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The Gua Musang Group: A newly proposed stratigraphic unit for the Permo-Triassic sequence of Northern Central Belt, Peninsular Malaysia

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Abstract: The close association between the Gua Musang formation, Telong formation, Aring Formation, and Nilam marble reflect the lateral facies changes among these formations. Poorly delineated boundaries between each formation calls for a reassessment on the genetic and stratigraphic correlation of these formations. The newly proposed Gua Musang Group is defined as argillite-carbonate-volcanic deposited within the same Gua Musang platform during Permo-Triassic period, which includes all four formations under study. High resolution stratigraphy is needed for each formation for better stratigraphic correlation between the various lithostratigraphic units of the Gua Musang Group and other chronologically related rock formations in the region.The new division of formations within this Group is proposed based on lithologies and stratigraphic correlation that could provide better understanding on the geology of northern section of Central Belt of Peninsular Malaysia.

Keywords: Gua Musang Group, Permian, Triassic, Central Belt, Peninsular Malaysia

Abstrak: Persamaan di antara formasi Gua Musang, formasi Telong, Formasi Aring, dan marmar Nilam melambangkan perubahan fasies secara lateral di antara formasi-formasi ini. Sempadan yang tidak ditandakan dengan sempurna antara formasi memerlukan penilaian semula terhadap korelasi genetik dan stratigrafi antara formasi-formasi ini. Kumpulan Gua Musang yang baru dicadangkan ditakrifkan sebagai batuan berargilit-berkapur-volkanik diendap di dalam pelantar Gua Musang sepanjang usia Perm-Trias, yang terdiri daripada empat formasi yang dikaji. Stratigrafi beresolusi tinggi ke atas setiap formasi diperlukan bagi mendapatkan korelasi stratigrafi yang lebih baik di antara unit litostratigrafi Kumpulan Gua Musang dengan formasi batuan lain yang seusia di rantau ini. Pembahagian baharu Formasi di dalam Kumpulan ini adalah berasaskan litologi dan mampu memberi gambaran yang lebih jelas mengenai geologi bahagian utara Jalur Tengah Semenanjung Malaysia.

Kata Kunci: Kumpulan Gua Musang, Perm, Trias, Jalur Tengah, Semenanjung Malaysia

INTRODUCTION

The Gua Musang formation in South Kelantan – North Pahang was mapped by Yin (1965) to describe Middle Permian to Late Triassic argillite, carbonate, and pyroclastic/volcanic facies within Gua Musang area. Now, the term has been loosely used for nearly all Permo-Triassic carbonate-argillite-volcanic sequences in the northern part of Central Belt Peninsular Malaysia.Widespread distribution of argillite-carbonate-volcanic across northern Central Belt has triggered issue regarding current names assigned. For example, similar lithologies to the Gua Musang formation in Felda Aring is named as Aring Formation, while those in Sungai Telong is called Telong formation (Aw, 1990). Mohamed and Leman (1994) and later Mohamed (1995) explained that these lateral facies changes could be gathered within the same group as long as these sediments were deposited in shallow marine environment of the Gua Musang platform during the Permo-Triassic period.The relevance of grouping these formations lies behind the close associations observed among these formations in terms of sedimentological and paleontological aspects. The authors find the need to reasses the usage of the informal 'Gua Musang formation' for future rank elevation, formalization, and clearer understanding on the geology of the northern Central Belt, particularly with regards to deposition of various lithostratigraphic units within the Gua Musang platform.

The proposed Gua Musang Group includes the current (i) Gua Musang formation, (ii) Aring Formation, (iii) Telong formation, and (iv) Nilam marble (Figure 1, Figure 2 and Table 1). The grouping of listed formations within the same group divides the new formations on the basis of lithologic units. Gunung Ayam Conglomerate which was named as the basal conglomerate of the Gua Musang formation (Aw, 1974) is now regarded as the Bentong Raub Suture Zone (Tjia & Almashoor, 1996), and thus need to be excluded. The correlation among these formations is presented in Figure 3. Up ranking of 'Gua Musang' instead of 'Aring', 'Nilam' or 'Telong', is due to its more extensive coverage in comparison to the other formations.

Argillo-carbonate sediments from Raub to Gua Musang were known as Permo-Carboniferous Raub Series

(Scrivenor, 1911). Later, Richardson (1939) divided rocks in Raub into Permo-Carboniferous Calcareous Formation and Triassic Arenaceous Formation. The former is divided into Calcareous and Argillaceous Facies, both interbeds with Pahang Volcanic Series. Calcareous Formation is unconformably bounded by Arenaceous Formation, with major outcrops created in the Main Range foothills, thus the term "Foothill Formation" (Richardson, 1946). The distribution of the proposed Gua Musang Group very much follows the distribution of this Calcareous Formation, which was later renamed to "Calcareous Series" by Richardson (1950), who divided the Calcareous Series in Chegar Perah-Merapoh (northern distribution) into Argillaceous, Calcareous, and Mixed/Transitional Facies. This series is bounded by the Older Arenaceous Series of Main Range sediments to the west and Younger Arenaceous Series to the east, with eastward younging direction. Alexander (1959) renamed the Older Arenaceous Series to Bentong Group, Calcareous Series to Raub Group, and Younger Arenaceous Series to Lipis Group. In Bentong, the southern extension of the Raub Group extends until the Klau plain, bounded by the eastern foothills of Main Range and western foothills of Gunung Benom (Alexander, 1968). Here, the calcareous sediment is more prominent to the west, represented by Bukit Chinta Manis and Bukit Batu Balong, while the east is dominated by argillite-pyroclast interbeds.

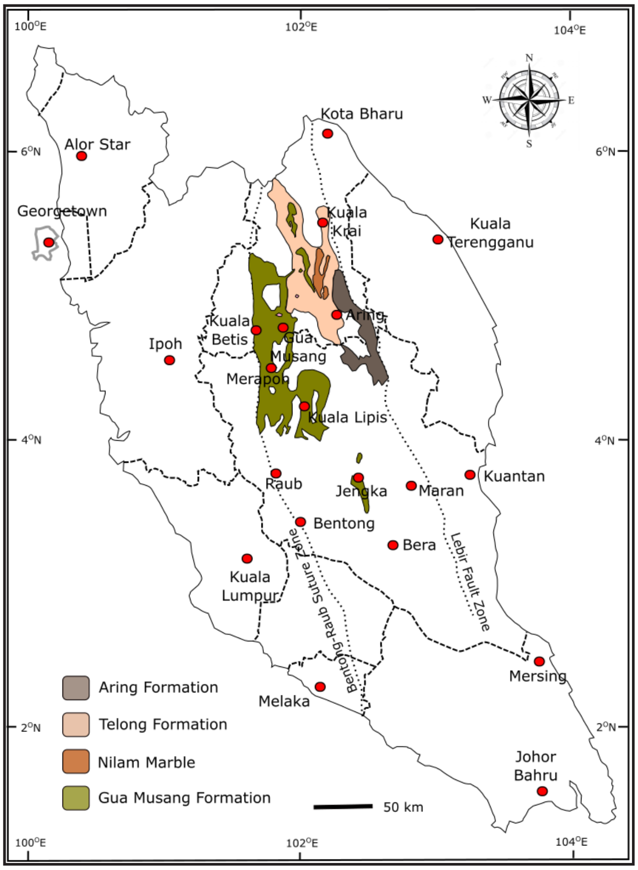

Figure 1: Distribution of the Gua Musang Group. Modified from Mohamed (1995).

Later, Ahmad (1976) proposed major changes in terms of characterization and distribution of the formations in the southern part of the Bentong-Raub-Lipis Group. In Karak-Temerloh, the southern extension of Bentong Group (Older Arenaceous Series) was renamed to "Karak Formation" and now is identified as Lower Devonian based on the latest findings of graptolites and bivalves (Ahmad, 1976). It now includes Bukit Batu Balong and Bukit Chinta Manis which were previously thought to be a part of Raub Group. To the east, the southern extension of Raub Group (Calcareous Series) is dominated by carbonaceous shale with rhyolitic tuff interbeds known as the "Semantan Formation", while the arenaceous band of the Lipis Group (Younger Arenaceous Series) is called the "Kaling Formation". The identification of ammonites and bivalves within both formations updated the age range to Middle-Upper Triassic. Ahmad (1976) suggested

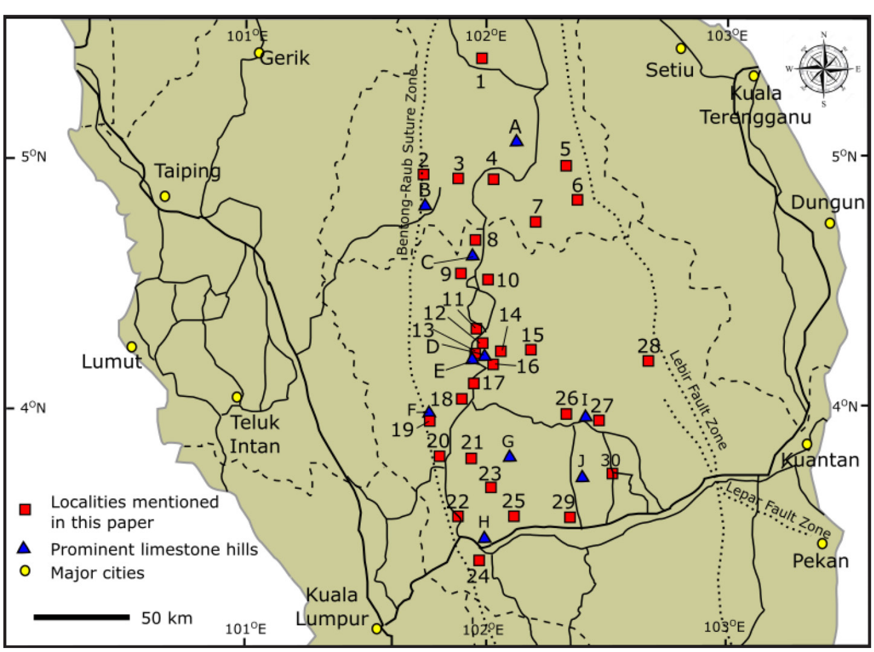

Figure 2: Locations mentioned in this paper: 1:Dabong; 2:Kuala Betis; 3:Blau; 4:Gua Musang; 5:Chiku; 6:Sungai Koh; 7:Sungai Telong; 8:Merapoh; 9:Chegar Perah; 10:Sungai Yu; 11:Padang Tengku; 12:Kampung Gua; 13:Kampung Relong; 14:Terenggun; 15:Kenong; 16:Kuala Lipis; 17:Penjom; 18:Benta; 19:Cheroh; 20:Raub; 21:Gali; 22:Bentong; 23:Klau plain; 24:Karak; 25:Semantan; 26:Jerantut; 27:Kota Gelanggi; 28:Sungai Kerum; 29:Temerloh; 30:Jengka; A:Nilam marble; B:Gunung Ayam; C:Gua Panjang; D:Gua Sei; E:Gua Bama; F:Jerus Limestone; G:Gunung Benom; H:Bukit Chinta Manis; I:Kota Gelanggi Limestone; J:Gunung Senyum.

Table 1: Formations included within Gua Musang Group. Modified from Lee (2004).

Name	Gua Musang formation	Telong formation	Nilam marble	Aring Formation
Origin of Name	Gua Musang, South Kelantan	Sungai Telong, South Kelantan	Sungai Nilam (of Sungai Chiku)	Sungai Aring, south Kelantan
Age	Middle Permian to Late Triassic	?Permian to Late Triassic	?Permian to Late Triassic	Carboniferous to EarlyTriassic
Boundary	Unknown lower boundary; Upper boundary overlain by Koh Formation	Lower boundary overlie Gua Musang formation; top boundary overlain by Koh Formation	Unexposed bottom and top boundary	Lower boundary unexposed. Tectonized upper contact with Telong formation and Koh Formation.
Correlation	Upper part of Gua Musang formation interfingers with Semantan Formation, Telong formation, and Gunung Rabong formation	Lateral equivalent to Gunung Rabung formation and Semantan Formation	Lower part coeval with Aring Formation, upper part coeval with Telong formation	Lateral equivalent to Gua Musang formation in Kelantan, metasediments in SE Pahang, Volcanic Series in NW Pahang
Lithology	Argillaceous and calcareous rocks interbedded with volcanic. Minor presecne of arenaceous rocks	Sequence of predominantly argillite associated with some tuff; turbidites	Calcitic marble interbedded with tuff and argillites	Basal dolomite marble, tuff, calcareous argillite, pyritiferous tuffs, subordinate lavas, argillo-tuffaceous limestone
Type Area	Gua Musang area (extended to north Kelantan and Pahang)	Sungai Telong, the upper reaches of Sungai Aring in south Kelantan	Upper reaches of Sungai Nilam	Sungai Aring, south Kelantan
Depositional Setting	Shallow marine shelf deposit, with active volcanic activity	Shallow marine environment with occasional pyroclastic	Open marine for growth of shelly fauna	Neritic with volcanic input

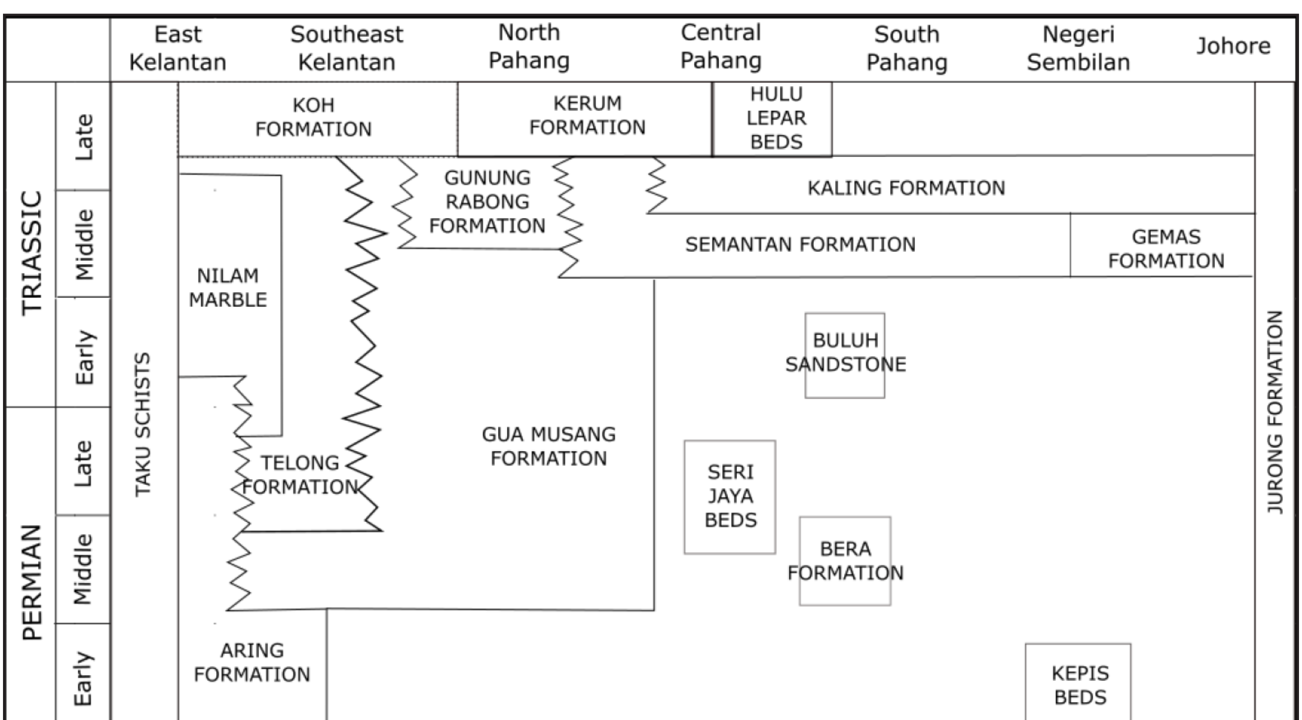

Figure 3: Permo-Triassic stratigraphic correlation chart of Central Belt Peninsular Malaysia. Modified from Metcalfe & Hussin (1995).

the usage of "Raub Group" for the Semantan and Kaling formations while the term "Lipis Group" is dropped entirely. The latest definition of the Raub Group covers most Middle to Upper Triassic rocks in Central - West Pahang, and also extends northward until just south of Jerus Limestone in Cheroh, north of Raub. However, the boundary between the Raub Group and Gua Musang formation, located in between Raub-Lipis is still unclear and needs to be properly defined in future studies. Procter (1980) still used the term "Raub Group" for the distribution of the Calcareous Series in the Benta-Padang Tengku area. He introduced three formations underlying the Lipis Group: Sungai Kenong, Sungai Sergis, and Padang Tengku formations. These formations were then included within current Gua Musang formation, and future Gua Musang Group.

Aw (1990) discussed the presence of Permo-Triassic argillite-volcanic-carbonate in southeast Kelantan, in which he introduced the Aring Formation for the dominant pyroclastic unit, Telong formation for the dominant argillite unit, and Nilam marble for the metamorphosed limestone within the Sungai Aring area. This distribution correlates with the Calcareous Formation previously discussed in northwest Pahang and it is possible that these three formations were deposited within the same Gua Musang platform.

The northern boundary of the Gua Musang platform is inferred to be bounded by low to medium grade metamorphic rocks of the Carbo-Permian Mangga formation (The Malaysian-Thai Working Group, 2006) and Taku schists (MacDonald, 1967) in the north. Just like the poorly delineated southern boundary, this northern boundary is subjected to future study for further refinement.

In short, the proposed "Gua Musang Group" also functions to distinguish central-northern distribution of the Calcareous Series deposited in the Permo-Triassic shallow marine from adjacent dominantly deep marine "Raub Group". This is done by reviewing the sedimentological and paleontological aspects of the Permo-Triassic formations in Central Pahang to Central Kelantan.

SEDIMENTOLOGY

Based on sedimentological assessment made through observation on type sections (Figure 4) and previous literature, it can be concluded that the study area is made up of the following facies: (i) Argillaceous; (ii) Carbonate; and (iii) Volcanics/pyroclastics.

Argillaceous Facies

Description: The Argillaceous facies which consists of shale, siltstone, mudstone, slate, and phyllite, is the dominant facies in Gua Musang and Telong formations, and occurs as interbeds or lenses in the Aring Formation and Nilam marble. The argillaceous facies is the most extensive and fossiliferous facies in the study area, with rocks distributed in the northern area being more fossiliferous compared to those occuring in the southern region of Gua Musang Group.

Depositional Environment: Rich brachiopod assemblages and other benthic faunas were found in Sungai Toh, Sungai Yu, Merapoh, Padang Tengku, Terenggun, Penjom, Sungai Aring, and Chegar Perah (Muir-Wood, 1948; Aw, 1990; Leman, 1993, 1994; Campi *et al.*, 2002, 2005; Leman *et al.*, 2004). Roadcuts and stream-cuts exposed good argillite

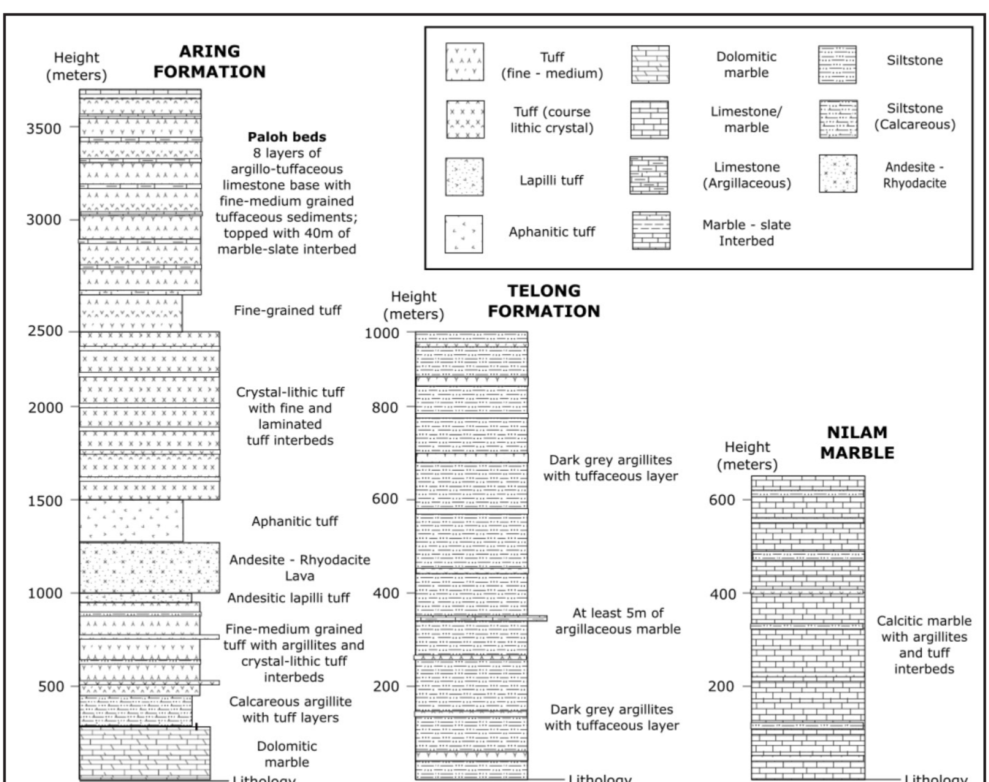

Figure 4: Comparison of type sections for Aring, Telong, and Nilam marble formations. Gua Musang formation has not been assigned with any type sections. Modified from Aw (1990).

outcrops which appear in various colors, from light to dark grey, reddish brown, brown, and black. Parallel laminations could be observed in some places, signifying deposition from suspension in low-energy environments. Rich benthic fauna such as brachiopods and bivalves represent shallow open marine setting, while parallel laminations signify occasional shifts into more restricted and closed environment.

*Variation:*Argillite-carbonate interbeds could be seen along the Merapoh-Kuala Lipis road and extend further south to northern Raub (Richardson, 1939). In Merapoh-Kuala Lipis roadcuts are hundreds of metres of light to medium grey fissile shale interbedded with thick-bedded medium gray carbonate bodies. In the Nilam marble, thin argillite interbeds with thick-bedded calcitic marble are found.

Depositional Environment: This interbeds represent a marine environment which was warm, shallow, and quiet, hence suitable for both carbonate and argillite deposition. In times of increase detrital supply, argillite were deposited. When there were less detrital influx, the water was clear and quiet, thus suitable for carbonate deposition.

Carbonates Facies

Description: Exposed carbonate bodies created unique karst topography such as steep-sided N-S trending limestone hills and pavement. Carbonate is the dominant facies in Nilam marble, and as extensive facies in the Gua Musang formation, and form beds or lenses within the Telong and Aring formations. The northern limestone bodies had been metamorphosed to marble while those in the south still shows distinction between micrites and allochems which consists of shallow marine benthic fauna such as brachiopods, bivalves, algae, and crinoids. Diagenetic processes such as micritization, compaction, dolomitization, and neomorphism had been observed (Idris & Hashim, 1988; Hussin, 1990; Metcalfe, 1995; Metcalfe & Hussin, 1995).

Depositional Environment: The abundant limestone mogotes in south Kelantan to north Pahang is inferred to be a continuous carbonate platform deposited within the Gua Musang platform during Permo-Triassic before subjected to erosion and karstification. Until further work is done on reassessing every limestone hill, the most plausible way for now is to divide limestone formations according to geographical distribution. The authors suggested division of carbonate facies into the Gua Sei limestone, Merapoh limestone, and Gunung Senyum limestone, according to names used by Metcalfe & Hussin (1995).

Variation: Carbonate-volcanic interbeds were observed in Gua Panjang, comprising bluish grey carbonate interbeds with greenish grey fine-grained tuff. These interbeds are less obvious in Gua Bama, where the tuff layers are pale green in color. In the Aring area, the presence of thin and localized carbonate beds/lenses within thick volcanic and pyroclastic sections suggest that Aring is located closer to the Permian volcanic source compared to Gua Musang.

Depositional Environment: During volcanic eruptions, carbonate deposition was suppressed due to the murky water conditions caused by volcanic debris fallout rendering it unsuitable for carbonate deposition. Once volcanic debris were deposited, the water became clear again for sunlight penetration and carbonate deposition resumed. These interbeds reflect the cycle between carbonate and volcanic deposition in times of active volcanism. The presence of various forms of volcanic/pyroclastic and carbonate represents shallow carbonate platform deposition near to a volcanic source within volcanic arc setting.

Volcanic/Pyroclastic Facies

Description: The volcanic facies is dominant in the Aring Formation and are interlayered with carbonate and argillite in other formations studied. Volcanic/pyroclastic facies exist in the form of agglomerates, tuffs, lapilli, volcanic breccias, and agglomerates which are interlaminated, interbedded, and interfingered with limestone, black carbonaceous shale, or tuffaceous shale (Abdullah, 1993; Leman, 1995).Tuffaceous sandstone and tuffaceous shale interbeds can be seen in the Merapoh-Kuala Lipis and Kuala Betis-Lambok roadcuts. In the field, the tuff layers are colored greenish grey and dark brown. In general, volcanism within this region is represented by more rhyolitic composition on the western side, near to the Gua Musang-Kuala Lipis region (SW Kelantan – NW Pahang), and more andesitic composition on the eastern side, near the Chiku-Sungai Aring region (SE Kelantan) (Lee, 2009). Subduction-related rhyolitic composition is also associated with the Middle-Upper Triassic roads while andesitic volcanism was more common during the Permian (Metcalfe, 2013).

*Depositional Environment:*These volcanic/pyroclastic created marine topographic highs for limestone deposition in shallow marine environment, thus enabling shallow marine fauna to fluorish in the Central Belt during the Permo-Triassic. The bulk volume of volcanic/pyroclastic deposited represents the level of volcanic activity at any particular instant. In limestone hills across Lipis, the volcanic-carbonate interbeds are common within the late Permian bottom section, which signify time of peak volcanism. This is followed by deposition of more pure carbonate upsection, deposited during the Triassic, where volcanism had become rare phenomenaand eventually absent.

PALEONTOLOGY

The Middle Permian to Late Triassic age of the Gua Musang formation and its lateral equivalents were determined based on fossil findings. Among them are Middle Permian fauna in Sungai Toh, Sungai Yu, and Padang Tengku (Leman, 1993; Campi *et al.*, 2000, 2002, 2005); Upper Permian fossils in Terenggun, Merapoh, Penjom, and Padang Tengku (Hussin, 1990, 1994; Leman, 1991, 1993, 1994; Abdullah, 1993; Lim & Abdullah, 1994; Fontaine & Amnan, 1994; Leman *et al.*, 2004); Lower Triassic conodonts and bivalves in Merapoh, Chegar Perah, Gua Sei and Aring (Igo *et al.*, 1966; Tamura, 1968, 1973; Aw, 1990; Metcalfe, 1992, 1995); Middle Triassic fauna in Jerus, Gua Bama, Felda Aring, and Merapoh (Metcalfe, 1990; Fontaine & Amnan, 1994; Sone & Leman, 2004;

Table 2: Diagnostic fossils in Gua Musang Group. G: Gua Musang; T:Telong;A:Aring; N:Nilam.

Period	Epoch	Stage	Macrofossils		G	T	A	N	Microfossils		G	T	A	N
Triassic	Late	Rhaetian												
		Norian												
		Carnian	Bivalvia	*Trigonodus* sp.	■									
			Bivalvia	*Entolium* sp.	■	■								
	Middle	Ladinian	Bivalvia	*Daonella* sp.	■	■	■							
			Bivalvia	*Lima* sp.	■		■							
			Bivalvia	*Costatoria quinquicostata*	■	■								
		Anisian	Ammonoid	*Balatonites* sp.	■	■			Conodont	*Neogondolella excelsa*	■			
	Early	Olenekian							Conodont	*Neospathodus waageni*	■			
		Induan	Bivalvia	*Claraia* sp.	■		■		Conodont	*Isarcicella isarcica*	■			
									Conodont	*Hindeodus parvus*	■			
Permian	Lopingian	Changhsingian	Brachiopod	*Haydenella minuta*	■		■		Foraminifera	*Colaniella parva*	■		■	
			Brachiopod	*Marginifera* sp.	■		■		Foraminifera	*Paleofusulina sinensis*	■			
			Brachiopod	*Meekella* sp.	■		■		Foraminifera	*Reichelina* sp.	■			
		Wuchiapingian	Brachiopod	*Transennatia gratiosa*	■				Foraminifera	*Misella* sp.			■	■
	Guadalupian	Capitanian	Brachiopod	*Vediproductus* sp.	■				Foraminifera	*Verbeekina* sp.	■		■	■
		Wordian	Brachiopod	*Neoplicatifera* sp.	■				Foraminifera	*Neoschwagerina* sp.			■	■
		Roadian	Brachiopod	*Phricodothyris* sp.	■		■							
	Cisurian	Kungurian							Foraminifera	*Paleotextularia* sp.	■		■	■
									Foraminifera	*Glomospirella* sp.			■	■
									Foraminifera	*Schwagerina* sp.			■	■
		Artinskian	Brachiopod	*Reticulatia uralica*	■		■							
		Sakmarian	Brachiopod	*Neochonetes* sp.			■							
		Asselian	Brachiopod	*Schizophoria* sp.			■		Foraminifera	*Tricitites* sp.			■	
Carboniferous	Pennsylvanian	Gzhelian	Brachiopod	*Choristites* sp.			■							
		Kasimovian												
		Moscovian							Foraminifera	*Fusulinella* sp.			■	
									Foraminifera	*Fusulina* sp.			■	
		Bashkirian												

Othman & Leman, 2010); and Lower Triassic bivalves in Sungai Telong (Aw, 1990).

Diagnostic fossils which serve as index fossils and age determinants were found within formations of interest are listed in Table 2. The signature Upper Permian *Paleofusulina – Colaniella – Reichelina* zone of Central Belt Peninsular Malaysia (Abdullah & Rahman, 1995) correlates with those in north Thailand (Sakagami & Hatta, 1982), Cambodia (Ishii *et al*., 1969), Kitakami Mountain of Japan (Tazawa *et al*., 2000), and the Lengwu fauna of South China (Liang, 1990). These regions harbor Paleotethys/Tethys realm fauna, signifying the warm tropical region during the Permo-Triassic.

DEPOSITIONAL ENVIRONMENT AND TECTONIC SETTING

Based on sedimentological and paleontological evidence, we conclude that the formations within the study area were deposited in a warm, shallow marine environment within the Paleo-Tethys Seaway of the Central Belt during Permo-Triassic time (Figure 5). This is substantiated by the dominance of benthic organisms such as brachiopods and bivalves which inhabited the sea floor. The presence of alga such as *Tubiphytes* sp. found in Gua Belong, Gua Senurat, Gua Henderik, Gua Batu Tinggi, and Merapoh suggests deposition within the photic zone (Fontaine *et al*., 1995; Abdullah & Rahman, 1995). In general, fossil assemblages in the northern Central Belt correlates with other regional warm Paleo-Tethys fauna such as the Lengwu fauna of South China (Liang, 1990) and Kitakami Mountains of Japan (Tazawa *et al*., 2000).

Widespread argillite and presence of extensive carbonate indicate deposition within a warm, shallow, and clear water platform (Fontaine, 1986). The presence of argillite-carbonate interbeds demonstrate depositional interplay during times of high-low detrital supply from a nearby landmass. The occasional presence of volcanics of all types and sizes (tuff, lapilli, agglomerates) indicate a depositional environment which was close to the volcanic source. Lim & Abdullah (1994) and Leman (1995) suggested that the regional volcanism in the area had caused deposition of volcanic and pyroclastic to build up marine topographic highs upon its deposition within the Seaway. These topographic highs created shallow environment which were favorable for limestone deposition and for diverse shallow water fauna to fluorish.

The limestone deposits were subjected to platform and shelf instability, thus creating the brecciated limestone when slumping occured on the slope. Instability continued until the Late Triassic as indicated by the occurrence of olistoliths and limestone blocks in the shale, and intraformational limestone conglomerates of the Kota Gelanggi Limestone (Abdul Rashid, 1994). This might be due to intensified volcanic activity, tectonic displacement (Abdullah, 2009), or a combination of these factors in times of peak volcanism.

This setting occured in the midst of the Indosinian Orogeny, as the Paleo-Tethys Ocean and Sibumasu terrane were being subducted under the Indochina volcanic arc

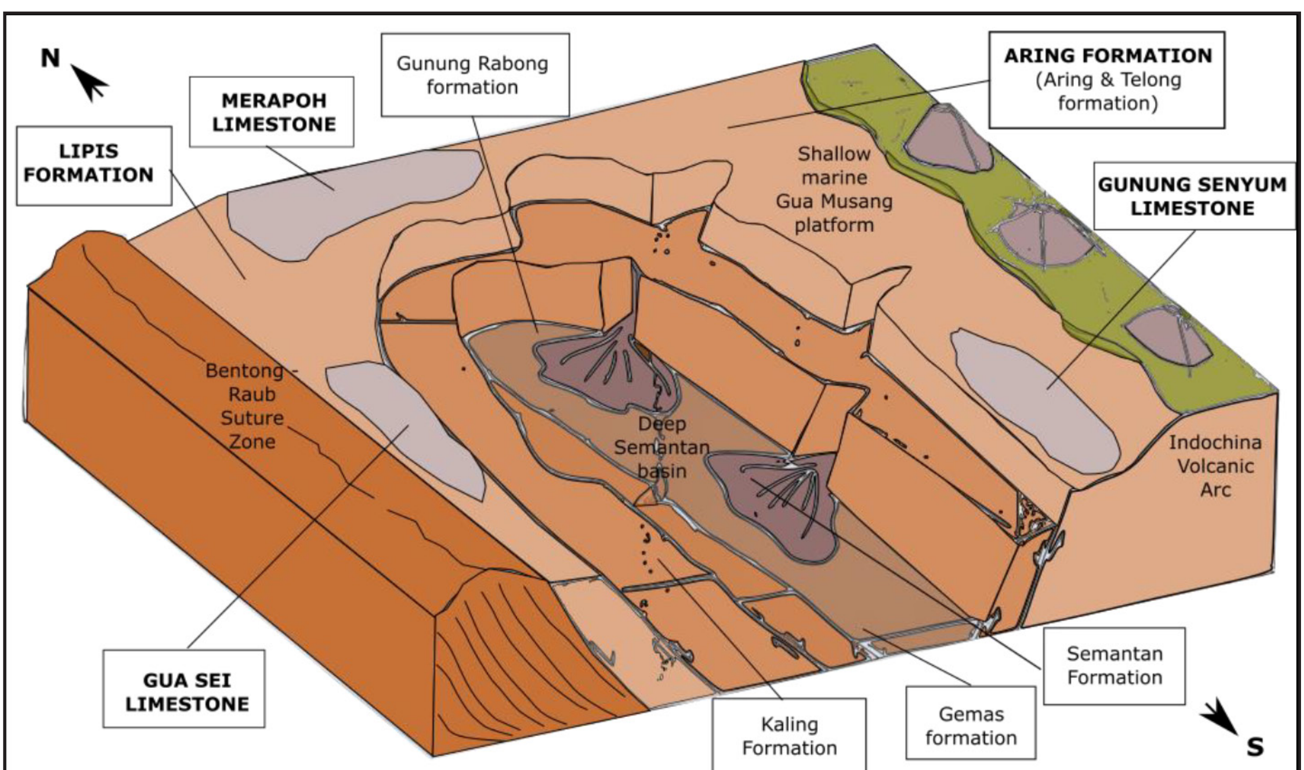

Figure 5: Middle Triassic depositional setting of Central Belt Peninsular Malaysia. Proposed formations are Aring formation, Lipis formation, Merapoh limestone, Gua Sei limestone, and Gunung Senyum limestone (in bold). Shallow marine platform extends further north until Malaysia-Thai border, while deep Semantan-Gemas basin extends south until Johore.

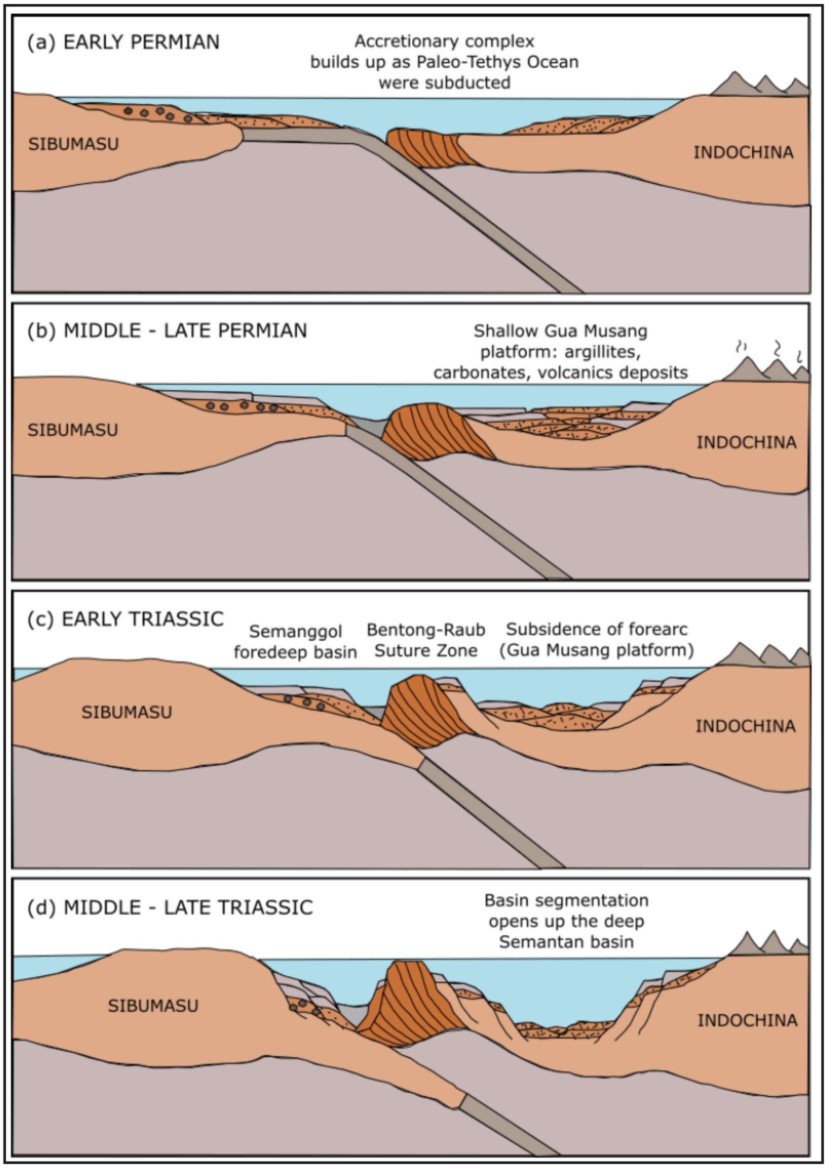

Figure 6: Permo-Triassic Indosinian Orogeny based on forearc basin subsidence and segmentation model. (a) Early Permian: Thick argillite and volcanic were deposited adjacent to Indochina volcanic arc, as the current Aring and Telong formations. In the west, pebbly mudstone of Singa formation and argillite of Kubang Pasu formation were deposited. Accretionary complex builds up as Paleo-Tethys Ocean were subducted. (b) Middle-Late Permian: Thick argillites and volcanics created shallow marine Gua Musang platform favorable for carbonate development and benthic fauna. The current Gua Musang formation started to develop in the east. Volcanism peaks while forearc basin started to subside. In the west, Kodiang-Chuping limestones were developed in a shallow setting while chert was deposited within Semanggol foredeep basin. (c) Early Triassic: Forearc subsidence intensified in Gua Musang platform, creating more accomodation space for carbonate-argillite-volcanis deposition. Paleo-Tethys Ocean had been completely subducted as Sibumasu docked into Indochina. (d) Middle-Late Triassic: Oblique subduction of Sibumasu aided process of basin segmentation on the subsiding Gua Musang platform, thus creating the deep marine Semantan-Gemas basin. This basin was bounded by shallow marine platform as portrayed by the geometry of Central Belt as we observe today. Basin faulting and segmentation caused the presence of slump deposits and intraclasts in Pos Blau, Krau, Raub, and Kota Gelanggi. In the west, rudite-arenite were deposited in submarine fans of Semanggol foredeep basin.

(Tjia & Almashoor, 1996; Metcalfe, 2000) as the suturing of Peninsular Malaysia was progressing. Tjia & Almashoor (1996) suggests that the Central Belt was created in response to divergence of two recently sutured continental plates (Western and Eastern belt) during middle to late Triassic, while Metcalfe (2000) is in support of the accretionary complex model in which the Central Belt Semantan basin act as the forearc basin. In this paper, the authors suggest the forearc basin subsidence and segmentation model in order to explain the geometry of shallow and deep marine setting within Permo-Triassic of Central Belt (Figure 6). This model is similar to sedimentation setting in West Sumatra (Beaudry & Moore, 1985; Izart *et al*., 1994), Chile (Coulbourn & Moberly, 1977), Great Valley of California (Moxon & Graham, 1987), and Tonga (Clift & MacLeod, 1999), among others.

Although forearc basin subsidence is the least understood basin tectonic setting (Xie & Heller, 2009), basin subsidence and segmentation were identified to happen due to: (1) relative motion between the volcanic arc and accretionary complex; (2) extensional faulting (Izart *et al.*, 1994); (3) reactivation of pre-existing fault zones in overriding plate (Dorobek, 2008); (4) growth, loading, and underplating of accretionary complex which caused tectonic rotation and basin widening (Coulbourn & Moberly, 1977); (5) thermal contraction due to cooling of magmatic arc (Moxon & Graham, 1987); (6) partitioned strain from oblique subduction (Izart *et al.*, 1994); (7) crustal thinning due to basal erosion by subducting plate (Clift & MacLeod, 1999); and (8) isostatic adjustment of subducting slab on the overlying plate (Moxon & Graham, 1987; Kobayashi, 1995).

As the Paleo-Tethys Ocean and Sibumasu terrane were being subducted obliquely under the Indochina volcanic arc (Metcalfe, 2013), the accretionary complex continues to grow while argillo-carbonate sediments were deposited within the shallow marine Gua Musang platform. Concurrently, pyroclastics/volcanics input were being supplied by the

Table 3: Suggestion on distribution of new formations within the proposed Gua Musang Group.

Current Rock Unit		Lithology	Proposed Formation	Age Range	Explanation
Aring Formation		Dominant pyroclastic facies with beds of argillite and carbonate	Aring formation	Late Carboniferous to Late Triassic	Argillite – andesitic (basic – intermediate) volcanic across Aring-Telong area. Includes minor occurence of arenite and carbonate, and subordinate rudite
Telong formation		Dominant argillite with beds of carbonate and tuff			
Gua Musang formation (including isolated limestone hills)	Low-lying argillo-volcanic	Dominant argillite, prominent carbonate with volcanic interbeds	Lipis formation	Middle Permian to Late Triassic	Argillite - rhyolitic (acidic – intermediate) volcanic across Lipis district – Gua Musang. Includes minor occurence of arenite and carbonate, and subordinate rudite
	Gunung Senyum limestone	Limestone body in Jengka-Jerantut	Gunung Senyum limestone	?Permian – Late Triassic	Limestone bodies in Jengka – Jerantut vicinity. Occasional presence of intraclasts and brecciated limestone. Non-tuffaceous.
	Gua Sei limestone	Limestone body in Padang Tengku – Kuala Lipis	Gua Sei limestone	Late Permian – Middle Triassic	Limestone bodies in Padang Tengku – Kuala Lipis – Kenong - Cheroh vicinity. Interfinger with argillite and tuff in Permian section.
	Jerus limestone	Limestone body in Cheroh			
	Merapoh limestone	Limestone body in Merapoh – Chegar Perah	Merapoh limestone	Middle Permian – Late Triassic	Limestone bodies in Aring - Merapoh vicinity. Recrystalized limestone body at northern distribution. Tuff and argillite interbeds.
Nilam marble		Marble with lenses of argillite and tuff in Aring – Chiku vicinity			

volcanic arc nearby, hence the presence of volcanics within Gua Musang Group. Shallow marine sedimentation progressed throughout the Permian until the Early Triassic.

During the Middle Triassic, subsidence intensified and basin segmentation happened within the forearc basin, thus opening the deep marine setting of the Semantan-Gemas Basin, analogous to the Aceh/Simeulue/Nias basins of West Sumatra. This explains the geometry of the Middle-Upper Triassic deep marine setting (Semantan, Gemas and Gunung Rabong formation) which was located in the middle of Central Belt and bounded by shallow marine platforms to the east (Gua Musang, Kaling formations) and west (Aring, Telong formations). In the north, this basin terminated in the Telong formation in Kelantan, while in the south, the basin terminated in the Jurong formation in Johore. The presence of deep marine Middle Triassic ammonoids within the Telong formation (Othman & Leman, 2010) indicate a steep continental slope environment which was developed during basin segmentation, and acted as the transition from the shallow Gua Musang platform, into the deep Semantan-Gemas basin. This is a new proposed model for the Central Belt, hence further studies and investigations need to be done.

PROPOSED FORMATIONS WITHIN GUA MUSANG GROUP

The variation and similarities in sedimentology and paleontology among the Gua Musang, Telong, Aring, and Nilam marble formations enable these rock units to be grouped into an informal Gua Musang Group, which is characterized by argillite-carbonate-volcanic deposited in a shallow marine platform environment during the Permo-Triassic period. The distibution of the formations within this Group is assigned based on lithologies (Table 3).

The new Aring Formation will be represented by the argillites and predominantly basic-intermediate volcanic/pyroclastic facies, including minor arenites – rudites in southwestern Kelantan (current Aring and Telong formations areas).The Lipis formation will be represented by argillite and predominantly acidic-intermediate volcanic/pyroclastic, including minor arenite-rudite in southwestern Kelantan – northwestern Pahang (current Gua Musang formation area). These argillite-volcanic facies are grouped together within the same formation due to their common occurence together.

Limestone facies, represented by thick successions of carbonate forming limestone hills and towers, is separated into three different formations which are distinguished on the basis of geographical distribution and subtle temporal differences. Here, the names proposed for the different limestone bodies of Metcalfe & Hussin (1995) are adopted: Gua Sei, Merapoh, and Gunung Senyum limestones (Figure 7).

ADJACENT ROCK UNITS EXCLUDED FROM GUA MUSANG GROUP

Other than the four formations included within the Gua Musang Group, there are many other formations within the Permo-Triassic Central Belt of Peninsular Malaysia.

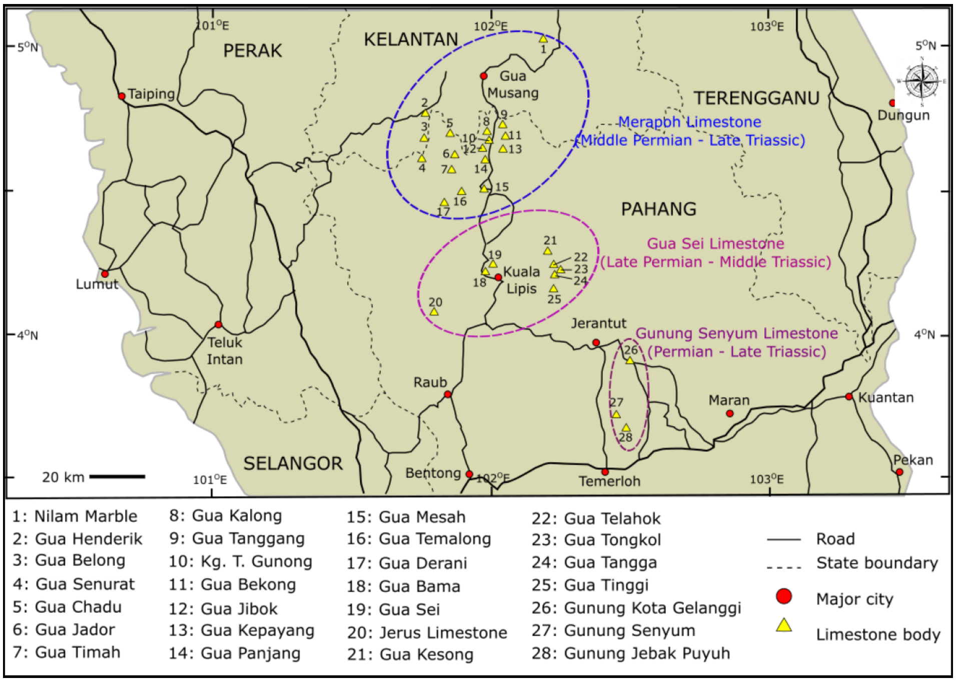

Figure 7: Distribution of limestone bodies across Gua Musang Group. Limestone bodies were segregated based on geographical distribution.

Nevertheless, they are excluded from the Group on the basis of lithology, depositional settings, and distance from the core Gua Musang Group.

The Gunung Ayam Conglomerate located in central-south Kelantan was previously perceived as the basal conglomerate for Gua Musang formation (Aw, 1974). The Upper Carboniferous to Lower Permian Conglomerate exposed in the Kuala Betis-Gunung Ayam area in central-south Kelantan and is inferred as deep-water deposits through the presence of debris flows which mass-transported large-sized rocks from the adjacent Bentong Group. Due to its distinctive conglomerate-rudite facies, different depositional setting, and its inclusion within the Bentong Raub Suture Zone area (Tjia & Almashoor, 1996), the authors propose to exclude the Gunung Ayam Conglomerate from the Gua Musang Group. This exclusion also applies to the Blau bedded chert, which is the easternmost extent of Bentong Raub Suture Zone, deposited from radiolarian ooze in a deep water setting (Tjia & Almashoor, 1996).

The Middle Permian Bera Formation (Leman *et al.*, 2000) and Lower Triassic Buluh sandstone (Lee, 1990) which lie at the eastern Semantan basin are being dominated by sandstone which signify deposition in a shallower region compared to Gua Musang Group. Major occurence of arenite with near absence of calcareous deposits in these formations suggest deposition in a high-energy shallow marine environment, different from the calm shallow water shelf setting of the Gua Musang Group. The Bera Formation was deposited in a littoral environment and prograding fan deposits within a deltaic environment while the Buluh sandstone within a near shore environment.The Kepis beds (Khoo, 1975) and Kaling Formation (Ahmad, 1976), located at the western side of the Semantan basin also exhibit dominance of shallow marine rudite-arenite. Similar to those at the eastern side, the Kepis and Kerum formations are also confined within a very short time range, which is during the Lower Permian and Middle-Upper Triassic respectively. In terms of lithology, depositional setting and timing, these formations are significantly different from those of the Gua Musang Group.

The dominance of carbonaceous shale with chert lenses, argillites and tuff reflects deposition in a reducing environment such as the distal turbidites of the Semantan (Ahmad, 1976) and Gemas formations (Foo, 1970; Khoo, 1983). Deep marine deposits of both formations within Middle-Upper Triassic Semantan Basin separate them from the Permo-Triassic Gua Musang Group in terms of lithology and depositional setting. In addition, the Gunung Rabong formation (Yin, 1965; Khoo, 1983), located at the northern extension of the Semantan basin harbor the same deep marine bivalves *Halobia* sp. and *Daonella* sp. just like in the Semantan formation. The opening of this basin and subsidence correlates with the final stage of the Indosinian Orogeny as portrayed in Figure 5. These formations dominate the major part of the southern half of the Central Belt.

The Hulu Lepar beds (Lee, 1990) and Koh Formation (Aw, 1990) represent continental deposits during the late Triassic until Jurassic-Cretaceous. This is substantiated by the dominance of rudite-arenite facies which were deposited in a high-energy environment as regression progressed during the last stage of the Indosinian Orogeny. Water levels continue to drop as terrestrial deposits took over the Jurassic in the Central Belt. The Upper Triassic Kerum Formation (Khoo, 1977) which was deposited in a paralic environment which was the transition from marine to terrestrial environment, was overlain by the continental Lanis Conglomerate (Khoo, 1977). Although these formations are located near to the core Gua Musang Group, the differences in timing, lithology, and depositional setting excluded them from the Gua Musang Group.

CONCLUSION

The Permo-Triassic Gua Musang formation, Telong formation, Aring Formation, and Nilam marble display close association in terms of sedimentology and paleontology. This paper proposes the new stratigraphic unit, the Gua Musang Group, for the four formations, to reduce the confusion on the Permo-Triassic stratigraphy of the study areas.

Future studies is required in order to refine the establishment of the Gua Musang Group. These will include the microfacies study on the limestone hills within the Gua Musang Group, assignments of type sections to the newly proposed formations in order to obtain its formal status, and boundary refinements between the Gua Musang Group and the adjacent Raub Group.

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