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Geological transport directions in Peninsular Malaysia

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Abstract: Fold asymmetry, isoclinal and recumbent folds, and low-angle reverse faults are unmistakable indicators of geologic transport direction. Some of the transport took place by gravity sliding when the sediments were still unconsolidated, but the majority was caused by tectonic processes. Five of the six major geologic settings may account for the transport directions determined in metasediments of various age groups of Peninsular Malaysia. Convergent transport occurs on limbs of anticlinoria. Divergent transport directions occur on limbs of warps developed by vertical uplift and in sediments that have been pressed out from sites between colliding continental plates. Three cases of unidirectional transport are possible and consist of overthrust and thrusts, subduction, and obduction. There is no indication that obduction ever took place in the peninsula. Cross-cutting structures, different fold sizes, and refolded folds are the main criteria for determining the relative ages of transport directions. From older to younger transport directions the movement was eastward, followed by movement towards south, then in a general westward direction (which is present in all geologic domains), succeeded by one towards east, and concluded by transport in south to southeast direction. The general westward transport probably took place during the Late Triassic-Early Jurassic deformation period and is interpreted as a consequence of eastward subduction of the Indian Ocean plate beneath the Eurasian plate in the vicinity of the peninsula. The cause of southward transport that probably occurred in two different deformation phases is an enigma.

INTRODUCTION

Under geologic transport is understood the tendency of a rock body to move or the actual displacement of the rock body. In this article the emphasis is on the lateral component of transport, which in many cases represent the direction of tectonic compression. The rock involved in the transport may be unconsolidated, indurated by diagenesis or recrystallized by metamorphism. This article does not consider primary movement of magma or lava.

Figure 1 depicts six main types of regional geologic transport. Lateral compression forming an anticlinorium produces drag folds or asymmetrical secondary folds on the limbs. These folds show convergent vergence (1.1). On the limbs of a synclinorium the drag folds exhibit divergent vergence. Vertical uplift resulting in warps may also develop in the unconsolidated sedimentary cover asymmetrical folds exhibiting divergent vergence (1.2). Sediments and other rock types that are compressed between colliding lithospheric plates eventually are pressed out of their original site. The up and outward spread of the rocks may begin with unidirectional vergence to the foreland. After extreme constriction, vergence towards the opposite direction also takes place. An example is the southerly vergence of the Dinaric Alps as compared with the northerly vergence of the main overthrusts of the Alpine Mountains. Vergence is usually lopsidedly divergent (1.3). Unidirectional geologic transport is known; an example are the thrusts and overthrusts of the Rocky Mountains of North America (1.4). In subduction regimes, unidirectional vergence is also present. The sediments of the trench are thrusted towards the subducting oceanic plate. In addition, gravity sliding of unconsolidated sediments from the trench slope into the trench is also directed towards the ocean (1.5). Karig *et al.* (1978) showed that rock and sediment of the trench slope should be

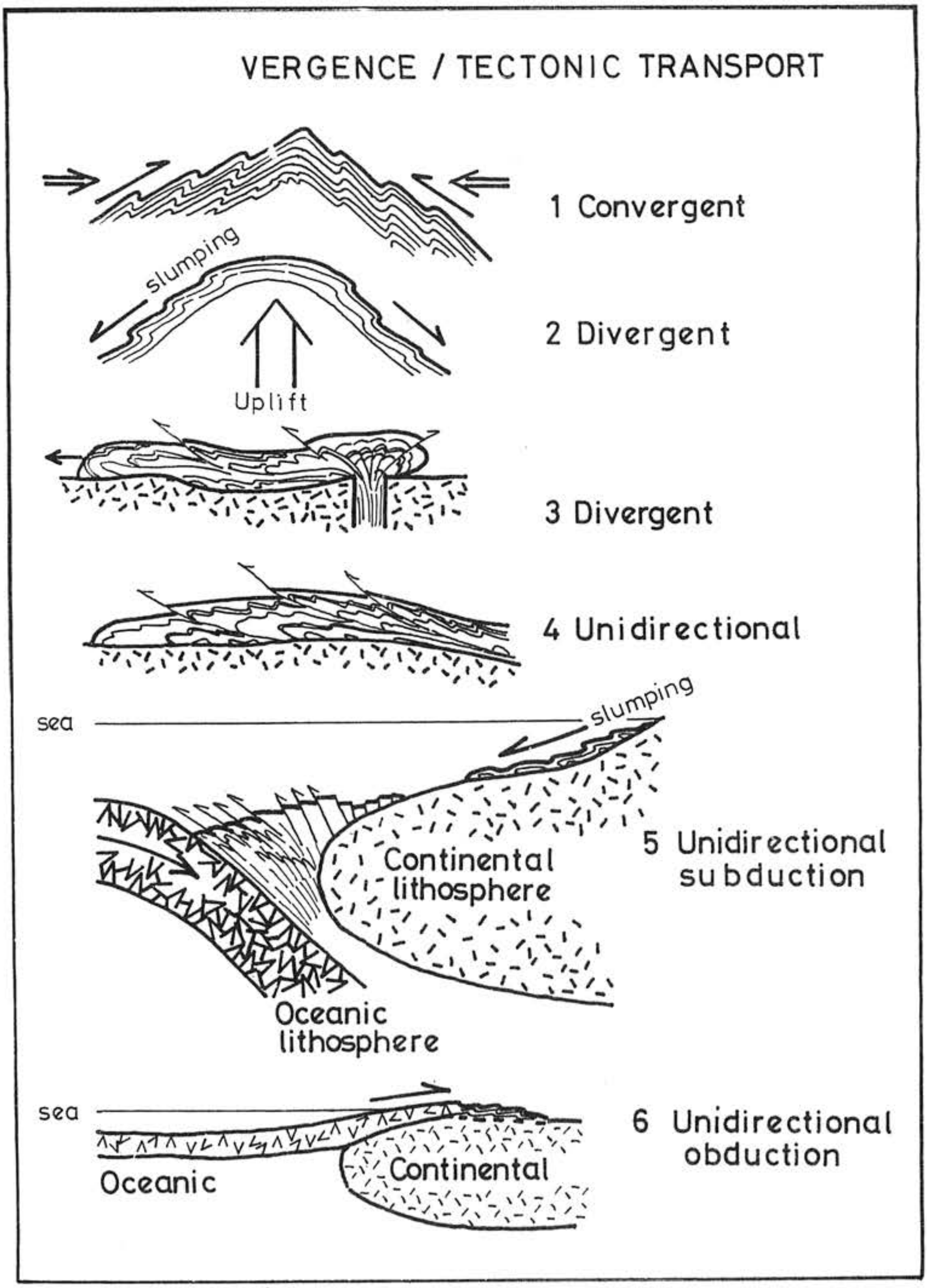

Fig. 1

1. Convergent vergence upon anticlinorium formed by lateral compression. The asymmetry of secondary folds is due to flexural drag.
2. Divergent vergence upon a warp caused by vertical uplift. The asymmetrical folds were formed by gravity sliding.
3. Divergent vergence in overthrust tectonic setting. Divergence of transport is due to extreme constriction of sediments between the colliding continental plates. An example are the Alpine overthrusts and Dinaric upthrusts (to left and right of the figure).
4. Unidirectional vergence of overthrusts and thrusts. An example is shown by the frontal thrusts of the Rocky Mountains in North America.
5. Unidirectional vergence in a subduction setting. Compressional thrusts and overthrusts occur in the trench sediments; gravity sliding involves unconsolidated sediments of the trench slope. An example is the Sunda Trench off Sumatra.
6. Unidirectional vergence in an obduction setting where the leading edge of the oceanic plate pushes sediments bulldozer fashion onto the continental plate. An example is the Batui obduction of ophiolite in eastern Sulawesi.

interpreted as thrusts towards the ocean side in the Sunda Trench west of Nias Island. Some reverse faulting towards the continent is also shown to occur on that side of the tectonic arc. Finally, obduction of an oceanic plate onto a continental plate generates another type of unidirectional vergence (1.6). An example is the Batui Nappe of the East Arm of Sulawesi.

In addition to the above described regional types of geologic transport, more localized types may be envisaged as radially divergent and radially convergent transport upon domes and basins, respectively.

Geotectonics teaches us that regional geological transport occurs over broad fronts and the direction of transport is more or less normal to the trend of the geotectonic feature, such as mountain range, continental slope, island arc, trench and trough. Gravity sliding in persistent directions usually occur normal to the same geotectonic structures. In other words, although the transport may be due to gravity, the inclination that facilities sliding is mostly due to tectonic processes. Along transform plate boundaries, drag may develop structures that strike oblique to the boundaries. The vergence of these structures may also be oblique to the regional trend. An example is probably in South Sumatra. The fold strikes of Tertiary rocks in the petroliferous basins curve away from the general structural strike of Sumatra. Some colleagues believe the deviation has been due to right slip motion along the Sumatra fault zone that strikes parallel to the island's axis.

Following Hans Stille (see Dennis, 1967), the term vergence (the anglicized version of Vergenz) in the article is used to indicate the "sense of asymmetry" of structures. In other words, vergence of an asymmetrical fold is that direction towards which the steeper or shorter anticlinal limb is facing. Tectonic transport is a special type of vergence in which part or all of the rock body was laterally displaced along thrust planes or through large-scale overfolding. In this article, the term slump is used to denote geologic transport of sediments before they became indurated.

TECTONIC FRAMEWORK OF PENINSULAR MALAYSIA

Most authors recognize a threefold geologic division of Peninsular Malaysia, that is, a western, axial or central, and eastern zone. In recent years the western zone has been subdivided into a smaller northwest domain (approximately north and northwest of Butterworth) and a western domain that includes the remainder of the earlier recognized western zone. Foo (1983) uses stratigraphical difference as basis for the finer subdivision; the lowermost Lower Palaeozoic rocks are only present in that domain. Tjia and Zaiton Harun (1983) point out that structural directions different from the main peninsular trend also possess surface expression in that domain. Discrimination between the western, axial and eastern domains is clearer and consists of differences in stratigraphy (Aw, 1977; Foo, 1983), igneous rocks (Hutchison, 1977), economic minerals (Hosking, 1977) and also structure (Tjia, 1978).

Previous authors have extended the three main geologic zones of the peninsula in southeasterly direction, forming a slightly convex curve southwestward enclosing the Riau-Lingga island groups, Bangka and Belitung (Billiton). Various lines of evidence, however, suggest that the axial zone continues due south across the Strait of Malacca into the Jambi and Palembang areas of Sumatra (Tjia and Zaiton Harun, 1983; Tjia, 1985).

Figure 2 schematically shows the tectonic history of Peninsular Malaysia. This figure summarizes information that is published in the *Geology of the Malay Peninsula* (Gobbett & Hutchison, 1973) and other articles cited in the present references. It should be pointed out that the occurrence of a Devonian unconformity in the northwest and west domains is not accepted by some authors (e.g. Yancey, 1975 and Foo, 1983). The existence of probable Precambrian rocks under the Macincang Formation in Langkawi (northwest domain) has been suggested based on the following evidence (Tjia, 1984MS). A 4-metre wide lag fault-zone outcrops on the east side of Teluk Anak Datai, Langkawi. The overlying meta-arenite and metalutite series is separated by this zone from closely fractured metaclastics of which the coarser grained metasediments had been deformed into flasers, often twisted and all folded tightly into isoclines plunging steeply to vertically. Carbonate films may line up the fractures. The rocks have been provisionally named Pre-Macincang and may therefore represent Middle Cambrian or even Precambrian material. Further work on this outcrop and a lithologically similar outcrop near Tanjung Buta is in progress.

Multiple Deformations. The tectonic history of Peninsular Malaysia already indicates that multiple deformations can be expected. Many publications, however, have only stated as evidence "*differences in structural complexity, or in metamorphic grade, or strong folding, or microfolding and crenulation*" for the existence of rocks that were folded "*at least twice*". The following are selected examples of multiply deformed rocks.

Figure 3 consists of a block diagram and a roadcut of deformed siliceous metapelite of the Baling Formation (age: Late Cambrian-Early Silurian according to Jones, 1970) that outcrop at the west end of the East-West highway near Sungai Rui. The roadcut suggests isoclinal refolding around approximately north-south axis of a steeply dipping fold plunging 70 degrees southwestward on the left-hand side of the roadcut. Vergence of the younger fold is towards west.

Figure 4 represents a roadcut a few kilometres before the entrance to the Muda Dam in Kedah. The rocks are Middle-Upper Triassic Semanggol siliceous (chert) pelites of the rhythmite member. The complex deformations are interpreted as the result of soft-sediment deformation, while the more regular folds were formed by tectonic movement, probably with vergence towards southwest.

Figure 5 is a hill section near the roundabout between Bangi New Town and the campus of Universiti Kebangsaan Malaysia. On the published geological map the rock is shown as part of the Kenny Hill Formation of Late Palaeozoic-Early Triassic age (Yin, 1976). This figure is a typical example of the fold style in this area. Quartz occurs subparallel to bedding and the general foliation as large sigmoidal flasers and as tight isoclinally refolded folds. The two fold generations are co-axial. The distinct southeastward transport direction is present throughout the Bangi area and often masks a younger westward vergence that is common in the western domain (see e.g. Tjia, 1978; Lim & Tjia, 1979; Zaiton Harun, 1981; Tjia & Ibrahim Komoo, 1983). It is possible that the west vergence represents a third phase of ductile deformation in this domain.

Lower Palaeozoic phyllite and schist occur near Kuala Sawah, Negeri Sembilan. Figure 6 shows an example of refolding: an older axial plane is folded and cleavage planes also show

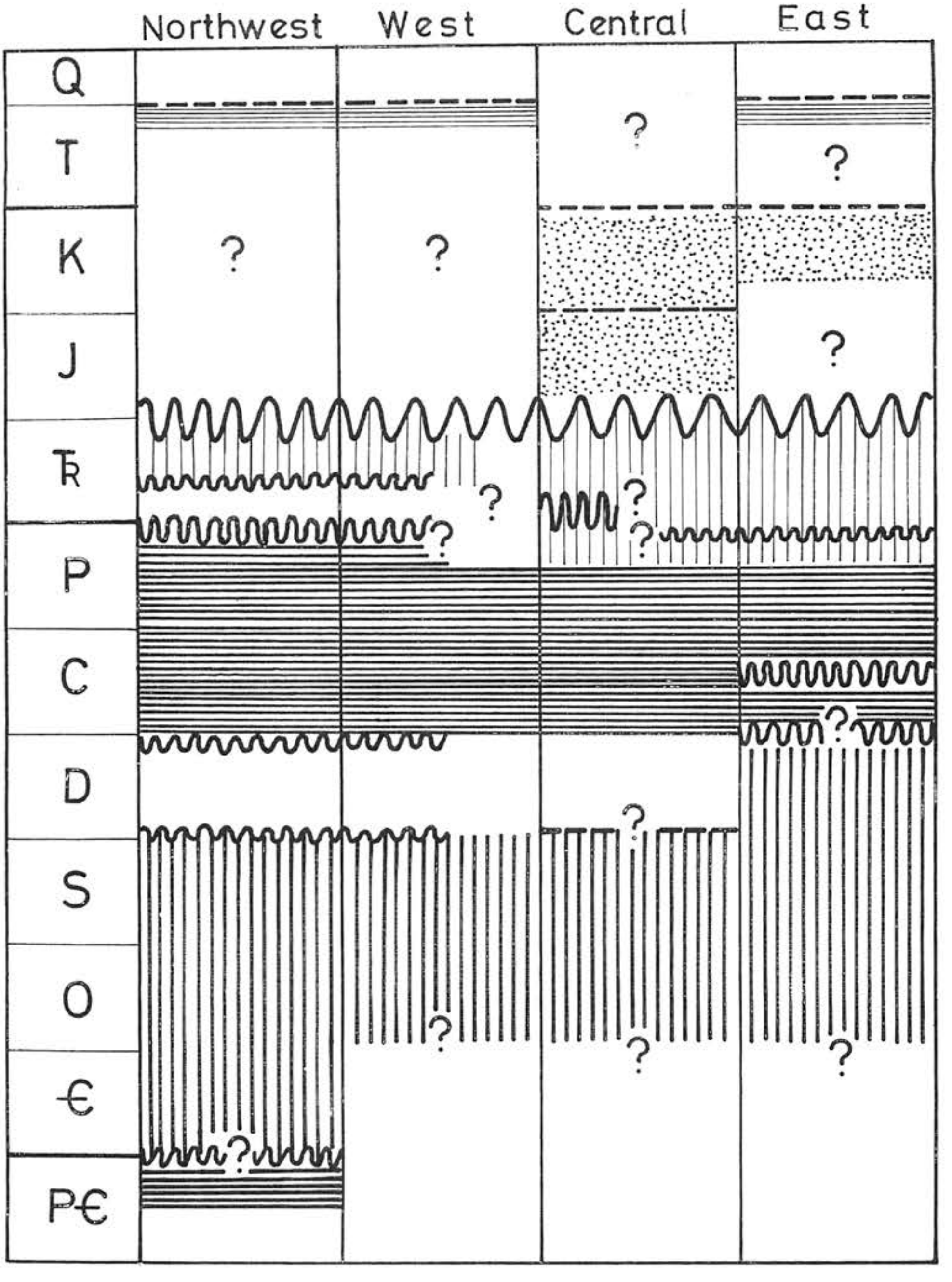

Fig. 2 Tectonic history of Peninsular Malaysia in schematic form. Deformation phases are indicated by wave-like lines; dashed horizontal lines denote uncertain character of the stratigraphic boundary; filled-in spaces represent sedimentation. The major geologic domains are indicated as Northwest, West, Central and East. This scheme is based on information contained in the references cited in the text.

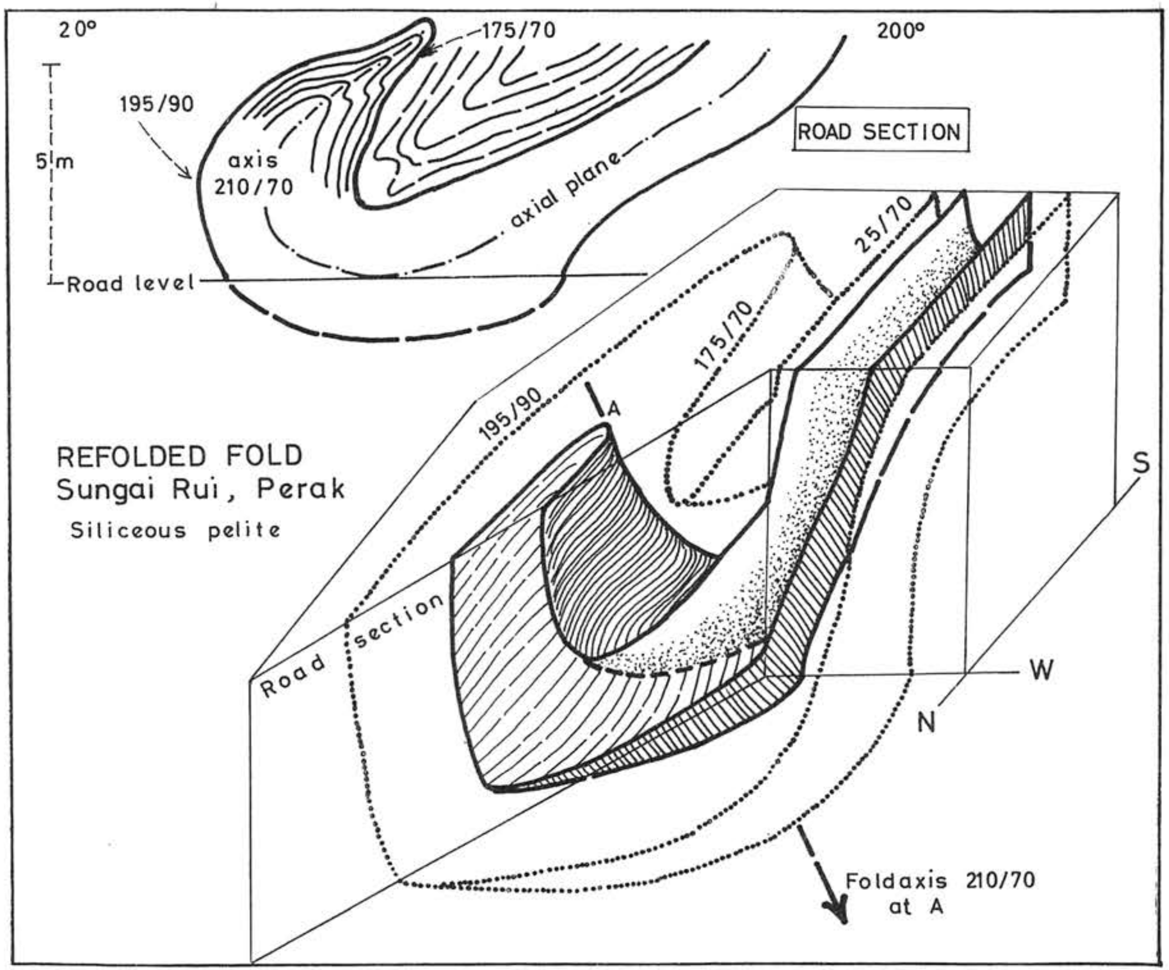

Fig. 3 Divergent vergence in overthrust tectonic setting. Divergence of transport is due to extreme constriction of sediments between the colliding continental plates. An example are the Alpine overthrusts and Dinaric upthrusts (to left and right of the figure).

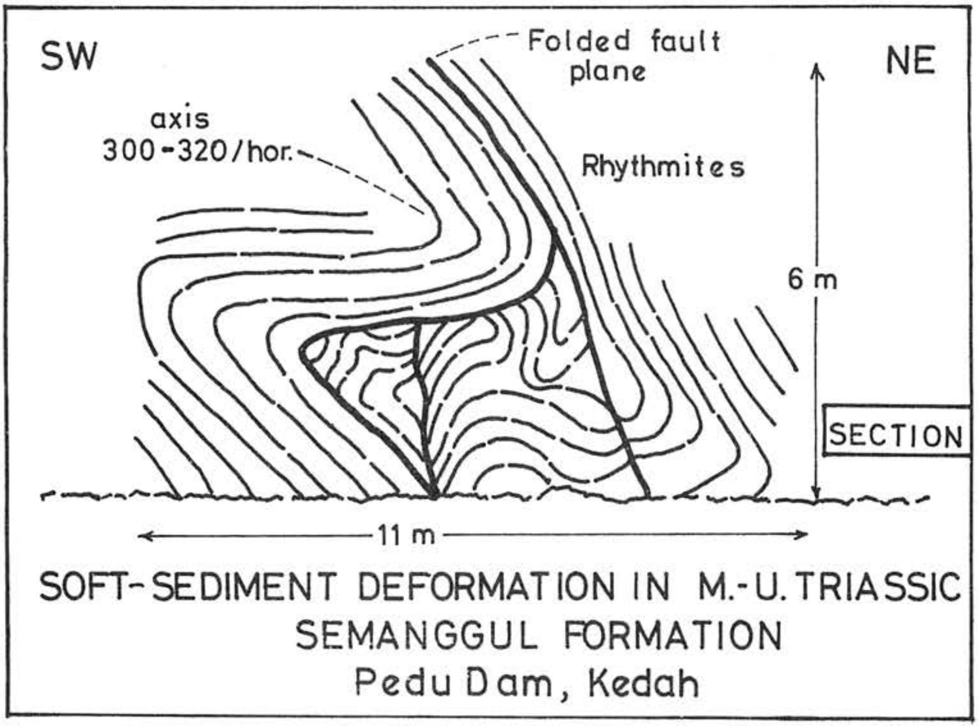

Fig. 4 Siliceous rhythmites of the Semanggol Formation outcropping in a roadcut leading to the Muda Dam. The complex structures were developed before diagenesis; the more regular folds and fault are tectonic.

this refolding. The outcrop is a long railroad cut where the general foliation strikes between 300° and 330° and vergence is towards southwest.

Small-scale refolding as depicted in figure 7 probably represents one type of deformation style in the Lower Palaeozoic Karak Formation along the west edge of the axial domain of the peninsula. The figure shows low-angle reverse faults cutting and evidently deforming a series of meta-sediments consisting of finegrained metasandstone layers intercalated with dark grey phyllite. The low-angle reverse faults indicate transport towards 300-305° and one of them deformed the metasediments into dragfolds. Stratigraphic top of the metasandstone is indicated by decapitation of cross laminae. The outcrop pattern suggests the sandstone layers to have been tightly, isoclinally folded before drag folding occurred through faulting.

The following two figures are examples of multiple deformation from the eastern domain. Figure 8 is a cliff exposure of disharmonic folds at Tanjung Mat Amin, Trengganu. Fold F_1 is large and recumbent; F_2 is an upright fold. Both folds are co-axial with approximately north-south strikes. Almost east-west across the previous fold directions is warp axis F_3 that represents the youngest deformation. It is also possible that F_3 only represents undulations that developed through plunging of F_2 folds. This structure was described in an earlier note (Tjia, 1982).

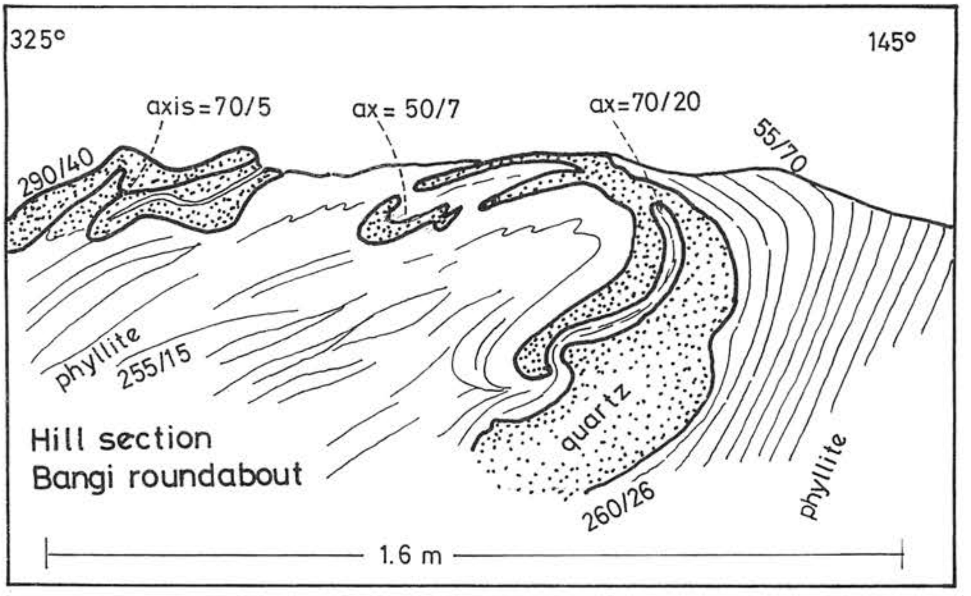

Fig. 5 A typical example of the fold style in Upper Palaeozoic metasediments occurring in the Bangi area, Selangor. Quartz occurs as sigmoids and as large plates, some showing refolding. Hill section at the Bangi roundabout between the new town and the campus of Universiti Kebangsaan Malaysia.

Midway on the eastern shore of Pulau Kapas, Trengganu, the geological situation is depicted in figure 9. An older north-south tectonic deformation developed the east-west striking reverse faults. In turn these faults were cut by an easterly verging reverse fault that is representative of a younger deformation phase.

Other examples of multiple deformations in the eastern domain that have been published are given by Tjia (1974, 1978) for the Dungun area and Bukit Cenering, both in Trengganu, and for Tanjung Gelang (Yap & Tan, 1980; Tjia, 1983).

SELECTED EXAMPLES OF GEOLOGIC TRANSPORT

On this and following pages will be discussed examples of geologic transport in the various domains of Peninsular Malaysia. Most are from field notes collected in the past 15 years. Only few examples published by other workers have been used to complement the description, especially those that cover areas where personal field experience is wanting. Despite the fact that the present coverage is incomplete in terms of area, yet the consisent directions of geologic transport at the localities that were visited, suggest that the data presented in this article is representative. Future work may be expected to detail the variations of transport directions and to separate local from regional directions of transport.

Northwest Domain

On the east shore of Teluk Datai, Langkawi island, a four metre zone of mylonite represents a lag fault zone between Upper Cambrian-Ordovician Macincang rocks and

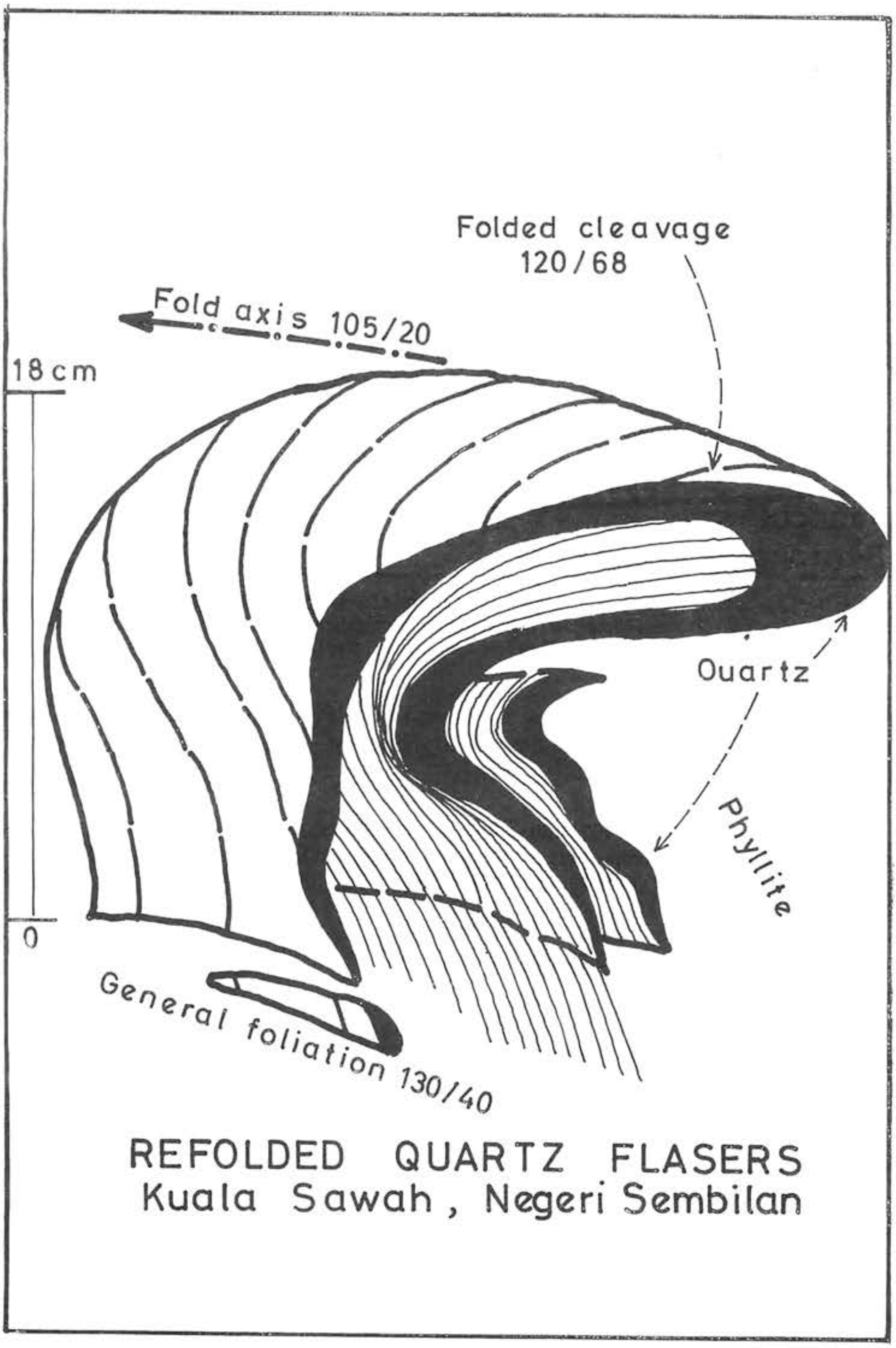

Fig. 6 A refolded fold consisting of a small quartz plate within Lower Palaeozoic phyllite outcropping in a railroad cut near Kuala Sawah, Negeri Sembilan. The multiple folding appears to have been co-axial.

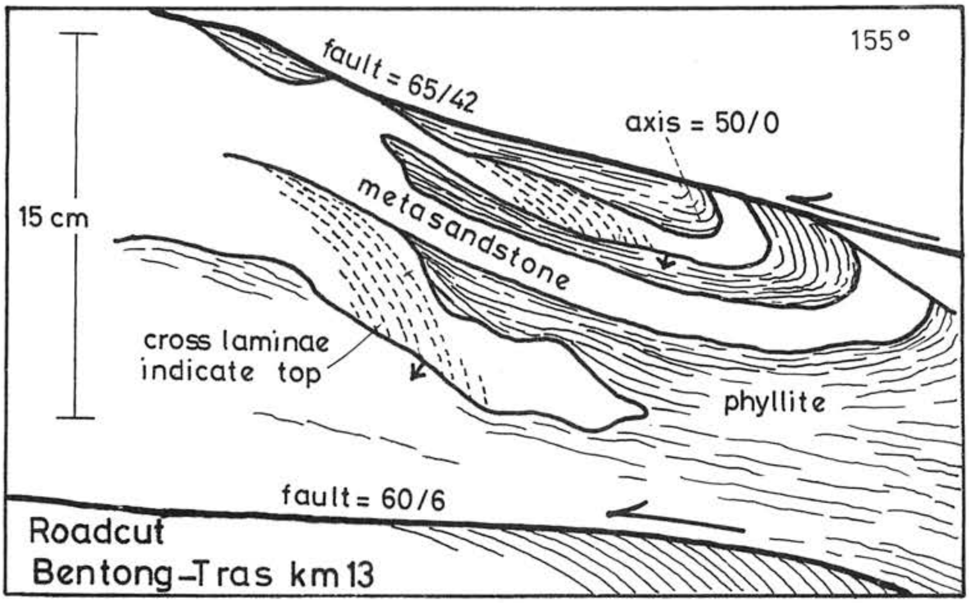

Fig. 7 Low-angle reverse faults cut and deformed a series of metasediments of the Lower Palaeozoic Karak Formation near Bentong, Pahang. These faults indicate transport towards 300-305°. The pattern of sandstone layers suggests isoclinal folding, probably before drag folding developed through faulting.

underlying Pre-Macincang quartzites, interpreted to be Precambrian age. The fault zone strikes between 310° and 320° and dips 15-20° northeast. Vergence is towards southwest (Tjia, 1984MS).

The Setul Formation, Ordovician-Silurian, consists of massive to bedded crystalline limestone with two clastic members. Large scale recumbent folds in this formation outcrops at Tanjung Dagu (strike 100°, vergence towards 190°), Tanjung Cawat (strike 350°, vergence

Structure in Setul Formation	Transport towards
PulauTimun, south; reverse fault 110/60, reverse fault zone 35/24	20° 305°
Pulau Nyiur Setali, north; asymmetrical crenulation strike18°	108°
Pulau Selang Kecil; asymmetrical crenulations upon medium size recumbent fold, both axes strike 340°	70°
Teluk Tuba, Pulau Tuba; asymmetrical antiform, axis = 70-90°	160 - 180°

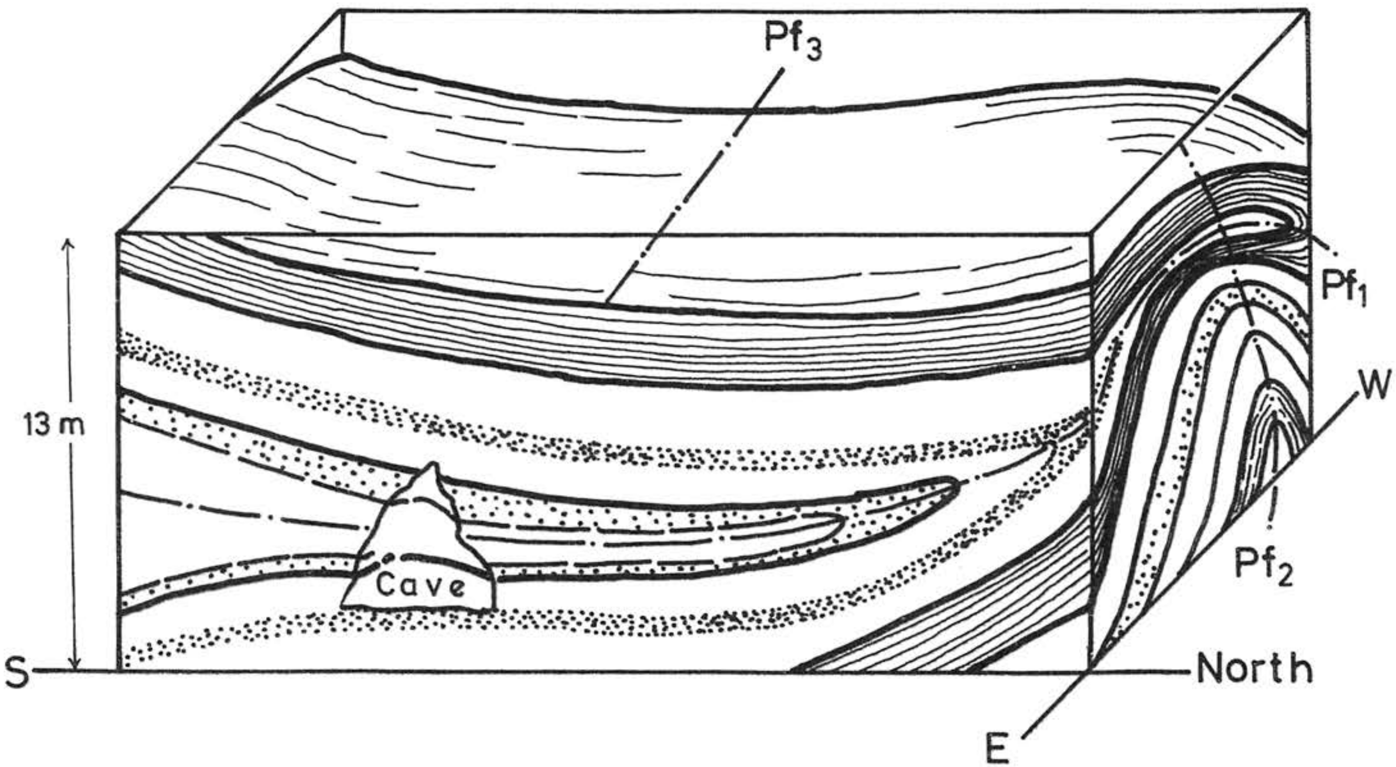

Fig. 8 Cliff exposure of superimposed folds in Upper Palaeozoic metasediments at Tanjung Mat Amin, Kemaman. Fold F1 is recumbent; fold F2 is upright and slightly asymmetrical. F1 and F2 were folded co-axially. The gentle warp with east-west represents the latest deformation phase.

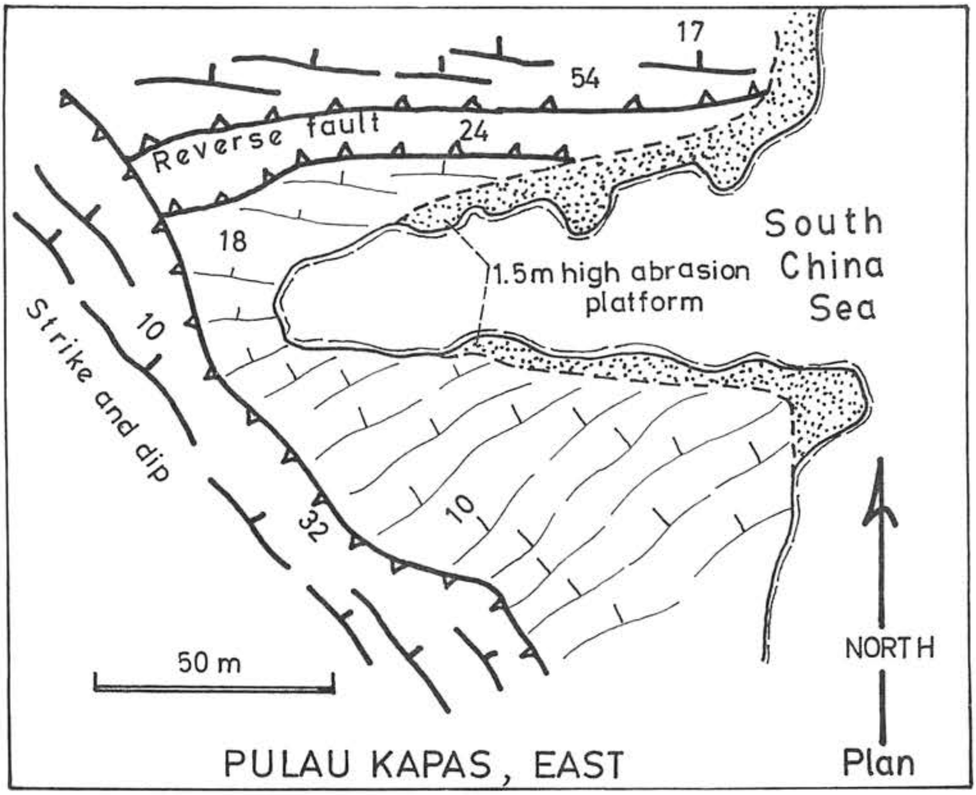

Fig. 9 Sketch map of a cross-cutting pattern of reverse faults on the east side of Pulau Kapas, Trengganu. The older fault motion verged south; the younger verged northeast.

towards 260°), behind the mosque at Pulau Tuba (strike 350°, vergence towards 260°), all in the Langkawi island group. Other structures in the Setul Formation indicate vergence towards east, southerly and northwesterly. An example of easterly vergence is on figure 11.

In addition, slump folds in the limestone at Teluk Bujur, Pulau Tuba, have axes striking 30° and 70°, suggesting transport towards 120° and 160°. It should be borne in mind that these directions do not represent the original slump directions, as the limestone also experienced tectonic deformations.

At the south end of Pulau Dayang Bunting, at Teluk Air Taun, of Langkawi geologic transport was determined at the outcrop shown as figure 10. A medium size recumbent fold consisting of Setul limestone strikes 130/18 and bulges towards southwest and rests upon dark phyllite. Between the two rock types is a 20-cm thick mylonite and beneath it a 3-m wide zone of parallel fractures in the phyllite. Subvertical pods of calcite rise from the mylonite zone into the Setul limestone. The fracture zone in the phyllite is a shear zone; fracture spacing is close near the mylonite but becomes wider farther downward. On the geological map Jones (1966) assigned the phyllite to the U. Devonian-Carboniferous Singa Formation. However, lithologically similar phyllite occurs in the so called Detrital Members of the Setul

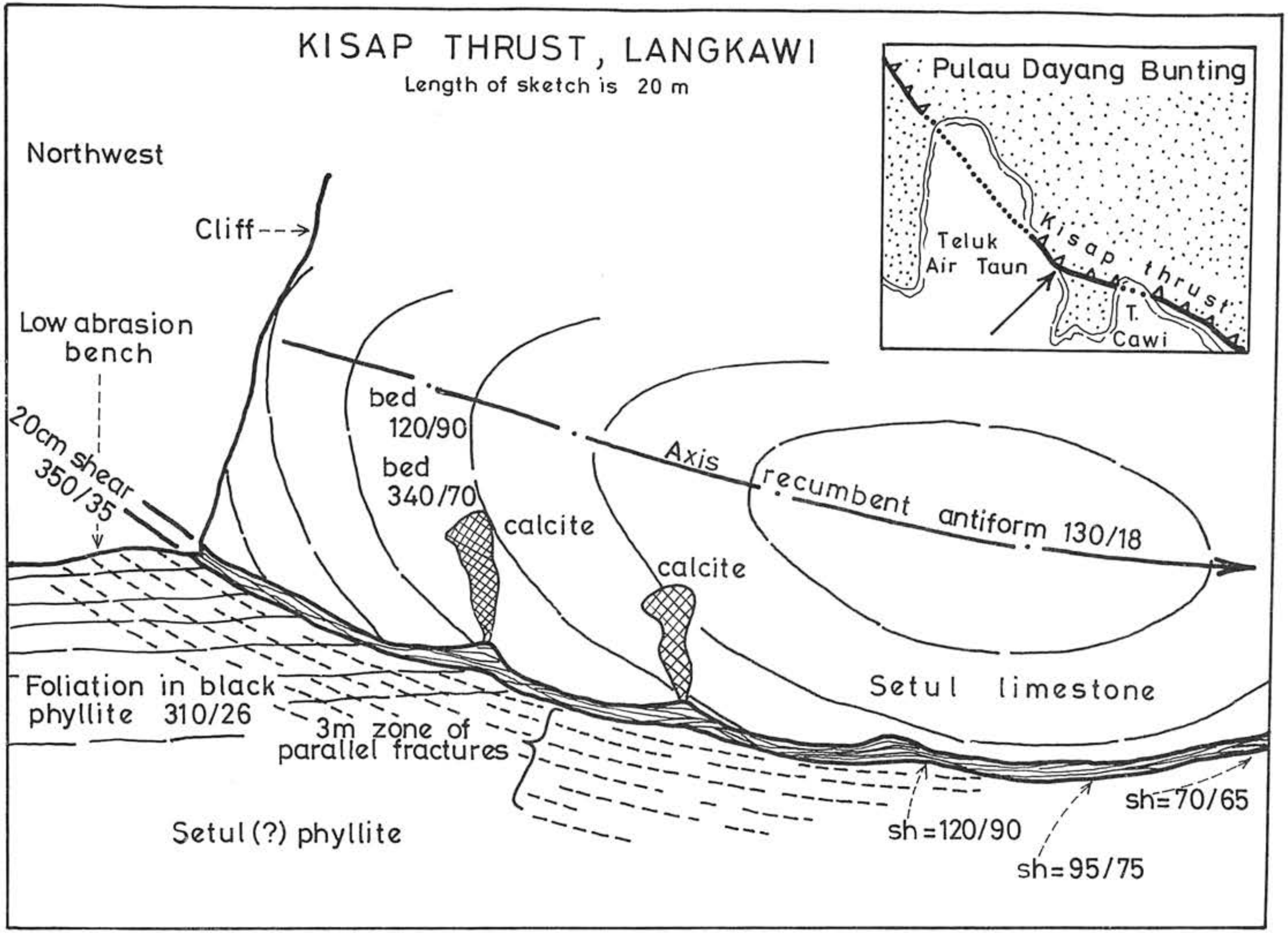

Fig. 10 A recumbent fold in Setul limestone developed as drag through thrusting southwestward upon phyllite of the same formation. The thrust fault zone consists of 20-cm mylonite overlying a 3-metre wide zone of shear fractures in the phyllites. Locality is on the east side of Teluk Air Taun, Pulau Dayang Bunting, Langkawi islands.

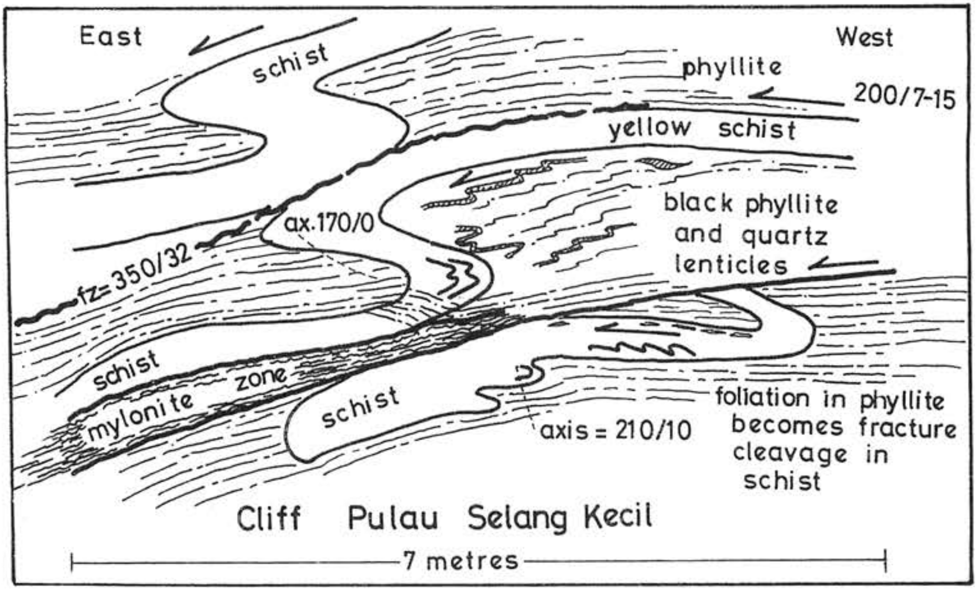

Fig. 11 Pulau Selang Kecil off Tuba island, Langkawi, consists of schist, phyllite and some slate belonging to the Ordovician-Silurian Setul Formation. This sketch is a cliff exposure on the north side of the islet. Geologic transport towards east (more exact 70°) is shown by the fold shapes of yellowish schist, sigmoidal quartz lenticles and drag folds. Transport was facilitated by the low-angle reverse faults.

Formation that outcrop along the east side of Pulau Tuba, Pulau Nyiur Setali, Pulau Enggang and Pulau Tiloi. The outcrop at Teluk Air Taun indicates that geologic transport through thrustfaulting was southwestward.

Recently, Tan (1981) challenged the field arguments used by Koopmans (1965) and Kimura and Jones (1967) to interpret the Langkawi or Kisap thrust in these islands. Tan also visited Teluk Air Taun but only referred to a photograph by Kimura and Jones as indication for the thrust zone there. The outcrop in that photograph lies a hundred or more metres north of that shown as figure 10 in the present article. Tan concluded that there the Setul limestone is in comformable contact with metaclastics. The outcrop of figure 10 was apparently overlooked. This outcrop indicates a thrust fault zone between Setul limestone and Setul clastics below with geologic transport towards southwest. It is probable that this thrust zone is part and parallel to the proposed Langkawi or Kisap thrust of Koopmans and of Kimura and Jones. Tan correctly points out that their field evidence is insufficient to establish the existence of a single, large thrust fault in the Langkawi islands.

At the north end of the same island, at Teluk Air Taun, Permian Cuping limestone is separated by steeply dipping shear zones (strike/dip 205/57 and 235/54) from the underlying Setul limestone. Drag folds in the Setul limestone indicate transport towards the east-southeast sector. In previous publications, this thrust zone has been considered part of the Langkawi or Kisap thrust and probably represents some form of backthrusting.

Geologic transport found in Upper Palaeozoic rocks of the Langkawi islands were determined from U. Devonian-Carboniferous Singa Formation. The formation consists of several slump intervals, as expected, with many directions of transport. However, the slump folds at Pulau Ular and Pulau Kentut Besar suggest slumping generally in east or westward directions. Reverse faults in the same formation with attendant drag folds show vergence towards 240° and 330° at Tanjung Sawa, and towards 280° at Pulau Ular.

In the northwest domain outside the Langkawi islands, geologic transport directions were determined at the following localities. At Pulau Bidan, Kedah, the Silurian Sungai Petani Formation has an asymmetric overfold suggesting northeast vergence (see Bradford, 1972). The Silurian Baling Formation at Sungai Pong exhibits isoclinal folds in limestone indicating northwest or north-northwest vergence (see Burton, 1970). Isoclinal folds, overturned folds, and thrustfaults at Permatang Dublin near Kulim, Kedah, within the L. Silurian Mahang Formation indicate north-northwest vergence (see Courtier, 1974).

Geologic transport directions in M.-U. Triassic rocks of the same domain were determined through asymmetrical folds verging west at Wat Lampan; thrust and reverse faults at the Muda Dam verging 25° or 205°; asymmetrical folds at Baling verging northwest and some southeast (see Burton, 1970 for Baling). The rocks all belong to the Semanggol Formation. At Bukit Kodiang, Kedah, the Late Permian-Norian limestone has large scale recumbent slump folds in certain intervals having vergence towards 235-250°.

West Domain

The Lower Palaeozoic metasediments, the Baling Formation and stratigraphic equivalents, outcropping along the East-West highway between Grik and the granitoid Main Range, represented by Bukit Ulu Merah-Bukit Ulu Laho-Bukit Kabut show two main vergences. On the Grik side large recumbent folds and smaller folds, reverse and thrust faults indicate westerly vergence. On the Main Range side on the east vergence is easterly. These vergences probably represent divergent drag folds in a synclinorium. Locally, such as at kilometre 19 (from Sungai Rui), north vergence is also present. Near Lawin asymmetrical folds indicate southeast vergence (see Jones, 1970).

Vergence towards east and east-northeast is indicated by isoclinal folds and asymmetrical folds in Upper Palaeozoic rocks outcropping near Simpang Pulai and Kampar, both in Perak (see Ingham and Bradford, 1960), in the Tanjung Malim-Fraser Hill area, Selangor (see Roe, 1951), and Rasa, Selangor (see Roe, 1953). These localities are all on the west flank of the Main Range and the vergence in easterly direction may represent drag features on the anticlinorial limb of the Main Range.

In the Genting Sempah area, Selangor, west to southwest vergence in the Lower Palaeozoic rocks is the rule. In the Upper Palaeozoic conglomeratic mudstone vergence is towards 150°. This direction of geologic transport can also be observed in the L. Palaeozoic schist in Sungai Badak where it occurs together with west vergence. Lim and Tjia (1979) described the Genting thrust belt that outcrops as wide belts of mylonite along the Karak highway a few kilometres before the entrance of the tunnel at Genting Sempah. Thrust movements were towards southwest and may have taken place in Triassic-Jurassic time.

The Upper Palaeozoic rocks in the Kuala Lumpur-Kelang area show vergence in the sector 230-305°. Large recumbent folds in Kenny Hill Formation were described from Kuala Lumpur (Tjia, 1979) and overturned folds from Bangi (Zaiton Harun, 1981) and from Sungai Buah (Zaiton Harun and Tjia, in press). Smaller asymmetrical folds, reverse and thrustfaults indicating transport towards the same direction are published in Tjia (1976 and 1984a). In addition, south-southeasterly transport in the same rock formation was measured at Subang, Shah Alam and Serdang. U. Palaeozoic metasediments on the islets off the coast, Pulau Angsa and Pulau Jemur show vergence towards 270°.

The Upper Palaeozoic metasediments in the Bangi area show vergence towards southeast but also towards west and southwest.

Farther south geologic transport in Lower Palaeozoic metasediments were determined at Kuala Sawah, Negeri Sembilan (vergence towards south) and at Tanjung Tuan, Negeri Sembilan (vergence towards west).

Central Domain

The Upper Palaeozoic (or perhaps older) Taku Schist in Kelantan, has asymmetrical folds and reverse faults indicating vergence towards 255° and 270°. A reverse fault transporting towards 70° is interpreted to represent backthrusting. These measurements were taken along Sungai Galas and at the abandoned Temangan iron mine. In the Sungai Mesek near Manikurai, a reverse fault (strike/dip 100/28) suggests transport towards 10°.

From the publication by Richardson (1950) on the Cegar Perah-Merapoh area were determined east and west vergence from U. Palaeozoic, stratified limestone that consists of isoclinal and overturned folds.

The geologic cross sections prepared by Alexander (1968) for the Bentong area of Pahang show asymmetrical and some isoclinal folds with axial planes dipping steeply to moderately east-northeast. General vergence is therefore towards west-northwest which may be a consequence of the development of the Main Range anticlinorium. The mentioned examples are all on the east flank of that anticlinorium. Detailed field observations, of which three examples are listed below, show greater complexity in transport directions in the Lower Palaeozoic rocks of the same area.

Structures in L. Palaeozoic rocks	Transport towards
* Bentong-Tras road	
Reverse fault 325/62, drag folds 130/0	220°
Reverse fault 10-25/12, drag folds	280-295°
Reverse fault 250/30, drag folds	340°
Low-angle reverse fault 60/6	330°
Overturned folds, axes 290/15	200°
Reverse fault zone 310/10, drag features	40°
* Karak highway at Bentong junction	
Isoclinal overturned folds, limbs 290/12	20° or 200°
Drag folds, axes 142/27	52°

Drag folds, axes 95/5	5°
Reverse fault 275/27	185°
Reverse fault 290/27; reverse fault 290/30-45	200°
Quartz flaser, sigmoidal	210°
Quartz flaser, asymmetry; enclosing foliation 320/42	230°
* Karak highway 2 km west of Bentong junction	
Reverse fault 310/43, drag features	220°
Isoclinal folds, axes 150/20	SW
Isoclinal folds, limbs=340/28	250°

It is shown that other transport directions are southerly and towards northeast. The various geologic transport directions near Bentong have also been discussed elsewhere (see Tjia, 1984b).

In a long roadcut approximately 11 km from Kuala Lipis towards Padang Tengku, Pahang, is seen a younger low-angle reverse fault displacing a steeper fault zone of similar strike (Fig. 12). Folds adjacent to the steeper fault zone suggest that eastward transport occurred along it. The 1-metre offset of the older fault zone also indicates eastward vergence by the younger reverse fault. The rocks are tuffaceous sediments that may be stratigraphic equivalents of the M.-U. Triassic Semantan Formation described by Jaafar Ahmad (1976).

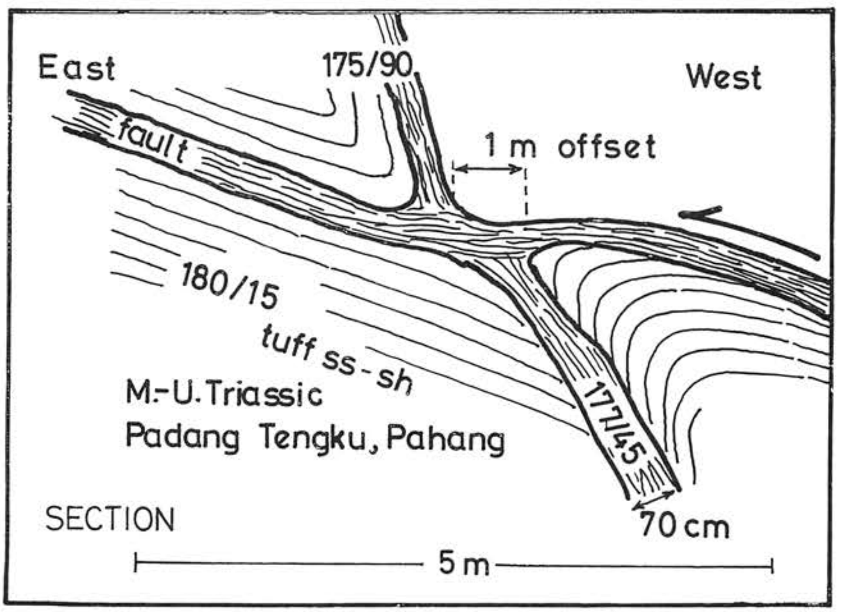

Fig. 12 Part of a long roadcut 11 km from Kuala Lipis towards Padang Tengku, Pahang, shows a younger low-angle reverse fault displacing a similarly striking but steeper fault zone. Drag folds suggest eastward transport and so does the 1-metre fault offset of the older fault zone. The rocks are tuffaceous metasediments, probably of M.-U. Triassic age.

East to northeast vergence is exhibited by M.-U. Triassic sediments of the Kaling and Semantan formations of Pahang. Jaafar Ahmad (1980) shows that the Kaling Formation possesses regional isoclinal folds with limbs inclined west-southwest, implying transport towards east-northeast. Detailed investigation of the Semantan sediments near Temerloh and Mentakab, Pahang, also indicates that east to northeast vergences are common. In addition, slump folds indicate sliding towards 20° and 557°. In figure 13 is an example of geologic transport through slumping in the Semantan Formation in Temerloh town. Sliding took place along subhorizontal planes.

Figure 14 shows a roadcut through the equivalent of the Karak Formation at Bukit Penagoh, Negeri Sembilan. The outcrop consists of reddish coloured schist and a series of tuffite, metasandstone and (meta?) conglomerate. As usual, the rocks are deeply weathered. Elsewhere in the roadcut the conglomerate and tuffite occur as large tumbled blocks within the rock mass. The tumbled appearance is strengthened by the varying attitudes of foliation and bedding in different blocks. They are interpreted as olistholiths. Lithologic offsets near the low-angle faults in figure 14 (125/10 and 270/5) suggest transport towards south-southwest. The younger fault zone 310/35, may have transported the rocks in northeast direction. This interpretation is based on the attitude of the fault and the pattern of *en echelon* quartz veins through the conglomerate.

Near Parit Sulung, Johor, are M.-U. Triassic clastics (Fig. 15). Small slump folds in argillaceous beds shows northeast vergence. Reverse faults in conglomerate are 160/15-32 and indicate geologic transport towards 70°. At the north foot of the ridge topped by Bukit Payung are several mylonite zones, each a few metres wide, with drag folds that indicate transport towards 30°.

East Domain

Upper Palaeozoic metasediments in the Sungai Sok area, Kelantan, are cut by many reverse faults with dips ranging between 10 and 44 degrees. Most vergences are towards 140-180°. Locally transport towards 25° and towards 215° was also measured. At Tanjung Cenering near Kuala Trengganu, asymmetrical and recumbent folds in Upper Palaeozoic metasediments indicate transport towards northwest and towards 245°. Thrusting was towards northeast to north-northeast. Multiple deformations could be traced and were discussed in another article (Tjia, 1978b).

In the Dungun area of Trengganu many instances of geologic transport in U. Palaeozoic metasediments were described (Tjia, 1974). Many overturned folds and reverse faults, some of which are low-angle, indicate vergence towards 222-280°. Some other directions of transport are towards south and northeast.

In the Ulu Paka area Fateh Chand (1978) mapped asymmetric to isoclinal folds with north-south strikes. However, vergence is not shown on the map or geological sections. The report further states that variations of structural strike exist as a result of the granitoid intrusions.

Asymmetrical and recumbent folds, some of large dimensions, occur in the Upper Palaeozoic metasediments at Tanjung Sulung and Tanjung Mat Amin near Kemaman, Trengganu. Their strikes are northerly and vergence is towards west. In addition, north

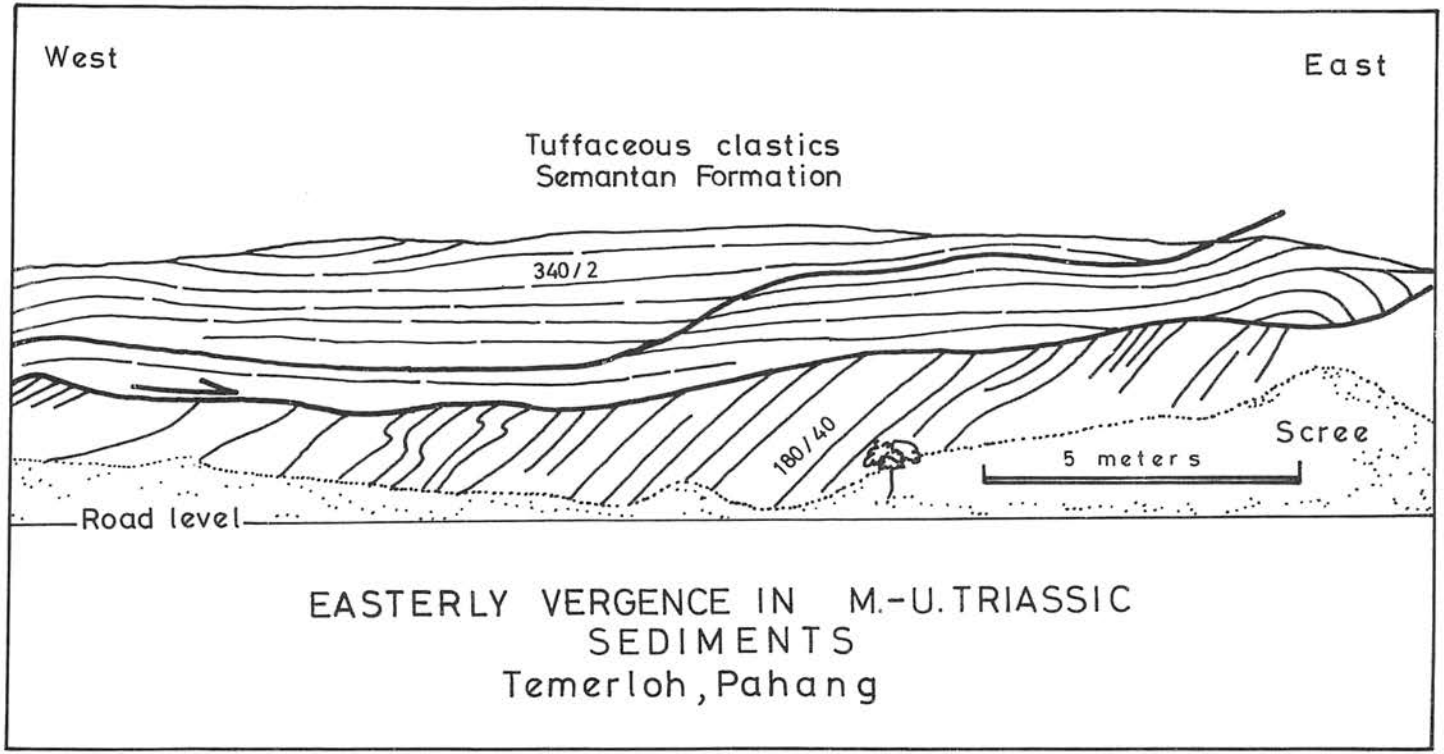

Fig. 13 Eastward slumping within the Semantan Formation outcropping in Temerloh town, Pahang.

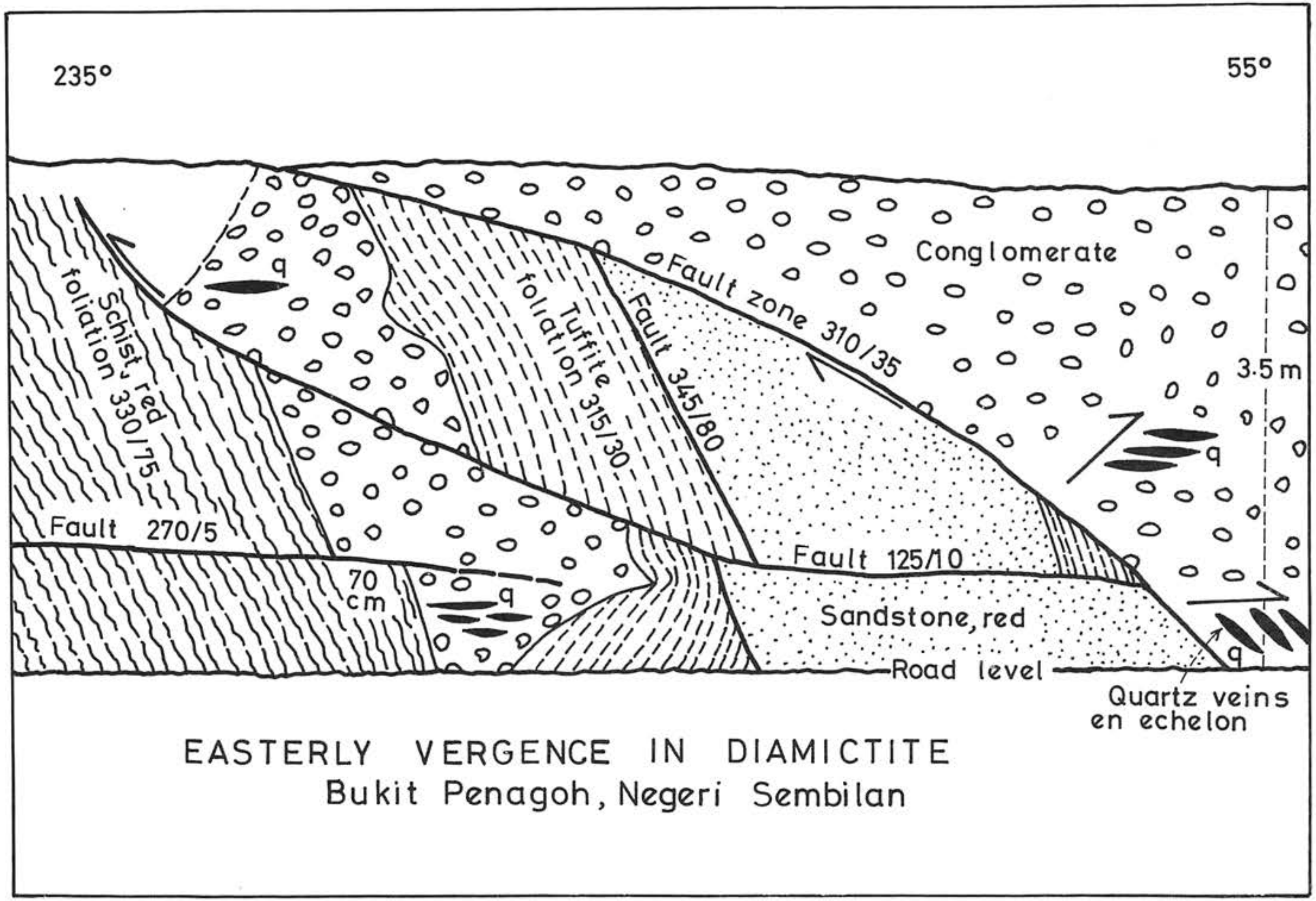

Fig. 14 Part of a roadcut through Lower Palaeozoic metaclastics at Bukit Penagoh near Simpang Pertang, Negeri Sembilan. Elsewhere in the roadcut the (meta?) conglomerate and associated clastics appear as large olistoliths. Southwestward transport along the low-angle faults was succeeded by transport towards northeast along the 310/35 fault zone.

verging asymmetric and recumbent folds have also been recorded. Figure 8 shows the structural style and multiple deformations at Tanjung Mat Amin.

At Tanjung Batu Lata, Trengganu, asymmetric antiforms indicate vergence towards 325°, whereas reverse fault zones indicate transport towards 250° and 280°. The rocks are Upper Palaeozoic metasediments.

In similar rocks at Pulau Kapas, an islet off Marang, Trengganu, many moderately to steeply dipping reverse faults indicte transport towards west and east. A large asymmetrical antiform verges 10° and other reverse faults show transport towards north and south. The general strike is north-south which appears to represent the younger deformation phase. See further figure 9.

Multiphase deformations also affected the Upper Palaeozoic metasediments at Tanjung Gelang, Pahang (see Tjia, 1983). Recumbent folds show vergence towards 210-220° as well as towards 50°. A refolded fold axis striking 200° and plunging 33 degrees in that direction suggest the younger phase of vergence towards 290°.

Vergence towards 250° is indicated by recumbent isoclinal folds in Upper Palaeozoic metasediments outcropping along the new Jabor road near Air Putih (old spelling: Ayer Puteh).

Probable Triassic and Lower Carboniferous metasediments in the Bukit Sagu-Bukit Kuantan area of Pahang have asymmetrical and overturned folds that indicate east vergence. This is indicated in cross sections prepared by Fitch (1952).

At Bukit Arang near Sri Jaya, Pahang, Upper Palaeozoic phyllite and coarse grained metaclastics consist of slump horizons where the folds are north-south and vergence is towards east.

At Tanjung Kempit, Johor, the Upper Palaeozoic metasediments have overturned and isoclinal folds verging 273° and 45-50°. The many reverse faults, however, show transport towards 250-280°.

Similar rocks at Mersing, Johor, consist of asymmetrical folds and isoclinal folds verging 45-60°. Farther south at Desaru, Johor, isoclinal folds in such rocks verge 225°.

At Teluk Dungun on Tioman island and overturned antiform suggests 320° vergence. The rocks are pre-granitoid (probably Triassic according to Bean, 1977) silicic metavolcanics and occur on the east flank of the north-south striking igneous mass. The vergence, therefore, may have been the result of the intrusion.

RELATIVE AGES OF GEOLOGIC TRANSPORT

The relative ages of vergence and geologic transport directions have been interpreted on the basis of the following arguments. Cross-cutting relationships between structures usually indicate decisively their relative ages. Smaller folds are usually interpreted to represent the result of a later deformation phase than the one that developed the larger folds. Older

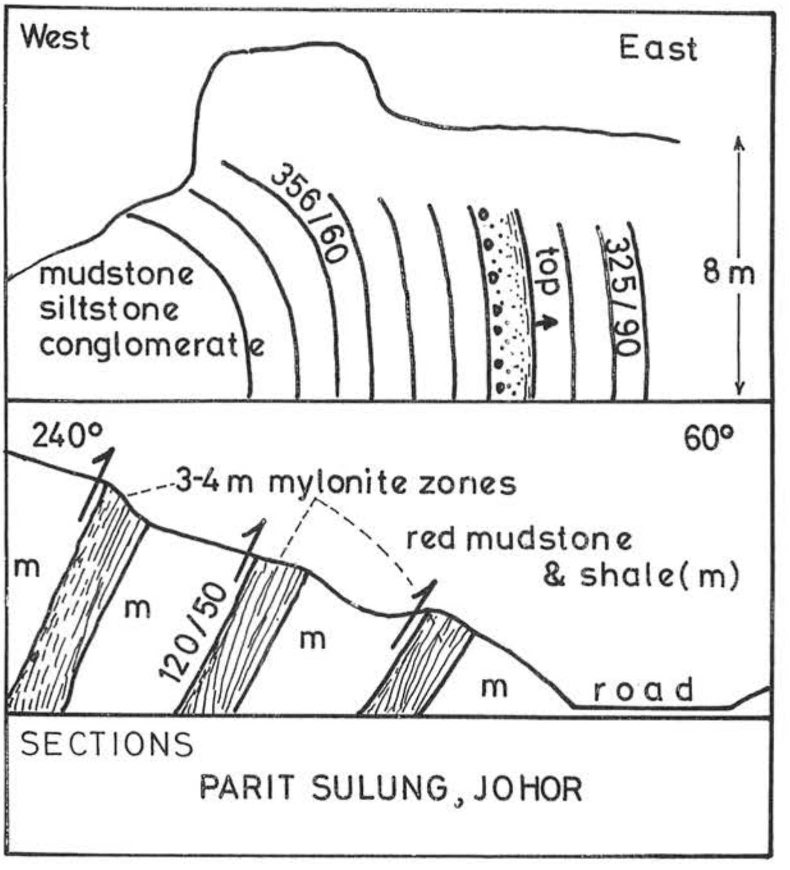

Fig. 15 Two outcrops of M.-U. Triassic reddish clastics near Parit Sulung, Johor. In the upper figure east vergence is suggested by the structure and the grading in a conglomerate bank. Wide zones of mylonite striking 120° represent reverse faulting towards northeast as shown by drag features near the fault zones.

structural patterns are less regular and may be very complex compared with younger patterns. Folded folds and folded axial plane cleavages clearly belong to earlier deformations compared with folds associated with parallel and planar axial plane cleavages. The youngest deformation phase in the peninsula is interpreted to be represented by warps and/or conjugate fracture patterns of which the fracture plans are in upright position. An example of the latter is figure 16 which is a plan view of two zones of en echelon quartz veins striking 35° and 310°, each indicating left and right slip, respectively. The bisectrix of the acute angle between the intersecting zones trends 343° and is interpreted to mark the direction of the maximum principal stress that caused the lateral slip movements. This compression direction is believed to represent the latest deformation phase in the peninsula and was responsible for geologic transport in south to southeast direction (see figure 17).

Figure 17 summarizes the interpreted sequence of geologic transport directions. The oldest that could be determined was eastward and occurs in the Lower Palaeozoic rocks in

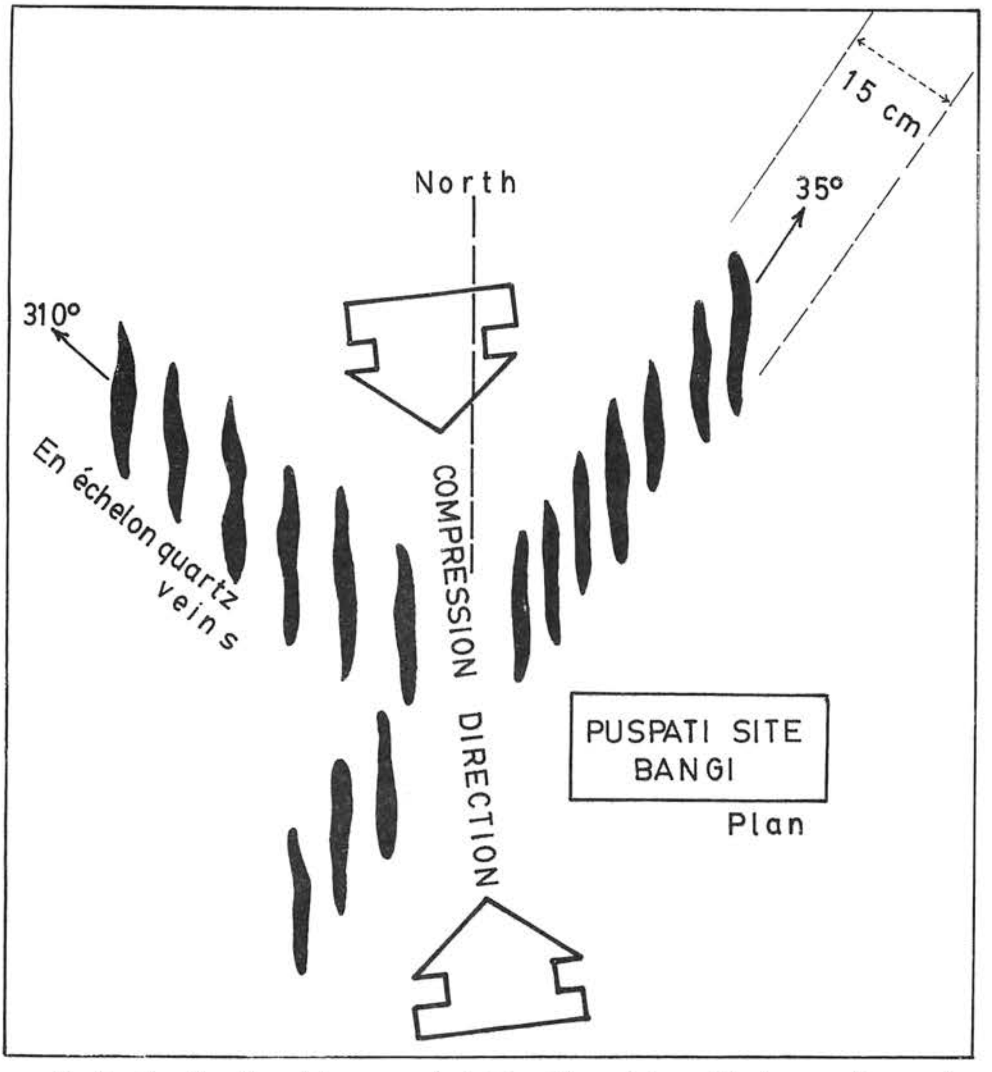

Fig. 16 Plan view of *en echelon* quartz veins in Upper Palaeozoic-Lower Triassic metasediments at the nuclear reactor centre Puspati at Bangi, Selangor. The left and right slips indicated by the *en echelon* intersecting zones were developed through lateral maximum compression in approximately 343° direction. The vertical attitudes of the veins suggest this compression to have occured during the youngest deformation phase that can be recognized in the peninsula.

the Langkawi islands, that is, the Macincang and Setul formations. The next transport direction was southward and is present in Lower as well as Upper Palaeozoic rocks in all four domains. This was superseded by geologic transport in a general westward direction with some variations towards southwest and northwest (see Fig. 17). Evidence for this episode of transport is widespread and occurs in all Palaeozoic to Mesozoic metasediments of the peninsula. The same deformation phase or of younger age then caused in the central and east

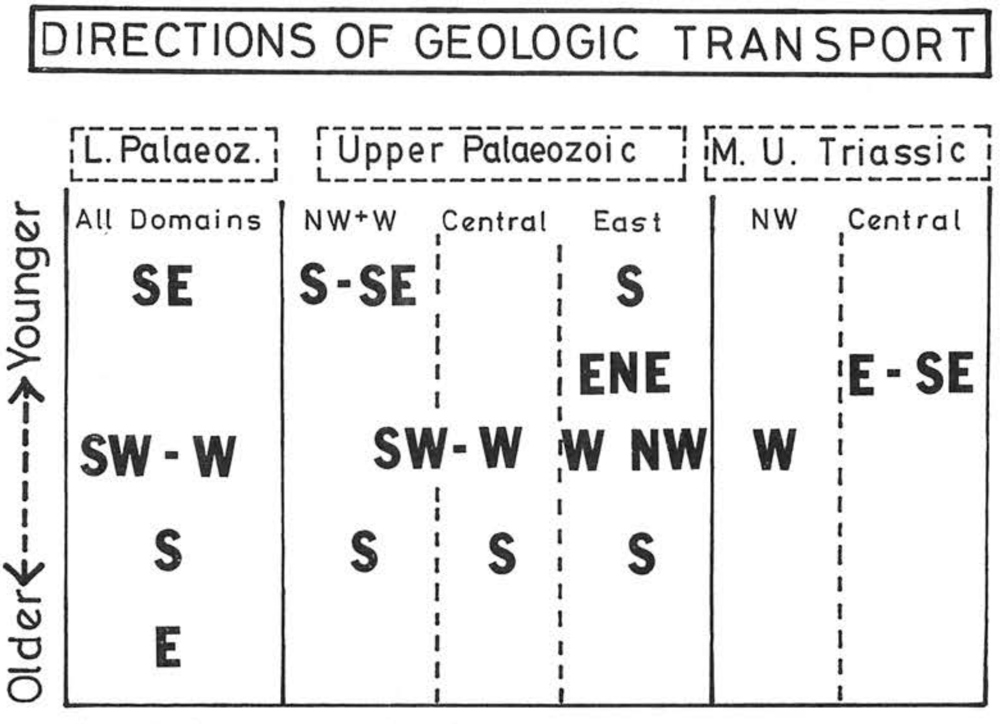

Fig. 17 The interpreted sequence of geologic transport directions that have place in Peninsular Malaysia. The geologic history as known today suggests that the widespread indications for a general westward transport developed during the Late Triassic-Early Jurassic deformation period.

domains geologic transport in a general eastward direction. The affected rocks are of Late Palaeozoic and Middle to Late Triassic ages.

The latest recognizable transport direction was towards south and southeast. This is based on cross-cutting relationships of reverse faults and the existence of north-south maximum compression direction. The latter is shown in figure 16. The former is described by Zaiton Harun and Tjia (in press) from Upper Palaeozoic rocks at Sungai Buah, Selangor. The article cited above describes a metasedimentary packet that was thrusted in southeastward direction upon another metasedimentary series in which west vergence can be determined. In that article the west vergence was interpreted as a youger deformation and the situation at Sungai Buah was interpreted as active underthrusting westward under an older thrust packet that verges southeast. In view of the existence of late southward geologic transport elsewhere in the peninsula, I now subscribe to the interpretation that at Sungai Buah southeastward geologic transport was younger than westward transport.

CONCLUSION

Summaries of geologic transport direction determined in Lower Palaeozoic, Upper Palaeozoic and including Lower Triassic, and Middle-Upper Triassic mtasediments of Peninsular Malaysia are shown on figures 18, 19, and 20. On the figures distinction is made

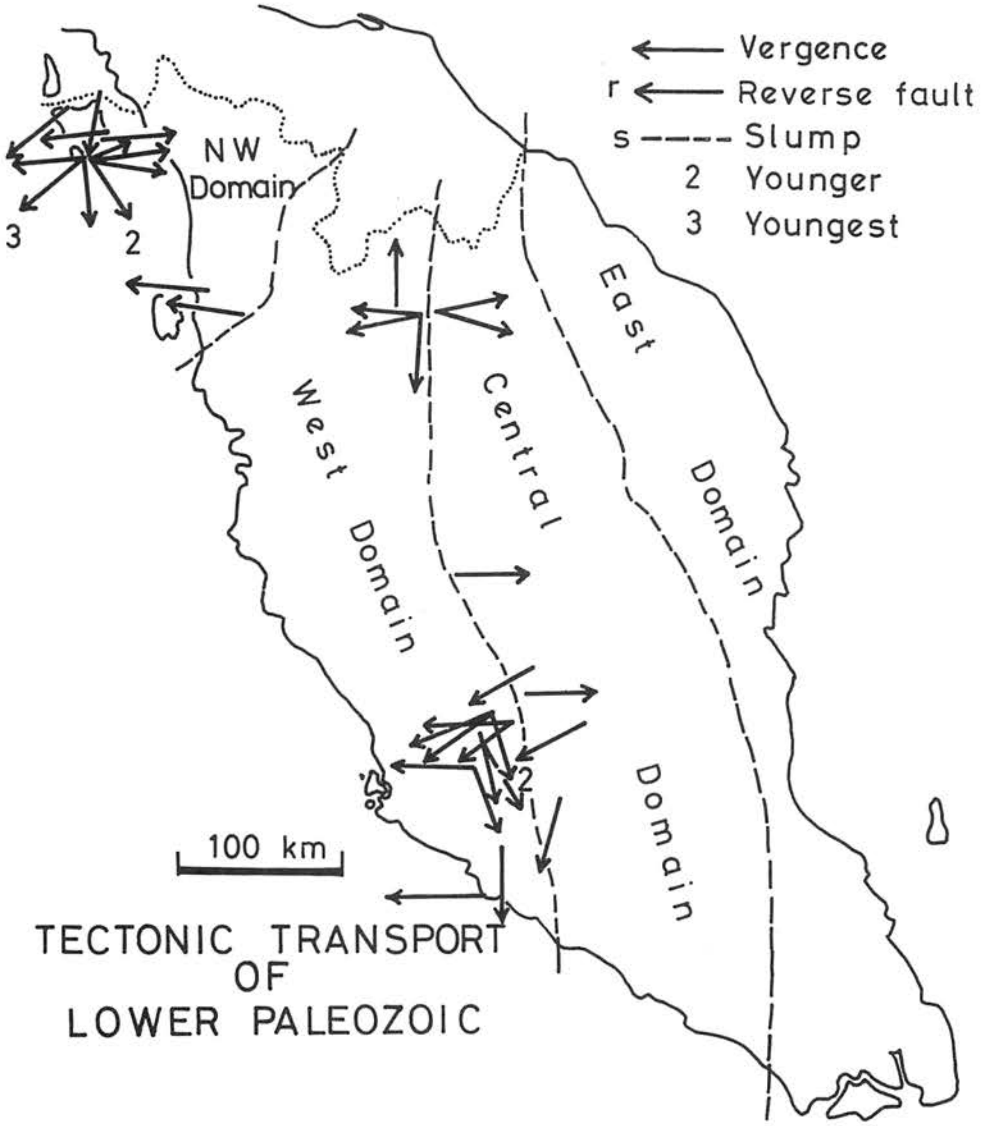

Fig. 18 Geologic transport directions determined from Lower Palaeozoic metasediments.

among slump direction, reverse faulting and vergence. Slump directions may be different from tectonic transport directions. Reverse faulting can cause transport in opposed directions during the same deformation period. Vergence is used to indicate that the geologic transport direction was determined through fold asymmetry, recumbent folds, and low-angle reverse faults. Sometimes it was possible to interpret which of the transport directions were younger (indicated by 2) or latest (indicated by 3).

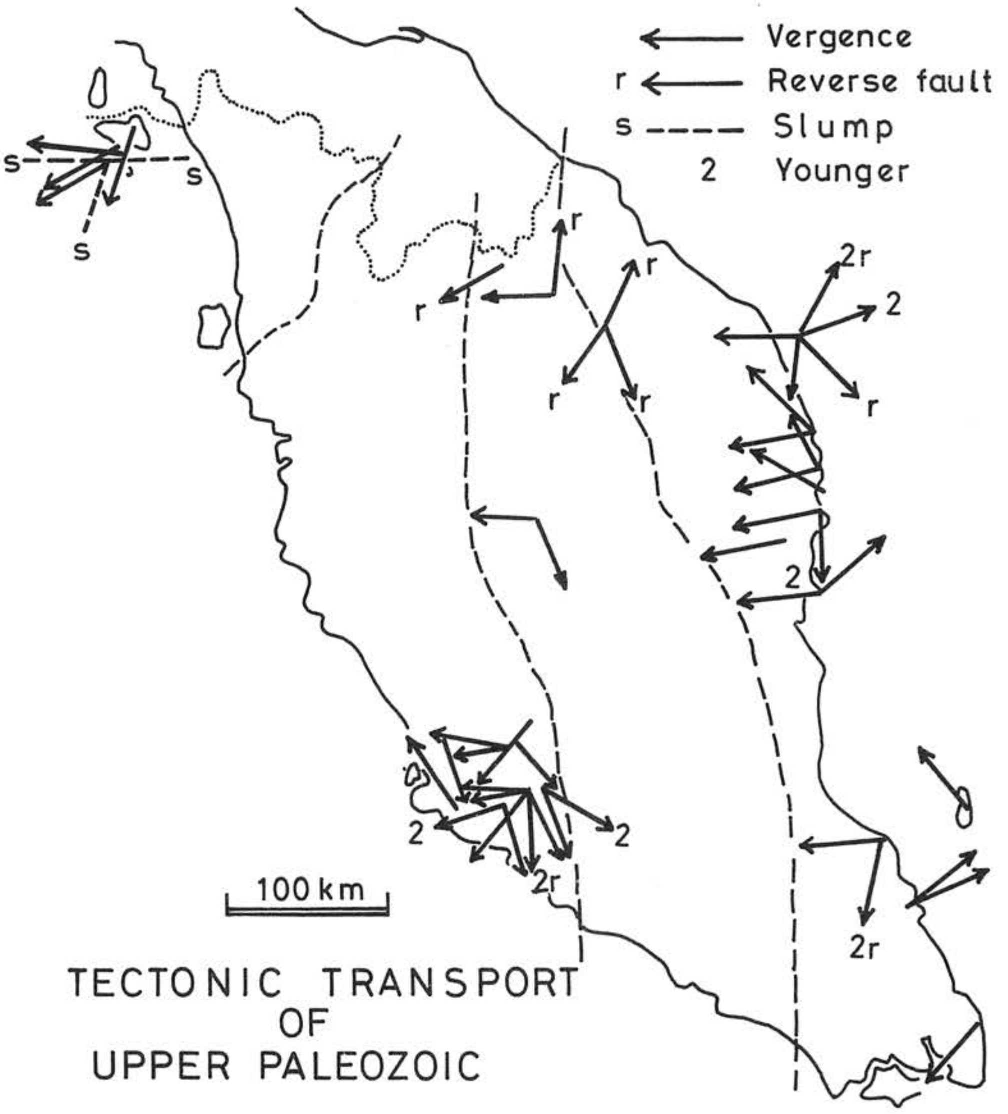

Fig. 19 Geologic transport directions determined from Upper Palaeozoic metasediments (including those of the Lower Triassic).

Figure 17 shows that transport in a general westward direction is widespread in the peninsula. In plate tectonic terms, this may reflect eastward subduction (Fig. 1.5) in post-Triassic time or more probably even before the Triassic. The east vergences are less common and may be interpreted as manifestations of asymmetrical folds on the west flanks of anticlinoria (Fig. 1.1), or as a result of plate collision as depicted in figure 1.3. A fourth possibility exemplified by Fig. 1.6 or obduction is not supported by our geologic knowledge

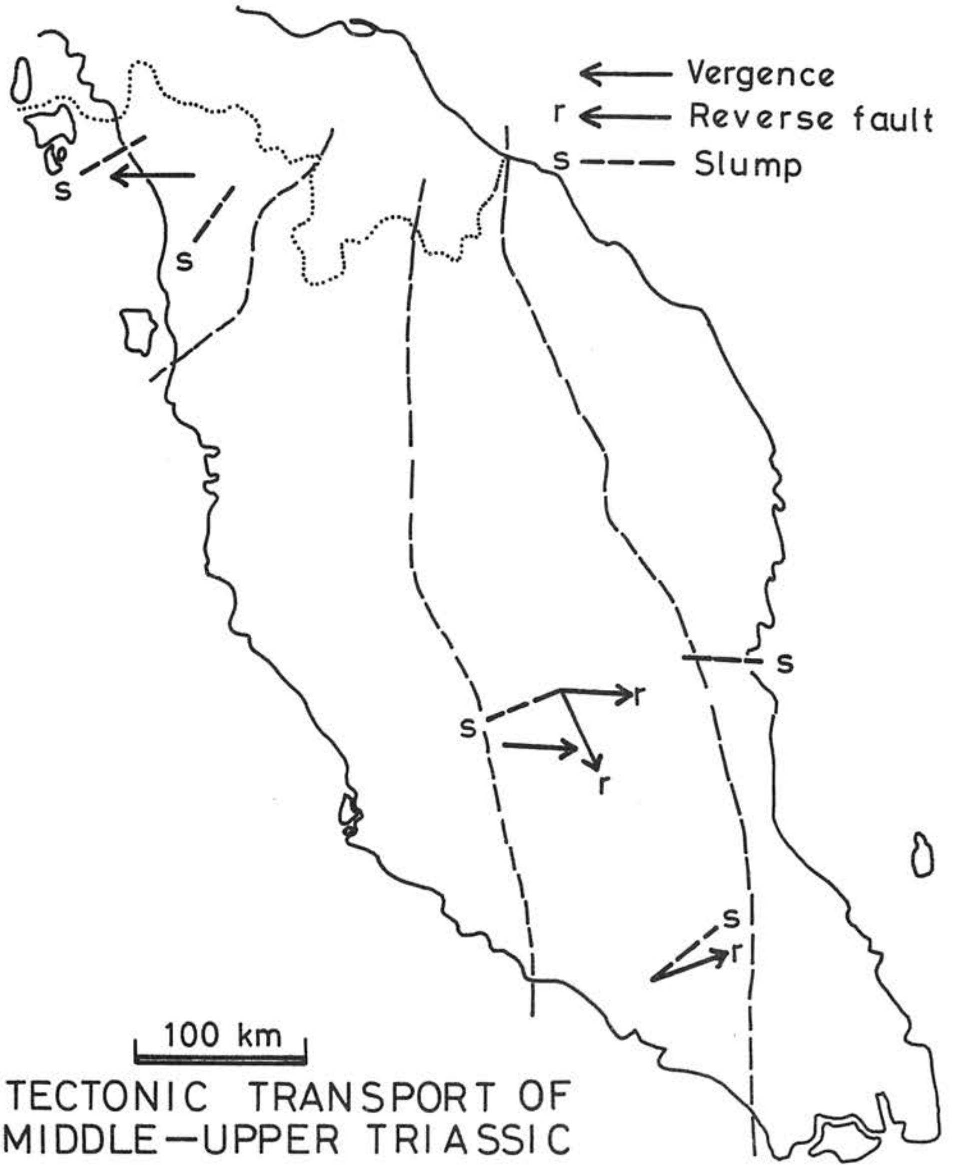

Fig. 20 Geologic transport directions determined from Middle-Upper Triassic metasediments.

of the peninsula. The geological situation shown by Fig. 1.2 seems applicable to the slump folds in the Semantan Formation of the central domain. The east vergences of metasediments on the west side of the Main Range along the East-West highway and at Simpang Pulai, Kampar, Tanjung Malim may be satisfactorily explained as the situation shown by Fig. 1.1.

The common occurrence of south to southeast vergences during two deformation periods poses an intriguing problem. Unidirectional vergence such as this may have developed in geological settings shown in figures 1.3 (to a certain extent), 1.4, 1.5 and 1.6. Based on current geologic knowledge of the peninsula, the geologic settings of figures 1.5 and 1.6 for southerly vergence cannot be considered, unless the peninsula rotated at least three times in the following manner. The rotations are relative to a plate boundary having the attitude parallel to the present junction between the Indian Ocean plate and the Eurasian plate off Sumatra. In the earliest situation the peninsula was positioned approximately normal to that plate boundary. A counterclock wise rotation of about 90° took place; in that position westward geologic transport was achieved in all four domains. This was followed by clockwise rotation of about 90°; in that position the peninsula's axis is again normal to the plate boundary and the latest geologic transport normal to the peninsular grain took place. After this was achieved, the peninsula rotated once more clockwise some 90 degrees and attained its present position.

At present, it seems more likely to interpret that the southerly vergence in Peninsular Malaysia is in some way related to continental accretion of the Indosinian massif. This line of thought will be pursued in another paper.

REFERENCES

ALEXANDER, J.B.,1968. The geology and mineral resources of the neighbourhood of Bentong, Pahang, and adjoining portions of Selangor and Negeri Sembilan. *Geol. Surv. West Malaysia, District Mem. 8*, 250 p.

AW P.C., 1977. Peninsular Malaysia – Western, Central and Eastern basins. *Atlas of stratigraphy*, IGC Project No. 32, p. 1-12.

BEAN, J.H., 1977. Geology, petrography, and mineral resources of Pulau Tioman, Pahang. *Geol. Surv. Malaysia, Map Bull. 5*, 92 p.

BRADFORD, E.F., 1972. The geology and mineral resources of the Gunong Jerai area, Kedah. *Geol. Surv. Malaysia, District Mem. 13*, 242 p.

BURTON, C.K., 1970. The geology and mineral resources of the Baling area, Kedah and Perak. *Geol. Surv. Malaysia, District Mem. 12*, 150 p.

COURTIER, D.B., 1974. The geology and mineral resources of the neighbourhood of the Kulim area, Kedah. *Geol. Surv. Malaysia, Map Bull. 3*, 50 p.

DENNIS, J.G., 1967. International tectonic dictionary. *Am. Assoc. Petroleum Geolgists, Mem. 7*, 196 p.

FATEH CHAND, 1978. The geology and mineral resources of the Ulu Paka area, Trengganu. *Geol. Surv. Malaysia, District Mem. 16*, 124 p.

FITCH, F.H., 1952. The geology and mineral resources of the neighbourhood of Kuantan, Pahang. *Geol. Surv. Dep. Fed. Malaya, District Mem. 6*, 144 p.

FOO, K.Y., 1983. The Palaeozoic sedimentary rocks of Peninsular Malaysia – stratigraphy and correlation. *Proc. Workshop on Strat. Correl. of Thailand and Malaysia, Vol. 1*, p. 1-19.

GOBBETT, D.J. and C.S. HUTCHISON, 1973. *The geology of the Malay Peninsula*. New York, John Wiley, 438 p.

HOSKING, K.F.G., 1977. Known relationships between the "hardrock" tin deposits and the granites of Southeast Asia. *Geol. Soc. Malaysia, Bull. 9*, p. 141-157.

HUTCHISON, C.S., 1977. Granite emplacement and tectonic subdivision of Peninsular Malaysia. *Geol. Soc. Malaysia, Bull. 9*, p. 187-207.

INGHAM, F.T. and E.F. BRADFORD, 1960. The geology and mineral resources of the Kinta valley, Perak. *Geol. Surv. Dep. Fed. Malaya, District Mem. 9*, 347 p.

JAAFAR AHMAD, 1976. The geology and mineral resources of the Karak and Temerloh areas, Pahang. *Geol. Surv. Malaysia, District Mem. 15*, 138 p.

JAAFAR AHMAD, 1980. The geology and mineral resources of the Sungai Teris area, Pahang. *Geol. Surv. Malaysia, District Mem. 18*, 148 p.

JONES, C.R., 1966. Pulau Langkawi (geological map 1:63,360). Geol. Surv. Malaysia.

JONES, C.R., 1970. The geology and mineral resources of the Grik area, upper Perak. *Geol. Surv. West Malaysia,. District Mem. 11*, 144 p.

KARIG, D.E., SUPARKA S., G.F. MOORE and P.E. HEHANUSSA, 1978. Structure and Cenozoic evolution of the Sunda Arc in the central Sumatra region. *Am. Ass. Petroleum Geologists. Mem. 29*, p. 223-237.

KIMURA, T. and C.R. JONES, 1967. Geological structures in the northeastern and southern parts of the Langkawi islands, northwest Malaya. *Geol. Palaeont. SE Asia, Vol. 3*, p. 123-134.

KOOPMANS, B.N., 1965. Structural evidence for a Palaeozoic orogeny in northwest Malaya. *Geol. Mag., Vol. 102*, p. 501-520.

LIM, P.L. and H.D. TJIA, 1979. The Genting thrust belt at Genting Sempah, Selangor. *Sains Malaysiana, Vol. 8* (2), p. 125-146.

RICHARDSON, J.A., 1950. The geology and mineral resources of the neighbourhood of Chegar Perah and Merapoh, Pahang, Malaya. *Geol. Surv. Dep. Fed. Malaya, District Mem. 4*, 162 p.

ROE, F.W., 1951. The geology and mineral resources of the Fraser's Hill area, Selangor, Perak and Pahang, Federation of Malaya, with an account of the mineral resources. *Geol. Surv. Dep. Fed. Malaya, District Mem. 5*, 138 p.

ROE, F.W., 1953. The geology and mineral resources of the neighbourhood of Kuala Selangor and Rasa, Selangor, Federation of Malaya, with an account of the Batu Arang coalfield. *Geol. Surv. Dep. Fed. Malaya, District Mem. 7*, 163 p.

TAN, B.K., 1981. On the supposed existence of the Kisap thrust in the Langkawi islands, northwest Peninsular Malaysia. *Geol. Soc. Malaysia, Bull. 14*, p. 127-133.

TJIA, H.D., 1974., Sesaran sungkup dan canggaan bertindan, kawasan Kuala Dungun, Trengganu. *Sains Malaysiana, Vol. 3*, p. 37-66.

TJIA, H.D., 1976. Isoclinal to recumbent folds and thrust faults in Selangor. *Sains Malaysiana, Vol. 5* (1), p. 49-65.

TJIA, H.D., 1978a. Structural geology of Peninsular Malaysia. *Proc. Third Region. Conf. Geol. Miner. Resour. SE Asia*, Bangkok, 1978, p. 673-682.

TJIA, H.D., 1978b. Multiple deformations at Bukit Cenering, Trengganu. *Bull. Geol. Soc. Malaysia No. 10*, p. 15-24.

TJIA, H.D., 1979. Westward tectonic transport of Kenny Hill rocks at Bukit Pantai, Kuala Lumpur. *Sains Malaysiana, Vol. 8* (2), p. 153-161.

TJIA, H.D., 1982. Disharmonic folds at Tanjung Mat Amin, Trengganu. *Warta Geologi, Vol. 8* (6), p. 258-259.

TJIA, H.D., 1983. Canggaan bertindan di Tanjung Gelang, Pahang. *Sains Malaysiana, Vol. 12* (2), p. 101-117.

TJIA, H.D., 1984a. A case of cross folding in Kenny Hill beds of Kuala Lumpur. *Sains Malaysiana, Vol. 13 (1)*, p. 131-136.

TJIA, H.D., 1984b. Multidirectional tectonic movements in the schist of Bentong, Pahang. *Warta Geologi, Vol. 10 (5)*, Sept-Oct 1984.

TJIA, H.D., 1984MS. *Geologi Formasi Macincang*. Universiti Kebangsaan Malaysia, Laporan penyelidikan No. 104/83 (unpublished).

TJIA, H.D., 1985. Gaya struktur Selat Melaka. *Sains Malaysiana, Vol. 14*.

TJIA, H.D. and ZAITON HARUN, 1983. Regional structures of Peninsular Malaysia. United Nations CCOP-IOC/Seatar, Ninth session, Kuala Lumpur, Nov. 1983; *CCOP-IOC/Seatar (IX0/14)*.

TJIA, H.D. and IBRAHIM KOMOO, 1983. Westward transport of Lower Palaeozoic rocks at Bukit Merah quarry near Butterworth. *Warta Geologi, Vol. 9 (3)*, p. 97-100.

YANCEY, T.E., 1975. Evidence against Devonian unconformity and Middle Palaeozoic age of Langkawi folding phase in northwest Malaya. *Am. Ass. Petroleum Geologists, Bull. Vol. 59*, p. 1015-1019.

YAP, L.S. and B.K. TAN, 1980. Deformation of the Upper Palaeozoic rocks at Tanjong Gelang, Pahang. *Geol. Soc. Malaysia, Bull. 12*, p. 45-54.

YIN, E.H., 1976. Sheet 94, Kuala Lumpur (geological map). Geol. Surv. Malaysia, scale 1:63,360.

ZAITON HARUN, 1981. *Kajian geologi struktur kawasan Bangi-Salak (Selangor-Negeri Sembilan)*. Universiti Kebangsaan Malaysia, MSc thesis (unpublished).

ZAITON HARUN and H.D. TJIA, in press. Overturned folds, superposed thrusts and structural overprints near Sungai Buluh, Selangor. *Geol. Soc. Malaysia, Bull.*

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