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Joint Patterns and Structural Analysis of Pulau Bunting, Yan, Kedah

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Abstract

The rocks of Pulau Bunting, which consist of metasediments and quartz porphyry, are faulted, sheared and fractured. Metasediments occur in the northern coast and the most eastern part of the island. In the northern coast of the island the metasediments form a broad open syncline plunging northwards, while in the eastern end of the island the rocks were tightly folded into a small anticline and syncline compressed within the axial zone of a broader syncline plunging into NNE direction. From the aerial photograph, several lineaments were traced. The lineaments are trending in the NNE-NE and NNW-NW directions. The lineament directions are in very good agreement with the observed faults and shear zones. Joint analyses indicate that there are five joint sets in the area, two of them partly filled by quartz to form quartz veins. Based on the field relationship of the structures observed, it is interpreted that the metasediments have undergone two phases of compression before the igneous intrusion, which took place during Jurassic-Cretaceous time. Following that, a tensional phase was responsible for normal faulting and quartz veins. The last compression took place in the area during Early Tertiary and resulted in the lateral faults and shear zones. This activity was also responsible for the formation of the foliation in the quartz porphyry.

Corak Kekar dan Analisa Struktur Pulau Bunting, Yan, Kedah

Abstrak

Batuan di Pulau Bunting, Kedah yang terdiri daripada metasedimen dan kuarza porfiri telah tersesar, tericih dan retak. Metasedimen didapati di bahagain utara dan hujung timur pulau ini. Di Pantai utara, batuan metasedimen terlipat membentuk satu lipatan terbuka yang menunjam ke arah utara, manakala pada metasedimen yang terdapat di hujung timur pulau, terdapat antiklin dan sinklin ketat yang terletak dalam satu zon paksi satu sinklin yang lebih besar yang menunjam ke arah timurlaut. Daripada fotograf udara didapati beberapa lineamen yang berarah sama ada timur-timurlaut atau baratdaya. Arah lineamen di sini sangat bersesuaian dengan arah sesar dan zon ricih yang dicerap di lapangan. Kedua-dua jenis batuan telah mengalami pengekaran. Analisis kekar menunjukkan di kawasan ini terdapat lima set kekar, dua set diisi oleh kuarza membentuk telerang. Berdasarkan kepada perkaitan antara struktur yang terdapat di sini ditafsirkan batuan di kawasan telah mengalami dua genesis mampatan sebelum perejahan igneus semasa Jura-Kapur. Selepas itu, fasa regangan telah menerbitkan sesar normal dan telerang kuarza. Fasa mampatan seterusnya pada Tersier Awal menyebabkan terbentuk sesar mendatar dan zon ricih sebelum pengenduran yang berasosiasi dengan pembentukan sesar normal. Aktiviti ini mungkin yang bertanggungjawab dalam pembentukan foliasi pada batuan kuarza porfir.

INTRODUCTION

Pulau Bunting is a small island (about 2 km in length x 1 km in width) located at about 2 km off the Central Kedah coast in the Yan District and about 12 km from Gunung Jerai. The island is elongated in shape and is oriented in an east-west direction. The shape of the igneous stock that contributes to the geology of the island itself could have controlled the trend. Topographically, the island can be considered as low hills surrounded by the sea with its highest peak reaching about 140 meter above sea level.

The purpose of this paper is to document the geology and structural geology of the island in detail. Every outcrop on the island was visited during this study and a geological and detailed structural geology map has been produced.

GEOMORPHOLOGY

Many parts of the island are characterized by a more or less smooth topography, which is underlain by homogeneous quartz porphyry. However in some parts, steeper slopes have developed and changed the topography into a slightly irregular type. Around the eastern section of the island, which is underlain by metasediments, the topography is more irregular. The irregularities are partly related to differences in lithology and the presence of normal faults.

Studies of aerial photographs show that the island is characterized by two prominent ridges. The longer ridge is aligned in a N70°E direction and the shorter ridge run in the N50°E direction. The major ridge follows the main trend of the island and is dissected several times by a series of faults and negative lineaments trending 150° and 230°.

Several minor ridges splay out from the major ridge in various directions. Some are controlled by fracture patterns on the island itself (Figure 1).

GENERAL GEOLOGY

The geology of the island was first mapped by Flinter and Chung (1958). Two distinct rock units can be recognized. They are quartz porphyry and metasediments. Contact between these two units can be clearly observed at several outcrops on the island.

Quartz porphyry

The Jurassic-Cretaceous (Bradford, 1972) quartz porphyry occupies about 80 percent of the island but in the eastern and northeastern portions there are sediments, which have been metamorphosed. The contact between the units is very sharp but in some places the quartz porphyry form sills in the metasediments (Figure 2).

The fresh rock looks grey in color with quartz grains randomly distributed in a fine groundmass. Field observations show that there are two types of quartz porphyry on the island. At places near the contact with metasediments, the rock shows larger phenocrysts and contains more tourmaline. In these areas, occurrences of tourmaline-rich nodules, sometimes with quartz cores, were observed. Most nodules have been compressed and aligned in a 230° direction, parallel to the major fault system on the island. In areas away from the contact, especially in the southern shore, the porphyry appears more homogeneous

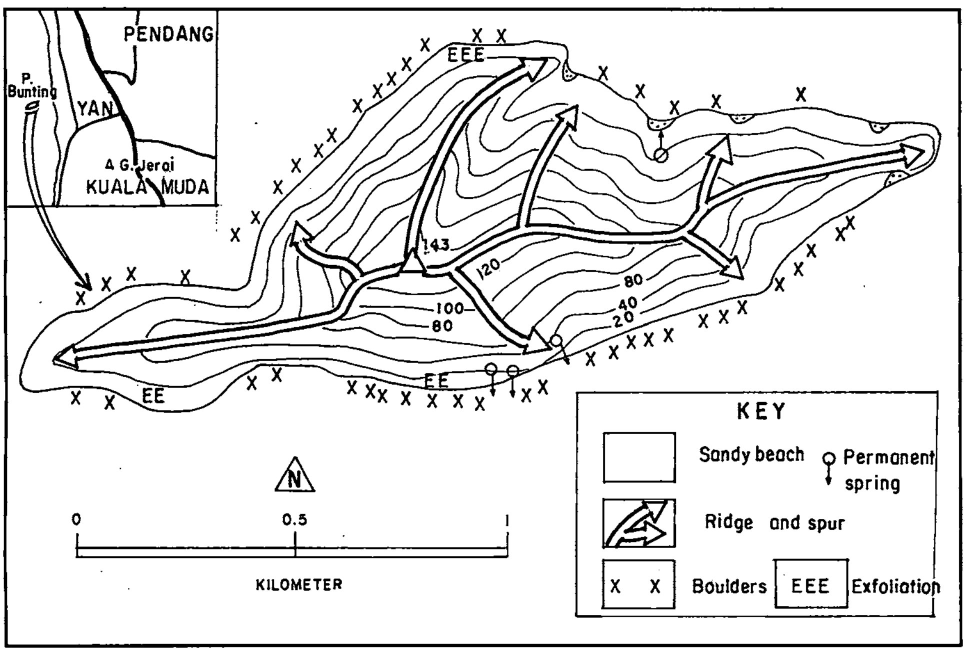

Figure 1: General morphology of Pulau Bunting, showing the main ridges and spurs.

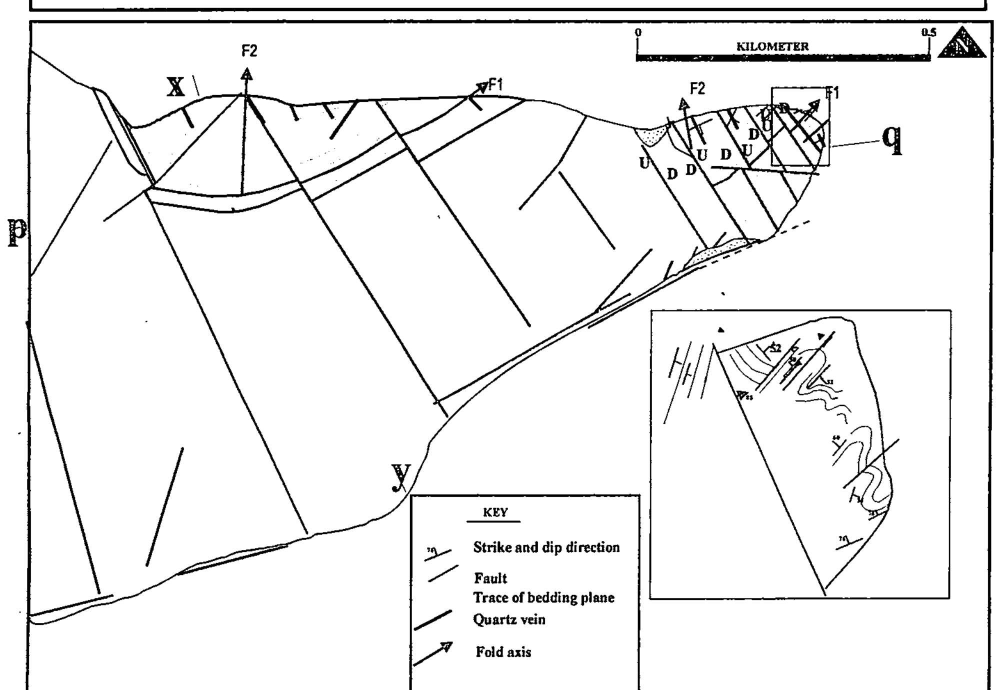

Figure 2: Geology and major structures of Pulau Bunting.

and contains less tourmaline. At places, especially in the northern part of the island, the rock is slightly foliated. Radiometric dating of biotite from the foliated granite, gave an age of Early Tertiary (Bradford, 1972), which could be related to tectonic activity of the area.

Metasediments (Jerai Formation)

Metasediments in Pulau Bunting consists mainly of quartzite with minor occurrence of phyllite and hornfels. The rock occurs in the most eastern part of the island and it is underlain by quartz porphyry at depth. Lithologically, the rock is very similar to the rock of the Cambrian Jerai Formation described by Bradford (1972) and Almashoor (1974).

The quartzite appears light grey or pinkish in color and massive while the phyllite is finely foliated and dark grey in colour. Hornfels is interbedded with quartzite in areas close to the contact with the porphyry and because of its limited occurrence, it is not possible to map it out.

STRUCTURAL OBSERVATION AND DATA COLLECTION

Folds

The metasediments in the northeastern coast shows simple structure. The strike line of the bedding planes change from NW-SE direction in the western part into NE-SW in the eastern part. Therefore, as a whole, this area forms a broad open syncline plunging towards north. In the eastern end of the island, the bedding changes from NW-SE to NE-SW directions, forming a similar fold trend as in the northeast coast. However, within the NE-SW trend, there are tight synclines and anticlines, plunging into the ENE direction. These tight folds are interpreted to represent the first generation folds, which were formed during the earliest orogenic event in the area (f1). The open folds, which more or less trend to the north, represent the second-generation folds (f2).

Faults

The aerial photograph of the area indicates two sets of lineaments occur in the area, which may represent major joints or faults. Several normal faults, which are trending in the NNW direction, are observed in the metasediment at the eastern end of the island. The fault throws are between 2 and 3 meters and the width ranges between several centimeters to about 1 meter. Some of the faults produced fault gorge, one of them is about 1 meter thick and the fault filling material has weathered into brownish soil. At other places, the fault gorges are much thinner, in the order of tens of centimeters.

On the southern coast of the island, there is an ENE trending fault zone in the quartz porphyry, which consists of a number of parallel fault planes, dipping steeply towards NNW. This fault system is likely to have played a very important role in controlling the topography and the coastline of this part of the island. In the northwestern coast, a number of faults and shear zones are also present. Within the shear zones, the rocks are more deformed and are highly fractured. The structure of the island is shown in Figure 2.

Joints and veins

The rocks in this island are moderately to well jointed. Most of the joints are close to tight but in some directions they are open. Occasionally they are filled by quartz-forming veins. A systematic joint survey was conducted in metasediments and quartz porphyry at thirteen localities in the eastern part of the island.

STRUCTURAL ANALYSIS

Bedding attitude and fault data, which are very simple are not analysed and plotted. Data of strikes and dips of the joint planes from each locality were analysed separately by the method of plotting the pole of the plane on equal-stereonet. The concentration and percentage of each data group within the 1% stereoplot was determined using the available computer program. The plane representing each concentration is plotted to display the average strike and dip of a joint set. Example of the pole concentration and plane plot for locality 10 is shown in Figure 3. All the joint plots are put together on the geological map to show their change in orientation (strike and dip) from one place to another (Figure 4).

DISCUSSION

From the geological map of the eastern part of the island (Figure 2), it is very clear that the tight folds which are plunging towards NE are of the early generation. This fold was refolded with N-S axis at at later stage. Therefore, the simple fold in the northern coast of the island represents the refolded limb. The folding probably took place before the intrusion of the quartz porphyry in the area. After the igneous intrusion, the area underwent lateral extension, which was responsible for the development of normal faults and the formation of quartz veins. The formation of lateral faults and shear zones observed in the metasediments as well as in the igneous rock is related to the compressional phase suffered by the area. The east-west normal faults are related to the relaxation period following the compression.

The results of the joint analyses in quartz porphyry are summarized in Table 1, while joints from metasediments are summarized in Table 2. There are five joint sets in the area. The joints of every locality are grouped according to their orientation as J1, J2, J3, J4 and J5. The joints of the same strike but different dip angle are classified into the same joint group with different annotation as a, b and c.

As shown in Table 1 and Table 2, two joint sets are very prominent. The joint sets, which are trending in the

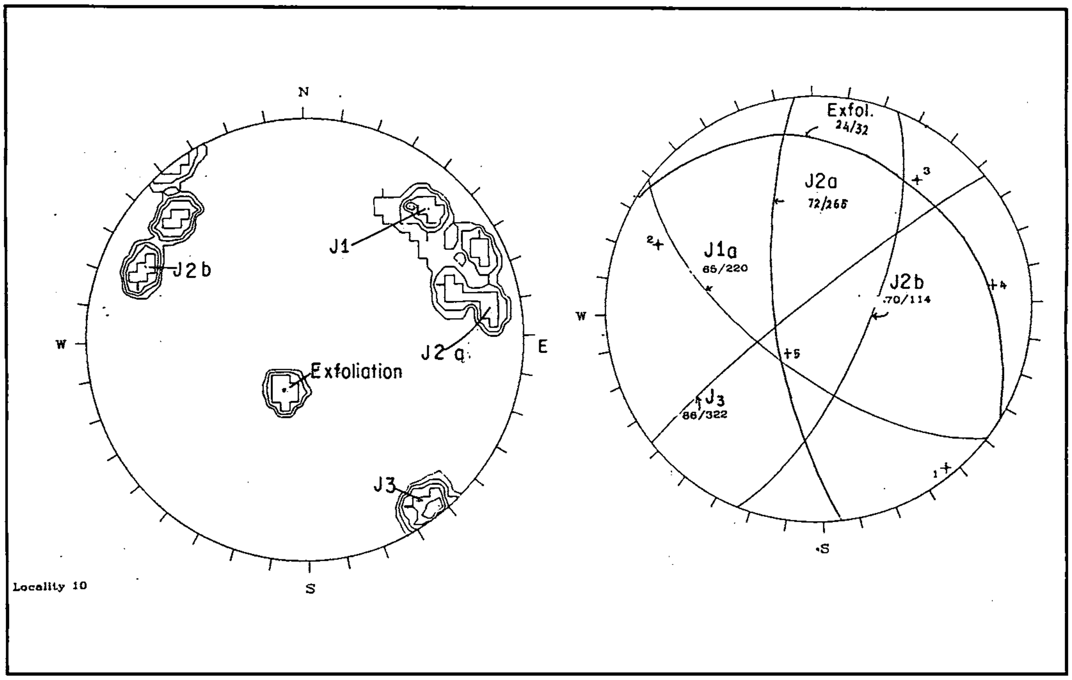

Figure 3: Pole concentration and joint plane plots at locality 10 indicating dip and dip direction of each joint set.

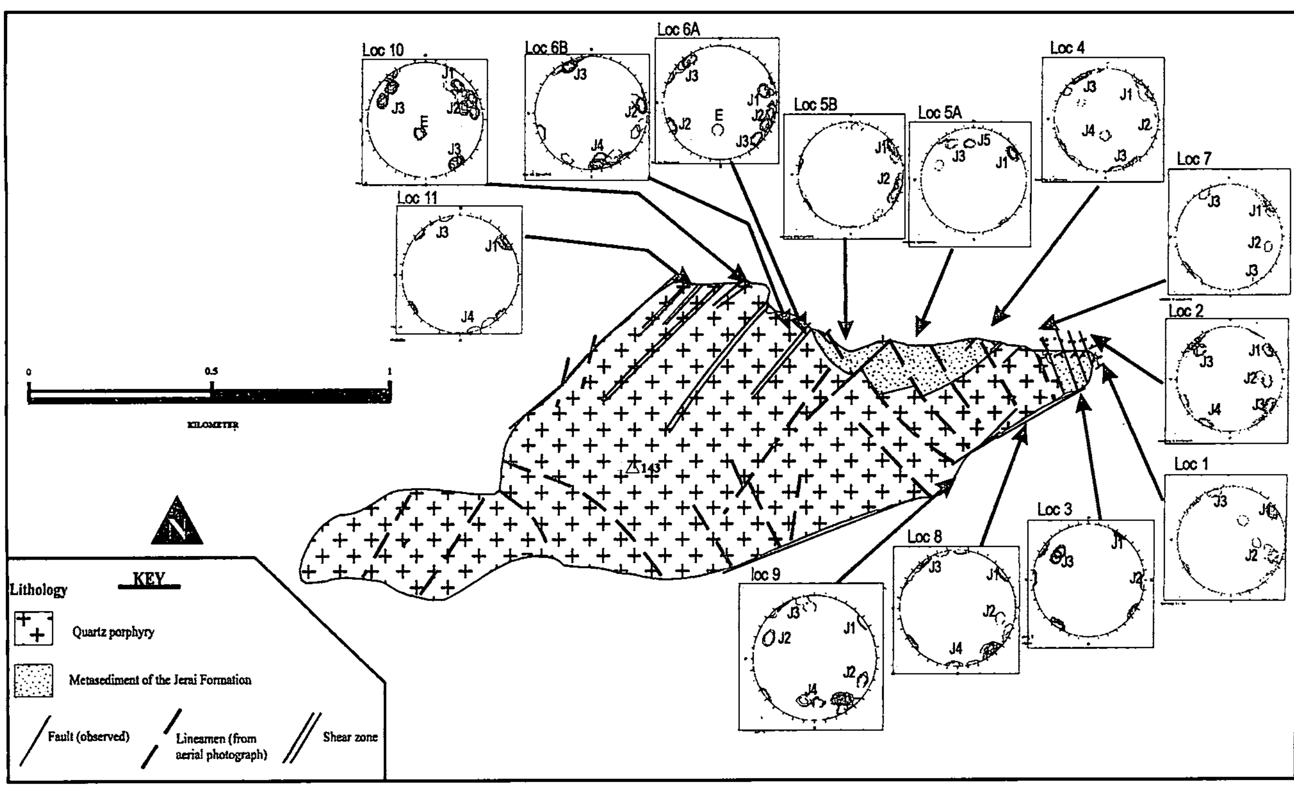

Figure 4: Geological map and joint orientation pole plots at various localities.

Table 1: Result of the joint analysis in the metasediments.

Locality	Strike/dip	Dip direction	Frequency %	Filling material	Slickensided	Remarks
1a-1c	J1a= 143/83	N 233 °E	25	Q (some)	Occasional	Major joint
	J1b= 327/88	N 57 °E	10	Nil	-	Minor
	J2 = 197/69	N 287° E	20	Nil	-	Major
	J3 = 222/84	N 312 °E	6	nil	-	Minor
2	J1 = 143/85	N 233 °E	15	Q (some)	Occasional	Major
	J2 = 180/66	N 270°E	10	-	-	Minor
	J3a=231/87	N 321 °E	20	-	-	Major
	J3b= 48/87	N 138 °E	15	-	-	Minor
	J3c= 46/73	N 136° E	12	-	-	Minor
	J4 =298/83	N 28 °E	12	-	-	minor
3	J1a=305/87	N 35 °E	25	-	-	Major
	J1b= 123/89	N 213 °E	25	-	-	Major
	J2 = 02/90	N 92°E	10	-	-	Minor
	J3a= 39/61	N 129°E	30	-	Occasional	Major
	J3b= 216/90	N 306 °E	20	Q (some)	-	major
4	J1a=128/82	N 218 °E	10	Q (some)	-	Major
	J1b=327/87	N 57° E	10	-	-	Minor
	J3a=239/87	N 329 °E	25	-	Occasional	Major
	J3b=59/87	N 149 °E	20	-	Occasional	Minor
	J4 = 273/24	N 03° E	5	-	-	minor
5a	J1 =145/80	N 235 °E	40	Q (some)	-	Major
	J3a=57/87	N 147 °E	10	-	-	Minor
	J3b=60/78	N 150 °E	10	-	-	Major
	J5 =86/58	N 176° E	10	-	-	minor
5b	J1 =143/85	N 233 °E	25	Q (some)	-	Major
	J2 =192/86	N 282° E	25	-	-	Major
	J2 = 235/79	N 325°E		-	-	Minor

Table 2: Result of joint analysis in the quartz porphyry.

Locality	Strike/dip	Dip direction	Frequency %	Filling material	Slickensided	Remarks
6a	J1=334/85	N 64 °E	15	Quartz	-	Major
	J2=172/75	N 262 °E	10	-	-	Minor
	J3a=48/81	N 138 °E	20	-	mostly	Major
	J3b=208/82	N 298 °E	25	-	mostly	Major
6b	J2a=171/80	N 261 °E	10	-	-	Minor
	J2b=340/82	N 70 °E	5	-	-	Minor
	J2c=200/80	N 290 °E	5	-	-	Minor
	J3=59/84	N 149 °E	25	-	occasional	Major
	J4=262/78	N 352 °E	25	-	-	Major
7	J1a=143/84	N 233 °E	40	Quartz	-	Major
	J1b=320/89	N 50 °E	25	-	-	Major
	J2=192/72	N 282 °E	10	-	-	Minor
	J3=238/88	N 328 °E	10	-	-	Minor
8	J1=325/89	N 55 °E	15	-	-	Major
	J2=194/72	N 284 °E	10	-	-	Minor
	J3=229/87	N 319 °E	30	quartz	-	Major
	J4=273/85	N 03 °E	10	-	-	Minor
9	J1=142/86	N 232 °E	10	-	-	Major
	J2a=206/73	N 296 °E	10	-	-	Minor
	J2b=23/70	N 113 °E	10	-	-	Minor
	J3=235/68	N 325 °E	25	-	occasional	Major
	J4=289/60	N 19 °E	10	-	-	Minor
10	J1a=130/65	N 220 °E	20	-	-	Minor
	J2a=175/72	N 265 °E	10	-	-	Minor
	J2b=24/70	N 114 °E	20	-	-	Major
	J3 =232/86	N 322 °E	25	-	occasional	Major
	E =302/24	N 32 °E	15	-	-	Minor, Exfoliation
11	J1a=144/85	N 234 °E	30	Quartz	-	Major
	J1b=325/87	N 55 °E	20	-	-	Minor
	J3=225/85	N 315 °E	10	-	occasional	Major
	J4= 255/87	N 345 °E	10	-	-	Minor

NNE and NW directions are named J1 and J3 respectively. Generally the prominent joints are steep to nearly vertical, some contain slickenside especially J3, indicating that they represent faults. At some localities, N-S trending (J2 set) and E-W trending (J4 and J5 sets) minor and major joints are present. The dip angle of the minor sets varies from steep to gentle. Apart from the prominent and minor joints, exfoliation joints have also developed at a number of localities. They are generally almost parallel to the topography, but at some places they are slightly steeper.

As indicated in Figure 4, Table 1 and Table 2, quartz veins have developed in two directions, parallel to either J1 or J3 joints. Most of the quartz veins are in the metasediments except for one which is in quartz porphyry, parallel to J3 joints (locality 8).

CONCLUSION

From the study it is concluded that there are five joint sets in the area. Each locality may have between two and four joint sets. The directions of two prominent sets are very consistent with the orientation of the faults and lineaments in this area. The quartz veins are also aligned in about the same direction as major joints.

The sequence of deformational events that have taken place in the geological history of the area can be summarized as follows:

a. Deposition and lithification of sedimentary rocks may have taken place in Cambrian times since this rock formation is equivalent to the Cambrian Machinchang Formation in Langkawi (Jones, 1968).
b. The sedimentary rocks were folded and underwent regional metamorphism, most possibly during the mid-Paleozoic time (Koopmans, 1972). Based on the regional trend of the rocks of the same age which is aligned in the NNW direction, the regional compression during the orogeny and folding phase was from the ENE direction.
c. Refolding of metasediments produced open folds trending towards the north as a result of mild east-west compression. This refolding has caused some degree of rotation on the pre-existing regional structural trend.
d. The intrusion of quartz porphyry has caused rotation and thermal metamorphism, which has resulted in the formation of hornfelsic rocks close to the contact with the igneous body.
e. The area has undergone a period of tension in the NE-SW direction. The event has brought about the development of normal faulting and quartz veining, both strike about perpendicular to the direction of tension.
f. Compression from almost N-S direction has resulted in the development of left lateral (sinistral) fault of shear zones striking NE-SW. This stress system may also have caused the right-lateral movement on the pre-existing NNW normal fault.
g. Relaxation during this period may have resulted in normal movements along pre-existing faults.
h. Weathering and erosion have removed most of the material (metasediments) overlying the quartz porphyry and caused pressure release and subsequently led to the development of exfoliation joint planes in the igneous body, almost parallel to the ground surface.

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