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Overturned folds, superposed thrusts and structural overprints near Sungai Buah, Selangor

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Abstrak: Berhampiran dengan sempadan Selangor—Negeri Sembilan, di Kampung Sungai Buah, terdapat lapisan batu pasir metamorf berfoliasi dan filit (1) membentuk lipatan-lipatan terbalik yang besar beramplitud sekitar 25 m dengan satah paksi berkemiringan sederhana hingga landai; (2) yang tersungkup ke arah barat di sepanjang sesar-sesar songsang yang bersudut kecil, di samping sungkupan ke arah tenggara yang menindan arah pertama; (3) mempamerkan foliasi tersendeng curam memotong foliasi berkemiringan landai, jurus kedua-duanya adalah serupa; (4) menunjukkan perhubungan yang tidak lazim di antara ira yang berkemiringan lebih curam daripada perlapisan dalam satu lapisan nipis yang terbalik. Kebanyakan struktur mencadangkan adanya canggaan polifasa. Dari segi litologi, batuan ini mempunayi keserupaan batuan Bukit Kenny di kawasan Kuala Lumpur. Oleh itu, canggaannya besar kemungkinan berlaku semasa Trias—Awal Jura. Selain dari kemungkinan canggaan polifasa, penyungkupan bertindan juga ditafsirkan sebagai hasil dari penyungkupan umum ke barat, sementara penyungkupan ke arah tenggara dianggap sebagai penyungkupan berlawanan secara tempatan.

Abstract: In the vicinity of the Selangor—Negeri Sembilan border, at Kampung Sungai Buah, are foliated metasandstone and phyllite (1) forming large overturned folds with moderately to gently dipping axial planes and amplitudes in the order of 25 m; (2) that were thrusted along low-angle reverse faults towards west and also superposed on this direction thrusted towards southeast; (3) exhibiting steeply inclined foliation transecting gentler dipping foliation, both having similar strikes; (4) showing anomalous relation of cleavage dipping steeper than bedding in an overturned layer. Polyphase deformation is suggested by most of the structures. Lithologically, the rocks are similar to Kenny Hill rocks of the Kuala Lumpur area. Therefore, the deformation very probably occurred in Triassic—Early Jurassic time. In spite of the probability of polyphase deformation, yet the superposed thrusts are interpreted as being products of general thrust westward, while the southeasterly directed thrust is considered as localized "backward thrusting".

INTRODUCTION

Improvements to narrow main roads in the surroundings of Bangi, Selangor, have exposed better and sometimes new outcrops. Several outcrops are shown by roadcuts near Sungai Buah village (fig. 1) displaying structural relationships that prove more complex than those reported in earlier investigations. The rocks are metamorphosed metasediments consisting of decimeter-meter thick bands of phyllite and similar to massive foliated metasandstone. Lithologically these rocks are indistinguishable from certain types described as Kenny Hill rocks of the Kuala Lumpur area, about 30 km to the north. Stauffer (1973, p.87 etc.) compiled the existing lithological information of the Kenny Hill formation and suggested that the rocks are most probably upper Palaeozoic. The rocks are transected by granitic and quartz dykes belonging to the last major episode of granitic intrusions of late Triassic-early Jurassic age. Structures in the Kenny Hill rocks were first considered to consist of simple open folds with general north-south strikes. However, a major roadcut in the Bukit Pantai—Damansara area of Kuala Lumpur shows conclusively large-scale recumbent folds and that imply main tectonic transport towards west (Tjia, 1979).

In a detailed study of structures in the Bangi-Salak area, Zaiton Harun (1981) found that there Kenny-Hill like rocks were also deformed into isoclinal to recumbent folds and are cut by reverse to low-angle thrust faults. Drag along these reverse faults suggests tectonic transport in a general westward direction. However, there is also evidence for movement towards the southeast. The second movement was then interpreted as minor manifestations in a rock series that mainly moved westward.

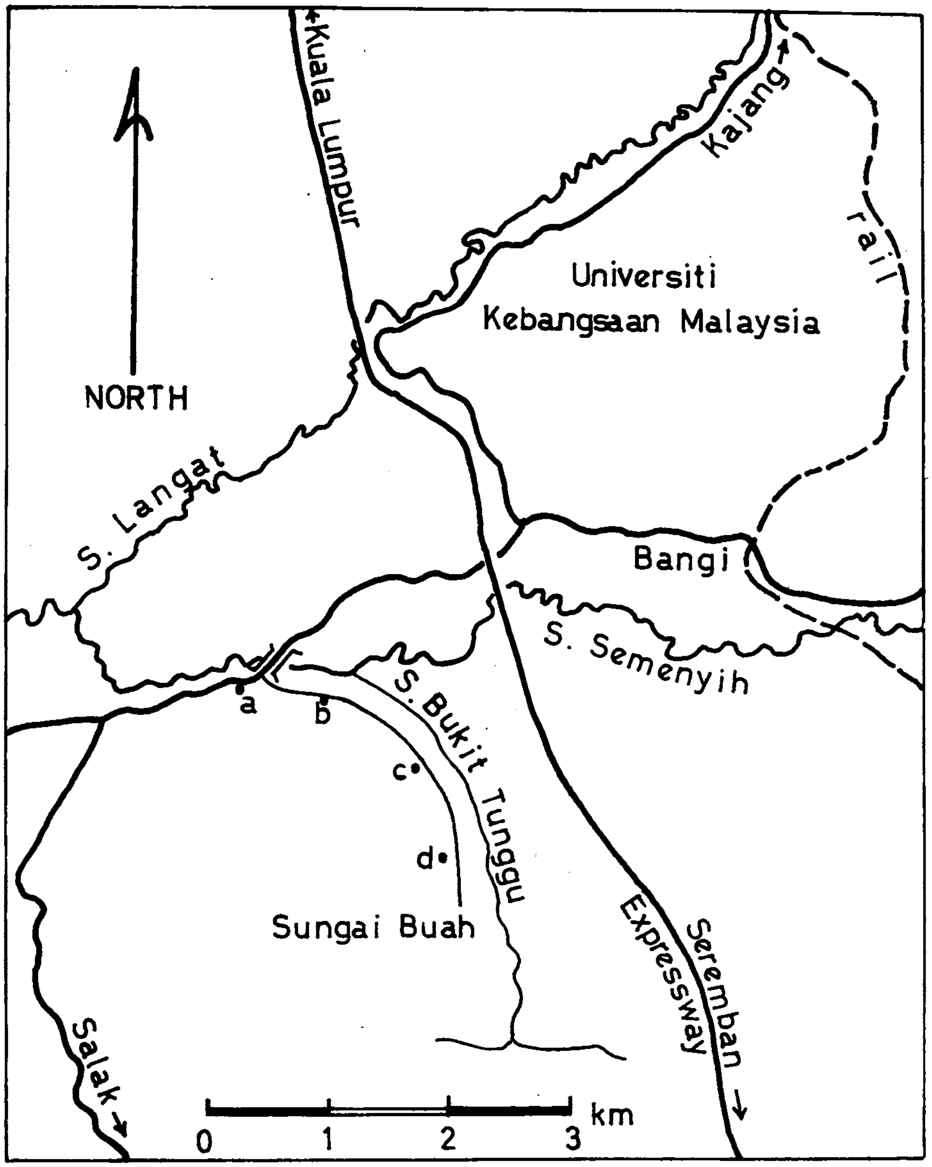

Fig. 1. Index map of outcrops a, b, c and d near Sungai Buah.

Petrofabric studies (Zaiton Harun, in press) show the rocks experienced compressions that acted in the northwest, north and northeast directions. The multiple compression directions may also be traced in outcrops, such as intersecting foliations in phyllite and warp axes striking oblique to well-defined fold axes.

In this paper we detail our observations at four roadcuts near Kampung Sungai Buah. The localities are indicated on fig. 1 by the letters a through d.

FIELD OBSERVATIONS

Locality a, Roadcut Near Sungai Buah

This roadcut is along the main road between Bangi and Salak (fig. 1) near the bridge across the Semenyih river. The roadcut on the south side of the road is about 15 meters high and almost 150 meters long, and exposes interbeds of foliated metasediments. Foliated metasandstone and phyllite were deformed into large overturned folds (fig. 2). The thickness of the metasandstone ranges from 2 m to massive, that of phyllite beds is between 1 and 4 m. A smaller roadcut on the north side of the road exposes mainly massive metasandstone. The following observations concern only the south roadcut.

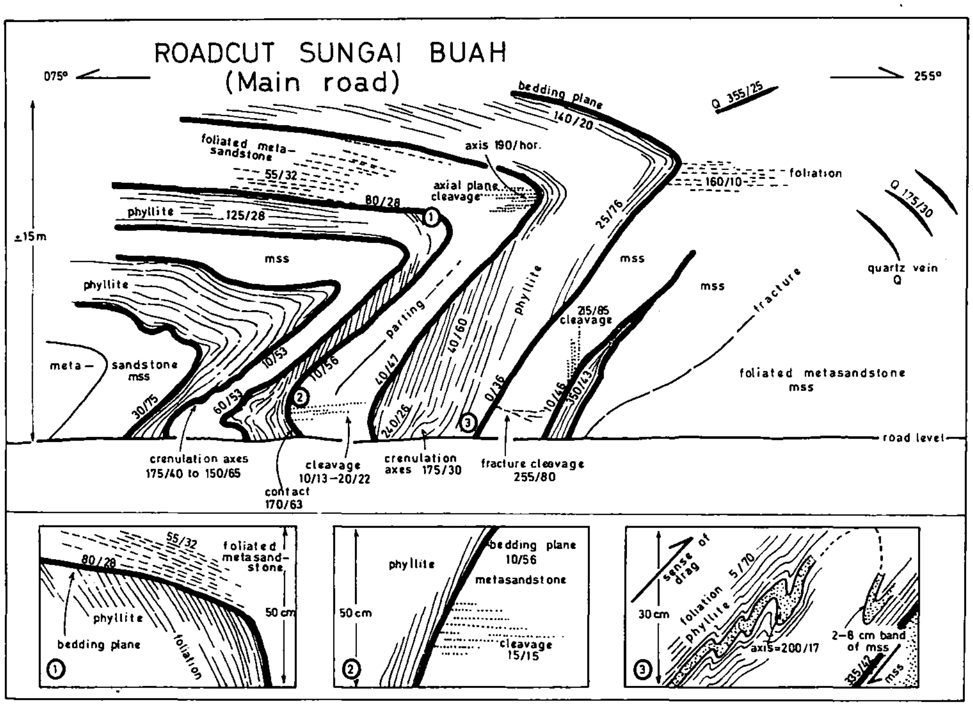

Fig. 2. Roadcut Sungai Buah (main road), locality a. Large asymmetrical folds with moderately inclined axial planes suggest tectonic transport towards west. Detailed relationships at various points of the large structures are shown in three insets.

In the phyllite the general foliation may follow lithological boundaries or are oblique to them. Sometimes two intersecting foliation planes are seen; one foliation dips steeply to vertically, the other dips at a small angle. At one locality the attitudes of intersecting foliations are 40°/80° and 35°/20°. In other words, their strikes are subparallel. In the metasandstone the foliation appears to be sub-parallel to lithological boundaries, but in fold bends axial plane cleavage may be developed.

The exposed general structure appears to consist of an overturned antiform and a small part of the adjoining synform in the lower part of the roadcut. The axial planes determined from the large structures have attitudes between 44°/26° and 64°/20°. One fold axis in the large antiform is horizontal and strikes 010°. These variations in the attitude of axial planes and the strikes of fold axes suggest that the rocks experienced more than one deformation event, in which the stress directions were orientated differently. Fig. 3a is an equal-area plot of poles to bedding (contoured) and poles of smaller folds in phyllite as measured along the lower section of the roadcut. Two different trends of fold axes suggest two compression directions, one acting ESE–WNW and the other east-west. The π-girdle defines an asymmetrical fold style; SE-facing limbs dipping very steeply and the other limbs dipping gently towards WSW. The statistical axial plane dips at moderate angle towards WNW.

Details of structures near lithological boundaries are shown as insets 1, 2 and 3 on fig. 2. Inset 1 displays the crosscutting relationship between bedding and foliation in the phyllite. Although the foliation in metasandstone is also oblique to bedding, the angle is smaller. Inset 2 shows that cleavage planes in metasandstone strike subparallel to bedding strike but that the cleavage dips at a gentler angle, suggesting that at 2 beds are overturned. If this is true, then the fold bend at 2 represents the trough of a syncline and the bend near 1 is the crest of an anticline. In other words, the folds indicate tectonic transport towards west. Inset 3 shows sense of drag between phyllite and metasandstone. This drag agrees with differential movement towards west.

There are three types of quartz veins in this outcrop.

(1) In the phyllite are folded quartz veins with variable attitudes; some folds are tight, other folds consist of simple warps, while still other folds pinch out possessing discontinuous limbs. In general, the folded quartz veins follow the foliation. Fold axes strike 175°–180° and plunge between 12° and 19°.

(2) Within the massive metasandstone may be thin and long quartz veins that follow planar foliation. These veins are straight in the outcrop.

(3) There are other quartz veins in the metasandstone that transect foliation. These veins may be arranged in complex patterns or in more systematical fashion, that is, *en echelon* or symmetrically disposed about the strike of large structures (fig. 2, right-hand side; fig. 4a). The complex appearance of some quartz veins may be only apparent and may be on account of outcrop face cutting obliquely across the strike of the veins.

In the massive metasandstone on the right-hand side of the roadcut are several 10-

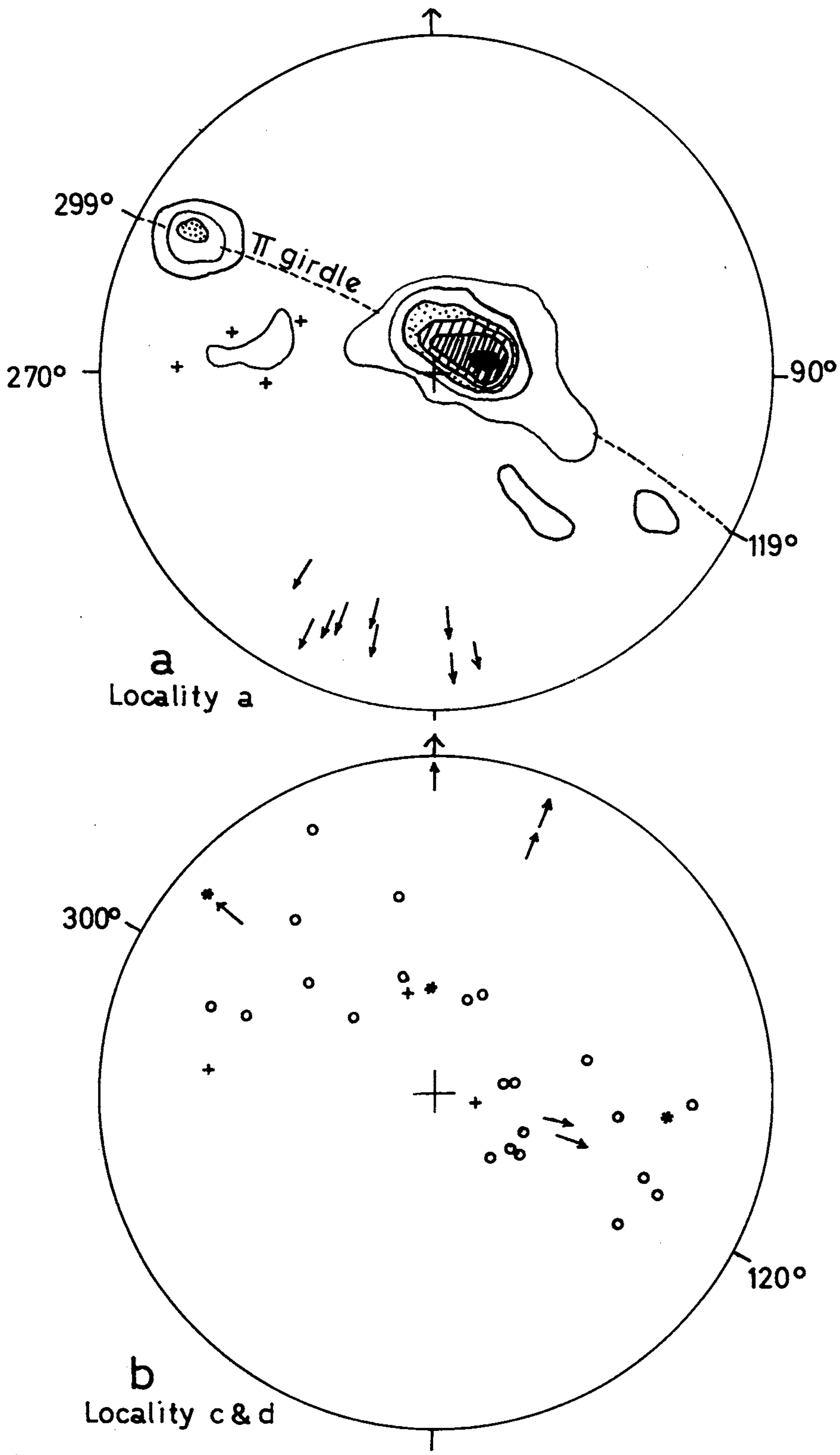

Fig. 3. (a) Equal-area projection, lower hemisphere, of foliation planes (contoured at 2 – 4 – 6 – 8 – 10 = 2 % per 1 % area), bedding planes (plus signs), and axes of small folds (arrows). Locality a.

(b) Equal-area projection, lower hemisphere, of foliation (small circles), fold axis (arrows), bedding planes (plus signs), and overturned beds (asterisks) at localities c and d.

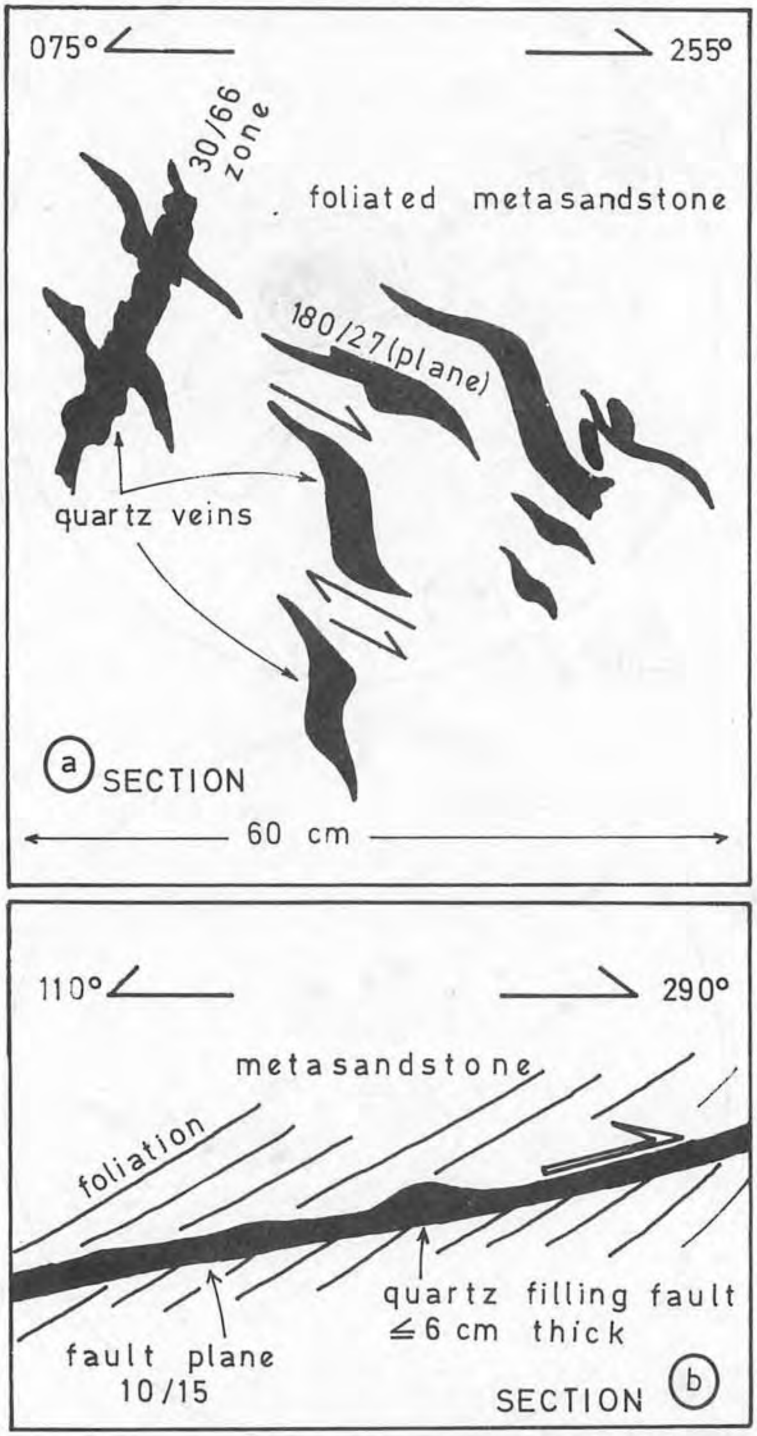

Fig. 4. (a) Pattern of quartz veins in foliated metasandstone near the west end of the roadcut at locality a. The two sigmoidal veins (centre and lower entre) suggest differential movement as indicated by the half-tipped arrows.
(b) Quartz filling a reverse fault zone through foliated metasandstone. Tectonic motion is towards 280°. Locality a.

cm wide, 75 cm to over a meter long and straight quartz veins, one group striking and dipping 355°/75° and the other 175°/30°. These two groups are arranged symmetrically about the axis of the anticline and their attitudes correspond with those of shear fractures that may be expected to form in a stress system in which the maximum horizontal stress was horizontal and acted in east-west direction normal to the fold axis, while the intermediate principal stress was also horizontal and acted north-south parallel to the fold axis. In other words, quartz filled fractures that were developed by the same stress system that formed the large folds. The almost similar dip angles between the west and east dipping quartz veins further suggest that after the fractures were formed, the rock mass of this roadcut did not experience appreciable dislocation or tilting.

About ten meters farther towards the west from the margin of the roadcut depicted in fig. 3, the massive metasandstone contains arrays of quartz veins as shown in fig. 4a. The sigmoidal quartz lenses suggest differential movement westward, that is, the upper part moved westward differentially with respect to the lower part of the roadcut.

Fig. 4b is a detail of quartz filling a fault through metasandstone in the same roadcut. The attitude of foliation adjacent to the fault agrees with differential motion westward along this low-angle reverse fault.

Locality b, Kampung Sungai Buah Roadcut

Metasandstone, phyllite and a zone of phyllite and metasandstone intercalations on the right-hand side of the roadcut represent a rock series that was thrusted over mainly massive foliated metasandstone that outcrops on the left-hand side of the roadcut (fig. 5). This roadcut is on the south bank of Sungai Semenyih and also flanks the feeder from Kampung Sungai Buah to the main Bangi-Salak road (fig. 1). The roadcut consists of two faces at different levels. In the massive foliated sandstone, the lower face is about twice as high compared to that displaying the mixed foliated rocks on the northwest side of the cut.

The sole of the above mentioned thrust packet of rocks is a relatively thin fault striking SW and dipping 22° towards NW. Drag folds indicate thrusting towards southeast, such as folds in phyllite above the thrust sole. The differential movement is also indicated by actual displacements along several other faults that run parallel to the thrust sole. Below this thrust packet of mixed rocks, the massive foliated metasandstone has a low-angle thrust fault (dips between 9° and 25°) that generally strike north-south. Drag phenomena near this fault indicate tectonic movement towards west. Also in this metasandstone, pre-thrusting and post-thrusting normal faults are represented by very steeply to vertically dipping faults. Through this lower thrust packet are also vertically dipping fractures striking 60°; some of them are filled by quartz. In contrast, the quartz veins within the upper thrust packet were deformed, probably even folded. In one instance a quartz vein was disrupted into flasers (near the right-hand margin of fig. 2). In the phyllite several occurrences of crenulation cleavage have been drawn in the figure.

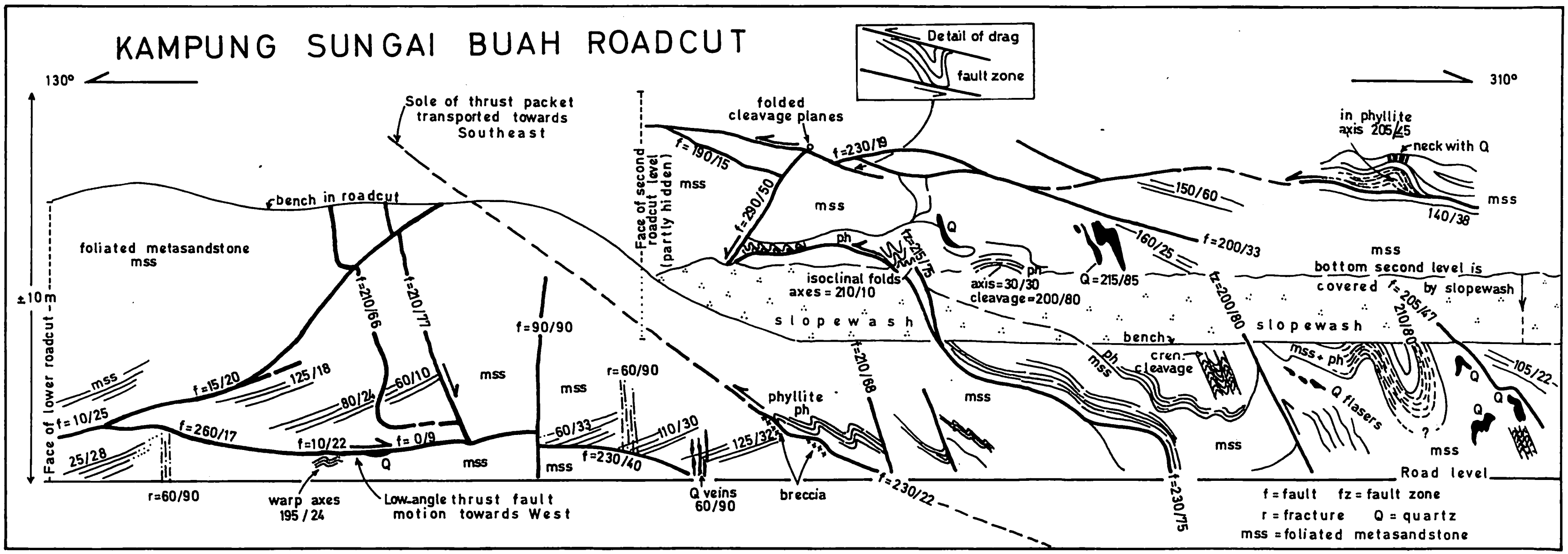

Fig. 5. Kampung Sungai Buah Roadcut, locality b.
The 230/22 fault (centre) separates an upper thrust packet from a lower thrust packet with tectonic transport towards southeast and west, respectively. Inset in the central top margin shows detail of drag along one of the south-eastward moving fault sets.

Localities c and d, Kampung Sungai Buah Road

Localities c and d are also roadcuts along the rural road leading to Sungai Buah village (fig. 1). At these roadcuts are exposed interbeds of phyllite and foliated metasandstone. The following structural observations were recorded at these outcrops.

At locality c: (1) A layer of metasandstone strikes 87° and dips moderately (25°) towards south. Cleavage in the same bed strikes 80° and dips 49° south. Graded bedding shows the metasandstone bed to be overturned. In general, bedding planes that dip steeper than cleavage (both dipping in the same direction) occur in overturned limbs of folds. However, this structural indication for determining top-and-bottom cannot be used if the beds were already juxtaposed before folding, or, if these structural features occur in recumbent folds with plunging fold crests (see Wilson, 1982, p. 43 etc.). In the second case cleavage dips less steeply than bedding even in the fold limb that is right-side up but the limb is plunging toward the recumbent fold crest (fig. 6.4 in Wilson). In the same fold, cleavage dips more steeply than bedding in the overturned fold limb that is plunging toward the recumbent fold crest.

The anomalous relationship between dip of cleavage and dip of bedding in the overturned metasandstone at locality c may represent the last mentioned case. However, in the absence of direct evidence of a plunging recumbent fold crest at this locality, we interpret the steeper cleavage in the overturned bed as the results of deformation subsequent to that which caused the overturning.

(2) The phyllite is always tightly folded; folds plunge towards 15°–20° at around 19°. The phyllite foliation (S_1) dips between 26° and 60° depending on its position in the fold structure. S_2 represents axial plane cleavage that transects these tight folds.

(3) Near a fold crest was seen a thin quartz vein folded about north-south axis.

(4) In another part of the roadcut, quartz veins show up as recumbent folds accompanying a low-angle fault dipping very gently southeast. The movement picture exhibited here (fig. 6) corresponds with tectonic movement into southeast direction.

At locality d is a $1\frac{1}{2}$ m wide fault zone striking 0° and dipping almost vertically. Mullions within the fault zone plunge 50° in 11° direction. In adjacent phyllite east of the zone, axes of drag folds also plunge 50° in 20° direction, indicating dip-slip faulting down-throwing to the east. The accompanying lateral slip component along the north-trending fault is sinistral.

SUMMARY AND CONCLUSIONS

Structures

From the roadcuts in the vicinity of Kampung Sungai Buah and the above discussions we conclude the following.

The metasediments were deformed into large, asymmetrical overturned folds with axial planes striking between north and northeast, dipping moderately to gently east.

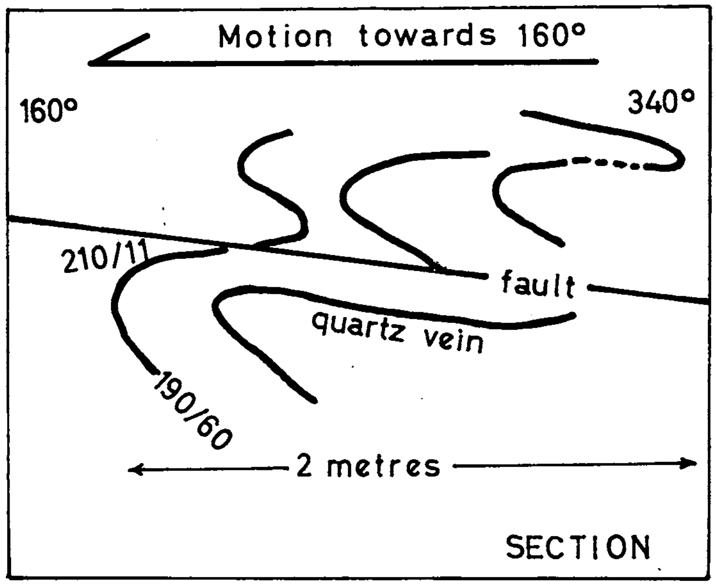

Fig. 6. Pattern of thin quartz veins parallel to phyllite foliation suggest tectonic transport in southeast direction along the low-angle reverse fault. Locality d.

Reverse and low-angle reverse (or thrust) faulting were also important modes of deformation. The tectonic transport by these faults movements were towards west and also towards southeast. The reverse fault movement towards southeast occurs in a rock packet containing folded and sometimes flasered quartz veins and isoclinally folded metasediments that now rests on top of another rock packet in which low-angle reverse faulting indicates motion towards west.

In the lower rock packet the attitude of the schistosity is distinctly regular compared to that in the upper thrust packet. The contrasting deformation styles in the two packets may be explained in two possible ways. First, it is possible that the difference in lithology between the lower thrust packet (almost entirely consisting of massive foliated metasandstone) and the upper packet (interbeds of some phyllite between thick layers of foliated metasandstone) was the cause of the different deformation styles. Second, the more intensely deformed upper thrust packet is older than the less deformed lower packet. This would mean that the lower packet was actively thrusted under the other rock packet. In older textbooks of structural geology, active underthrusting was seldom mentioned, probably because it is difficult to prove. According to the theory of plate tectonics, however, active underthrusting is an accepted mode of deformation in subduction zones.

We subscribe to the first mentioned explanation about the different deformation styles exhibited by the raodcut at locality b (fig. 5). In other words, the difference in style was caused by difference in lithology. We further believe that the superposed thrusting in different directions were developed contemporaneously by the same regional stress field. Our conclusion is based on the following.

(1) For tens of meters farther northwestward from the edge of fig. 5 the rocks of the upper thrust packet also consist of massive foliated metasandstone in which the foliation dips regularly in northwesterly direction. This regular structural appearance is similar to that exhibited by the massive foliated metasandstone of the lower thrust packet (shown on the left-hand side of fig. 5), albeit dips are in different directions.

(2) In the Kenny Hill rocks the dominant structures strike north-south implying east-west compression. Although differential tectonic movement in a general southerly direction has also been observed elsewhere in the Bangi area (Zaiton Harun, 1981) and in Shah Alam (Tjia, 1976), these occurrences appear to be of local importance. Therefore, we envisage that in Selangor regional thrusting towards west may be accompanied locally by "back-thrusting" in directions approximately opposite to the general tectonic transport direction. Back-thrusting probably occurred where westward moving thrust packets ecountered geological barriers, such as plutonic bodies or projections of tectonic basement. By "tectonic basement" we mean that part of the rock mass that is not involved in the thrust movements.

Multiple Deformations

The rocks in the Sungai Buah area appear to have experienced at least two events of deformation. Indications consist of intersecting foliation planes in phyllite, the anomalous relationship between cleavage dipping steeper than bedding in an overturned, graded arenaceous bed, and the preferred orientations of axes of small folds in at least two directions (fig. 3a, fig. 3b). We interpret the two fold directions south and south-southwest in fig. 3a, and those in north and northeast directions in fig. 3b as products of the same stress system that caused westward thrusting. The regional compression was east-west producing the north and south plunging folds, while "backward thrusting" as we explained above produced the north-northeast and south-southwest trending folds. The age of thrusting and formation of associated structures is uncertain. If the Sungai Buah rocks belong to the Kenny Hill formation, the deformation may have occurred during the Triassic up to Early Jurassic. This age is based on that of the major granitic bodies such as the Titiwangsa (Main Range) granitoid. It is generally envisaged that granitic intrusions accompany major crustal movements.

We are equally uncertain about the deformation indicated by fold axes trending NW-SE in fig. 3b. This fold direction may be a local variation in the general northerly strike. However, a similar fold trend was also mapped in the southeast corner of the campus grounds of Universiti Kebangsaan Malaysia at Bangi (Zaiton Harun, 1981, map 5). More field data are needed to determine the role of this fold trend.

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