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Some thoughts on the crustal structure of Peninsular Malaysia– results of a gravity traverse

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Abstract: A gravity profile was made across Peninsular Malaysia from Kuantan to Kuala Selangor. After Bouguer and terrain corrections, the major features of the profile are a gravity minimum over the granite of the Main Range and a maximum in the central Mesozoic sedimentary basin. The anomaly over the Main Range is caused by the contrast between the granite and the denser metamorphosed Palaeozoic rocks on each flank. The maximum may be caused by either near-surface dense igneous rocks associated with the Kampong Awah andesitic agglomerate or by thinning or absence of the sialic layer under the central basin.

INTRODUCTION

While the geology of Peninsular Malaysia has been extensively studied, there has been little supporting geophysical work even though there are programmes recommending such work (CCOP-IOG, 1974). Attempts to devise a geological cross-section of the peninsula have been based solely on extrapolations from surface geology (e.g. Hutchison, 1973).

The geology across the peninsula in the survey area is shown in Figure 1 (adapted from Gobbett, 1972). Briefly, the peninsula may be considered to be divided into three: mountainous eastern and western belts of Palaeozoic rocks intruded by granite and a central Mesozoic section with fewer granite intrusions. The two major granite batholiths are the Main Range in the west which forms the main watershed of the peninsula, and the east coast ranges of more subdued topography.

Both flanks of the Main Range are formed of belts of metamorphosed Palaeozoic rocks. The eastern flank is formed of the Lower Devonian Karak Formation (Jaafar bin Ahmad, 1976) which is predominantly argillaceous in the survey area. Similar rocks occur to the west of the Main Range (Roe, 1951). These metamorphics are mainly low grade schists adjacent to the granite grading to slate, phyllite and shale away from the contact. Other Palaeozoic rocks stretch towards the west coast and presumably underlie the Quaternary coastal alluvium. There are minor outcrops of granite in this region, one of which forms the prominent hill at Kuala Selangor, just north of the western end of the profile.

The east coast granites have intruded into a Lower Carboniferous to Permian, predominantly argillaceous sequence, which has been metamorphosed to varying degrees. Generally the argillaceous rocks extend east from the Lebir Fault to the coast, although in the vicinity of the survey the coastal bedrock is granite at Kuantan.

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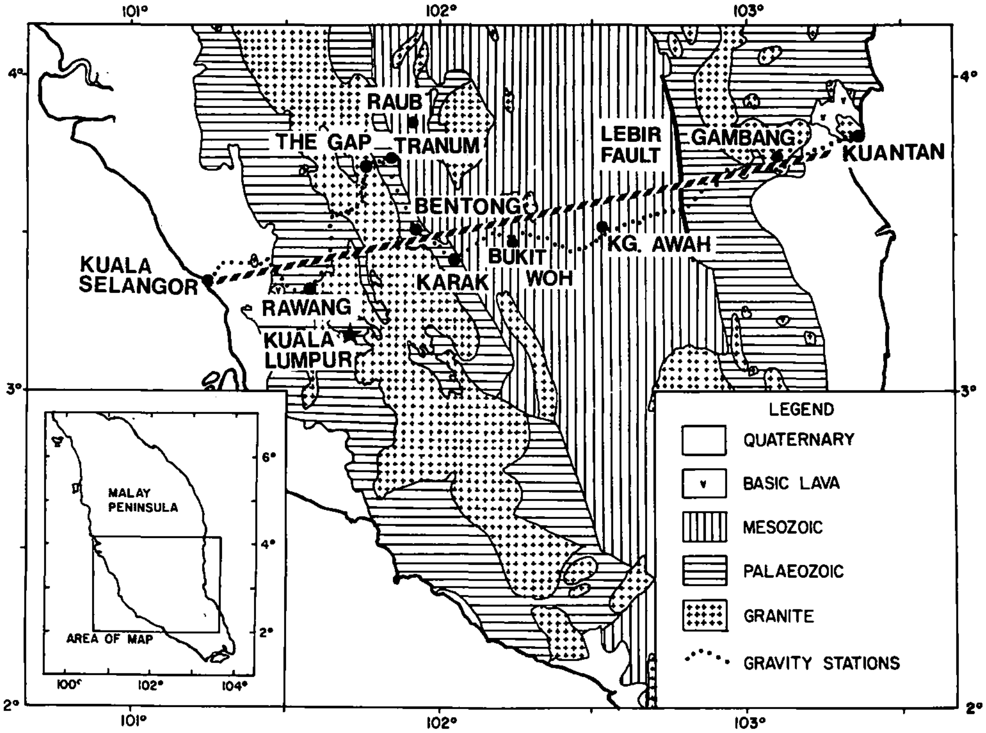

Figure 1. Simplified geologic map showing survey route. Based on Gobbett (1972).

The central third of the peninsula between the eastern foothills of the Main Range and the Lebir Fault is largely of Triassic marine sediments capped in some areas by Jurassic-Cretaceous continental sediments. The Triassic rocks have been called the Raub Group (Jaafar bin Ahmad, 1976). The major component of this unit is the argillaceous Semantan Formation in which the alteration of shale and tuff beds is a common feature. Only scattered granite outcrops are shown in this region (Gobbett, 1972), but more recent work (Jaafar bin Ahmad, 1976) shows the granite and related rocks to be more extensive.

An obvious first step in the geophysical investigation of the peninsula was a gravity survey across it. While such a profile, in the absence of other geophysical constraints, could not provide a unique solution to the gross structure of the peninsula, it could at least put some constraints on geological speculations. Also, such a profile might highlight some problem areas for further investigation.

Since the strike of the geologic feature is essentially NNW-SSE, an E-W survey line was necessary. Since there is only one E-W road across the peninsula at the time of the survey, hence the choice of the survey route was simple. To the west of Bentong there was a choice between a southern route through Kuala Lumpur and a northern route through the Gap and Rawang to the coast just south of Kuala Selangor. This northern route was chosen because the light traffic along it makes gravity measurement much easier.

PROCEDURE

The survey route is shown in Figure 1, where each dot represents one of the 112 gravity stations. Stations are usually spaced approximately two miles apart. The original intention had been to site stations at survey bench marks which are shown at one mile intervals on the published topographic maps. Unfortunately, only a few of these can now be located along most of the route. Presumably many have been destroyed during road imrpovements or by heavy traffic.

Because of the difficulty in locating benchmarks, elevation control was not as good as anticipated. There are three different degrees of accuracy for the stations: (1) Those stations located at benchmarks where elevation is known to better than ± 0.1 foot; (2) Those stations located at the supposed locations of benchmarks as determined from topographic maps. Accuracy here will depend on local topography, being better than ± 1 foot in flat country but perhaps as bad as ± 20 feet in mountains; (3) Those stations located at convenient places to pull the car off the road. In this case elevation was determined solely from topographic maps and may, in a few cases, be in error by up to ± 50 feet in the mountains. Generally systematic results in the survey indicate that the errors were seldom, if ever, as great as these maximum estimates.

The gravity readings were corrected for latitude and the free-air correction was applied. The data points were projected onto a line bearing 078.5° which was judged to be perpendicular to the strike of the main geological features. Figure 2 shows the free-air gravity profile along the route compared to the elevation. Bouguer and terrain corrections out to Hanmer (1939) zone L were then applied. Errors in Bouguer gravity

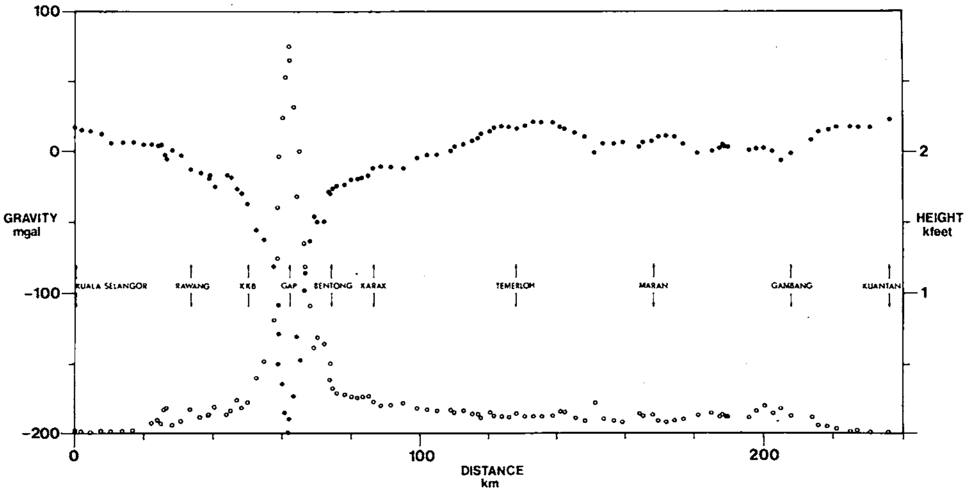

Figure 2. Free-air gravity and topography projected onto a line bearing 78.5° through Kuala Selangor. Open circles—height, closed circles—gravity.

arising from errors in elevation are shown by the length of the bars used as data points in Figs. 3–5. Most points are represented by a bar whose length is equivalent to an error of ± 5 feet because this is the smallest size which would reproduce clearly. This gravity profile was then modelled using a simple two-dimensional model to represent the structures. The gravity anomalies were calculated using a programme by McNab (1966).

INTERPRETATION

Interpretation of the profile is subject to certain limitations. First, a few of the data points are up to 30 km from the projected straight line, although most are within 10 km. Since these offsets are along the strike they will not have a major effect on the validity of the model; however due to local irregularities; uncertainties will be introduced. Second, the data will reflect the effect of small local sources as well as larger deep-seated sources. Because of the scale of this survey, interpretation is solely in terms of large scale features.

There are very few controls on the interpretation of the observed profile. The major control is the surface geology as shown in the Geological Survey memoirs: Roe (1951), Fitch (1952), Alexander (1968), Jaafar bin Ahmad (1976). Unfortunately these memoirs do not cover the entire survey route—there being a gap between 102°30'E and 103°E which straddles the Lebir Fault, as well as from 101°30'E to the west coast. Information from Gobbett (1972) has been used to fill in these areas.

While the geologic map provided surface widths of the prisms used in the modelling, the depths of the prisms were generally unknown, although stratigraphic thickness had been estimated in some areas (e.g. Alexander, 1968). Seismic work offshore in the South China Sea (Parke *et al.*, 1971) suggests thicknesses of 2–3 km for the sedimentary rocks. Similar, if not slightly lesser, thicknesses have been reported under the Malacca Straits. The densities of the different rock types were not usually well known. I have used a value of 2.65 g cm^{-3} for granite and allied rocks which is an average of eight values from Roe (1951) and seven from Alexander (1968). The metamorphosed rocks flanking the granite are more variable ranging from 2.81 g cm^{-3} for an amphibolite schist through 2.71 g cm^{-3} for a composite reddish and grey quartzite to 2.67 g cm^{-3} for a composite light buff quartzite (Alexander, 1968). The arenaceous rocks contain a small proportion of volcanics and the schists contain small amounts of pre-granite basic igneous rocks. Since the prisms used in the interpretation are several kilometres across and will contain a range of rock types, I have used an "average" value of 2.74 g cm^{-3}. This value may be too high (Stauffer, personal communication).

Determination of a suitable density for the Mesozoic sedimentary rocks is more difficult. Little density information is available from this region and no information is available on the proportions of the various rocks within the area. Within the Semantan Formation densities range from lows of 1.76 g cm^{-3} for a weathered resedimented tuff and 1.79 g cm^{-3} for a nearby shale (Stauffer, personal communication) to a high of 2.72 g cm^{-3} for a crystal lithic tuff (Lum Koke Cheong, 1976). Low densities and a lack of reliability obtained from surface samples has been pointed out by Whetton *et al.*

(1957) in temperate zones. The problems are even greater in tropical areas where weathering is more pervasive. Thus the measured densities are treated as a lower limit and since the Semantan Formation is predominently shale, value of 2.5 g cm^{-3} has been chosen in view of the effects of age and compaction.

There are two simple approaches to modelling the gravity profile. One is to assume that the main features are caused by the boundary between the granite and the underlying crustal layer. The other is to assume a flat base to the granite (as in Bott *et al.*, 1958) and model the features of the profile with prisms of denser metasedimentary rock. While the first approach can produce sufficiently large anomalies, the steepness of the observed features, especially on the east side of the Main Range requires a source nearer the surface. While the second approach can model the observed profile quite successfully, it is geologically untenable because of the low density Mesozoic sediments in the centre of the peninsula.

Therefore the approach used in this paper is a composite one in which the lower boundary to the granite is used to produce the large scale features and the more dense, near surface, metasediments provide the steeper features. The surface boundaries for the various prisms were initially determined from the geological memoirs and maps already referenced. Some of these boundaries were moved slightly during modelling. The result of this approach is shown in Figure 3. Going along the profile from west to east the major features of this model are:

(1) A 2 km thick metasedimentary layer above the granite from the coast to the Main Range. The base of this layer is irregular. The rise shown between 10 km and 20 km is related to a small granite outcrop and the small deep prism adjoining the Main Range corresponds to the Palaezoic rocks between Rawang and Kuala Kubu Bharu. The granite rising to the surface west of this prism is a spur from the Main Range.

(2) A thick section, up to 5 km of Karak Formation (Alexander, 1968, has estimated a maximum possible thickness of 21,000 feet) stretching from halfway along the Tranum-Gap road to Karak on the surface and underlying the Mesozoic Raub Group between Karak and the Bukit Besar/Bukit Woh complex. The nature of the contact betwen the Palaeozoic Karak Formation and the Mesozoic Raub Group is open to discussion. The precise position of the contact has not been established during field work (Jaafar bin Ahmad, 1976). Richardson (1950), who mapped the northern prolongation of these rock units in the Raub area, noted a regular difference of 10°–20° in their strike and suggested a major depositional break. Alexander (1968) seems to prefer a more or less conformable contact dipping east, while Jaafar bin Ahmad (1976) proposes that the contact is a high angle west-dipping thrust fault. Gravity interpretation favours Alexander's hypothesis because the increase of gravity to the east is not consistent with a change from a more dense to a less dense rock type at the surface unless dense rock is underlain by denser rock. Hence the interpretation shown here supposes that the Raub Group is underlain by the Karak Formation. The validity of this interpretation depends entirely on the density assumptions made previously.

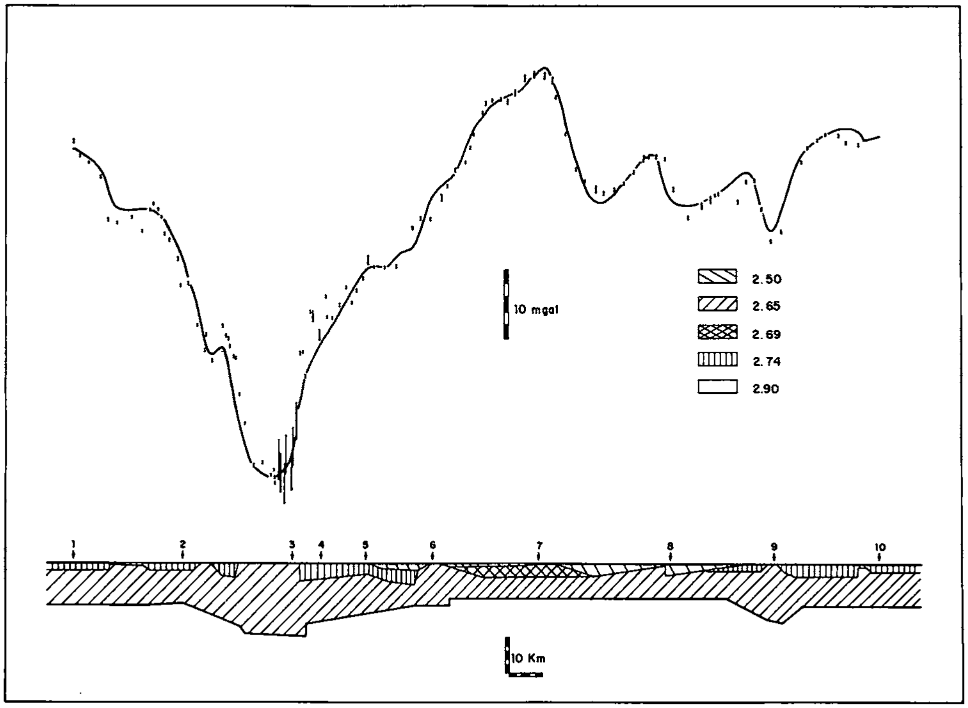

Figure 3. Observed Bouguer gravity and gravity calculated for a model with a dense subsurface prism in the Central Belt. (No vertical exaggeration.) Numbers denote places: 1— Kuala Selangor, 2— Rawang, 3—The Gap, 4—Bentong, 5—Karak, 6—Bukit Wah/Bukit Besar complex, 7—Kampong Awah, 8—Lebir Fault, 9—Gambang, 10—Kuantan.

(3) Granite and allied rocks are seen at the surface in the region of the Bukit Besar/Bukit Woh complex.

(4) The major problem is to reconcile the presence of lighter Mesozoic sediments in the centre with the gravity maximum. There are two possible methods of modelling the gravity high. one is to postulate the presence of a higher density prism just below the exposed Mesozoic sedimentary formations. This supposition is not without basis since the gravity maximum coincides with the exposure of an andesite/limestone agglomerate at Kampong Awah. The other possibility is that the sialic layer is thinner or absent in the central section of the profile. The model in Figure 3 uses a near surface block of slightly denser rock and a slightly thinner sialic layer. In an alternative model (Figure 4) the near-surface denser prism is dispensed with and the anomaly modelled by bringing the denser crustal material nearer to the surface. While this approach can produce the amplitude of the anomaly, it cannot produce the small scale features which require a near-surface source such as the Kampong Awah agglomerate.

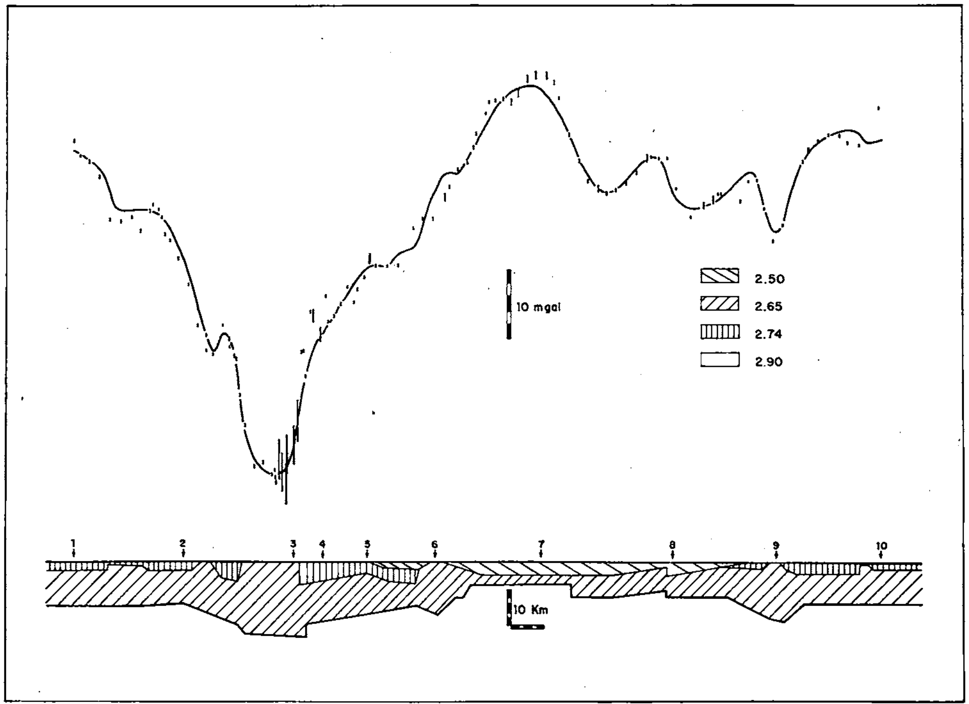

Figure 4. Observed Bouguer gravity and gravity calculated for a model with a thinning of the sialic layer in the Central Belt. (No vertical exaggeration.) Numbers denote places: 1—Kuala Selangor, 2—Rawang, 3—The Gap, 4—Bentong, 5—Karak, 6—Bukit Wah/Bukit Besar complex, 7—Kampong Awah, 8—Lebir Fault, 9—Gambang, 10—Kuantan.

(5) The Lebir Fault shows clearly on the gravity profile and is modelled here (Figure 3) by a vertical fault in the sediments with a throw of about 3 km down to the east. A more realistic representation may be that of Figure 4 where the granite is also shown faulted, since the Lebir Fault is younger than the granite. In this case only about 2 km of vertical offset is required. In both these models the rocks to the west (Mesozoic) and to the east (Palaeozoic) of the fault are represented by the same densities. This treatment is not consistent with the actual densities of the Palaeozoic formations around the Main Range which are denser than the Mesozoic formations. However, the fact that gravity is lower to the east of the Lebir Fault is inconsistent with the presence of denser surface rocks. The sharpness of the anomaly over the Lebir Fault precludes compensation of dense surface rocks by less dense rocks at depth.

(6) The next prism to the east is composed of Palaeozoic metasediments given a density of 2.74 g cm^{-3}. Since this block is west of Gambang—a highly mineralized zone—and is in contact with the granite of Gambang, this is quite reasonable. The sloping line on the west of this prism which divides it from the Palaeozoic formations to the east of the Lebir Fault is better considered not as

a lithologic boundary but as marking a gradation of density from 2.74 g cm^{-3} to 2.50 g cm^{-3} within the same basic rock types.

(7) The small granite exposure around Gambang is reflected by a very sharp gravity minimum (half width $<$ 8 km). This can only be explained by a near surface cause such as the granite being bounded by denser metasedimentary rocks as shown here.

(8) The Palaeozoic metasediments between the granite and the east coast are shown as a layer of constant density of 2.74 g cm^{-3} and varying thickness. This region could equally well be modelled by a layer with density varying horizontally generally decreasing with distance from the granite at Gambang. In the absence of firm density information or seismic studies there is no way to decide between the two possibilities.

Since this model is based on relative gravity data there is no way to determine the thickness of the sialic layer ("granite"). The thickness used is probably close to the maximum because increasing the thickness of granite will broaden the effects from the boundary. The major problem with the foregoing interpretation has been to produce

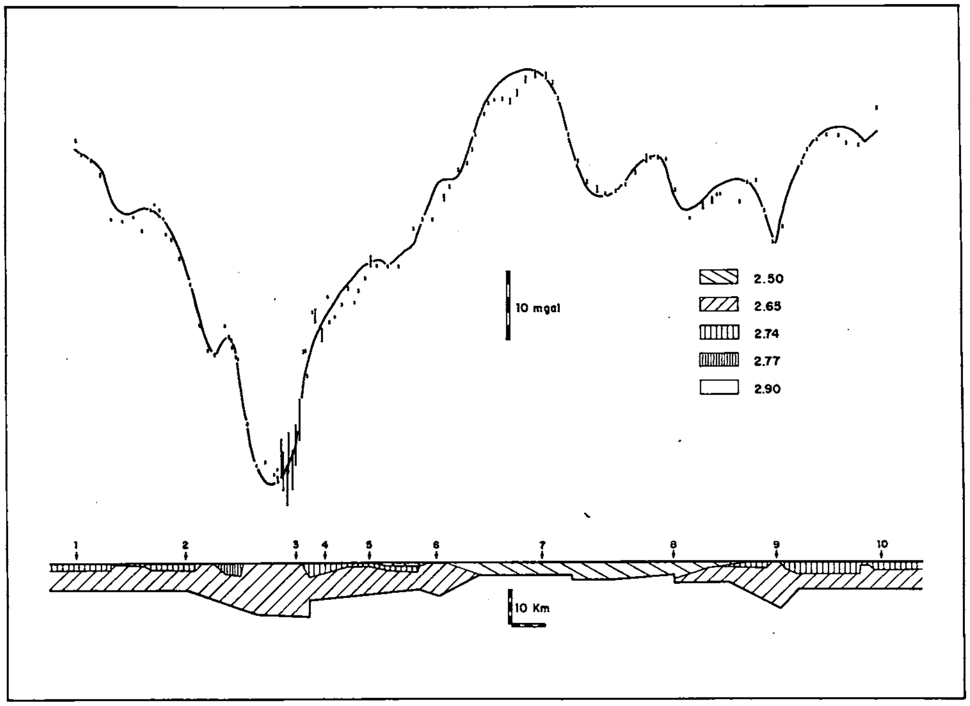

Figure 5. Observed Bouguer gravity and gravity calculated for a model with no granite in the Central Belt. (No vertical exaggeration.) Numbers denote places: 1— Kuala Selangor, 2— Rawang, 3— The Gap, 4—Bentong, 5—Karak, 6—Bukit Wah/Bukit Besar complex, 7—Kampong Awah, 8—Lebir Fault, 9—Gambang, 10—Kuantan.

sufficiently narrow anomalies. If the lower boundary of the granite is raised by 3.5 km and minor adjustments are made, then the result is the model shown in Figure 5. This model implies that there is no granite underlying the central basin and opens the possibility that the denser rock underlying the Triassic sediments is oceanic crust. Purely on gravity information it is not possible to distinguish between the models of Figures 3, 4 and 5 or anything in between them. Furthermore, the exact shapes of the prisms used should not be taken literally but rather as representative of the general shape of the geologic structures.

SUMMARY

There are three main features to the gravity profile: (1) the gravity is the same at each coast; (2) a sharp gravity minimum is associated with the granite of the Main Range and a lesser minimum with the east coast range; (3) there is a gravity maximum in the centre of the peninsula.

Although gravity interpretation is essentially non-unique, the sharpness of the features of the profile and reasonable geologic assumptions combine to constrain the interpretation. In particular, the negative anomalies over the granites require the presence of blocks of dense rocks to each side. The blocks shown in Figures 3, 4 and 5 are all for an average density of 2.74 g cm^{-3}. If the densities are higher, the blocks can be thinner and vice-versa.

The gravity high in the centre of the peninsula is probably produced by a combination of surface/near-surface causes (e.g. the Kampong Awah andesite-limestone agglomerate) and a shallow lower boundary to the granite. If indeed there is very little or no granite at all then perhaps the central belt of the peninsula, the belt of Triassic sedimentation, is underlain by oceanic crust and hence marks the site of an incipient marginal basin (Karig, 1976) which never fully developed. This basin would have developed over the postulated west-dipping subduction zone responsible for the emplacement of the Bentong-Raub ophiolite assemblage in Ordovician to Carboniferous time (Hutchison, 1975).

No matter which interpretation is preferred to explain the gravity high in the centre of the peninsula, there can be no doubt that the crustal structure in the central belt is fundamentally different from that of the mountain belt to each side.

The major uncertainties in this work arise from the lack of information on densities of the sedimentary rocks and the complete absence of any other geophysical information. This work emphasizes the need for further study, especially seismic, in the centre of the peninsula. The validity of the interpretations of this paper could be tested to some degree by further gravity work in the peninsula to see if the profile from this survey is a truly representative one for the peninsula and not unduly influenced by some local feature which this survey happened to encounter.

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