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A gravity survey of Perlis, Kedah and Penang

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Abstract: The results of a gravity survey of northwest Peninsular Malaysia are presented, forming the first stage of a survey of the whole Peninsula. The aim is to obtain as uniform a coverage as possible, initially using 4WD vehicles and boats for transport. At a later stage it is anticipated that areas not otherwise accessible will be reached using a helicopter. The results can be largely explained in terms of the configuration of granitic rocks. A steep gravity gradient follows approximately the boundary of the Main Range granite in a series of *en echelon* northwest and northeast trending sections. The extent and steepness of the gradient along some sections implies steeply dipping contacts between granite and sediments extending to depths of a few kilometres. It is steepest along the section coinciding with the Bok Bak fault, for which there is some indication of a possible extension northwestwards into Perlis: here it could have influenced the deposition of the Tertiary Bukit Arang coal beds, which show a significant gravity response. If there has been major lateral movement along this fault and/or faults parallel to it, a *net* sinistral displacement of about 30 kilometres is suggested by the gravity results.

The Gunung Jerai granite is shown to be much more extensive underground than at outcrop, and the results show that the Pulau Pinang, Kulim and Main Range granites are all connected at relatively shallow levels. The Sintok granite on the Thai border may also be connected to the Main Range granite at considerable depth. In Langkawi the various granite outcrops are probably all parts of a single body. There is no evidence of any change in crustal thickness between Langkawi and the mainland.

This work was done with the cooperation of the Department of National Mapping, who provided a surveyor, maps and height information, and the Universiti Teknologi Malaysia who established the gravity base network used in this survey.

INTRODUCTION

This work represents the first stage of a gravity survey of the whole of Peninsular Malaysia. It is being done in cooperation with the Directorate National Mapping, who provided a surveyor, maps and height information, and the Universiti Teknologi Malaysia (U.T.M.) who established the gravity base network (Ayob, 1986). Results presented here are based on field work during the period July to September 1988. The La Coste and Romberg meter being used is on loan from the British Geological Survey. The survey was started in the northwest because most of the new L 7030 series 1:50 000 topographic maps are now available for this part of the country. The availability of these up to date maps is particularly important if a good uniform coverage is to be obtained as it allows measurements to be made on the large number of roads and tracks constructed since the old 1 inch to 1 mile series maps were compiled.

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Previous regional gravity measurements have been made in this area by the Universiti Sains Malaysia School of Physics (Lee and others, 1983) in a series of profiles along main roads. The principal difference in the present survey is in the attempt to obtain a uniform areal coverage of about 1 measurement every 25 km^2, representing an everage station spacing of 5 km. Over most of the area this presented no difficulty as the road network is good, but it was not possible in the mountainous areas close to the Thai border (Figure 1). The use of boats in the Langkawi islands, the islands west of Gunung Jerai and on two reservoirs in Kedah helped to improve the coverage.

At each measurement point (station) it is necessary to determine gravity, height and location as accurately as is practically possible in order to obtain a reliable Bouguer anomaly value, which is the quantity related to the underlying geological structure.

GRAVITY MEASUREMENTS

These were related to the national gravity base network established by U.T.M. (Ayob, 1986) so that all gravity values are based on the internationally recognised IGSN 71 system. In Pulau Langkawi, a temporary base was established, connected to U.T.M. bases at Alor Setar and Kangar. Corrections for lunar and solar tides and instrument drift were made to all readings.

HEIGHT MEASUREMENTS

These were made using altimeters and the 'single base' system. Two sets each comprising two Wallace and Tiernan altimeters were used, one set located at a base of known height, usually a bench mark, and the other set used for the field measurements at each gravity station. By restricting measurements to periods of reasonably stable weather conditions and ensuring that where possible field and base altimeters were separated by not more than 100 metres vertically and 15 kilometres horizontally, average accuracies of about ± 1½ metres were obtained. This accuracy was determined by repeating some of the measurements on different days, using different height bases, and where possible, locating stations at points of known height, such as benchmarks, sea level or reservoir levels. Spot heights were also used but in some areas were found to be not sufficiently accurate for this purpose. In mountainous areas it was sometimes not possible to keep the difference in height between field and base altimeters to within 100 metres, and in these cases larger errors are likely.

POSITION

Stations were located at positions easily identifiable on the topographic maps, such as road junctions and stream crossings, and are considered to be accurate to within ± 100 metres.

ACCURACY OF RESULTS

The gravity meter was read to the nearest 0.01 milligal, and the observed gravity values derived from these readings are estimated to have an accuracy within ± 0.1 milligals in relation to the U.T.M. base network.

The Bouguer anomaly, which is the quantity presented in Figure 1, is calculated from the observed gravity, normal gravity (calculated from the position of the station) and a correction for the height of the station which reduces all values to a constant height, in this case mean sea-level. The effect of an error of 100 m in position on the normal gravity is negligible at these low latitudes. The chief sources or error are the uncertainty in the height of the station, and the absence of any correction for terrain (topography) effects. An error of 1½ metres in height corresponds to an error of 0.3 milligals in the Bouguer anomaly. Terrain corrections are likely to be small (0.1 milligals or less) over most of the area covered as it is relatively flat. However in the mountainous areas they are likely to be a few tenths of a milligal, though the station locations were chosen to minimise these effects. It is intended that all terrain corrections will be calculated, but it is a laborious process, and has not yet been done. Allowing for these various sources of error, the Bouguer anomaly values can be relied upon to within ± 1 milligal, which is half the contour interval used in Figure 1.

DATA BANK OF RESULTS

All results are stored in a computer data bank enabling listings and computer contoured maps to be produced as required.

DISCUSSION OF RESULTS

The gravity effect of the granitic rocks

Figure 1 shows the Bouger anomaly map of the area. The main features can be explained in terms of the configuration of the granitic rocks. They correspond to Bouguer anomaly 'lows' because their mean density is less than the mean density of the surrounding sediments. Although this density contrast is not large, probably about 0.1 g/cm^3, the granites extend to depths of many kilometres, so that their total gravity effect dominates the Bouguer anomaly map.

Density contrasts within the sediments may be larger, but the depth extent of such contrasts is usually relatively small, with a correspondingly small gravity effect. An exception is the Bukit Arang Tertiary basin along the Thai border, which shows a strong negative anomaly, though it is not well demarcated in this survey.

Faults

The most conspicuous feature of the gravity map is the steep gravity gradient which approximately follows the mapped boundaries of the Main Range granite

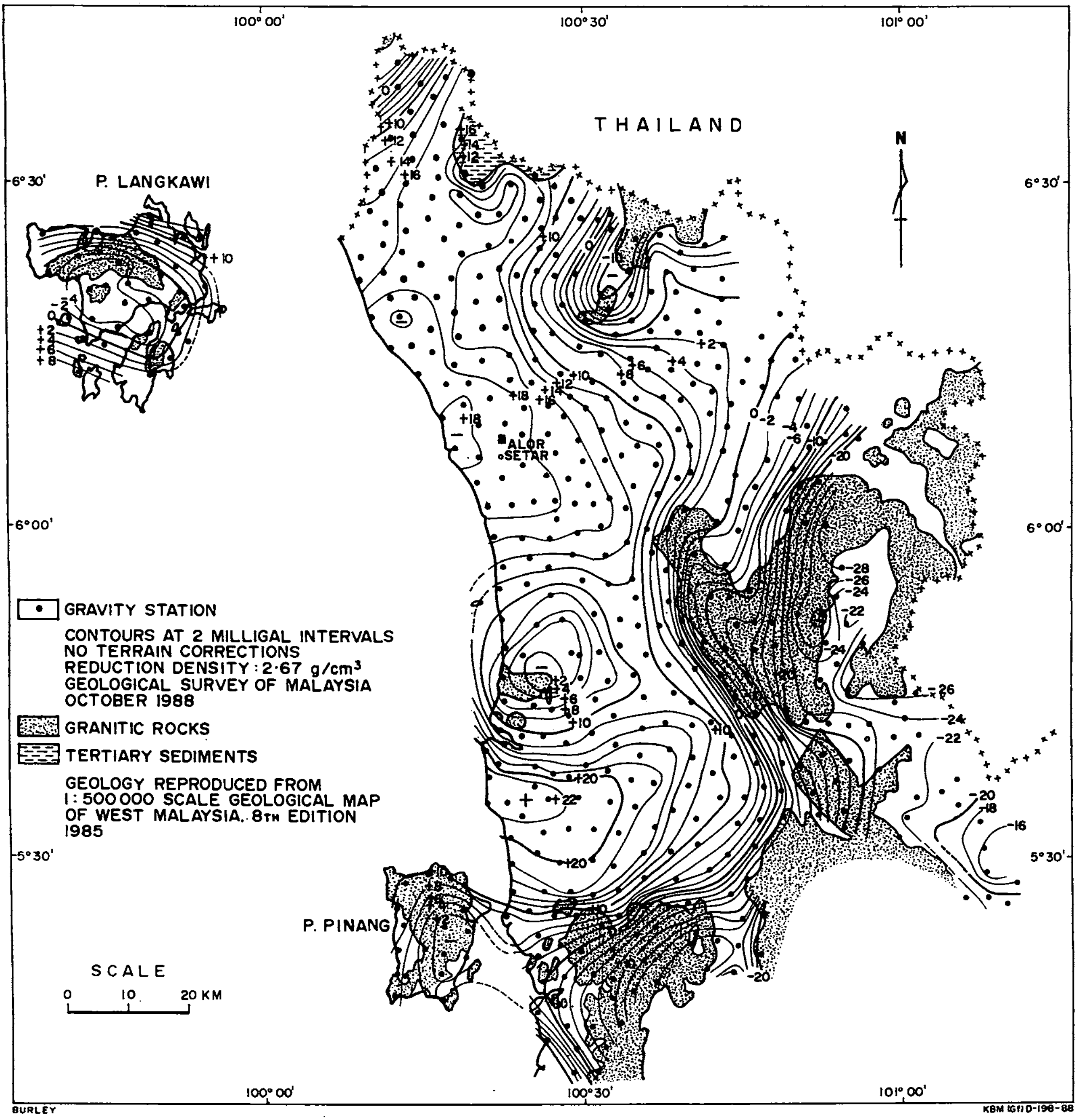

Figure 1: Bouguer gravity anomaly map of Perlis, Kedah and Penang.

in a series of NE and NW trending sections *en echelon.* These correspond to the main fault directions in the area, though not all of the sections of steep gradient correspond to mapped faults. The steep gradient indicates a steeply dipping contact between the granite and sediments, extending to a depth of several kilometres. The linearity of parts of the sections suggests that the contacts may be fault controlled, though this is not always evident at the surface. The mean direction of the NW trending sections is 325° and of the NE trending sections, 37°, i.e. approximately 36° east and west of north.

The steepest and straightest section of the gradient lies along the Bok Bak fault zone (Figure 2) which Burton (1970) described as a major strike-slip sinistral fault with possibly 30 miles (48 km) or more lateral displacement. He pointed out that there is evidence for both sinistral and dextral movement along parallel faults in the area, but that the dominant direction is sinistral. The gravity results suggest that a *net* sinistral shift of about 30 kilometres displaced the two north-east trending sections of steeps gravity gradient labelled A and B in Figure 2. Reversing this displacement would also approximately align the Gunung Jerai and Sintok granites, both of which are evidently much more extensive underground than at outcrop. However, the past alignment may be coincidental: if the two bodies were once parts of the same granite mass, there must also have been dextral displacement in a northeast-southwest direction.

A possible northwest extension of the Bok Bak fault towards Perlis is also shown in Figure 2: it could have influenced the deposition of the Tertiary Bukit Arang basin.

Pulau Pinang and Kulim Granites

The results show clearly that these bodies are connected to each other at shallow depth, as indicated in Figure 2. Similarly the Kulim and Main Range granites appear to be connected, though some extension of the gravity coverage is needed to define this properly. The gravity anomaly over Penang Island is relatively weak, suggesting that the granite there is not very thick. The asymmetry of the contours with respect to the island indicates extensions of the granite offshore to the south and east, but little extension to the north and west.

Gunung Jerai Granite (also known as the Kedah Peak Granite)

The gravity results indicate that at shallow depth this granite extends for some 10 km or more to the northeast, much as predicted by Bradford (1972). At greater depths the body is still larger and more circular in shape, with an extension towards the Bok Bak fault and the Main Range granite. There is clearly no direct connection either to Pulau Pinang or to the Kulim granite to the south.

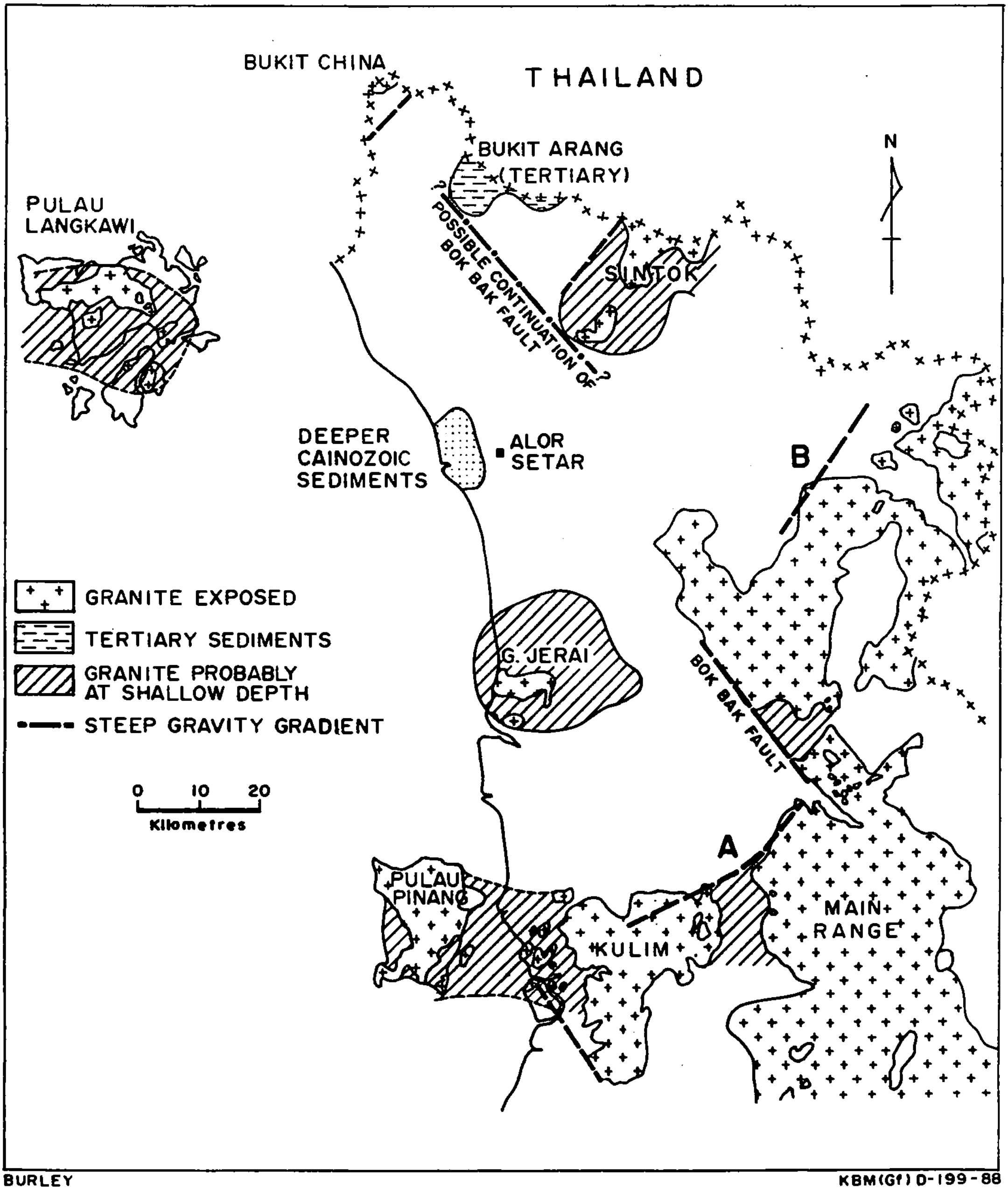

Figure 2: Structural interpretation.

Sintok Granite

The northwesterly continuation of part of the gravity gradient over the Bok Bak fault as far as the Sintok granite, although not pronounced, is an indication that at a depth of some kilometres this granite may form a part of the Main Range. If it is part of a larger granite mass at depth, this could explain why the Bouguer anomaly values over the Sintok granite are as low as – 10 milligals, compared to about 0 over granite masses having a similar or larger area under P. Pinang and G. Jerai.

An alternative explanation for the gradient is that it is an effect of isostatic compensation, as discussed below.

Bukit China Granite

Although the outcrop is very small in Malaysia, it marks the edge of a large batholith extending into Thailand. This helps to explain the steep gravity gradient extending some way south of the contact into Perlis.

Langkawi Granite

The results show that the various outcrops are probably all part of the same granite mass at depth. The extension of the granite under alluvium and the sea floor on the western side of the main island, as proposed by Jones (1978), is supported by the granite evidence. The gravity gradients indicate a more steeply dipping granite contact in the north than to the south and east. To the west the anomaly is not defined.

Variation in crustal thickness: isostatic effects.

The Bouguer anomaly values over the Langkawi granite are not very different from those over similar masses (G. Jerai and P. Pinang) on or near the mainland. Therefore it is unlikely that there is much change in crustal thickness between Langkawi and the mainland. In the east of the survey area an increase in crustal thickness may have occurred as a result of isostatic compensation for the mountains formed by the granite. Isostatic compensation probably accounts for some of the eastward decrease in Bouguer anomaly values, but the effect is not clearly distinguishable from the gradient due to the granite itself.

Bukit Arang Tertiary basin

These coal bearing deposits clearly produce a prominent negative gravity anomaly, but it is poorly defined by this survey. A more detailed gravity survey of the area should indicate the areal extent and approximate shape of the basin. The coal bearing beds have been proved to a depth of at least 600 ft (183 m), (Jones, 1978).

Cainozoic deposits in the Alor Setar area.

In northern Kedah the Bouguer anomaly values increase westwards away from the Sintok granite and the supposed northern extension of the Main Range granite. However, in the vicinity of Alor Setar, the values start decreasing towards the coast, as indicated by the +18 mgal contour just west of the town. The most likely reason is that the depth of the relatively low density, poorly consolidated Quaternary sediments (or possibly underlying Tertiary sediments) increases here.

CONCLUSIONS

A uniform gravity coverage of about 90% of the target area has been achieved, enabling delineation of the regional granite structure. The results confirm an *en echelon* pattern of possible faults or fractures trending northwest and northeast controlling the shape of the Main Range granite: they indicate its probable extent underground, and that of the other granite masses in the area, showing where there are likely to be connections between them.

It will obviously not be possible to obtain such a uniform coverage over much of the rest of the Peninsula using surface transport alone, and it is hoped that helicopter transport for the least accessible areas will be made available.

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