*Bulletin of the Geological Society of Malaysia, Volume 72, November 2021, pp. 1 - 13*
DOI: https://doi.org/10.7186/bgsm72202101

# Zircon U-Pb ages of the Benom Complex: Implications for a Late Triassic uplift event in Central Peninsular Malaysia

Choong Chee Meng[1,*], Manuel Pubellier[2], Benjamin Sautter[1], Mirza Arshad Beg[1]

[1] Universiti Teknologi PETRONAS, Geosciences Department, Seri Iskandar, 32610, Perak, Malaysia
[2] Ecole Normale Superieure, PSL Research University, CNRS UMR 8538, Laboratoire de Géologie, France
* Corresponding author email address: choong.meng@utp.edu.my

**Abstract:** The Benom Complex, located in the Central Belt of Peninsular Malaysia, has recorded the dynamics of the orogeny with multiple igneous intrusions emplaced during the late tectono-magmatic stages of the Paleo-Tethys closure. Three new zircon U-Pb ages of igneous rocks from the Benom Complex reveal the crystallization of diorite and syenite (alkaline series) at 221.8±2.4 Ma and 226.6±3.5 Ma respectively, and granite (calc-alkaline series) at 207.2±2.0 Ma. The sedimentation of the Central Belt shifted from a marine to a terrestrial environment at the Middle-Late Triassic boundary, which marked the beginning of uplift due to the Sibumasu-Indochina collision. The emplacement of alkaline series of Benom Complex during the early Late Triassic (226.6 Ma to 221.8 Ma) are interpreted as related to a slab break off and mantle upwelling. Most of the Central Belt region has no records of sedimentation since the mid Late Triassic due to continuous uplift and/or erosion. The subsequent emplacement of the Gunung Benom granite (calc-alkaline series) took place at the end of the Triassic (207.2 Ma). The red bed deposition and the emplacement of the Benom Complex (together with S-type Main Range granite) result from a continuous Late Triassic orogenic uplift event in Peninsular Malaysia.

**Keywords:** Benom Complex, Central Belt, uplift, zircon U-Pb

## INTRODUCTION

The Sibumasu-Indochina collision had a direct influence on the magmatism, uplift and sedimentation in the surrounding region during the Late Triassic time. The S-type Main Range granites in Peninsular Malaysia are the syn-/post-collisional products (Krähenbuhl, 1991; Ng *et al.*, 2015a) that witnessed the complete closure of the Paleo-Tethys with their ages commonly defining the timing for the collision. However, the wide age range of the S-type Main Range granite (Bignell & Snelling, 1977; Krähenbuhl, 1991) gives limited constrains on the initial collision timing. The Benom Complex is a major 20 km wide plutonic dome, located east of the Bentong-Raub Suture zone (Figure 1), has and shows a large diversity of igneous rocks ranging from felsic to mafic compositions (e.g. Hutchison, 1971; Jaafar Ahmad, 1979). The formation of the Benom Complex is believed to be closely associated with the closure of the Paleo-Tethys despite its peripherial position compared to the Main Range Province granites. However, the timing of emplacement of these contrasting igneous rocks is not properly constrained, impeding a precise reconstruction of the magmatic evolution of the region. The previously published K-Ar and Rb-Sr data of both alkaline and calc-alkaline series of Benom Complex are included into a wide age bracket from Late Triassic to Early Cretaceous (Table 1) (Bignell & Snelling, 1977; Jaafar Ahmad, 1979; Darbyshire, 1988; Mohd Rozi Umor & Syed Sheikh Almashoor, 2001). The large age difference was interpreted as due to the high mobility of parent and daughter isotopes of Rb-Sr during successive magmatic and hydrothermal events, a low closure temperature (300-350 °C) of mica for K-Ar age (Searle *et al.*, 2012), as well as a potential argon loss in the K-Ar system after the rock formation (Krähenbuhl, 1991). Here we provide newly acquired zircon U-Pb ages of the different units of the Benom Complex, to constrain the timing of the different magmatic episodes and corresponding geological events. The ages of magmatism are juxtaposed to the timing of sedimentation of the nearby red beds and marine deposits, to propose an updated scenario for the tectonic events during Sibumasu-Indochina collision.

## LATE PALEOZOIC TO MESOZOIC STRATIGRAPHY OF THE CENTRAL BELT

The Central Belt is located on the western margin of the Indochina block that presently lies east of the Bentong-Raub Suture Zone (Figure 1 & 2). It is the locus of thick Permo-Triassic marine sedimentary deposits which are thought to be associated with the subduction and the closure events of the Paleo-Tethys (e.g. Lim & Abdullah, 1994; Leman, 1995; Metcalfe, 2000; Metcalfe, 2013; Kamal Roslan *et al.*, 2016). Based on the sedimentary facies and depositional setting analysis, four sedimentary packages have been identified in the Central Belt. They are namely platform sediments, tuffaceous flysch, red beds and continental molasses (Hutchison, 2007).

The platform sediments consist of limestones, calcareous shales, and argillaceous rocks interbedded with limestones and pyroclastic rocks, which have been named

0126-6187; 2637-109X / Published by the Geological Society of Malaysia.

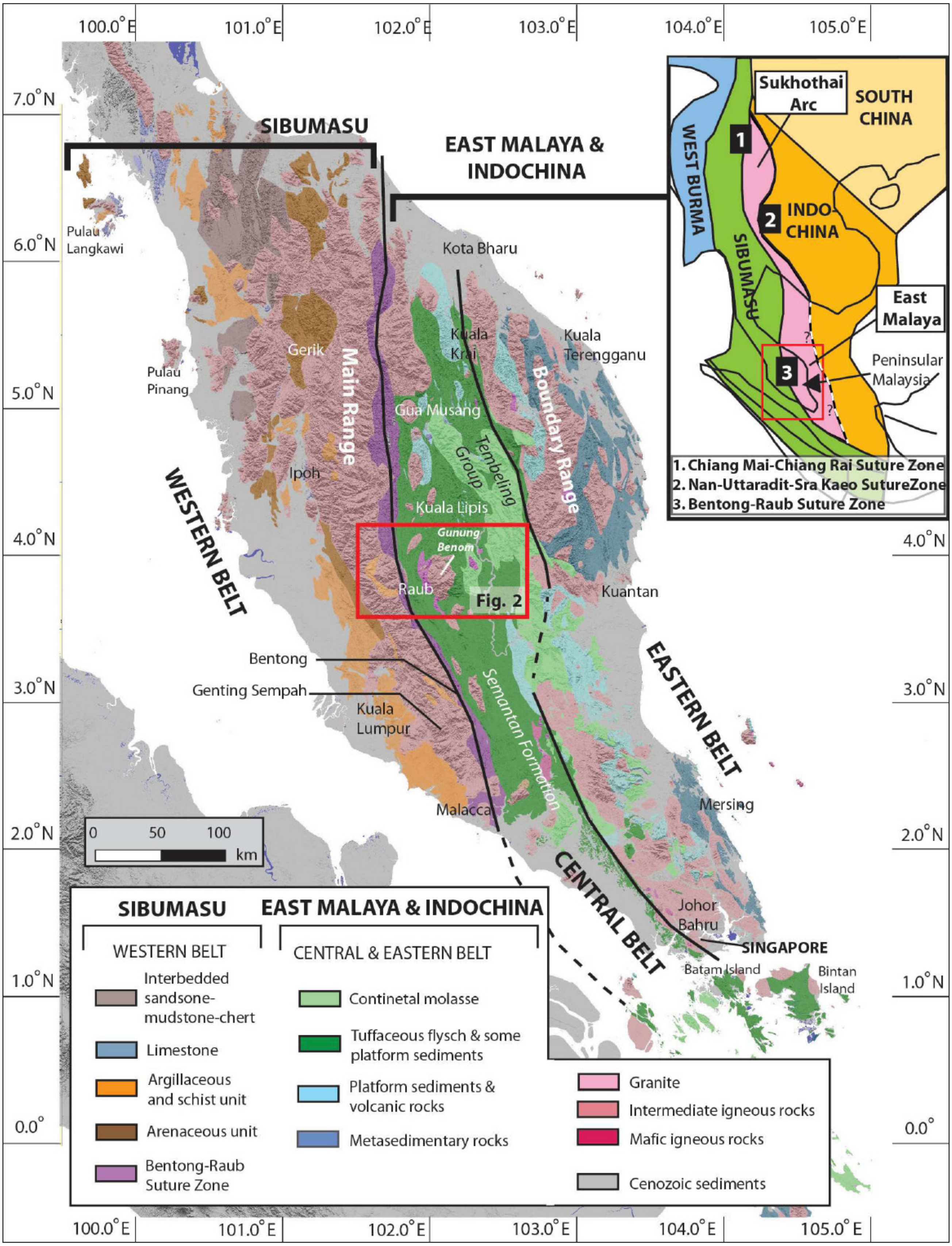


**Figure 1:** Geological map of Peninsular Malaysia. The red box marked the Gunung Benom area and its detailed map is shown in Figure 2.

**Table 1:** Published absolute ages of igneous rocks in Gunung Benom area.

| Series | Locality | Lithology | Dating method | Age (Ma) | References |
|---|---|---|---|---|---|
| Alkaline | Sg Ngiang | Weak foliated gabbro | K-Ar (mica) | 180±8 | Jaafar Ahmad, 1979 |
| | Benta JKR Quarry | Diorite | K-Ar (whole rock) | 122±6 | Mohd Rozi Umor & Syed Sheikh Almashoor, 2001 |
| | | Monzonite | | 128±6 | |
| | Jeram Besu | Diorite | K-Ar (whole rock) | 157±8 | |
| | | Syenite | | 127±4.6 | |
| | | Monzonite | | 163±8 | |
| - | Penjom gold mine | felsite dyke | U-Pb (zircon) | 222.4 ± 1.8 | Ng *et al.*, 2015b |
| Calc-alkaline | Gunung Benom | Not specific | Rb-Sr (whole rock) | 197±16 | Bignell & Snelling, 1977 |
| | | | K-Ar (biotite) | 123-199 | Bignell & Snelling, 1977 (summarized in Ghani, 2009) |
| | | | K-Ar (muscovite) | 169 | Bignell & Snelling, 1977 |
| | Gunung Benom | Not specific | Rb-Sr (whole rock) | 219±10 | Darbyshire, 1988 |
| | Sg. Kelau Kecil | Coarse-grained biotite granite | K-Ar age (mica) | 190±5 | Jaafar Ahmad, 1979 |
| | | Leucocratic fine-grained biotite granite | K-Ar age (mica) | 125±5 | Jaafar Ahmad, 1979 |
| | | Pegmatite | K-Ar age (mica) | 170±6 | Jaafar Ahmad, 1979 |

as the Gua Musang Formation (Yin, 1965), Raub Group (Alexander, 1968) and Kepis Formation (Khoo, 1973) respectively in different localities by previous studies. The platform sediments are partly metamorphosed, locally fossil-rich, and ranges from Permian to Late Triassic in age (Hada, 1966; Igo *et al.*, 1966; Idris & Hashim, 1988; Leman, 1995; Leman *et al.*, 1999). They were interpreted to have been deposited on a shallow shelf peripheral to an island arc system, with abundant limestones and submarine volcanoes emerging above sea-level (Hutchison, 2007). Part of the folded platform sediments are unconformably overlain by younger sub-horizontal molasse deposits in Jengka Pas area, Pahang (Ichikawa *et al.*, 1966; Harbury *et al.*, 1990), suggesting a pre-molasse folding event that may be related to the closure of the Paleo-Tethys.

The platform sediments are followed by the deposition of tuffaceous flysch with locally angular unconformities (Hutchison, 2007). The tuffaceous flysch is a sequence of rapidly alternating carbonaceous shales, siltstones, and rhyolitic tuffs with minor lenses of crystalline limestone. Shales and tuffaceous siltstones to sandstones are dominant in the formation (Jaafar, 1976). The tuffaceous flysch series are widespread in Central Pahang and West Johor, and have been grouped under the Semantan Formation (Jaafar, 1976; Khoo, 1983; Kamal, 1996; Ong, 2001; Figure 1). The Semantan Formation is fossiliferous with the presence of *Halobia* and *Posidonia*, typical of deep-water formations that yield a Middle to early Late Triassic age (e.g. Metcalfe *et al.*, 1982; Metcalfe & Chakrabroty, 1994; Leman & Sone, 2001; Wahid Abdul Rahman, 2015). Previous studies interpreted the deposition of the tuffaceous flysch on the western flank of a Triassic volcanic arc or more specifically in a fore-arc basin (e.g. Hutchison, 1989, Sashida *et al.*, 1995; Metcalfe, 2013) within a deep marine setting. The presence of Late Triassic shallow water fossils of *Myophoria* discovered in Kuala Lipis and Bahau (Metcalfe *et al.*, 1985), south

Johor (Burton, 1973) and Singapore (Kobayashi & Tamura, 1968a; Gobbett & Hutchison, 1973) (Figure 1), also suggests progressive shoaling particularly at the basin edges.

The red beds (Sungei Bilut Formation) were initially observed in Raub (Richardson, 1939), Bentong and Genting Sempah area (Haile *et al.*, 1977) (Figure 1). They are composed of unmetamorphosed, red-coloured conglomerates, sandstones and mudstones which unconformably rest on the strongly folded chert and schist unit of the Bentong Raub suture zone (Haile *et al.*, 1977). The pebbles constituting the conglomerates include unsorted chert, sandstone and schist. This succession is interpreted to have been deposited in a continental environment following the uplift triggered by the collision between Sibumasu and Indochina Blocks (Hutchison, 2007). Late Triassic shallow water *Myophoria* fossils were also discovered along the eastern region of the Sungei Bilut exposures (Richardson, 1939), marking the further eastern locus extent of the shallow marine conditions.

After the continuous uplift and/or erosion in the Early to Middle Jurassic, sedimentation resumed in the Late Jurassic as continental molasses, commonly named the Tembeling Group (Khoo, 1977). It is composed of more than 6.5 km thick of polymict conglomerate, quartzose sandstone and shale with common reddish and ferruginous appearances (Khoo, 1983). Late Jurassic to Early Cretaceous plants (e.g. Kon'no, 1966; Norizan Yaacub & Uyop Said, 2002) and palynomorphs (e.g. Uyop Said & Che Aziz Ali, 2000; Uyop Said *et al.*, 2003) are relatively abundant in these sequences making them an excellent chronological marker of the Mesozoic tectonic events that affected the region. The erosional surfaces and unconformities at the lower boundaries of the molasse strata (Rishworth, 1974; Loganathan, 1977; Rajah, 1986) illustrate the missing Early-Middle Jurassic section/hiatus which may evidence a regional uplift event.

## BENOM COMPLEX

The Benom complex is composed of alkaline series with intermediate to mafic igneous rocks and calc-alkaline series made of granitic rocks (Jaafar Ahmad, 1979). The igneous complex has prompted the interest of researchers on the occurrences and the origin of the alkaline series (Hutchison, 1971; Jaafar Ahmad, 1979; Mohd Rozi Umor & Syed Sheikh Almashoor, 2000; Ghani *et al.*, 2002; Ghani *et al.*, 2006), which mostly appear to be located along the western and northwestern flanks of Gunung Benom (Figure 2). The petrogenesis and magmatic source origin of the alkaline and calc-alkaline series are considered different based on previous petrological and geochemical studies (Mohd Rozi Umor, 2008).

### Alkaline series

The alkaline series consists of intermediate to mafic igneous rocks such as syenite, monzonite and gabbro (Hutchison, 1971). The alkaline series extend from Sg. Kelau in the south to Jeram Besu in the north (e.g. Hutchison, 1971; Yong *et al.*, 2004; Ghani, 2006; Mohd Rozi *et al.*, 2008) (Figure 2). Published K-Ar dating of these alkaline series yielded ages ranging from Late Jurassic to Early Cretaceous (180 to 122 Ma) (Mohd Rozi Umor & Syed Sheikh Almashoor, 2001; Jaafar Ahmad, 1979) (Table 1).

The prefect alignment of K-feldspar crystals in the syenite of the complex used to be interpreted as a foliation resulted from metamorphism (Hutchison, 1971). But recent studies demonstrated an igneous origin of this fabric as evidenced by xenolith in igneous rocks of the complex, and the presence of euhedral crystals in the alignment band that implies a crystallization resulting from a melt (Mohd Rozi Umor & Syed Sheikh Almashoor, 2000; Yong *et al*., 2004). The alkaline series are characterized by a high potash content, very high large ion lithophile elements (LILE), i.e. Ba and Sr, and the concentration of the Ba has recorded >10,000ppm (Ghani *et al.*, 2002; Ghani *et al.*, 2006). The geodynamic origin of these igneous bodies has been debated, given the small volume of mantle material being enriched in LILE (i.e. Ba and Sr in this case) that penetrated the lower lithosphere (Ghani *et al.*, 2002). The upwelled mantle material might be associated with the partial melting of eclogite (Mohd Rozi Umor & Syed Sheikh Almashoor, 2000) possibly resulting from a slab break-off (Mustaffa Kamal Shuib & Ghani, 2003; Mohd Rozi Umor, 2008).

### Calc-alkaline series

The Gunung Benom granitoid (Figure 2) located on the eastern side of the complex, has been classified as part of the calc-alkaline series (Jaafar Ahmad, 1979). It is mainly defined by a coarse-grained non-porphyritic biotite granite (Hutchison, 1977). K-Ar datings of the granitoid cover a wide range between the Triassic and Cretaceous (219 Ma to 123 Ma) (Bignell & Snelling, 1977; Jaafar Ahmad, 1979; Darbyshire, 1988) (Table 1). The wide range of ages do not all correspond to the true magmatic ages, with younger ages that could result from argon loss in the K-Ar system. These series are characterized by a moderate negative Eu anomaly and a rather high total amount of REE (Wan Fuad Wan Hassan & Mohd Suhaimi Hamzah, 1999). The major and trace elements including strontium data of the granite belt of the Central Belt including Gunung Benom granite suggest a primitive oceanic or mantle source with little crustal contribution (Hutchison, 1977). A more recent geochemical study by Mohd Rozi (2008) suggests that the magma origin varies from partial melting of metabasalt to metagreywacke and metaphyllite.

## ANALYTICAL TECHNIQUES

Three samples of the Benom Complex have been collected for zircon U-Pb (ZrnUPb) dating, from which two samples are in the alkaline series and one from the calc-alkaline series (Gunung Benom granite). Thirty (30) zircon grains from each rock sample were isolated and prepared for further analysis using standard procedures

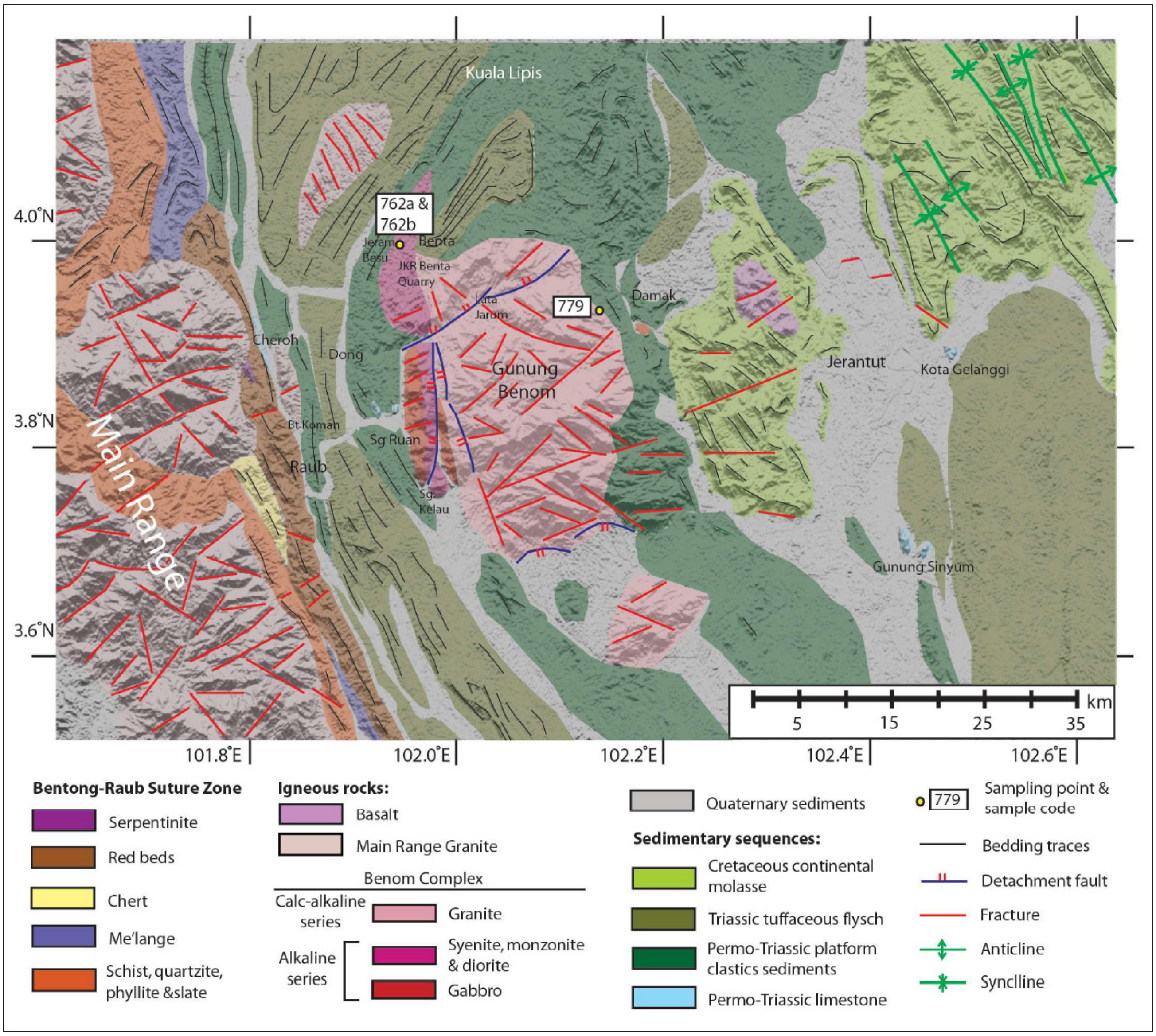


**Figure 2:** Structural map of Gunung Benom area. The sampling locations for zircon U-Pb age dating are marked within the white boxes. The map was constructed on the digital elevation model of SRTM (Jarvis *et al*., 2008).

combined with specific customized procedures described in Donelick *et al.* (2005). At least one 1 cm$^2$ grain mount was prepared, consisting of some quantity of zircon grains immersed in epoxy resin. Each grain mount was subsequently cured at 90 °C for at least 4 hours. Once cured, each grain mount was polished manually to a glass-like finish using 3.0 µm and 0.3 µm $Al_2O_3$ slurries to expose internal grain surfaces. The ZrnUPb analytic methods are as described in Bradley *et al.* (2009), Hults *et al.* (2013), and Moore *et al.* (2015). ZrnUPb LA-ICP-MS analysis was performed at the Geoanalytical Laboratory, Washington State University, USA. Individual zircon grains were targeted using a New Wave YP213 213 nm solid state laser ablation system using either a 20 or 30 µm diameter laser spot size, 5 Hz laser firing rate, and ultra high purity He as the carrier gas. Isotopic measurements of the ablated zircon material were performed using an Agilent 7700x quadrapole mass spectrometer. ZrnUPb age standards such as the 1099±0.6 Ma FC zircon (FC-1 of Paces & Miller, 1993) were used as the primary age calibration. Uranium decay constants and the $^{238}U/^{235}U$ isotopic ratio were taken from Steiger & Jäger (1977). $^{207}Pb/^{235}Uc$ ($^{235}Uc$ = 137.88238U), $^{206}Pb/^{238}U$, and $^{207}Pb/^{206}Pb$ ages were calculated for each data scan and checked for concordance. The obtained results were plotted using an online software, *IsoplotR* (Vermeesch, 2018).

## ZIRCON U-PB AGES OF BENOM COMPLEX

### Intermediate-mafic igneous rocks

Most of the intermediate to mafic rocks occur along the western and northwestern flanks of Gunung Benom. The igneous series are dominated by syenite, monzonite, diorite and gabbro. Syenite-monzonite related rocks are essentially made up of pale pink to whitish feldspar (mostly K-feldspar). Sample 762a is a fine-grained mafic rock classified as diorite and was found in the Jeram Besu. It is composed of predominantly dark-coloured ferromagnesium minerals and minor light-coloured feldspars (Figure 3a), all measuring up to a few millimeters in grain size. A total of 30 analyses were conducted on the zircon grains of sample 762a. Three analyses of the sample yielded discordant ages ranging between 240.3 Ma and 247.1 Ma, which are likely reflecting the inheritance (<95% concordant), thus not included in the

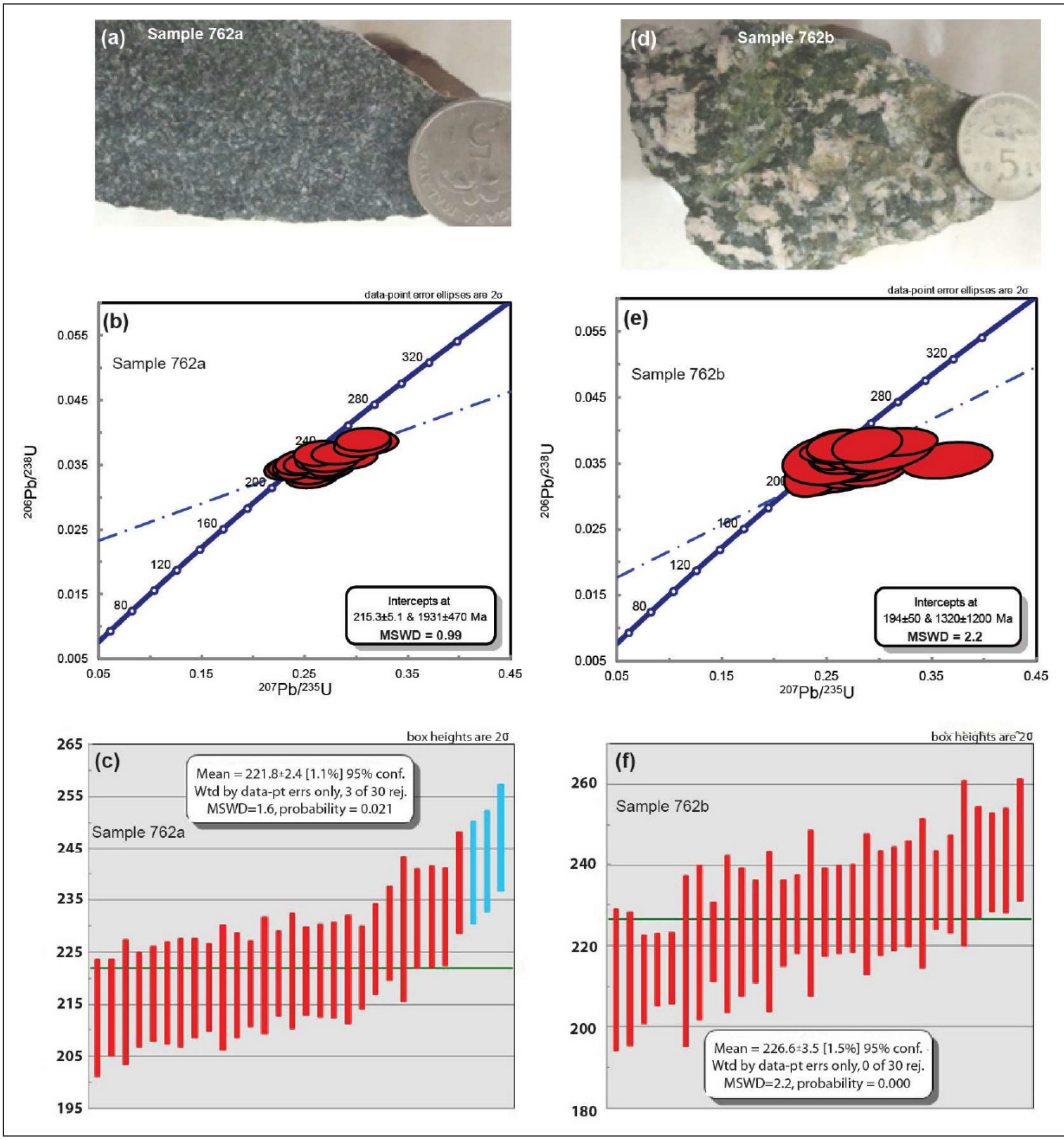


**Figure 3:** (a) Sample 762a is a diorite from Jeram Besu, predominantly with fine-grained, dark-coloured ferromagnesium minerals. (b) Sample 762a showed the intercept at 215.3±5.1 Ma (MSWD=0.99) in the concordia diagram and (c) weighted mean age of 221.8±2.4 Ma (MSWD=1.6). (d) The syenite (sample 762b) from Jeram Besu, made up of light-coloured, euhedral-subhedral feldspar and dark-coloured hornblende and biotite. (e) The concordia diagram of sample 762b indicated the intercept at 194±50Ma with MSWD of 2.2. (f) The weighted mean age of sample 762b is 226.6±3.5Ma with MSWD=2.2.

age calculation. The other 27 zircon grains have consistent $^{206}Pb/^{238}U$ ages ranging from 212.4 Ma to 238.4 Ma. The concordia diagram showed a lower intercept at 215.3±5.1Ma (MSWD =0.99) (Figure 3b) and the weighted mean age of 221.8 ±2.4Ma (95% conf., MSWD=1.6, n=27) (Figure 3c) (Table 2). The weighted mean age (221.8 ±2.4Ma) is taken as the crystallization age of the diorite which excludes the possible inheritances.

Sample 762b is a syenite which was also collected from Jeram Besu (Figure 2). It is composed of K-feldspar, hornblende, plagioclase, quartz and biotite (Figure 3d). The K-feldspars are pink-coloured, 0.5 to 3 cm in grain size, commonly euhedral, formed in alignment, and exhibit clear twinning. The plagioclase are white-coloured, subhedral and measure between 2-4 mm in size. The hornblendes are greenish coloured while biotite crystals are dark brown coloured, 1-2 mm in size, but can measure up to 4 mm. 30 zircon grains have been extracted from sample 762b to perform U-Pb age dating. All zircons have consistent $^{206}Pb/^{238}U$ ages ranging from 211.6 Ma to 246.2 Ma. The raw isotopic values from all data scans show the lower intercept on the concordia diagram at 194±50 Ma with MSWD of 2.2 (Figure 3e) and the weighted mean age of 226.6±3.5Ma (95% conf., MSWD=2.2, n=30) (Figure 3f) (Table 2). The intercept age shows a wide error range, hence the weighted mean age (226.6±3.5Ma) is taken as the crystallization age of syenite which fall in the range of U-Pb ages of individual zircons.

### Gunung Benom granite

A granite sample (779) was extracted along a river side of the northeast part of Gunung Benom (Figure 2). This granite is composed of 45% K-feldspar, 30% quartz, 20% plagioclase and 5% biotite minerals (Figure 4c) and exhibits a typical phaneritic texture. K-feldspars are light pink in colour and the grain size ranges from 5 to 8 mm. Quartz minerals are colourless and 2 to 5 mm in sizes. Plagioclase are whitish in colour and 1 to 5 mm in sizes while biotite minerals range between 1 to 2 mm. All minerals are either anhedral or subhedral in shape.

A total of 30 analyses were performed on zircon grains of sample 779. All zircons have consistent $^{206}Pb/^{238}U$ ages ranging from 194.4 Ma to 217.4 Ma. The analyses yielded a concordia age of 206.1±2.1 Ma (MSWD =1.3) (Figure 4a) and the weighted mean age of 207.2±2.0Ma (95% conf., MSWD=1.09, n=30) (Figure 4b) (Table 2). There is no significant difference between the concordia age and the weighted mean age for this sample. The weighted mean age of 207.2±2.0Ma has been selected as the crystallization age of the granite.

## DISCUSSION ON SEDIMENTATION, MAGMATISM AND UPLIFT IN CENTRAL BELT FROM PERMIAN TO TRIASSIC TIME

### Permo-Triassic marine sedimentation

Since the early stages of the subduction of the Paleo-Tethys Ocean in the Middle Permian times (Tjia & Syed Sheikh Almashoor, 1996; Metcalfe, 2000), platform sedimentation (carbonate rocks and argillaceous rocks) was taking place in the warm, shallow, and clear water setting that dominated the Central Belt (Figure 5) (Fontaine, 1986). It was concomitant with regional volcanism leading to widespread buildup development on structural highs across the Eastern Belt (Lim & Abdullah, 1994; Leman, 1995). Local interbedded argillite-carbonate sequences also demonstrated a shallow marine environment with fluctuated detrital supply from nearby continents (Kamal Roslan *et al.*, 2016). An exception is present in Central Pahang, where late Middle Permian radiolarian have been reported at Jengka Pass (Basir Jasin *et al.*, 1995) (Figure 5, no. 20) that could represent a deepening event, initiating the formation of a Middle Triassic deep flysch basin.

The Central Belt basin later experienced intensive subsidence (Kamal Roslan *et al.*, 2016) during the Middle Triassic to early Late Triassic period (e.g. Metcalfe *et al.*, 1982; Metcalfe & Chakrabroty, 1994; Ong, 2001; Wahid Abdul Rahman, 2015) that led to a deep water environment particularly in southern Pahang and western Johor area (Figure 5). This is also supported by the presence of flysch

**Table 2:** Zircon U-Pb ages of igneous rocks in Gunung Benom area in this study.

| Series | Locality | Coordinate | Lithology | Lower intercept age on the concordia plot (Ma) | Weighted mean age (Ma) |
|---|---|---|---|---|---|
| Alkaline | Jeram Besu | 4.013349°N, 101.936959°E | Diorite (sample 762a) | 215.2±5.1 (MSWD=0.99) | 221.8 ±2.4 (MSWD=1.6) |
| | | | Syenite (sample 762b) | 194±50 (MSWD=2.2) | 226.6±3.5 (MSWD=2.2) |
| Calc-alkaline | Northeastern foothill of Gunung Benom | 3.887403°N, 101.169158°E | Granite (sample 779) | 206.1±2.1 (MSWD=1.3) | 207.2±2.0 (MSWD=1.09) |

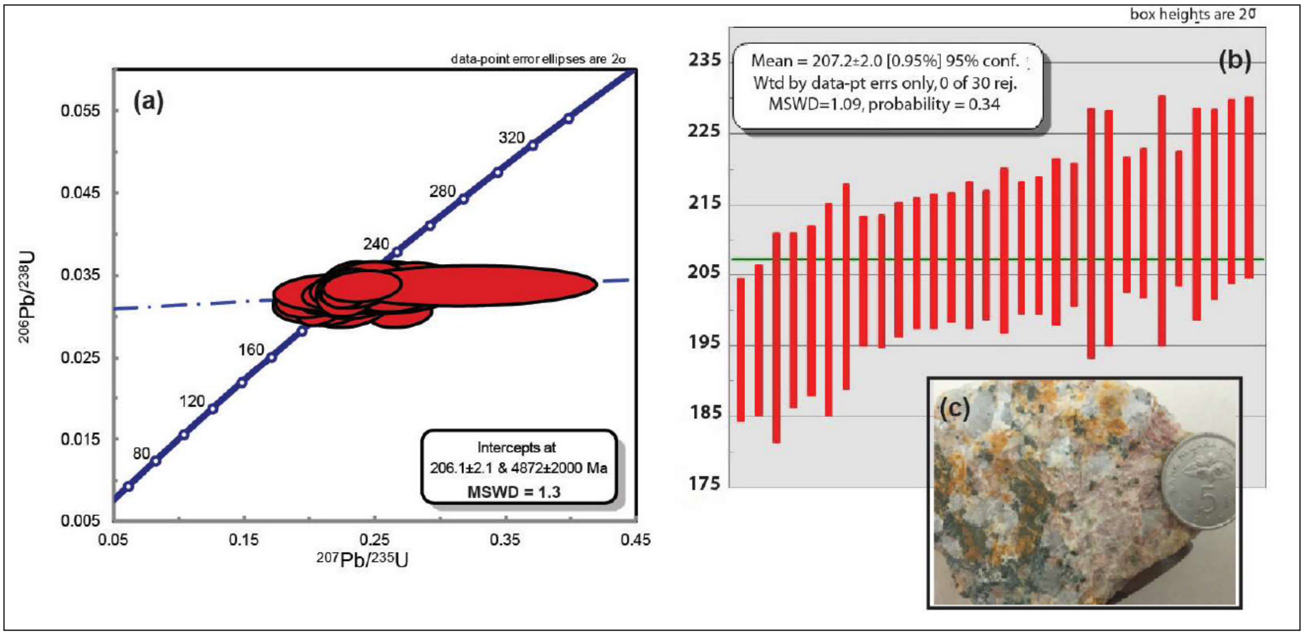


**Figure 4:** The granite (sample 779) from northeast part of Gunung Benom. (a) The concordia diagram showed the intercept at 206.1±2.1 Ma with MSWD=1.3. (b) U-Pb mean weighted age is 207.2±2.0 Ma with MSWD=1.09. (c) The rock is dominated by coarse-grained feldspar and quartz minerals.

series in the Semantan formation with high tuffaceous material supplied from the nearby active volcanic arc (e.g. Jaafar Ahmad, 1976; Khoo, 1983; Kamal, 1996; Ong, 2001). The main paleo-flow directions recorded in the flysch series indicate a westward to southwestward trend (Metcalfe *et al.*, 1982; Kamal, 1990; Metcalfe & Chakraborty, 1994), which suggest a sediment source from volcanic belt highs in the east. At the Middle-Late Triassic boundary, terrestrial deposits have been recorded locally near Raub and Singapore area, which indicate a major transition in the dynamics of the orogeny.

## Late Triassic uplift: Termination of deep marine sedimentation, red beds deposition and Benom Complex emplacement

By Late Triassic times, the entire Paleo-Tethys oceanic crust was finally consumed, ending the subduction-related volcanism at the western margin of Indochina block. Terrestrial deposits or red beds first appeared locally in Middle-Late Triassic boundary, while marine sedimentation was still ongoing during Carnian (early Late Triassic). The Late Triassic red beds present in Raub, Bentong and Genting Sempah are found to be unconformably overlying the Bentong-Raub Suture Zone (Richardson, 1939; Haile *et al.*, 1977). The uppermost part of the Clementi Member (late Middle Triassic) in the Boon Lay Formation in Singapore is characterized by well-developed, reddened palaeosols interbedded with channelized sandstone (Dodd *et al.*, 2019) and possibly marks the initiation of widespread terrestrial sedimentation. The absence of metamorphism and their younger age implies that the red beds were not part of the Paleo-Tethys accretionary wedge but likely originated from continental deposition on top of the wedge during the uplift caused by the collision.

The alkaline series of the Benom Complex were emplaced in the vicinity of Raub around 226.6-221.8 Ma and their chemical signature indicates partial enrichment in LILE from the mantle (Ghani *et al.*, 2002). The LILE enrichment fluids were derived from the partial melting of (probably metasomatised) peridotite and later migrated to the lower crust (Ghani *et al.*, 2006) during slab break-off (Mohd Rozi Umor, 2008; Mustaffa Kamal Shuib & Ghani, 2003) (Figure 6A). The subsequent calc-alkaline magmatism (Gunung Benom granite) is centered at 207 Ma, and may result from continuous mantle upwelling, or eventually the melting of both crustal (metaphyllite and metagreywacke) and mantle material (metabasalt) (Figure 6B).

## CONCLUSIONS

The Benom Complex is an igneous dome surrounded by Late Paleozoic to Mesozoic sedimentary rocks in the Central Belt, Peninsular Malaysia. It is one of the magmatic bodies which delineate a nearly N-S orientated igneous belt, adjacent to the Main Range and Bentong-Raub Suture Zone. The collision between the Sibumasu terrane and Indochina terrane resulted in the emplacement of the S-type Main Range granites, the Benom Complex and the deposition of syn-orogenic red beds during Late Triassic time. Our newly acquired zircon U-Pb ages evidence the crystallization of diorite and syenite (alkaline series) at 221.8±2.4 Ma and 226.6±3.5 Ma respectively, as well as granite (calc-alkaline series) at 207.2±2.0 Ma. By the early Late Triassic (226.6-

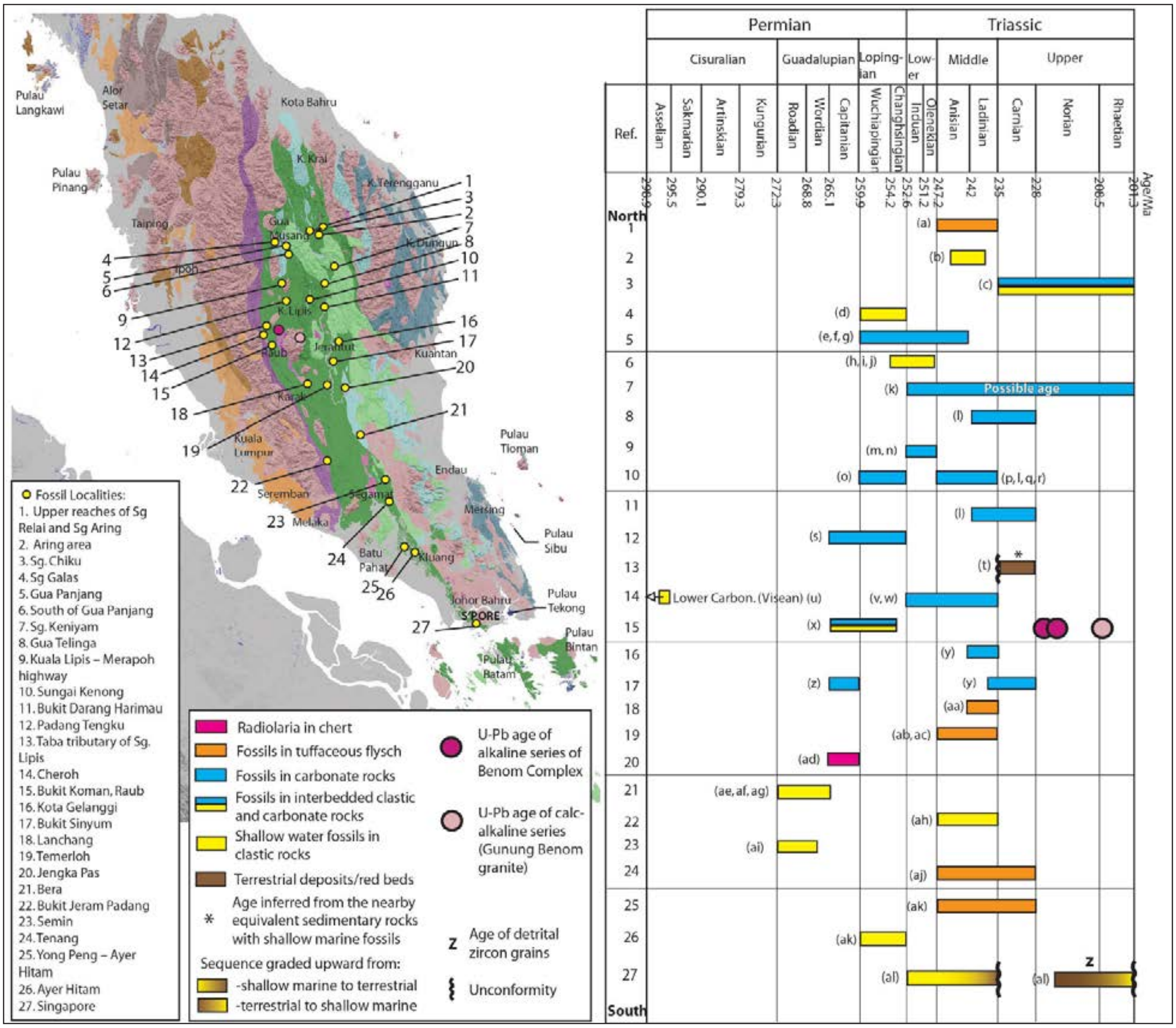


**Figure 5:** Localities of published fossil occurrences in the sedimentary rocks of Central belt. Summary of the ages of fossils occurring in the Central Belt from north to south, together with the new U-Pb ages of igneous rocks in Gunung Benom area. All fossil records are Permo-Triassic, except the fossils discovered in Sg. Cheroh area which date from Early Carboniferous (Visean). The sedimentation began by Middle Permian in Central Peninsular Malaysia with shallow water environment. The shallow water sedimentation persisted until Late Permian and Early Triassic in the north. In the Middle to early Late Triassic, the fossil records are mostly shallow water in northern area and deep water at the Central and southern area. When the emplacement of Benom Complex took place, no fossils (probably no sedimentation or being eroded) are found in the Central Belt, except Singapore which are shallow water-terrestrial environment and northernmost area i.e. Sg. Chiku.

The publications that reported the ages of the fossils are listed here: (a) Mohd. Razali, 1986; (b) Dony & Ahmad Rosli Othman, 2014; (c) Aw, 1990; (d) Jones *et al.*, 1966; (e) Nuraiteng, 2009; (f) Hada, 1966; (g) Igo *et al.*, 1966; (h) Leman, 1994; (i) Ichikawa & Yin, 1966; (j) Tamura, 1968; (k) Leman *et al*., 1999; (l) Fontaine & Ibrahim Amnan, 1994; (m) Metcalfe, 1992b, (n) Metcalfe & Azhar Hussin, 1995; (o) Abdul Hadi & Nuraiteng, 1994; (p) Jasmi, 1992; (q) Fontaine *et al*., 1994; (r) Nuraiteng & Abdul Hadi, 1995; (s) Leman, 1995; (t) Richardson, 1939; (u) Yancey, 1972; (v) Metcalfe, 1990; (w) Metcalfe, 2016, (x) Metcalfe, 1993; (y) Fontaine *et al*., 1988; (z) Idris & Hashim, 1988; (aa) Metcalfe *et al*., 1982; (ab) Metcalfe & Chakrabroty, 1994; (ac) Leman & Sone, 2001; (ad) Basir Jasin *et al*., 1995; (ae) Leman *et al.*, 2000; (af) Sone & Leman, 2000; (ag) Leman & Sone, 2002; (ah) Metcalfe *et al*., 1985; (ai) Sone *et al*., 2003; (aj) summarized in Khoo, 1983; (ak) Wahid Abdul Rahman, 2015; (al) Dodd *et al*., 2019.

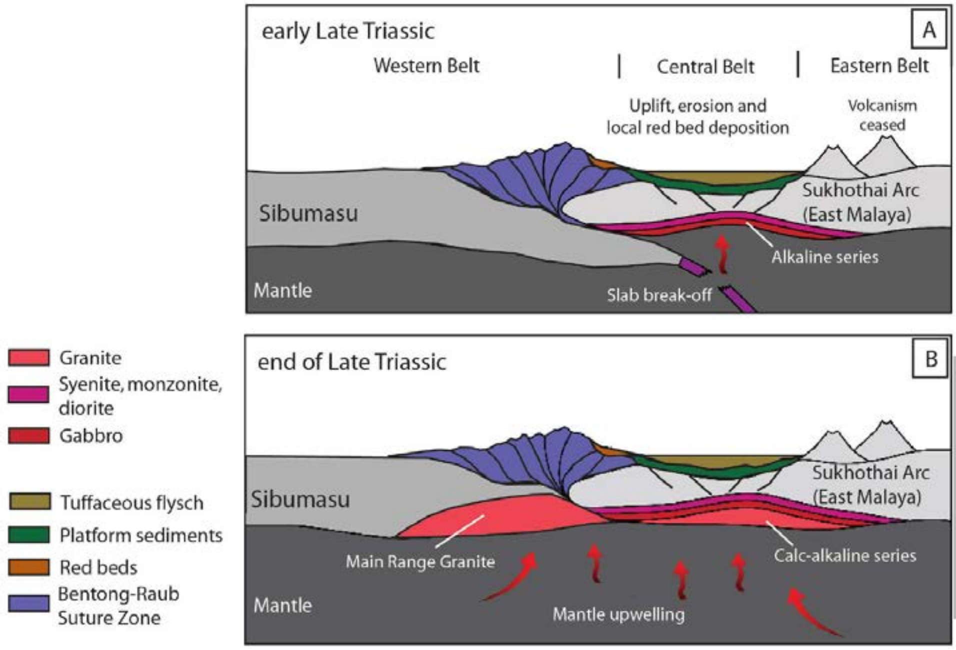


**Figure 6:** Tectonic evolution of the Gunung Benom area at Late Triassic time. [A] At early Late Triassic, slab break-off of the Paleo-Tethys triggered the emplacement of the alkaline series of Benom Complex beneath Central Belt. It was associated with the uplift, erosion and red beds sedimentation on suture zone. [B] The upwelling of mantle materials, and emplaced the calc-alkaline series (granite) of Benom Complex at the end of Triassic.

221.8 Ma), the alkaline series of the Benom Complex were most likely formed as a result from slab break-off of the Paleo-Tethys oceanic lithosphere. The earlier widespread Permo-Triassic shallow-deep marine sedimentation at Central Belt has been replaced by localized red beds-shallow marine deposition after the emplacement of the alkaline series at early Late Triassic. The non-metamorphosed Late Triassic red beds are different from the underlying suture zone units suggest they are not part of an accretionary complex, and should be a continental deposition associated with an orogenic uplift event. The alkaline series were later intruded by the calc-alkaline series (Gunung Benom Granite) by the end of the Triassic period (207 Ma) within the period of S-type Main Range granite emplacement, marking the end of the collision in the region.

## ACKNOWLEDGEMENTS

The authors would like to thank the YUTP -Fundamental Research Grant (015LC0-030) for providing the funding for field data acquisition and dating analysis. Thanks are also due to the zircon U-Pb dating service by GeoSep. Two anonymous reviewers are thanked for thoughtful and critical reviews, which greatly improved the manuscript.

## AUTHOR CONTRIBUTIONS

CCM carried out the field investigation and sampling, participated in the sequence alignment, prepared the data illustration and figures and drafted the manuscript. MP participated in the field investigation and conceptualized the main idea of the manuscript. BS participated in the field investigation, prepared the figures and participated in the sequence alignment. MAB helped to draft the manuscript. All authors read and approved the final manuscript.

## CONFLICT OF INTEREST

The authors have no conflicts of interest to declare that are relevant to the content of this article.

## REFERENCES

Abdul Hadi, R. & Nuraiteng, T. A., 1994. Himpuan fosil-fosil foraminifera dan alga yang terdapat di dalam singkapan-singkapan batu kapur di kawasan sekitar Sungai Kenong, Pahang. Warta Geologi, 20(3), 207.

Alexander, J.B., 1968. The geology and mineral resources of the neighbourhood of Bentong, pahang, and adjoining portions of Selangor and Negeri Sembilan. Me. MGeol. Surv. Dept. West Malaysia 8. 250 p.

Aw, P.C., 1990. Geology and mineral resources of the Sungai Aring area, Kelantan Darul Naim. Geological Society of Malaysia District Memoir, 21. 116 p.

Basir Jasin, Uyop Said & Rosmah Abdul Rahman, 1995. Late Middle Permian Radiolaria from the Jengka area, central Pahang, Malaysia. Journal of Southeast Asia Earth Sciences, 12, 79-83.

Bignell, J.D. & Snelling, N.J., 1977. Geochronology of Malayan granites. Overseas Geology and Mineral Resources (IGS), 47. 70 p.

Bradley, D., Haeussler, P., O'Sullivan, P., Friedman, R., Till, A., Bradley, D. & Trop, J., 2009. Detrital zircon geochronology of Cretaceous and Paleogene strata across the south-central Alaskan convergent margin. In: Haeussler, P.J. & Galloway

(Eds.), J.P. Studies by the U.S. Geological Survey in Alaska, 2007: U.S. Geological Survey Professional Paper 1760-F. 36 p.

Burton, C.K., 1973. Geology and Mineral Resources Johor Bahru – Kulai area, south Johore. Geological Survey of Malaysia, Map Bulletin 2, Malaysia. 72 p.

Darbyshire, D.P.F., 1988. Geochronology of the Malaysian granites. NERC Isotope Geological Report. British Geological Survey, 3. 60 p.

Dodd, T.J.H., Gillespie, M.R., Leslie, A.G., Kearsey, T.I., Kendall, E.S., Bide, T.P., Dobbs, M.R., Millar, I.L., Lee, M.K.W., Chiam, K. & Goay, M., 2019. Paleozoic to Cenozoic sedimentary bedrock geology and lithostratigraphy of Singapore. Journal of Asian Earth Sciences, 180, 103878.

Donelick, R.A., O'Sullivan, P.B. & Ketcham, R.A., 2005. Apatite fission-track analysis. Reviews in Mineralogy and Geochemistry, 58, 49-94.

Dony, A. N. & Ahmad Rosli Othman, 2014. Geoheritage Conservation of Paleontological Sites in Aring Area, Gua Musang District, Kelantan, Malaysia. International Journal on Advanced Science Engineering Information Technology, 4 (1), 14-19.

Fontaine, H., 1986. The Permian of Southeast Asia. CCOP Technical Bulletin, 18, 1-109.

Fontaine, H., Khoo, H.P. & Vanchard, D., 1988. Discovery of Triassic fossils at Bukit Chuping, in Gunung Senyum area and at Kota Jin, Peninuslar Malaysia. Journal of Southeast Asian Earth Sciences, 2, 145-162.

Fontaine, H. & Ibrahim Amnan, 1994. The importance of Triassic limestone in Central Belt of Peninsular Malaysia. Proceeding International Symposium on Stratigraphic Correlation of Southeast Asia, Bangkok, 195-205.

Fontaine, H., Ibrahim Amnan, Khoo, H.P., Nguyen, D.T. & Vachard, D., 1994. Discovery of Upper Permian to Triassic limestone in the lower basin of Sungai Kenong, Kuala Lipis area, Pahang. Geological Society of Malaysia Geological Paper, 4, 45-55.

Ghani, A.A., 2006. Field Evidence of Magma Mixing in Plutonic Rock from the Benom Complex, Central Belt of Peninsular Malaysia. Bulletin of the Geological Society of Malaysia, 52, 55-58.

Ghani, A.A., 2009. Volcanism. In: Hutchison, C.S. & Tan, D.N.K. (Eds.), Geology of Peninsular Malaysia, Universiti Malaya and Geological Society of Malaysia, Kuala Lumpur, 197-210.

Ghani, A.A., Ramesh, V., Yong, B.T. & Khoo, T.T., 2006. Geochemistry and petrology of syenite, monzonite and gabbro from the Central Belt of Peninsular Malaysia. Bulletin of the Geological Society of Malaysia, 49, 25-30.

Ghani, A.A., Ramesh, V., Yong, B.T., Khoo, T.T. & Shafari Muda, 2002. High Ba igneous rocks from.the Central Belt of Peninsular Malaysia and its implication. Geological Society of Malaysia Annual Geological Conference 2002, May 26-27 2002, Kota Bharu, Kelantan, Malaysia.

Gobbett, D.J. & Hutchison, C.S., 1973. Geology of the Malay Peninsula. Wiley-Interscience, New York. 438 p.

Hada, S., 1966. Discovery of Early Triassic ammonoids from Gua Musang, Kelantan, Malaya. Journal of Geosciences Osaka City University, 9, 111-113.

Haile, N.S., Stauffer, P.H., Krishnan, Lim, T.P. & Ong. G.B., 1977. Paleozoic redbeds and radiolarian chert: reinterpretation of their relationship in the Bentong and Raub areas, West Pahang, Peninsular Malaysia. Bulletin of the Geological Society of Malaysia, 8, 45-60.

Harbury, N.A., Jones., M.E., Audley-Charles, M.G., Metcalfe, I., & Mohamed, K.R., 1990. Structural evolution of Mesozoic Peninsular Malaysia. Journal of the Geological Society, London, 147, 11-26.

Hults, C.P., Wilson, H., Donelick, R.A. & O'Sullivan, P.B., 2013. Two flysch belts having distinctly different provenance suggest no stratigraphic link between the Wrangellia composite terrane and the paleo-Alaskan margin. Lithosphere, 5, 575-594. doi:10.1130/L310.1.

Hutchison, C.S., 1971. The Benta Migmatite Complex: Petrology of Two Important Localities. Bulletin of the Geological Society of Malaysia, 4, 49-70.

Hutchison, C.S., 1977. Granite emplacement and tectonic subdivision of Peninsular Malaysia. Bulletin of the Geological Society of Malaysia, 9, 187-207.

Hutchison, C.S., 1989. Geological Evolution of South-East Asia. Oxford Monograph on Geology and Geophysics No. 12. Oxford Science Publications, Clarendon Press. 345 p.

Hutchison, C.S., 2007. Geological Evolution of South-East Asia (2nd Ed.). Geological Society of Malaysia, Kuala Lumpur. 433 p.

Ichikawa, K., Ishii, K., & Hada, S., 1966. On the remarkable unconformity at the Jengka Pass, Pahang, Malaya. Journal of Geoscience, Osaka City University, 9, 123-130.

Ichikawa, K. & Yin, E.H., 1966. Discovery of Early Triassic Bivalves from Kelantan, Malaya. Journals of Geosciences, Osaka University, 9, 101-105.

Idris, M.B. & Hashim, C.N., 1988. An Upper Permian fossil assemblage from Gunung Sinyum and Gunung Jebak Puyoh limestone, Pahang. Warta Geologi, 14(5), 199-204.

Igo, H., Koike, T. & Yin, E.H., 1966. Triassic Conodonts from Kelantan, Malaya. In: Kobayashi, T. & Toriyama, R. (Eds.), Geology and Paleontology of Southeast Asia, 2, 157-177.

Jaafar, A., 1976. Geology and mineral resources of the Karak and Termerloh areas, Pahang. Geological Survey of Malaysia District Memoir, 15. 127 p.

Jaafar Ahmad, 1979. The petrology of the Benom igneous complex. Geol. Surv. Malaysia Spec. Paper 2, Malaysia. 141 p.

Jarvis, A., Reuter, H.I., Nelson, A. & Guevara, E., 2008. Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org.

Jasmi, A. T., 1992. Geologi dan Sumber Mineral kawasan Kuala Tembeling (Syit 69), Pahang Darul Makmur. Proceedings of 23rd Geological Conference, Technical Papers, Geological Survey of Malaysia, 1992, 59-71.

Jones, C.R., Gobbett, D.J. & Kobayashi, T., 1966. Summary of fossil record in Malaya and Singapore 1900-1965. Geology and Palaeontology of Southeast Asia, 2, 309-359.

Kamal, R. M., 1990. Sistem Trias di Jalur Tengah. Sains Malaysiana, 19, 11-22.

Kamal, R.M., 1996. Taburan Formasi Semantan Semenanjung Malaysia. Sains Malaysiana, 25, 91-114.

Kamal Roslan, M., Nelisa Ameera Mohamed Joeharry, Mohd Shafeea Leman & Che Aziz Ali, 2016. The Gua Musang Group: A newly proposed stratigraphic unit for the Permo-Triassic Sequence of Northern Central Belt, Peninsular Malaysia. Bulletin of the Geological Society of Malaysia, 62, 131-142.

Khoo, K.K., 1973. Geology of the central part of sheet 104, Kuala Pilah, Negeri Sembilan. Geological Survey of Malaysia annual report, 133-143.

Khoo, H.P., 1977. The geology of the Sungai Tekai area. Geological Survey of Malaysia Annual Report, 1977, 93-103.

Khoo, H. P., 1983. Mesozoic Stratigraphy In Peninsula Malaysia. Workshop on Stratigraphic Correlation of Thailand and Malaysia. Haad Yai, Thailand, 8-10 September, 1983. 370-383.

Kobayashi, T. & Tamura, M., 1968a. *Myophoria* (s.l.) in Malaya with a note on the Triassic Tigoniacea. In: Kobayashi, T. & Toriyama, R. (Eds.), Geology and Palaeontology of Southeast Asia, vol. 5. University of Tokyo Press, Tokyo. 88–137.

Kon'no, E., 1966. Some younger Mesozoic plants from Malaya. Geol. & Paleon. S.E.A., 3, 135-164.

Krähenbuhl, R., 1991. Magmatism, tin mineralization, and tectonics of the Main Range, Malaysian Peninsula: Consequences for the plate tectonic model of Southeast Asia based on Rb-Sr, K-Ar and fission track data. Bulletin of the Geological Society of Malaysia, 29, 1–100.

Leman, M.S., 1994. The significance of Upper Permian brachiopods from Merapoh area, northwest Pahang. Bulletin of the Geological Society of Malaysia, 35, 113-121.

Leman, M.S., 1995. The Significance of Permian Volcanic Activity Towards Faunal Development in Padang Tengku Area, Pahang. Sains Malaysiana, 24(1), 17–28.

Leman, M.S., Kamal Roslan Mohamed, Uyop Said, Ibrahim Amnan & Juhari Mat Akhir, 1999. Geomorfologi dan geologi Bukit Batu Besar, Taman Negara Pahang. In: Ibrahim Komoo & Leman, M.S. (Eds.), Warisan Geologi Malaysia, Lestari, 209-240.

Leman, M.S., Mohamed, K.R. & Sone, M., 2000. On the New Permian Bera Formation from the Bera District, Pahang, Malaysia. Proceedings of Geological Society of Malaysia Annual Geological Conference 2000, 14, 151-58.

Leman, M.S. & Sone, M., 2001. Conglomerate from Setia Jasa near Temerloh, Pahang, Peninsular Malaysia: its stratigraphic position and depositional environment. Proceedings of the Geological Society of Malaysia, 2001, 115-119.

Leman, M.S. & Sone, M., 2002. A Permian phillipsiid trilobite from Peninsular Malaysia. Geosciences Journal, 6(2), 125-129.

Lim, K. K. & Abdullah, N.T., 1994. Development of Permian Volcaniclastics Limestone Succession at Gua Bama, Pahang Darul Makmur. Warta Geologi, 20(3), 243-244.

Loganathan, P., 1977. The Geology and Mineral Resources of the Segamat Area (Sheet 115), Johore. Geo. Surv. Malaysia Ann. Rept. 1977.

Metcalfe, I., 1990. Lower and Middle Triassic conodonts from the Jerus Limestone, Pahang, Peninsular Malaysia. Journal of Southeast Asian Earth Sciences, 4(2), 141-146.

Metcalfe, I., 1992b. Lower Triassic (Smithian) conodonts from northwest Pahang, Peninsular Malaysia. Journal of Micropaleontology, 11, 13-19.

Metcalfe, I., 1993. Permian conodonts from the Raub Gold Mine, Pahang, Peninsular Malaysia. Warta Geologi, 19(3), 85-88.

Metcalfe, I., 2000. The Bentong–Raub Suture Zone. Journal of Asian Earth Sciences, 18, 691–712.

Metcalfe, I., 2013. Tectonic evolution of the Malay Peninsula. Journal of Asian Earth Sciences, 76, 195-213.

Metcalfe, I., 2016. A new Lower Triassic (Induan) Jerus Limestone locality in northwest Pahang, Peninsular Malaysia: Conodont fauna, depositional and tectonic settings. Island Arc, 25, 126–136.

Metcalfe, I. & Azhar Hussin, 1995. Implications of new biostratigraphic data for stratigraphic correlation of the Permian and Triassic in Peninsular Malaysia. Bulletin of the Geological Society of Malaysia, 38, 173-177.

Metcalfe, I. & Chakraborthy, K.R., 1994. A stratigraphic log of Semantan Formation along part of the Mentakab-Temerloh Bypass, Pahang. Bulletin of the Geological Society of Malaysia, 35, 37-46.

Metcalfe, I., Chakraborty, K.R., Foss, C.A. & Samsudin, H.T., 1985. A Middle Triassic fauna from the Bt. Jeram Padang Ridge at Bahau, Negri Sembilan, Peninsular Malaysia. Warta Geologi, 11, 111-115.

Metcalfe, I., Sivam, S.P. & Stauffer, P.H., 1982. Stratigraphy and sedimentology of the Middle Triassic rocks exposed near Lanchang, Pahang, Peninsular Malaysia. Bulletin of the Geological Society of Malaysia, 15, 19-30.

Mohd. Razali, C. K., 1986. Sedimentologi, Stratigrafi dan Struktur Kawasan Sg. Sam – Sg. Sam, Kuala Krai, Kelantan. Unpubl. BSc (Hons) thesis, Dept. of Geology, University of Malaya.

Mohd Rozi Umor, 2008. Petrogenesis dan Geokimia Batuan Igneus Jalur Tengah, Semenanjung Malaysia. PhD thesis (unpubl.), Universiti Kebangsaan Malaysia.

Mohd Rozi Umor & Syed Sheikh Almashoor, 2000. Tren Unsur-Unsur Surih dan Nadir Bumi Batuan Kompleks Benta, Pahang sebagai Petunjuk kepada Proses Pembentukan dan Evolusi Batuan. Geological Society of Malaysia Annual Geological Conference 2000, September 8-9 2000, Pulau Pinang, Malaysia .

Mohd Rozi Umor & Syed Sheikh Almashoor, 2001. Jujukan usia batuan di Dalam Kompleks Benta, Pahang berdasarkan cirian lapangan dan penentuan usia batuan secara K/Ar keseluruhan batuan. Geological Society of Malaysia Annual Geological Conference 2000, September 8-9 2000, Pulau Pinang, Malaysia, 111-120.

Mohd Rozi Umor, Azman Abdul Ghani & Hamzah Mohamad, 2008. The Genesis of the Alkaline Rock Series of the Benom Complex, Central Belt of the Peninsular Malaysia. Proceedings of the International Symposia on Geoscience Resources and Environments of Asian Terranes (GREAT 2008), 4th IGCP 516 and 5th APSEG, November 24-26, 2008, Bangkok, Thailand.

Moore, T.E., O'Sullivan, P.B., Potter, C.J. & Donelick, R.A., 2015. Provenance and detrital zircon geochonologic evolution of lower Brookian foreland basin deposits of the western Brooks Range, Alaska, and implications for early Brookian tectonism. Geosphere, 11, 93–122. doi:10.1130/GES01043.1.

Mustaffa Kamal Shuib & Ghani, A.A., 2003. 'Mantle plume' type magmatism in the Central Belt of Peninsular Malaysia and its tectonic implications. Bulletin of the Geological Society of Malaysia, 46, 365-371.

Ng, S.W.P., Chung, S.L., Robb, L.J., Searle, M.P., Ghani, A.A., Whitehouse, M.J., Oliver, G.J.H., Sone, M., Gardiner, N.J. & Roselee, M.H., 2015a. Petrogenesis of Malaysian granitoids in the Southeast Asian tin belt: Part 1. Geochemical and Sr-Nd isotopic characteristics. Geological Society of America Bulletin, 127(9-10), 1209–1237. doi: 10 .1130/B31213.1.

Ng, S.W.P., Whitehouse, M.J., Searle, M.P., Robb, L.J., Ghani, A.A., Chung, S.L., Oliver, G.J.H., Sone, M., Gardiner, N.J. & Roselee, M.H., 2015b. Petrogenesis of Malaysian granitoids in the Southeast Asian tin belt: Part 2. U-Pb zircon geochronology and tectonic model. Geological Society of America Bulletin, 127(9-10), 1238–1258. doi: 10.1130/B31214.1.

Norizan Yaacub, S. & Uyop Said, 2002. Plant fossils from Bukit Belah, Batu Pahat, Johor. Geological Society of Malaysia Annual Geological Conference 2002, May 26 - 27 2002, Kota Bharu, Kelantan, Malaysia.

Nuraiteng, T.A. & Abdul Hadi, R., 1995. Discovery of Upper Permian carbonates from Kenong Wildlife Reserve, Pahang, Malaysia.

Bulletin of the Geological Society of Malaysia, 38, 79-89.

Nuraiteng, T.A., 2009. Mesozoic stratigraphy. In: Hutchison, C.S. & Tan, D.N.K. (Eds.), Geology of Peninsular Malaysia. University Malaya and Geological Society of Malaysia, Kuala Lumpur, 67-131.

Ong, Y.H., 2001. Geology and mineral resources of the Gunung Ledang Area, Melaka and Negeri Sembilan. Mineral and Geosciences Department Malaysia Map Report, 14. 93 p.

Paces, J.B. & Miller, J.D., 1993. Precise UPb ages of Duluth Complex and related mafic intrusions, northeastern Minnesota: Geochronological insights to physical, petrogenic, paleomagnetic, and tectonomagmatic processes associated with the 1.1 Ga Midcontinent Rift System. Journal of Geophysical Research, 98(B8), 13997-14013.

Rajah, S.S., 1986. Geology and Mineral Resources of the Gunung Belumut Area, Johor. Memoir 19, Geological Survey Malaysia. Geological Survey Headquarters, Kuala Lumpur. 191 p.

Richardson, J. A., 1939. The geology and mineral resources of the neighbourhood of Raub, Pahang, Federation Malay States. Memoir Geological Survey Department 13, Malaysia. 166 p.

Rishworth, D. E. H., 1974. The upper Mesozoic terrigenous *Gagau* Group of Peninsular Malaysia. Special paper - Geological Survey of Malaysia, no. 1. 78 p.

Sashida, K., Adachi, S., Igo, H., Koike, T. & Ibrahim, B.A., 1995. Middle and Late Permian radiolarians from the Semanggol Formation, Northwest Peninsular Malaysia. Transactions and Proceedings of the Palaeontological Society of Japan, New Series 177, 43–58.

Searle, M.P., Whitehouse, M.J., Robb, L.J., Ghani, A.A., Hutchison, C.S., Sone, M., Ng, S.W.-P., Roselee, M.H., Chung, S.-L. & Oliver, G.J.H., 2012. Tectonic evolution of the Sibumasu-Indochina terrane collision zone in Thailand and Malaysia: Constraints from new U-Pb zircon chronology of SE Asian tin granitoids. Journal of the Geological Society, 169, 489–500. doi: 10.1144/0016-76492011-107.

Sone, M. & Leman, M.S., 2000. Some mid-Permian fossils from Felda Mayam, Central Peninsular Malaysia. Proceedings of the annual Geological Conference 2000, Geological Society of Malaysia, 8-9th September 2000, Penang, 143-149.

Sone, M., Metcalfe, I. & Leman, M.S., 2003. Palaeobiogeographic implications of Middle Permian brachiopods from Johore (Peninsular Malaysia). Geol. Mag. 140(5), 523–538.

Spencer, C.J., Kirkland, C.L. & Taylor, R.J.M., 2016. Strategies towards statistically robust interpretations of in situ U-Pb zircon geochronology. Geoscience Frontiers, 7, 581-589.

Steiger, R.H. & Jäger, E., 1977. Subcommission on geochronology: Convention on the use of decay constants in geo- and cosmochronology. Earth and Planetary Science Letters, 36, 359-362.

Tamura, M., 1968. Claraia from North Malaya, with a note on the distribution of Claraia in Southeast Asia. In: Kobayashi, T. & Toriyama, R. (Eds.), Geology and Paleontology of Southeast Asia, 5, 78-87.

Tjia, H.D. & Syed Sheikh Almashoor, 1996. The Bentong Suture in southwest Kelantan, Peninsular Malaysia. Bulletin of the Geological Society of Malaysia, 139, 195-211.

Uyop Said & Che Aziz Ali, 2000. On the Palynomorph Assemblage from the Panti Sandstone, Kota Tinggi, Johor. Geological Society of Malaysia Annual Geological Conference 2000, September 8-9 2000, Pulau Pinang, Malaysia.

Uyop Said, Rasanubari Asmah Rahman Abdul Hamid & Mohd Musryzal Mohamed Ariffin, 2003. Early Cretaceous palynomorphs from Kampung Tanah Runtuh, Kluang, Johor. Bulletin of the Geological Society of Malaysia, 46, 143-147.

Vermeesch, P., 2018. IsoplotR: a free and open toolbox for geochronology. Geoscience Frontiers, 9, 1479-1493. doi:10.1016/j.gsf.2018.04.001.

Wahid Abdul Rahman, 2015. Geologi dan Sumber Mineral Kawasan Yong Peng Johor Darul Takzim. Jabatan Mineral dan Geosains, Laporan Peta 26, Malaysia. 114 p.

Wan Fuad Wan Hassan & Mohd Suhaimi Hamzah, 1999. Rare Earth Element patterns in some granitic rocks of Peninsular Malaysia. GEOSEA '98 Proceeding. Bulletin of the Geological Society of Malaysia, 43, 515-528.

Wendt, I. & Carl, C., 1991. The statistical distribution of the mean squared weighted deviation. Chemical Geology Isotope Geoscience Section, 86, 275-285. http://dx.doi.org/10.1016/0168-9622(91)90010-T.

Yancey, T.E., 1972. Carboniferous fossils from the Raub Group near Cheroh Village, western Pahang, West Malaysia. Newsletter Geol. Soc. Malaysia, 34, 5-9.

Yin, E.H., 1965. Provisional draft report on the Geology and Mineral Resources of the Gua Musang Area, Sheet 45, South Kelantan. Geological Survey of Malaysia. 49 p.

Yong, B.T., Azman A. Ghani, Khoo, T.T. & Shafari Muda, 2004. Benom Complex: Evidence of magmatic origin. Bulletin of the Geological Society of Malaysia, 48, 55-60.

*Manuscript received 28 September 2020;*
*Received in revised form 16 January 2021;*
*Accepted 20 January 2021*
*Available online 16 November 2021*