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Original article

Grain size statistics and morphometric analysis of Kluang-Niyor, Layang-Layang, and Kampung Durian Chondong Tertiary Sediments, Onshore Peninsular Malaysia: Implications for paleoenvironment and depositional processes

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ABSTRACT

Grain size statistics, morphometric and petrographic analyses of sediments and pebbles from the Tertiary sedimentary basins in Johor, onshore Peninsular Malaysia were carried out and presented in this article. The objective of the study was to interpret the depositional processes and paleoenvironment of the Tertiary sediments in the Kluang-Niyor, Layang-Layang, and Kampung Durian Chondong basins. Petrographic analysis reveals that the sandstones are mainly arenites and subfeldspathic arenites, based on the relative proportions of quartz, feldspar and lithic fragments. The textural immaturity of the sandstones suggests that the sediments were transported from a close source, and deposited along a passive continental margin. Grain size results indicate that the mean, standard deviation (sorting), skewness and kurtosis values for the sediment samples range from -0.57 Φ to 0.68 Φ (very coarse-grained to coarse-grained sandstones); 1.35 Φ to 2.27 Φ (indicating poorly sorted to very poorly sorted sandstones); 0.00 Φ to 0.36Φ (nearly symmetrical, finely skewed to strongly fine skewed); and 0.71Φ to 1.32Φ (platykurtic, mesokurtic to leptokurtic), respectively. The predominance of very coarse to coarse-grained sediments suggests low energy conditions of deposition and the poor sorting is the result of rapid deposition by strong, fluctuating currents. This, in conjunction with the various bivariate plots employed, including the Linear Discriminant Analysis (LDA) diagrams, has aided in discriminating fluvial from other depositional environments. Using Passega's diagram, the C-M pattern of these Tertiary sediments indicated that they were transported by rolling and bottom suspension. Moreso, pebble morphometric results show the mean values of the various morphometric parameters as follows: flatness ratio ($S/L = 0.49$), elongation ratio ($I/L = 0.73$), maximum projection sphericity ($\Psi P = 0.69$), Oblate-Prolate index ($OPI = 0.45$), and roundness (50.526). The pebbles of these basins were shaped in a river environment, based on measured and computed morphometric indices. Results of granulometric statistics, morphometric indices and petrography together with bivariate plots, as well as the absence of fossils/trace fossils suggest that these isolated Tertiary basins' sediments were transported by rolling and bottom suspension (a very short distance of transport), deposited by a high-energy fluvial depositional system, close to the source.

1. Introduction

Statistical grain size, morphometric and petrographic analyses have been widely used in sedimentology as powerful tools for identifying sedimentary processes and depositional environment. One of the essential physical characteristics of sediment is the distribution of the particle sizes (Wang et al., 2021), and this has been considered to be an important tool for sedimentary environment classification (Blott and Pye, 2001). Sediments' components are a

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result of the source composition, weathering, and transportation; thus, sandstone framework compositions are related to the provenance (Dickinson et al., 1983). Grain size affects sediments' entrainment, transport and deposition, and provides clues to the sediments' transport history and energy condition, depositional conditions, provenance, paleodepositional environment and mode of transportation (Blott and Pye, 2001; Boggs, 2009; Rahman et al., 2022). Moreover, grain properties/textures affect porosity, permeability and other rock properties (Boggs, 2009; Folk, 1966). The morphometric analysis could be used to determine provenance, weathering and transport history, energy condition, as well as depositional environment (Barudžija et al., 2020; Boggs, 2006; Wadell, 1934). Sedimentary particles may display a wide range of morphometric properties/shapes, depending upon their history (Boggs, 2006). Information can be obtained from the clasts' size and shapes, their overall distribution and size fraction percentages, the textural maturity of the sediment, the surface texture, and the general morphology of particles (Krumbein and Sloss, 1963; Syvitski, 2007).

Many researchers have reported the use of a framework composition and attempted to improve provenance models to deduce the tectonic provenance of sandstones (Crook, 1974; Dickinson et al., 1983; Suttner et al., 1981; Weltje and Von Eynatten, 2004). Provenance analysis of siliciclastic sedimentary rocks havebeen used to reveal the composition and geological evolution of sediment sources as well as to characterise the depositional basin's tectonic setting (Zaid, 2013). Textural characteristics of sediments are a function of sedimentary processes such as weathering, erosion and transportation (Ilevbare and Omodolor, 2020). Sediment grain size parameters such as mean, sorting, skewness and kurtosis provide information on grain size, shape and sorting. Earlier work on the grain size statistics was used to interpret sandstone environments-e.g. Keller (1945) and Mason and Folk (1958) in beaches versus dunes; Friedman (1961) in fluvial versus beaches vs dunes; and Rogers and Strong (1959) in beaches versus fluvial. Numerous modal distributions in grain size, which correspond to differences in the transport and depositional processes, reflect the differences in the sedimentary environments (Ma et al., 2020). Sedimentologists focus on three main aspects of grain size (Boggs, 2006); these are (a) how the grains are measured (b) techniques for expressing and presenting the data (graphically or statistically) for easy evaluation, and (c) the genetic relevance of the data. Grain size data are commonly represented graphically or mathematically/statistically. The graphical technique involves a plot that represents a grain size data set. The mathematical method, on the other hand, involves the use of mathematical expressions or statistical variables such as mean, sorting/standard deviation, kurtosis and skewness. In pebble morphometric studies, form indices have been demonstrated to be a useful indicator of depositional environment (e.g. Pettijohn, 1975; Barudžija et al., 2020). Three parameters have been known to control the morphometric characteristics of clastic sediments: shape, roundness and sphericity (Boggs, 2006). Clast shape is a function of various factors such as original shapes of grains from the source area, orientation and fracture spacing in bedrock, intensity and nature of sediment transport and post-depositional processes which might affect the original shape of the clast (Boggs, 2006). For instance, the sphericity reflects depositional conditions while the roundness of sedimentary grains indicates abrasional history degree (Pettijohn, 1975). Pebble morphometry has also helped in discrimination between modern (known environments) beach and river sediments, making it useful in reconstructing ancient sedimentary environments (Blatt, 1959; Cailleux, 1945; Dobkins and Folk, 1970).

It is worth noting that, despite their usefulness in the study of siliciclastic sedimentary rocks; grain-size parameters have some drawbacks. Changes or later modifications that a framework component undergoes when affected by diagenesis are among these restrictions (Ahmad et al., 2021; Ghaznavi et al., 2019). Regardless of these limitations, previous research have effectively used grain-size parameters, and have proven to be useful in understanding sediment transportation mechanisms, provenance, and depositional environments.

This research focuses on Tertiary sedimentary basins exposed in Johor and its surroundings. The semi consolidated to unconsolidated sediments occur as onshore sedimentary deposits in small, isolated basins. The basins are fault-controlled, as most of them are aligned parallel to the major regional faults system (Raj et al., 1998). The earliest previous research on the onshore Tertiary sedimentary basins focused on the general geological knowledge (Alexander, 1959; Liew, 1995; Munif, 1993; Raj, 1998; Raj et al., 1998; Renwick and Rishworth, 1966; Scrivenor, 1931; Stauffer, 1973; Suntharalingam, 1983; Vijayan, 1990). Recent works on the Tertiary basins are very limited (e.g. Kasim et al., 2020; Mahmud and Sautter, 2022; Meng et al., 2017a). These Tertiary basins have been reported from seven known localities: Bukit Arang, Enggor, Batu Arang, Kampung Durian Chondong, Kluang-Niyor, Layang-Layang and Lawin. The Batu Arang Basin in Central Selangor is the only Tertiary sedimentary basin that has been extensively studied. A detailed sedimentological understanding of the other six basins is still deficient. Hence, comprehensive sedimentological research of these basins is required. In this study, the focus is on the use of statistical and morphometric parameters, as well as petrography of sedimentary grains from the three basins in Johor (Kluang-Niyor, Layang-Layang and Kampung Durian Chondong basins), Peninsular Malaysia. The specific aim is to utilise these statistical/textural parameters, pebble morphometric attributes and petrographic characteristics of sediments with the view to interpreting the depositional processes and paleoenvironment, as well as to decipher the basins' provenance. It is believed that several combinations of these parameters are environmentally sensitive (Moiola and Weiser, 1968).

2. Regional geological setting

Peninsular Malaysia, which lies at the southeastern tip of Asia, consists of two continental terranes; the Sibumasu, which is the western terrane; and the Indochina/East Malay, which is the eastern continental terrane (Metcalfe, 1988). Geologically, the Peninsular is divided into three main belts (Fig. 1a); Western Belt, Central Belt and Eastern Belt, based on stratigraphy, structures, mineralization and geological history. The Bentong-Raub Suture zone, the main Palaeo-Tethyan suture in the Peninsular, separates the Western and Central belts, while a major fault, the Lebir Fault zone, separates the Central from the Eastern belt. The Bentong–Raub suture zone contains cherts and deep-sea sediments of Middle Devonian to Middle Triassic (Hutchison, 1977; Metcalfe, 2000; Sone and Metcalfe, 2008). Hutchison (1977) subdivided the Peninsular based on tectonic history into four belts: the Western stable shelf, the Main Range, the Central belt and the Eastern belt. Except for Jurassic and younger deposits, the structure of sedimentary basins in Peninsular Malaysia has been distorted by tectonic deformations, widespread granitic intrusions and repetitive denudation (Tjia, 1999).

The Western Belt consists of Triassic granitic bodies and a Paleozoic continental margin sequence. The continental margin sequence contains both siliciclastic and carbonate rocks that are scattered within the volcanics. These rocks are found in Kedah and northern Perak, as well as Kinta valley in Perak (as extensive Silurian-Permian limestones). Carbonate platforms (Kodiang and Chuping Formations) in Kedah and Perlis and the deep water

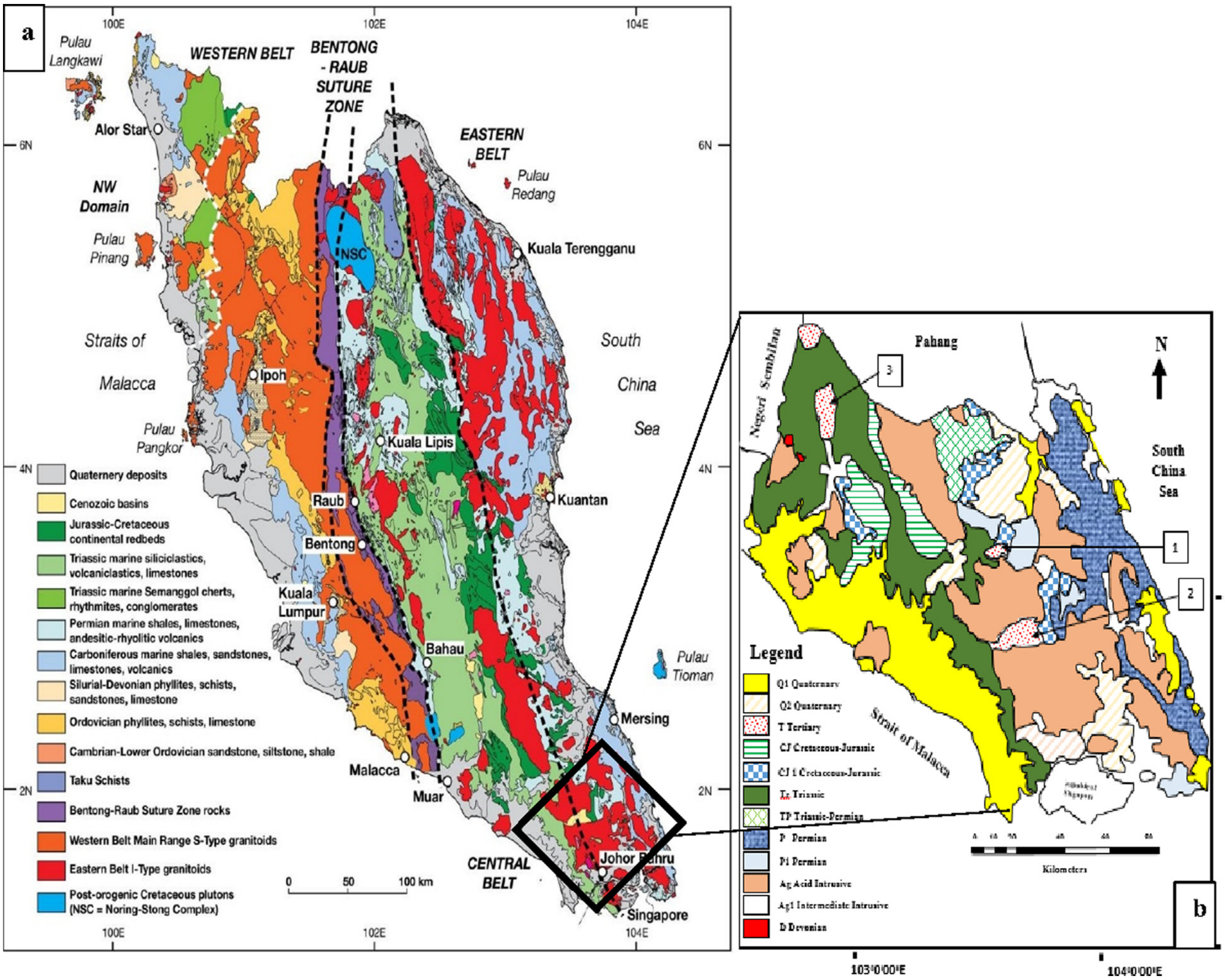

Fig. 1. (a) Simplified geological map of Peninsular Malaysia (Modified from Metcalfe, 2013) (b) Geological map of Johor showing the studied and surrounding areas (1 = Kluang-Niyor Basin, 2 = Layang-Layang Basin and 3 = Kg. Durian Chondong Basin) (Redrawn and Modified from Saleh et al. (2015).

Semanggol Formation found in Kedah and Perlis are of Triassic age (Metcalfe, 1999). Most of the Tertiary sedimentary basins are situated in the Western Belt. The Central Belt, which is an extensional graben, essentially contains marine carbonates, shales, volcaniclastic and andesitic volcanics of Paleozoic and Triassic rocks, and a few rocks of the Jurassic and Cretaceous periods (Metcalfe, 1999; Metcalfe and Azhar, 1995; Nuraiteng, 2009). Marine sedimentary rocks from the Raub Group, Gua Musang Formation, Aring Formation, and Kepis Beds make up the Permian strata in the Central Belt (Lee, 2009). Other rock groups within Central Belt include the Mesozoic rocks of Koh Formation, Semantan Formation, Tembeling Group, Bertangga Sandstone, Paloh Formation and Ma'Okil Formation (Nuraiteng, 2009), as well as Kg. Durian-Chondong onshore Tertiary basin. The Eastern Belt consists of Cretaceous continental deposits overlying the deformed Paleozoic sedimentary rocks unconformably (Chakraborty and Metcalfe, 1984). The dominant rock groups in the Eastern Belt are; shallow marine Carboniferous sediments of the Kuantan Group, Kamning and Seri Jaya beds, and Permian conglomeratic deposits such as the Linggui and Dohol formations. In the Eastern Belt, the Mesozoic period saw the deposition of Lotong Sandstone and its underlying Badong Conglomerate, which belong to the thick succession of the Continental Gagau Group.

The onshore Tertiary sedimentary basins are sparsely distributed throughout the Western geologic belt as small, isolated basins over the Peninsular. Among the seven onshore Tertiary sedimentary basins of Peninsular Malaysia, three are situated in Johor, i.e., Kluang-Niyor Basin, Kg Durian Chondong Basin and Layang-Layang Basin (Fig. 1b). The other four Tertiary basins outside Johor are Bukit Arang, Enggor, Batu Arang and Lawin basins. The basins' occurrences are limited and localized. They developed as pull-apart basins after the collision of the Indian Plate and the Eurasian Plate some 50 million years ago, and are hence connected by NW-SE trending strike-slip faults (Raj, 1998; Raj et al., 1998). The basins, which are oval/elliptical, are half-graben or small depressions aligned to major fault zones (Liew, 1995). The fact that most of these basins are located along major structural discontinuities indicates that they were formed by structural adjustment with faulting as the major controlling factor (Stauffer, 1973). The basins were initially formed as a result of NW-SE, left/sinistral fault displacements and, at a later time, normal faulting set in, which resulted in the deposition of Boulder Beds (Raj et al., 1989). These basins are stratigraphically subdivided into upper boulder beds and lower coal measure strata. The upper boulder beds are composed of gravels and boulders in a sandy matrix, while the lower sequences are composed of shales, sandstones and clays with a coal seam layer.

3. Methodology

3.1. Location of the study area

Kluang-Niyor, Layang-Layang, and Kampong Durian Chondong are the three Tertiary basins in the Johor area (Fig. 1**b**). Kluang is a town in Johor's central region. It has an undulating terrain, with Gunung Lambak, a 510 m tall mountain, as its highest point. The main river that drains the area is the Mengkibol River, which drains through the interior of Kluang town. Layang-Layang is located 32 km south of Johor and 72 km north of Johor Bahru in southern Johor. The age of the Layang-Layang Basin is thought to be Pliocene-Pleistocene. The Kampung Durian Chondong basin is in Johor's northwestern region, situated 10 km to the east of Gunung Ledang. The Muar River is the area's main water source.

3.2. Sediments and pebbles sampling

Fourteen-day fieldwork was conducted and samples were collected from the three Tertiary sedimentary basins in Johor. The fieldwork involves collection of physical sediment and pebble samples to cover the possible textural variations from the various localities in the three basins: Kluang-Niyor, Layang-Layang and Kg. Durian Chondong. In Kluang-Niyor, samples were collected from Taman Saujana, Taman Sri Permai and along the River Mangkibol; in Layang-Layang, from the Pekan Layang-Layang and Bandar Tenggara parts of the Pengeli Sand Member; and in Kg. Durian Chondong, samples were collected from Muar and Bukit Kepong. Sediment samples from the partly consolidated to unconsolidated pebbly sandstones were collected for textural and sieve analyses. These surface samples were collected from top 0 to 5 cm at each sample location. The samples were placed in polythene bags and taken to the Department of Geoscience, Universiti Teknologi PETRONAS, for sieve, morphometric and petrographic analyses. Using a handheld GPS, the geographic locations of samples were identified.

3.3. Petrography

A total of twelve (12) thin sections were made for selected consolidated samples of sandstones at the Universiti Teknologi PETRONAS's Department of Geoscience thin section laboratory. Petrographic analysis consisted of the description of the thin sections was conducted using optical microscope, with Leica Application Suite. The distinct minerals in each rock sample, especially the major ones (quartz, feldspar and lithic fragments) were depicted using varying optical properties such as texture, sorting, extinction, and colour, through point counting method of 200 to 300 count per sample.

3.4. Sediment grain size analysis

Thirty (30) collected sediment samples were subjected for sieve analysis to determine the grain size distribution and textural characteristics. Grain size distributions of sediment samples were determined for the unconsolidated and poorly consolidated sandstones, using mechanical sieving. The sieving was carried out according to theFriedman (1979) procedure. Grain size statistical parameters were computed using the Folk and Ward (1957) graphical measures (Table 1a). Using the equation, -log size/log2, sediment size was converted to phi scales, which was initially measured in microns. The grain size statistical parameters, together with bivariate plots, linear discriminant function (LDF) diagram and C-M plot were used to interpret and reveal depositional processes, energy of transporting medium and determine environments of deposition (Folk, 1968; Folk and Ward, 1957; Friedman, 1967; Passega, 1964; Sahu, 1964).

Table 1a
Formulae used in calculating the grain size parameters (Folk and Ward, 1957).

Grain size parameter	Formula
Graphic mean	$\mathrm{Mz} = \frac{\Phi_{16}+\Phi_{50}+\Phi_{84}}{3}$
Inclusive graphic standard deviation	$\delta_1 = \frac{\Phi_8-\Phi_{16}}{4} + \frac{\Phi_{95}-\Phi_5}{6.6}$
Inclusive graphic skewness	$\mathrm{SKi} = \frac{(\Phi_{84}+\Phi_{16}-2\Phi_{50})}{2(\Phi_{84}-\Phi_{16})} + \frac{(\Phi_{95}+\Phi_5-2\Phi_{50})}{2(\Phi_{95}+\Phi_5)}$
Graphic kurtosis	$\mathrm{KG} = \frac{\Phi_{95}-\Phi_{50}}{2.44(\Phi_{75}-\Phi_{25})}$

3.5. Pebble morphometric analysis

A total of one hundred and ninety (190) pebbles, ten (10) each from nineteen locations, were collected from the unconsolidated outcrops and measured for pebble morphometric studies. The total averages of the samples were recorded and analysis was made on these 19 average results. Pebble morphometric analysis involves measuring the long (L), intermediate (I) and short (S) axes of pebbles with the aid of a Vernier caliper (Folk, 1968; Krumbein, 1941). The measured axes were used to calculate the morphometric parameters, which include elongation ratio (ER) (Luttig, 1962), maximum sphericity projection (MSP) (Sneed and Folk, 1958), oblate prolate index (OPI) (Dobkins and Folk, 1970), and Flatness Ratio (Luttig, 1962) (Table 1b). Visual estimation (Powers, 1953) chart was used to determine the roundness of these pebbles. The roundness of a sedimentary particle refers to how sharp the corners and edges of the grain are (Boggs, 2006). Sphericity of the three major axes can be measured using one of the several methods (e.g. Krumbein (1941); Sneed and Folk (1958); etc.). In this study, the Sneed and Folk (1958) method of sphericity was used. These parameters were also presented on bivariate plots as dependent variables. The ratios listed above, according to Tucker (2001), are significant in classifying the pebbles into four-end members (blade, discord, prolate and equant). Zingg (1935) formula, which expresses the ratio between two shape indices b/a and c/b, was employed to define the four shape fields using a bivariate diagram.

4. Results and discussion

4.1. Petrography

The analysed sandstone samples exhibit a homogenous texture (very coarse to coarse grained), and are poorly to very poorly sorted, light brown to grey and semi consolidated to unconsolidated. The grains have subrounded to subangular shapes. The sandstone samples typically display different contacts ranging from tangential, concavo-convex to suture, and grains have are loosely packed. Compositional framework of the samples consisted of high quartz content, moderate to low feldspar content and low lithic fragment content. Quartz is mainly monocrystalline (single-crystal quartz), and feldspar has both plagioclase and orthoclase

Table 1b
Morphometric parameters used with their formulae.

Morphometric parameter	Formula	Author
Elongation Ratio	I/L	(Luttig, 1962)
Flatness Ratio	S/L	(Luttig, 1962)
Oblate Prolate Index	$(S^2/LI)^{1/3}$	(Dobkins and Folk, 1970)
Maximum Projection Sphericity Index	10[(L-I)(L-S)-(0.5)]/SL	(Sneed and Folk, 1958)
Roundness	Visual Estimation	(Powers, 1953)

grains with plagioclase variants of the feldspar being the most common (Fig. 2). Using Pettijohn et al. (1987) scheme, the studied sandstones are classified mainly as arenite and subfeldspathic arenites. Samples from Kluang-Niyor Basin (KL2 and KL9A; Fig. 2a and 2b) (Table 2) are very coarse-grained and poorly sorted. Based on their compositional framework, they are considered to be arenites. Selected sandstone samples from Layang-Layang Basin (LL4B and LL5; Fg 2c and 2d) show a higher percentage of feldspar than those of Kluang-Niyor Basin, and are respectively very coarse and coarse, poorly to moderately sorted sandstones. They are classified as subfeldspathtic arenites. These quatzofeldspathic sandstones from Layang-Layang Basin owe their characteristics due to high alkali feldspars than the plagioclase. In the Kg. Durian Chondong Basin, the selected samples (LL4B and LL5; Fig. 2e and 2f) are classified as arenites. Here, the basic composition of the majority of quartz grains is made up of a single quartz unit with several grains inclusions that are unevenly distributed within the grains.

4.2. Grain size statistics/textural characteristics

The results presented herein for the grain size indicate that there are little variations in the distribution, texture, and statistical properties within the depositional environment. Grain size/textural parameters are commonly used to categorize sedimentary environments and understand transport mechanisms as they reflect the depositional history and mode of transportation of a sedimentary basin. Granulometric data showing the various grain-size parameters and their basic interpretation were presented in (Table 2). For each of the thirty (30) samples, the cumulative frequency curves were used to calculate the mean, median, standard deviation, skewness, and kurtosis (Φ units). The grain size distribution variables of sediments reveal differences in their structural composition as well as the properties of the sediments, which would be employed as significant sediment discriminating markers

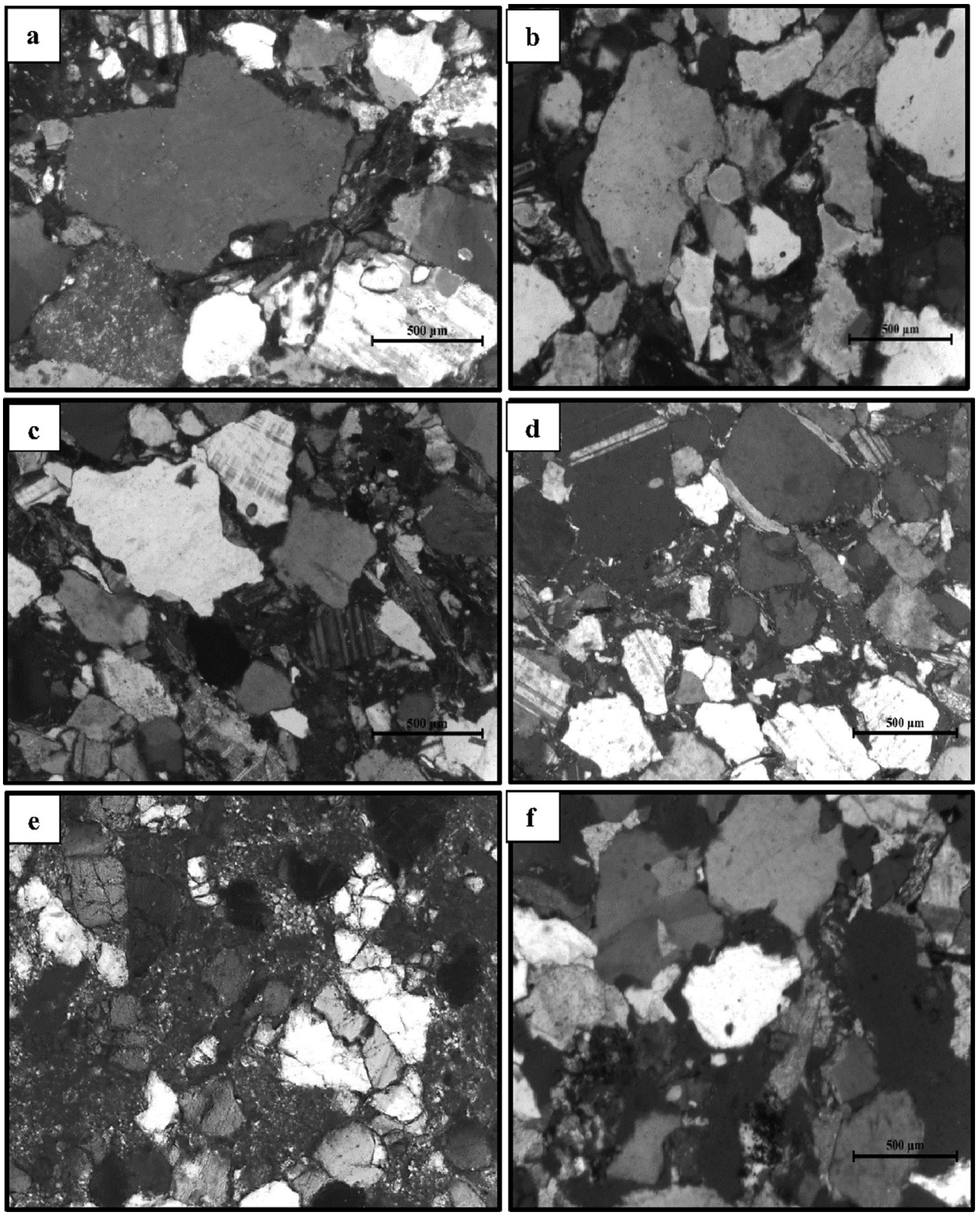

Fig. 2. Thin section photomicrographs of selected samples from Tertiary basins (a,b) Very coarse, poorly sorted sands/conglomerates from Kluang-Niyor Basin (c, d) very coarse sands and coarse sands which are poorly to moderately sorted coarse-grained sandstones from Layang-Layang Basin (e, f) coarse to very coarse, poorly sorted sandstones from Kg. Durian Chondong Basin.

Table 2
Table of values for statistical analysis of grain size of the onshore Tertiary sediments in Johor ((keys: KL = Kluang-Niyor, LL = Layang-Layang, and DC = Kg. Durian Chondong).

Sample ID	Mean	Standard deviation	Skewness	Kurtosis	Mean	Sorting	Skewness	Kurtosis
KL1 (Taman Sri Permai 1)	0.27	1.51	0.14	0.82	Coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Platykurtic
KL2 (Taman Sri Permai 2)	−0.44	2.00	0.30	0.84	Very coarse sand	Very poorly sorted	Fine skewed/ positively Skewed	Platykurtic
KL3B (Taman Sri Permai 3)	−0.24	1.89	0.29	0.96	Very coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Mesokurtic
KL4 (Taman Sri Saujana 1)	−0.06	1.76	0.24	0.82	Very coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Platykurtic
KL5 (Taman Sri Saujana 2)	0.20	1.66	0.00	0.77	Coarse sand	Poorly sorted	Nearly symmetrical	Platykurtic
KL7 (Taman Sri Saujana 3)	−0.54	1.94	0.30	0.96	Very coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Mesokurtic
KL9A (River Megkibol 1)	−0.53	2.03	0.26	0.76	Very coarse sand	Very poorly sorted	Fine skewed/ positively Skewed	Platykurtic
KL9B (River Megkibol 2)	−0.13	1.76	0.20	0.78	Very coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Platykurtic
KL9C (Taman Desa 1)	−0.17	2.06	0.17	1.21	Coarse sand	Very poorly sorted	Fine skewed/ positively Skewed	Leptokurtic
KL12C (Taman Desa 2)	0.37	1.52	0.08	0.86	Coarse sand	Poorly sorted	Nearly symmetrical	Platykurtic
LL1 (Pekan 1)	−0.29	1.89	0.28	0.81	Very coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Platykurtic
LL2B (Pekan 2)	−0.20	2.27	0.28	0.81	Very coarse sand	Very poorly sorted	Fine skewed/ positively Skewed	Platykurtic
LL3 (Pekan 3)	−0.05	1.85	0.36	0.80	Very coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Platykurtic
LL4A (Bandar Teggara 1)	0.03	1.79	0.26	0.81	Coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Platykurtic
LL4B (Bandar Teggara 2)	−0.27	1.91	0.24	1.12	Very coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Leptokurtic
LL4C (Bandar Teggara 3)	−0.10	1.85	0.26	0.85	Very coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Platykurtic
LL5 (Bandar Teggara 4)	0.67	1.51	0.21	1.15	Coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Leptokurtic
LL6 (Bandar Teggara 5)	−0.16	1.82	0.34	1.05	Very coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Mesokurtic
LL9A (Bandar Teggara 6)	−0.30	1.73	0.24	0.99	Very coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Mesokurtic
LL9B (Bandar Teggara 7)	−0.30	1.89	0.25	0.98	Very coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Mesokurtic
DC1B (Muar 1)	−0.29	1.80	0.28	0.96	Very coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Mesokurtic
DC1D (Muar 2)	0.67	1.35	0.02	0.76	Coarse sand	Poorly sorted	Nearly symmetrical	Platykurtic
DC1F (Muar 3)	−0.30	1.82	0.25	0.90	Very coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Mesokurtic
DC2A (Muar 4)	−0.57	2.08	0.16	1.13	Very coarse sand	Very poorly sorted	Fine skewed/ positively Skewed	Leptokurtic
DC2B (Muar 5)	−0.33	1.77	0.29	0.90	Very coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Mesokurtic
DC2C (Bukit Kepong 1)	0.68	1.74	0.13	0.79	Coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Platykurtic
DC2D (Bukit Kepong 2)	0.43	1.57	0.19	1.10	Coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Mesokurtic
DC3A (Bukit Kepong 3)	−0.47	1.93	0.18	0.71	Very coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Platykurtic
DC3B (Bukit Kepong 4)	−0.27	1.87	0.26	0.79	Very coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Platykurtic
DC3C (Bukit Kepong 5)	0.27	1.50	0.13	1.32	Coarse sand	Poorly sorted	Fine skewed/ positively Skewed	Leptokurtic

(Wang et al., 2021) such as mechanism, and sediment transport intensity.

4.2.1. Statistical Measures/grain size parameters

The graphic mean (Mz) parameter corresponds to the overall size of the grains. It represents the arithmetic average size of the sediment diameter values (Φ mean size) and connotes the index of energy conditions. The graphic mean size values for all samples range from −0.57 Φ to 0.68 Φ, with an average of −0.08 Φ (Table 2). This indicates that the average grain size values for all studied samples point to the predominance of very coarse-grained to coarse-grained sandstones, with twenty-one (21) samples being very coarse-grained sandstone and the remaining nine (9) samples being coarse-grained sandstone. The predominance of very coarse to coarse-grained sandstones indicates high-energy conditions of deposition. The mean size of the sediment samples shows little fluctuation, indicating a more or less consistent depositional pattern within the basins under study.

Graphic standard deviation is an approximate measure of sorting or uniformity of grain size distribution. The values obtained for standard deviation for all samples range from 1.35 Φ as a minimum to 2.27 Φ as a maximum (Table 2), indicating poorly sorted to very poorly sorted sandstones according to the grade of sorting. Twenty-five (25) of the samples are poorly sorted, while the remaining five (5) indicate very poor sorting condition. The sorting measure in the samples indicates a little distinction among the studied samples from the three basins. The predominance of poorly sorted sediments is due to the short distance of transportation of sediments and their characteristics show that they must have been deposited in a fluviatile environment.

Skewness is a measure of the distribution's symmetry or the proportion of coarse and fine fractions. When the mean deviates from the median, the grain size distribution is said to be skewed. Skewness values range from 0.00 Φ to 0.36 Φ, indicating that the distribution is finely skewed to nearly symmetrical, with only a few samples exhibiting strongly fine skewness (Table 2). The distribution of the skewness in the studied samples shows that twenty-five (25) are finely skewed, three (3) are nearly symmetrical, and two (2) exhibit strongly finely skewed characteristics. The positive skewness is an indication of the fluvial or aeolian environment. However, combining the skewness with other grain parameters, it could be suggested that the sediments are of fluvial origin.

Kurtosis indicates a state of being distorted or lack in symmetry, i.e. how the distribution is bell-shaped or shifted from normality. It shows the peakedness of the grain size distribution. Kurtosis alone may not be an environmentally diagnostic parameter, but this can provide valuable information when used with other granulometric parameters. Kurtosis values of the studied samples range from 0.71Φ to 1.32Φ, i.e. from platykurtic, mesokurtic to leptokurtic (Table 2). The average value of kurtosis for all the samples is 0.92, which indicates the predominance of the platykurtic distribution.

4.2.2. Grain-size bivariate plots

Bivariate plots (Fig. 3) were widely used to express the relationship between several statistical variables and to be able to deduce the environmental conditions at the time of sediments deposition. These bivariate plots, which combine the grain size parameters, have been used to discriminate different depositional environments. The distribution of the grain size (from very coarse to coarse sands) for all samples from the three basins could be shown on a very simple plot (Fig. 3a). The plots of mean versus standard deviation, skewness, and kurtosis (Fig. 3b-d) show that the sediments are poorly to very poorly sorted, finely skewed to nearly symmetrical, and mostly platykurtic and mesokurtic, with a few leptokurtic samples, respectively. The bivariate plot of standard deviation versus skewness (Fig. 3e) shows that the samples are clustered in the fluvial field.

4.3. Linear Discriminant analysis (LDA)

The Linear Discriminant Analysis was proposed by Sahu (1964), and it has been employed for multivariate evaluation of river and beach sediments. This statistical method of sediment analysis, which is used to understand and interpret variation in the energy and fluidity factors, has a strong connection to various sedimentary processes and depositional environments.

The formulae below have been used to calculate the graphical parameters for paleoenvironmental discrimination as follows:

$$Y1 = -3.5688\ MZ + 3.7016\ \delta_1{}^2 - 2.0766\ SK_1 + 3.1135\ KG.$$

$$Y2 = 15.6534\ MZ + 65.7091\ \delta_1{}^2 + 18.1071\ SK_1 + 18.5043\ KG.$$

$$Y3 = 0.2852\ MZ - 8.7604\ \delta_1{}^2 - 4.8932\ SK_1 + 0.0482\ KG.$$

$$Y4 = 0.7215MZ - 0.4030\ \delta_1{}^2 + 6.7322\ SK_1 + 5.2927\ KG.$$

where MZ is the mean value, δ_1^2 is the standard deviation, SK_1 is the skewness and KG is the kurtosis.

Y1 equation is used to distinguish between aeolian and littoral (intertidal zone) settings ($Y1 < -2.7411$ indicates an aeolian deposit, whereas $Y1 > -2.7411$ suggests a beach environment). For discrimination between beach (backshore) and shallow agitated marine environments (sub-tidal environment), the Y2 equation is used (where $Y2 < 65.3650$ indicates a beach deposition and $Y2 > 65.3650$ suggests a shallow agitated marine environment). The Y3 discrimination equation is used to distinguish between shallow marine and fluvial settings ($Y3 < -7.419$ suggests a fluvial deposit, while $Y3 > -7.419$ shallow marine deposit). Equation Y4 is used to distinguish between deltaic and turbidity current deposits, and if $Y4 < 9.8433$, it indicates turbidity current deposition, whereas $Y4 > 9.8433$ indicates deltaic deposition (Sahu, 1964).

From the computed statistical parameters, and using the above formulae, the values for Y1, Y2, Y3 and Y4 for all samples range from 4.94, 113.43, −21.22 and 3.57 to 9.36, 138.05, −16.84 and 5.55, respectively (Table 3). This range of values reveal that when Y1 is used, 100 percent of the samples fall in the beach environment. For Y2, Y3 and Y4, the studied samples exhibit shallow agitated water environment, fluvial regime, and turbidity current, respectively. Using the combined LDA plots, Y1 against Y2, Y2 against Y3, Y3 against Y4, it can be concluded that sediments from the three basins in Kluang-Niyor, Layang-Layang and Kg. Durian Chondong basins were deposited in a fluvial environment (Fig. 4-a-c).

4.4. C-M diagram

The C-M diagrams are constructed to indicate the relationship between C, the coarsest one percentile of the grain size distribution, and M, the median grain size distribution. This relationship has been used to distinguish distinct types of sediments from various environments (Passega, 1964; Visher, 1969). The correlation between C and M is the sorting effect of bottom turbulence. CM pattern is partitioned into segments as follows; NO, OPQ, QR, RS and S, which denote rolling, bottom suspension and rolling, graded suspension no rolling, uniform suspension and pelagic suspension, respectively. Passega (1957, 1964) and Passega and Byramjee (1969) have demonstrated that the one percentile of the grain size distribution represents the maximum competence of the transporting medium. Thus, Passega and Byramjee (1969) identified three basic limits in their analysis of river and marine coastal sediments using the CM plot: Cr denotes rolling, Cu denotes uniform suspension, and Cs denotes gradated suspension.

The CM pattern of the sampled sediments from the three onshore Tertiary basins in Johor is presented in Fig. 5. From the figure, there is a shift towards a higher C-value compared to the Passega (1964)'s region. Sediment samples from all the basins fall within the PQ portion of the Ludwikowska-Kędzia (2000), indicating that they were transported by rolling and bottom suspension.

4.5. Pebbly morphometry parameters

The results of pebble morphometric properties from the three Tertiary basins in Johor were presented in (Table 4). The morphometric parameters computed include sphericity (Maximum Projection Sphericity) index, oblate-prolate Index, elongation ratio and flatness ratio as well as roundness. Based on the above-mentioned factors, it is believed that sedimentary particles may exhibit a wide range of morphometric properties, reflecting the history during the sedimentary cycle. The mean value of the oblate-prolate index (OPI), elongation ratio (ER), flatness ratio (FR) and maximum projection sphericity index (MPSI) ranges from −6.78 to 6.37; 0.62 to 0.94; 0.36 to 0.64 and 0.57 to 0.79, respectively. The maximum projection sphericity average value is 0.69, with a larger percentage of the samples having values above

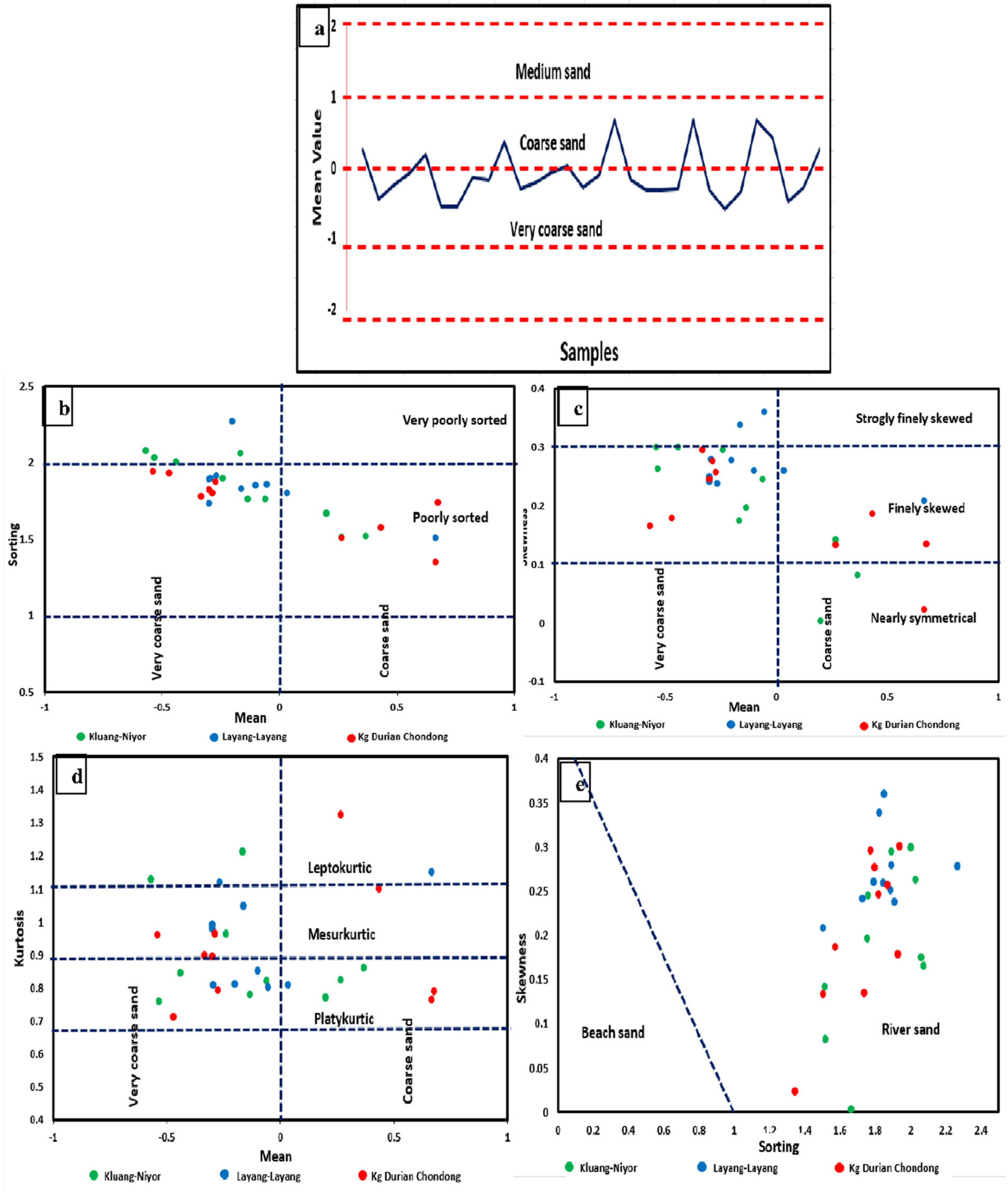

Fig. 3. (a) Variation of graphic mean among all the samples (b) Bivariate scatter plot showing mean versus sorting (boundary after (Tanner, 1991)) (c) Bivariate scatter plot showing skewness versus mean (boundary (Friedman, 1967; Tanner, 1991)) (d) Bivariate scatter plot showing kurtosis versus mean (after (Folk and Ward, 1957)) (e) Grain-size bivariate plot of inclusive graphic skewness vs standard deviation (after (Friedman, 1967)).

0.65, which gives an excellent indication of fluvial dominance. The average value of ER in all the samples (0.73) falls within the elongation ratio of Hubert (1968) (0.6 to 0.9) for the fluvial environment. The results of the elongation ratio (ER) and maximum projection sphericity index (MPSI) agree with and reflect the deposition of the pebbles in a fluvial setting. Morphometric indices indicated that the OPI average value of 0.45 satisfies the limit for fluvial pebbles. The average flatness index for samples from the three basins is 49.27 %.

4.5.1. Scatter/ bivariate and ternary plots

From the morphometric parameter results, scatter/bivariate plots of coefficient of flatness versus sphericity (Stratten, 1974), Maximum Projection Sphericity Index (MPSI) versus Oblate-Prolate Index (OP) (Dobkins and Folk, 1970), and MPSI versus roundness were plotted (Fig. 6a-c). The MPSI versus OP plot points to the fluvial process as the dominant depositional process for all samples from the three basins. The plot (Fig. 6a) indicates that pebbles were shaped by fluvial processes. However, plots of coefficient

Table 3
Linear Discriminant Function (LDF) values for Tertiary sediments, Johor, Onshore Peninsular Malaysia (keys: KL = Kluang-Niyor, LL = Layang-Layang and DC = Kg. Durian Chondong).

Sample ID	Y1	Y2	Y3	Y4
KL1	6.92	121.32	−13.82	4.89
KL2	10.99	145.66	−19.08	5.36
KL3B	10.24	143.62	−18.03	6.13
KL4	8.77	134.18	−16.58	5.23
KL5	7.83	126.65	−14.48	3.57
KL7	11.46	142.04	−18.55	5.93
KL9A	11.23	143.76	−19.18	4.57
KL9B	8.99	131.26	−16.34	4.64
KL9C	11.63	158.30	−18.89	6.63
KL12C	6.81	122.76	−13.54	4.75
LL1	9.99	139.79	−18.00	5.16
LL2B	11.05	165.71	−21.22	5.09
LL3	8.79	142.10	−17.94	5.88
LL4A	8.50	137.99	−16.93	5.32
LL4B	11.01	146.25	−17.91	6.55
LL4C	9.31	140.31	−17.45	5.43
LL5	6.34	134.37	−13.96	7.35
LL6	9.89	142.78	−17.63	6.96
LL9A	10.05	131.58	−16.36	5.95
LL9B	10.59	142.01	−17.81	5.88
DC1B	10.11	136.50	−17.14	6.03
DC1D	4.94	113.43	−11.68	4.13
DC1F	10.08	135.83	−17.18	5.44
DC2A	12.89	151.36	−19.11	5.82
DC2B	9.93	133.18	−17.02	5.79
DC2C	6.19	141.69	−15.63	4.87
DC2D	7.31	133.84	−14.51	6.75
DC3A	10.66	135.72	−17.86	3.84
DC3B	9.82	137.74	−17.66	4.96
DC3C	8.46	129.84	−13.68	7.49

of flatness versus sphericity and MPSI versus roundness show that 89 % of the mean sample values fall within the fluvial field while the remaining 11 % fall in the beach field. A few samples (three from Kluang-Niyor, one each from Layang-Layang and Kg. Durian Chondong; which account for about 17 % of the total samples) have OP Index and Sphericity values of <0.66 and −1.55, respectively, and this is typical of high-energy beach environment. From the Zingg plot (Fig. 6d), spheres, disc, and rod were the dominant shape types. This scattered distribution of the pebble shapes indicates multiple sources of provenance, some of which might probably be local. The Sneed and Folk (1958)'s ternary diagram allows samples to be plotted on the three vertices corresponding to Compact, Platy and Elongate form. Pebble form indices are diagnostic of depositional environment, for instance, compact (C), compact bladed (CB), compact elongate (E) point to fluvial settings, whereas platy (P), bladed (B), very platy (VP) and very bladed (VB) are common pebble forms in a beach depositional environment. The Sphericity-Form diagram was used to plot all of the clasts (Fig. 6e), and this shows that the bladed and compact-bladed forms are the modal classes. A few samples fall into the compact-bladed, bladed and platy categories.

5. Discussion

In order to understand the depositional processes and conditions of sediment samples from the known Tertiary sediments in Johor, thorough quantitative textural, morphometric and petrographical analyses were carried out on the sediment samples. Sedimentary depositional processes and paleoenvironment could be described in terms of physical characteristics of sediments, morphometric parameters and petrography (Reineck and Singh, 1980). Integration of grain size, morphometric and petrographic data has proved beyond doubt to be a good indicator of distinguishing sedimentary processes and paleodepositional environments, especially in situations where fossils are lacking, and particularly in a continental setting. Additionally, bivariate plots that combine a number of textural parameters have been utilised to further confirm the depositional environment and flow mechanism of sediment transportation and depositional processes.

The petrographic characteristics of the examined sandstone indicate that they consisted of high quartz percentage (averagely over 90 % in most samples), a predominance of monocrystalline quartz grains, more potassic than plagioclase feldspars, and a low percentage of lithic fragments. These characteristics are consistent with sediments that were deposited along a passive continental margin (Taylor and McLennan, 1985). Quartz is a hard mineral and remains the dominant component in most sandstones, therefore, it could be used to determine the source provenance from which sedimentary rocks originated (Basu et al., 1975). The predominance of monocrystalline in quartz grains in most of the studied samples indicates that the sediments are predominantly granitic sourced (Basu et al., 1975). The sandstones are poorly sorted, with subangular to subrounded grains, and texturally are of moderate maturity, implying that they were not sedimentary milled for lengthy periods. The very coarse to coarse grains indicate that they are not texturally matured. The immaturity of the sandstones suggests that the sediments were transported from a close source. Mechanical compaction is also common in these sandstones (Fig. 2). The plastically deformed quartz grains in the sandstone suggest that they were buried deeply enough or heated to a high enough temperature. The low percentage of unstable grains (feldspar and other lithic fragments) of <5 %, the dominance of monocrystalline quartz, and modification of feldspar grains indicate that these sandstones were produced from low-lying granitic sources and/or recycled sedimentary rocks (Zaid, 2013). The sandstones from the Pengeli Sand Member of the Layang-Layang Basin

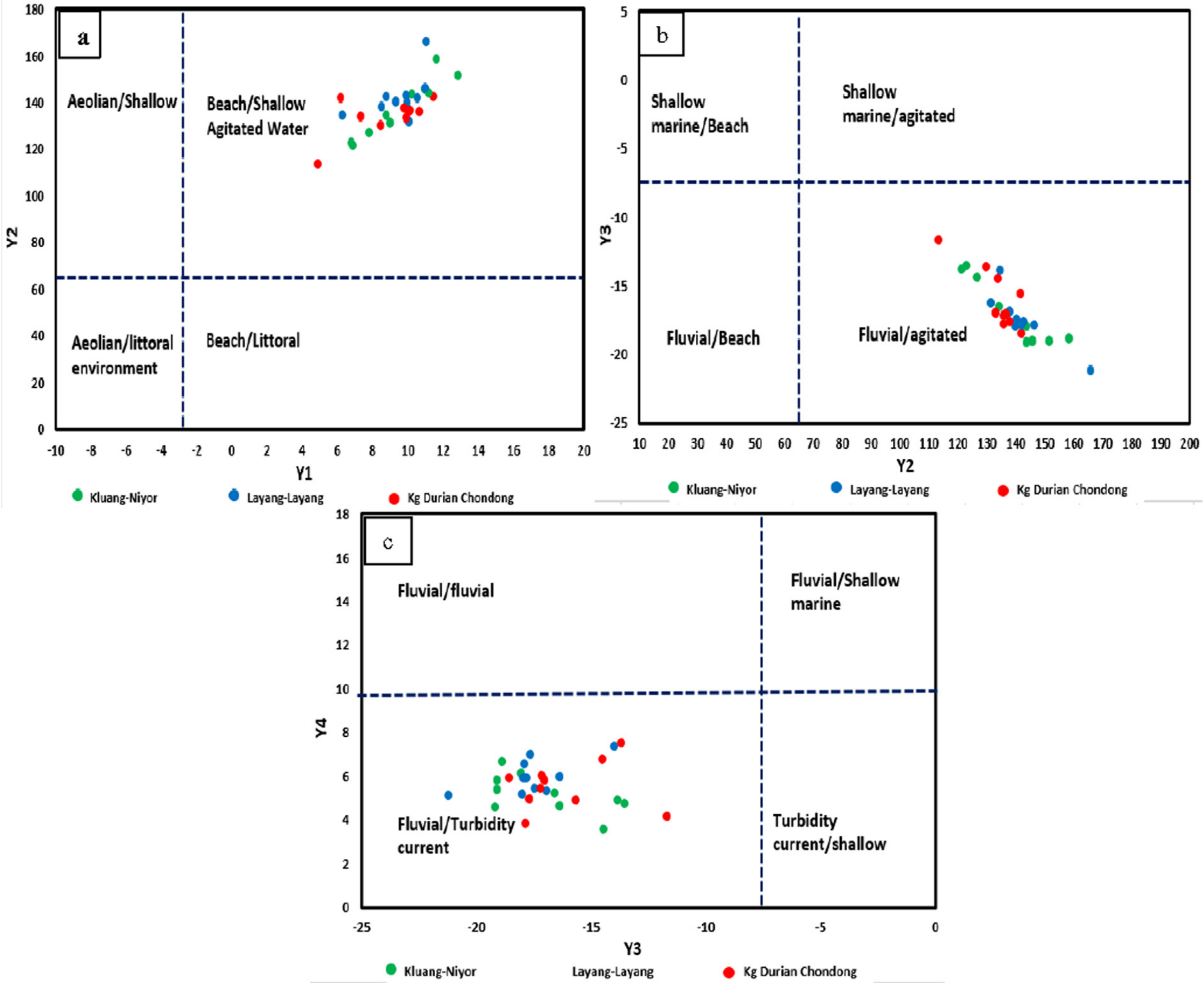

Fig. 4. (a–c): Linear Discrimination Function (LDF) plot for the onshore Tertiary sediments in Johor, Peninsular Malaysia.

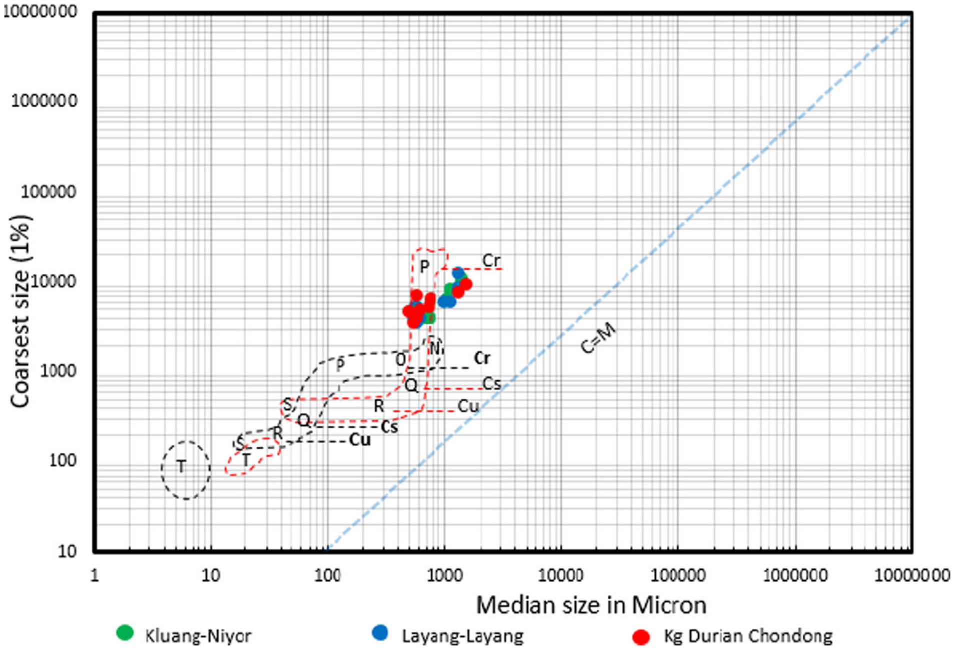

Fig. 5. C-M plot for onshore Tertiary basins in Johor, Peninsular Malaysia ((Black line: according to Passega (1964) and Passega and Byramjee (1969); Red line: according to Ludwikowska-Kędzia (2000)).

Table 4
Results of the mean total average values of morphometric properties from 19 outcrop locations of Tertiary Sediments, Johor (keys: KL = Kluang-Niyor, LL = Layang-Layang and DC = Kg. Durian Chondong).

Samples ID	L(cm)	I(cm)	S(cm)	S/L (Flatness Ratio)	I/L (Elongation Ration)	MPSI	OP INDEX	L-I/L-S	ROUNDNESS
KL2	3.03	2.03	1.45	0.48	0.67	0.70	2.76	0.63	46
KL3B	3.34	2.71	1.87	0.56	0.81	0.73	−1.32	0.43	48
KL4	3.02	2.76	1.94	0.64	0.91	0.77	−4.00	0.24	41
KL5	3.14	1.99	1.43	0.46	0.63	0.69	3.78	0.67	39
KL7	3.08	2.90	1.68	0.54	0.94	0.68	−6.78	0.13	45
KL9A	1.45	1.07	0.67	0.46	0.73	0.67	−0.10	0.50	32
KL9B	3.67	2.77	1.65	0.45	0.75	0.65	−1.12	0.45	40
KL9C	3.44	2.21	1.45	0.42	0.64	0.65	2.76	0.62	47
KL12C	3.00	1.99	1.35	0.45	0.66	0.67	2.50	0.61	47
LL1	2.68	1.73	1.26	0.47	0.65	0.70	3.55	0.67	40
LL2B	2.35	1.65	0.87	0.37	0.70	0.58	−0.88	0.47	30
LL3	2.77	1.97	1.23	0.45	0.71	0.66	0.48	0.52	41
LL4B	3.54	2.35	1.65	0.46	0.66	0.69	2.82	0.63	37
LL4C	3.46	2.91	2.19	0.63	0.84	0.78	−1.10	0.43	31
DC1B	2.02	1.35	0.97	0.48	0.67	0.70	2.87	0.64	46
DC1F	3.10	2.30	1.13	0.36	0.74	0.57	−2.64	0.40	45
DC2A	3.24	2.00	1.78	0.55	0.62	0.79	6.37	0.85	40
DC3A	3.11	2.76	1.90	0.61	0.89	0.75	−3.49	0.29	31
DC3B	3.46	2.43	1.77	0.51	0.70	0.72	2.07	0.61	35

have indicated a high similarity with the highly weathered or decomposed granite (Vijayan, 1990), and this has confirmed the granitic source. The quartzofeldspathic sandstones with high alkali feldspar to plagioclase ratios reported in the Layang-Layang Basin (Vijayan, 1990) could be linked to the continental block that has recently split as a result of continental rifting.

Grain size data offer useful suggestions for depositional condition interpretation, as sedimentary particles are separated during deposition based on their grain sizes and hydrodynamic behaviour. Primarily, mean particle size and sorting are the most sensitive parameters used in identifying potential depositional environment (Wang et al., 2021). Our findings have indicated that the mean values show little variation, which indicate little or no change in the energy of deposition. From the mean size values (−0.5 to 0.68), the sediments were thought to be deposited in a high-energy environment (Friedman, 1961; Sahu, 1964). The coarse-grained and poorly sorted nature of sediments suggests stable conditions of energy during deposition. It has been established that the maximum capacity of rivers during transport decreases with increasing distance from the source. Consequently, finer sediments are found in the environment with low energy and coarser sediments are found in the environment with high energy. The poor sorting characteristics of the samples further imply that it was generated by a variety of current velocities with turbulent flow, which may have led to the deposition of sediments in the basins of different sand sizes (Ganjoo and Kumar, 2012; Miall, 1992). This was responsible for the observed little variation in the sorting. The strongly fine skewed nature of the sediments indicates significant winnowing (Aigbadon et al., 2022). Using the skewness parameter scale of Folk and Ward (1957), it could be concluded that, since most of the samples are positively (fine) skewed, with some few other samples having nearly symmetrical and strongly fine skewness characteristics, the pattern of sediments' deposition was uniform or regular. Some of the sediment samples (KL9C, LL4C, LL5, DC2A, and DC3C) show characteristics of very positively skewed nature with leptokurtic distributions, which indicate that they belong to deposits with a high degree of textural maturity and reworking (Román and Achab, 1999). The values for kurtosis show a range from platykurtic, mesokurtic to leptokurtic. This difference in kurtosis value reflects the flow characteristics of the deposition medium (Ilevbare and Omodolor, 2020; Ray et al., 2006), and reveals compositionally and mineralogically matured sands (Ilevbare and Omodolor, 2020). The predominance of platykurtic in most of the samples suggest a higher energy of deposition. Extremely low kurtosis values suggest that the sediments have been sorted in a high-energy environment (Folk and Ward, 1957). Sediment deposition was through rolling and bottom suspension, as indicated by the CM diagram, which denotes materials carried by fluvial processes and deposition. A fluvial depositional environment is further supported by Y2 and Y3 values from sieve data.

Interpretation of morphometric parameters and their scatter plots in the study area is generally consistent with the fluvial delineation based on grain size analysis. Based on the flatness ratio (Stratten, 1974) of >45 % for fluvial, nine (9) samples from Kluang-Niyor, four (4) from Layang-Layang and three (3) from Kg. Durian Chondong fall within the fluvial environment. Furthermore, MPSI values of all samples from the three basins, except samples from localities LL2B and DC1F that fall in the beach environment, reflect fluvial depositional environment (Dobkins and Folk, 1970). Moreso, OPI interpretation of all samples from the three basins, except four (4) localities, two each from Kluang-Niyor and Kg Durian Chondong (KL4, KL7, DC1F and DC3A), indicate fluvial depositional environment. Characteristics roundness of the samples do not agree with fluvial interpretation following Powers (1953), which indicates that values < 35 % typify fluvial environments, while > 45 % are typical of littoral environments. However, using Sames (1966) roundness versus elongation plot, 95 % of the data points plot in the fluviatile regime. Furthermore, 95 % of the data points fall in the fluviatile environment when the sphericity versus oblate-probate index is plotted. The observed relationship between OP index, > −1.5 in most of the sediment samples that suggest fluvial origin (Dobkins and Folk, 1970), and roundness of the pebbles that are estimated to be subrounded to subangular, it could be concluded that the distance of travel of the pebbles is short and the provenance is not too far away from the depositional basins. The sphericity-form diagram shows a predominance of Bladed and Compact-Bladed pebbles. According to Dobkins and Folk (1970), Platy, Very Platy, and Very Bladed are the three shape classes diagnostic of the beach environment, while Compact, Compact-Bladed, and Compact-Elongate are the forms most diagnostic of fluvial action. Blades are common in both settings. The predominance of Bladed and Compact-Bladed pebbles is overwhelmingly in favour of fluvial-shaping processes. The scattered distribution of shapes (from sphere to disc) indicates possible multiple, but a local source (Barudžija et al., 2020). These multiple sources could be nearby granitic bodies and sedimentary sources. A highly weathered or decomposed granitic source has been attributed to the sandstones from Layang-Layang (Vijayan, 1990). Also,

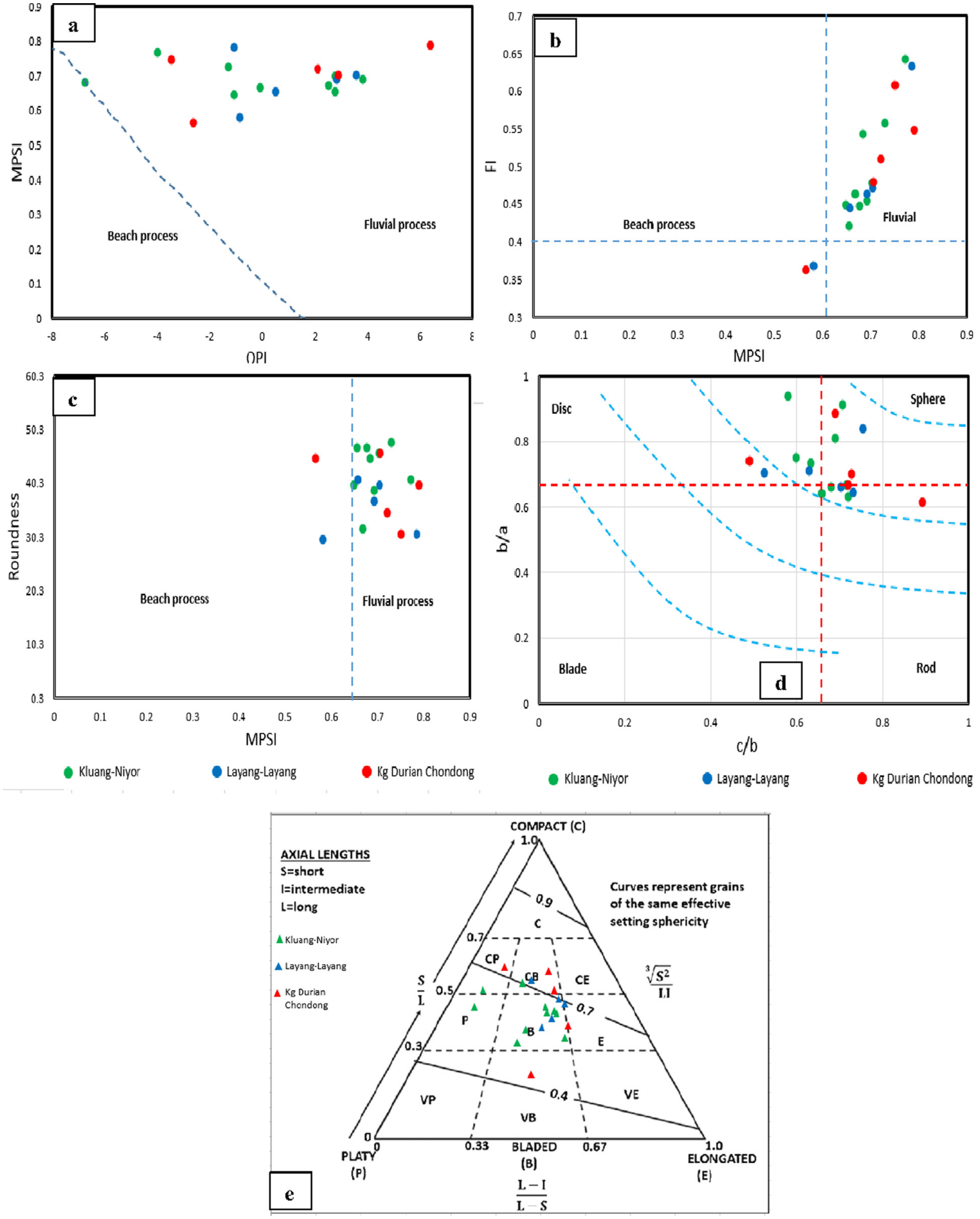

Fig. 6. (a) Plot of maximum projection sphericity index (MPSI) versus OPI (fields after Dobkins and Folk (1970), (b) flatness index (FI) against maximum projection sphericity index (MPSI) (Fields after Dobkins and Folk (1970), (c) Roundness against maximum projection sphericity (after Dobkins and Folk (1970) (d) Pebbles shape based on Zingg diagram of sediments from Kluang-Niyor, Layang-Layang and Kg Durian Chondong basins (e) Sphericity-form diagram of Sneed and Folk (1958) (from Lewis and McConchie, 1994).

the Gunung Ledang granite, which is located 10 km east of the Kg. Durian Chondong Basin (Meng et al., 2017b), could be the source provenance for this basin.

6. Conclusion

Paleoenvironment and depositional processes of the Tertiary sediments in Kluang-Niyor, Layang-Layang and Kg. Durian Chondong, onshore Peninsular Malaysia, were evaluated using granulometric, petrographic and pebble morphometric analyses. Petrographic analysis reveals that the sandstones are mainly classified as arenites and subfeldspathic arenites based on the relative proportions of quartz, feldspar and lithic fragments. The clastic sediments of these basins are composed of very coarse to coarse-grained sandstones; the characteristics of whole-grain size statistics has shown that the graphic mean value indicates the dominance of very coarse sand-size particles, which points to relatively high energy conditions of accumulation and deposition. Positive skewness values of all the samples is an indication of river sands. The very poorly to poorly sorted nature of the sediments was due to different regimes of sediment deposition by river action. In most cases, both the peak and tails are very poorly to poorly sorted, resulting in the mesokurtic to platykurtic grain-size pattern. Deductions from the grain size statistical parameters and bivariate plots suggest that the sandstones have a fluvial origin. The use of combined LDA plots; Y1 against Y2, Y2 against Y3 and Y3 against Y4, has confirmed that sediments from the three Tertiary basins were deposited in a fluvial environment. The CM pattern of the Tertiary sediments, using Passega's diagram, has indicated that the sediments were transported by rolling and bottom suspension. The results of the average sphericity, flatness ratio and oblate-prolate index values,as well as bivariate plots for the samples indicate a fluvial environment. The mean roundness index calculated for pebbles of the study area suggests a very short distance of transport; the sediments are deposited close to the source. The bivariate and ternary plots indicated the dominance of fluvial environment. The absence of carbonate rocks, which is a significant characteristic of sediments in these basins, and marine fossils are clear evidence of continental settings. Lack of fossils/trace fossils also suggests a high-energy fluvial environment. This sedimentological evidences-high energy flow deposition, poorly sorted sediments, sediments deposited near to the source, the short distance of transport as shown by poorly rounded clasts-along with earlier investigations by Meng et al. (2017); Raj et al. (1998)-have indicated that these rocks were deposited in a fluvial environment.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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