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Depositional Environment Characteristic of The Late Miocene Kerek Formation in Kendeng Basin: A Case from Cipluk Area, Kendal Regency, Central Java

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Abstract
This study focused on the Late Miocene Kerek Formation in Cipluk, Kendal Regency, Central Java, which belongs to the Kerek Formation, a lithostratigraphy unit characterized by Early Miocene - Late Miocene turbidite deposits. The research aims to comprehensively interpret the depositional environment characteristics of the Late Miocene Kerek Formation based on lithofacies, thin section analysis, and micropaleontological analysis. Gaining insights into facies characteristics and the depositional environment will offer novel perspectives for the exploration and development of oil and gas resources in the Kendeng basin. The methodology consists of data collection, analysis, and synthesis. Results indicate that the study area is dominated by classical turbidite facies, suggesting a distal zone with slow sediment settling. The analysis reveals that the Late Miocene Kerek Formation was deposited in a deep marine environment within the inner bathyal—outer bathyal bathymetry zone, specifically in the lower fan section of a submarine fan system. Based on the characteristics of existing deposits and facies, the deposition environment is identified as a fine-grained, mud-rich complex in an elongated submarine fan. These findings contribute to a better understanding of the Late Miocene depositional environment in the Kendeng Basin, Central Java.

1. Introduction

The research area is located in the area of Cipluk, Kendal Regency, Central Java (see Figure 1), which physiographically belongs to Kendeng Zone [2] and stratigraphically belongs to the Kerek Formation [3], [4], [5]. Kerek Formation is a lithostratigraphy unit of the Kendeng Basin in central Java that is characterized by Early Miocene – Late Miocene turbidite deposits [3]. Otherwise, it is stated that Cipluk Area belongs to the Kalibeng Formation instead of the Kerek Formation [6]. The authors are more in agreement that this area belongs to Kerek Formation.

Kerek Formation is stratigraphically divided into three stratigraphy members: the Early Miocene Kerek Formation, Middle Miocene Kerek Formation, and Late Miocene Kerek Formation [5]. Several studies of the Late Miocene Kerek Formation have been conducted yet restricted to the geological regional, stratigraphy, structural geology, and general depositional environment [3] - [7]. This research specifically discusses the Late Miocene Kerek Formation. The depositional environment of this area is a part of the channel portion lobes to an outer fan in the bathyal submarine fan system [6]. Nevertheless, the characteristics and specific types of the depositional environment are still not discussed yet. This research aims to provide a comprehensive interpretation of depositional environment characteristics of the Late Miocene Kerek Formation based on: 1) Lithofacies; 2) Thin section analysis; and 3) Microfossil analysis. Understanding the facies characteristics and depositional environment will provide new insights into the exploration and development of oil and gas in the Kendeng basin, especially in determining the petroleum system play.

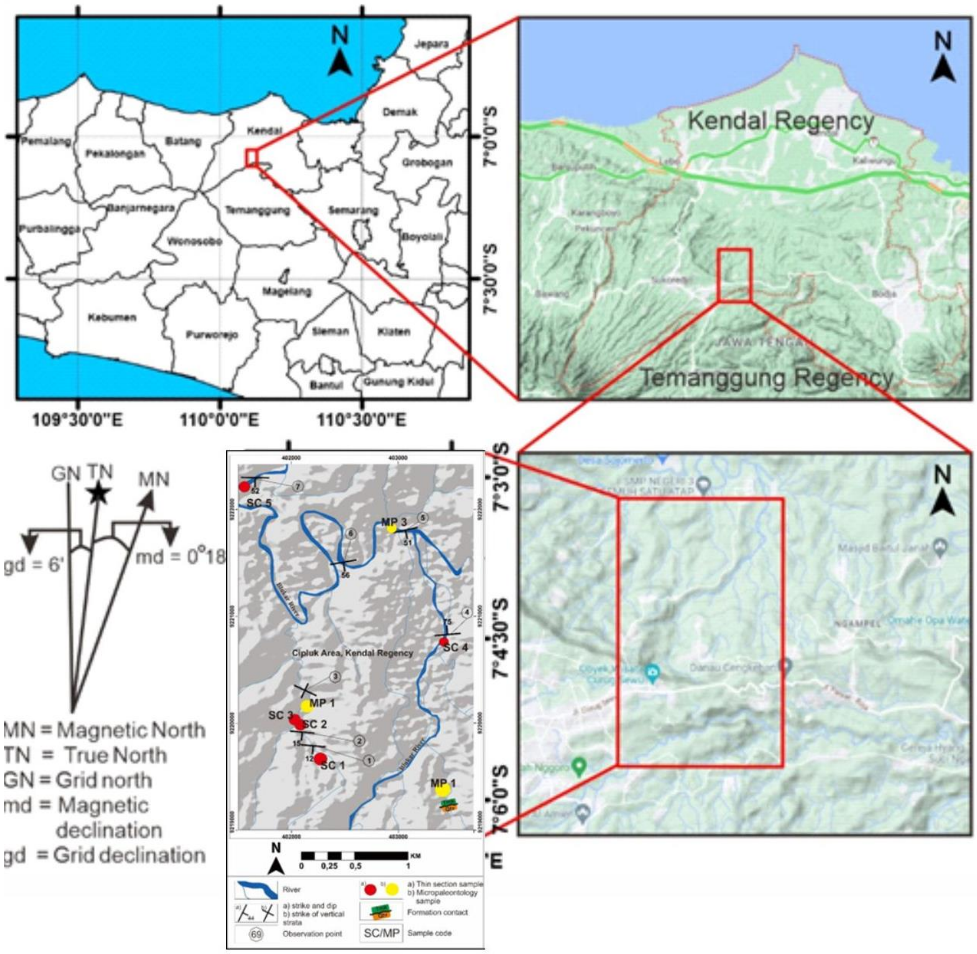


Figure 1. Location of research area.

2. Methodology

This research was conducted in three stages: data collection, data analysis, and data synthesis. The collection phase includes the study of literature and field observations. Field observations included observation of rock outcrops, preparation of lithological profiles, documentation and sampling for thin section analysis, and micropaleontology analysis. Data analysis included lithological profile analysis, thin section analysis, and micropaleontology analysis. The data obtained are synthesized to respond to the research issue.

The purpose of the analysis of lithology profiles is to identify and classify lithofacies which furthermore use in determining the depositional environment and its characteristics. Facies identification in the field is based on the turbidite model [8]. The clustering of defects and interpretation of the deposition environment is based on the submarine fan model by [9]. The determination of the characteristics of the deposition environment refers to the [10] assessment.

The thin section analysis is performed in five samples (see Figure 1). Sample selection considers differences in the type of lithofacies. Thin section analysis is used to determine the grain shape of sedimentary rock which is further used as the parameter in determining the characteristics of the depositional environment, the assessment accords to [10].

The micropaleontological analysis is performed in three samples representing the bottom, middle, and upper parts of the Late Miocene Kerek Formation in the investigation area (see Figure 1). The micropaleontological analysis is specific to the analysis of the benthic species, therefore palaeobathymetry zone is maintained. The determination of paleobathymetry is based on bathymetry zonation by [11].

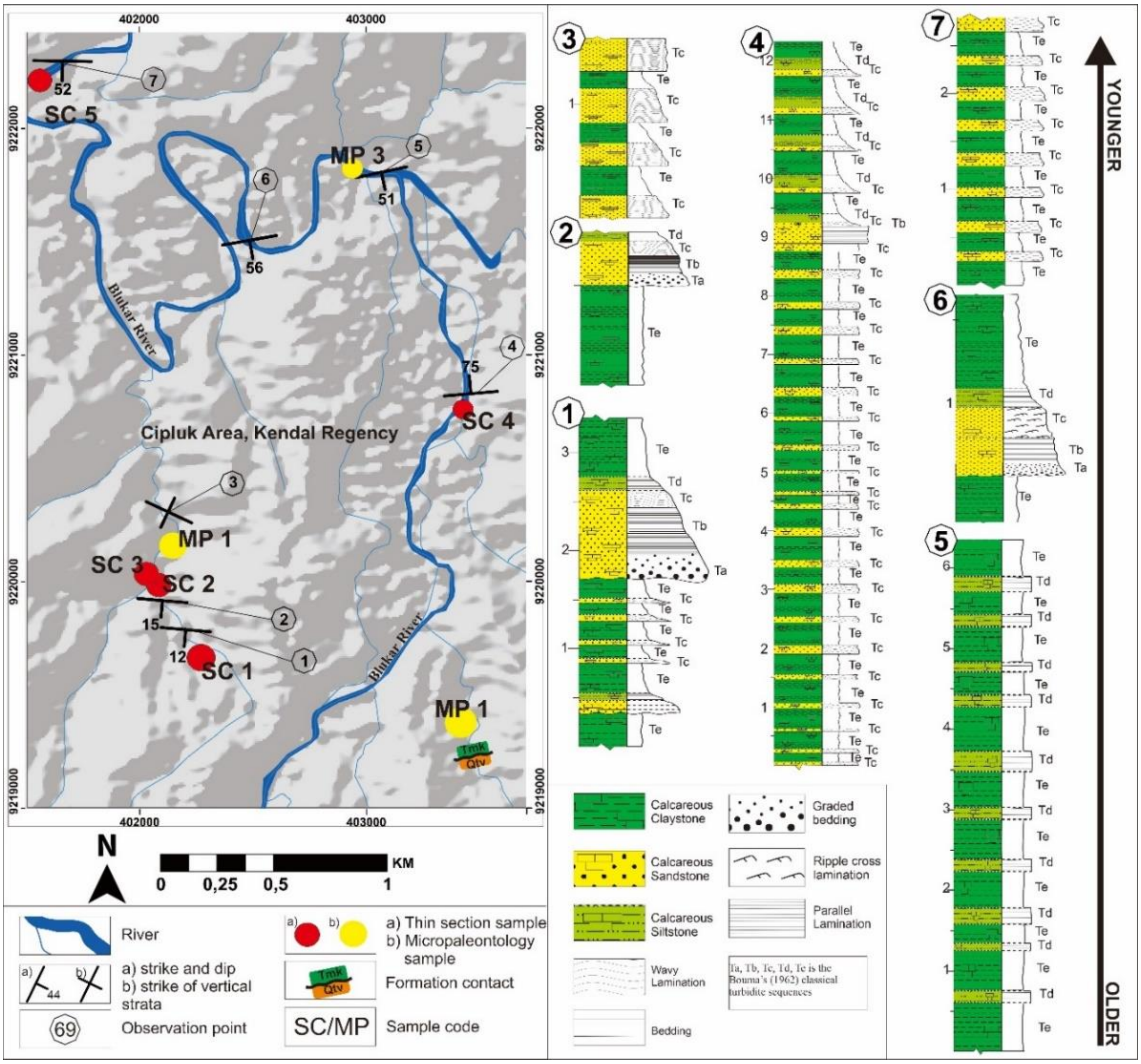


Figure 2. Maps of geological point and sample location, shows the lithological profile of Late Miocene Kerek Formation from the Cipluk area.

3. Results and discussions

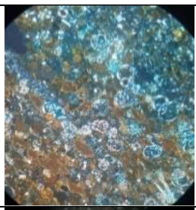
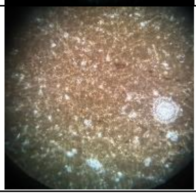
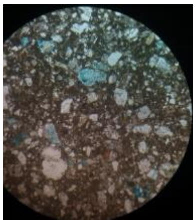
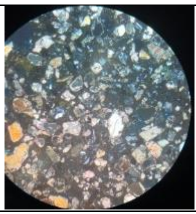
3.1. Lithofacies Variation

The classical turbidite facies group is the most dominant facies group found in the study area. This facies group is characterized by well-stratified deposits, generally stratified sandstones and claystone, does not show depletion and channeling geometries, and is strongly characterized by the presence of the Bouma Sequence (see Figure 2). The Bouma sequence is a sedimentary sequence that describes the vertical progression of sedimentary structures and sedimentary rock layers commonly found in turbidite deposits. The presence and facies pattern of classical turbidite can be used to determine the position of the deposit (proximal or distal). The more it leads to the distal area, the lower the sandstone/claystone ratio and the Ta sequence does not develop [9] (see Figure 2).

The classic turbidite facies is present in a repeating pattern. In the study area, it is known that there are several observation sites with sequenced and complete Bouma sequences, but incomplete and unsequential Bouma sequences are more dominant (see Figure 2).

The Te interval is present most dominantly compared to the other intervals, with a thickness ranging from a few (one to two) centimeters to ten centimeters. The Te interval in the investigation area is found as calcareous claystone with no known internal structure, and grain sizes ranging from silt to clay (see Figure 2).

Table 1. Photomicrograph of thin section samples (40x magnification), classification and texture, and grain maturity

Sample Code	XPL Photo	Classification and Texture	Interpretation
SC 1		- Wackstone [12] - Grain size: 0,125 – 0,25 mm [1] - Roundness: subrounded – rounded - Sortation: well sorted - Support: matrix supported	Mature (distal area)
SC 2		- Packstone [12] - Grain size: 0,125 – 0,625 mm [1] - Roundness: subrounded – rounded - Sortation: well sorted - Support: grain supported	Mature (distal area)
SC 3		- Wackstone [12] - Grain size: < 0,004 mm [1] - Roundness: rounded - Sortation: well sorted - Support: matrix supported	Mature (distal area)
SC 4		- Feldspathic Wacke [13] - Grain size: 0,125 – 0,5 mm [1] - Roundness: subangular – subrounded - Sortation: poorly sorted - Support: matrix supported - Feldspar presence as a fragment	Mature (distal area)
SC 5		- Wackstone [12] - Grain size: 0,125 – 0,5 mm [1] - Roundness: Subrounded – rounded - Sortation: poorly sorted - Support: grain supported - Feldspar presence as a fragment	Mature (distal area)

The Td interval is quite dominant in intensity, but not in thickness. This interval has a thickness of several centimeters to ten centimeters. In the study area, the Td interval is characterized by the lithology with grain sizes of very fine sand to silt, the sedimentary structures that develop are parallel laminations and low-relief wavy lamination (see Figure 2).

The Tc interval is quite dominant in intensity, but not in thickness. This interval is one to two centimeters to ten centimeters thick. The Tc interval is identified by the development of wavy laminated sedimentary structures, through cross-stratification, and ripple cross-stratification (see Figure 2).

The Tb interval is quite common but not predominant. The thickness of this interval varies from a few centimeters to ten centimeters. The Tb interval in the investigation area is characterized by the presence of parallel laminar sedimentary structures, sometimes slightly wavy, with medium to fine sand grain sizes (see Figure 2).

The Ta interval is not dominant in the investigation area with a thickness of only one to two centimetres. The sedimentary structures found in this interval are without internal structure, erosional boundary planes, and graded bedding, which gradually changes to the Tb interval with an upward fine grain pattern (see Figure 2).

Table 2. Benthonic fossils analysis and the bathymetry zone interpretation

Benthic Species	Depth Marker (meters)	Paleobathymetry zone [11]
Top Strata (MP 1)		
Euuvigerina peregrina (a)	713.7	Inner Bathyal – Outer Bathyal (200 – 2000 meters)
Cibicides subhaidingerii (b)	283.65	
Planulina wuellestrofi (c)	503.25	
Eponides umbonatus (d)	320.25	
Dentalina advena (e)	713.7	
Bulimina costata (f)	631.35	
Middle Strata (MP 2)		
Planispira communis (g)	311.1	Inner Bathyal – Outer Bathyal (200 – 2000 meters)
Miliolinella oblonga (h)	1116.3	
Amphistegina gibbose(i)	796.05	
Quinqueloculina auberiana (j)	713.7	
Eponides umbonatus (k)	320.25	
Cyclammina trullissata(l)	713.7	
Bottom Strata (MP 3)		
Euuvigerina peregrina(m)	713.7	Inner Bathyal – Outer Bathyal (200 – 2000 meters)
Bolivina quarilatera(n)	750.3	
Planulina wuellerstorfi(o)	503.25	
Quinqueloculina auberiana (p)	713.7	
Steblus batavus(q)	334.89	
Anomalia colligera(r)	384.3	

3.2. Thin Section Analysis

The thin section analysis was specifically performed to determine grain maturity levels (see Table 1). Grain maturity was analyzed qualitatively to become one of the parameters for determining the properties of the deposit environment. The maturity of the grains concerned is the degree of roundness of the grains identified by thin sections, where most of the grains are slightly subrounded – rounded in shape. The more rounded shape reflects the longer transport distance [10].

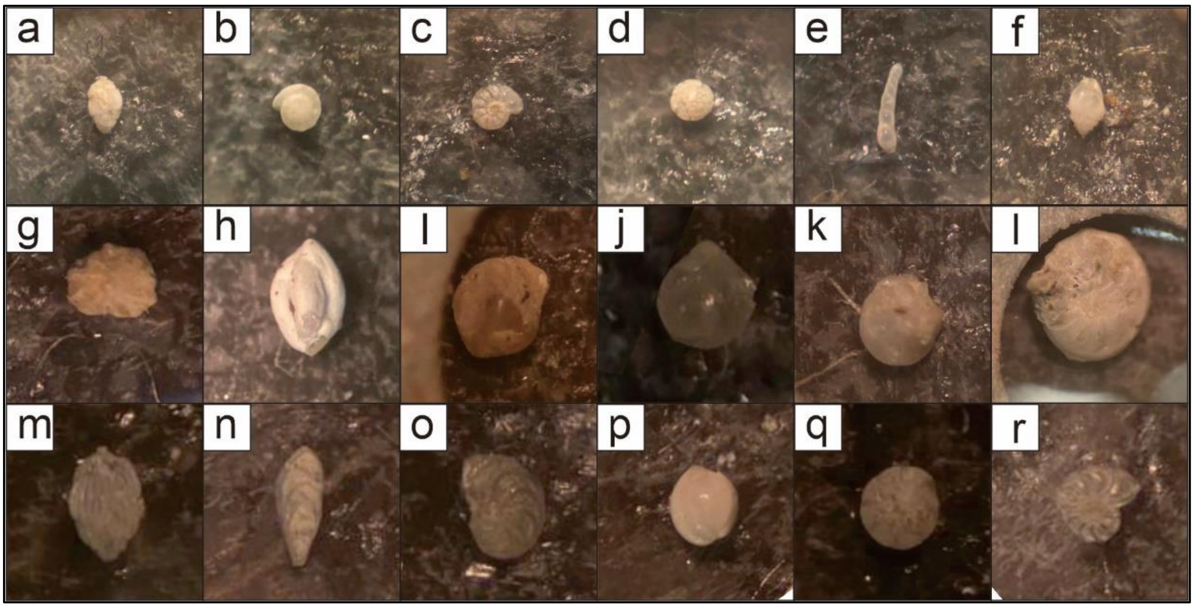


Figure 3. Photomicrograph of benthic species fossils alphabetically refers to Table 2.

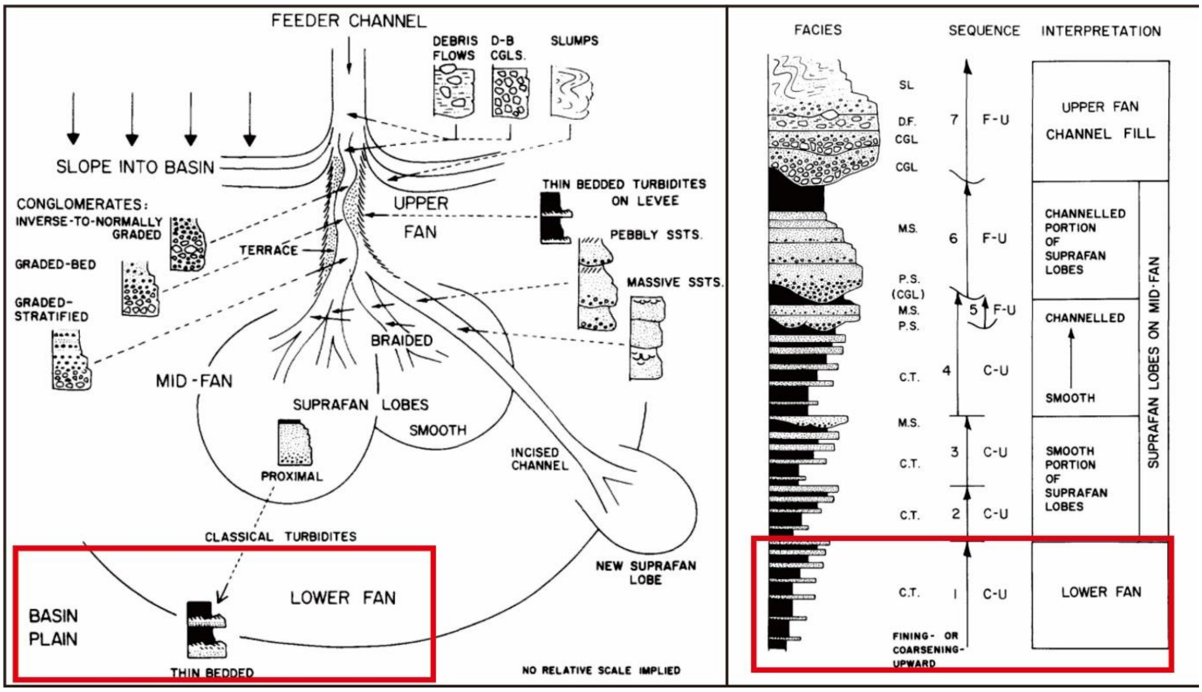


Figure 4. Depositional environment by [9]; Late Miocene Kerek Formation in research area marked by the red square.

3.3. Paleobathymetry

Micropaleontology samples were taken from Te intervals in terms of the results obtained could represent paleobathymetry. The micropaleontological analysis is restricted to the analysis of benthic species with the aim of interpreting the depositional environment (see Table 2 and Figure 3). The analysis of three samples shows consistent results. The abundance of fossils indicated the Inner Bathyal-Outer Bathyal paleobathymetry zone (200–2000 meters) [11]. Table 2 shows the interpretation of paleobathymetry based on the depth marker.

3.4. Depositional Environment

Examination and analysis of benthic micropaleontology in three samples consistently showed the Inner Bathyal - Outer Bathyal bathymetry zone (200 - 2000 meters) *[11]*. These results are similar to previous studies *[6]*. The benthic species indicate the Upper Miocene Kerek Formation was deposited in a deep marine environment.

The lithology profile shows the characteristics of the turbidite deposit sequence by the classical turbidite facies dominated. This facies group is associated with the submarine fan environment. Considering the variation of lithofacies, stratified calcareous claystone that is identified as the Te interval is more present than the Ta, Tb, Tc, and Td intervals. Ta and Tb intervals are present locally non-dominantly. The Tc and Td intervals are present frequently and are associated with the Te interval.

In terms of transport and deposition mechanisms, the facies pattern indicates a low flow of energy and density flow that is strongly influenced by turbulent currents *[14]*, *[15]*. This indicates a distal zone with slow sediment settling. The thin section analysis data in Table 2 concordantly show the distal deposition adjustment in a consistent manner (see Table 2).

Referring to the existing facies model, the Late Miocene Kerek Formation was deposited in a deep-water deposition environment, the inner bathyal - outer bathyal bathymetry zone, in a submarine fan system specifically in the lower fan section *[9] [11]*(see Figure 4).

Table 3. The depositional environment of the research area

Key Controls and Main Characteristics	Late Miocene Kerek Formation Data
Length of transport overland	Relatively long (distal)
Type of margin	Passive [16]
Location of receiving basin	Continental Crust
Main grain size at the coast	Fine grain
Shelf width	Wide
Size of submarine fan	Medium to very large *
The ratio of sandstone/shale of the turbidite system	High
The ratio of sandstone/shale of the turbidite complex	Low
Type of fan building	-
Sandstone/shale ratio in the dip direction	-
Influence of sea-level variations	-
Canyon fill	Mainly mud
Petrography	Mature
Submarine fan type: Fine-grained, mud-rich complex submarine fan	
*) This research interpretation -) No data exists yet	

3.5. Depositional Environment Characteristics

The characteristics of the depositional environment discuss identified aspects of existing deposits or facies which are then used to determine the type, size, and geometry of the submarine fan depositional environment. Interpretation of the characteristics of the submarine fan depositional environment refers to the parameters of [10].

The depositional environment of the research area (Kendeng Basin) has features dominated by distal facies with long transportation distances, develops during passive tectonics (back-arc basin) [16], wide shelf width, the geometry of the submarine fan is elongated with a medium–large size; characterized by a low ratio of coarse grain/fine grain, mature grain, therefore designated as a fine grain, mud-rich complex; elongated submarine fan [10] (see Table 3).

4. Conclusion

From the conducted study and detailed analysis, several conclusions can be drawn. Our research sheds light on the depositional environment of the Late Miocene Kerek Formation in Cipluk, Kendal Regency, Central Java. It pinpoints a deep marine backdrop ranging from the inner to the outer bathyal zone. Evidently, as Figure 2 suggests, the presence of classic turbidite facies in the lower fan section highlights the influence of turbulent currents within a submarine fan system, further detailed in Figure 4. Moreover, meticulous micropaleontological assessments reinforce the deep marine classification of the Late Miocene Kerek Formation, establishing its depth within the inner bathyal to outer bathyal zone (200-2000 meters), as depicted in Table 2. This formation showcases characteristics of a fine-grained, mud-dominant composition, situated within an expansive submarine fan system. Such traits resonate with the low-energy and density flows that are typically observed in submarine fan environments, with further elaboration found in Table 3. Ultimately, these comprehensive insights are pivotal for the future exploration and development of the oil and gas sector in the Kendeng basin, specifically in devising prospective petroleum system plays.

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