

The Bentong Suture in southwest Kelantan, Peninsular Malaysia

H.D. TJIA¹ AND SYED SHEIKH ALMASHOOR²

¹Petronas Research & Scientific Services
Lot 1026 PKNS Industrial Estate
54200 Hulu Kelang

²Department of Geology
Universiti Kebangsaan Malaysia
43600 Bangi

Abstract: A newly constructed dirt road between Kampung Raja, Cameron Highlands, and Pulai, Ulu Kelantan, crosses the Bentong Suture which here is at least 18 km wide. The eastern border zone of the suture consists of bedded chert containing an internal low-angle thrust and is separated from olistostrome to its west along a vertical fault. The western border zone comprises an igneous injection complex — several hundred metres wide — into the schist-phyllite component of the suture. This injection complex is the eastern fringe of the Titiwangsa granitoid complex. Rocks within the suture are thick packets of parallel to subparallel stratified olistostrome (types: with tuffaceous mudstone matrix, with tuffaceous phyllite matrix, and with phyllite matrix), thoroughly weathered, massive tuffaceous mudstone, well-bedded chert, phyllite, phyllite-schist and a serpentinite lens. The olistostromal packets contain bedding-parallel mylonite zones. The general strike is NW-SE; dips are moderately steep to vertical; dip inclinations are towards NE. Reverse faults and low-angle thrusts also indicate SW-vergence. Along two stretches of the road that crosses the suture, low-angle thrusting towards south represents a younger tectonic activity.

The various rock types of the suture seem to occur as at least seven tectonic units. From west to east (or from stratigraphically lower to higher levels) a complete tectonic unit is composed of a systematic sequence of schist and phyllite, olistostrome with or without massive mudstone interval, and bedded chert. The recurring rock sequence in each tectonic unit suggests that the units are stacked rock assemblages or form an imbricated structure, presumably as result of collision between the continental lithospheric plate in the east with a Gondwana continental crustal sliver to the west of the suture. Subduction northeastward appears consistent with dominant southwest vergence that is shown by the outcrops. The tectonic units of the suture proper were probably crustal and supracrustal rocks occupying a marine — very likely oceanic — environment between the colliding continental lithospheric masses. The presence of serpentinite and abundance of volcanogenic material suggest that the particular marine environment also included an island arc.

INTRODUCTION

The Bentong-Raub line (now known as the Bentong Suture zone) was proposed by Hutchison (1973) as the major tectonic boundary between the western and central belts of Peninsular Malaysia. Since its initial recognition as a tectonic line, most researchers have interpreted the suture as a subduction plate-margin mainly on the basis of serpentinite and other metabasic bodies occurring within the zone. On account of the uncertainties about the time of docking, nature of the lithosphere beneath the Central Belt, and subduction-associated volcanism, views were held for subduction westward or in the opposite direction (Hutchison, 1973, 1975; Mitchell, 1977; Bignell and Snelling, 1977). Tan (1981; in Khoo and Tan, 1983) believed that the Bentong zone marked an extensional tectonic line on the west side of the Central belt, while this belt

was interpreted to represent an aborted rift. The relatively minor serpentinite bodies were considered non-representative of supposedly oceanic crustal fragments, and instead were interpreted as small mafic intrusions, as did Hutchison (1977). Harbury *et al.* (1990) supported this rift model and went so far as to consider the granitoid bodies of the Eastern Belt as parts of the Titiwangsa granitoid complex that became separated more than a hundred kilometres by the rifting. Chakraborty (1988) advanced petrogenetic arguments for the absence of subduction processes and proposed that the suture was a dextral transcurrent feature accompanied by mantle rock diapirism.

The discovery of olistostrome and sheared olistostrome near Bentong, Pahang and along the East-West Highway (Metcalf and Chakraborty, 1988; Tjia, 1987, 1989a, 1989b) do not support an extensional origin for the Bentong Suture zone.

Olistostrome is more consistent with collisional plate boundaries. Its origin at a transform fault boundary, as suggested by Chakraborty (1988), is questionable for the lack of large-scale drag features and the fact that shearing had predominantly occurred in subvertical to vertical sense (see descriptions in the above references). However, Tjia (1984) has demonstrated that the *latest detectable* fault movement along part of the Bentong Suture that trends north-south was indeed right-lateral. The apparently conflicting views on the nature of the Bentong Suture held by most authors mentioned above mainly arose from the fact that *at one time or another*, compressional reverse faulting resulting in imbricated structures, lateral fault movements as well as large-scale extensional faulting had occurred. What became confusing was the superimposition of evidence for these varieties of tectonic movements. At the end of this paper, a tectonic synthesis on the suture aims to address its complex history.

Until our study of the Bentong Suture in southwest Kelantan, the following are its salient features. The suture is an approximately 13-km wide zone of deformed rocks and extends from the Thai border near Sungai Tiang southward as far as Karak town, whence its strike changes to SSE until it crosses the coast line between Melaka and Muar. The suture has been interpreted to cross into Central Sumatra and to continue as the south-trending Bengkalis trough until it ends against the Tigapuluh Mountains (Tjia, 1989b). The suture is lithologically divided into pre-Silurian schists in the west adjoining the Titiwangsa mountain range, while its eastern zone consists of lower Silurian to Permian clastics and chert. The Geological Survey of Malaysia has indicated the Bentong Suture rocks as Silurian-Ordovician, and part of the unit in the Bentong area as the Karak Formation. Within the eastern rock unit are small, but mappable occurrences of serpentinite, metabasites, crystalline limestone and red clastic sediments together with up to several hundred metres wide packets of olistostrome alternating with similarly thick packets of non-olistostrome sedimentary and metasedimentary rocks. Within and between the olistostrome and non-olistostrome units are mylonite zones that may reach widths exceeding fifty metres. The Bentong Suture assemblage has been considered an accretionary prism of a subduction zone. Earliest vergence was east to southeast which was consistent with west to northwest-ward subduction. Later vergence in general west direction was considered as a possible result of a flip of the subduction process in the opposite direction (Tjia, 1989a; fossil ages for the Karak Formation are in Jaafar Ahmad, 1976;

fusulinids and conodonts are of Permian age in limestones of Raub, see Chakraborty and Metcalfe, 1987). Detailed descriptions of structures of the olistostrome are in Tjia (1987, 1989a).

In the late eighties, a 60-km long road was constructed connecting the Yakin Tea plantation, Cameron Highlands in Pahang with Pos Blau in southwest Kelantan. Pos Blau is connected by a timber track with Pulai south of Gua Musang. This paper contains geological observations of the road outcrops between Penangau and Pos Blau (Fig. 1). Two thirds of the road's western segment traverse granitoids of the Titiwangsa mountain range, while the remainder exposes subparallel packets of olistostrome and melange alternating with several scores of metres-wide intervals of metasedimentary rocks and a single fault-bounded serpentinite body, probably a 100-metre wide lens. The geographical position of this eastern road segment and the presence of olistostrome and melange coincide with the Bentong Suture zone (inset of Fig. 1). One result of the study in southwest Kelantan is confirmation of the tectonic model of the Bentong Suture as an imbricate assemblage of tectonic units, as one would expect in an accreting prism above a subduction zone (Fig. 2). The suture rocks in SW Kelantan are marked at its western boundary by an injection complex belonging to the Titiwangsa granitoids, while its eastern boundary zone consists of well-bedded chert (Tjia, 1994). Our study did not extend beyond the chert at Pos Blau, that we believe is not far from suture's eastern limit. Each of the schist/phyllite-olistostrome-occasionally also chert sequence that we mapped along the Penangau-Pos Blau road is interpreted as a tectonic unit (Fig. 2). Stacking of the seven tectonic units is thought to have occurred in sequence beginning with unit H and ending with unit A that have built up an accretionary prism above a northeast-ward subducting oceanic plate (see Fig. 19).

DESCRIPTIONS OF OUTCROPS BETWEEN PENANGAU AND POS BLAU

Figure 1 is a geological sketchmap of the road stretch between Penangau and Pos Blau. The outcrops were studied on several visits from 1990 to 1992.

Locality 1

A shear zone, at least 50-metres wide, trending 345°–350° and dipping vertically cuts across medium-grained granitoid. Bundles of shears, each up to several metres wide, alternate with unfractured granitoid. Fault striations on shear planes pitch 10 to 12 degrees in 350°-direction. Accretion steps, accretion spalls, and fault *roche*

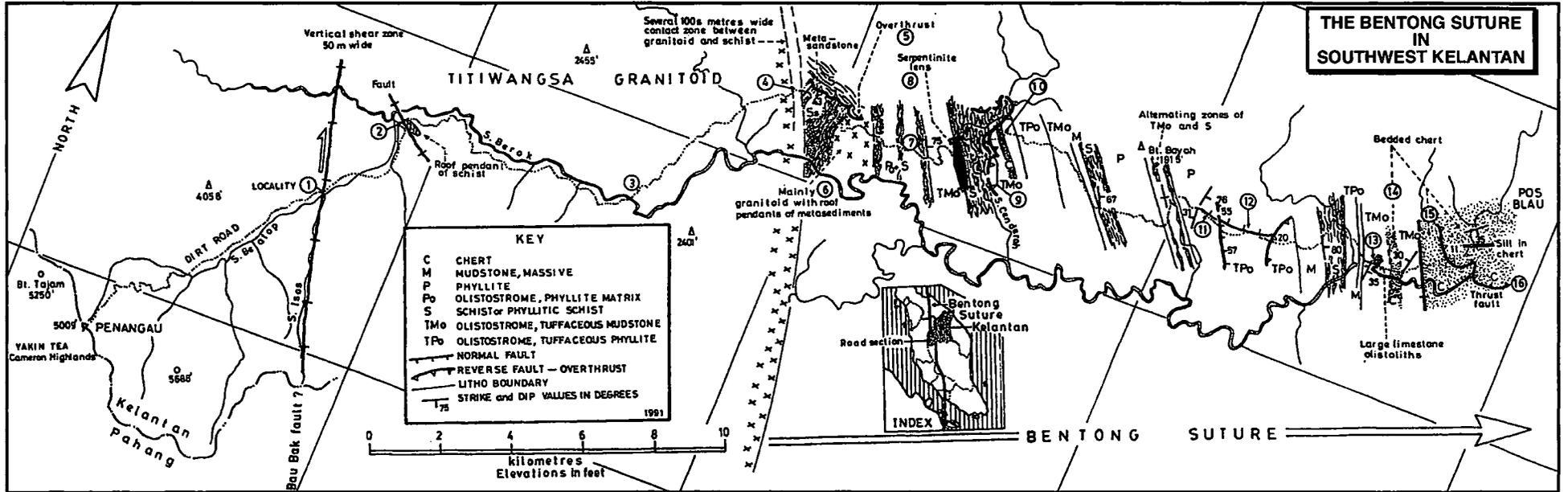


Figure 1. Geological sketchmap of the Bentong Suture in southwest Kelantan. Strike and dip symbols are conventional.

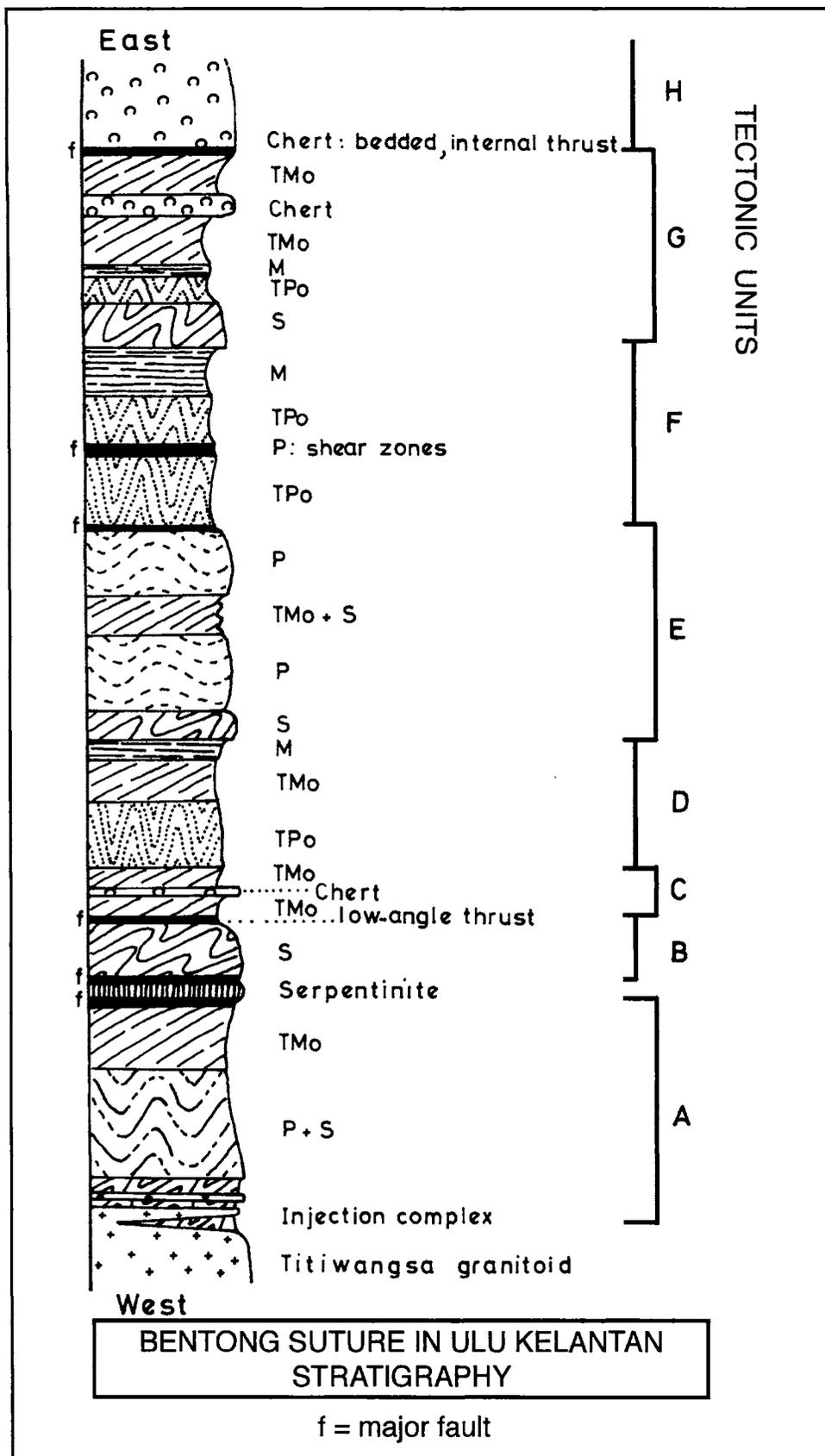


Figure 2. Stratigraphy of the Bentong Suture in southwest Kelantan on the Penangau-Pos Blau road. Seven tectonic units, each consisting of schist/phyllite-olistostrome-non-olistostrome and occasional chert sequences, are stacked, presumably progressively from unit H to unit A in an accretionary prism above a plate subduction northeastward.

moutonnees are the fault-plane markings (see explanation in e.g. Tjia, 1994) that indicate right lateral slip on this shear zone. A segment of the shear zone controls the linearity of the Isos river valley.

Locality 2

In this medium large outcrop, granitoid flanks a metamorphic rock complex consisting mainly of quartzitic metasandstone and hornfels. Several parallel, less than a metre wide mylonite zones (attitude: strike 310° and dip vertical), cut the non-granitoid complex. In addition, the complex is transected by many parallel fractures of which the more significant representatives have the attitudes $60/90$, $75/30$ and $110/90$. The above mentioned mylonite zones occasionally displace the parallel fractures. The metamorphic rock complex represents a roof pendant or a large xenolith in the Titiwangsa granitoid. Smaller metasedimentary xenoliths are exposed in weathered granitoid of other roadcuts nearby.

Locality 3

Over an outcrop distance of about a hundred metres is seen a host of decimetre-wide pegmatite dykes in weathered granitoid. Schorl is a characteristic mineral of the dykes. Some of the dykes are displaced left-laterally for up to 1.1 m by $340/\text{very steep}$ and by $315/90$ faults, and right-laterally by $90/90$ shears. If both lateral displacements were caused by the same deformational phase, the lateral compression acted within the sector $090^\circ\text{--}145^\circ$.

Figure 3 is a lower-hemisphere equal-area plot of the dykes. Poles to the dykes fall into four clusters. These clusters possess systematic angular relationships that could be expected if the fractures, into which the pegmatites intruded, developed in one stress field. We interpret the fractures to have resulted from lateral compression along NNE-SSW direction and, subsequently the fractures together with the host rock experienced tilting 15 to 20 degrees towards SSW. The interpreted lateral compression direction is approximately perpendicular to the general strike of the major structures in this area. The lateral slips demonstrated by the faulted pegmatite dykes suggest another maximum lateral stress in a direction normal to above interpreted regional compression direction. This second stress field probably resulted from relaxation of the regional compression, and thus a rearrangement of the maximum and minimum principal stress directions.

Locality 4

Over a distance exceeding 200 metres in the direction perpendicular to the general NW-SE structural trend are outcrops of weathered granitoid alternating with schist and phyllite intervals. The metasedimentary rocks are sometimes laced by networks of quartz veins. The granitoid bodies may be in the form of sills, dykes, or irregular shapes. The pegmatite dykes strike 210° and dip 65° to the northwest.

The schist and phyllite intervals are considered to belong to the Bentong Suture. Its degree of metamorphism was enhanced by the granitic intrusions of the Titiwangsa igneous complex, that was dated to have occurred mainly in late Triassic-early Jurassic (see review by Cobbing *et al.*, 1992).

Locality 5

The curving roadcut at this locality exposes a section across the frontal part of a 2–3 metres thick overthrust zone that is a complex of discrete low-angle fault planes (Fig. 4). The appearance of the overthrust zone in the outcrop is that of stacked lensoid rock portions, each bounded by fault planes. Individual faults strikes and dips $260/17\text{--}19$ and $275/22$. The hanging wall and overthrust zone consist of phyllite-schists, whereas the foot wall is made up of massive-bedded sandstone. An isoclinal antiform, probably a drag fold, in the hanging wall immediately above the overthrust zone has $260/10$ axis, suggesting tectonic transport perpendicular to it and most probably towards south. Figure 4 also shows a small part of the overthrust zone as "bleached", possibly by hydrothermal activity.

Locality 6

Locality 6 comprises a 3-km long road stretch which exposes weathered granitoid that is intermittently interrupted by intervals of metasedimentary rocks. In the latter, bedding can still be observed.

Farther eastward, the road stretch up to locality 7 consists of foliated phyllite and schist (Fig. 1).

Locality 7

Olistostrome and melange are exposed at various intervals between locality 7 and the bedded chert near Pos Blau (Fig. 1).

At locality 7, large (in the metre range) and smaller olistoliths consisting of light coloured tuff, quartzite (mainly rounded), and metasandstone are embedded in a groundmass of tuff, tuffaceous siltstone or tuffaceous mudstone. Packets of olistostrome (with internally chaotic arrangement

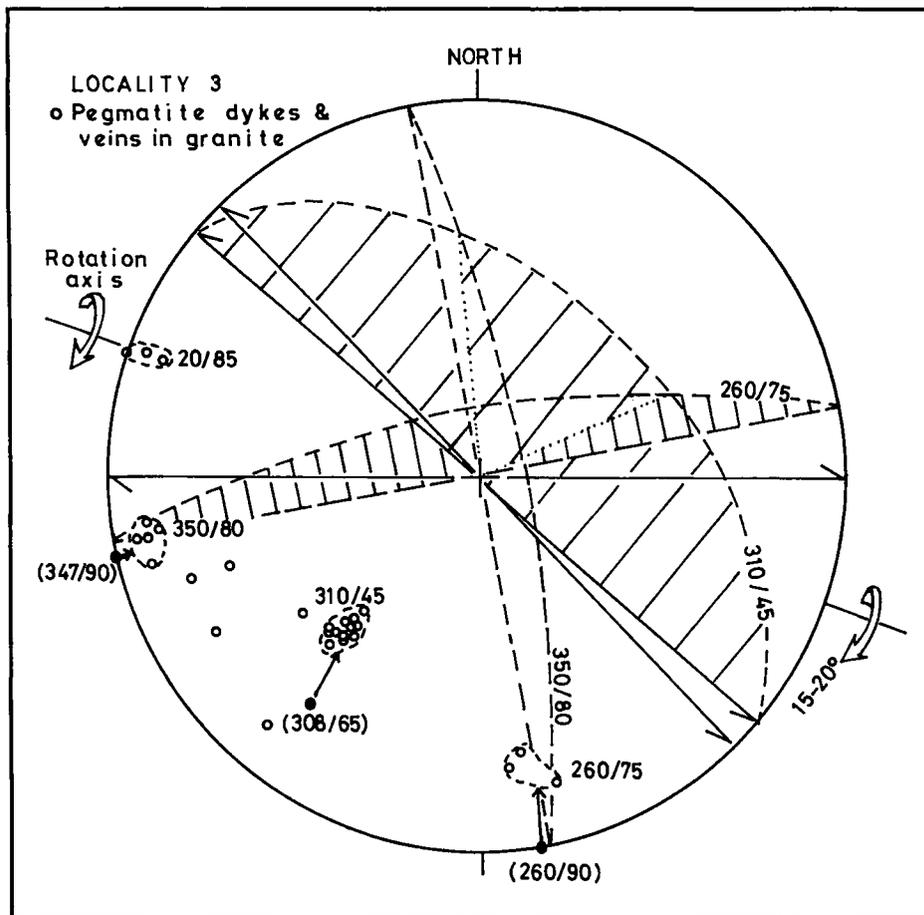


Figure 3. Equal-area plot, lower hemisphere, of dykes and veins of pegmatite in granitoid. Locality 3. Interpretation in the text.

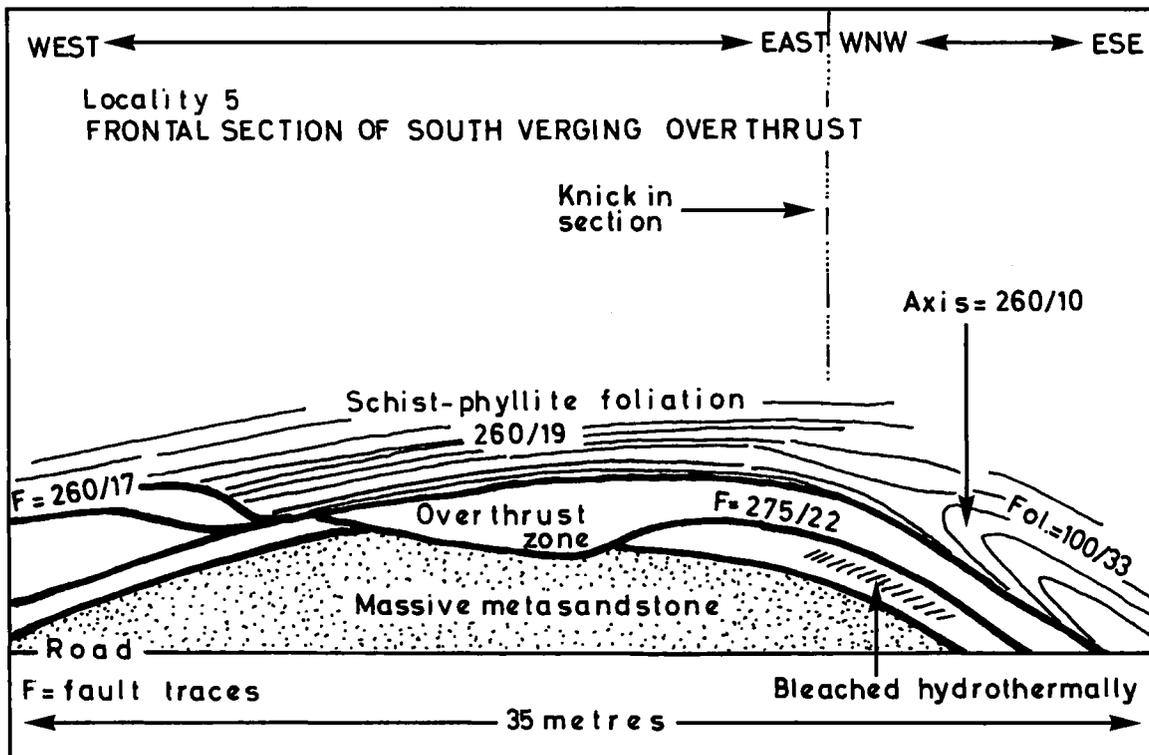


Figure 4. Overthrust zone at locality 5. Schist-phyllite in the hanging wall, massive sandstone in the footwall. Tectonic transport southward. Explanation in the text.

of olistoliths, bedding or foliation) alternate with thick intervals of regularly bedded tuffaceous clastics and/or bedded chert (Fig. 5a) On their east sides, a few olistoliths sag into steeply inclined foliations of the matrix. These are interpreted to indicate that stratigraphic bottom is towards east. Sometimes a highly disturbed zone separates an olistostrome packet from the adjacent packet of regularly bedded rocks. The disturbed zones probably represent tectonic shear zones or glide planes due to slumping. Some of the olistostromes are tectonic melanges, occupying widths of up to 50 metres, with sheared matrix and olistoliths appearing streamlined, probably through shearing. Figure 6 shows olistostrome with sheared phyllitic groundmass. The large olistolith of tuffite is about 40 cm long.

Locality 8

A hill of serpentinite at this locality is about seventy metres wide at road level (Figs. 5b and 7a). Phyllitic schist forms the hanging wall and is separated from serpentinite by a 3-metre thick zone of fault breccia of attitude 140/25. On the NE side, the serpentinite is separated by a sharply defined fault, striking 106° and dipping 82°, from brown phyllitic schist, that strikes 78–90° and dips about 34°. Foliations of the serpentinite are 55/80 and 130/80, the latter representing the dominant attitude. We have not mapped the extent of the serpentinite, but in accordance with other such bodies in the Bentong Suture, we believe that this particular serpentinite body is also of lenticular shape parallel to the general strike, but cut off by

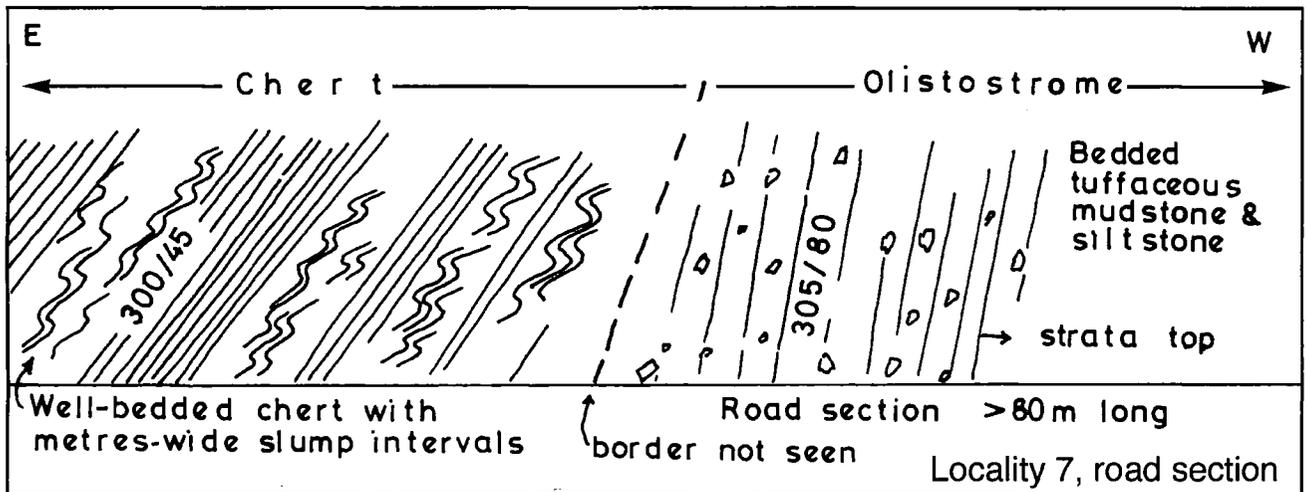


Figure 5a. General situation of olistostrome and chert sequences in the vicinity of locality 7. Note the conformable strikes although dips may be different. The border is believed to consist of wide fault zones now eroded into valleys.

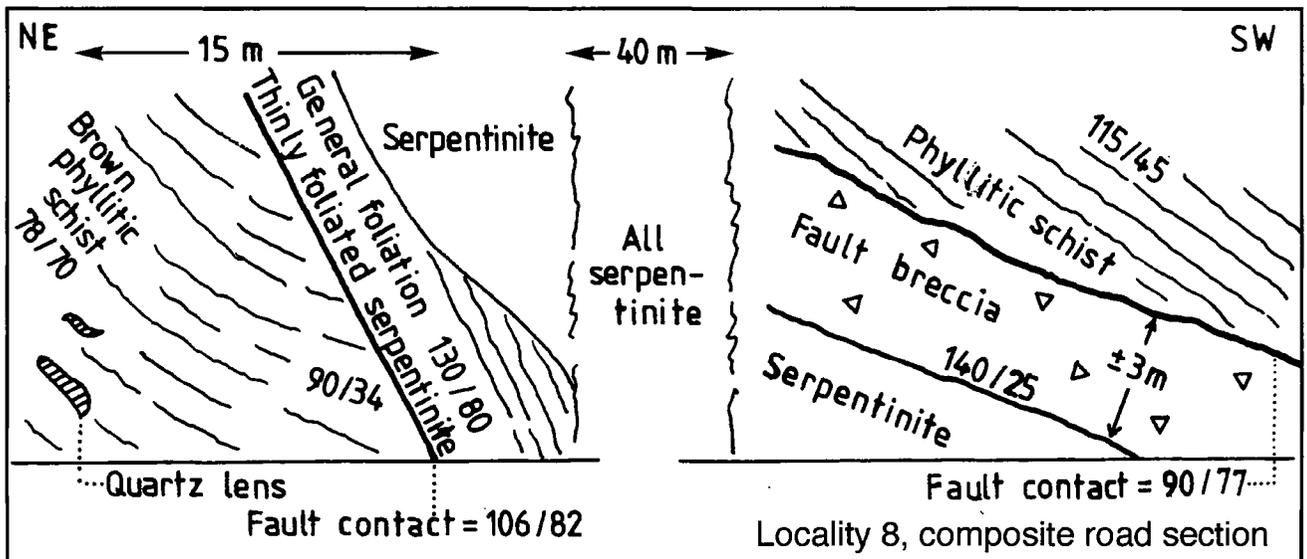


Figure 5b. Field relation of the serpentinite lens near Sungai Cenderoh, locality 8. Explanation in the text.



Figure 6. A large (40 cm long) tuffite olistolith in phyllitic olistostrome near locality 7.

steeply south-dipping E-W faults. Drag in the schist of the hanging wall (Fig. 5b) suggest reverse faulting (Fig. 7b). Locally antigorite fibres form centimetres-wide seams within the rock.

On an equal-area plot we found that most faults within the serpentinite body strike approximately east-west, dipping vertically or south at moderately steep angles (50°). Fault markings (accretion spalls and gouge marks) indicate reverse motion; thus tectonic transport was northward.

Locality 9

The long outcrop at locality 9 shows olistostrome of tuffaceous mudstone-sandstone matrix that is folded into overturned and recumbent folds resting upon mylonitic olistostrome with internal convolute structures (Figs. 8 and 9). The boundary between the two structural units is also folded into narrow overturned antiforms alternating with relatively wide synforms. The general appearance is that of drag folds resulting from tectonic transport towards southwest. The same vergence is indicated by the patterns of folds in the upper olistostrome unit. The mylonitic olistostrome represents a low-angle reverse fault zone that according to its phyllonite foliation has the general attitude of $310/20$. The olistoliths in the upper unit are angular and comprise tuff sandstone, tuffite, silicified tuffite, tuffaceous mudstone, phyllitic tuff, quartz sandstone, quartzite, laminated siltstone, light coloured as well as reddish chert. Most of these types also occur within the mylonitic olistostrome

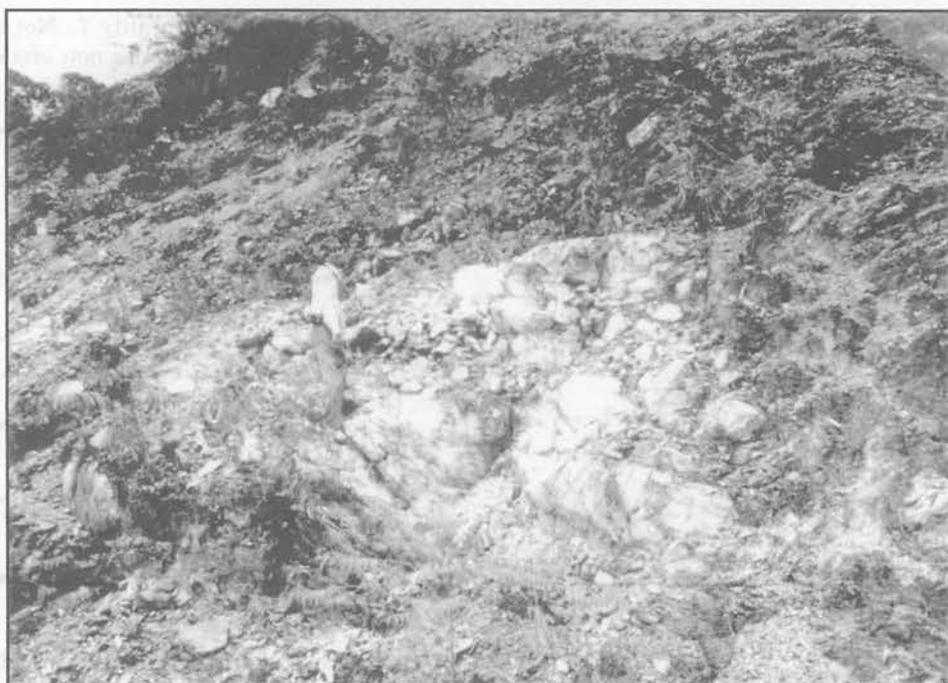


Figure 7a. The core of the serpentinite lens at Locality 8 is light coloured.

of the lower unit; and in addition its matrix contains streaks of black mylonite.

On the NE end of the road exposure is a set of high-angle faults striking 325° and inclined $50\text{--}55^\circ$ towards NE. One of these faults separates the folded olistostrome unit — presumably also the lower unit of mylonitic olistostrome that is not exposed there — from undeformed olistostrome farther to the northeast. Drag features adjacent to this particular fault suggest reverse motion. On two of the surfaces of these high-angle faults are minor fault markings that indicate a later phase of motion as left-lateral faults.

Interpretation. The low-angle reverse fault zone consisting of mylonitic olistostrome developed

penecontemporaneously with the olistostrome. The high-angle reverse faults at the NE side of the outcrop represent a later tectonic activity, whereas the left-lateral slip is the youngest detectable fault motion in this outcrop.

Locality 10

Figure 10 shows structures in a roadcut a few hundred metres farther towards Pos Blau from Locality 9. The rocks are tuffaceous mudstone containing olistoliths of chert and metasedimentary clastics plus brownish soil. The general impression is that of a NE-inclined assemblage of olistostrome slabs with subsidiary overturned and isoclinal folds, intercalated with rock that has completely weathered into brown soil. The structures appear to be drag folds on a limb of a larger overturned fold. The brown soil may represent thoroughly weathered fine-grained tuff. A similar looking soil near Locality 11 has faint laminae that together with the fineness of the partly decomposed rock could represent tuff. Here at Locality 10, most contacts between the brown soil and olistostrome



Figure 7b. A photograph taken at an oblique direction (camera pointing towards east) to the roadcut at the SW end of the serpentinite exposure (see Fig. 5b), which exhibits the nature of the fault contact between serpentinite (left) and phyllitic schist. Book (height = 15 cm) lies on the fault contact. Lighter coloured patch immediately to the left of the book is debris. Drag foliations of the phyllitic schist adjacent to the fault plane implies a reverse fault. The fault strikes 90° and dips 77° to the south (right).



Figure 8. Mylonitized olistostrome in the low-angle reverse fault zone at Locality 9. High-oblique view onto the mylonite zone.

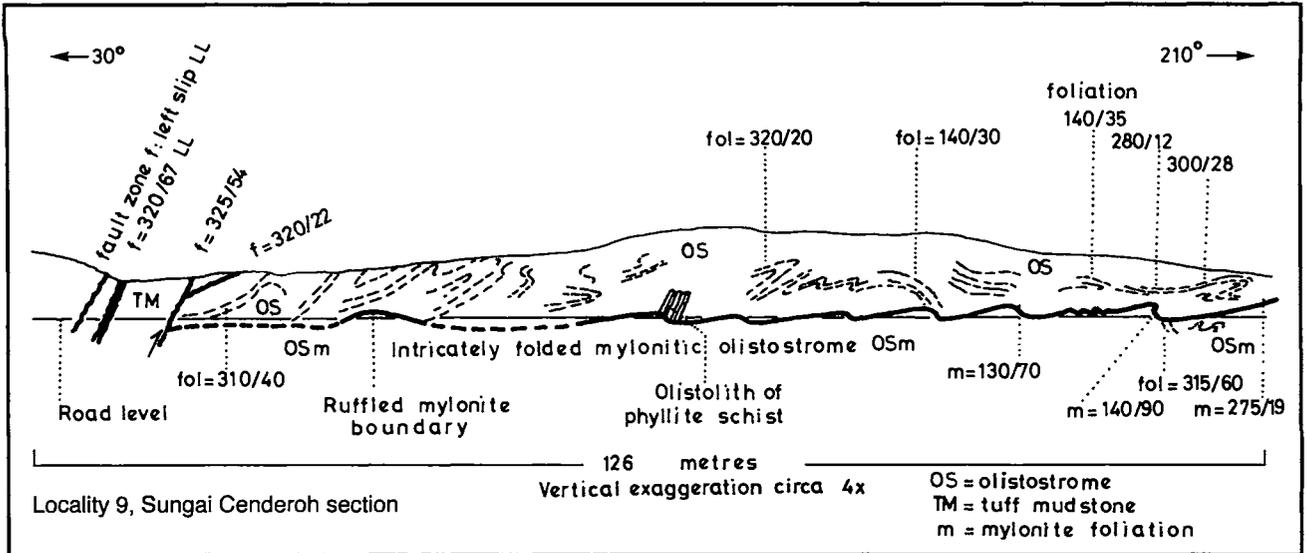


Figure 9. Low-angle thrust fault verging southwest at locality 9. Overturned folds in olistostrome of the hanging wall; mylonitic olistostrome in the upper part of the footwall; drag folds mark the top surface of the mylonite and also indicate sense of tectonic transport.

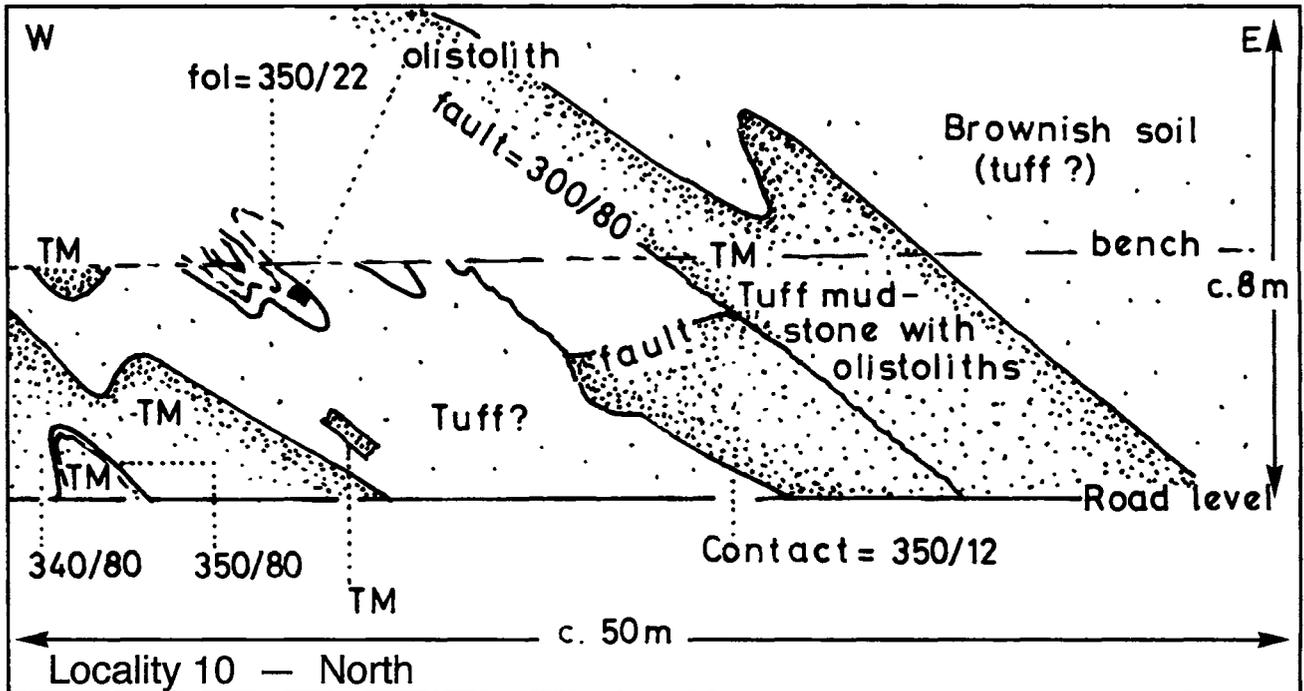


Figure 10. Drag-folded, alternating tuffaceous olistostrome and weathered tuff(?) layers near locality 9 indicate southwest transport direction. See text.

slabs are conformable, but one or two cross cutting relationships are also seen. Therefore, we do not rule out the possibility that the brown soil in this outcrop represents weathered igneous intrusions.

Figure 10 further shows that tectonic vergence is southwest, consistent with that deduced from locality 9.

Locality 11

The rock is foliated and deformed tuffaceous phyllite (Fig. 11a). In places, silicified clasts of tuffite(?) may represent metamorphosed olistoliths. The clasts are elliptical and often contain streaks of black material. The sparse and relatively small

clasts of limited lithological variation suggest the original deposit to be a diamict. Secondary quartz occurs as veins and broad lenses. A beta-pole plot of the few foliations measured in the field suggests an about 20° north-inclined fold axis that appears superimposed upon earlier developed east-west folds.

A kilometre farther towards Pos Blau is the outcrop shown in Figure 11b. The rock is an olistostrome with phyllitic groundmass. Regularly foliated phyllite in the west is separated by a major fault zone (attitude 325/57) from folded phyllite in the east. The western two thirds of the fault zone consist of phyllite slabs of internally variable

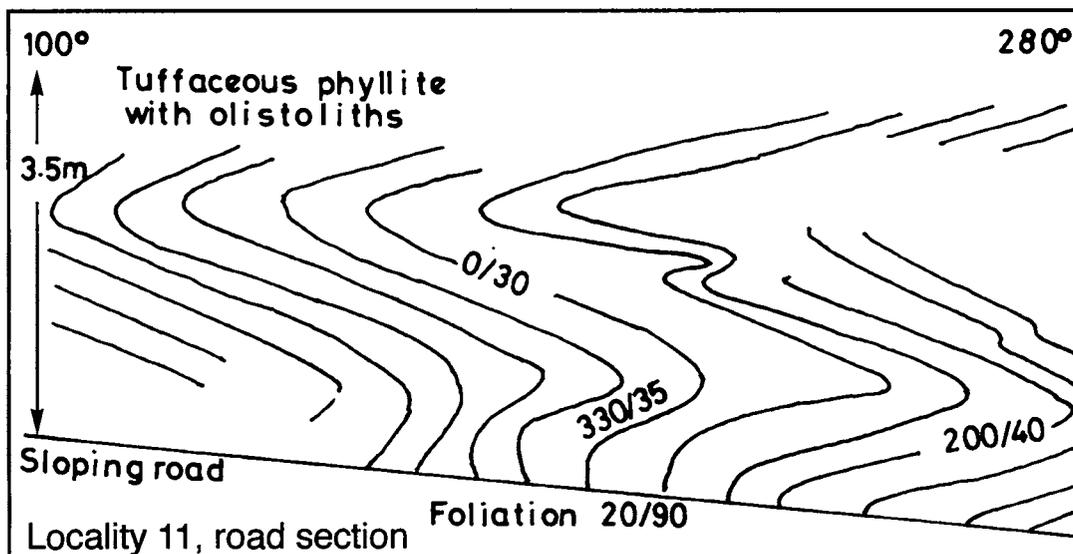


Figure 11a. Fold style in tuffaceous phyllitic olistostrome at locality 11.

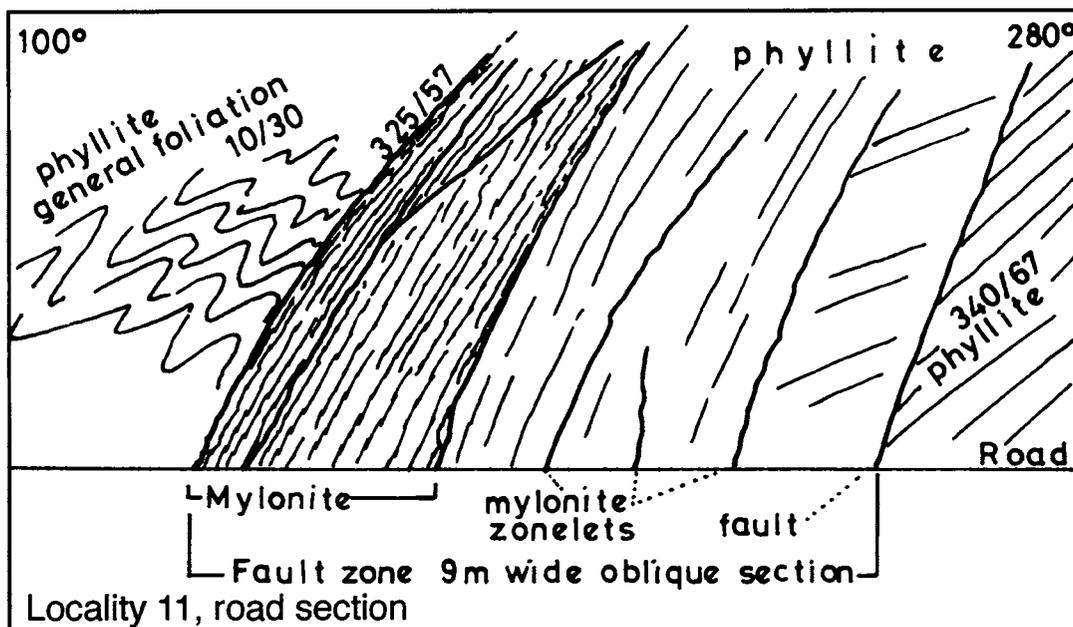


Figure 11b. Phyllite sequences of different structural styles are separated by a wide zone of mylonite and phyllite containing widely spaced mylonite seams. Locality 11.

foliation separated from each other by thin mylonite seams that are parallel to the main fault zone. The eastern one-third consists of well-developed mylonite. The olistoliths are up to 0.6 m long, of rounded to subrounded shapes, and consist of greywacke, metasandstone, crystalline schists, and quartzite. The general foliation is 330/60–70, which is roughly parallel to the bounding faults.

In the vicinity of locality 11 also occurs olistostromal schist together with olistostromal tuffaceous phyllite.

Locality 12

Locality 12 consists of olistostrome with tuffaceous phyllite matrix that contains a number of reverse fault zones represented by mylonite. Each fault zone is generally between 10 and 30 metres thick. They are separated from one another by unfractured olistostrome, generally between 15 and 30 m wide, but hardly in excess of 60 m. The phyllite matrix and the confining reverse faults exhibit nearly the same strike, i.e. $340^{\circ} \pm 15^{\circ}$, although the dip readings of the faults are steeper (50° to 75°) and that of the phyllite matrix are confined within wider limits (40° to 85°). The olistoliths are commonly tuffaceous mudstone or siltstone. Figure 12 shows a drag fold in olistostrome with tuffaceous matrix on the hanging wall side of a wide fault zone at Locality 12.

Slip faults with small degrees of reverse movements were also seen. They commonly strike between northeast and north-northeast directions.

One right-lateral fault was found cutting across one of the reverse fault zones and therefore, should be the product of a younger stress regime. It strikes 10° and dips steeply eastwards.

Locality 13

Around this locality olistostrome with tuffaceous mudstone groundmass contains very large olistoliths of crystalline limestone (Fig. 13). The olistoliths lie conformable with the foliation of the groundmass which is 0/35 to 0/65. The width of this type of olistostrome is about a kilometre (Fig. 1).

Locality 14

Well-bedded chert is the dominant lithology at the Pos Blau end of the surveyed road. Within the chert sequence are convoluted chert-intervals of irregular thickness (Fig. 14). The complex structures were most probably developed by penecontemporaneous slumping. At this locality, large chert olistoliths (on the west side of Fig. 14) are among the clasts in the tuffaceous mudstone olistostrome (TMO). Note that the majority of faults are subparallel to the chert stratification.

Locality 15

Alternating intervals of metres-wide bedded chert and yellow brown soil of unknown parentage form the foot wall of a thrust fault that has well bedded chert in the hanging wall (Fig. 15). The thrust fault is 310/11 and chert layers in its hanging wall are parallel with the thrust plane. Attitudes of the chert of the foot wall and their contacts with yellow brown soil are 310/65. We were not able to determine if the thrust was synsedimentary or otherwise, but we noted that the transport direction was towards SSW, that is, consistent with tectonic vergence shown in many of the outcrops of the Bentong Suture of SW Kelantan.

Also near this locality was seen at least one tuffite layer conformable within the chert beds. Further, one 0.7 m thick igneous sill, now weathered into pinkish brown soil, was traced along the road to taper off to one end. The other end of the sill is not exposed.

Locality 16

Faulted, regular bedded chert rests upon weathered tuffaceous material (Fig. 16, lower) in which outlines of medium large clasts (also completely weathered to purplish and whitish patches) are visible. The clasts could be olistoliths, but the weathered rock could also represent tuff breccia. The upper figure shows a complex of bedded chert with variable attitudes. The regularly bedded chert (70/50) is probably the representative set of bedding, the other abruptly terminated stratifications may have resulted from slumping. This outcrop indicates stratigraphic top towards south, that is, where the regular beds occur.

STRUCTURAL AND TECTONIC INTERPRETATION

Figure 17 is an equal-area projection, lower hemisphere, of various structural elements recorded in outcrops between the Cenderoh bridge (close to Locality 9) up to and including Locality 12. For brevity, this segment of the Bentong Suture is called the Cenderoh segment. The low-angle thrust fault of 140/10 at Locality 9 caused tectonic transport towards southwest. The same sense is also indicated by the moderately-steep dipping reverse faults. Most bedding and foliation are associated with a Pi-pole = 142/14. Lateral compression directions based on sense of reverse faulting and on the Pi-pole were in the sector $N046^{\circ}E$ and $N052^{\circ}E$. The normal faults strike either parallel to the NW-SE structural grain, or strike at 45° angles to that direction. The lateral slip senses on faults striking approximately normal to the regional NE-

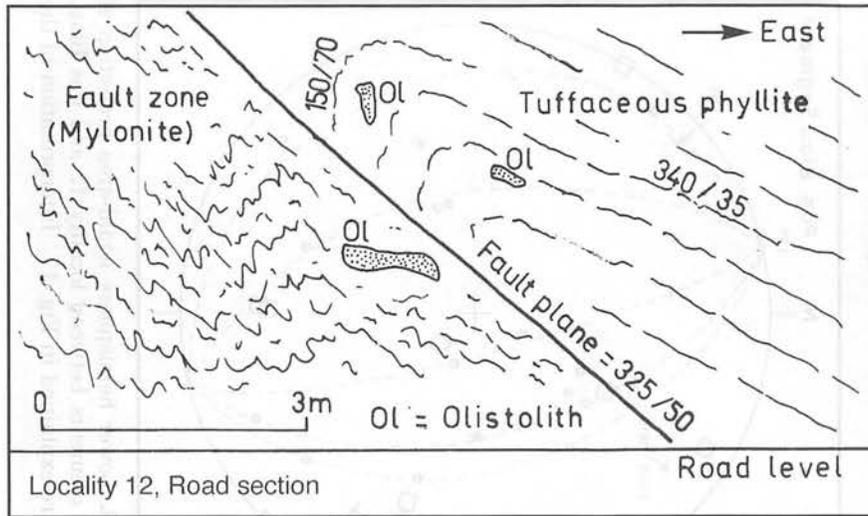


Figure 12. Drag fold in olistostrome with tuffaceous phyllite matrix on the hanging wall side of a ten metre fault zone at Locality 12.



Figure 13. Photograph of large olistolith of crystalline limestone in the vicinity of locality 13. The length of the clast is 10 metres.

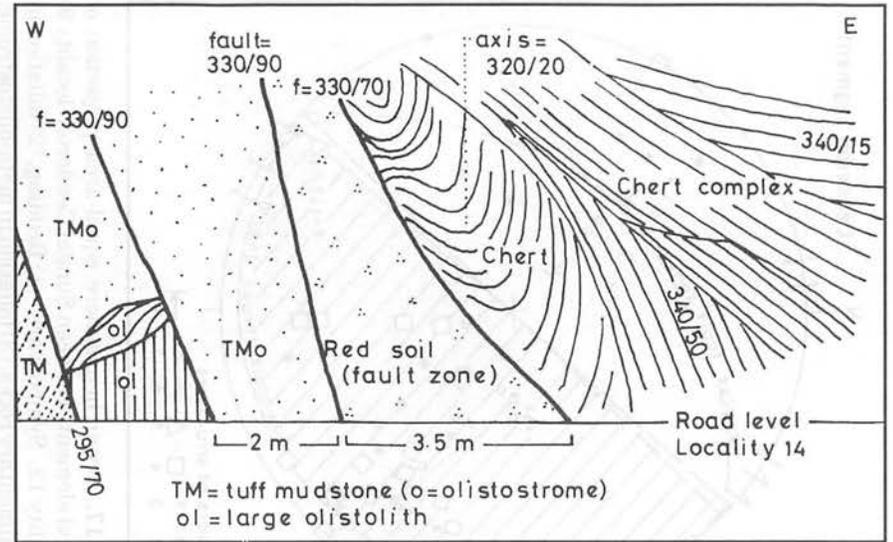


Figure 14. A representative exposure of sometimes internally convoluted bedded chert in contact with tuffaceous mudstone olistostrome. Locality 14 west of Pos Blau.

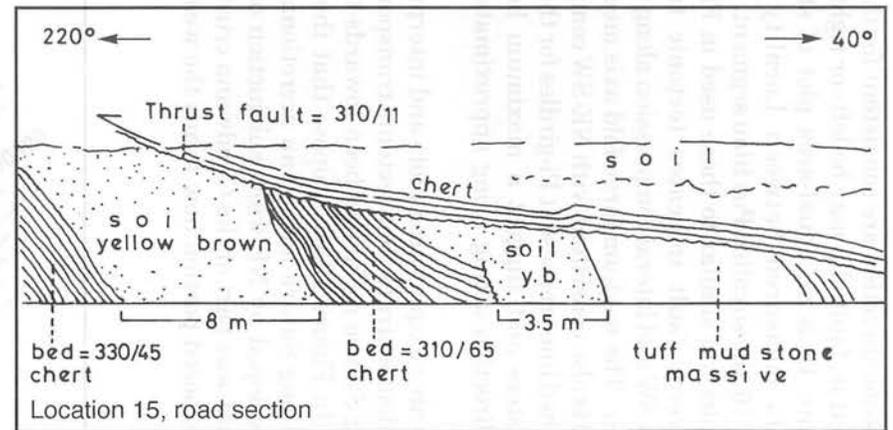


Figure 15. A southwest verging low-angle thrust fault, or overthrust, of bedded chert top alternating bedded chert and yellow-brown soil, probably a weathered tuff. Locality 15 near Pos Blau.

compression direction are consistent for that stress field, that is, fault slip may be left- or right-lateral.

Figure 18 is an equal-area plot of structural elements measured between Locality 12 and Locality 16, the so called Pos Blau segment. Symbols on the plot are similar to those used in Figure 17. The reverse fault indicates tectonic transport towards SW and lateral compression along the same direction. The medium large fold axis measured in the field is also consistent with NE-SW compression. The dashed lines represent Pi-girdles for the various bed clusters and suggest a maximum horizontal stress direction acting along approximately 013°-193°.

The above equal-area plots and interpretations clearly demonstrate that tectonic transport for the Bentong Suture rocks had been towards the SW-S sector. In Figure 19 we propose that the rocks of the Bentong Suture formed an accretionary prism that developed by NE-ward subduction of oceanic crust that was part of the Gondwana crustal sliver whose exposed portion now forms the western belt

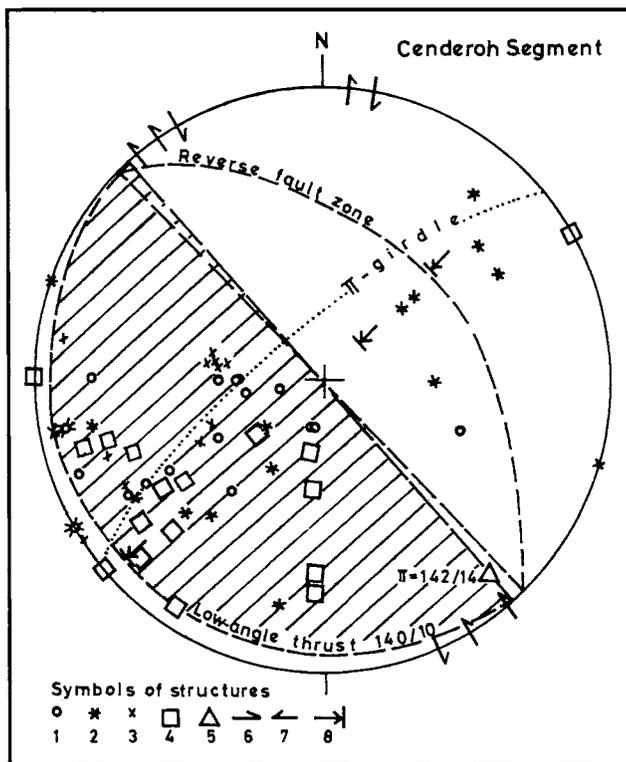


Figure 17. Lower hemisphere equal-area projection of structural elements between Sungai Cenderoh (locality 9) and locality 12. Symbols are: (1) Bedding, (2) foliation in metasedimentary rocks, (3) foliation in meta-olistostrome, (4) fault zone, (5) Pi-pole to bedding, (6) right-lateral fault slip [tip of half-arrow indicates pitch angle], (7) left-lateral fault slip, (8) reverse fault. Interpretation in the text.

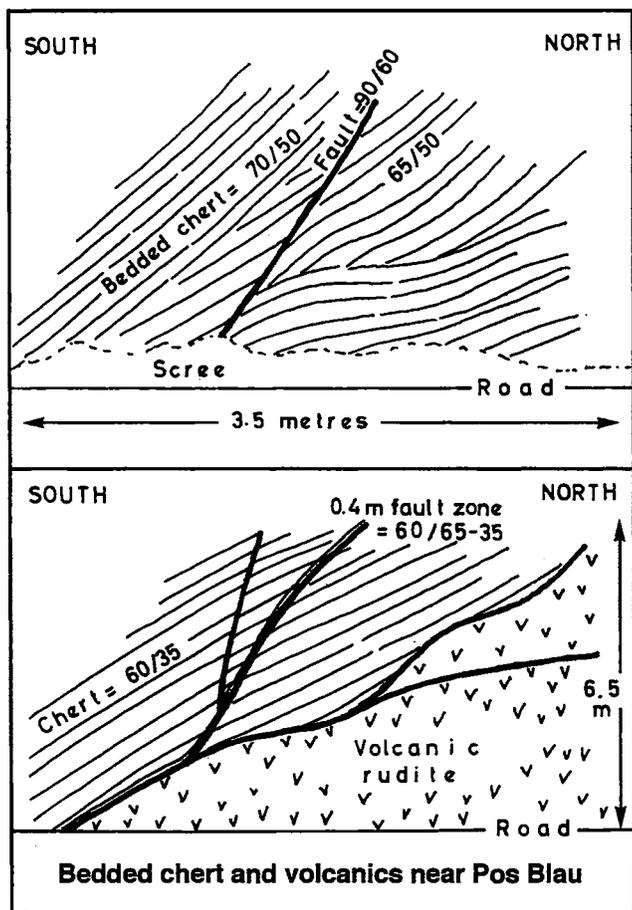


Figure 16. Another view of bedded chert near Pos Blau. The variable attitudes could be due to slumping (upper figure). A SE-sloping fault separates bedded chert in the hanging wall from weathered volcanic rudite (lower figure).

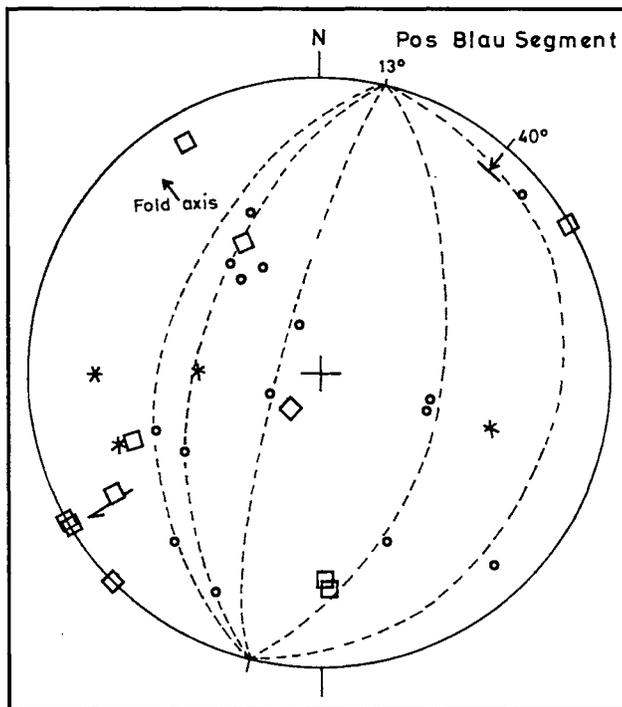


Figure 18. Lower hemisphere equal-area projection of structural elements between locality 12 and Pos Blau. Symbols are explained in Fig. 17. Interpretation in the text.

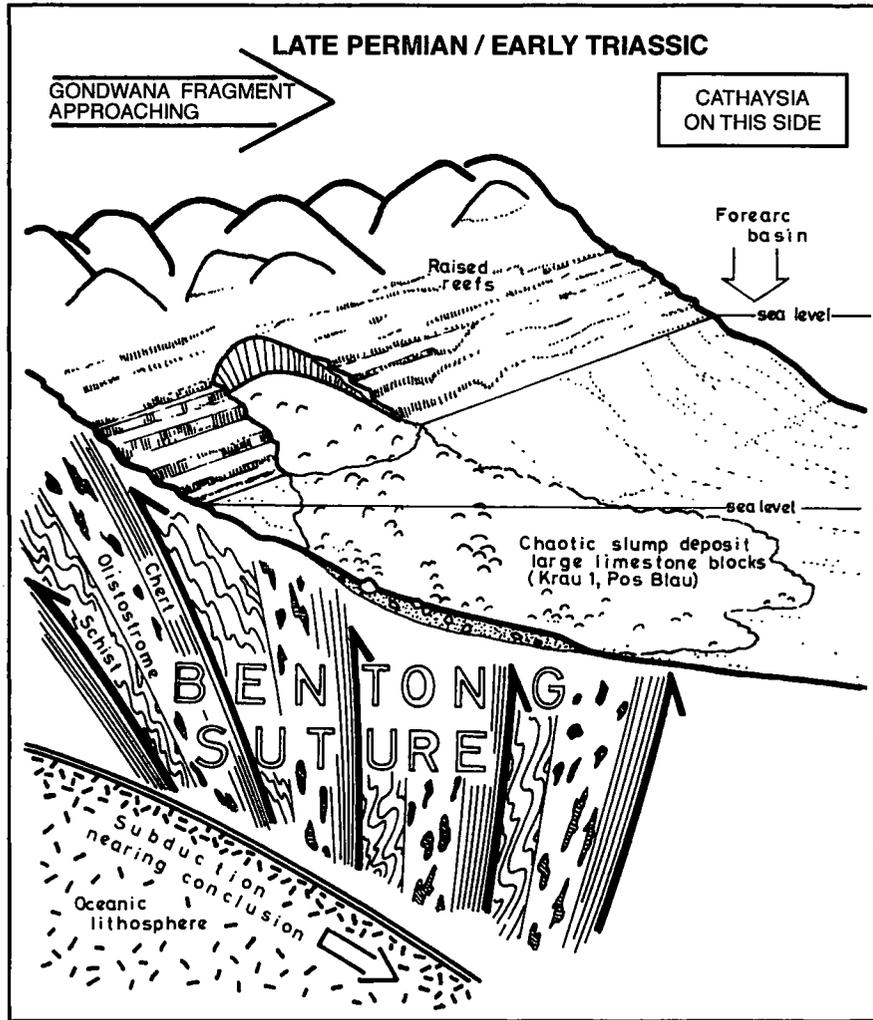


Figure 19. Diagram of the Bentong Suture in southwest Kelantan at the time of docking in ?Late Permian or ?Early Triassic. The suture is an accretionary prism consisting of imbricated tectonic units of olistostrome and other rock types that developed above a northeastward subducting oceanic plate attached to a fragment of the Gondwana continent. Tremors caused a younger unit of chaotic slump deposits in which large olistoliths of Permian limestone is characteristic.

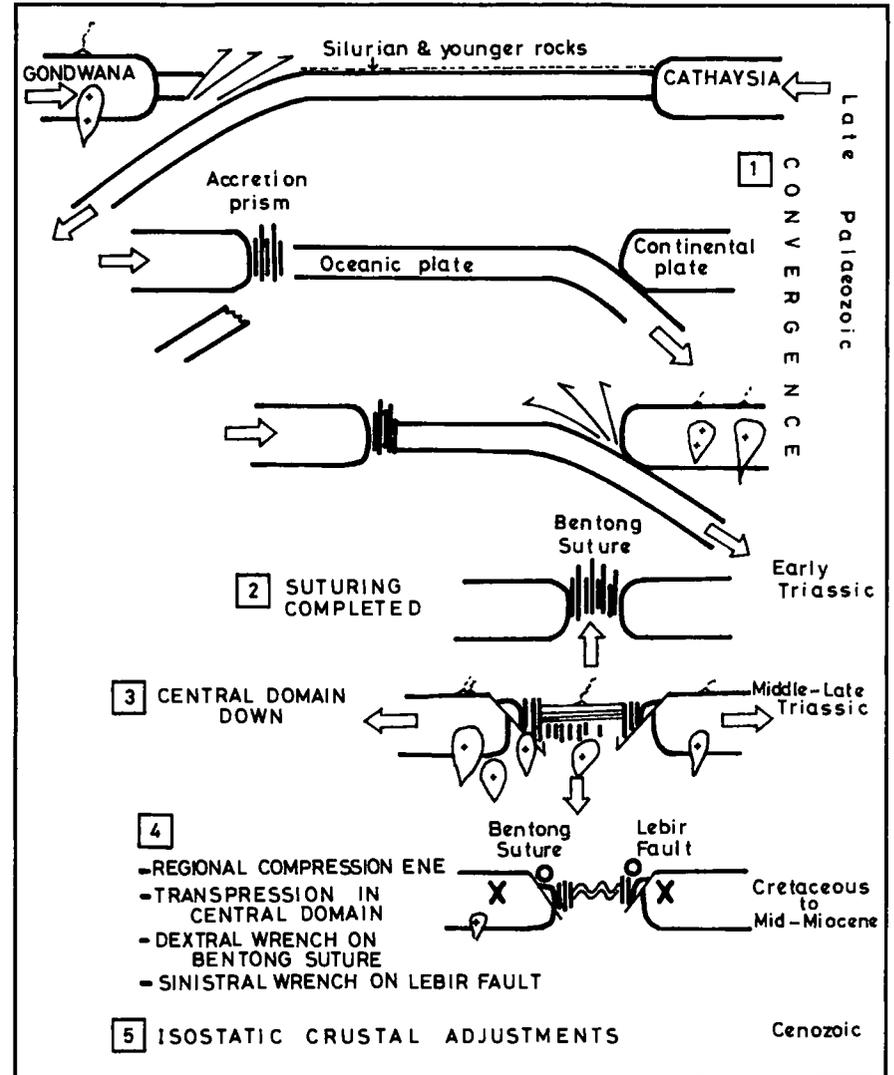


Figure 20. Tectonic development of the Bentong Suture and the Central Belt of Peninsular Malaysia. Explanation in the text.

of Peninsular Malaysia. The outcrops along the Penangau-Pos Blau road show repetition of schist/phyllite-olistostrome-chert intervals (Fig. 2). In Figure 19 this is interpreted as representing repetitive packets of those rock types separated by major reverse fault zones from each other. The major faults separating the packets are thought to have developed during periodic pulses of stronger/faster subduction. Based on stratigraphic/palaeontological considerations (see Tjia, 1989a, 1989b), the docking of the Western Belt with the Cathaysian plate was most probably completed by the Early Triassic. The large limestone olistoliths at Krau 1 estimated as Permian (Chakraborty and Metcalfe, 1987), and those near Pos Blau are interpreted to be part of a younger chaotic unit of probable olistostromal nature. The younger olistostromes probably mark the final stages of suturing along the Bentong tectonic line. Figure 19 illustrates our interpretation that the limestone olistoliths originated from reef buildups around land masses (islands) created by the rising accretionary prism. A current analogue is Timor island. Large scale slumping can be expected in such a tectonically mobile environment at converging plate margins.

Figure 20 summarizes the tectonic development of the Bentong Suture and Peninsular Malaysia. In Stage 1, the proto-Western Belt (indicated as Gondwana: thick continental lithosphere and thinner oceanic lithosphere) converges with Cathaysia. The oceanic lithosphere between the two continental plates is shown subducting below Gondwana to account for lower Palaeozoic volcanic activity that is recorded in the Baling Group and in formations of the Sungai Siput area, north of Ipoh. In the next substage, subduction below the Western Belt had ceased, but the oceanic plate is then subducting below the Eastern Belt. Volcanic products have been recorded in the Carboniferous and Permian formations of that geological domain. Tectonic transport of the accretionary prism is towards the Western Belt, while the two continental plates continue converging. In Stage 2, docking is completed and the Bentong Suture, marked by tectonic vergence towards the SW-S sector has come into being. Strong earthquakes cause large scale slumping, among other forming younger olistostromes containing Permian and ?Triassic olistoliths, such as near Raub and near Pos Blau. In our model, the Bentong Suture thus consists of an older prism that developed next to the Gondwana margin and is now presumably located in the west side of or has become buried under the younger prism that formed at the Cathaysian margin (Stage 1, second illustration). In Stage 3, the two continental plates (Western and Eastern belts)

diverge, creating a marine environment in the so called Central Belt, where in the northern part middle-upper Triassic limestone buildups develop in shallow seas while in the southern part Semantan-Gemas turbidites were deposited in deeper marine surroundings. This divergence explains the presence of serpentinite bodies and diamictite/olistostrome. Diamictite was described as "breccia" in the Lepar fault zone (Tjia, 1976); another outcrop north of Segamat is illustrated in Metcalfe and Chakraborty (1988). Some isolated mafic-ultramafic bodies along the eastern margin of the central belt are known in the Taku Schists of Kelantan (MacDonald, 1967 p. 42 and 52); also at the Bukit Ibam mine near Muadzam Shah (Murthy, 1976). In other words, these representatives of collisional plate margins may represent fragments of the Bentong Suture that became displaced by the middle to late Triassic diverging plate motion. In Stage 3, volcanism is widespread in Peninsular Malaysia. The divergent movement ceases by late Triassic-early Jurassic when the Titiwangsa granitoid complex becomes orogenically emplaced. In Stage 4, late Jurassic-Cretaceous the Peninsula has achieved relative tectonic stability and the regional stress field has become tensional (Tjia, 1996). In early Tertiary (up to middle Eocene), mild regional compressional conditions recur causing only reactivation of major faults, but no folding. Along the margins of the Central Belt, the NNW-Lebir fault zone moves left-laterally, faults in the north-striking Bentong Suture move right-laterally. Other large north-south faults on the margin of the Central Belt, such as the Cini and Bera faults also move in dextral sense, creating NNW-trending drag folds in the adjacent Jurassic-Cretaceous sedimentary strata. Such drag folds occur in the Tembeling Group and the Bertangga Sandstone (Tjia, 1996). Finally, in Stage 5 (post-middle Eocene), the lithosphere of the peninsula has completely stabilized and only minor, vertical crustal movements have occurred as result of isostatic adjustments.

CONCLUSIONS

1. The Bentong Suture in southwest Kelantan is 18 km wide. Its western border is an injection complex with Titiwangsa granitoids, its eastern border consists of bedded chert.
2. Seven tectonic units, each comprising schist/phyllite, olistostrome, mudstone and chert form the suture zone. A single serpentinite body occurs between two of the tectonic units. The structural imbrication developed through sequential stacking of tectonic units, of which the first is now the eastern-most unit, while the

- last unit forms the western border zone.
3. These units are stacked at moderate dips to vertically and southwest vergence could be determined.
 4. Between and within the tectonic units are fault zones. Some of the olistostromal packets are sheared into melange.
 5. The youngest faulting event comprises low-angle thrusting towards south. An example is at Locality 5.
 6. The eastern border zone has a younger, post-docking chaotic assemblage in which large crystalline limestone clasts are common. This is probably also an olistostrome.
 7. The suture rocks originated in a lower-middle Palaeozoic marine or oceanic region that became closed by early Triassic through convergence of a sliver of Gondwana plate in the west with the Cathaysian plate in the east.

ACKNOWLEDGEMENTS

Our colleague P. Loganathan, Geological Survey of Malaysia, created our interest for studying the road stretch. Azhar Haji Hussin, C.P. Lee and Mustaffa Kamal Shuib, all of Universiti Malaya, and Mohd Shafeea Leman, Universiti Kebangsaan Malaysia, discussed various geological problems of the area. To all of them our heartfelt thanks.

REFERENCES

- BIGNELL, J.D. AND SNELLING, N.J., 1977. Geochronology of Malaysian granites. *Institute of Geological Sciences, Overseas Geology and Mineral Resources No. 47*, 70p.
- BURTON, C.K., 1965. Wrench faulting in Malaya. *Journal of Geology* 73, 781–798.
- COBBING, E.J., PITFIELD, P.E.J., DARBYSHIRE, D.P.F. AND MALICK, D.J., 1992. The Granites of the South-East Asia Tin Belt. *British Geological Survey, Overseas Memoir No. 10*, 369p (radiometric ages: 321–325).
- CHAKRABORTY, K.R., 1988. Subduction-collision models from the Malay Peninsula: an appraisal (abstract). *Geological Society of Malaysia, Warta Geologi* 14(6), 266–267.
- CHAKRABORTY, K.R. AND METCALFE, I., 1987. Occurrence of sheared diamictite in the Raub area, its possible extensions and tectonic implications (abstract). *Warta Geologi* 13(2), 62–63.
- GEOLOGICAL SURVEY OF MALAYSIA, 1985. Geological Map of Peninsular Malaysia, 8th edition. Scale 1:500 000 (2 sheets).
- HARBURY, N.A., JONES, M.E., AUDLEY-CHARLES, M.G., METCALFE, I. AND MOHAMED, K.R., 1990. Structural evolution of Mesozoic Peninsular Malaysia. *Journal Geological Society* 147, 11–26.
- HUTCHISON, C.S., 1973. Tectonic evolution of Sundaland: a Phanerozoic synthesis. *Bull. Geological Society of Malaysia* 6, 61–86.
- HUTCHISON, C.S., 1975. Ophiolite in Southeast Asia. *Geological Society of America Bulletin* 86, 797–806.
- HUTCHISON, C.S., 1977. Granite emplacement and tectonic subdivision of Peninsular Malaysia. *Bull. Geological Society of Malaysia*, 9, 187–207.
- JAAFAR AHMAD, 1976. Geology and Mineral Resources of the Karak and Temerloh Areas, Pahang. *Geological Survey of Malaysia, District Memoir* 15, 138p.
- KHOO, T.T. AND TAN, B.K., 1983. Geological evolution of Peninsular Malaysia. Workshop on Stratigraphic Correlation of Thailand and Malaysia. *Geological Society of Thailand and Geological Society of Malaysia, Proceedings* 1, 253–290.
- MACDONALD, S., 1967. Geology and Mineral Resources of North Kelantan and North Trengganu. *Geological Survey West Malaysia, Memoir* 10, 202p.
- METCALFE, I. AND CHAKRABORTY, K.R., 1988. Diamictite along the eastern margin of the central basin of the Malay Peninsula. *Warta Geologi* 14(5), 191–198.
- MITCHELL, A.H.G., 1977. Tectonic settings for emplacement of Southeast Asian tin granites. *Bull. Geological Society of Malaysia*, 9, 123–140.
- MURTHY, K.N., 1976. A brief note on the varieties and uses of serpentinite at Bukit Ibam, Pahang. *Geological Survey Malaysia, Annual Report for 1976*, 166–169.
- TJIA, H.D., 1976. Lepar fault zone, Pahang. *Warta Geologi* 2(5), 99–101.
- TJIA, H.D., 1984. Multi-directional tectonic movements in the schist of Bentong, Pahang. *Warta Geologi*, 10(5), 187–189.
- TJIA, H.D., 1987. Olistostrome in the Bentong area, Pahang. *Warta Geologi*, 13(3), 105–111.
- TJIA, H.D., 1989a. The Bentong Suture. *Proceedings Regional Conference on Geology, Mineral and Hydrocarbon Resources of SE Asia, GEOSEA 6*, Jakarta, July 1987, 73–85.
- TJIA, H.D., 1989b. Tectonic history of the Bentong-Bengkalis suture. *Geologi Indonesia* 12(1), 89–111.
- TJIA, H.D., 1994. Kinematic analysis of striated fractures in Titiwangsa granitoid, Karak Highway — Selangor side. *Bull. Geological Society of Malaysia*, 35, 25–35.
- TJIA, H.D., 1996. Tectonics of deformed and undeformed Jurassic-Cretaceous strata in Peninsular Malaysia. *Bull. Geological Society of Malaysia Bulletin*, 9, 131–156.