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Textural Characteristics and Depositional Environment of Ngrayong Sandstone (Middle Miocene) from Rembang Area, Northeast Java, Indonesia

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Abstract

Granulometric analysis of Ngrayong sandstone samples from Rembang area of NE Java (Indonesia) has been carried out to examine the textural characteristics and elucidate depositional environment. The result data from the grain size analysis indicates that the Ngrayong sediments are classified as sand or muddy sands. They are very fine- to medium-grained (phi values: 1.67 to 3.35), moderately- to well-sorted (standard deviation: 0.19 to 0.57), strongly fine-skewed to strongly coarse-skewed (skewness values: 4.82 to −5.97), and very platykurtic to very leptokurtic (kurtosis values: 0.36 to 2.41). Sandstone samples show unimodal grain size distribution. The sediments are interpreted to be transported in all three modes-traction, saltation and suspension, however, suspension and rolling are the major processes during transportation. Discriminant functions indicate diversity in the depositional environment for the sandstones. However, shallow marine is regarded as the dominant depositional environment. The preponderance of fine-grained sediments and lack of coarse sands suggest low to moderate energy conditions during deposition of Ngrayong sediments.

Keywords

Granulometric Analysis, Ngrayong Sandstone, Rembang, Textural Characteristics, Depositional Environment

1. Introduction

Grain size is a unique descriptive property and used as an important textural character in classifying the siliciclastic sedimentary rocks. The distribution of grain size and textural characters in the clastic rocks generally reflects the physical changes in transporting media, the depositional processes and environment. Granulometric or sieve analysis is a technique widely applied in studying sandstones and sandy rocks by sedimentologists. Hence, systematic presentation and analysis of grain size data provide basis for the interpretation of nature of sediments, transportation process, hydrodynamic conditions, and depositional environment. Grain size data have been widely applied in deciphering various depositional environments and hydrodynamics condition of clastic sediments ([1]-[17]).

The Ngrayong Sandstone (Middle Miocene) is one of the important reservoirs in the Northeast Java Basin of Indonesia and hydrocarbon production from its reservoir has been carried out since the 19th century [18]. A total of 150 million barrels of oil have been produced from this reservoir sandstone, reaching about 75% of the total production of petroleum from the NE Java basin [19] [20]. The Ngrayong Sandstone is widely exposed in the Rembang area, Northeast Java, Indonesia (**Figure 1**). These sandstones are classified as sub-feldspathic and sub-lithic arenite and have exhibit excellent reservoir properties [20].

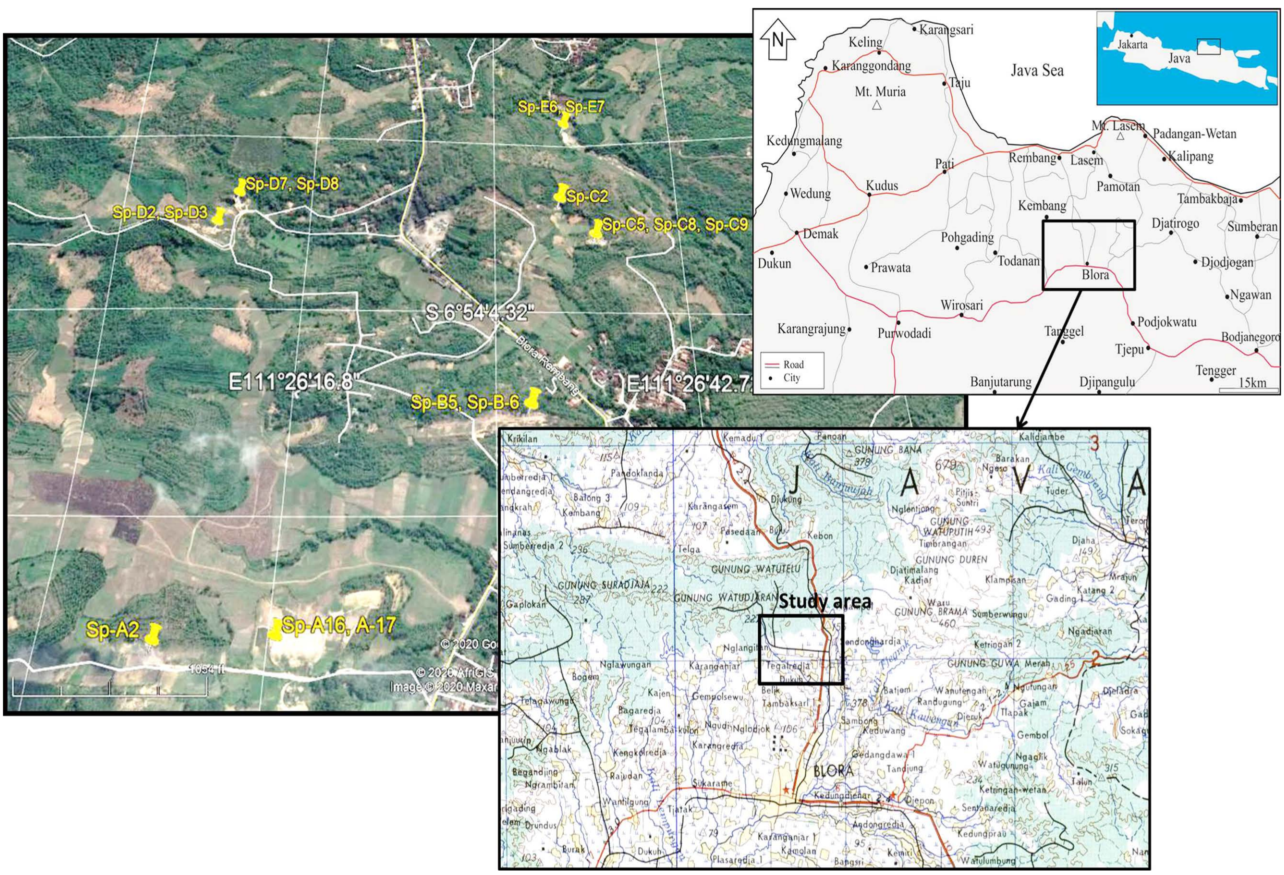


Figure 1. Location map of Rembang area in Northeast Java, Indonesia.

In the present study, an attempt has been made to undertake a detailed grain size analysis of sandstone samples from the Rembang area. Statistical parameters such as mean, median, standard deviation, skewness and kurtosis have been deduced from the grain size analysis data. These statistical data have been utilized to infer the textural characteristics of the clastic sediments. Bivariate plots have also been constructed and utilized in the interpretation of the depositional pattern of the sedimentation and depositional environment.

2. Regional Geology

The research area is located in the Rembang Zone [21] of Northeast Java Basin. The Northeast Java Basin was developed as a back-arc basin behind the active volcanic arc of the Central Java. It consists largely of a foreland shelf dipping gently southward. It is comprised of a large number of east-west trending anticlinorium, alternating with alluvial plains. Lithology was dominated by mix siliciclastic of shallow marine with shelf carbonate and clastics derived from continent. The Rembang Zone sequence was strongly influenced by continental-derived sediment. Seven major lithostratigraphic units have Middle Miocene to Quaternary age's occurr in the Rembang Zone. They are, from oldest to youngest; the Tawun, Ngrayong, Bulu, Wonocolo, Ledok, Mundu, Piciran and Lidah Formations. The Ngrayong Sandstone (Middle Miocene) was the main petroleum reservoir in the Rembang Zone (e.g. Cepu Oil Field). Total thickness of Ngrayong Formation was varied, with an average more than 300 m. Regional geological map of Northeast Java area is shown in **Figure 2**.

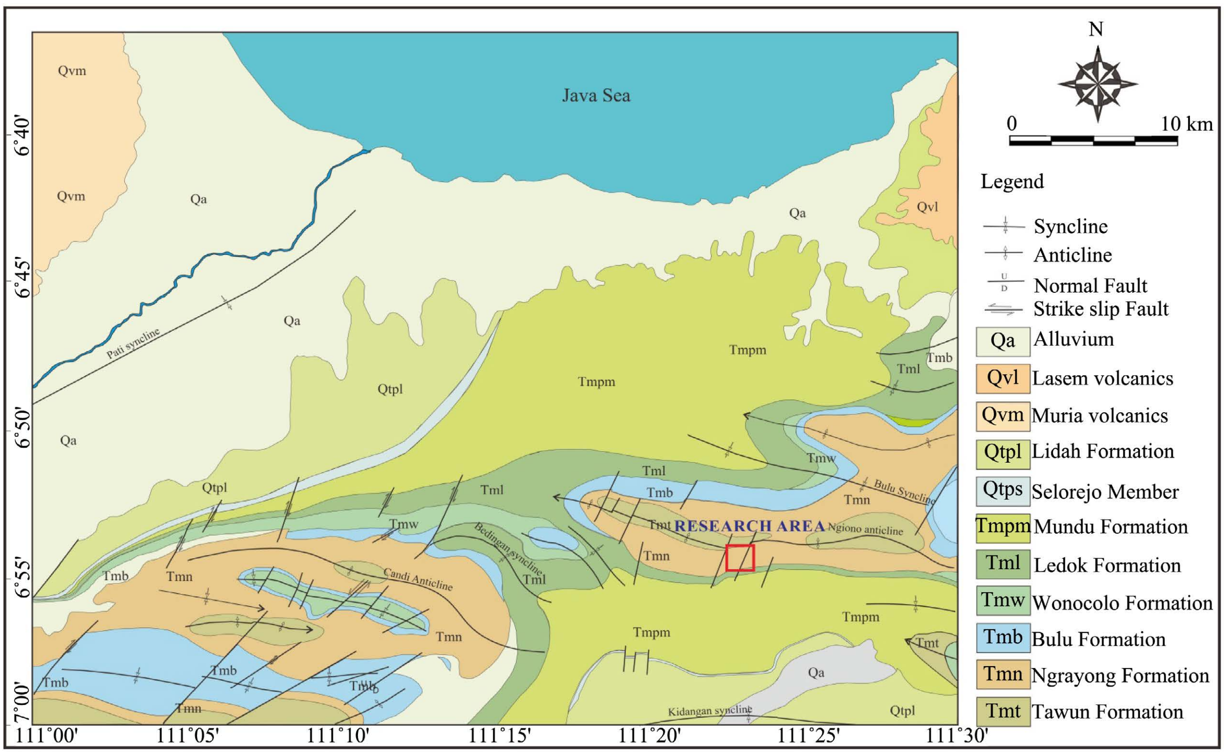


Figure 2. Regional geological map of Rembang area and surrounding area, Northeast Java, Indonesia [20].

3. Materials and Methods

During field investigation, about fifty representative sandstone samples were collected from different layers of Ngrayong Sandstones from different locations (**Figure 1**) in the Rembang Area. Of these samples, fifteen sandstone samples have been selected and subjected to grain size analysis. The selected sandstone samples were disaggregated and 100 grams of clean and dry loose sands were sieved for at least 30 minutes using Retsch vibratory sieve shaker for proper separation of each grade. Different grain sizes of the samples were screened by conventional sieving technique and sieves used in the analysis follow the US standard sieve mesh system (*i.e.* 10, 18, 35, 60, 120, 230, and the remainder in the pan). The phi (ϕ) values of the sieves mesh size represent the grain diameter for each sieve fraction.

The sand grains retained by each different sieve were taken, weighed and weight percentage calculated. Subsequently, the frequency for cumulative weight percent and corresponding phi data was applied to plot on a log-linear graph. Percentiles values (5, 16, 25, 50, 75, 85 and 95) were recorded on the cumulative curves and calculate statistical measures like graphic mean (Mz), inclusive graphic standard deviation (σ_I), inclusive graphic skewness (SK_1) and kurtosis (K_G) were calculate using the formulae provided by [2] [22]. The depositional processes and environments of the Ngrayong Sandstone were deduced from the linear discriminant functions proposed by Passega [3] [4] and Sahu [10]. C-M plot of Passega [4] is carried out to determine different depositional processes, mechanism of sedimentation and hydrodynamic condition of the transporting medium. Granulometric analysis was performed at the laboratory of Geological Engineering Department, Gadjah Mada University, Indonesia.

4. Result and Discussion

In the Rembang area, Ngrayong Sandstone is generally exposed along the Blora-Rembang Car Road, in which outcrops are well-exposed at the quarries. Sandstone samples were collected from these outcrops (**Figure 1**). Detailed description on measured stratigraphic sections, lithostratigraphic facies and sample distributions are fully described in [20]. Samples A16 and A17 were collected from the cross-bedded sandstone in the upper part of the stratigraphic section whereas sample A2 was collected from the bioturbated sandstone in the lower part of the section. Samples B5 and B6 were collected from laminated sandstone and shale in the middle part of the stratigraphic section. Samples C2 and C5 were collected from massive sandstone outcrop in the middle part of the stratigraphic column whilst samples C8 and C9 were collected from cross-bedded sandstone in the lower part of the column. Samples D2 and D3 were collected from fossilliferous sandstone in the upper part of the stratigraphic section whereas sample D7 and D8 were collected from massive sandstone in the lower part of the section. Sample E6 was collected from laminated sandstone in the middle part of the geologic section and E7 from cross-bedded sandstone in the upper part of section.

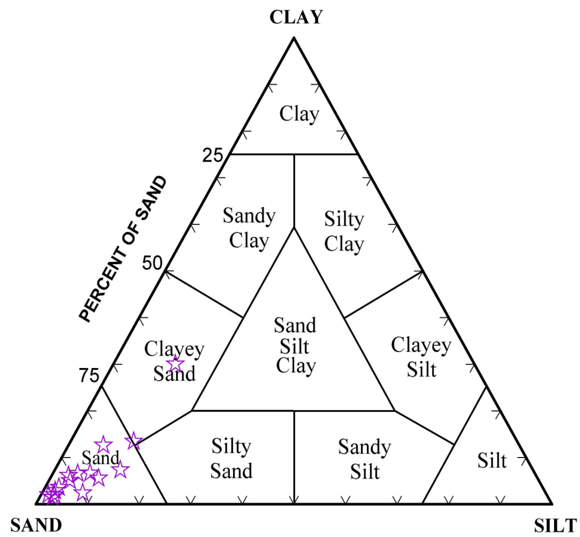
4.1. Textural Characteristics

The result data from sieve analysis indicates that the study samples are dominated by sand-size sediments (Table 1). The sand content of the samples varies from 57.97% to 96.57%. Sample D7 has the lowest sand concentration (57.97%) whereas Sample A2 has the highest percentage of sand (96.57%). The silt content in the samples ranges from 1.47% to 30.01%. The lowest silt percentage is observed in sample E6 (1.47%) and the highest content is seen in samples D7 (30.01%). The clay content varies from 1.42% to 12.25%. The clay content is lowest at sample A2 (1.42%) and highest at B5 (12.25%). A2 has the lowest clay content and the highest sand content, while D7 has the lowest sand content and the highest silt content. The overall percentage composition of grain size distribution showed that the studied samples are sand dominated. The distribution of higher percentage of sand-size sediments in the studied samples from Ngrayong Sandstone is probably due to the prevailing high-energy environment during deposition of these clastic sediments.

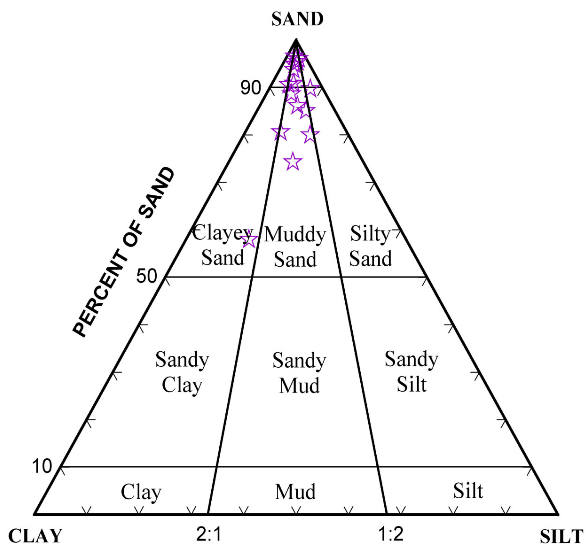
Figure 3(a) [23] and Figure 3(b) [24] show the textural classification of sediments based on sand/silt/clay ratios. The Ngrayong sediments are classified as sands (except one sample which falls in the clayey sand) (Figure 3(a)), whereas the majority of the Ngrayong samples are classified as muddy sands (Figure 3(b)).

Table 1. Textural composition (wt%) of Ngrayong sandstone samples.

Sample ID	Sand	Silt	Clay
A2	96.57	1.41	2.01
A16	95.37	2.64	1.98
A17	86.16	7.17	6.67
B5	74.30	12.25	13.45
B6	93.75	2.66	3.59
C2	89.71	7.89	2.41
C5	80.61	6.74	12.65
C8	94.83	2.29	2.88
C9	90.58	3.26	6.16
D2	88.60	4.81	6.59
D3	85.07	9.36	5.56
D7	57.97	12.01	30.01
D8	79.98	12.69	7.33
E6	96.03	2.50	1.47
E7	90.86	4.10	5.04



(a)



(b)

Figure 3. (a) Ternary diagrams for textural classification of sediments based on sand/silt/clay ratios [23] and (b) ternary diagrams for textural classification of sediments based on sand/silt/clay ratios [24].

4.2. Statistical Parameters

Statistical parameters deduced from grain size data for the sandstone samples and interpretation for classes of class, sorting, roundness and skewness are shown in Table 2.

Graphic Mean (Mz)

The mean value of the graph is the average grain size of the overall data. Graphic means corresponds very closely to the mean as computed by the method of moments, yet it is much easier to find. It is calculated based on three points and gives a better overall picture. Graphically, the calculation of mean value is calculated by the following formula [2] [22]:

Table 2. Data summary of grain size parameters for fifteen Ngrayong sandstone samples.

Sample ID	Mean	Size class	Std. Dev.	Sorting class	Skewness	Class	Kurtosis	Class
A2	2.07	Fine	0.39	Well	0.25	Fine-skewed	1.26	Leptokurtic
A16	1.67	Medium	0.57	Moderate	−2.53	Strongly coarse-skewed	2.41	Very leptokurtic
A17	2.61	Fine	0.54	Moderate	−2.93	Strongly coarse-skewed	1.44	Leptokurtic
B5	3.35	Very fine	0.53	Moderate	−5.97	Strongly coarse-skewed	1.8	Very leptokurtic
B6	2.57	Fine	0.21	Very well	3.75	Strongly fine-skewed	0.53	Very platykurtic
C2	2.53	Fine	0.22	Very well	1.09	Strongly fine-skewed	0.82	Platykurtic
C5	3.19	Very fine	0.45	Well	−0.55	Strongly coarse-skewed	1.4	Leptokurtic
C8	2.56	Fine	0.21	Very well	3.74	Strongly fine-skewed	0.52	Very platykurtic
C9	2.76	Fine	0.34	Very well	2.25	Strongly fine-skewed	0.67	Platykurtic
D2	2.79	Fine	0.35	Well	2.05	Strongly fine-skewed	0.69	Platykurtic
D3	2.79	Fine	0.42	Well	−0.74	Strongly coarse-skewed	0.99	Mesokurtic
D7	3.2	Very fine	0.56	Moderate	−3.09	Strongly coarse-skewed	2.43	Very leptokurtic
D8	3.22	Very fine	0.51	Moderate	−3.97	Strongly coarse-skewed	1.93	Very leptokurtic
E6	2.53	Fine	0.19	Very well	4.82	Strongly fine-skewed	0.36	Very platykurtic
E7	2.73	Fine	0.34	Very well	0.59	Strongly fine-skewed	0.84	Platykurtic

$$Mz = \frac{\varnothing 16 + \varnothing 50 + \varnothing 84}{3}$$

Classification scheme of [22] was used in order to classify the sand size grain from the mean value. Graphic mean values of the sandstones range between 1.67 and 3.35 and fall in the size class very fine to medium (**Table 2**). The average mean value (2.7) of the studied samples indicates the dominance of fine-grained sand. The size of the sand can be used as to infer the medium of transportation and average kinetic energy that prevailed during deposition of sediments. Coarse sands are transported as bed loads, medium sand are carried by saltation and finer grains are transported via suspension. The variation in grain size in the studied samples indicates the variable kinetic energy at the time of deposition. However, the dominance of fine-grained sediments in the Ngrayong sandstone samples implies low energy condition during the deposition of these sediments.

Inclusive Graphic Standard Deviation (σ_1)

It is a measure and mathematical expression of sorting. Sorting value indicates the level of uniformity of grain sorting. In other words, the sorting of a given population is a measure of the range of grain-size present and the magnitude of these sizes around the mean sizes. The graphic standard deviation (δG) is a good measure of sorting and is computed as $\delta G = (\varnothing 84 - \varnothing 16)/2$. It takes in only the central two-thirds of the curve. Inclusive graphic standard deviation (σ_1) formula includes 90% of the distribution and is the best overall measure of sorting. Standard deviation values also represent changes in the kinetic energy or the velocity of depositional agent during deposition [11]. It is defined from the standard deviation and mathematically expressed as follows [2]:

$$\sigma_1 = \frac{\varnothing 84 - \varnothing 16}{4} + \frac{\varnothing 95 - \varnothing 5}{6.6}$$

The classification of the sorting class from the standard deviation values follows the scheme of [25]. Standard deviation values of the sandstone samples from the study area range from 0.19 to 0.57 (**Table 2**). These standard deviation values indicate that the sandstones are moderately to very-well sorted. These values also imply that perhaps the energy level of depositing medium fluctuated from time to time during the deposition of these sediments.

Inclusive Graphic Skewness (SK_1)

It is an analysis of grain distribution of sediments as fine or coarse. It indicates the degree of asymmetry of the population or entire sediment distribution. The graphic skewness only covers the central 68% of the curve, mostly in the "tails" of the curve. Therefore, this is not sensitive enough measure. However, the Inclusive Graphic Skewness (SK_1) is a better statistic one that includes 90% of the curve and skewness value is computed by the following equation [2]:

$$SK_1 = \frac{\varnothing 84 + \varnothing 16 - 2\varnothing 50}{2(\varnothing 84 - \varnothing 16)} + \frac{\varnothing 95 + \varnothing 5 - 2\varnothing 50}{2(\varnothing 95 - \varnothing 5)}$$

It is mathematically expresses as positive or negative. Positive skewness means symmetry curve peaked to the left of mean and sediment is dominated by coarser grain size. In contrast, negative skewness indicates symmetry curve peaked to the right of mean and sediment is dominated by finer grain size.

Sorting skewness values is in the range of −5.97 and 4.82 (**Table 2**). In case of skewness, only one sample is fine-skewed, seven samples are very fine-skewed and seven samples are coarse-skewed. Variation in the sorting skewness values of the sandstone samples indicate that these sandstones may have been deposited under fluctuated (low and high) energy conditions.

Graphic Kurtosis (K_G)

The graphic kurtosis represents a measure of the peakedness of curves and a valuable test normality of a distribution. According to Folk and Ward [2], it is mathematically expressed as:

$$K_G = \frac{\varnothing 95 - \varnothing 5}{2.44(\varnothing 75 - \varnothing 25)}$$

Kurtosis values range from 0.36 (very platykurtic) to 2.43 (very leptokurtic) (**Table 2**). The lowest value is seen at sample E6 where the sediments are very plakykurtic and highest at D7 where the sediments are very leptokurtic. Variation in kurtosis values of the sandstone samples indicates that variation in the flow characteristics of the depositional medium occurs at the time of deposition.

4.3. Relationship between Grain Size Parameters

The relationship between different grain size parameters help to understand, the nature of sediments, transportation processes, energy level of depositing agents and depositional environments of siliciclastic sediments ([2] [3] [4] [9] [12] [26] [27] [28] [29] [30]).

The bivariate plot between mean and standard deviation (**Figure 4(a)**) [30] indicates that sandstones are moderately- to very well-sorted. Moderately to very-well sorting are likely due to winnowing action of depositing agent under moderately to high energy level conditions.

The plot between mean and skewness also shows a wide range of plot from strongly fine skewed to strongly coarse skewed zones (**Figure 4(b)**) [30]. Sandstones having very fine-skewed and coarse-skewed natures indicate that these sandstones were deposited under low to high energy conditions. Mean versus kurtosis scatter diagram shows variation in kurtosis from very leptokurtic to very platykurtic (**Figure 4(c)**) [30].

Variation in these values expresses the reflection of the flow characteristic of the depositing medium [31] [32]. Platykurtic show low energy and mesokurtic show moderate energy flow whereas leptokurtic show high energy flow. This fact indicates that Ngrayong sediments were deposited under extreme environments characterized by low to high energy flow environment.

4.4. Frequency Diagrams

Modal distribution of the sediments is described by the frequency diagrams whereas the description of the transportation medium is generally given by the curves.

Histograms: The histogram distribution of different grain size for some selected samples given in **Figure 5**. All samples show uni-modal distribution (except sample Sp-D7 which shows bimodal distribution). Bimodal distribution is likely to be the sub-populations. In most cases, modal class lies in the range of phi value 2 to 3.

Cumulative curves: and cumulative weight percent versus phi (ϕ) value of all studied samples were shown in **Figure 6(a)** and **Figure 6(b)**. Cumulative curves

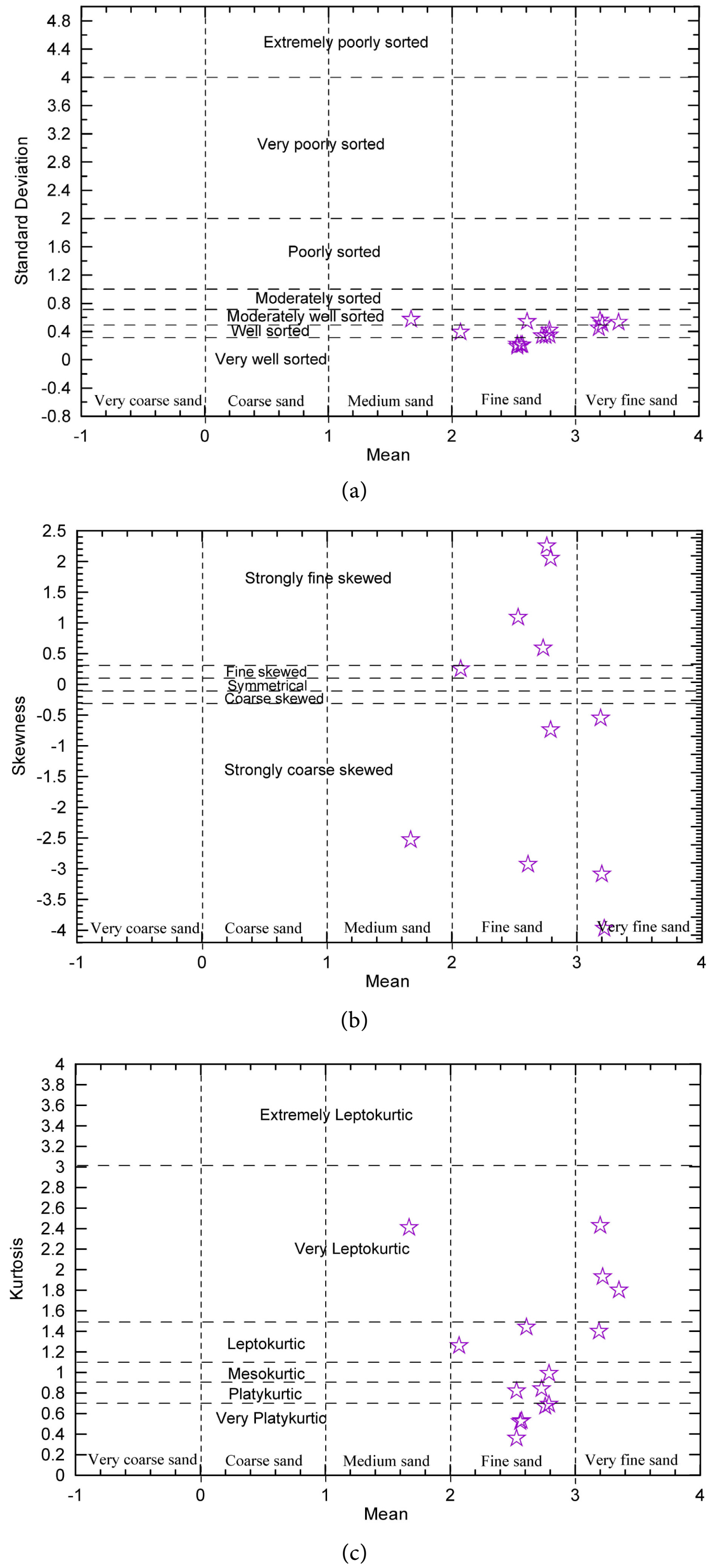


Figure 4. Bivariate plots of the sandstones samples Rembang area (a) mean vs. standard deviation (b) mean vs. skewness and (c) mean vs. kurtosis. Fields are classified according to [30].

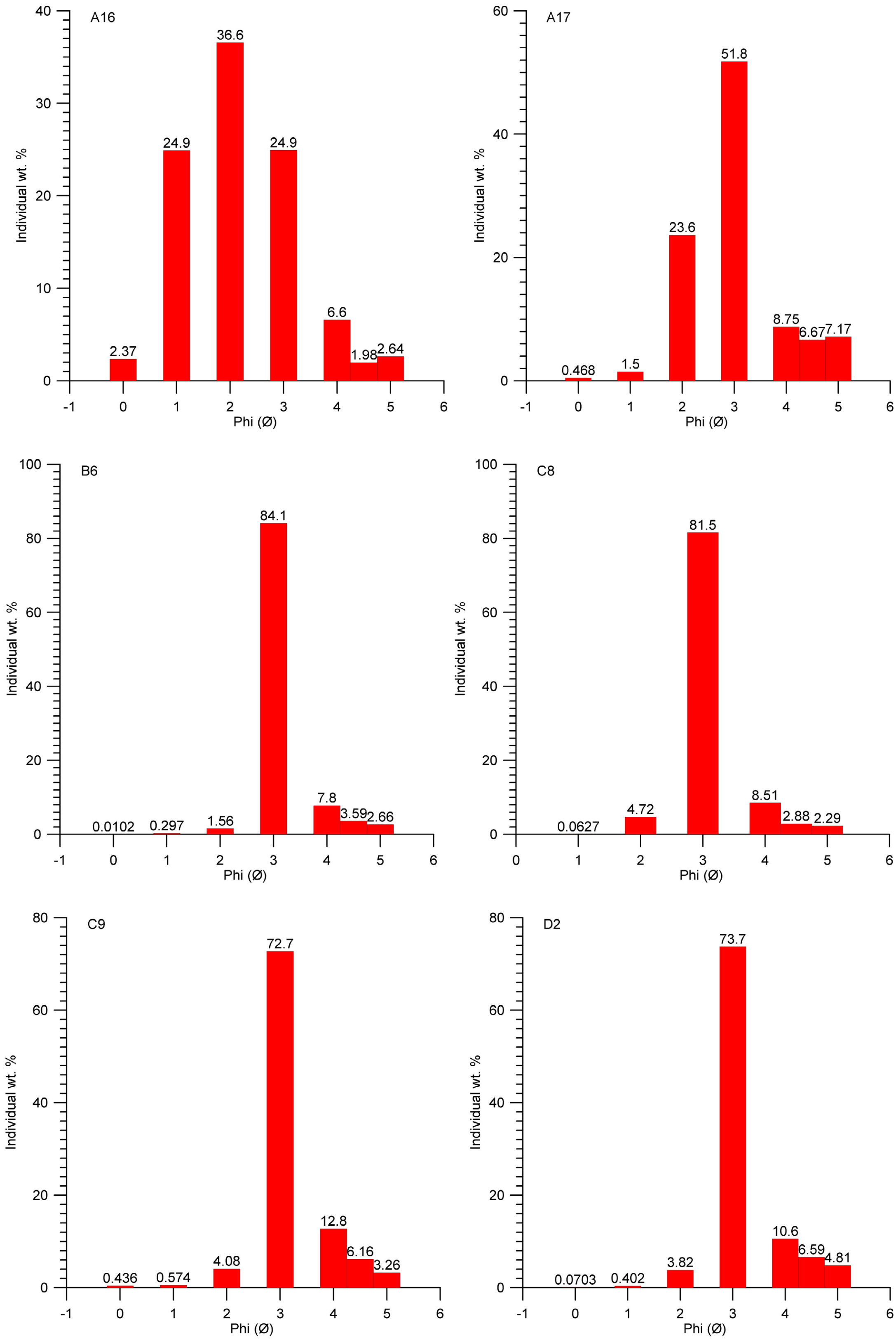
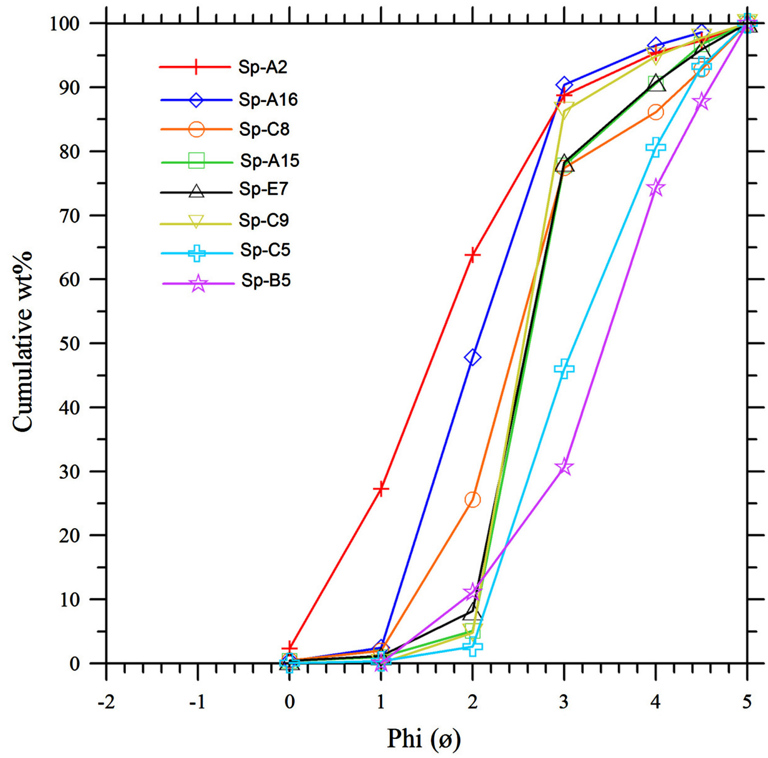


Figure 5. Histograms showing the distribution of grain size in nine selected analyzed sandstone samples (A16, A17, B6, C8, C9, and D2). Histograms show uni-modal distribution and modal class lies in the range of phi value 2 - 3.



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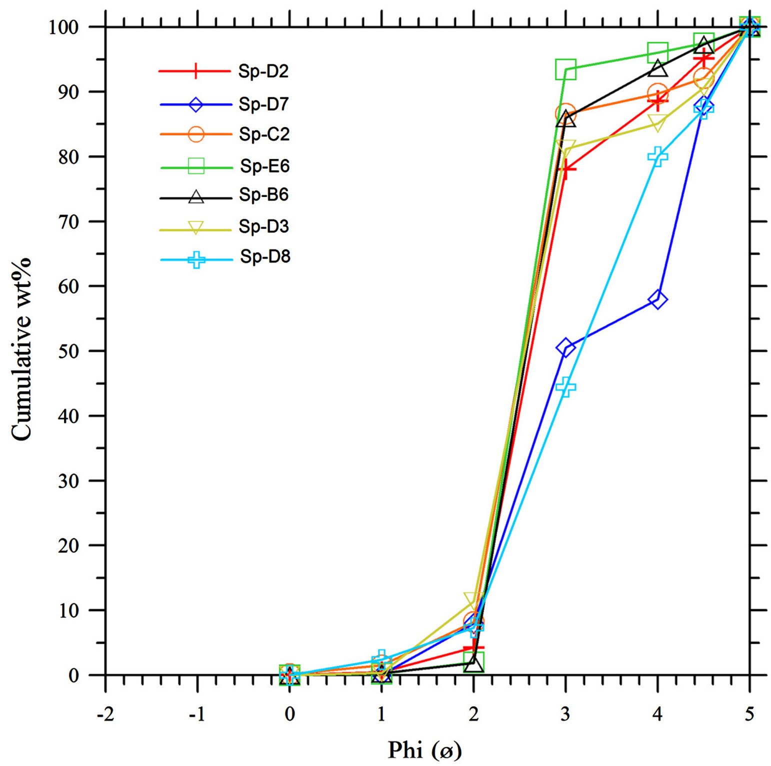

(b)

Figure 6. (a) Cumulative curves for eight sandstone samples (A2, A16, C8, A-15, E5, C9, Sp-C5 and B5) (b) cumulative curve for seven sandstone sample from Rembang area (D2, D7, C2, E6, B6, D3 and D8).

plotted on the probability ordinate scale do not form continuous straight line except few samples curves which show two, three or more straight line segments. Each segment carries different slopes which indicate the presence of more than one population of grains. Different population is likely to be related with different modes of transportation—traction, saltation and suspension [13] [33] [34]. Cumulative curves indicated that the processes such as saltation, traction and suspension have played an important role during deposition of sandstones.

4.5. Linear Discriminant Functions

The statistical parameters (mean, inclusive graphic standard deviation, skewnessand graphic kurtosis) are also used to decipher the depositional environment following discriminant function analysis (**Table 3**) [10]. The following equations are applied in order to distinguish the different depositional environments:

$$\mathrm{Y1} = -3.5688\,\mathrm{Mz} + 3.7016\,\sigma_1^2 - 2.0766\,\mathrm{SK} + 3.1135\,\mathrm{KG} \quad (1)$$

$$\mathrm{Y2} = 16.6534\,\mathrm{Mz} + 65.7091\sigma_1^2 + 18.1071\mathrm{SK} + 18.5043\,\mathrm{KG} \quad (2)$$

$$\mathrm{Y3} = 0.2852\,\mathrm{Mz} - 8.7604\,\sigma_1^2 - 4.8932\,\mathrm{SK} + 0.0482\,\mathrm{KG} \quad (3)$$

where Mz, σ_1, SK and KG represents mean grain size, standard deviation, skewness and kurtosis respectively. Equation (1) is applied to distinguish between shallow agitated water and beach environment of sediment deposition. In order to differentiate between beach and shallow marine environment, Equation (2) is used. Equation (3) is for the discrimination of fluvial and shallow marine environment of depositon.

The following parameters are used to distinguish the different depositional environments:

Y1 > −2.7411 beach; Y1 < −2.7411 shallow agitated

Y2 < 65.365 beach; Y2 > 65.365 shallow marine

Y3 < −7.419 fluvial; Y3 > −7.419 shallow marine

In this research, the value of Y1 ranges from −17.78 to 8.0, (**Table 3**) suggesting most sandstones were laid down in shallow agitated water, whilst the remaining samples show deposition in beach environment. Y2 values in the samples range from −3.90 to 135.91 (**Table 3**), thus, suggesting the deposition of sandstones in shallow marine and beach environments. The result of Y3 equation for the samples ranges between −1.90 and 27.79 (**Table 3**) indicating the deposition of these sediments under shallow marine and lacustrine conditions. Therefore, these sediments were mainly deposited in shallow marine environment by beach and wave processes.

Figure 7 and **Figure 8** are cross plots of linear discriminants of the Ngrayong sediments of Rembang area. These plots indicate that Ngrayong sandstones were deposited under diverse conditions. Large numbers of samples show combine effect of Lacustrine, beach, shallow marine, and turbidity environment. However shallow marine is regarded as the most influential environment.

Table 3. Linear discriminant functions and depositional environments of Ngrayong Sandstones.

ID	Discriminant Function			Depositional Environment		
	Y1	Y2	Y3	Y1	Y2	Y3
A2	−3.42	70.24	−1.90	Shallow agitated	Shallow Marine	Shallow Marine
A16	8.00	46.27	10.13	beach	beach	Shallow Marine
A17	2.33	33.61	12.60	beach	beach	Shallow Marine
B5	7.09	3.90	27.79	beach	beach	Shallow Marine
B6	−15.15	120.84	−17.98	Shallow agitated	Shallow Marine	Lacustrine
C2	−8.56	77.69	−5.00	Shallow agitated	Shallow Marine	Shallow Marine
C5	−5.13	79.19	1.89	Shallow agitated	Shallow Marine	Shallow Marine
C8	−15.12	120.31	−17.93	Shallow agitated	Shallow Marine	Lacustrine
C9	−12.00	103.94	−11.20	Shallow agitated	Shallow Marine	Lacustrine
D2	−11.61	101.61	−10.28	Shallow agitated	Shallow Marine	Lacustrine
D3	−4.68	60.18	2.92	Shallow agitated	Shallow Marine	Shallow Marine
D7	3.72	59.71	13.40	beach	beach	Shallow Marine
D8	3.72	31.32	18.16	beach	beach	Shallow Marine
E6	−17.78	135.91	−23.16	Shallow agitated	Shallow Marine	Lacustrine
E7	−7.92	76.56	−3.08	Shallow agitated	Shallow Marine	Shallow Marine

4.6. Passega Diagram

The Passega diagram (C-M Pattern) (**Figure 9**) is commonly applied to determine the environmental conditions of sediment deposition. Passega diagram is based on parameter C (one percentile value) and M (the Median: 50 percentile value). The relationship between C and M helps to understand the nature of sediment types and energy of transporting medium [4] [9]. The diagram involves several fields, pelagic suspension (T field), uniform suspension (SR field), graded

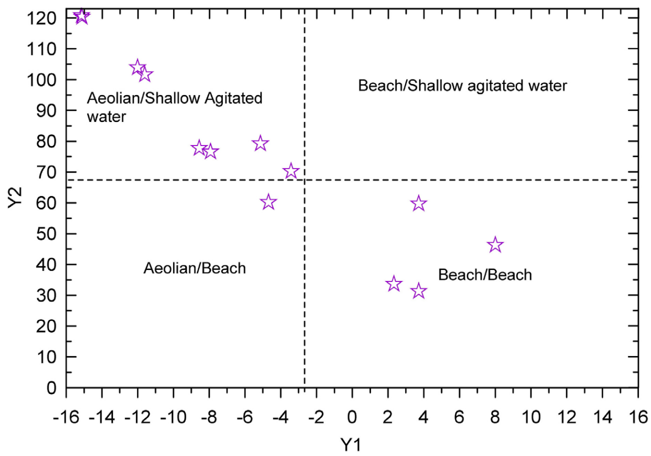

Figure 7. Cross plots of the linear discriminant functions (Y1 vs. Y2) of the Ngrayong sediments.

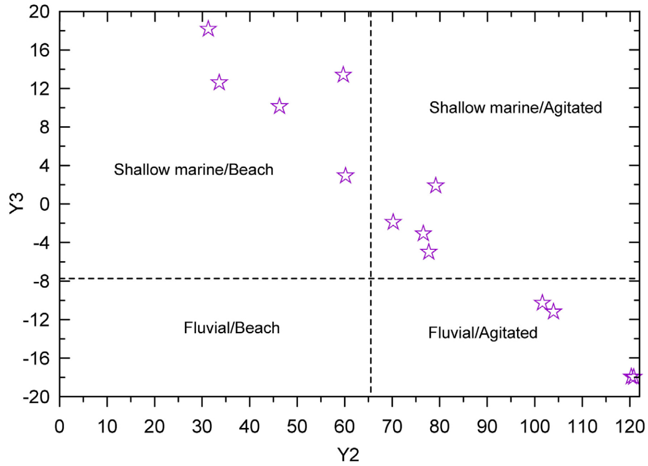

Figure 8. Cross plots of the linear discriminant functions (Y1 vs. Y2) of the Ngrayong sediments.

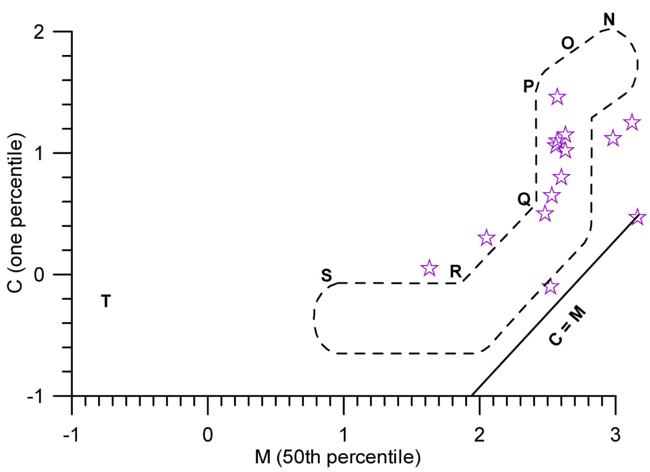

Figure 9. C-M plot showing the transporting mechanism of Ngrayong Sandstones. Rolling (ON); rolling and suspension (PO); suspesion and rolling (QP): graded suspension, mainly saltation (QR); uniform suspension (SR); pelagic suspension (T).

suspension (QR field), suspension and rolling (QP field), rolling and suspension-(PO field), rolling (ON field) corresponding to the various transports and sedimentation conditions in the marine, littoral or fluvial regimes.

On the Passega diagram (**Figure 9**), eight samples plotted in the suspension and rolling zone (QP zone). Two samples plotted near the graded suspension (QR) zone, a sample plotted around the uniform suspension (SR) zone, and other three samples plotted outside the featured fields. The C-M diagram reveals that the sediments from Rembang area were deposited under diverse conditions and transportation. However, transportation by suspension and rolling is the dominant process.

5. Conclusions

Present research investigates the grain size distribution, statistical parameters and interrelationship of Ngrayong Sandstone from Rembang area, NE Java of Indonesia in order to explore the textural characteristics and depositional environment of the sandstone based on granulometric analysis.

The following summary conclusions were made from the results of granulometric analysis. The Ngrayong sandstones show the dominance of fine to very fine grained particles. The sediments are classified as sands or muddy sands. They are moderate to very well-sorted due to winnowing action of depositing agent. Most samples show uni-modal distribution. The modal class lies between 2 - 3ϕ (0.125 to 0.25 mm) in most samples. The median value ranges from 0.3 to 3.75. Mean size of the study ranges between 1.67 and 3.35. This high variation in grain size indicates the variation in the kinetic energy at the time of deposition. Due to fluctuation in the kinetic energy there was mixing of sediments of various subpopulations transported in different modes. Samples are positively, negatively as well as nearly symmetrical.

The sediments were transported in all three modes-traction, saltation and suspension. However suspension and rolling remain the major process of transportation. The preponderance of fine grained sediments and lack of coarse sands suggest low to moderate energy conditions of deposition Bivariate analysis indicates diversity in the depositional environments. However, shallow marine is regarded as the dominant depositional environment.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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