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Polyphase deformations and quartz development at Bandar Baru Bangi (south), Selangor

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Abstract : The general structural strike at Bandar Baru Bangi south is NE to ENE, which clearly deviates from the structural grain of Peninsular Malaysia. The major overturned and isoclinal folds were coaxially folded by compressional stress acting in the section 323° to 354°. Some of the older folds appear twisted. Open warps that also strike parallel to the general trend were produced at a later stage by similarly directed compression. The east-west compressional stress, so common in Peninsular Malaysia, produced north trending open warps; this represents the latest episode of ductile deformation in the area. At least five quartz generations can be identified. The youngest, Quartz-5, intersects and often offsets Quartz-4 which trends roughly parallel to the general strike. Quartz-3 is characterised by an over-turned open fold striking 105° with horizontal axis. Quartz-2 and Quartz-1 look alike and occur as tight, overturned folds consisting of closely and irregularly fractured quartz. However, Quartz-1 fold mullions are twisted, producing fold plunges in various directions at various plunge angles. The general fold style indicates tectonic transport towards southeast. However, at three localities, graded bedding and gentler dipping cleavage in steep, overturned fold limbs suggest stratigraphic facing towards northwest. If the latter is the common situation, the Bandar Baru Bangi south outcrop may represent part of the lower limb of a large fold nappe with northwest vergence.

Abstrak : Jurus umum struktur di bahagian selatan Bandar Baru Bangi ialah timurlaut hingga timur-timurlaut. Ini menyimpang jelas dari struktur am Semenanjung Malaysia yang berjurus antara utara dan baratlaut. Tegasan mampatan dalam sektor 323° hingga 354° telah menerbitkan lipatan terbalik yang utama dan melipat semula lipatan isoklin secara kopaksi. Mampatan pada arah ini juga telah memulas setengah-setengah lipatan yang lebih tua. Apabila tegasan mampatan dalam arah tersebut mengendur, ledingan terbuka berarah timur-timurlaut terbentuk. Ledingan terbuka berarah utara disebabkan kemudian oleh mampatan timur-barat yang juga bertindak di seluruh Semenanjung. Sekurang-kurangnya terdapat lima generasi kuarza, iaitu Kuarza-5, yang termuda, berjurus utara dan merentasi Kuarza-4 yang kadangkala teranjak oleh Kuarza-5. Kuarza-4 terletak dalam sektor jurus yang hampir selari dengan jurus umum kawasan ini. Kuarza-3 wujud sebagai lipatan terbuka dan terbalik berarah 105° dan berpaksi mendatar. Kuarza-2 dan Kuarza-1 mempunyai persamaan ciri. Kedua-duanya terdiri daripada kuarza yang retak-retak serta membentuk lipatan ketat dan terbalik. Yang tertua, mulion lipatan Kuarza-1 telah terpulas sehingga menyebabkan paksi lipatannya menunjam ke berbagai arah dengan berbagai sudut tunjaman. Gaya am lipatan di sini menunjukkan bahawa angkutan tektonik ialah ke tenggara; namun keadaan sebaliknya, iaitu angkutan ke baratlaut juga mungkin berpandukan kepada kedudukan lapisan tergred dan ira yang berkemiringan sederhana pada sayap terbalik curam beberapa lipatan. Jika keadaan terakhir ini adalah yang umum, maka singkapan boleh mewakili sebahagian daripada sayap bawah sebuah kelopak lipatan besar yang telah mengalami angkutan tektonik ke baratlaut.

INTRODUCTION

Between the Universiti Kebangsaan Malaysia campus and Bangi Baru town are two roundabouts. The southernmost roundabout is flanked on three sides by topographic highs; only on the northwest it adjoins flat land. Isoclinal folds, zigzag folds and a few reverse faults in well-bedded and foliated metaclastics outcrop in the two southern roadcuts and have been analyzed by Zaiton Harun (1981). After the completion of this report, the southwestern topographic high was cut into a series of terraces, probably for a housing project. This resulted in exposing many more structures and enabled us to trace various structures in three dimensions. In the past four years the quality of the outcrops has deteriorated somewhat, but the general structural style and most of the details can still be observed. The locality is shown in the inset of figure 1.

The rocks are all metaclastics transected by quartz-iron oxide veins and almost pure quartz. The metaclastics consists of white and light grey phyllite intercalated by thin metasandstone, very fine-grained white metasandstone that often occur as massive banks enclosing thin phyllite as interbeds, and rarely laminated fine to medium grained quartzite. Quartz occur as veins, sometimes accompanied by iron oxide, and as impregnations into the country rock. The quarzitic layers may have been quartz sandstone originally, but altered by metamorphism. Other quartzitic layers may have been veins that became deformed. The quartz-iron oxide veins are steeply dipping and are straight; some may be arranged *en echelon.*

Zaiton Harun (1981) studied in detail the roadcuts flanking the main road between Bandar Baru Bangi and the Universiti Kebangsaan Malaysia campus. Base on the attitude of small fold (believed to represent drag folds), medium size zig zag folds, a pair of conjugate kink bands, and equal-area plot of foliation and fold axes, she interpreted that these structures developed as result of a maximum compression that acted in approximately 153°-333° (figure 2).

On the geological map of Kuala Lumpur (Yin, 1976), the area of Bandar Baru Bangi is underlain by the Kajang formation, schist with limestone intercalations and phyllite of middle to late Silurian and in parts perhaps of Devonian age.

DESCRIPTION OF OUTCROPS

Primary Structures

Occasionally compostional layering can be determined, but in general, foliations in the phyllite and metasandstone are more distinct. Finegrained grading is exemplified by very finegrained, laminated metasandstone that

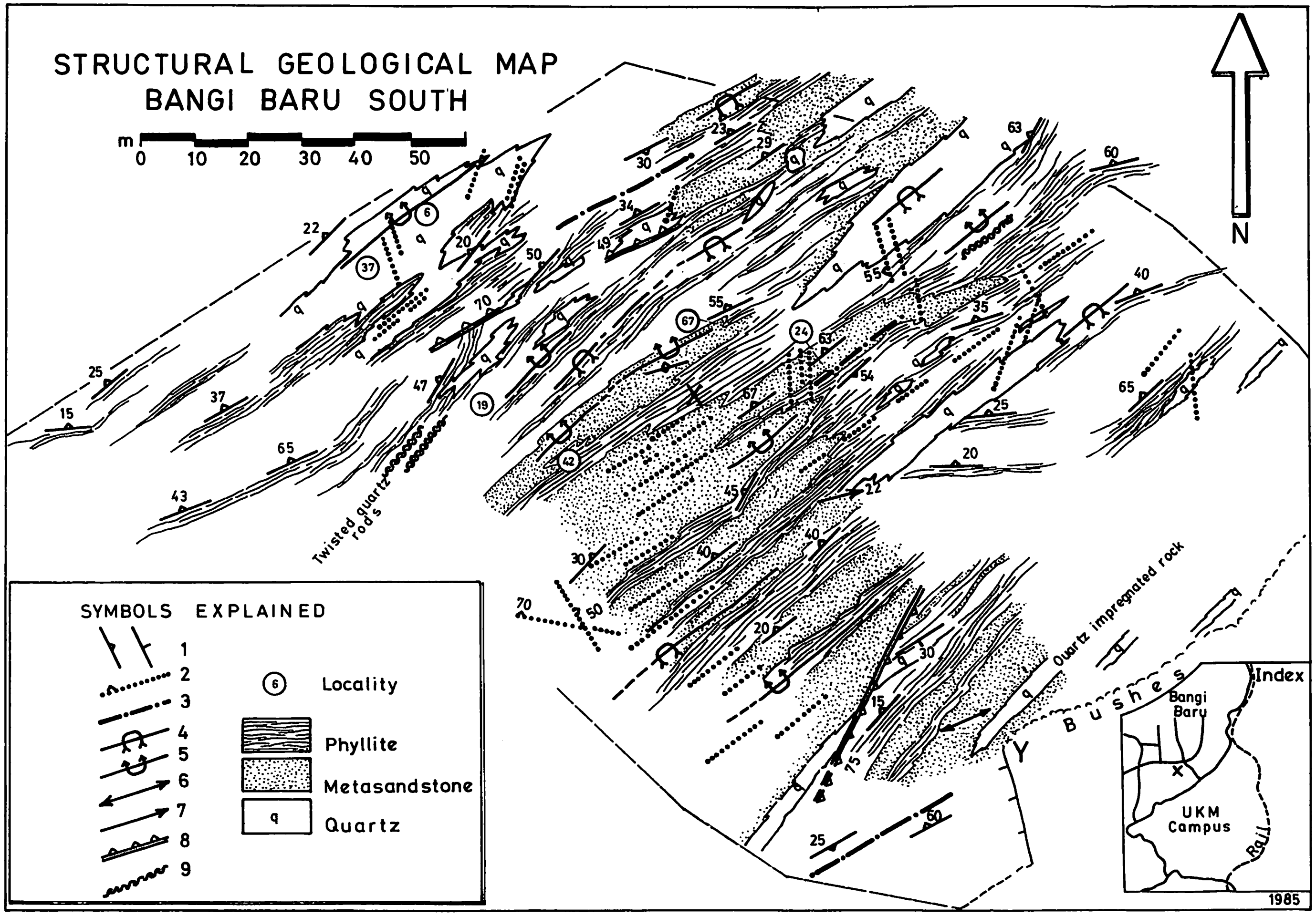

Figure 1 : Structural geology of an area near the roundabout, Bangi Baru (south); inset indicates the locality. Explanation of symbols : 1 = foliation, bedding; 2 = quartz veins (with or without iron oxide); 3 = warp axis determined from foliation patterns on the map; 4 = synform, overturned to isoclinal; 5 = antiform, overturned to isoclinal; 6 = medium fold, horizontal fold axis; 7 = medium fold axis with plunge direction and plunge angle; 8 = fault, triangles indicate dip direction; 9 = twisted, quartz-impregnated fold hinge. The scarp outcrop of figure 9 extends between X and Y. Localities referred to in the text or on other illustrations are indicated on the map.

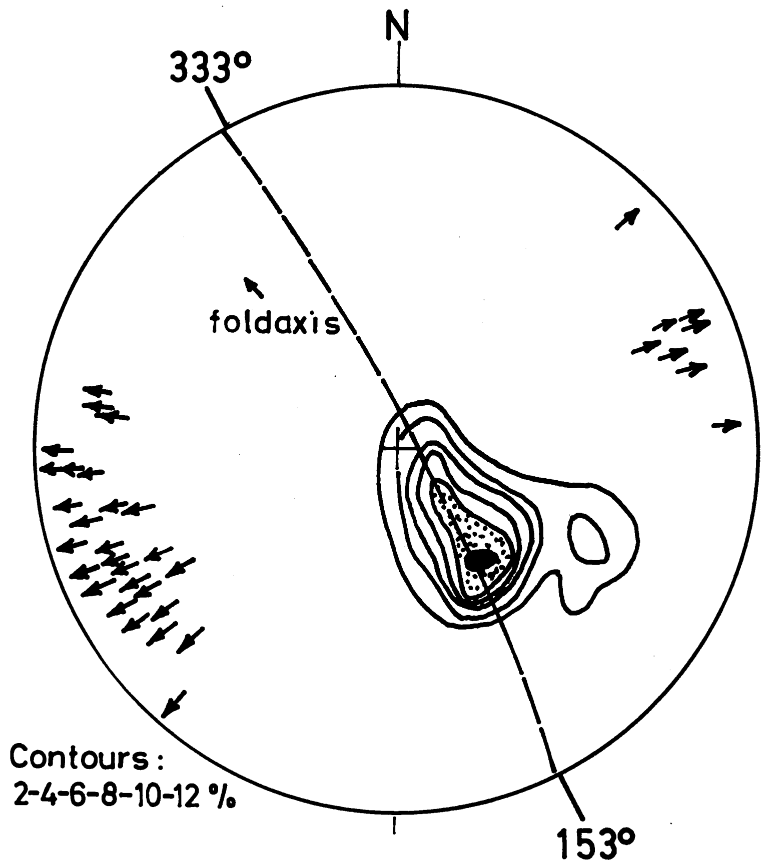

Figure 2 : Lower hemisphere, equal-area projection of foliations (contoured) and small to medium size fold axes indicate maximum compression in 153-333°. Fold plunges are gentle to almost horizontal; a single fold axis strike parallel to the interpreted compression direction and may represent soft-sediment deformation. Data are from the roadcut at the southeast side of the roundabout (Zaiton Harun, 1981, p. 18a).

gradually changes into grey, foliated phyllite. Each couplet of metasandstone and phyllite is separated by sharp surfaces from the adjacent couplets (figure 3, locality 24). In that figure, laminations are parallel to the different zones of lithology, while foliation (255/62) is oblique to bedding. The direction of grading suggests that stratigraphic top is towards north, in spite of the fact that cleavage anomalously dips less steeply compared to dips of bedding.

At locality 42 (figure 3), small folds with amplitudes that attenuate in the direction of the sandwiching phyllite bands suggest soft-sediment deformation. The shapes of the folds further indicate that the metasandstone-phyllite interface on the northwest side was the basal gliding plane, and, therefore, stratigraphic top is towards southeast.

Generally foliation is subparallel to parallel to compositional bedding. In the crests and troughs of folds, however, axial plane cleavage forms systematic fan patterns (figure 3, loc. 19; figure 4). Deformed phyllite foliation occuring together with planar axial plane cleavage show that two or more deformation phases had taken place (figure 3, loc. 67).

Quartz-impregnations and Quartz Veins

Parts of the metaclastics were impregnated by quartz. We have the impression that impregnation occurred more often near fold hinges than elsewhere. The quartz in the hinges and attendant minor folds developed into quartz rods. Some of these lineations were twisted along their strikes. In three cases that we observed (figure 1), twisting was clockwise when viewed from the northeast along the length of the rods.

Straight lineations consisting of small beads of quartz and iron oxide material define intersection lineation between axial-plane cleavage and bedding of medium size folds (figure 6B).

There are five types of quartz structures, which may also represent five different generations. The youngest quartz generation (called Quartz-5) developed as straight, steeply dipping veins, up to 8 cm wide, in which the quartz exhibits planar structures and an undeformed appearance. These veins may be lined by up to 1.5 cm wide hardened country rock. The hardening was probably caused by baking and iron-oxide impregnation as its red colour suggests (figure 5). Differential weathering has raised the veins and their linings of country rock a decimetre or more above the adjoining surfaces. Quartz-5 veins trend northerly; some are arranged *en echelon*. Occasionally the quartz is columnar.

The next older generation of quartz also forms straight veins that dip steeply but strike in the sector northeast to east. Moreover, these Quartz-4 veins may be up to 20 cm wide and lengths of many metres are usual. The quartz seems denser than Quartz-5 and together with iron-oxide may form bulbous cyclindrical rods (figure 6A). Built of similar material but of bead-like appearance are intersection

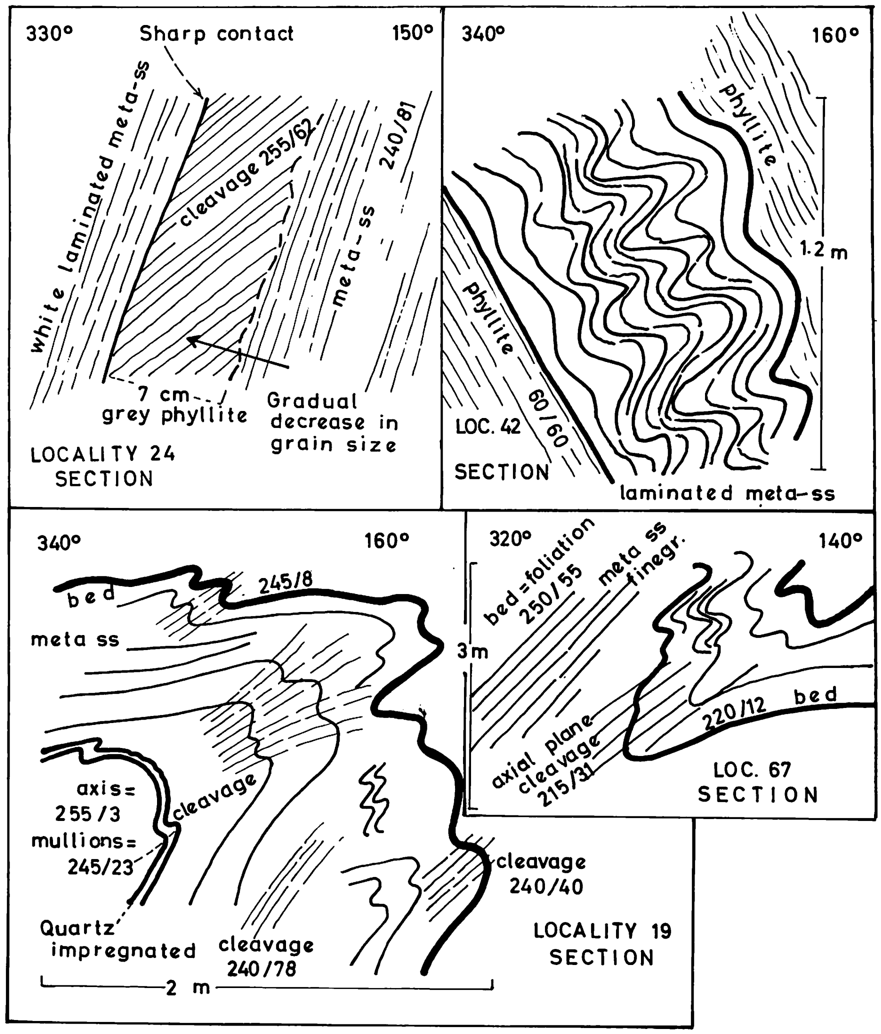

Figure 3 : Locality 24.- Stratigraphic facing is towards northwest as indicated by the gradual change in grain size from medium-grained metasandstone into grey phyllite, and the sharp boundary between phyllite and laminated metasandstone.

Locality 42.- Metre-thick, laminated metasandstone between phyllite indicates in northwest, the lithological contact is sharp and planar; the amplitudes of slump folds increase in the opposite direction and eventually die out into warps at the boundary with phyllite.

Locality 19.-A representative of fold style of the area. The asymmetrical fold possesses an axis = 255/3. Coaxial folding with steeper plunge is indicated by fold mullions = 245/23. Note the fan-shaped cleavage. Vergence of the fold is towards southeast.

Locality 67.- The first generation foliation is subparallel to bedding and dips 55 degrees; axial plane cleavage 215/31 is probably a second-generation foliation. Tectonic transport towards southeast is indicated.

Figure 4 : Hinge of overturned fold illustrating the general fold style. Compare with locality 19 on Figure 3.

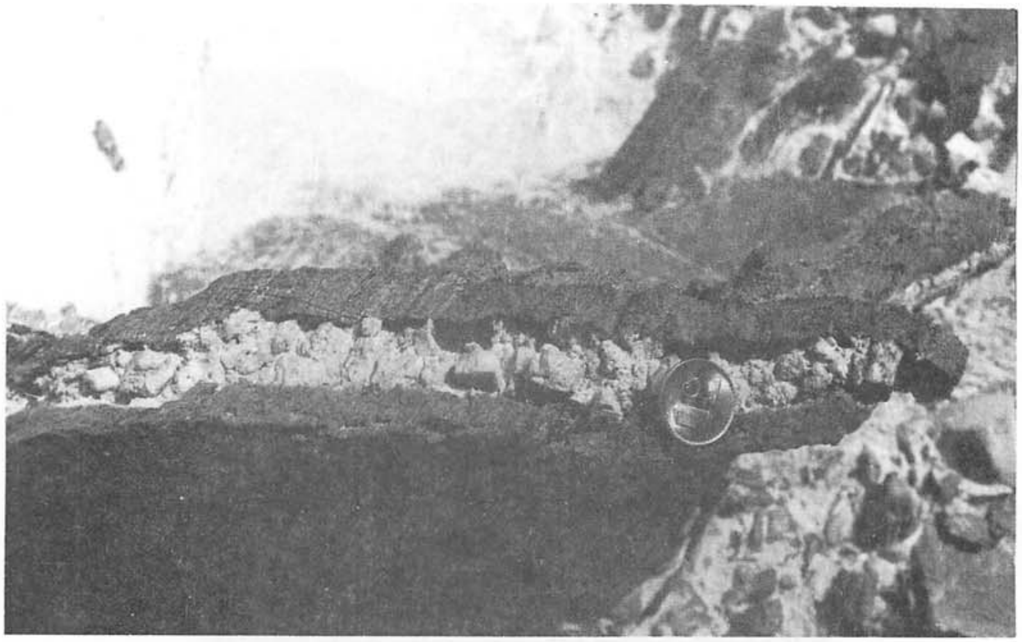

Figure 5 : Quartz-5 generation, straight and trending north, lined by hardened phyllitic rock; fine stripes upon the latter represent foliation.

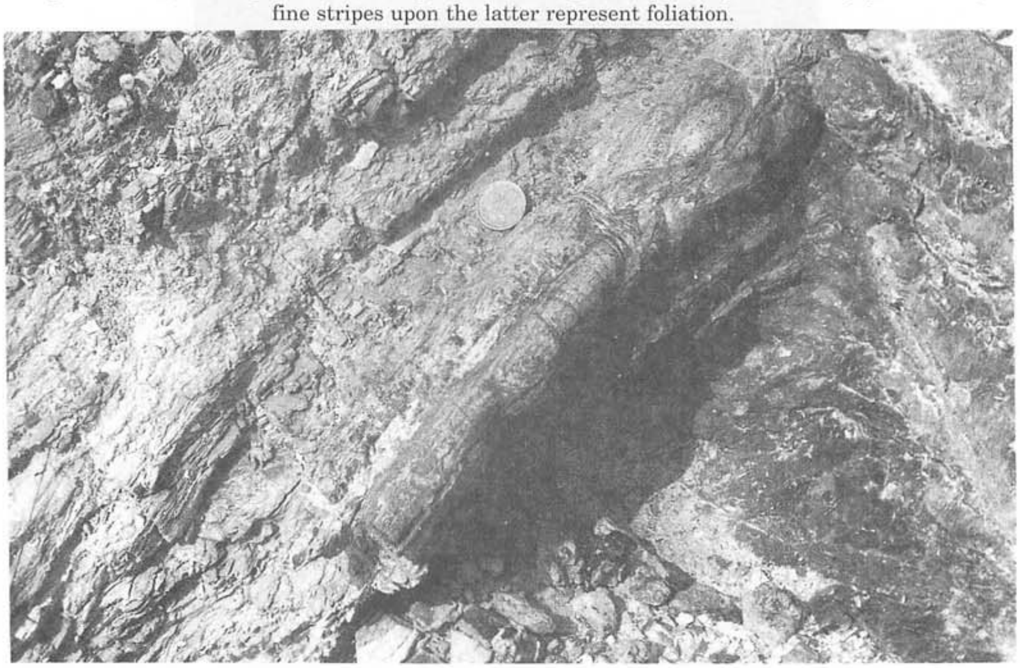

Figure 6A : Quartz-4 generation consisting of cylindrical structures, mostly parallel to the general foliation. Iron oxide association is also common.

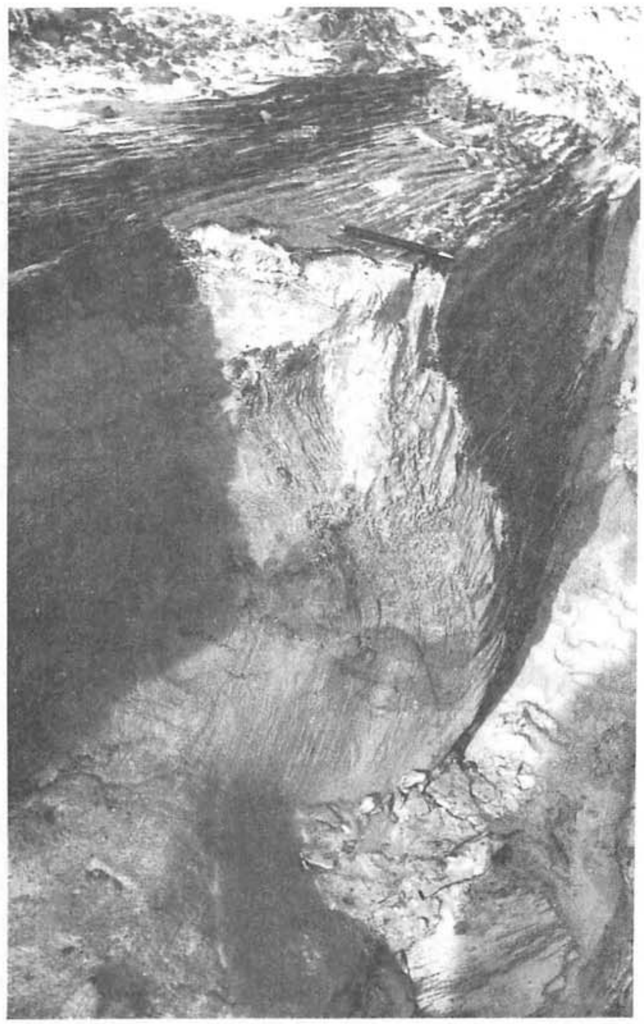

Figure 6B: Quartz-4 generation consisting of bead-like ridges formed by intersection of axial- plane cleavage and lamination. This particular outcrop represents the hinge of an overturned fold.

lineations (figure 6B). Both types of Quartz-4 are parallel to subparallel to the general strike at this locality. Quartz-5 veins transect and often offset Quartz-4 veins.

Quartz veins similar in nature to those of Quartz-5 occur together with iron-oxide lining as folded bands in granular metaclastics. Fractures through the quartz are planar and the quartz does not appear as deformed as the next two older quartz types to be described below. One of these Quartz-3 bands, a few centimetres thick, seems to define a medium size, overturned but still open synform that strikes 105° and is horizontal. By virtue of their parallelism with lamination, such Quartz-3 bands may be metamorphosed equivalents of originally silica-rich layers in the rock. However, an intersecting network of quartz-iron oxide ridges is sometimes found on one of the bounding surfaces of Quartz-3 plates. Such networks should owe their existence to veinlike intrusions.

Quartz-2 is represented by very tightly folded, silica-impregnated rock and bands that were originally silica-rich such as quartzitic sandstone. This quartz presents irregular surfaces, is pervasively fractured and occurs as continuous to discontinuous bands of irregular thickness. Together with the country rock, Quartz-2 was deformed into tight, overturned (often even isoclinal) folds of small to moderate dimensions (figure 7A and 7B). In many places, the pattern of folded quartz suggests coaxial refolding of isoclinal folds (figure 7B).

The oldest generation, Quartz-1, has the appearance of Quartz-2, but the fold mullions of Quartz-1 indicate twisting resulting in fold axes plunging in various directions (figure 8).

Folds and Faults

The dominant fold style is shown clearly in a 7-metre high hill side (figure 9). Other terraces also show similar structures, but on account of their lower heights, lithological relationships are less well exposed. Figure 9 shows that the metaclastics were deformed into medium scale, asymmetric folds overturned towards southeast. The metaclastics essentially consist of thick to massive, foliated or laminated, bands of fine-grained metasandstone and thinner bands of grey to white phyllite. Crumpling of the phyllite foliation is common. Quartz may have impregnated the metaclastics in the fold hinges; an example is shown near the left side of the outcrop in figure 9. Straight Quartz-4 veins accompanied by iron oxide are common on the lower flat adjoining the terrace scarp. In the scrap proper, weathering made these veins almost inconspicuous. Quartz-5 veins may also be present. The wedged-out portions of phyllite bands may represent their original shapes, that is, lenses of argillaceous material within arenaceous rock. It is also possible that the phyllite wedges represent cores of folds. In the latter case, their occurrence indicates refolding of the sequence. The

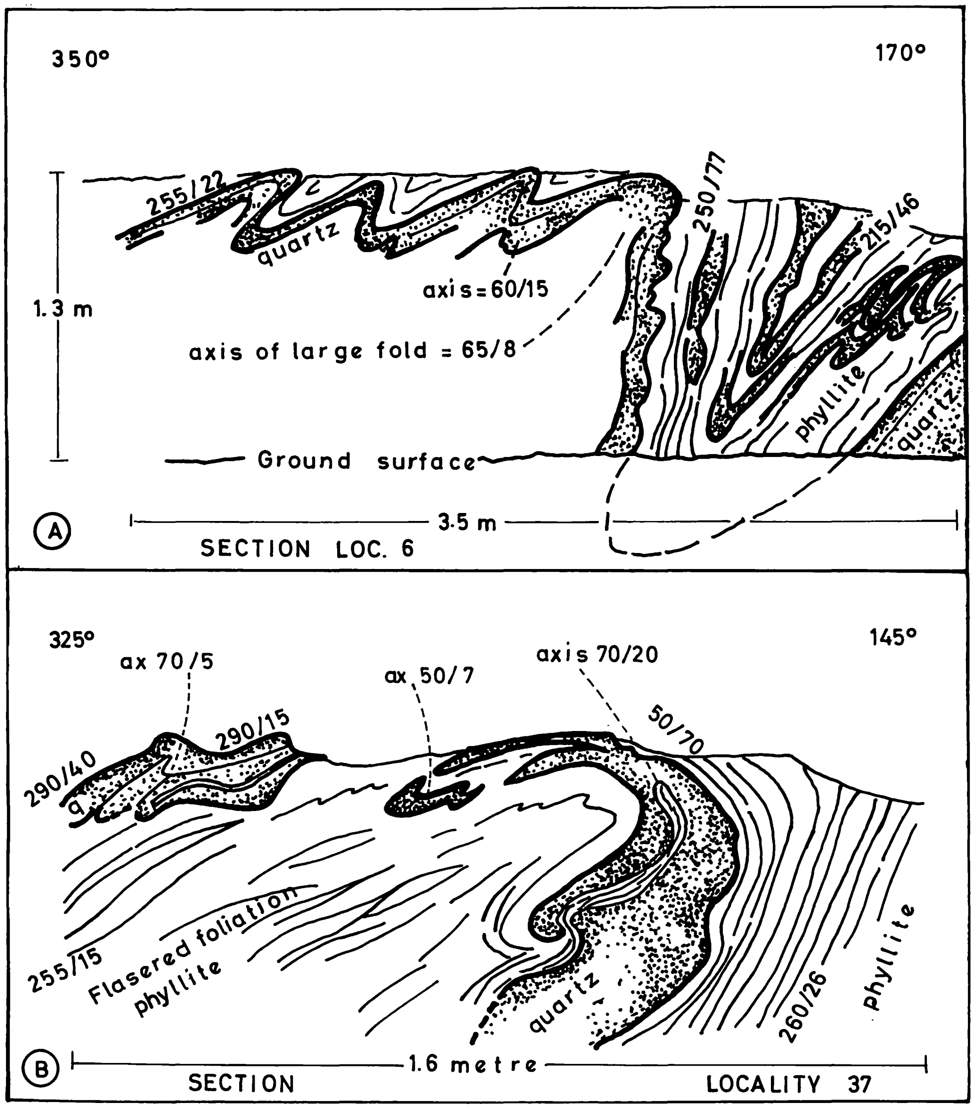

Figure 7A : Moderately large asymmetrical folds with attendant drag folds on the limbs indicate transport towards southeast. The rocks are phyllite interbedded with quartzite, the latter experiencing pinch-and-swell deformation and occasional disruption. Locality 6.

Figure 7 B : Coaxial refolding about 70°-direction is suggested by the quartzitic layers, which form closed, isoclinal folds and indicate a moderately large, overturned antiform. The phyllite within the antiform is locally deformed into wavy and discontinuous foliation, or flasering. Tectonic transport towards southeast is indicated. Locality 37.

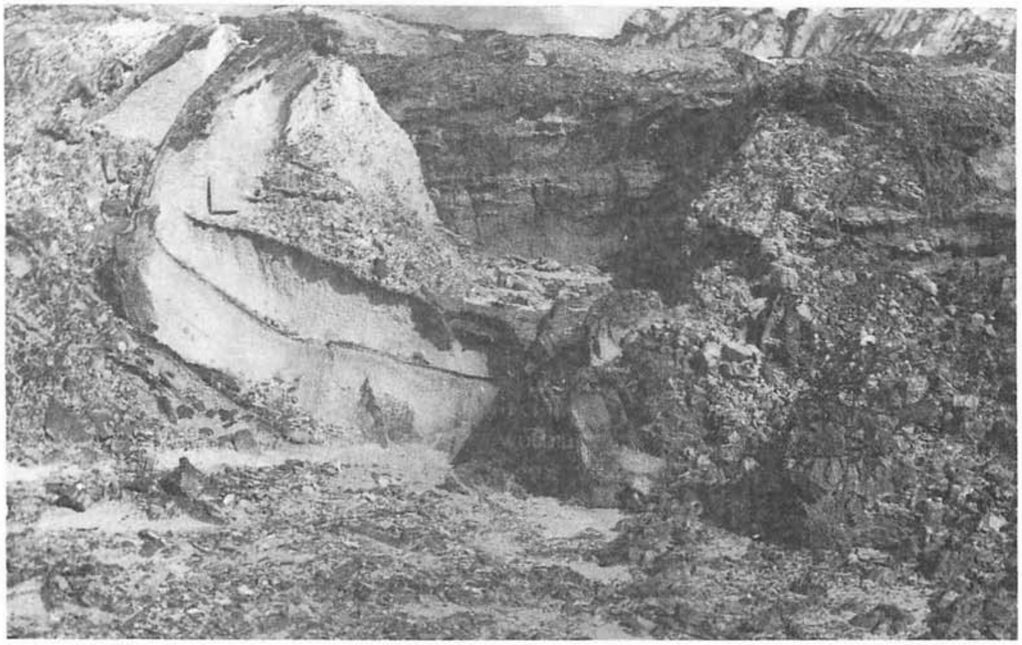

Figure 8A : The relatively resistant bands are composed of Quartz-3 generation accompanied by iron oxide and form open folds.

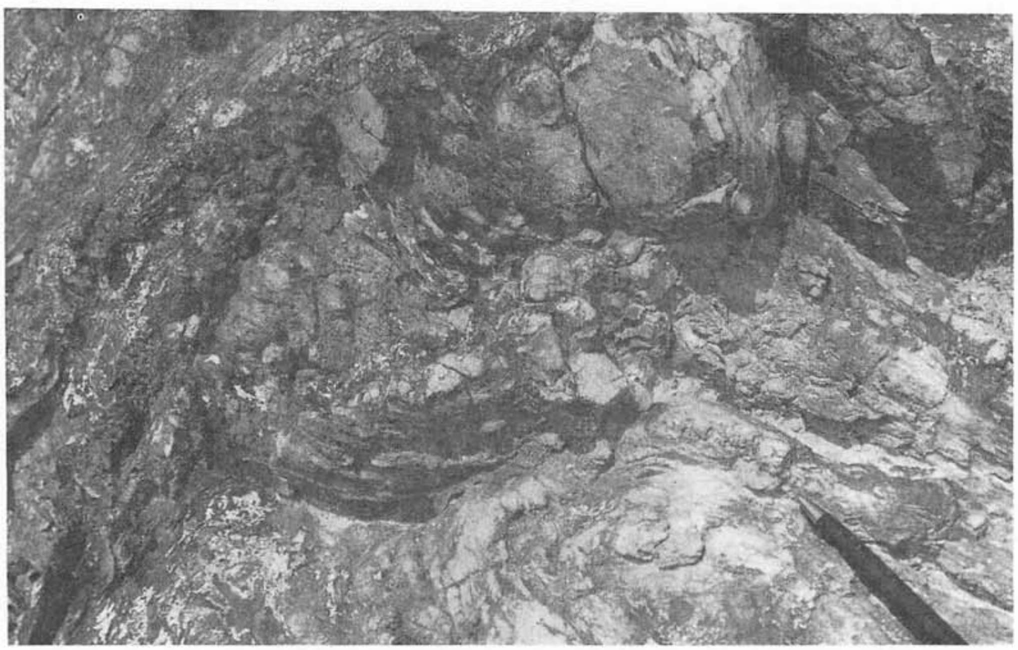

Figure 8B : Diverging fold axes, broken and sometimes flasered appearance of Quartz-1 generation.

dominant fold trend is approximately 70° with plunges of less than 10 degrees. However, locally smaller folds with axes striking into the sector 60° to 100° plunge at steeper angles ranging from 20 to 60 degrees and give a somewhat twisted appearance to the layered rock. These smaller folds are probably best explained as representing soft-sediment deformation. Their range of strike direction, steeper fold plunges and yet in size smaller than the folds representing the dominant structural grain are consistent with that interpretation.

The latest deformation of ductile nature is represented by open warps. The larger warps strike subparallel or parallel to the structural grain and are indicated by the attitude of closely situated foliations as shown on figure 1. A similarly striking downwarp is exposed in the roadcut that borders the southeast side of this particular roundabout. There, its half wavelength is about 7 metres. Smaller open warps with half wavelengths in the order of a metre or slightly more plunge at moderate angles towards the sector between northwest and northeast as indicated on the equal-area projection of figure 10. A representative of this type of warp is shown on figure 8, right-hand side.

Figure 1 shows that across the general strike occur nine overturned antiforms and synforms of moderate dimensions (figure 4). The strike is approximately 50°, and plunges are horizontal to low angle. The general vergence shown by overturning it towards southeast. In addition, smaller open folds striking ENE to E are locally present; plunge ranges from horizontal to 22°. At certain places, foliation also strike in the direction parallel to the smaller folds (eg. east of centre on figure 1). By virtue of their open nature and smaller size, the open folds should represent folding subsequent to the phase that developed the large, overturned folds.

The area contains a number of faults, a few metres in traceable length, zones several centimetres wide and showing displacements in the centimetre order. Many of these faults are filled by quartz, which is usually fractured and sometimes flasered, and thus indicating repeated movements along the faults. The smaller faults are low-angle reverse and normal faults possessing strikes that are commonly consistent with the structural grain. Three larger faults of the area are shown on figure 1 and two of them also on figure 9. Two of the larger faults are high-angle reverse faults; one strikes parallel to the general strike, the other strikes NE. The latter truncates an 80 cm wide, vertical fault zone that also strikes parallel to the structural grain (figure 9). No sense of motion could be determined from the thoroughly weathered fault zone.

On figure 1, the straight and steeply dipping quartz and quartz- iron oxide veins show the following preferred orientations: (a) parallel to strike (Quartz-4 generation); (b) northerly (Quartz-5 generation); (c) north-northeast (Quartz-4 generation; often with much iron oxide); (d) rarely perpendicular to strike (Quartz-4 generation); and (e) rarely ESE (Quartz-4 generation).

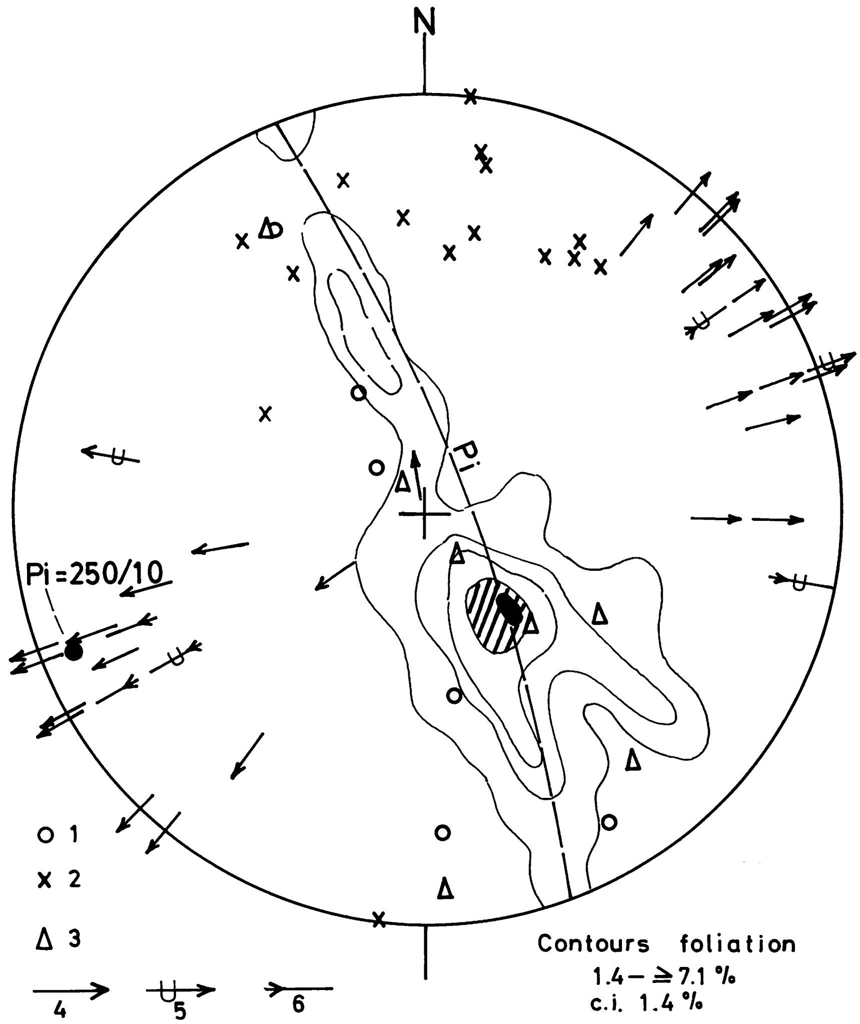

Figure 10 : Lower hemisphere, equal-area projection of structural elements in the western part of the area. Key to symbols: (1) bedding, (2) warp axis, (3) cleavage, (4) fold axis, (5) overturned fold axis, (6) synform axis. Preferred orientations of foliation are contoured with interval (c.i.) of 1.4 per cent. Discussion in the text.

Figure 1 also shows that the larger complexes of quartz and quartz-impregnated rock are generally parallel to the strike. Some of these complexes are podlike, other smaller complexes strike northeasterly (north of centre, for example). The boundaries of these quartz complexes are not sharp and consist wedge-shaped protrusions that invade the country rock for lengths in the cm - dm range.

EQUAL-AREA PROJECTIONS

Figure 10 is a lower hemisphere, equal-area plot of certain structural elements that outcrop in the west half of the area. The attitudes of 72 foliations are shown by density contours which indicate a statistical fold axis plunging 10 degrees in 250°-direction. The fold axes measured in the field, including those of overturned folds, show a spread of strikes in the sector between NE and ESE and in its opposite sector. The majority of fold axes is consistent with the statistically determined axis. The range in fold strikes and the occurrence of moderate to steep plunges suggest that multiple deformation had taken place, although generally parallel structures were developed. This could happen through coaxial folding.

Open warps with half wavelengths of a metre or slightly more all plunge within the NW - NE sector, horizontally or at moderate angles. Only one warp plunges more steeply in WNW direction (figure 10). By virture of the open nature of the warps, they should represent the latest phase of ductile deformation in the area. The youngest quartz generation, Quartz-5 also strikes northerly and its formation was very probably facilitated by tensional fractures that developed together with the warping.

Figure 11 is a lower hemisphere, equal-area projection of structural elements occurring in the east half of the area.

Sixty-one foliation planes show their preferred orientations as indicated by contours. These orientations and the fold axes measured in the field suggest compression directions in the following sectors: (a) 323-143°, and (b) 354-174°. The statistical fold axes plunge 4 degrees in 234° and 20 degrees in 264° direction. Most measured axes strike in the sector 30°-105° (and its opposite sector). The statistical fold axes fall into this sector. A few measured fold axes strike N - NNE and SSE, plunging at moderate angles or horizontally. These strikes corresponds with those of the warp axes shown on figure 10. Two other fold axes plunge at moderate angles in NW (a synform) and in SE direction or perpendicular to the general strike. These cross folds may represent one of the results of multiphase deformations along non-coinciding directions.

The overturned folds strike within a narrower range, that is, between (50-230)° and (75-255)°. The generating compression direction was 143-323° and was also responsible for tectonic transport towards southeast.

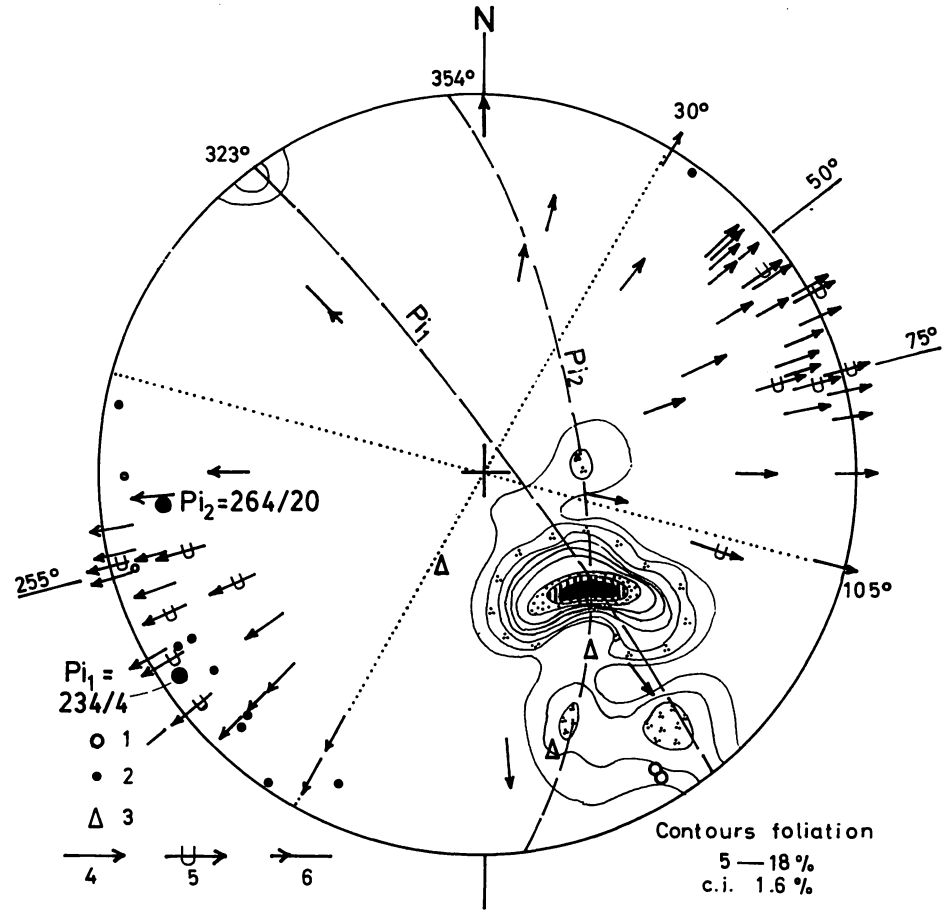

Figure 11 : Lower hemisphere, equal-area projection of structural elements in the eastern part of the area. Key to symbols: (1) bedding. (2) quartz rods plotted as lineations, (3) cleavage, (4) fold axis, (5) axis of overturned fold, (6) synform axis. Preferred orientations of 61 foliations are contoured with interval (c.i.) 1.6 per cent. Discussion in the text.

The preferred orientations of foliations on figure 11 further suggest a small-circle distribution around an axis of approximately 45 degrees plunging in the 140° direction. This can be interpreted as the result of interference by different folding directions.

The general, southeast verging, overturned folding is reflected by the preferred orientations of foliations that lie on the Pi_1 - girdle.

TECTONIC TRANSPORT DIRECTION

The asymmetrical overturned folds (figure 3, loc. 19 and 67; figures 7A and 7B; figure 9) represent the general deformation style at this locality. Their strikes between NE and ENE contrast sharply against the regional north to northwest structural grain of the Peninsula. However, the exceptional strike is widespread in the area of the Selangor - Negeri Sembilan border (see Zaiton Harun, 1981; Zaiton Harun and Tjia, 1984) and also exists in the northwest corner of Peninsular Malaysia (see Geological map by Gobbett, 1972; figure 10.2 in Gobbett and Tjia, 1973). The general fold style at Bandar Baru Bangi points to tectonic transport towards southeast. However, at two localities, grading from metasandstone into phyllite suggests stratigraphic top towards northwest (figure 3, loc. 24 is one of the examples). At both localities, the graded beds occur in the steeper, overturned limb of medium-size antiforms. Cleavage inclined at an angle smaller than compositional layering also supports the overturned position of those limbs (see figure 3, loc. 24).

We can think of two possibilities to explain the situation.

(1) Bearing in mind that several small-scale structures consist of coaxially refolded isoclinal folds, the stratigraphic facing at the two localities mentioned, may only represent local phenomena and do not indicate stratigraphic succession for the entire area. At one other locality, facing towards southeast was also recorded (figure 3, loc. 42).

(2) If the stratigraphic facing towards northwest is representative for the whole area, then, the medium-size overturned folds with horizontal to subhorizontal axes may be drag folds on the lower limb of a large recumbent fold verging northwest (figure 12). This means that the main structure may be a large overfold (even a fold nappe) or overthrust. Vergence in a general westerly direction is common in Peninsular Malaysia (see Tjia, 1986), but alpine-like nappe structures have not yet been determined.

We prefer the first possibility and suggest that tectonic transport exhibited by the rocks at Bandar Baru Bangi south was towards southeast.

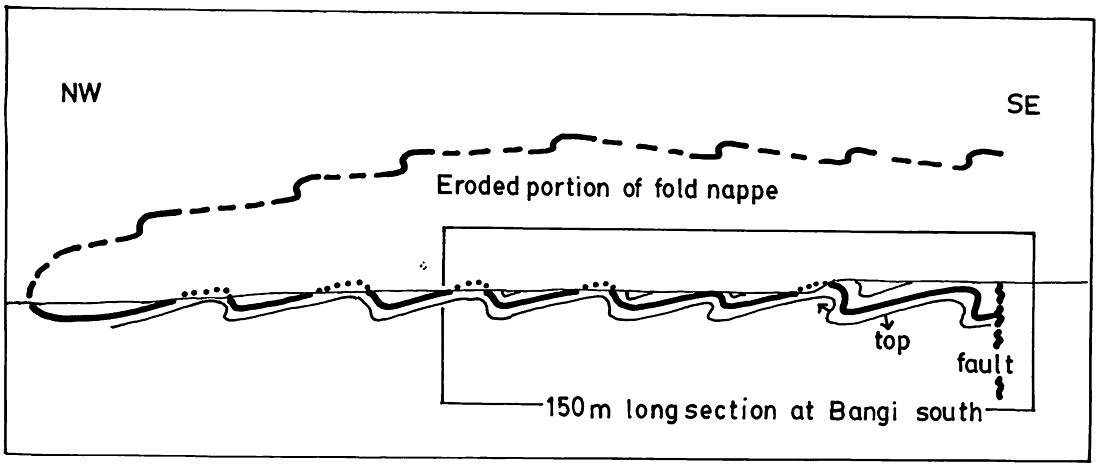

Figure 12 : An alphine-type fold nappe could explain the position of stratigraphic facing (top) in the Bangi folds. Discussion in th text.

SUMMARY AND CONCLUSIONS

The structural strike at Bandar Baru Bangi south is different from the regional strike of the Peninsula. At Bangi the strike is northeast to east-northeast. The dominant structure consists of asymmetrical, overturned folds of moderate size. The steeper limbs suggest vergence towards southeast, although at two localities, stratigraphic facing favouring transport towards northwest, has also been recorded. Small scale, twisted folds in quartz and quartz-impregnated rock and equal-area plots of structural elements (figure 2, 10 and 11) indicate that multiple deformations have taken place. The dominant maximum compression directions are also the oldest and acted between 323° and 354°. These compressions resulted in the main overturned folds and coaxially refolded isoclinal folds and probably also twisted some of the folds. The same compressions ended by developing the ENE-striking open warps of several metres wavelength. The latest deformation represented by warps of several decimetres to about a metre long wavelengths reflects east-west compression; these open warps strike northerly or parallel to the general strike of folds in the Kenny Hill formation. This formation has been estimated to range in age from the Carboniferous to Early Triassic (see discussion by Stauffer, 1973).

Quartz occurs as five different types, indicated as Quartz-5 through Quartz-1. The youngest, Quartz-5, consists of northerly striking veins and intersect Quartz-4 structures that may consist of veins, rods and intersection lineation between lamination and cleavage, and strike between northeast and east-northeast. Quartz-3 consists of plates parallel and subparallel to lamination and folded into overturned but still open folds. Quartz-2 consists of fractured quartz bands of irregular thickness that became coaxially and tightly refolded into recumbent isoclines. Quartz-1, the oldest, resembles Quartz-2 in appearance, but refolding about different directions produced twisted folds. Quartz-5 and Quartz-4 are fracture and cleavage filling. The older quartz generations may be partly also venis, but many structures indicate them to have been originally silica-rich sediment and/or quartz-impregnated country rock.

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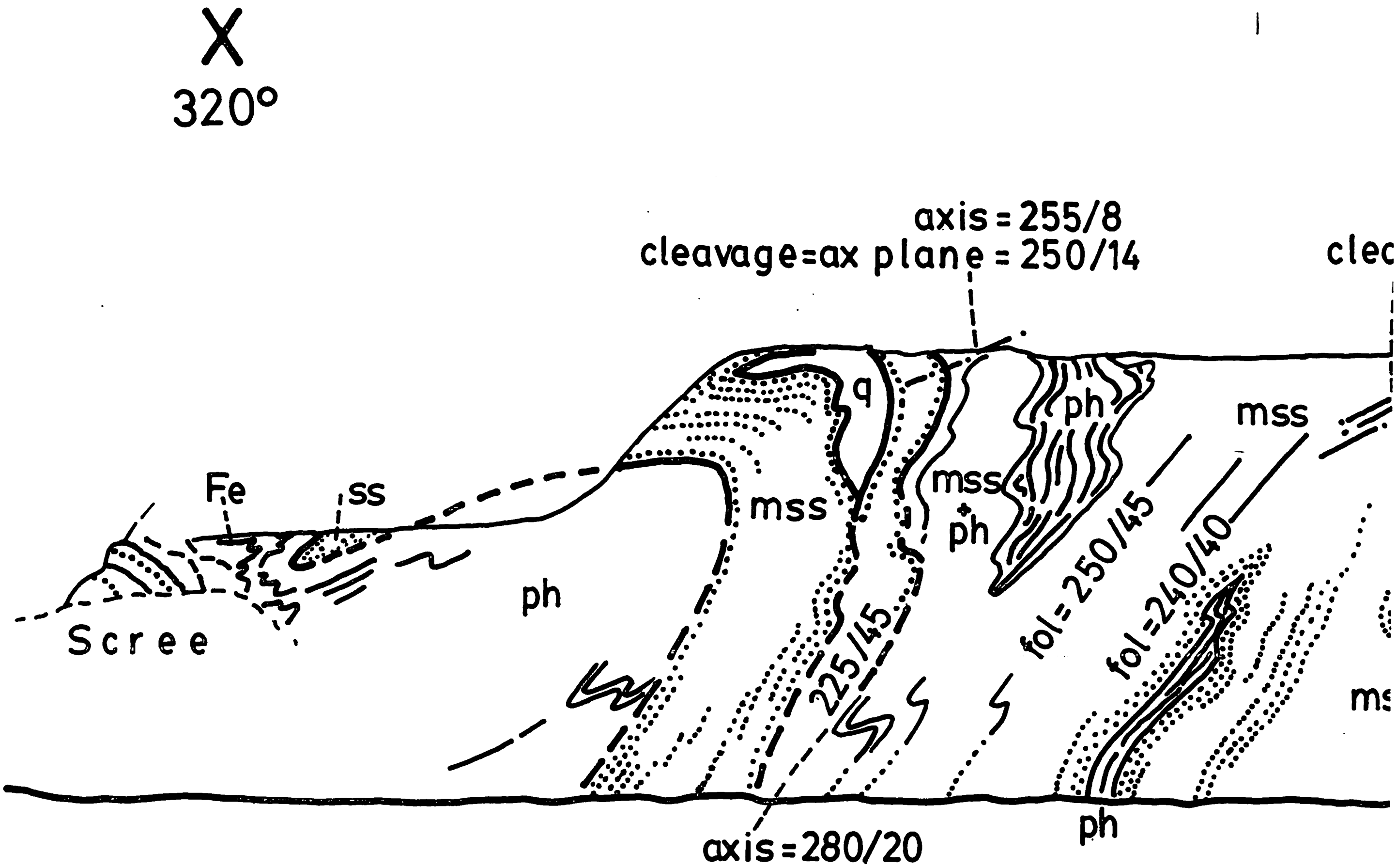
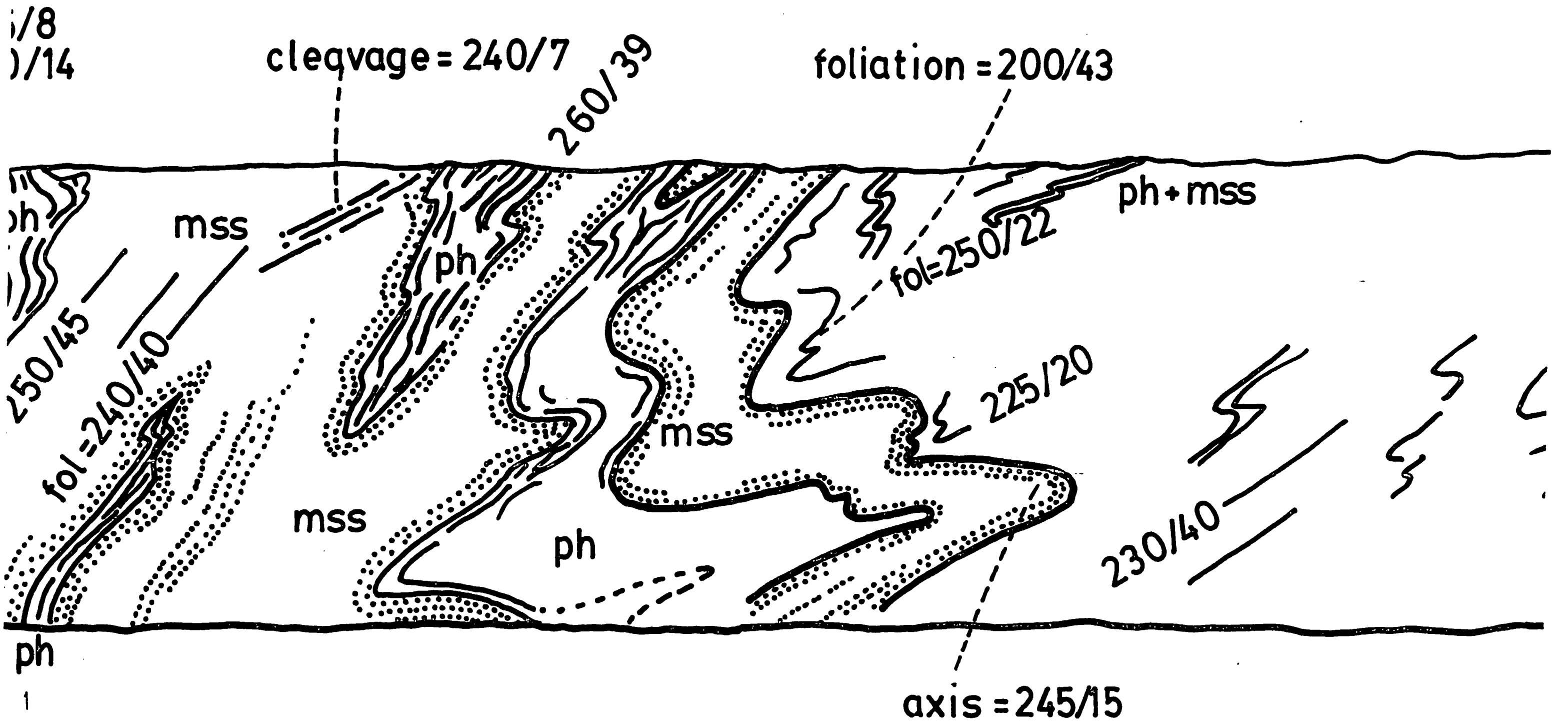


Abbreviations:

ph	phyllite
mss	metasandstone
q	quartz
Fe	iron oxide "layers"

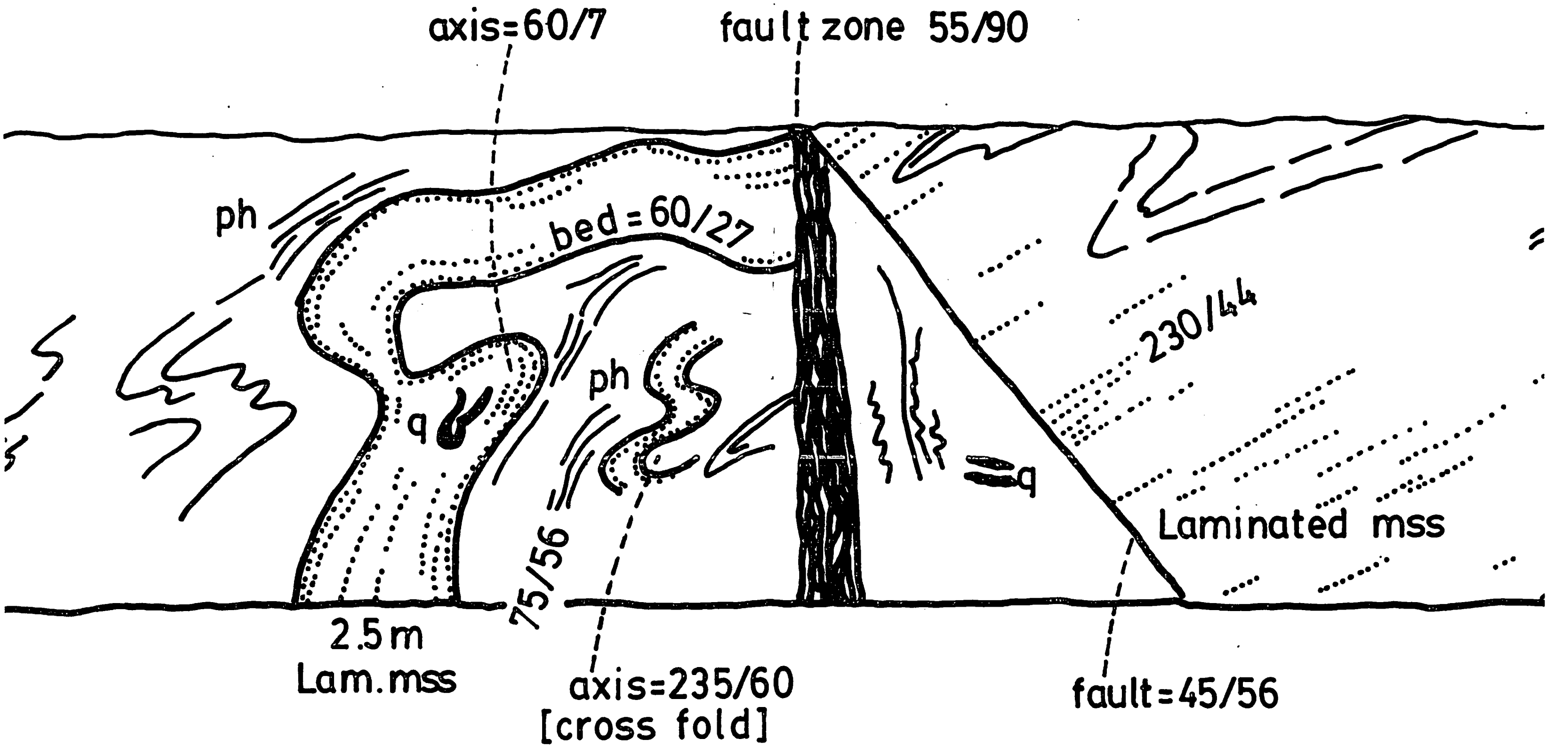
Figure 9 : 1/4



OUTCRO

Figure 9: Outcrop of 7 metre high terrace scarp between
metasandstone band that includes detail 1 (circled on right
intercalations that display zig zag folds of generally horizo
transport towards southeast. Further discussion is in the te

Figure 9 2/4



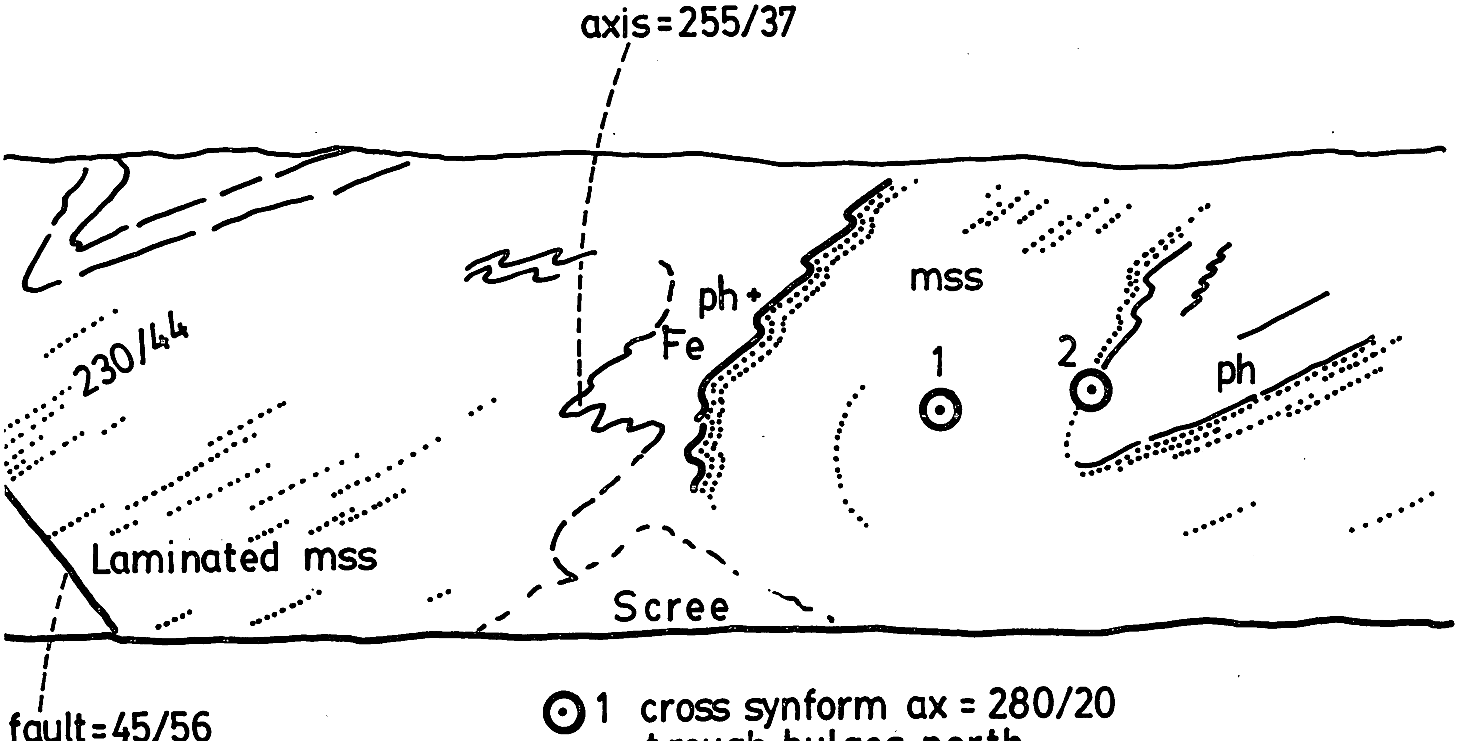
CROP PATTERN IN HILL SIDE

Length 66 metres

:arp between points X and Y shown on figure 1. The
rcled on right hand side of the figure) has phylitte
ıerally horizontal axes. The folds suggest tectonic
on is in the text.

Figure 9: 3/4

Y
120°



⊙1 cross synform ax = 280/20
trough bulges north

⊙2 cross synform ax = 240/25

. SIDE

Figure 9: 4/4