for interpretation of the Lubok Antu Mélange and the Lupar Line

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Abstract: The Lupar Line is regarded by many geologists as a major suture which has resulted from plate movements that largely determined the Cretaceous to Paleogene history of northern Borneo. Nevertheless, there remain many uncertainties regarding the relationship of the various belts and rock types that have been distinguished. Most of the many attempts to reconstruct the history of Borneo and the South China Sea involve the incorporation of a model of the nature and timing of events along the Lupar Line. Thus new factual observations in this area are of regional significance.

The gabbro and pillow lavas within the Lupar Formation have been interpreted as faulted-in slices of oceanic crust, and by implication as older than the Lupar. However, an examination of quarries and excavations made in the areas of dams and quarries constructed for the Batang Ai Hydroelectric Project has shown that at least some of the gabbro within the bedded flysch typical of the Lupar Formation is intrusive, and pillow lava interbedded, contrary to the view that they represent older oceanic crust emplaced tectonically as faulted slices within the Lupar. The evidence for this is:

a) Unfaulted contacts of concordant sills of gabbro within the formation, which is thermally metamorphosed for at least 50 m at the contact.
b) Pillow lavas in contact and concordant with the Lupar Formation along an unfaulted contact. At one place both the base and top of a small flow is exposed.

This implies that the lavas are contemporaneous with the Upper Cretaceous Lupar Formation, and at least some of the gabbro is probably also of the same age, although it could be younger, if unrelated to the lavas.

Consideration of this evidence and the results of recent mapping in adjacent parts of Kalimantan to the south, suggests that:

i) the gabbro and pillow lava are not oceanic crust, but intrusive into and extrusive within the Lupar Formation;
ii) the junctions between the Lubok Antu Mélange and the Lupar Formation, and that between the Lupar and Layar Formation, may be major sutures, whereas the Lupar Valley itself may only be a fault zone within a broad mélange belt that extends south beneath the northern rim of the Ketungau Syncline.

INTRODUCTION

The Lupar Valley has long been recognized as one of the most geologically interesting and important areas of northern Borneo. The great Dutch geologist Molengraaff mapped adjacent parts of Kalimantan and made a short incursion into Sarawak near Engkilili (Molengraaff, 1900, 1902). He introduced the term Danau Formation for characteristic radiolarian cherts, with basic lavas and gabbros, which he considered were Jurassic to Cretaceous deep sea deposits, formed in a trough which extended west-east across Borneo (Molengraaff, 1909). Later, other Dutch geologists mapped and wrote on the Lupar Valley (Ubaghs and Zeijlmans van Emmichoven, 1936; ter Bruggen, 1935, 1936; Zeijlmans van Emmichoven and ter Bruggen, 1935; Zeijlmans van Emmichoven, 1939). Accounts of the evolution of the stratigraphic knowledge of the area, and the attendant controversies, are contained in Haile (1955a & b; 1957) and Liechti *et al.* (1960).

Reconnaissance mapping by geologists of the Shell Group and the Geological Survey in the 1950s showed that the Lupar Valley marks a fundamental tectono-stratigraphic boundary between bathyal, strongly folded flysch to the north and continental deposits to the south (Haile, 1957). The term Lupar Line appeared (probably for the first time) in the joint Survey/Shell publication (Liechti *et al.*, 1960).

The existence of an extensive mélange belt in the area was recognized only when a road was built

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across it in the early 1970s (Tan, 1973). A number of authors interpreted the Lupar Valley as a southwards directed subduction zone (Haile, 1973a & b, 1974; Hamilton, 1973, 1976, 1979; Hutchison, 1973, 1982, 1986, 1988, 1989; Katili, 1973).

Knowledge of the geology of the area was greatly advanced by the detailed mapping of Tan, the results of which were published as a survey memoir (Tan, 1979) and in several papers (Tan, 1973, 1975, 1977, 1978a & b, 1982, 1986).

Investigations of the area for the proposed hydroelectric scheme (Lam, 1980; Liaw, 1980) were concerned with engineering geology rather than the relationships of the formations. Significantly, these found no major faults bounding the gabbro and lava, in spite of an extensive drilling campaign.

OUTLINE OF GEOLOGY

The excellent geological map by the Survey Department (Tan, 1979) shows a series of NW-SE or WNW-ESE belts in the Lupar Valley, which are, from north to south:

Belaga Formation, Layar Member (part of Rajang Group):

Thick flysch succession: slaty to phyllitic argillite, metagreywacke sandstone. Bathyal, probably distal turbidites. Intensely folded. Upper Cretaceous.

Lupar Formation:

Flysch succession: greywacke, slaty argillite and mudstone. Bathyal, probably proximal turbidites. Strongly folded, with slumping. Upper Cretaceous.

Included in this belt are elongated bodies of basic lava (including pillow lava) and gabbro.

Lubok Antu Mélange:

Typical mélange, with blocks, lenses, boulders, pebbles and granules of sandstone, radiolarian chert, basic igneous rocks, and limestone, in a sheared argillaceous matrix. Tectonic mélange. Age of blocks ranges from Lower Cretaceous (the radiolarian chert) to lower Eocene; the matrix is in part at least Eocene, indicating that the latest movement of the mélange was at least as young as Eocene.

Silantek Formation:

Shale, mudstone, sandstone, and coal. Shallow marine to fluviatile and lacustrine. Upper Eocene to ?Oligocene.

GABBRO AND BASALT

The gabbro and basalt occur as elongated ridge-forming bodies up to 10 km long in the belt of Lupar Formation, which is only 4–5 km wide (see Fig. 1). Molengraaff (1902) mapped gabbro and diabase as steeply dipping concordant intrusive sheets (i.e. sills) on a traverse across Bukit Pan, which is the east end of the ridge which extends from the Main Dam (Fig. 2). The gabbro and dolerite were recorded by Haile (1957, p. 75) as occurring "mainly as sills, up to several hundred feet thick, steeply dipping, concordant with the strata". The lithology was described in detail by Tan (1979), and the rocks were interpreted by Tan as an incomplete ophiolite (lacking ultramafic rocks) and termed the Pakong Mafic Complex. The gabbro and basalt are typically associated and intruded by sheets of microgabbro (diabase of Tan, 1979; dolerite of Haile, 1957). Tan noted, however, that the actual relationship between the basalt and gabbro has not been observed.

In contrast to previous views, Tan (1979) interpreted the Pakong Mafic Complex as oceanic crust, older than the Lupar Formation, and incorporated into it as faulted slices. Later, however, Tan revisited the area and recorded that, from field evidence in the Batang Ai (Ai River: the upper reaches of the Lupar) "parts of the Pakong Mafic Complex may be intrusive into, and in the case of the lavas, extrusive within the Lupar Formation" (Tan, 1982).

Banda mapped the area around the present main dam, in particular the rapids at Wong Irup and Wong Pakong, in detail (Banda, 1981; Figs. 3 and 4) and concluded that the gabbro there is clearly intrusive into the Lupar Formation. On the access road near Wong Pakong he mapped a gabbro sill 60 m wide with a 5 m fine-grained chilled edge on at each contact. Microgabbro dykes there are intrusive into gabbro and sedimentary rocks, and basalt is concordant with the strata of the Lupar Formation (Fig. 4). He concluded that the basic rocks are not ophiolites but are intrusive gabbro and extrusive pillow lava within the sedimentary rocks of the accretionary prism.

Except for the sketch section by Molengraaff (Fig. 2) and the unpublished mapping of Banda (1981), no field evidence has been given for the view expressed. This note records such evidence from the area of the Main Dam and the Sebangki Saddle Dam confirming the views of Molengraaff (1902), Haile (1957), Banda (1981), and Tan (1982), regarding the intrusive nature of the gabbro. Further evidence is also given confirming that the

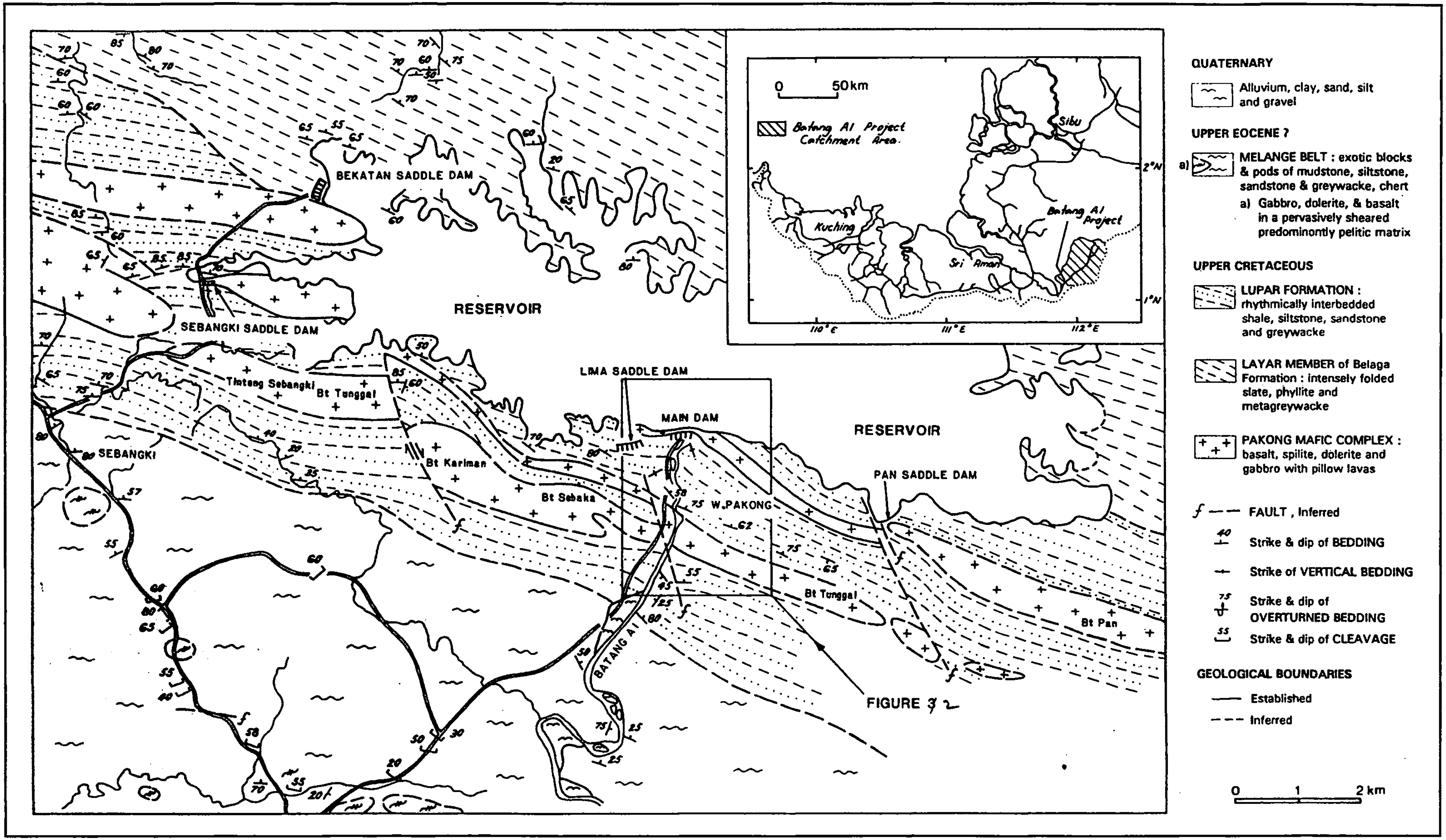

Figure 1. Geology of the Batang Ai hydroelectric project area (after Tan, 1978a, and Liaw, 1980).

pillow lavas are interbedded in the Lupar Formation, and not faulted into it.

MAIN DAM

Along the approach to the west abutment of the Main Dam (Figs. 4 to 7) interbedded sandstone and shale are exposed. The sandstone makes up about 90% of the strata, in beds 0.1–0.2 m thick, graded, with ripple structure and lamination, interbedded with thin shale. The sequence dips to 015° at 66°, and is overturned (youngs to the south). The features are characteristic of the Lupar Formation. A sill of microgabbro is seen intruding the strata (Fig. 8).

Towards the abutment the strata become very hard, and consist of light grey metaquartzite and very hard splintery hornfels; this zone is at least 40 m thick. The northern part of the abutment is formed of gabbro, which can be seen to be concordantly in contact with the sedimentary rocks, along a near vertical face (Figs. 5 and 9). The gabbro appears to be two separate intrusive sills, one about 3 m thick, the other more than 40 m thick, separated by a 1 m bed of hornfels.

SEBANGKI SADDLE DAM

On the approach road to the Sebangki Saddle Dam, another contact of gabbro and Lupar Formation is exposed. Here again, over about 100 m the sandstone and shale becomes progressively harder to the north where the contact with gabbro is exposed.

At the saddle dam itself, pillow lava in contact with the Lupar Formation is exposed at the eastern abutment (Fig. 10). The Lupar Formation, on the southern side, dips towards 345° at 45°, and is overturned. The contact is somewhat overgrown, but appears to be concordant (Fig. 11). The surfaces of the pillows below the original top of the flow show some vertical slickensiding, indicating movement upwards of originally higher pillow relative to the lower ones, but there is no evidence of faulting at the top of the flow, or at its contact with the Lupar Formation strata. Stratigraphically above this flow about 40 m of sandstone/shale interbeds, dipping north-northeast and overturned is exposed, and above this there is a concordant pillow lava about 3–4 m thick. Both the base and the top can be seen in contact with sediment. A gabbro sill cuts the sedimentary rock that overlie the flow.

At an abandoned quarry about 0.5 km northwest of the dam, a 30 m face of lava, with indistinct pillow is exposed. A conformable contact of lava with bedded sandstone and shale is seen in a large block of pillowed lava (Fig. 12).

CONCLUSIONS

1) Relation of the gabbro and lava to the Lupar Formation.
   These detailed observations confirm those of previous investigators, that (at least part of) the gabbro is intruded into the flysch-like strata of the Lupar Formation. New observations show that the lava is clearly interbedded with the Lupar. There is no evidence suggesting that any of the gabbro or lava occurs as faulted slices in the Lupar.
2) Age of the pillow lavas
   It follows that the pillow lavas are the same age as the Lupar, which is dated as Upper Cretaceous, probably Santonian-Maastrichtian, on fairly good foraminiferal evidence (Tan, 1982).
3) Age of the gabbro
   The gabbro and dolerite sills are intruded into and thus younger than the Lupar Formation. They appear to be related to the lavas and so were probably intruded at a high level, at the same time or soon after the lavas were extruded.

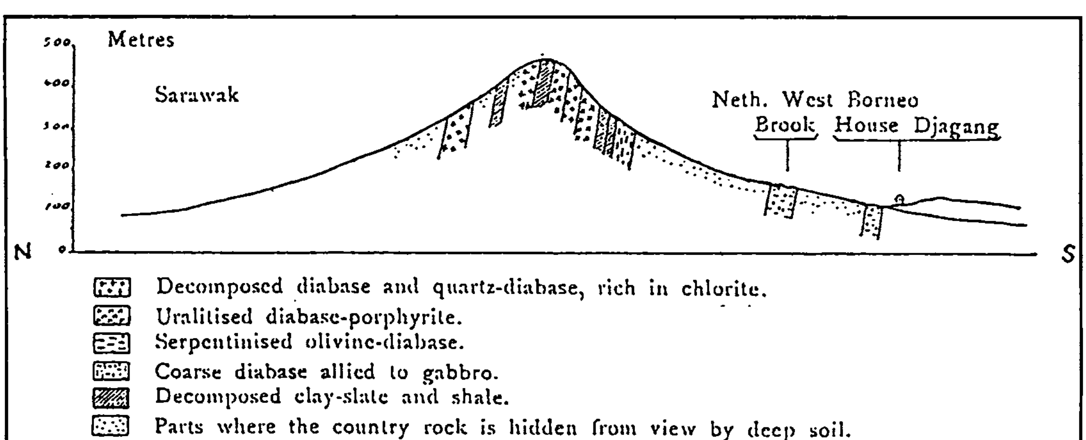

Figure 2. Section through Mount Pan (Molengraaff, 1902).

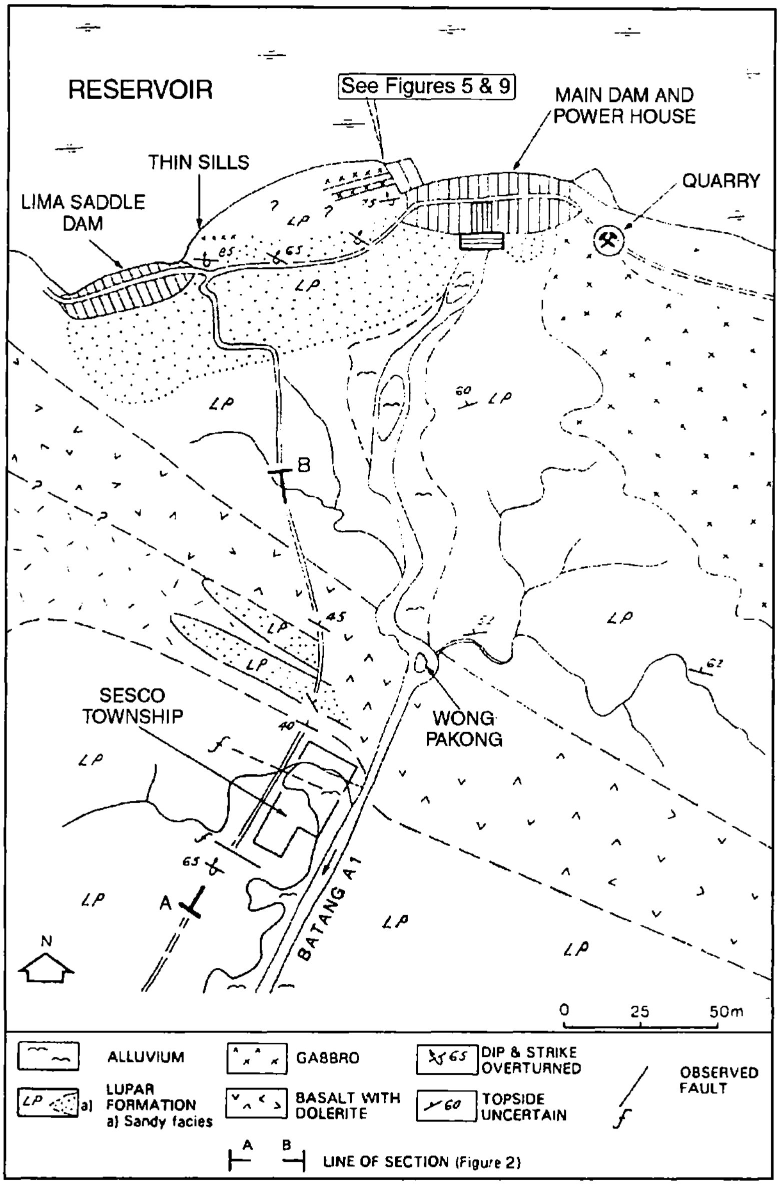

Figure 3. Geology of the Wong Irup and Wong Pakong area (after Banda, 1981).

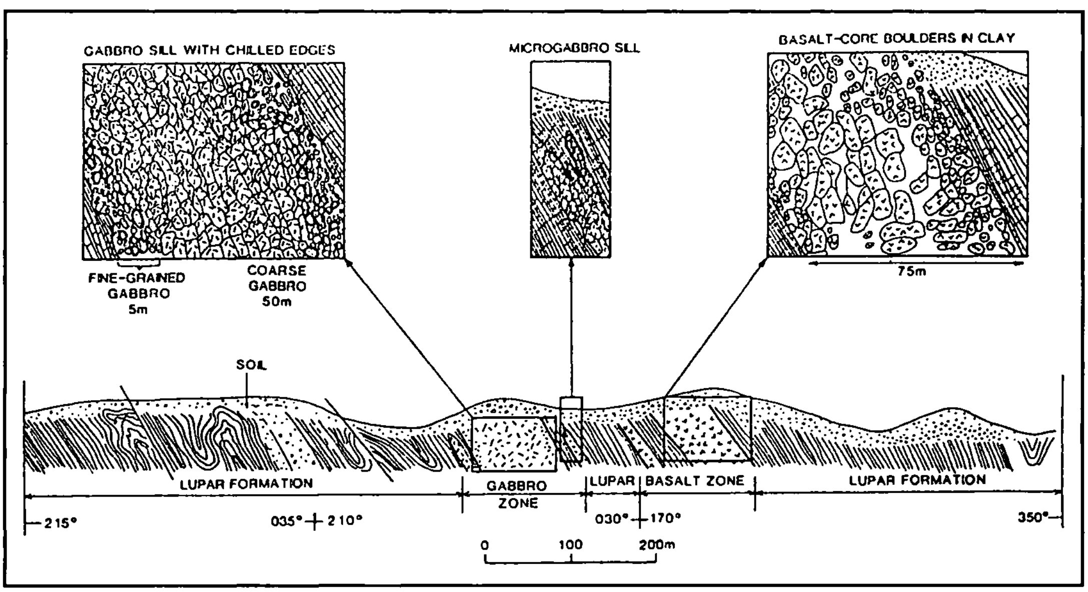

Figure 4. Schematic section along the road near Wong Irup and Wong Pakong (after Banda, 1981).

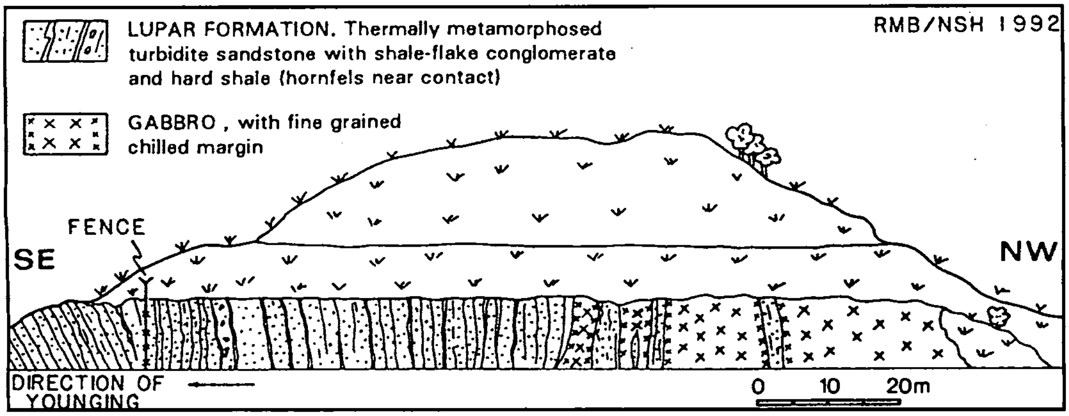

Figure 5. Gabbro sills intrusive into hard shale and quartzite of the Lupar Formation, west abutment, Main Dam.

The microgabbro (dolerite) sills and dykes are probably also Upper Cretaceous.

4) There is no evidence of older pillow lavas or gabbros within the Lupar Formation.
5) No ultramafic rocks have been found in the Lupar Formation, and in the Lubok Antu Mélange the only recorded occurrences are of a 2 m-block of serpentinite (Tan, 1978, p. 70), and serpentine, derived from lherzolite, found by Molengraaff "in Sarawak near to the Dutch frontier, on the path from Na. Badau to Loeboek Hantoe [Lubok Antu]" (Molengraaff, 1902, p. 434). Thus, the mafic and rare ultramafic rocks north of the Lupar Line can only be tenuously regarded as making up an ophiolite or even an "incomplete ophiolite" belt.
6) The Lupar Valley may well be underlain by oceanic crust; indeed gravity data suggest this (Pieters and Supriatna, 1990; Untung, 1990). Rare blocks of mafic rock within the Lubok Antu Mélange could be from older oceanic crust but are more likely to have been derived from the nearby gabbro and pillow lava within the Lupar Formation, as postulated by Tan (1978, p. 70).
7) The Jurassic age assigned to the extension of the gabbro and pillow lavas into the Putussibau Depression (Lake District) of Kalimantan (as shown on the map of Pieters and Supriatna, 1990) and their depiction as faulted slices needs reconsideration. These gabbros and lavas are likely to have the same relationship to the adjacent sediments, and to be Upper Cretaceous. Details of the field relationships and age of these rocks, and of isolated occurrences further east, would be most useful.

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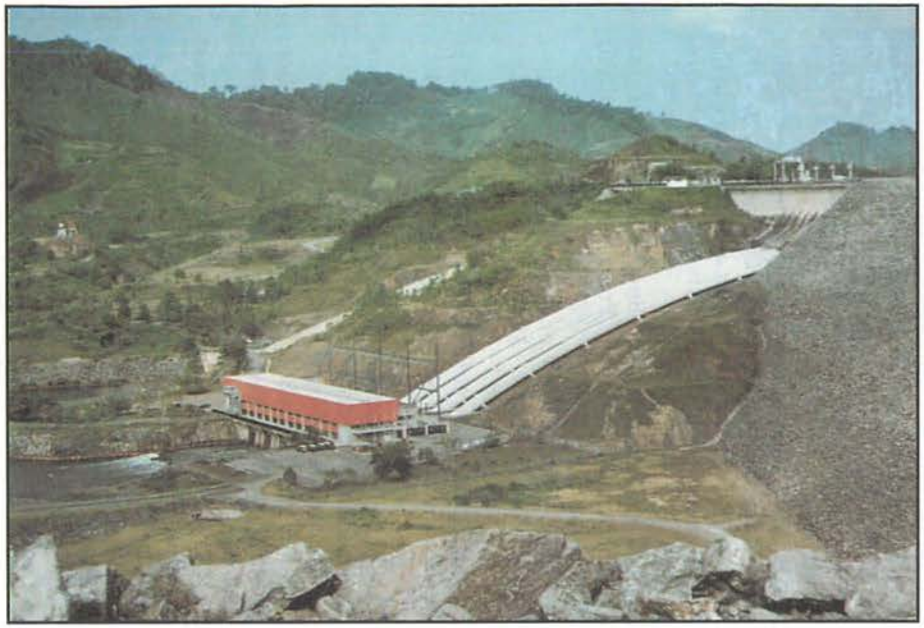

Figure 6. Main dam and power station, Batang Ai.

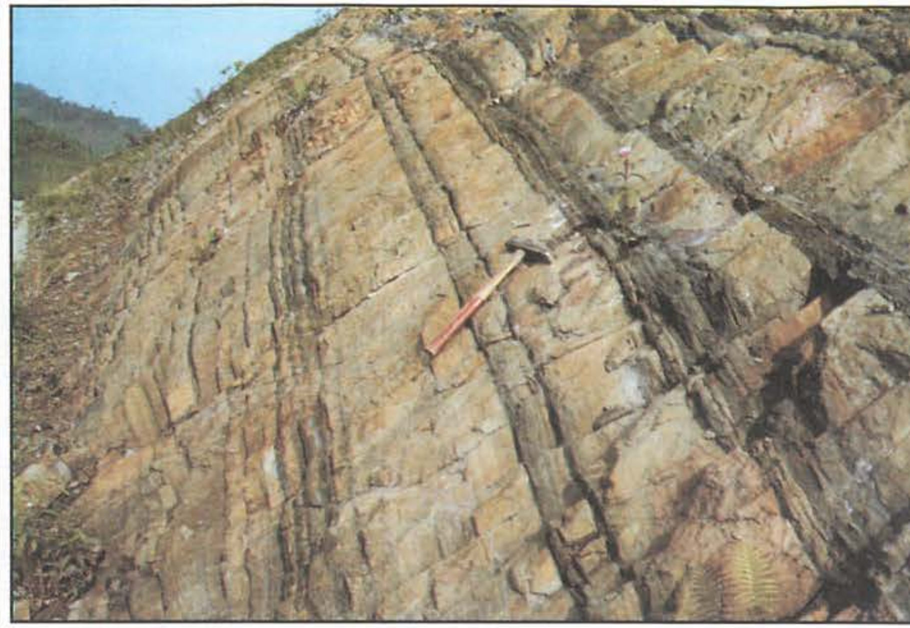

Figure 7. Overturned sandy turbidites, west abutment, Main Dam.

Figure 8. Microgabbro sill in Lupar Formation, west abutment, Main Dam.

Figure 9. Gabbro sills (on right) intrusive into Lupar Formation, west abutment, Main Dam.

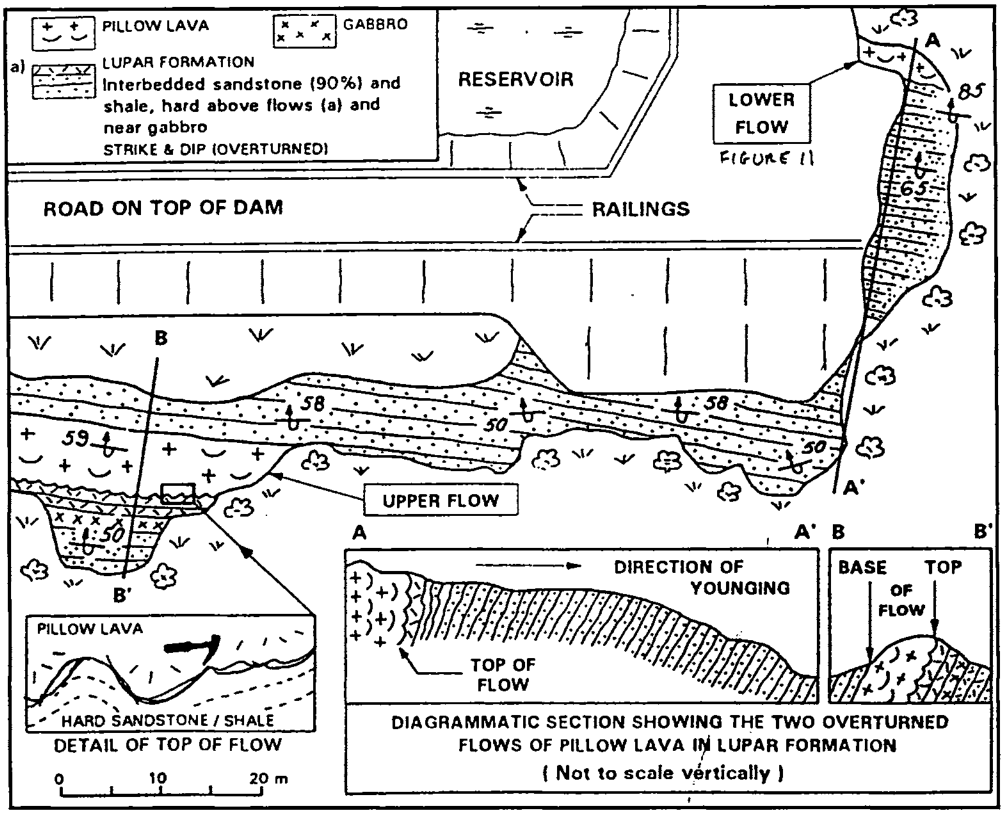

Figure 10. Sketch map of pillow lavas interbedded in Lupar Formation, east abutment, Sebangki Saddle Dam.

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Figure 11. Top of pillowed lava flow, overlain by Lupar Formation, Sebangki Saddle Dam.

Figure 12. Block of pillow lava overlain (on right) by sandstone and shale, Sebangki Saddle Dam.

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