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Multiple Deformations at Bukit Cenering, Trengganu

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Abstract: An interfoliated series of metaclastics at Bukit Cenering displays cross-stratification, scour-fills, graded bedding (sometimes indicating overturning) and tectonic structures including ordinary to contorted foliations, crenulation lineation, lineation by intersections of slaty cleavage and foliation, mullions, regular to streaked quartz injections, thin and up to 8 metres wide mylonite zones in which are drag and rotation phenomena. Fault sense is further indicated by bruised steps, accretion steps, and fault roches moutonnees. All three fault types are present. Folding is tight and ranges from overturned to recumbent forms.

Two different stress systems with lateral maximum compression directions in the sectors N310°—325°E and N46°—72°E were responsible for the deformations. The N46°—72°E compression was the younger system; it folded the rocks around NNW-axes, tilted to almost vertical positions earlier-formed NE-striking folds, created NW-lineations as crenulations, caused reverse faulting towards northeast and strike-slip faulting along existing and newly-formed faults in directions compatible with the compression direction.

The older stress system is shown by overturned folds and NE-trending foliations, reverse faulting towards northwest and presently reoriented to east-striking foliations and thrust faults.

The two tectonic events are probably correlatable with Permian to Early Triassic diastrophism (indicated by East Coast granite ages) and Late Triassic to Early Jurassic orogenesis that affected almost the entire Malay Peninsula.

INTRODUCTION

Several kilometres south of Kuala Trengganu is a headland that forms one of the few interruptions along the NNW-striking smooth coastline of Trengganu. The cape is capped by a low hill, 74.5 m high, designated as Bukit Cenering (old spelling 'Chenering') (Fig.1). Towards the north and the south of the cape shifting beach sands cover the probable extensions of the metaclastic rocks.

The metaclastics of the hill comprise a well foliated succession that outcrops between a spot 50 metres to the north of the actual cape and the south point of the headland, covering a distance of about 500 metres. The rocks are interfoliated slate, quartzite, phyllite, and schist. A few scourfills of moderate to small dimensions are present and have been used to determine facing. The Seventh Edition of the Geological Map of West Malaysia, compiled by Yin and Shu (1973), shows the rocks to be Carboniferous. In an earlier publication, MacDonald (1967) grouped the Cenering outcrop into the so called 'Arenaceous Sediments' of Kelantan and Trengganu. MacDonald's 1:250,000 geological map simplified the complex structures of Bukit Cenering into N330 to 350E striking, very steep, eastward dipping to vertical foliations.

Details of the interesting structures exposed near the waterline at Bukit Cenering were studied on three separate occasions during the past two years. In addition to the earlier mentioned metaclastic rocks the cape is laced by quartz veins, zones of phyllonite and flasered rock, and has a 5.5 metre wide, weathered dolerite dyke. The attitude of the dyke is 50/56 (see Fig. 6). The seaward portion of the dyke has been eroded into a linear gully. Another linear gully, 7 metres wide and striking 90° occurs near the north end of the outcrop and may represent an other dyke. Ismail

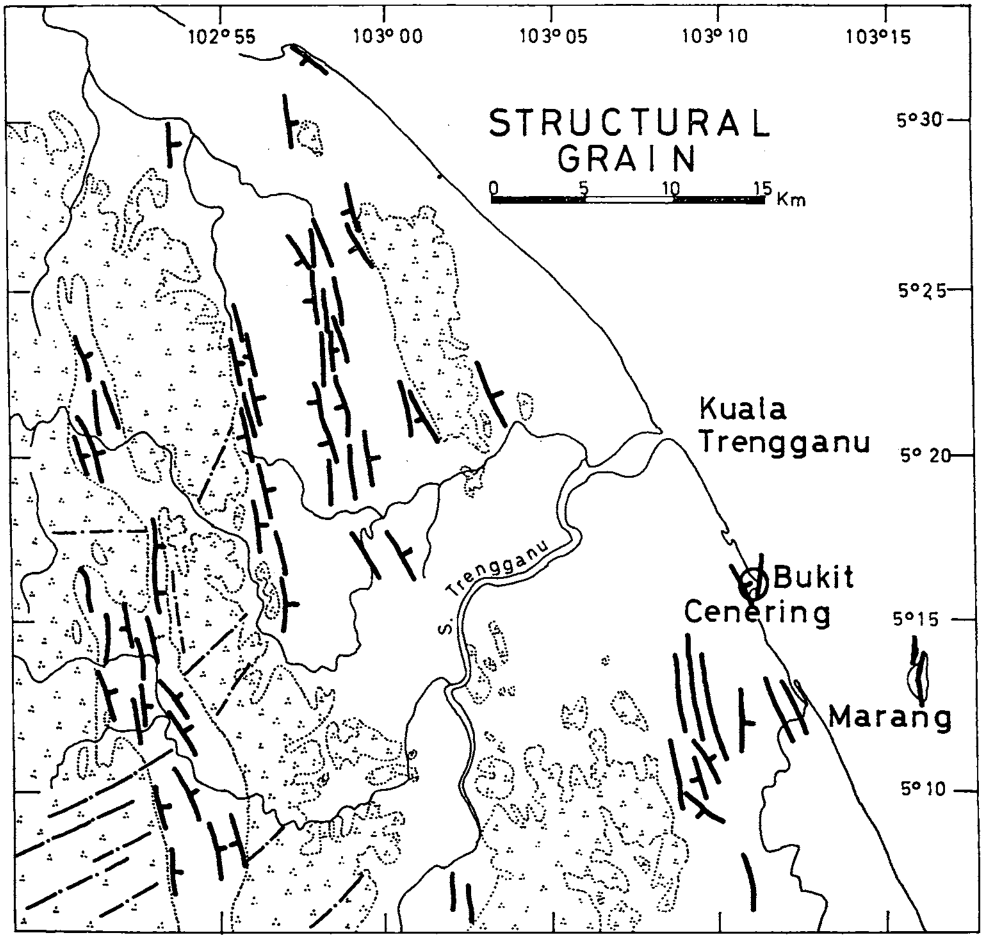

Fig. 1 Index map of Bukit Cenering and structural grain of similar rocks in northern Trengganu. Strike lines are indicated by heavy lines; short dashes indicate dip directions; dash-dot lines are stream or ridge lineaments; triple dots are granite outcrops. Structural trends and lithologic boundaries are based on MacDonald's map (1967).

bin Abu Bakar (1976) studied the structural geology of Bukit Cenering in detail as part of his investigation of the Marang area. He deduced for the Cenering locality three lateral compression axes: (a) N345°E, (b) N15°E, and (c) N50°E.

STRUCTURES

Primary Structures

(1) *Stratification.*—The original bedding is preserved in the metaclastic rocks of Bukit Cenering. The stratification is of the cm to dm-types, each corresponding to finer and coarser grain sizes. Occasionally the metarenite occurs as massively bedded rock. Textural differences commonly define the stratification, but sometimes light and blackish coloured strata occur as interbedded sequences.

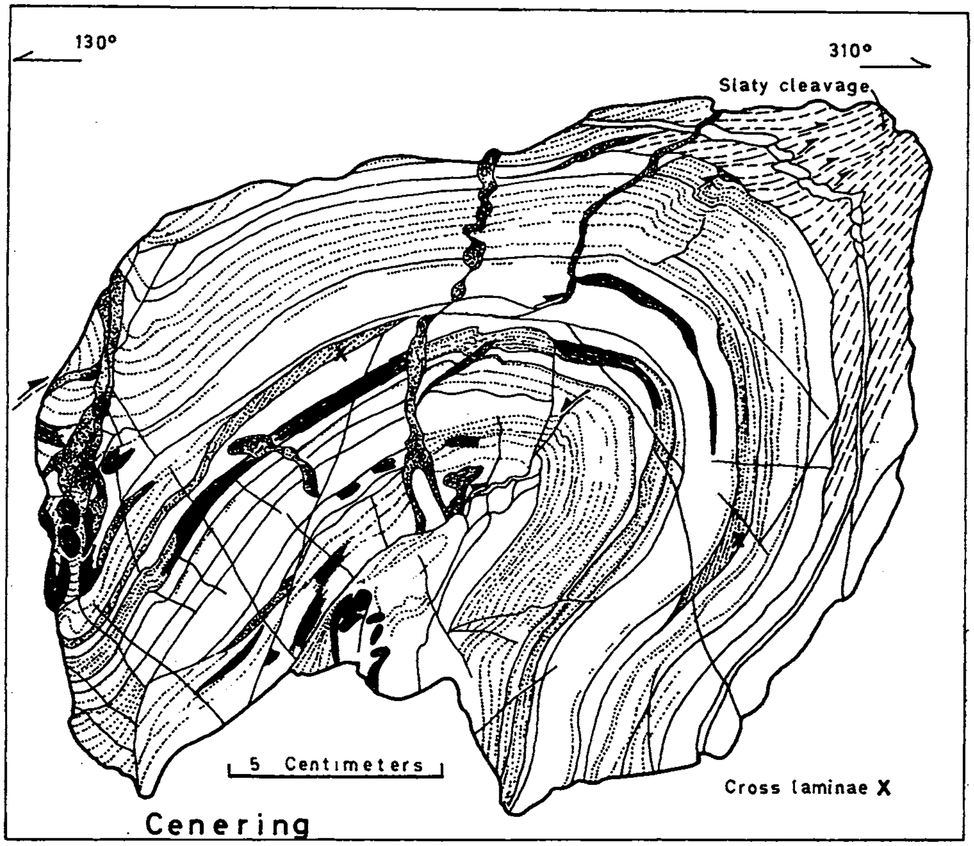

Fig. 2. Vertical section of fold hinges exhibited by a handspecimen depicted in its field position. The fold axes plunge at moderate angles towards N40 E. The rock is a well-laminated series of siliceous metalutite and slate; occasional cross-laminae are indicated by X. The dark material is probably carbonaceous. Dots indicate lamination; irregular patches of closely spaced dots represent reddish ferruginous material staining quartz veinlets that show plastic deformation, e.g. in the top central part. Slaty cleavage occurs in the antiformal hinge. The handspecimen displays overturned folding accompanied by small-scale thrusting towards NW and is representative of many larger structures at Cenering.

(2) *Cross-strata and graded bedding.*—At a few localities small scale planar cross-bedding occurs in metarenite. Cross-lamination in cm-thick metalutite is shown by a hand specimen (Fig. 2).

Graded bedding is not obvious in the field, but under the microscope some metarenites display this phenomenon.

(3) *Scour-fills.*—The metarenite may contain 20 to 30 cm long, and 15 cm deep or less deep scour-fills. In one such fill cross-bedding shows up.

The overturned positions of several uniformly dipping metaclastic strata have been determined by the recognition of inverted scour-fills and cross-beds. The fact indicates that isoclinal folds are present.

On one occasion probable (4) *current ripple casts* were measured upon a foliation plane (=original bedding plane) striking 260° and dipping 82° towards north. The structures were considered as casts on account of the fact that the present outcrop has rounded crests and peaked trough-lines. The original current flowed from north to south, disregarding possible diastrophic rotation around a vertical axis.

Tectonic Structures

(5) *Foliation (=banding in metamorphic rocks)*.—In the metaclastics the foliation is generally parallel to the stratification as far as I could determine. Disrupted and contorted to convoluted foliations are common.

In addition to the primary structures, the foliation planes may contain very fine to ordinary-sized (6) *crenulations* that show up as lineations upon phyllite interfoliae, (7) *intersection lineation* between foliation surfaces and (8) *slaty cleavage*, and patterns of systematically intersecting (9) *fractures* that stand perpendicular or highly oblique to the foliation planes. Most fractures are genetically related to tectonic deformation. The slaty cleavage is roughly parallel to the axial planes. A hand specimen displays slaty cleavage that is confined to a very fine-grained metaclastic band and that converges towards the fold hinge (Fig. 2).

(10) *Mullions* occur in two or three metarenite bands and appear to be the result of small-scale folding of a particular layer. The mullion diameters do not exceed 20 cm. (11) *Quartz veins* attain widths up to 30 cm but are usually less than 10 cm wide. Regularly shaped veins distinctly follow fractures, but contorted and streaked appearances of quartz veins are also common. The latter types occur within or adjacent to fault zones.

(12) *Faults* are represented by very narrow breaks in the rock with noticeable offsets and range in widths up to 8 metres as zones of distorted rock or phyllonite. The phyllonite is usually bluish black and may contain boudinaged to lenticular clasts of harder material like arenite, quartzite and the like. (13) *Drag phenomena* within or adjacent to faults are often obvious indicators of fault sense (Fig. 3). Interesting drag features are *en echelon* sigmoidal quartz veins (Figs. 3a, 3c, 3d) and disrupted quartz veins suggesting rotation (Fig. 3b). Fault sense indicators of smaller scales are to be found on most fault planes and include (14) *striations*, (15) *bruised fault steps*, (16) *accretion fault steps*, and (17) *fault roche moutonnee* (Fig. 4). These small-scale fault markings have been discussed elsewhere (Tjia, 1968, 1972). The sense indicators show that three fault types are present: strike-slip, reverse, and normal faults.

Near the north end of the Cenering shoreline is a 5.5 m wide, curvilinear gully that strikes 50° and dips 56° towards south. At the land end of the gully, weathered dolerite represents a remnant of the (18) *dyke* that has partially become eroded to form the gully. About 50 metres to the north of this dyke is another, 7 metre wide gully trending 90° and it may represent another eroded dyke or a fault zone.

(19) *Folds* are generally tight and range from highly asymmetrical to isoclinal to recumbent forms (Fig. 5). The observable fold amplitudes range from several metres to smaller dimensions. However, the existence of parallel sequences of overturned bands and right-side-up strata without outcropping fold hinges suggests larger scale recumbent and isoclinal folds. The fold axes plunge up to 60° and are rarely subhorizontal. A few small folds have vertically plunging axes. In descending order

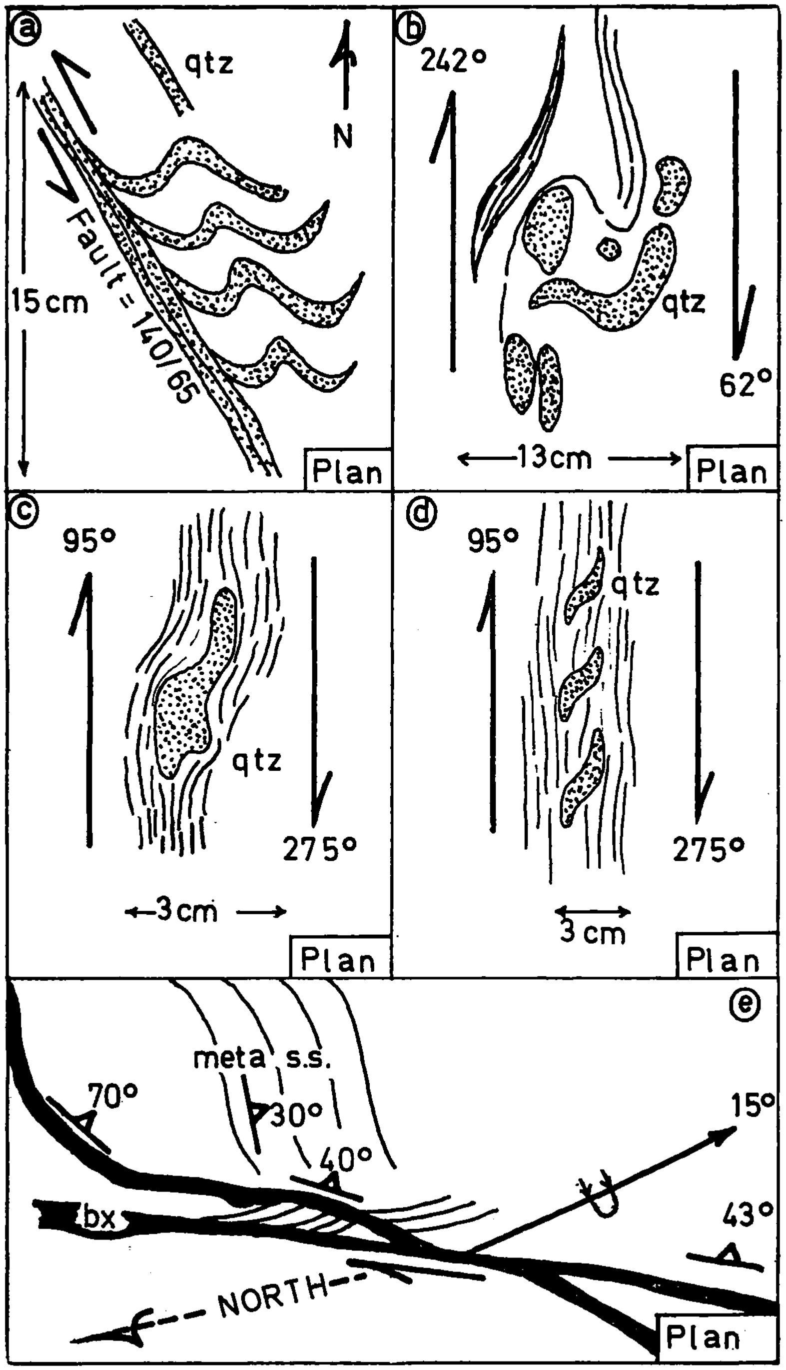

Fig. 3. *a* through *d* are indications of displacement sense in the specified directions at various localities at Bukit Cenering; qtz=quartz or quartzite. *e* is a structural plan describing the recumbent fold and its environment shown in figure 5. Length of figure 3*e* is approx. 15 metres. The thick solid lines are fault zones with mylonite.

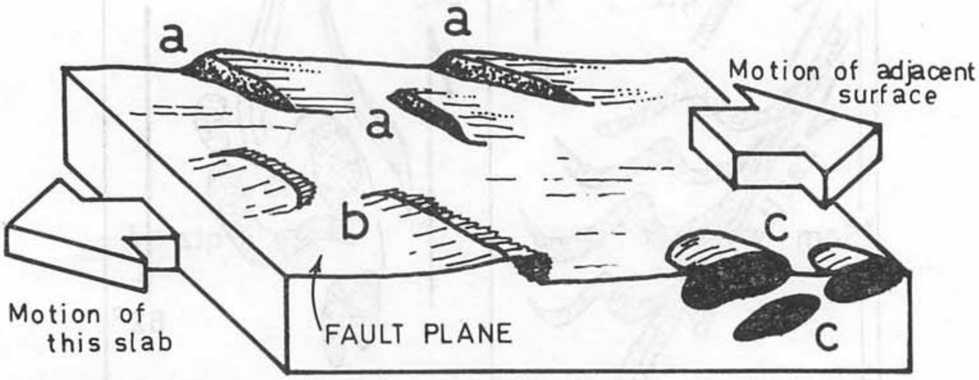

Fig. 4. Most common fault-plane markings that are good indicators at Bukit Cenering. (a) Bruised steps; dots represent recrystallized gouge with random crystal orientation. (b) Accretion steps consisting of recrystallized gouge on lee sides of protuberances; the new crystals are oriented parallel to fault motion. (c) Imbricated boudin-clasts with smoothed stoss sides (indicated by parallel lines) called roches moutonnees.

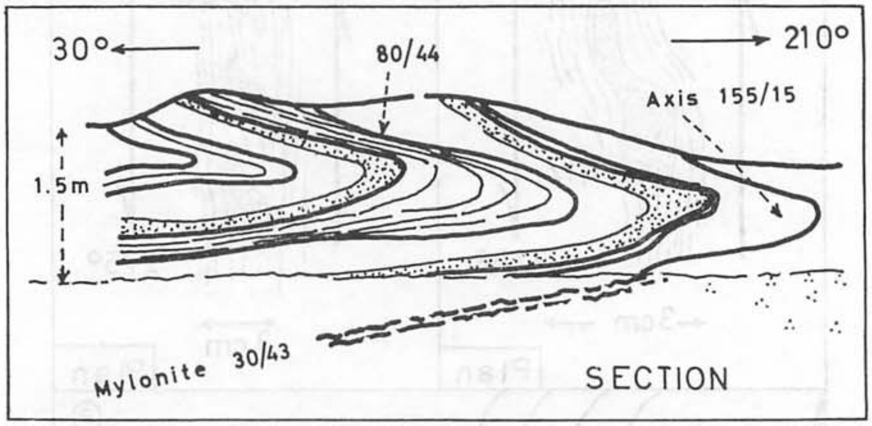

Fig. 5. Outcrop of recumbent synform at Locality S on figure 6 consisting of interfoliated metarenite and schist.

of frequency the fold axes strike with wide dispersion about southeast, some trend northwest, and a few strike almost east-west (see also the structural map, Fig. 6). One (20) *warp*, 25 metres or more across its axis, has been observed near the south end of the Cenering rocky shore. The warp plunges 28° in N200°E direction. Fractures upon the warp are genetically related, the fact being shown by the regular pattern. Long fractures stand normal to the foliation planes and strike either perpendicular or parallel to the warp's axis. Sets of shorter fractures strike in directions that make angles of 30 and 50 degrees with the warp's axis. The shorter fractures apparently indicate shear fractures.

DISCUSSION

The various observations are plotted on the structural map of Tanjung Cenering (Fig. 6). Beyond the confines of the map are additional outcrops 50 to 75 metres

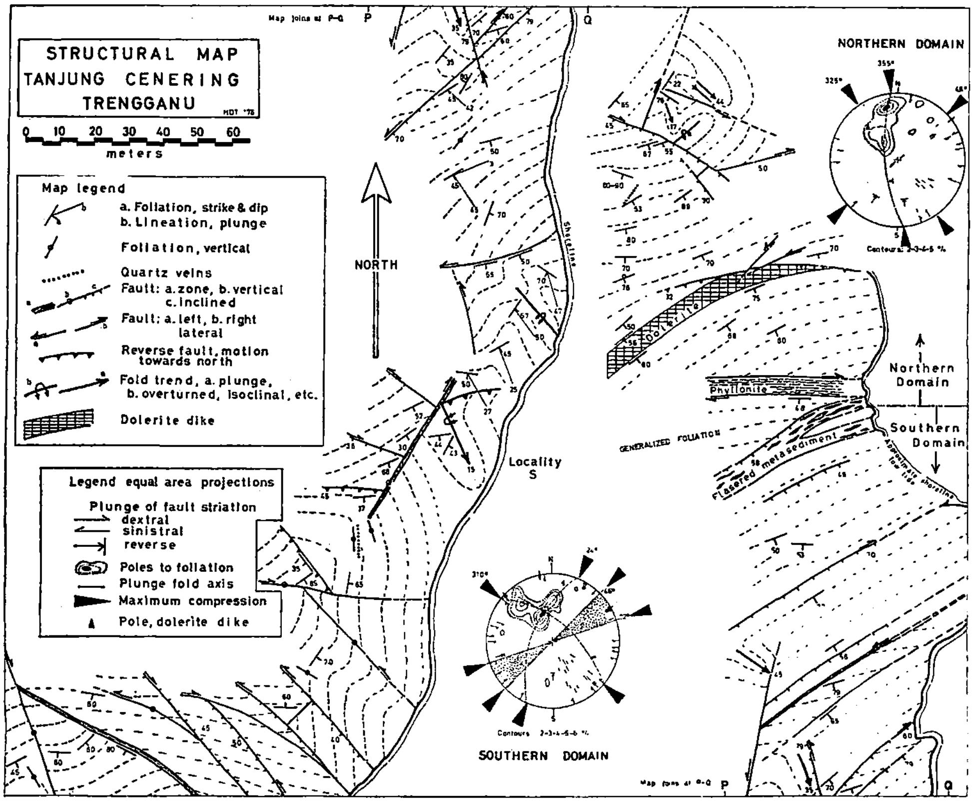

Fig. 6. Structural map of the Cenering shore. Equal-area plots show concentrations of foliations that define π-girldes, fold axes, and indicate senses of fault displacement that were determined in the field. The compression directions are shown by large triangles. Dashed lines represent generalized foliation trends. The two wide fault zones separate a Northern from a Southern Domain. See text for discussion.

farther towards north as well as south of the map boundaries. In the discussion the coastal stretch has been divided into a northern and southern domain that are separated by wide fault zones of phyllonite and flasered metaclastics.

Northern Domain

In this domain the foliations mainly define east-west structures. Smaller folds, however, strike northwest and a few indicate isoclinal to recumbent structures that strike northeast with axial planes dipping southeast. Three small folds plunge almost vertically and have limbs striking northeast (see equal-area plot).

Where fault sense could be determined this is indicated on the structural map. The fault senses and those of smaller faults (not shown on the map) are also plotted on the equal-area projection. Two cases of reverse faults towards NNE and NE have been recorded. Gently pitching fault striations on highly inclined to vertical fault planes suggest lateral motions. The sense of many strike-slip fault motions may be explained by lateral compression in N325°E direction. The same compression also accounts for folds striking northeast.

Another system of lateral compression with the maximum principal stress directed in N46°E was responsible for the development of fold axes that plunge towards southeast at moderate angles.

A third lateral compression acted in N355°E direction and left its imprint on the foliations. The equal-area plot suggests that the foliations define asymmetrical folds with axial planes dipping towards southeast. One limb dips steeply while the other averages an inclination of 25°.

The fracture zone that is occupied by the dolerite dyke is parallel to and perpendicular to the compression direction in N46°E and in N325°E respectively. Apparently the particular fracture zone is an extensional or tensional feature of the respective compression system.

The directions of thrust movements towards north-northeast and northeast (see equal-area plot, Fig. 6) have been determined as being normal to the axes of drag phenomena adjacent to the faults. As such, the motions appear to have been controlled by the compressions in N355°E and in N46°E directions.

The thin dashed lines in figure 6 indicate the general trend of foliations and folds.

Southern Domain

In the north the Southern Domain is bounded by two wide fault zones; one strikes east-west and dip at a moderate angle towards south, the other strikes northeast and is demarcated by a steeply dipping southern boundary but a moderately, southward dipping northern limit (see structural map). The phyllonitic fault zone contains slices of less disturbed metaclastic rock. Its sense of movement is indicated by drag features, subhorizontal striations, and fault roches moutonnees (Fig. 4). The second fault zone contains smaller flaser to lenticular, competent metaclastics in a phyllitic to schistose groundmass displaying wavy structures and steeply dipping foliation.

Foliation trends of the Southern Domain vary considerably. The structural map indicates that the northern part of this domain is controlled by east-northeast striking foliations and faults. The middle part of the Domain displays northwest trends which are especially pronounced by the presence of medium-sized recumbent folds (Fig. 5 and also the structural map). The south portion of the Domain presents variations of the foliations which strike from north-south to approximately east-west.

The medium-sized recumbent fold with its axis plunging 15 degrees towards N155°E (Figs. 3e and 5) is associated with a curving mylonite zone that runs parallel to the fold limbs. Drag indicates a right-lateral component of fault movement in addition to reverse faulting towards northwest. The equal-area plot of structural elements that were observed in the Southern Domain (Fig. 6) suggests one fold trend in N40°E and another in N114°E direction. The interpreted lateral compression directions are respectively N310°E and N24°E. The 40°-striking folds may be represented by asymmetrical to isoclinal folds with axial planes dipping at moderate angles towards southeast.

Folds of smaller dimensions suggest another system of lateral compression that acted within the sector N46°—72°E (dotted sectors in Fig. 6). The smaller folds seem to define two families, one plunges at about 15 degrees, the other plunges at angles of 50 to 60 degrees. The NNW-striking, medium sized folds, many of which are recumbent, appear to have been controlled by the same stress system.

Approximately three quarters of the lateral fault senses are compatible with lateral compression that acted in the sector N46°—72°E. This stress system also explains reverse faulting towards ENE. The remainder of strike-slip motions very probably were under the influence of the N310°E lateral compression.

Different fault trends appear to characterize different parts of the Domain. In the north, northeast trending faults predominate while the south portion has many northwest-striking faults. The central portion of the Southern Domain has no dominant fault trend.

CONCLUSIONS

The rocky shore of Bukit Cenering shows that multiple deformations must have taken place to account for the various fold trends and fault movements. In both domains two compression directions are represented, that is N310°E or N325°E and N46°—72°E. The Northern Domain is further characterised by lateral compression in N355°E; the Southern Domain has also a compression direction in N24°E. Both directions may be variations of the earlier mentioned stress systems, respectively, N310°—325°E and N46°—72°E. Several crenulations seem to represent the result of N24°E compression.

In short, two major maximum compression directions appear to have controlled the structures at Bukit Cenering. One of these compressions acted in the sector N310°—325°E and the other acted in the sector N46°—72°E. The later mentioned stress system is probably the younger event. The interpretation is based on the following features.

(1) The maximum compression direction is perpendicular to the general structural trend of the peninsula. The NNW structural grain of Peninsular Malaysia is recognized as the result of the last major orogenic event that occurred in Late Triassic—Early Jurassic time.

(2) The majority of crenulation lineations strikes about southeast-northwest direction, that is approximately perpendicular to the above named compression direction.

(3) Brittle deformation, which usually follows ductile deformation, is represented at Bukit Cenering among other things by strike-slip faulting. The majority of slip senses is compatible with compression in N46°—72°E.

The youngest stress system also caused normal to overturned to recumbent folding. The latter structure has axial planes dipping towards southwest. The stress system further tilted NE-trending fold axes to approximately vertical positions (see equal-area plot, Northern Domain, Fig. 6) and caused some reverse faulting moving towards northeast.

Effects of the other stress system are represented by an overturned fold with its axial plane dipping towards southeast (Northern Domain), the northeasterly trending foliation, and reverse faulting towards northwest (e.g. near the recumbent fold in the middle section of the Southern Domain, Fig. 6). The east-west directed structures (foliations, reverse faults) are very probably also results of the N310°—325°E stress system and attained their present strikes through reorientation by the N46°—72°E compression.

Radiometric ages indicate that the granite of the east coast of Peninsular Malaysia is of Lower Triassic to Permian age (see Hutchison, 1973, p. 216). The granite intrusion probably accompanied diastrophism which I interpret to have been controlled by a maximum compression in N310°—325°E direction. Subsequently, the major diastrophic event of the peninsula took place in Upper Triassic to Lower Jurassic and is represented at Bukit Cenering by results of a maximum compression in N46°—72°E direction.

A similar interpretation of structural events explains multiple deformations in Carboniferous metaclastics near Dungun (Tjia, 1974).

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