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A Combined Petrographic-Geochemical Provenance and Tectonic Setting Study of Palaeozoic Rocks, in East Johor Basin, Peninsular Malaysia

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Abstract - Several greywacke sandstones considered as Paleozoic rocks are found in three different formations, *i.e.* the Dohol, Linggiu, and Tanjung Leman Formations within the Palaeozoic East Johor Basin. The compositions of twenty-nine sandstone samples were identified using petrographical and geochemical methods to determine the provenance of sandstones as well as the tectonic setting of pre-and syn-sedimentation. Seven samples of them were examined using point counting method to obtain the mineralogical compositions. This petrographical point counting was done by plotting composition percentages to QFL and QmFLt triangular diagrams. The results showed a magmatic arc for Dohol Formation, a change from a magmatic to a recycled orogen for Linggiu Formation, and a recycled orogen for Tanjung Leman Formation. The recycled orogen tectonic setting of Linggiu and Tanjung Leman may have come from the underlying metamorphic and sedimentary rocks of Mersing and Murau Formations. Meanwhile, twenty-two samples were examined using a geochemical method by utilizing the ratio of K_2O/Na_2O and SiO_2 . The samples suggest a tectonic setting from both passive continental margin (PM) and active continental margin (ACM). Based on these findings, it is interpreted that the sedimentary rocks in East Johor were deposited in a subduction-related basin, such as fore-arc, magmatic arc, and back-arc.

Keywords: Paleozoic rocks, petrography, geochemistry, provenance, tectonic setting

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INTRODUCTION

Background

The East Johor Palaeozoic Basin is a Palaeozoic sedimentary basin which covers the whole southern part of the Eastern Belt of Peninsular

Malaysia (Surjono, 2007). It is mainly composed of the Carboniferous to Permian rocks which have a trend of northwest-southeast from Sungai Endau to Tanjung Pengerang areas. According to Metcalfe (2013), the Eastern Belt represents the arc and its continental basement derived from

Indochina that has been eroded to a lower level than the central belt. The researched area overwhelms about 6,250 km² in the eastern part of Negeri Johor. It roughly lies within the latitude of N 1°40' to N 3°00', and the longitude of E 103°20' to E 104°20' (Figure 1). The provenance studies within petrographic and geochemical approaches are actually related to various variables, such as climate, tectonic setting, and tectonism (Basu *et al.*, 1975; Dickinson and Suczek, 1979; Suttner *et al.*, 1981; Bhatia, 1983, 1985; Roser and Korsch, 1986; Dickinson, 1988). This study has been widely carried out by many researchers as a tool for analyzing source rock and tectonic setting which will then be developed according to the purposes of each study. This research aims to reveal the tectonic setting of source rocks within the East Johor Basin Formations to reconstruct the palaeogeographical condition of the basin within the period of Permian age based on the integrated data of geochemical and petrographical study.

Geological Setting and Stratigraphy

According to Hutchison and Tan (2009), the geology of Peninsular Malaysia is grouped into

four main tectonostratigraphic units, *i.e.* the Western Belt, Central Belt, Eastern Belt, and Bentong-Raub Suture Zone. In this case, the researched area is located in the Eastern Belt which is mainly composed of shallow marine Carboniferous sediments with minor Permian conglomerates and associated rhyolite-andesite volcanics (Oliver *et al.*, 2014).

The Palaeozoic rocks in East Johor Basin comprise several metasedimentary to metamorphic rocks, siliciclastic, and volcanic rocks that have Carboniferous and Permian ages. These sequences are grouped into seven different lithostratigraphic units comprising Mersing, Murau, Dohol, Linggiu, Sedili, Pengerang, and Tanjung Leman Formations. The distribution of the Palaeozoic rocks in East Johor Basin as well as the stratigraphic relationship among them can be seen in the Figure 2. The brief summary of those is explained below:

Mersing Formation is well-known as the basement rock in Johor as stated by Hutchison (1989). The outcrop can be found in some areas of eastern Peninsular Malaysia including the coastal area from the bauxite-mining district of Pengerang, Desaru, Mersing, and Endau area in

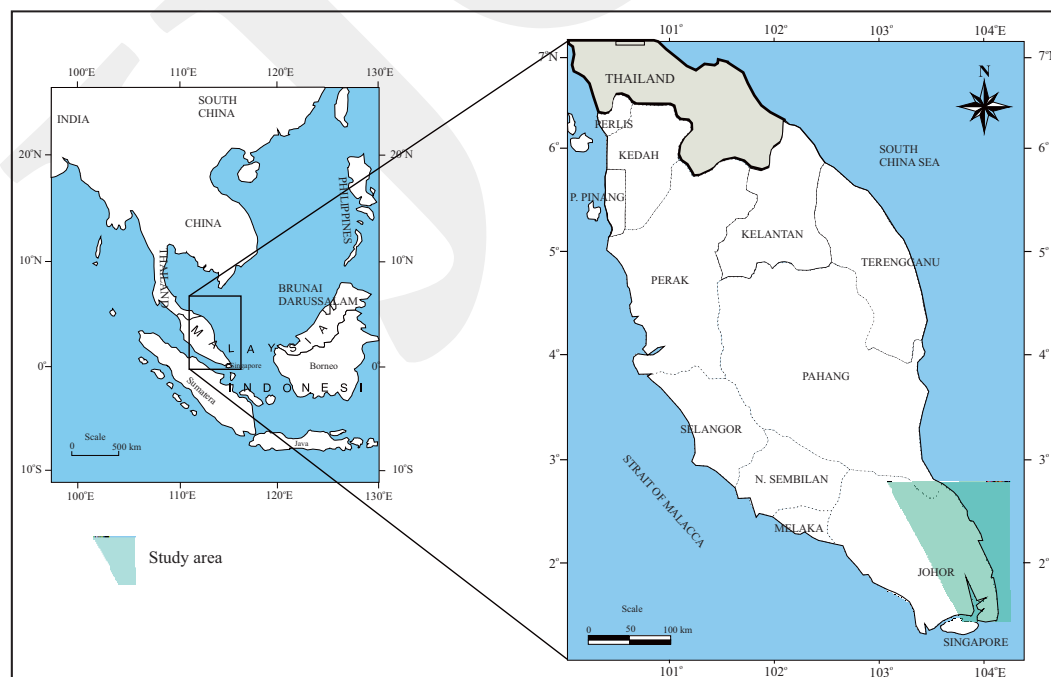


Figure 1. Location of the study. Eastern part of Negeri Johor is considered as the East Johor Basin consisting of Paleozoic metamorphic, sedimentary, and volcanoclastic rocks to the recent sediments.

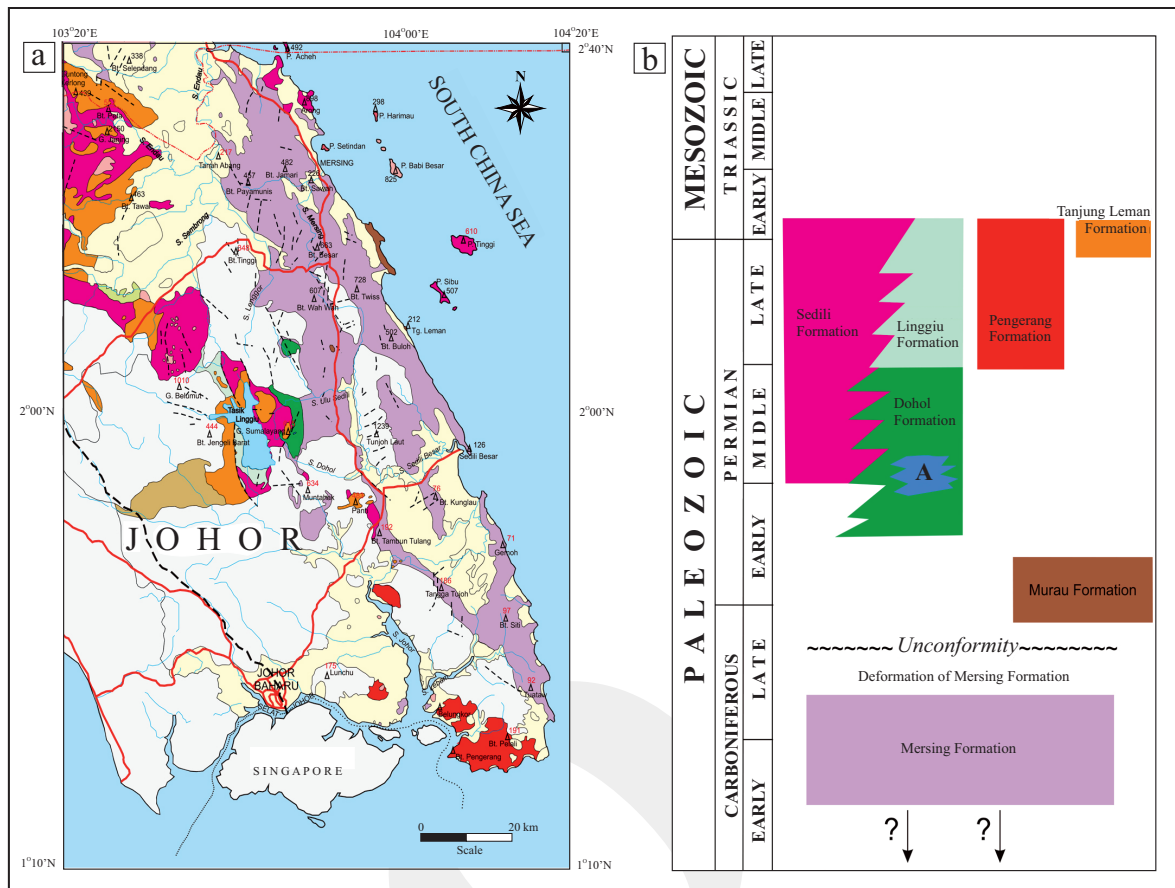


Figure 2. (a). Palaeozoic-Mesozoic geological map of Eastern Belt of Peninsular Malaysia and (b). Stratigraphic relationship of East Johor Palaeozoic rock formations (Modification after Surjono *et al.*, 2006).

Southeast Pahang. This formation mainly consists of slate, phyllite, argillite, schist, quartzite, and metaquartzite. The age of the formation is determined by correlating it with several other Carboniferous rocks in the northern part of Eastern Belt of Peninsular Malaysia. Thus, the age of this formation is assumed as Carboniferous. Surjono and Leman (2010) stated that the general fining-upward sequence with numerous linear, thin sandstone bodies, cross-stratified, and interbedded sandstone was similar to the shallow marine transgressive sequence. It is also found on a detailed relict structure within the metasandstone that the rocks were deposited in a shallow sea. In addition, the relationship between the basement rock and other younger rocks is unconformable.

Murau Formation lies in the southernmost of Eastern Peninsular Malaysia, and comprises a disorganized and thick breccia, gravelstone, and also sandstone. It should be Late Carboniferous

in age based on the unraveled fact of volcanic elements absence in Murau Formation.

Dohol Formation is mostly found in Gunung Sumalayang. The lithology within the formation is argillaceous sediments comprising the interbedded mudstone, shale, siltstone, and sandstone with the subordinate composition of tuffaceous sandstones. In the middle of the Dohol Formation succession, lenses of limestone develop inserting the whole sequences. Its age has been claimed by Igo *et al.* (1979) as late Early Permian to early Middle Permian based on the microfossil analysis. Furthermore, the deposition of Dohol Formation was coetaneous with the Sedili Formation deposit and it is conformably overlain by the Linggiu Formation.

Linggiu Formation can be discovered in the west of Gunung Sumalayang area. Its lithology consists of sandstone, siltstone, shale, phyllitic-shale, with a minor composition of conglomerate

and tuffaceous sandstone. Based on the observation of plant fossil contents within the siltstone, the age of this formation has been determined by Kon'no *et al.* (1971) as Late Permian.

Sedili Formation is distributed in several wide areas involving the Gunung Sumalayang, Sungai Ulu Sedili, and Gunung Chemendong. The dominant constituents of this formation are lava and volcanoclastic rocks, either pyroclastic fall or flow deposits. The compositions of those rocks are acid and intermediate volcanic types according to given data by Rajah (1968, 1986). Since the Sedili Formation interfingers with Dohol and Linggiu Formations, its age should be similar to them which are Early to Late Permian. The Pengerang Formation mostly spreads in Pengerang area. The rocks dominantly contain a rhyolitic to andesitic lava and resedimented volcanoclastic deposits. The Pengerang Formation probably has a frontier age with upper Sedili Formation.

Tanjung Leman Formation dominantly spreads in the Tanjung Leman area. The lithology encompasses conglomerate, sandstone, and mudstone. This is known as the youngest Palaeozoic rocks in East Johor Basin. It is also inferred to be equivalent with the topmost of Sedili Formation.

Tectonic Events

According to Mustafa and Abdul Hadi (1999), the tectonics in Peninsular Malaysia can be grouped into four events, *i.e.* Early to Middle Devonian, Middle Permian (the Variscan event), Late Triassic (Indosinian event), and Middle to Late Cretaceous events. Meanwhile, Surjono (2007) identified tectonic events in East Johor during Palaeozoic as follows: (1) the uplifting and metamorphism of Mersing Formation, (2) formation of Murau half graben (3) volcanism, and (4) uplifting and metamorphism of all Palaeozoic rocks forming subaerial depositional environment. The uplifting and metamorphism of Mersing Formation is started by the regional metamorphism. This metamorphism is interpreted to take place prior to the sedimentation of Murau Formation in Late Carboniferous–late Early Permian Murau Formation. In accordance

with this, the subduction of Palaeo-Tethys into Indochina-East Malaya terrane took place after the metamorphism causing a pressure accumulation which initiated deformation and uplifting of the sedimentary rocks.

According to Surjono (2007), after the uplifting and metamorphism of Mersing Formation, the tectonic event continued to an extensional phase within the continental plate when Palaeo-Tethys oceanic plate broke up and began to create a subduction beneath the Indochina-East Malaya continental plate. As the result, a northward compression was undergone by the Indochina-East Malaya continental plate during the northward movement of Palaeo-Tethys oceanic plate. This compression has caused the oceanic plate to shorten and fold. The subduction of Palaeo-Tethys into East Malaya continental block during the late Early Permian was more active forming volcanic arc in the region. This last period of volcanism resulted in Tanjung Leman Formation. The volcanism was finally stopped during the Middle Triassic time when Eastern Granite Belts regionally intruded all Palaeozoic rocks as interpreted by Metcalfe (2000).

MATERIALS AND METHODS

All twenty-nine samples used in this paper were obtained using a purposive sampling method for representative all stratigraphic succession. Some were used in a petrographic observation, and the others were used in a geochemical analysis. The quantification of sandstone composition used point-counting method by using Glagolev Chayez (Galehouse, 1971) on seven thin sections. Three hundred minerals and lithic grains of sediment in total were identified from each thin section. The result was plotted following the concept of Dickinson and Suczek (1979) triangular diagram to determine the source rocks and the tectonic setting. This method has been utilized for decades until now, such in the study of Tertiary and Mesozoic rocks in Asia (Jianghai *et al.*, 2009; Kundu *et al.*, 2016). This method calculates the

number of quartz, feldspar, and detrital lithic in sandstone samples to determine the tectonic setting which is divided into three main groups: continental block, magmatic arc, and recycled orogen. The observed samples for petrographic analysis were counted based on seven samples acquired from three different formations: Dohol, Linggiu, and Tanjung Leman. These formations were selected for provenance study, because they consist of clastic sedimentary rocks. The geochemical approach in this paper refers to the classification of Roser and Korsch (1986) to interpret the tectonic setting. The percentage of SiO_2 against $\text{K}_2\text{O}/\text{Na}_2\text{O}$ is plotted in a scatter diagram to result in the type of the tectonic setting. In this case, it can be classified into three kinds of tectonic settings: the oceanic- island-arc margin (ARC) which is marked by the lowest content of SiO_2 and $\text{K}_2\text{O}/\text{Na}_2\text{O}$, the passive margin (PM) which is marked by the highest content of SiO_2 and $\text{K}_2\text{O}/\text{Na}_2\text{O}$, and the active continental margin (ACM). The samples used in the geochemical analysis are twenty-two samples consisting of eight samples of phyllite, schist, and metasandstone from Mersing Formation, two mudstone samples from Murau Formation, eight samples of shale, sandstone, and tuffaceous sandstone from Dohol Formation, and four samples of siltstone, sandstone, and tuffaceous sandstone from Linggiu Formation. Those samples were considered to be representative for the formations of Paleozoic

rocks in the studied area. The chemical composition of those was examined by using X-ray fluorescence technique (XRF). In other cases, this geochemical method can also be applied to igneous rock such as granite, and commonly elaborated with the trace element and REE data analysis (Irzon, 2015; 2017).

DATA ANALYSES

Petrographic Approach

The result of point counting method in the petrographic analysis is synthesized in Table 1. The detrital rock composition is divided into eight components: quartz monocrystalline (Qm), quartz polycrystalline and chert (Qp), plagioclase feldspar (P), K-feldspar (F), volcanic lithic (Lv), sedimentary lithic (Ls), metamorphic lithic (Lm), and matrix (Mt). The mineralogical component was examined using a petrographical analysis (Figure 3) used for the rock classification and provenance study.

The significant difference of mineralogical component is represented by quartz content of LGU-6 around 65.5% compared to LGU-5 which relatively has a lower abundance that is only 15.40%. This reflects a source rock mixing in Linggiu Formation from both continental source and any other sedimentary supply during the deposition of this formation which likely to occur

Table 1. Percentage of Detrital Composition in Sandstone Samples

Sample Code	Formation	Qm (%)	Qp (%)	P (%)	F (%)	Lv (%)	Ls (%)	Lm (%)	Mt (%)
SML-1	Dohol	7.00	2.00	12.00	2.50	6.50	2.00	15.00	53.00
SML-6	Dohol	9.50	3.50	40.00	5.00	9.00	1.00	6.00	26.00
LGU-5	Linggiu	15.40	5.40	12.00	6.60	11.50	0.50	13.10	35.50
LGU-6	Linggiu	65.50	10.50	0.50	0.00	3.50	9.25	8.25	2.50
TGL-1	Tg. Leman	4.25	8.00	0.00	0.00	8.00	3.50	68.75	7.50
TGL-2	Tg. Leman	13.25	37.25	0.00	0.00	4.50	2.00	20.50	22.50
TGL-4	Tg. Leman	12.50	32.00	3.00	2.25	7.25	7.00	10.75	25.25

(*) Mineral abbreviations: Qm= monocrystalline quartz, Qp= polycrystalline quartz, P= plagioclase, F= fragments, Lv= volcanic lithics, Ls= sedimentary lithics, Lm= metamorphic lithics, Mt= matrix.

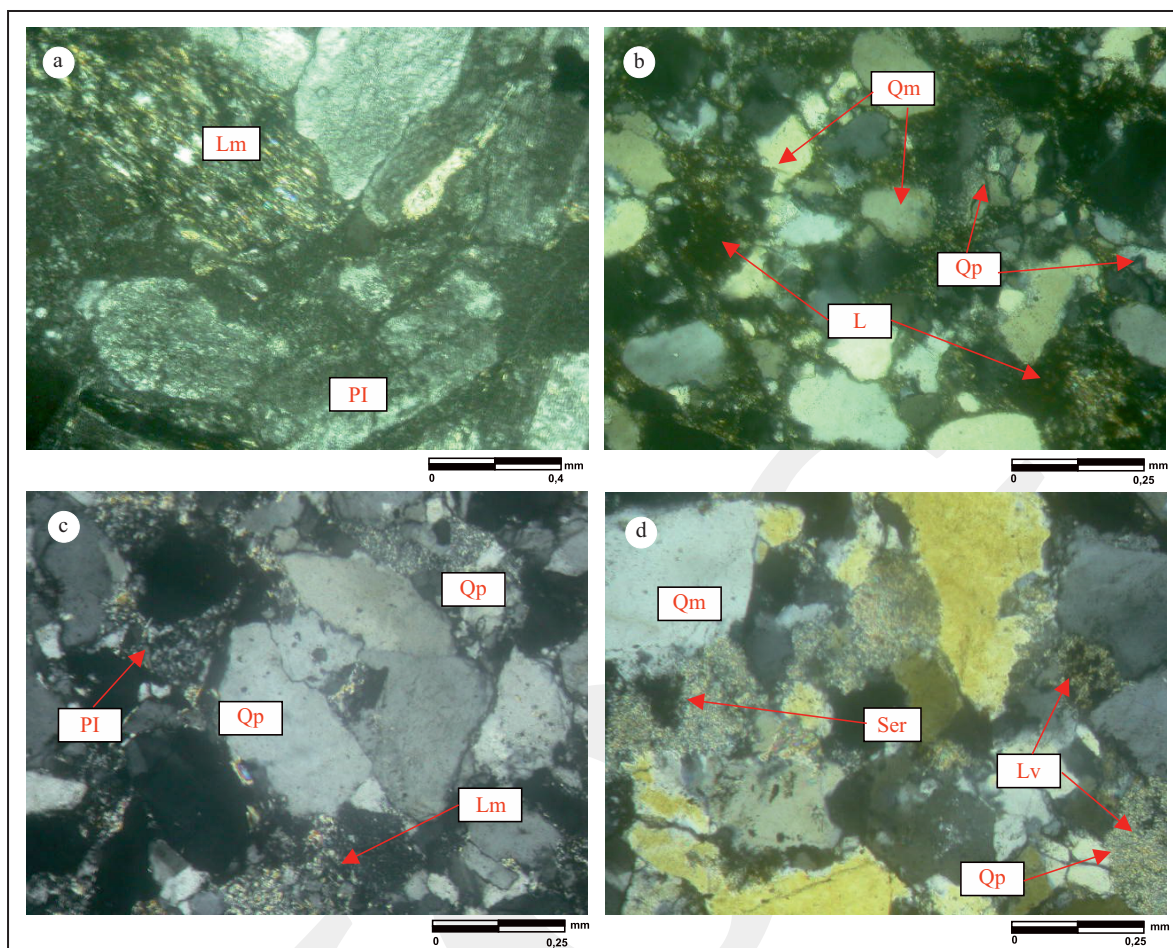


Figure 3. Photomicrographs of thin sections of sandstones under the cross-polarized microscope: (a) fine-grained volcanic material of clay sized mineral (altered to minor sericite) and metamorphic lithics (shale and argillite) observed in Dohol Formation; (b) LGU-6 from Linggiu Formation mainly consists of mono-, poly-crystalline quartzs, and weathered lithics; (c) TGL-2 from Tanjung Leman Formation mainly comprises polycrystalline quartz, lithics (quartzite and schist), and weathered plagioclase; (d) TGL-1 from Tanjung Leman Formation composed mainly of volcanic lithics, sericite, and quartz. *Min. Abbreviations: Qp= polycrystalline quartz; Qm= monocrystalline quartz; L= Lithics; Lm= metamorphic lithic; Lv= Volcanic lithic; Ser= Sericite; Pl= Plagioclase (mineral abbreviations following Siivola and Schmid, 2007).

when the depositional environment was placed between two source-rock areas. Meanwhile, plagioclase also exhibits distinctive mineralogical content ranging from 0% to 40%, particularly in Tanjung Leman and Dohol Formation. A less abundance of plagioclase in Tanjung Leman can be associated with the source area which has undergone a massive tectonic phases and erosion supplying sedimentary material for this formation (recycled orogen). As for the Dohol Formation, a high abundance of plagioclase may have been derived from any magmatic arc which continuously supplied plagioclase-rich material to the depositional environment.

Two Dohol sandstones portray a quite different composition. SML-1 is dominated by matrix component, while SML-6 dominantly constitutes feldspar particle. Similarly, there is also a significant difference in Linggiu sandstone. LGU-5 mostly contains matrix with subordinate quartz, whereas LGU-6 is clearly dominated by quartz. On the other hand, Tanjung Leman sandstones exhibit a low content of feldspar.

It can also be seen that five out of seven observed samples have more than 15 % of matrix content. It indicates that those are plotted as a type of greywacke sandstone following the classification of Pettijohn (1975). Those five samples

are classified as greywacke sandstones (Table 2). Both greywacke and sandstone can more specifically be defined by the dominant constituent of the detrital grain (quartz, feldspar, and lithic) within the sandstone samples. The specific names of samples obtained from Dohol, Linggiu, and Tanjung Leman for petrographical analysis are listed on Table 2.

Table 2. Petrographic Name of Sandstone Samples According to Classification of Pettijohn (1975)

Sample Code	Formation	Pettijohn's Name
SML-1	Dohol	Lithic greywacke
SML-6	Dohol	Feldspathic greywacke
LGU-5	Linggiu	Lithic greywacke
LGU-6	Linggiu	Sublitharenite
TGL-1	Tg. Leman	Lithic arenite
TGL-2	Tg. Leman	Lithic greywacke
TGL-4	Tg. Leman	Lithic greywacke

The detrital components of quartz, feldspar, and lithic within the sandstones are advantageous not only to define the specific rock name but also to determine the tectonic setting. The matrix contained within the rock has to be excluded from the calculation, therefore, the amount of detrital particles should be normalized to 100% (Table 3). The resulted data are plotted into basic ternary diagrams of Qt-F-L (Figure 4a) and Qm-F-Lt (Figure 4b) (Dickinson *et al.*, 1983). Qt reflects the abundance of polycrys-

talline and monocrystalline quartzs, while Lt portrays the accumulation of rock fragments/lithic and polycrystalline quartz. Based on the plotting in the two diagrams (Figure 4), the tectonic setting of the Dohol Formation falls in a magmatic arc, whilst Linggiu Formation is a mixing of magmatic arc and a recycled orogeny.

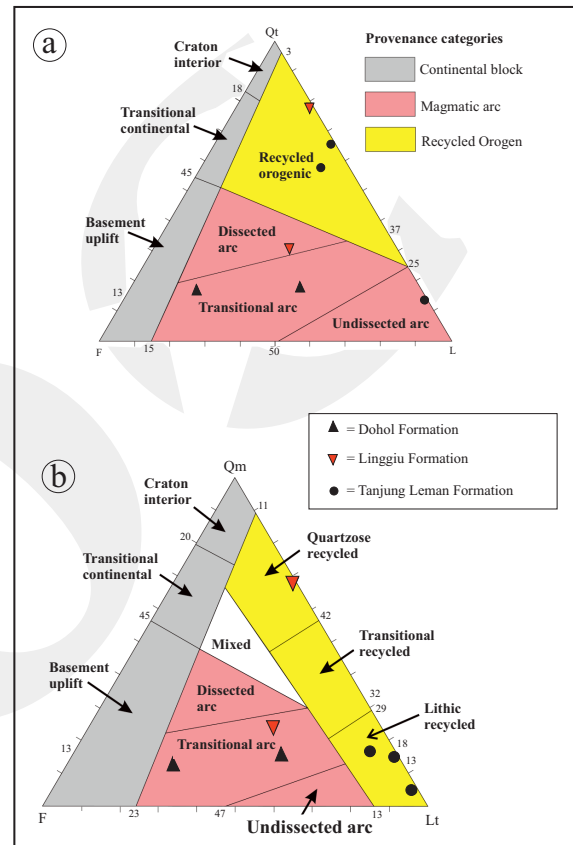


Figure 4. QtFL and QmFLt plotting (a and b) of Dohol, Linggiu, and Tanjung Leman sandstones in Dickinson triangle diagram (after Dickinson *et al.*, 1983).

Table 3. Petrographic Percentage Composition of Sandstone (Matrix excluded; normalized to 100%)

Sample Code	Formation	Qm (%)	Qt (%)	F (%)	L (%)	Lt (%)
SML-1	Dohol	20.00	25.70	7.15	67.15	72.80
SML-6	Dohol	27.90	38.25	14.70	47.05	57.40
LGU-5	Linggiu	29.40	39.70	12.60	47.70	58.00
LGU-6	Linggiu	67.50	78.35	-	21.65	32.50
TGL-1	Tg. Leman	5.03	13.25	-	86.75	94.97
TGL-2	Tg. Leman	17.10	65.15	-	34.85	82.90
TGL-4	Tg. Leman	17.40	62.00	3.15	34.85	79.45

Meanwhile, the Tanjung Leman Formation is a recycled orogeny.

The provenance of Dohol and some parts of Linggiu Formations are from magmatic-arc tectonic setting. It indicates that the rocks were partially supplied by the volcanic materials which are rich in feldspar content. Possibly, those volcanics came from Sedili Formation interfingering with both formations above, or it can also be from the previous volcanism event. It can also be interpreted that the lithology within the Sedili Formation was subsequently resedimented and mixed with other siliciclastic particles forming Dohol and Linggiu sandstones. The occurrence of Linggiu sandstone in recycled orogenic setting (Figure 4a) suggests that the provenance was possibly also from the orogenic uplift or basement metamorphic rock. Based on the plotting result in QmFLt diagram (Figure 4b), it indicates that the Linggiu sandstone was also primarily resulted from quartzose recycled. Thus, the parental rock must be rich in quartz. In this study, in East Johor Basin, the provenance rock of the Linggiu quartz-rich sandstone was probably the exposed proto-East Malaya continental block. The long transportation process of particles had enriched the quartz content within sandstone. During this process, the non-resistant components such as lithic or any unstable minerals had been selectively removed along with the process (Dickinson *et al.*, 1983).

Based on the plotting result of Tanjung Leman Formation (Figure 4), the provenance is mainly a recycled orogen. Related to its contact with other formations, the source rock of this formation can be interpreted from metamorphic and sedimentary rocks of Mersing and Murau Formation evidenced by the high abundance of quartz and metamorphic lithics. However, Surjono (2007) added that volcanic materials are present within the Tanjung Leman Formation as fragments and matrix. This condition also indicates that Tanjung Leman Formation was deposited contemporaneously or post volcanism in East Johor Basin. Deposited contem-

poraneously with the Tanjung Leman, Linggiu Formation exhibits a minimum abundance of observed feldspar. This condition is possibly triggered by the low stability of the mineral so that it can be easily exsolved in solution during the transportation process (Pettijohn *et al.*, 1987). Therefore, the depositions of these two formations were relatively affected by the same depositional mechanism.

The Dohol, Linggiu, and Tanjung Leman reflect a significant change as relation to the tectonic setting occurring within the Peninsular Malaysia, particularly during the Early to Late Permian (255 to 300 Ma). This exhibits both volcanic source and recycled lithic material from the older sediments. The Linggiu and Dohol Formations were directly affected by the volcanism event that possibly occurred within the period of Early to Late Permian. Meanwhile, the Tanjung Leman shows a lithic recycled provenance indicating a post or contemporaneous deposition with this volcanism event (Surjono, 2007). The effect of volcanism can be interpreted from the occurrence of volcanic clay-sized matrix material altered to sericite (Figure 3).

Geochemical Approach

The geochemical analysis in this paper is only stressed on major elements, *i.e.* SiO_2 , Na_2O , and K_2O , from Mersing, Murau, Linggiu, and Dohol Formations of late Early Carboniferous to Late Permian (320 Ma to 255 Ma) in age.

From the geochemical data analysis (Table 4), it shows that most of the samples are strongly rich in SiO_2 which has an average of approximately 76%. The obtained data are used for the calculation to determine the tectonic setting based on the classification of Roser and Korsch (1986) using the ratio of three main major elements: SiO_2 , K_2O , and Na_2O . All three observed data resulted in either passive continental margin (PM) or active continental margin (ACM). It is characterized by a distinctive decrease of $\text{K}_2\text{O}/\text{Na}_2\text{O}$ against increasing of SiO_2 value (Figure 5). Referring to Roser and Korsch (1986), PM is

Table 4. Major Element Concentration in Weight Percent of Twenty-two Observed Samples in the Studied Area

Samples	Formation	Lithology	SiO ₂ (%)	Na ₂ O (%)	K ₂ O (%)
Kpt-1	Mersing	Schist	96.32	0.50	0.42
Kpt-2	Mersing	Schist	97.72	0.50	0.20
Kpt-4	Mersing	Phyllite	63.20	0.75	4.99
Mrs-1	Mersing	Metasandstone	94.42	1.00	0.82
Mrs-3	Mersing	Metasiltstone	92.40	1.05	1.24
Mrs-4	Mersing	Schist Chlorite	60.24	2.16	5.49
Tmr-1	Mersing	Schist Chlorite	94.43	0.87	1.01
Tmr-2	Mersing	Phyllite	69.88	2.46	3.36
Skp-2	Murau	Mudstone	61.67	0.72	5.32
TM-1	Murau	Mudstone	61.76	1.55	4.71
SML-1	Dohol	Tuffaceous Sandstone	72.35	2.30	4.45
SML-2	Dohol	Tuffaceous Sandstone	74.68	0.58	3.40
SML-3	Dohol	Fine Sandstone	68.40	0.43	3.58
SML-4	Dohol	Mudstone	71.54	0.41	1.89
SML-6	Dohol	Calcareous sandstone	55.01	4.41	2.1
SML-10	Dohol	Calcareous shale	57.69	1.04	3.46
SML-11	Dohol	Calcareous shale	27.89	0.34	0.91
LGU-4	Linggiu	Siltstone	70.69	0.79	4.76
LGU-6	Linggiu	Sandstone	98.82	0.83	0.45
LGU-7	Linggiu	Tuffaceous Sandstone	74.34	3.78	2.81
LGU-8	Linggiu	Tuffaceous Sandstone	77.23	3.83	4.06

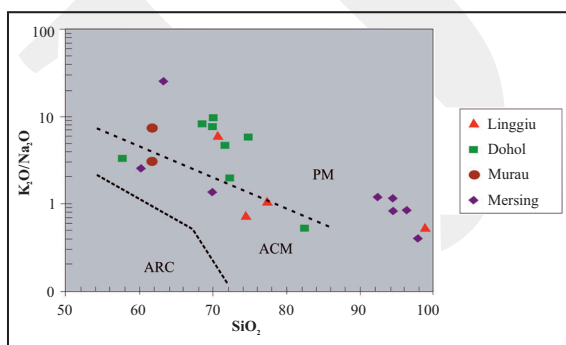


Figure 5. K₂O/Na₂O against SiO₂ diagram of observed samples in the studied area based on the classification of Roser and Korsch (1986).

mineralogically marked by quartz-rich sediments deposited on a plate interior at stable continental margins or intracratonic basins. Meanwhile, ACM sediment usually has an intermediate abundance

of quartz derived from tectonically active continental margins.

Based on the diagram in Figure 5, it shows that East Johor Palaeozoic Basin is composed of mixed-derived material sources which came from both Passive Margin and Active Continental Margin. Once, Roser and Korsch (1986) interpreted that PM and ACM usually indicated a fore-arc basin setting product. In addition, Einsele (2000) claimed that an ideal succession of fore-arc basin comprises fluvial and deltaic sands, shallow marine sands and shale, flysch-like shale-sandstone sequences, and abyssal-plain sediments.

Based on Figure 5, it can be inferred that passive margin tectonic setting is mainly resulted from the older sediment samples in East Johor

comprising the Mersing and Murau Formations. Surjono (2007) and Surjono and Leman (2010) interpreted that metasedimentary and metamorphic rocks of Mersing Formation are rich in quartz mineral, indicating a cratonic-derived material originated from the East Malaya Continental Block. In Early Permian (300 Ma), Murau Formation was deposited as a product of sedimentation and transportation process of uplifted Mersing Formation which had undergone a massive weathering and erosion forming several alluvial fans along the boundary. This condition is somehow similar to the depositional process of early deposited Dohol Formation composed of polycrystalline quartz grain originated from Mersing metamorphic rocks (Surjono, 2007). The abundance of Mersing-derived material has affected the Passive Margin (PM) source in Dohol and Murau Formations as indicated in Figure 5. Based on the above explanation, the tectonic setting model can be established (Figure 6). Thus, it could be interpreted that the tectonic setting of Murau Formation was in the back-arc basin of intraplate, while Dohol and Linggiu Formations were deposited whether in a fore-arc, magmatic arc, as well as back-arc basin tectonic setting which was contemporaneous to

Sedili Formation and Pengerang Formation (volcanics) that strongly indicate to develop within magmatic arc.

The result of sample diagram plotting which is within Active Continental Margin (ACM) (Figure 5) indicates that the existence of a volcano in eastern Johor probably occurred after the deposition of Early Dohol Formation (Middle Permian). Hutchison (1973a, 1973b) suggested that the age of granite and the volcanic rocks in eastern Johor Basin was around Carboniferous to Permian. However, Metcalfe (2000) also claimed that some Carboniferous volcanoes existed in the Eastern Belt based on his discovery of numerous volcanic rock contents in Charu and Sagor Formations. A latest research done by Searle *et al.* (2012) suggests that the Eastern Malaya granitoid plutons mainly comprise I-type subduction related, and have U-Pb zircon ages ranging from early Middle Permian to early Late Triassic. This subduction-related pluton can justify that this ACM condition should exist during the Permian time. Since Mersing Formation is originally parental rocks of Murau Formation, the volcanic material within Mersing Formation should have been resedimented into Murau depositional environment. Therefore, the plotting of chemi-

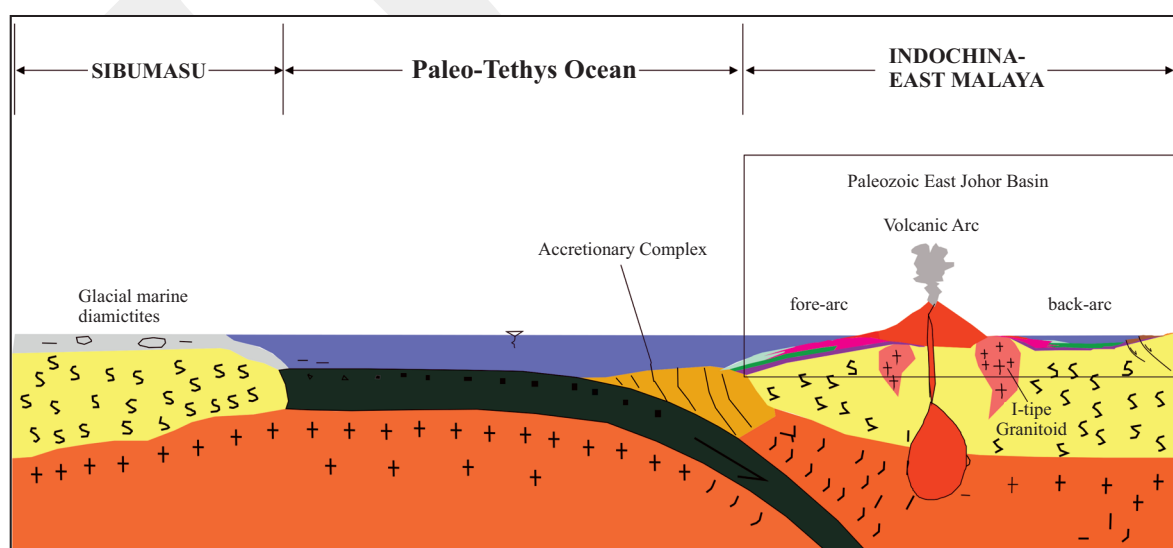


Figure 6. Geological reconstruction of East Johor Basin during Early Permian to Late Permian when the Mersing, Murau, Dohol, Linggiu, Sedili, and Tanjung Leman Formations were situated in the active margin tectonic setting in association with volcanic arc (modified after Surjono, 2007).

cal analysis of Murau samples partially results in Active Continental Margin tectonic setting (Figure 5). However, the present study did not discover the presence of volcanic rocks within Mersing Formation.

TECTONIC SETTING MODEL

Regarding the above discussion, it can be inferred that the tectonic setting of East Johor Palaeozoic Basin in the period of Carboniferous to Late Permian is a subduction-related basin. In this way, a sedimentary basin may exist as a back-arc basin, a fore-arc basin, a magmatic or a volcanic arc, subduction zone, trench, or sea floor (Boggs, 1987). The tectonic setting of East Johor Basin during the Early Permian and Late Permian time is modelled in Figure 6. It exhibits that East Johor Basin has been influenced by eastwards subduction of Paleo-Tethys into Indochina-East Malaya continental block. This subduction originated East Malaya magmatic arc in the middle axis of East Johor, fore-arc basin in the west of the magmatic arc, and back-arc basin in the eastern of the volcanic arc. Thus, it could be interpreted that volcanics of Sedili and Pengerang Formations are largely deposited in a volcanic-arc basin. Contemporaneously, Dohol and Linggiu Formations are also deposited whether in fore-arc, magmatic-arc, or back-arc basins. This interpretation is also supported by recent distribution of both formations around Sedili Formation in Gunung Sumalayang area. Murau Formation was deposited in a back-arc basin of intraplate, while Tanjung Leman Formation was deposited in a continental plate in association with the volcanic arc. On the other hand, the oldest Palaeozoic rocks in East Johor Basin, Mersing Formation, should be deposited preceding subduction of Paleo-Tethys oceanic plate into East Malaya continental blocks. Therefore, Mersing Formation was possibly deposited in a passive margin tectonic setting (Surjono and Leman, 2010).

The origin of Peninsular Malaysia strongly fits Wilson cycle theory explained by Condie (1997) and Allen and Allen (2005). In this case, the continental extension was declared by rift-ing of Indochina-East Malaya continental blocks from Gondwanaland (Metcalf, 2000). A new oceanic spreading centre which continuously expands is declared by the creation of Paleo-Tethys oceanic basin. It was caused by the first continental sliver rifting which continues to expand resulting three thousand kilometers wide of an oceanic basin (Metcalf, 2000). The subduction is declared by the subduction of Paleo-Tethys oceanic plate into Indochina-East Malaya continental blocks along the Bentong-Raub suture line. Lastly, collision is declared by Sibumasu and Indochina-East Malaya collision happened in the Middle to Late Triassic (Surjono, 2007).

CONCLUSION

The petrographic studies reveal that sandstones in the studied area comprise lithic greywacke, litharenite, sublitharenite, and feldspathic greywacke. Tectonic phases gave significant effects on detrital material in sandstones within several formations of East Johor Basin. In a short explanation, this was started by the break-up of Gondwanaland forming the Tethys Ocean. A continuous force of Sibumasu Block generated subduction in the region which gradually closed the Tethys Ocean during the Middle Permian. This has implied a massive structural events and volcanic arc along the peninsular supplying material for Dohol Formation proved by the high abundance of plagioclase contained in the sample. As for Linggiu Formation, the plotting result exhibits a magmatic arc and a recycled orogeny from the significant differences of quartz content ranging from 39.70 to 78.35%. Meanwhile, the Tanjung Leman Formation was a recycled orogen that was likely to be derived from the area which had undergone a massive tectonic phase and erosion. The geochemical analysis shows that tectonic setting of the studied area is chiefly in a passive

margin during the early deposition represented by Mersing Formation (Carboniferous ~340 Ma to 300 Ma) and subsequently developed into an active continental margin represented by the Early Permian sequences.

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