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The structure and deformation history of the serpentinite bodies along the Bentong Suture: a case study at Bukit Rokan Barat

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Abstract: Along the boundary of the Western and the Central Belts of Peninsular Malaysia, there are a number of relatively small bodies of serpentinite outcrops. It is believed that these outcrops represent the serpentinised ultramafic rocks, which intruded the Lower Devonian rock formations. The serpentinite outcrop at Bukit Rokan Barat, Negeri Sembilan can be considered as one of the best that can be found in this area. The structure observed at this outcrop could represent the structure of the other serpentinite bodies situated along this boundary. Furthermore the deformation history, which is deduced from this structural study, may be used to describe the deformation history that took place along the boundary between the Western and Central Zones of Peninsular Malaysia.

The observed serpentinite body at Bukit Rokan Barat is well foliated, trending approximately in north-northwest and northwest direction and moderately to steeply dipping towards northeast. This rock body had suffered at least three phases of shearing, the earlier two (D_1 and D_2), were related to ductile, while the third (D_3) was related to brittle deformation. The ductile deformations are indicated by the presence of shear zones, foliations and crenulations folds (microfolds) and lenticular-shaped structures, and the brittle deformation by the lateral faults. The maximum principal paleo-stresses (s1) related to the ductile deformations (D_1 and D_2) were acting from NE and ENE directions respectively and the brittle deformation (D_3) from NNE direction. The approximately EW tension cracks developed within the lenticular shaped structures are interpreted as the last phase of deformation suffered by this rock body.

Abstrak: Di sepanjang sempadan antara Jalur Barat dan Tengah Semenanjung Malaysia, terdapat beberapa singkapan jasad-jasad kecil serpentinit. Singkapan-singkapan tersebut dipercayai mewakili batuan ultramafik yang telah berubah menjadi serpentinit, yang dahulunya merejah formasi batuan Devon Bawah. Salah satu singkapan yang terbaik didapati di Bukit Rokan Barat, Negeri Sembilan. Struktur yang dicerap di singkapan ini boleh mewakili struktur untuk jasad-jasad serpentinit lain yang terletak di sepanjang sempadan tersebut. Seterusnya sejarah canggaan yang ditafsirkan berdasar kepada kajian struktur di sini juga boleh digunakan untuk menjelaskan sejarah canggaan yang telah berl;aku di sepanjang sempadan zon Barat dan Tengah Semenanjung Malaysia.

Jasad serpentinit yang dicerap di Bukit Rokan Barat mempunyai foliasi yang sangat baik, berarah hampir utara-bratlaut hingga baratlaut. Jasad batuan ini mengalami sekurang-kurangnya tiga fasa ricihan, dua yang awal (D_1 dan D_2) berkaitan dengan canggaan mulur, manakala yang ketiga (D3) berkaitan dengan canggaan rapuh. Canggaan rapuh ditunjukkan oleh kedapatan zon ricih, foliasi, lipatan kerdut dan struktur berbentuk lentikular, manakala canggaan rapuh oleh sesar mendatar. Tegasan kuno utama maksimum (s1) yang berkaitan dengan canggan mulur (D_1) dan (D_2) masing-masing telah bertindak dari arah timurlaut dan timur-timurlaut dan canggaan rapuh (D_3) dari utara-timurlaut. Rekahan tensi berarah hampir timur-barat yang terbentuk pada jasad berbentuk lentikular merupakan canggan terakhir yang alami oleh jasad batuan di sini.

INTRODUCTION

There are a number of relatively small serpentinite bodies present along the boundary of the Western and Central Belts of Peninsular Malaysia, namely at Kg. Durian Tipus, Kg. Selaru, Felda Bukit Rokan Barat and Petasih, Negeri Sembilan and Bentong and Cheruh, Pahang. The serpentinites are interpreted as a result of alteration of ultramafic rocks such as pyroxenite or peridotite. The serpentinites found along the boundary between these two belts was assigned as ophiolite origin, marked the site of a paleo-subduction zone, known as Bentung-Raub line (Hutchison 1973, 1977) or Bentong Suture Tjia (1989). The distribution of the serpentinite bodies in Peninsular Malaysia is shown in Figure 1. This paper will describe a detailed structural account and deformation history of the serpentinite body based on observation at one of the best serpentinite outcrops found at Felda Bukit Rokan Barat, along the Bentong Suture.

Felda Bukit Rokan Barat is situated about 15 km south of Bahau. It can be reached by car, following the main road from Bahau south-easterly to Rompin and then turn right towards west until reaching small junction to the left (Fig. 2A). A relatively fresh rock outcrop, sized about 10 meters x 30 meters is found along a road cut in a residential area (Figs. 2B, 3). The GPS reading for this location is 02°40.409'N, 102°22.915'E. The rock is pale to dark green in colour, well foliated, sheared and some parts are fibrous. Lenticular shaped structures occur in the less sheared parts of the rock body (Fig. 4). The striations and other phenomena, resulted from the shearing are still well preserved on shearing planes (shear zones or faults). The rock outcrops in the area are covered by dark reddish residual soil.

The purposes of this study are to describe the structure of the serpentinised body in the area, which had subjected to shearing stress. The emphasis of this study is to determine the direction of the maximum principal stress (s1) for each period of deformation, and the sequence of deformation suffered by this rock body. From the striations and other related features preserved on the shear planes which may either representing faults (formed during brittle deformation) or shear zones (produced during the ductile deformation) the shearing direction and the sense of shearing can be determined as described by Tjia (1964, 1968). STRESS 3.31 programme, is used in the faults and shear zones analysis to determine the paleo-stress orientations (s1, s2 and s3) and the stress field which were related to movement of faults and shear zones in the study area. The interpretation of the paleo-stress history is based on the crosscutting relationships and the displacements that took place along the fault planes or shear zones.

GEOLOGY OF THE SERPENTINITE BODY

Most of the serpentinite bodies found along the Bentong Suture occur within mainly Lower Devonian schistose rocks,

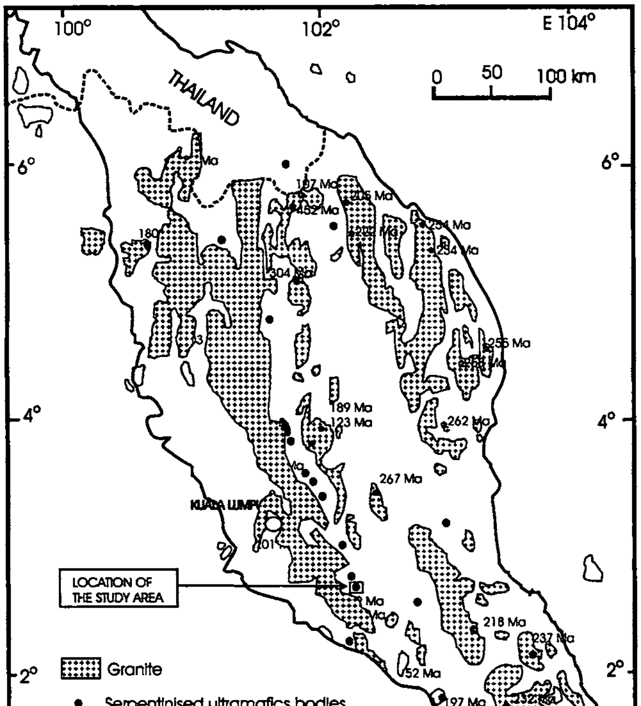

Figure 1. Distribution of serpentinised ultramafics in Peninsular Malaysia (after Tan, 1996).

mapped as part of the Foothill Formation (Richardson, 1939). In Felda Bukit Rokan Barat, the contact between the serpentinite body and schist (Pilah Schist) is not exposed. However, an exposure at Petasih, Kuala Kelawang (at the back of Petasih School), clearly shows that these two rock units are separated by faults. Apparently, the serpentinite was following the faults plane before intruded into the schist. The Pilah Schist consists of quartz-mica schist, mica-quartz schist, hornfels and quartzite. It is classified as low-grade metamorphic rocks of green-schist facies, formed at the temperature about 250°C.

The serpentinites were believed to be altered ultramafics such as pyroxenite or peridotite (Jones, 1973; Tan, 1996). Generally, serpentinite consists of ilminite, magnetite, crimite, picitite, pyrrhotite, tremolite and clorite (Hutchison, 1973). Serpentinite could be formed by local or regional alteration of olivine or pyroxene, as a result of hydrothermal metamorphism by a chemical reaction involving mainly magnesium and silica in the form of solution. According to Turner and Verhoogen (1962), the serpentinization can take place at the temperature between 100°C-500°C, but Bowen (1956) suggested the temperature is between 350°C-450°C.

STRUCTURAL DESCRIPTIONS

A detailed structural mapping was done at the serpentinite outcrop at Bukit Rokan Barat. The result of the mapping is shown in Figure 2B. Two cross-sections are also provided in Figure 2B to illustrate the internal structure of the rock body. As it is shown in Figure 2B, the general orientation of the serpentinite body is approximately in north-northwest direction, almost parallel to the Bentong Suture as well as to the axis of the Peninsular Malaysia. The rock has been sheared, faulted and fractured. At least there are two directions of shear zones present; the NNW are generally wider and major which formed earlier, while NNE are narrower, cut and displaced some of the early formed shear zones. The earlier shearing, dominated by reverse-right movements was responsible in the formation of the foliation in this rock. However, the second shearing, with right-reverse movements rotated the foliation especially at the vicinity of the related shear zones and at the same times the foliation here became steeper. As a result of shearing, lenticular shaped structures were developed in the less foliated parts of the serpentinite body (Fig. 4). The second shearing was also responsible for the formation of small-scale crenulation folds (Fig. 5) within the earlier formed shear zones that are plunging towards WNW direction. Finally, the foliation, shear zones and lenticular shaped structures had been sliced and displaced by right-reverse fault that were formed during the brittle deformation, producing a well developed striations on the fault plane (Fig. 6). Open cracks occur in the less foliated lenticular shapes structures. This east-west orientation cracks are interpreted to represent tension fractures that was formed as a result of the last deformation affected this area.

STRUCTURAL ANALYSIS

The attitudes of the fault planes and shear zones (strike and dip) and the directions and sense of movements (as shown by the lineations) were plotted using STRESS 3.31 programme. Figure 7A shows the result of the analysis of the earlier formed shear zones, which were related to the first deformation (D_1) suffered by this rock unit. The analysis indicates that the plunge and direction of the maximum principal paleo-stress that was related to the first deformation was 8°, N51°E. Figure 7A also shows the compression and tension fields related to this deformation. The result for the second deformation (D_2) is shown in Figure 3B, with ($\sigma 1$) plunge 9° towards N70°E. The result of analysis of the third deformation (D_3) which is represented by right-lateral faults, is shown in Figure 7C. The responsible paleostress was 14° towards N204°E. Other structural elements of this rock body are analyzed using stereo programme as shown in Figure 8, summarizing the orientation off all the structural elements found as well as the period of deformation. This figure shows the attitudes of the foliations and the micro-folds as well the general

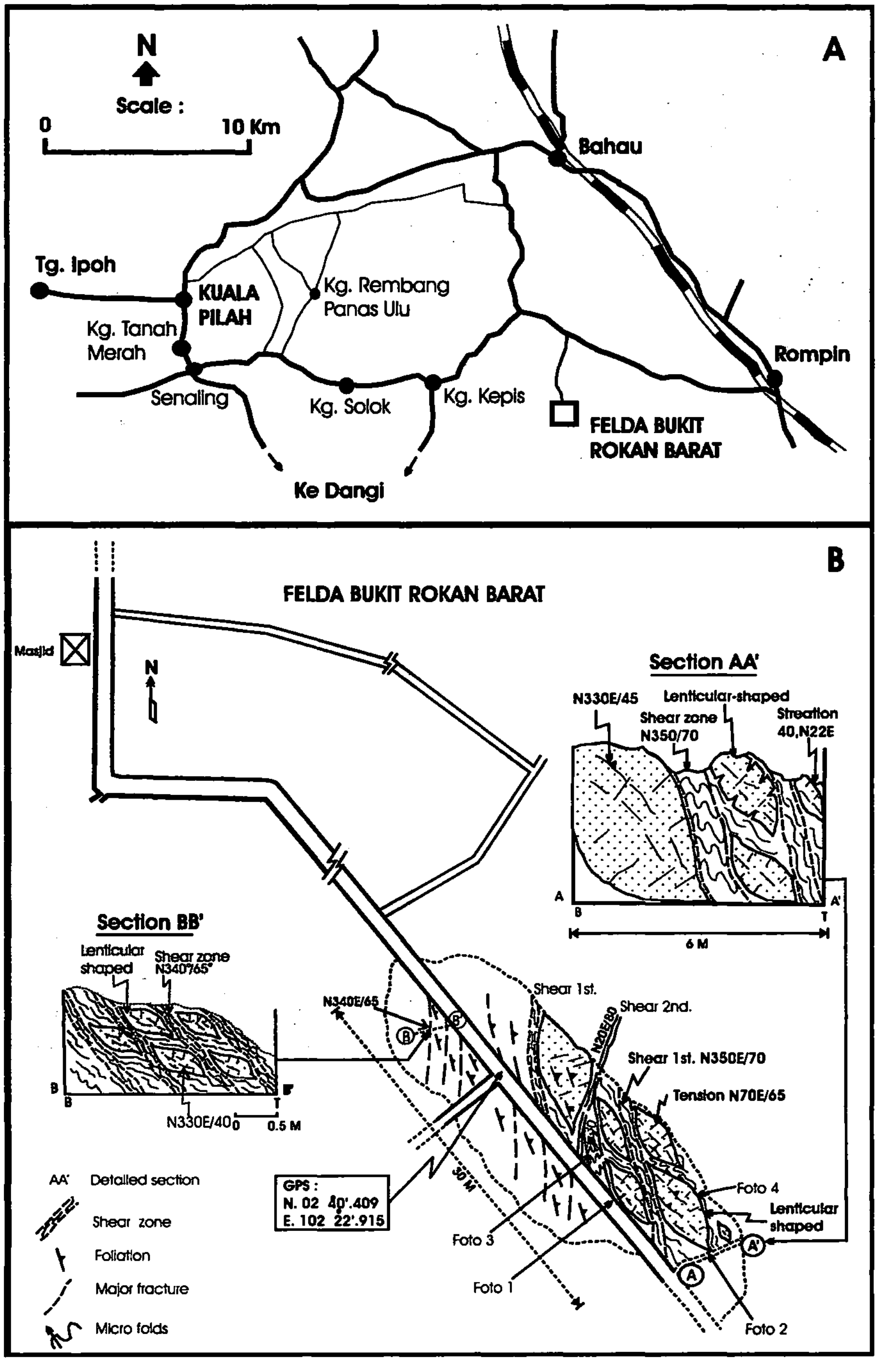

Figure 2. (A) Map of Kuala Pilah area, showing the location of Bukit Rokan Barat. (B) Structural geological map of serpentinite bodies in Felda Bukit Rokan Barat.

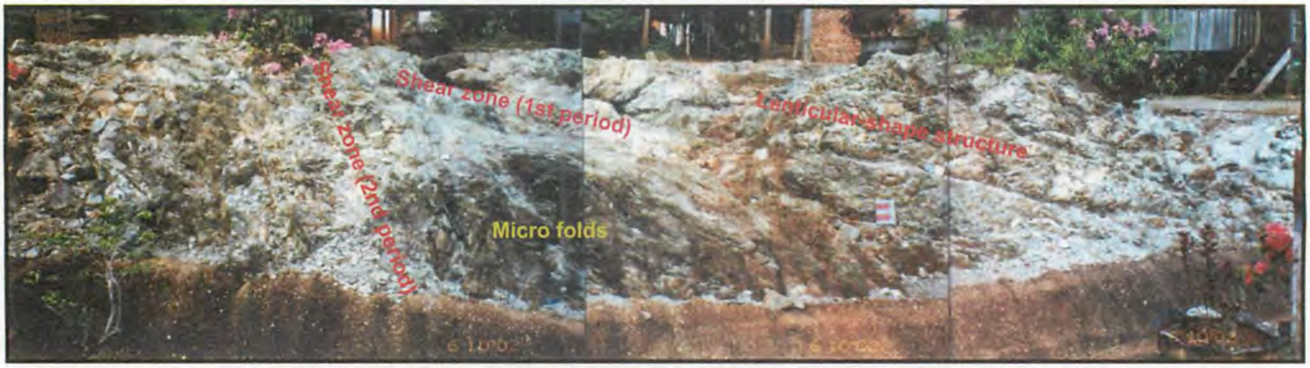

Figure 3. Outcrop of serpentinite body in Felda Bukit Rokan Barat. Photo direction to NE.

Figure 4. Lenticular-shaped structure in cross section, dipping towards east. Photo direction to NE.

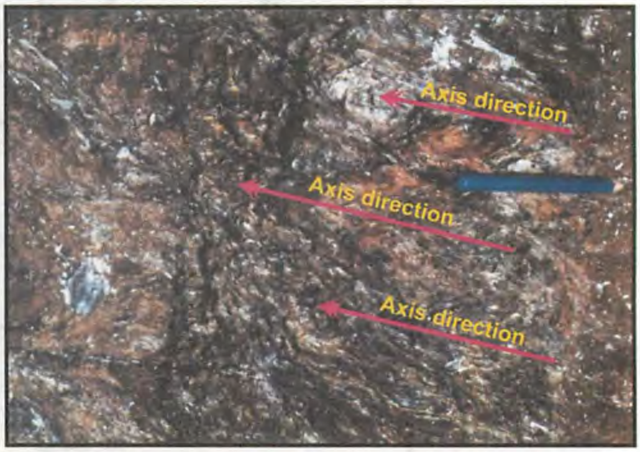

Figure 5. Microfolds within the shear zone (1st period). Photo direction to NE.

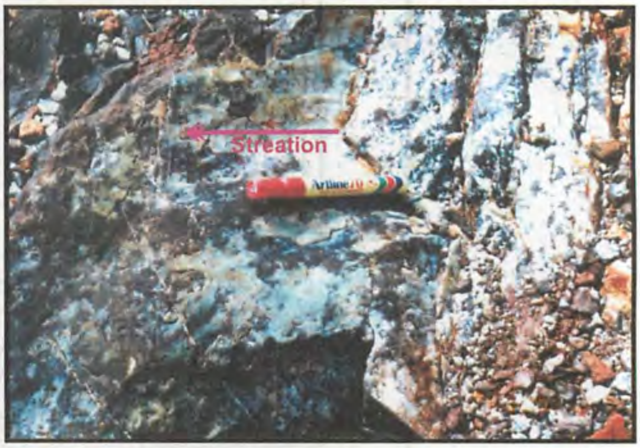

Figure 6. Striation on the shear plane, cutting the boudinage. Photo direction to NW.

orientation of the shear zones related to the first and second deformation (D_1 and D_2) as well as lateral fault formed by third deformation (D_3).

DISCUSSIONS AND CONCLUSIONS

The serpentinite outcrop, at Felda Bukit Rokan, is aligned in NNW direction, almost in the same direction as the shear zones. It is interpreted that this shear zone governs the shape and the orientation of this rock body, which dip about 60° to 70° towards east. The field evidence observed at Kampung Petasih supports this interpretation. Furthermore, this direction is also almost parallel to the Bentong suture as well as the axis of Peninsular Malaysia. This structural study indicates that this rock unit had suffered at least three phases (periods) of deformation, which could also be interpreted as representing the deformations that had been taken place along the boundary of the western and the central zones of Peninsular Malaysia since this serpentinised ultramafic rock intruded the lower Devonian rock formations. Since a number of structures were formed during the first and second phase of deformations (D1 and D2), it is interpreted that formation of these structures during D_1 and D_2 could be as a result of progressive deformation.

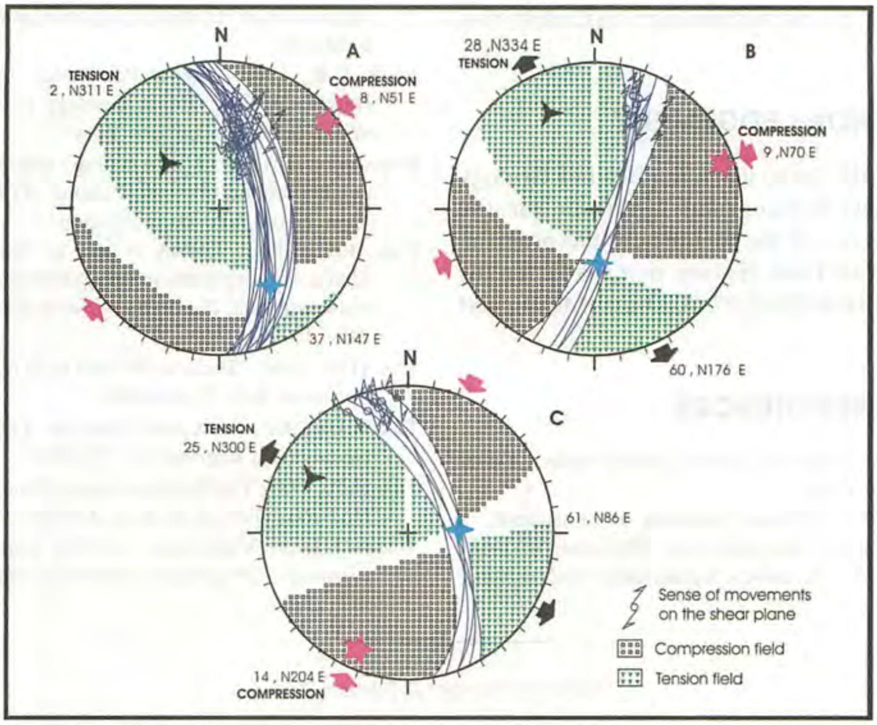

Figure 7. Paleostress and stress field responsible for the deformation of the serpentinite bodies in Felda Bukit Rokan Barat. (A) First period (D1), (B) Second period (D2), (C) Third period (D3).

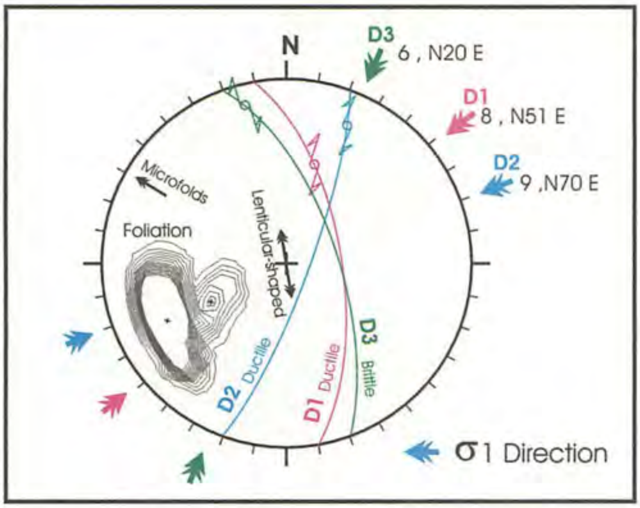

Figure 8. The structural elements of the serpentinite bodies and the direction of σ1 related to D1 (ductile), D2 (ductile) and D3 (brittle).

The first phase of deformation (D_1-ductile deformation) suffered by this rock unit was related by paleo-stress with plunge and direction of maximum principal stress ($\sigma 1$) = 8° towards N51°E. This deformation produced reverse-right shear zones, aligning in NNW direction. The striations on this shear zones indicate oblique movement (reverse-right), with the reverse component is greater than the lateral (Fig. 7A). This paloe-stress system was also responsible for the formation of the well-developed foliation in this rock unit.

The second phase of deformation (D_2) was also took place in ductile manner as what had happened during D_1. The stress system with ($\sigma 1$) = 9° towards N70°E was responsible for the formation of second sets of shear zones (with right lateral movement) in this rock unit. This stress system had modified the orientation and the steepness of the foliations that were developed during the first deformation especially in the vicinity of the second shear zones. At the same time, crenulations fold were developed in the well-foliated area, while lenticular-shaped structures were formed in the less foliated parts within this shear zones.

The NNW lateral faults resulted from stress system with ($\sigma 1$) = 6°, towards N20°E, are considered as a result of the third phase of deformation (D_3) suffered by this rock unit. These lateral faults cut the first and second shears zones, lenticular shaped structures as well as the foliations. It is interpreted that the stress system related to this deformation was also responsible in the fracturing of this rock unit. The approximately east-west open cracks were formed as a result of the last deformation suffered by this rock body.

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