

Sedimentary Facies of the Miocene In Block 103, Offshore Northern Vietnam: Grain Size Distribution Based on SEM Analysis

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Abstract: Grain size distribution by Scanning Electron Microscope (SEM) analysis of a core sample collected at -2281.17 meters from the Miocene formation in Block 103, offshore North Vietnam, provide valuable information on the sedimentary characteristics and depositional environment. These methods are fundamental for reconstructing sediment transport processes and paleoenvironmental conditions. Grain size analysis, using statistical parameters and bivariate scatter plots, shows that the sediments are predominantly fine to very fine-grained sands, with mean sizes ranging from 0.06 to 0.09 mm. The samples are generally well-sorted, suggesting a uniform depositional energy, likely associated with a stable shallow marine environment. SEM observations reveal microtextural features formed by both mechanical and chemical processes. Characteristics such as conchoidal fractures, abrasion marks, and solution pits suggest transport by subaqueous currents followed by early diagenetic alteration under marine conditions. The C-M (coarsest percentile vs. median) plot further supports bottom suspension as the main sediment transport mechanism, indicating deposition under relatively low-energy conditions typical of shallow marine settings. Overall, the integration of grain size and SEM data highlights a calm depositional regime, dominated by bottom suspension transport and marine influences. These findings contribute to understanding the sedimentary evolution and environmental history of the Miocene offshore North Vietnam.

Keywords: Grain-size analysis; depositional environment; block 103; sandstone, SEM.

1. Introduction

Depositional environments of the Miocene sediments in northern Song Hong basin was identify by many method like Biostratigraphy, Lithological logging, Geophysical logging, and Seismic interpretation. According to Cuong et al. (2023), Thanh et al. (2017) pointed out During most of the Upper Miocene period, the region was influenced by the marine process, the fining upward and shale-dominant deposit shows trend of the marine transgression. Most of the authors have studied on a large scale, the entire sediment of lot 103 - 107, on sedimentary facies. There is a lack of research on locality and clarification of the sedimentary mechanism as well as the deposition environment. To clarify the sedimentary environment of the upper Miocene, sedimentary facies as well as the formation regime, the group of authors used the method of grain size analysis on drill core samples.

Grain-size analysis is a widely applied sedimentological tool that provides critical insights into the depositional environment, hydrodynamic regime, and transportation processes of sediments. Originally developed by Folk and Ward (1957), this method quantifies statistical parameters such as mean grain size, sorting (standard deviation), skewness, and kurtosis. These parameters are directly related to the energy conditions and sedimentary processes that controlled deposition. According to Friedman (1961), variations in these grain-size metrics can distinguish between fluvial, deltaic, marine shelf, and deep-sea environments. Subsequent studies, including Boggs (2009), Edwards et al. (2001), and Baiyegunhi et al. (2017), confirmed that each depositional setting exhibits a distinct grain-size signature. For instance, well-sorted fine sand typically suggests a high-energy shallow marine environment, while poorly sorted silt and clay mixtures may indicate deposition under low-energy conditions such as floodplains or offshore basins. The integration of grain-size data with statistical tools like Linear Discriminant Function (LDF) or CM plots (Passega, 1957) enhances the ability to interpret sedimentary regimes with higher resolution.

2. Geological Framework

Block 103 is located in the offshore area of northern Vietnam, within the western part of the Gulf of Tonkin. This region is geologically significant due to its complex tectonic evolution and high hydrocarbon potential. Numerous gas-bearing structures have been identified in the block, associated with both structural and stratigraphic traps (Phạm & Luru, 2014).

2.1. Basement Composition

The Mesozoic basement of Block 103 is composed predominantly of acidic volcanic rocks, including rhyolite and tuff. These lithologies reflect a tectonically active magmatic arc system during the Mesozoic era, likely related to subduction or continental margin volcanism. The weathering and erosion of this volcanic basement contributed to the detrital sediment load found in overlying Cenozoic formations (Hà et al., 2005).

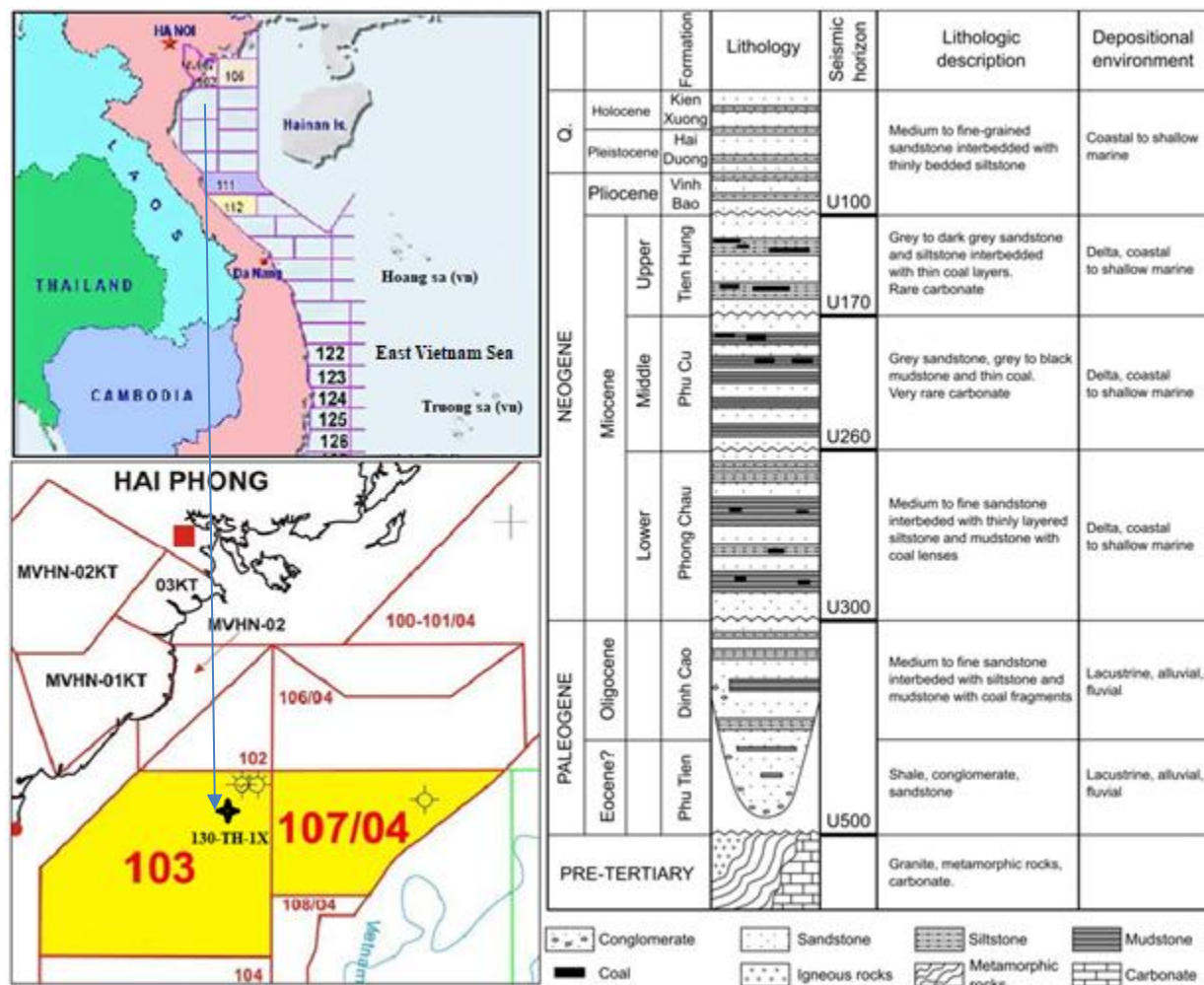


Fig. 1. Location and Geology column of the area where the sample was taken for analysis

2.2. Cenozoic Sedimentary Succession

Post-basement sedimentary fill comprises a substantial Cenozoic succession, which is subdivided into the following principal stratigraphic units:

Eocene is represented by the Phu Tien Formation, consisting predominantly of claystone and siltstone with intercalated sandstone beds. These lithofacies are interpreted as having been deposited within a transitional deltaic to shallow marine environment.

Oligocene Dinh Cao Formation is characterized by coarse-grained clastic sediments, including conglomerates and sandstones, which are indicative of a fluvial-deltaic depositional system.

Miocene interval constitutes the primary hydrocarbon-prospective section of the basin. It includes: Phong Chau Formation, comprising fining-upward sequences of sandstone and siltstone, commonly exhibiting bioturbation. Phu Cu Formation, dominated by fine-grained sandstones and mudstones that

frequently display turbidite features. Tien Hung Formation, consisting of intercalated sandy and silty facies which contain evidence for deposition from slope-related gravity flows.

Pliocene–Quaternary succession (Vinh Bao – Hai Duong – Kien Xuong Formations) is composed of coastal to deltaic plain deposits, representing the most recent phase of sedimentation sourced from the Red River delta system.

2.3. Structural and Tectonic Context

The tectonic architecture of Block 103 is shaped by deformation events associated with the evolution of the Red River Shear Zone and Beibu Gulf extensional system. Key structural elements include:

- Miocene inversion structures in the northwest Red River Basin, linked to fault reactivation and localized uplift (Tran & Nguyen, 2012).
- Dong Quan Depression: A major syn-rift basin and depocenter.
- Ha Long Shelf and Bach Long Vi Inversion Zone: Areas of moderate subsidence and fault-controlled sedimentation.
- Thanh–Nghe Monoclinic Shelf: A stable platform region dipping gently basinward. Two dominant fault systems control the structural configuration:
 - North West – South East trending faults: Related to the Red River shear system.
 - North East – South West trending faults: Possibly acting as transfer zones or accommodating oblique slip.

These structural elements influence sediment distribution, thickness, and petroleum system development (Edwards et al., 2001).

By integrating grain-size analysis with the stratigraphic and structural context, this study enhances understanding of sedimentological processes, tectono-stratigraphic evolution, and petroleum system elements in Block 103. These insights are essential for guiding hydrocarbon exploration in the offshore basins of northern Vietnam.

3. Materials and Methods

This study investigated a core sample at - 2281.17 m of the Miocen Formation located north-west of 103 Block. This core sample was then cut to create a cross-section; the sample surface was ground smooth and then coated with carbon for SEM analysis. To measure the grain size from SEM images, authors used ImageJ software (Schneider, 2012). Grain size analysis using GRADISTATv9.1 software (Blott, 2023).

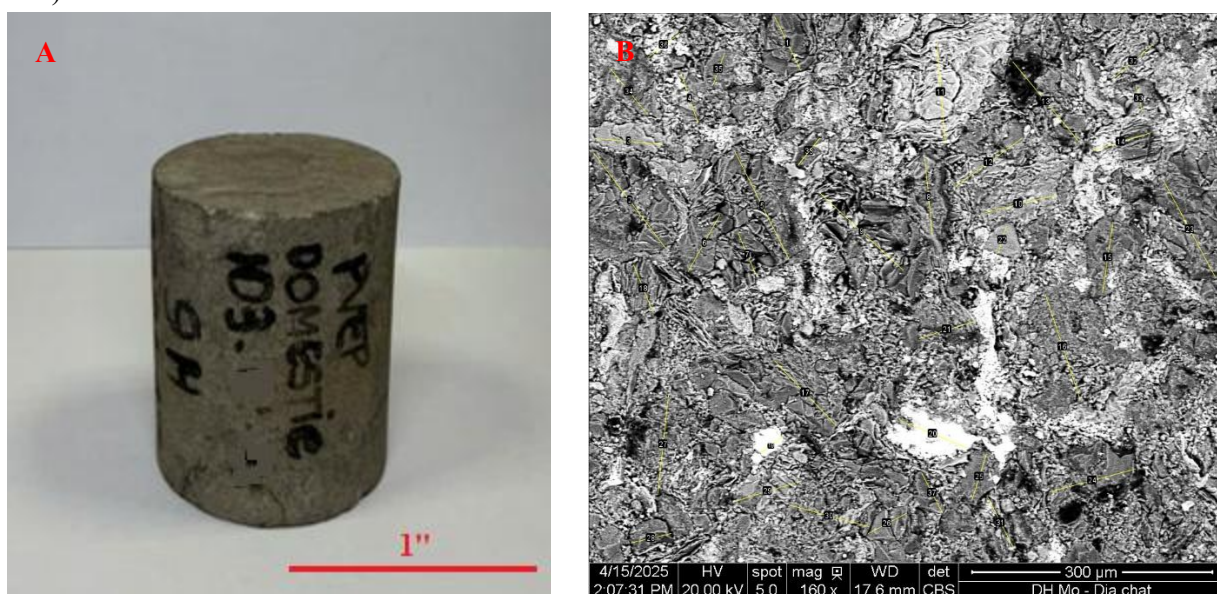


Fig. 2. A: Core sample from Block 103; B: Sem image processed to measure particle size on image software

Parameters of the grain-size analysis, C-M plots (one-percentile value versus the median) were used to distinguish depositional processes, sedimentation mechanisms and transportation methods by Passega

1964 . The four parameters of the grain-size analysis are defined as follows: - The inclusive graphic mean (M_z) is a descriptive measure that represents the grain-size distribution of sediments. - The inclusive graphic standard deviation (σ), commonly known as grain-size sorting, measures the degree of scattering of grain-size around the mean size. - The inclusive graphic skewness (Sk) is a descriptive parameter that displays the symmetry of the grain-size distribution. - The graphic kurtosis (K) represents the sharpness of grain-size frequency curve.

4. Results and Discussion

4.1. Grain-Size Statistics

The cross-section of the sample was gridded for electron microscopy analysis. The electron microscopy images were then processed in ImaginJ software for particle size measurements. The 635 particles were counted and converted to the Folk 1980 scale output frequency then the Grain-size statistics were estimate by GRADISTATv9.1 software. The results are ordered according to their stratigraphic deposition in the formation. The sandstone core sample are composed of fine sandstone to very fine sands. The fine sandstone percentage is 20.8% and very fine sands (70.6%). Particle size composition of core sample is presented in Tab. 1.

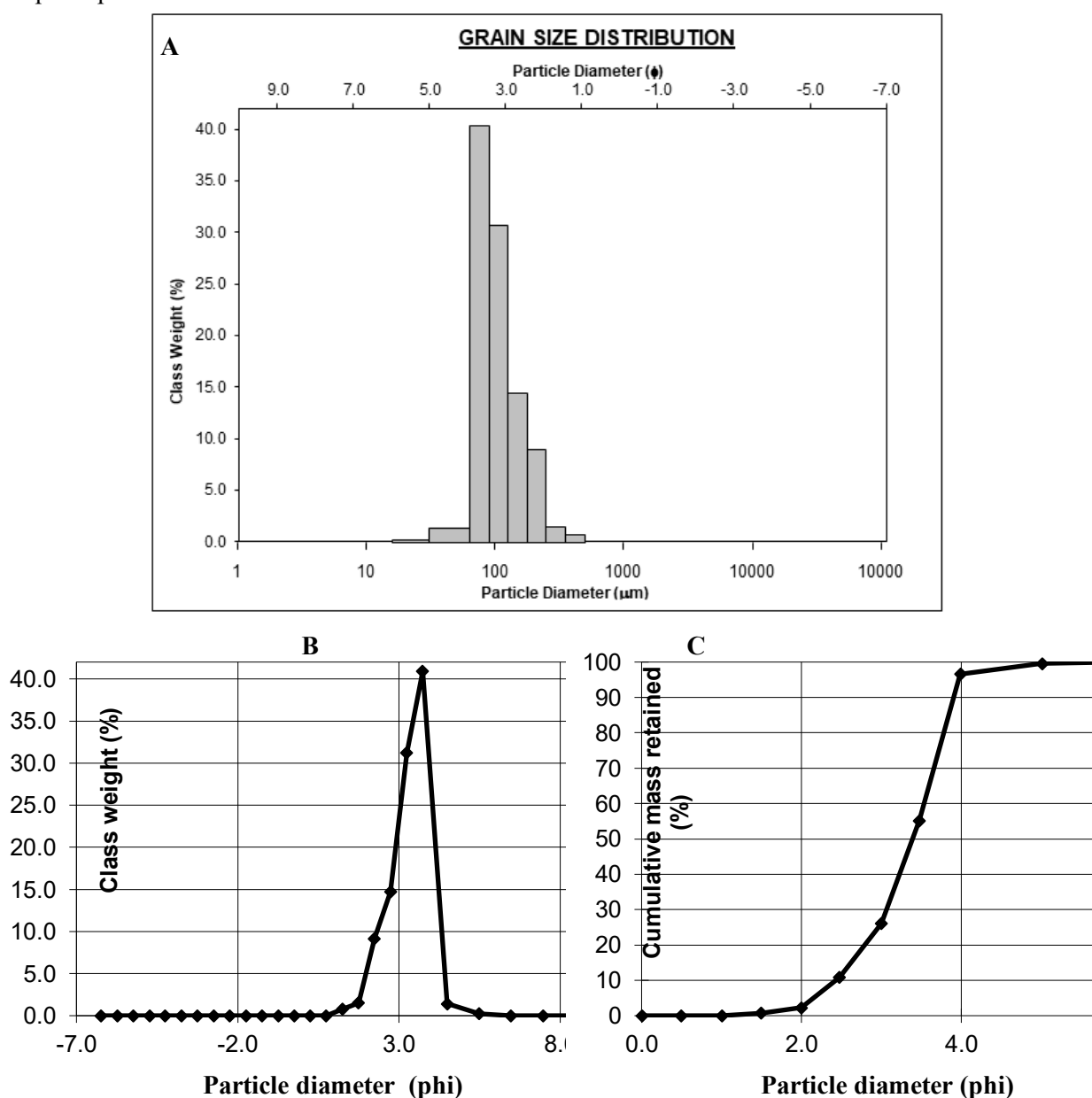


Fig. 3. Grain size distribution of core sample

Tab. 1. Grain size distribution

Grain size distribution of core sample			
gravel:	0.0%	coarse sand:	0.0%
sand:	96.7%	medium sand:	2.3%
mud:	3.3%	fine sand:	23.8%
		very fine sand:	70.6%
very coarse gravel:	0.0%	very coarse silt:	2.8%
coarse gravel:	0.0%	coarse silt:	0.5%
medium gravel:	0.0%	medium silt:	0.0%
fine gravel:	0.0%	fine silt:	0.0%
very fine gravel:	0.0%	very fine silt:	0.0%
very coarse sand:	0.0%	clay:	0.0%

4.2. Grain-Size Parameters

The analysis of grain size distribution for the core sample reveals valuable insights into its central tendency, sorting characteristics, and overall sedimentary regime. According to the Folk and Ward (1957) statistical method, the mean grain size (M_z) of the sample is 3.2 phi, which corresponds to very fine sand in the Wentworth scale. The weighted mean further confirms this classification, indicating a dominance of very fine sand-sized particles, suggesting a relatively low-energy depositional environment typical of shallow marine settings.

The sorting coefficient (σ), which measures the uniformity of grain size distribution, is calculated at 0.5, classifying the sediment as moderately well sorted. Sorting reflects the variation in energy conditions during sediment transport and deposition. In this case, moderate sorting suggests relatively stable but not entirely uniform hydrodynamic conditions, possibly affected by episodic currents or turbidity flows.

Skewness (Sk), which quantifies the asymmetry of the grain size distribution curve, is -0.307. This negative value indicates a very coarse skewness, meaning that coarser grains are slightly over-represented relative to a normal distribution. Such skewness often implies influence from a secondary transport mechanism or sediment source with intermittent higher energy pulses.

The kurtosis (K_g) value of the sample falls within the mesokurtic range, indicating a distribution curve with moderate peakedness. This suggests that the majority of particles are concentrated around the mean grain size with no significant dominance of either tails, implying relatively uniform sedimentation under consistent environmental conditions.

Furthermore, the textural classification based on the triangular diagram of gravel, sand, and mud shows that the sample is composed almost entirely of sand-sized particles, with minimal contributions from mud or gravel fractions. This positions the sample within the sand field, more precisely as Moderately Well Sorted Very Fine Sand with a dominant sand texture (Fig. 4).

These sedimentological characteristics reflect deposition in a shallow, moderately agitated marine environment, likely influenced by low to moderate energy currents, with intermittent turbidity events. Such conditions are consistent with inner to mid-shelf depositional settings, potentially associated with slope-fronted deltaic systems or reworked marine shelves.

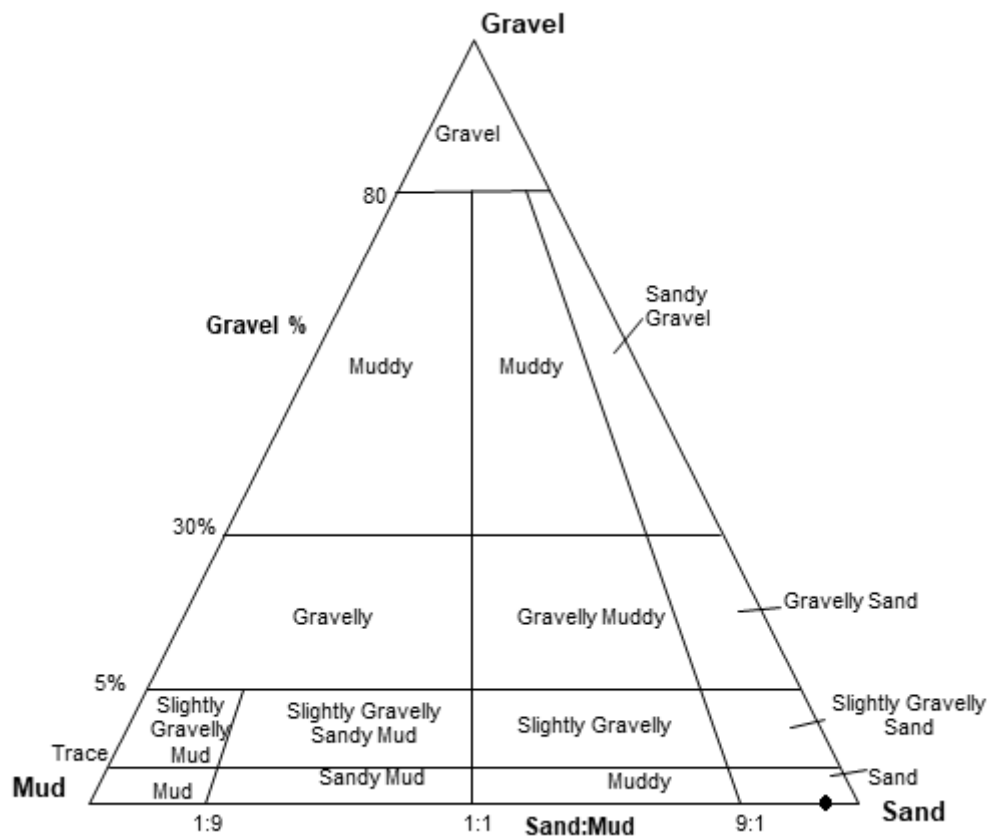


Fig. 4. Sand-mud-clay triangle diagram (Folk 1984)

4.3. Linear Discriminate Function (LDF)

Sahu 1964 introduced the linear discriminant function (LDF) to define the energy fluctuations and fluidity during sediment depositions. Four LDFs (Y1, Y2, Y3, and Y4) can be used to determine depositional processes and environments as follows: Y1 can distinguish between beach and aeolian, Y2 between shallow agitated water and beach, Y3 between fluvial and shallow marine, and Y4 between turbidity and fluvial current processes. All of the abovementioned functions are controlled by the grain-size analysis parameters, including graphic mean (Mz), inclusive graphic standard deviation (σ), inclusive graphic skewness (Sk), and graphic kurtosis (K).

The following equation (Y1) can be used to discriminate between aeolian and beach processes. The cutoff of this equation is -2.7411. The environment can be defined as aeolian if Y1 is lower than -2.7411, while it can be defined as beach if Y1 is higher than -2.7411.

$$Y1 = -3.5688 Mz + 3.7016 \sigma^2 - 2.0766 SK + 3.1135 K \quad (1)$$

The Y2 equation distinguishes between beach and shallow agitated water. The cutoff in this equation is 65.365. The environment is shallow agitated water if Y2 is more than 65.365, while it is beach if it is less than 65.365.

$$Y2 = 15.6534 Mz + 65.7091 \sigma^2 + 18.1071 SK + 18.5043 K \quad (2)$$

The Y3 equation distinguishes between fluvial and shallow marine. The cutoff in this equation is -7.419. The environment is shallow marine if Y3 is more than -7.419, while it is fluvial if it is less than -7.419.

$$Y3 = 0.2852 Mz - 8.7604 \sigma^2 - 4.8932 SK + 0.0482 K \quad (3)$$

Finally, the Y4 equation can be used to distinguish between fluvial process and turbidity current depositions. If the majority of the depositional process was controlled by turbidity currents, Y4 is supposed to be below 9.8433, while it should be controlled by fluvial processes if Y4 is above 9.8433.

$$Y4 = 0.7215 Mz - 0.40304 \sigma^2 + 6.7322 SK + 5.2927 K \quad (4)$$

The LDFs analysis result are shown in Tab. 3. The values of Y1 is -6.84, which discriminate aeolian process. The results of Y2 is 85.51, indicating that the bed were deposited in shallow agitated water environments (Fig. 5B). The results of Y3: -0.36 and Y4: 5.38 respectively, meaning that core sample were

deposited in shallow marine environments under turbidity currents..

Tab. 2. Linear discriminate functions (LDF) and depositional environment interpretations of sediment core sample

Sample	Discriminate Function				Environment of Deposition			
	Y1	Y2	Y3	Y4	Y1	Y2	Y3	Y4
Core sample	-6.84	85.51	-0.36	5.38	aeolian	shallow agitated	shallow marine	turbidity currents

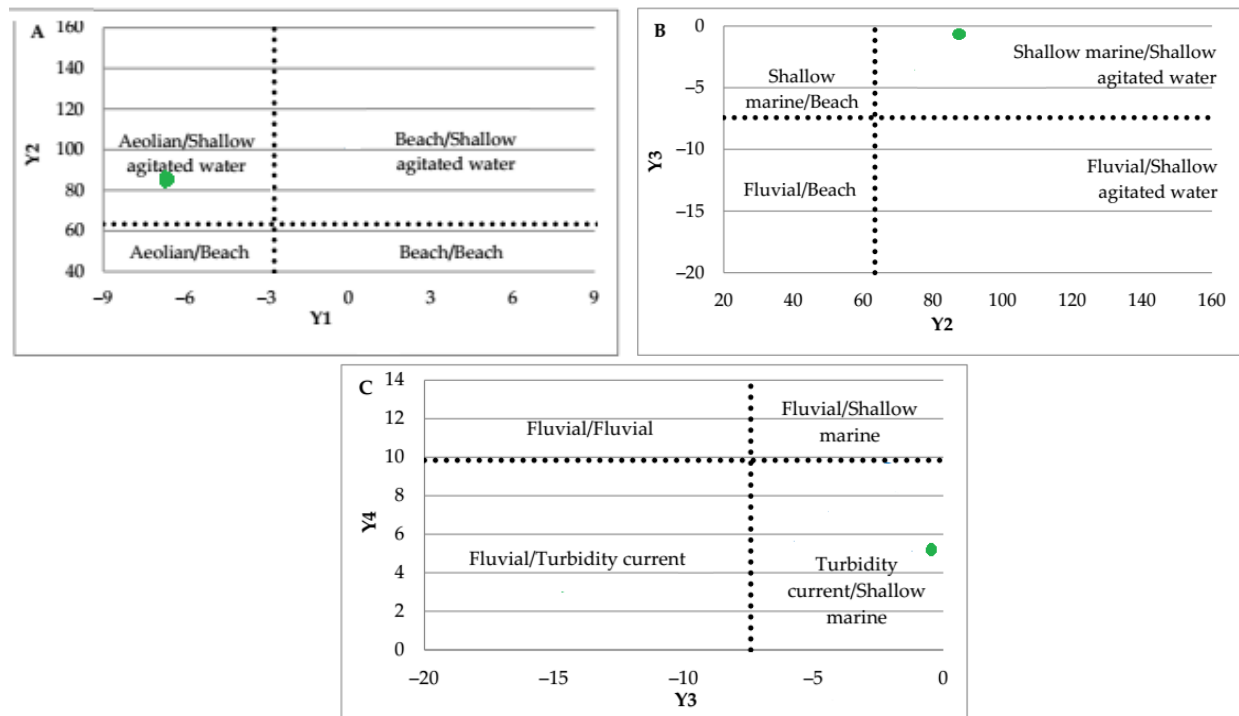


Fig. 5. Binary plots of linear discriminate functions (LDF): (A) Y2 versus Y1; (B) Y3 versus Y2; and (C) Y4 versus Y3

4.4. Facies Analysis

In this research, the environments were investigated through grain-size parameters with the facies' elements. Based on grain-size analysis and the common characteristics of each environment, the depositional environments of core sample (upper Miocen) were identified (Fig. 5) shallow agited water is characterized by well-sorted deposited under turbidity currents.

4.5. Passega Diagram (C-M Pattern)

The C - M diagram, also known as the Passega Diagram to predict the predominant hydrodynamic forces prior to particles' deposition. It is a significant geological method to reconstruct the depositional conditions of modern and ancient grains. It is a bivariate curve of coarser one-percentile (C) against the median (M). The diagram can identify the transportation mode from rolling (N-O: No overlapping line), suspension Uniform (SU) and Traction: bedload. Fig. 6 shows that sample were transported dominate by bedload finer grains with turbidites flow.

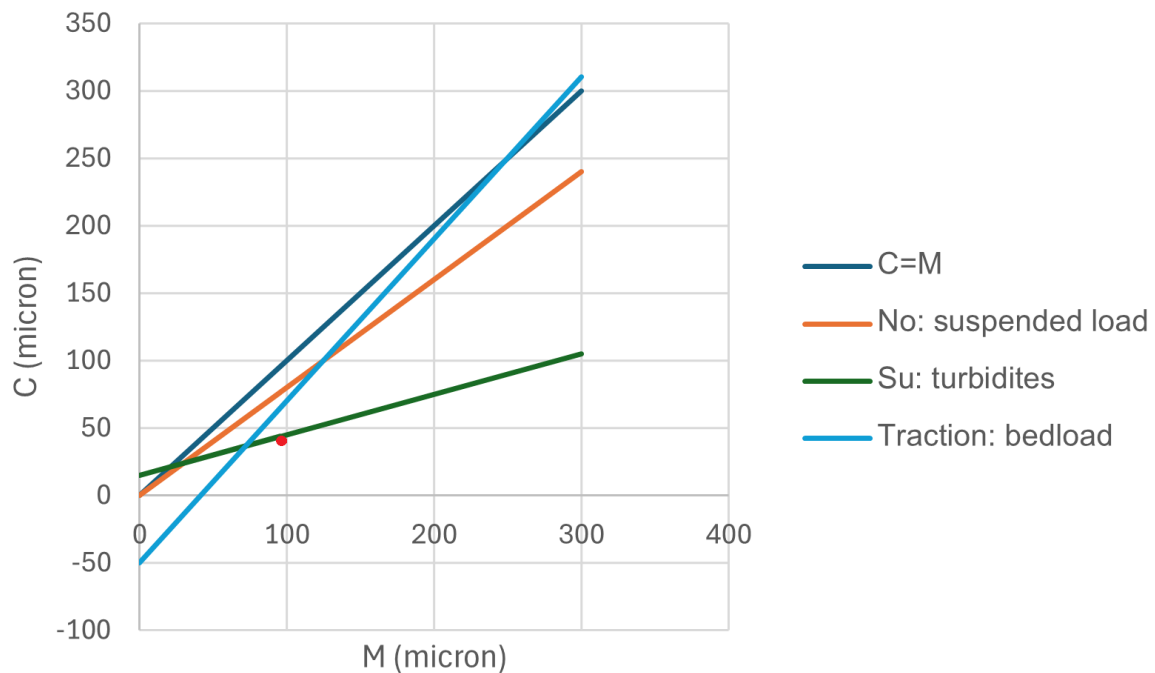


Fig. 6. Passega diagram (C-M plot) showing transportation mechanism of core sample

5. Conclusions

Based on grain size analysis, the core sample is classified as Moderately Well-Sorted Very Fine Sand with a predominant sand texture. The granulometric characteristics, when combined with the Linear Discriminant Function (LDF) analysis, suggest that the depositional environment corresponds to a shallow, agitated water setting. This environment is marked by well-sorted sediments deposited primarily under the influence of turbidity currents.

The sediment transport mechanism indicates that the sediments were predominantly transported as bedload, comprising finer grains carried by turbidite flows. These observations point to dynamic sedimentary processes likely linked to slope-related marine systems or shelf-edge deltas.

This study provides valuable insights into the sedimentary environment of the Upper Miocene in offshore North Vietnam. The results serve as an important reference for regional geotectonic interpretations and hold significance for future oil and gas exploration in the area..

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