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Lithofacies Analysis and Architectural Elements of Interbedded of Carbonate Sandstone and Carbonate Mudstone in the Kerek Formation in the Kauman and Surrounding Areas of Wonosegoro District, Boyolali Regency, Central Java Province

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ABSTRACT: A study was carried out involving the analysis of lithofacies and architectural elements in the Kauman area and vicinity, Wonosegoro District, Boyolali Regency, Central Java Province. The objective of this research is to determine the characteristics of the sedimentation processes, facies, facies associations, and the depositional environment of the research area. Sedimentation in the research area occurred via two depositional processes: mass transport deposits (MTD) and turbidite currents manifested as slumps and Bouma sequence intervals (Ta–Te). Nine lithofacies were identified: Facies 1(Pebbly sandstone), Facies 2 (Massive sandstone), Facies 3 (Bedded sandstone), Facies 4 (Parallel-laminated sandstone), Facies 5 (Wavy, Convoluted and Cross-Laminated Sandstone), Facies 6 (Sandstone and mudstone interbedded), Facies 7 (Massive mudstone), Facies 8 (Sandstone and siltstone interbedded), and Facies 9 (Slump deposits). In terms of architectural elements, the study area exhibits six facies associations: distal levee, silty-sandy distal lobes, sandy lobes, mud-filled channels, distributary channels, and mid fan/slope channels. Facies model in the study area is classified within the classical turbidite (CT), massive sandstones (MS), and pebble sandstones (PS) facies. These were deposited in a submarine fan system, specifically in the middle fan section within the depositional sub-environment of the channelled-smooth portion of the suprafan lobes.

KEYWORDS: Mass Transport Deposit, Lithofacies, Architectural Elements, Depositional Environment, Kauman, Wonosegoro

I. INTRODUCTION

The research area is included in the physiography of the Kendeng zone which is the main depocenter of Paleogene-Neogene deposits, recording thick turbidite and pelagic sediment sequences (Bemmelen, 1949). The stratigraphy of the Kendeng Zone began when sediments deposited in the Kendeng basin originated from erosional products of sedimentation sequences that occurred in the East Java Basin (Sukardi and Budhitrisna, 1992) . The stratigraphy of the research area is composed of sedimentary deposits that are part of the Kendeng Zone, namely the Kerek Formation (Tmk). The exposure of the Kerek Formation in the research area provides information on the characteristics of the Kerek Formation, including lithology, facies, and depositional environment. Based on this, research can be conducted in the form of lithofacies analysis and architectural elements in the Kauman area and its surroundings, Wonosegoro District, Boyolali Regency, Central Java Province.

Depositional environmental analysis involves identifying elements or features that are meaningful to the depositional environment. These features include sedimentary structure and texture, sedimentary facies associations, and fossils. These features can be used to reconstruct facies models for each depositional environment (Boggs, 2006). Environments, both terrestrial and underwater, can be characterized by the physical and chemical processes operating there and the organisms that lived under those conditions at the time (Nichols, 2009).

Turbidite deposits are described in detail by Walker (1984), while mass transport (MTD) deposits can be divided into two types according to Shanmugam (2012), based on the sedimentation and transformation processes of sediment flows: slumps and debris flows. Mass transport generally consists of slides, which are coherent sediment masses that move along planar slip planes and exhibit no internal deformation, and slumps, which are coherent sediment masses that move on concave slip planes and undergo rotational movement that causes internal deformation. Sediment flows are divided into two distinct groups: sediment-gravity flows and fluid-gravity flows. In sediment-gravity flows, fluid is driven by grains moving downslope under the influence of gravity. These flows are grouped into four types based on their sediment-support mechanism: turbidite currents with turbulence, sediment flows characterized by upward intergranular flow, grain flows with grain interactions, and debris flows with matrix strength. Sediment-gravity flows are the most important deep-sea process in the development of submarine fans. Channelized turbidite currents and debris flows are two dominant types of sediment gravity flows that play a role in carrying and depositing submarine fan sediments (Shanmugam & Moiola, 1988).

Facies is the physical, chemical, or biological aspects of a sedimentary rock over a period of time. Two rock bodies deposited at the same time are said to have different facies if they differ in their physical, chemical, or biological characteristics (Martodjojo and Djuhaeni, 1996; Darman, et al., 2023). Lithofacies are individual rock units defined by their distinct lithological characteristics, including composition, grain size, layering characteristics, and sedimentary structures. Each lithofacies represents a depositional event.

The purpose of this study is to discuss the characteristics and depositional environment of the Kerek formation found in the research area. The aim is to determine the types of lithofacies and describe facies associations in determining the characteristics of the sedimentation process and depositional environment in the alternating carbonate sandstone and carbonate claystone units of the Kerek Formation in the research area, so that an analysis and interpretation of mass transport deposits, lithofacies, and architectural elements related to determining the depositional environment in the alternating carbonate sandstone and carbonate claystone units of the Kerek Formation in the Kauman area and its surroundings are obtained.

II. METHODOLOGY

The study of lithofacies and architectural elements of the interbedded carbonate sandstone and carbonate claystone of the Kerek formation in the Kauman area and its surroundings was carried out through several stages, including the literature study stage, the field observation stage and the laboratory analysis stage.

The study begins with a literature review or desk study aimed at gathering as much information as possible on the related topic. This information was obtained from previous studies related to the Kerek depositional environment. The next stage is field observation, which is the primary method based on field mapping. This stage is carried out to determine the location for data collection, namely by observing the condition of the outcrop and the position of the rock. After finding a location that meets the requirements, the next stage is data collection. This stage includes measuring the position of the rock, measuring the measured stratigraphic cross-section, taking rock samples, a detailed description of the outcrop in the stratigraphic cross-section measurement conducted to determine lithological variations, and documentation. After collecting the field data, the next stage is the laboratory analysis stage. At this stage, the measured stratigraphic cross-section is analyzed and interpreted. This stage obtains an overview of the depositional mechanisms and the depositional environment, until these results serve as the basis for determining the lithofacies and architectural elements of the research area.

III. RESULTS AND DISCUSSION

A. Observation location

The object of this research is clastic sedimentary rocks in outcrops located on the Serang River, Kerek Formation, Kauman Village, Wonosegoro District, Boyolali Regency, Central Java (Figure 1). This research was conducted using the measured section method with a track length of 250 m and an actual thickness of 231.4 m.

Figure 1. Location map and measured stratigraphic cross-sections

B. Mass Transport Deposit (MTD)

Based on the concept of the deep-sea gravitational sedimentation process according to Shanmugam (2012), sedimentation in the study area consists of two types of deposition processes, namely mass transport deposition (MTD) and turbidite currents. In the Serang River, there are carbonate sandstones that show the results of the deposition process in plastic conditions indicated by the presence of sedimentary structures in the form of slumps. The presence of slump sedimentary structures can be interpreted during the deposition process in the deformation layer of a slope (Figure 2). This deposit has a layer thickness of 60 cm-2.2 m in the study area.

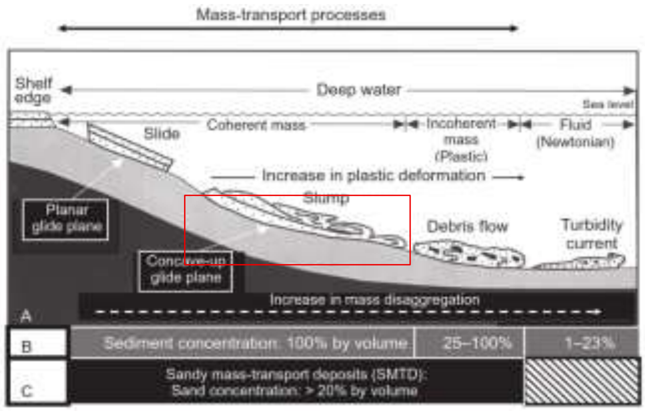

Figure 2. Interpretation of MTD of the research area (red box), (Shanmugam, 2012)

On the Serang River traverse, it is also clear that there is a sedimentary structure that characterizes the influence of turbidite currents in accordance with the Bouma sequence concept, namely sandstone with a massive, graded structure (Ta), medium sandstone with a laminated sedimentary structure (Tb), fine sandstone with a wavy, cross-bedded, and convoluted laminated sedimentary structure (Tc), siltstone (Td), and claystone as the final stage of the Bouma sequence deposition process, namely pelagic/interval sediment (Te). In the Ta-Te interval, it can be interpreted that the lithology on the Serang River track profile is included in the distal facies of turbidite deposits from submarine fans (Figure 3).

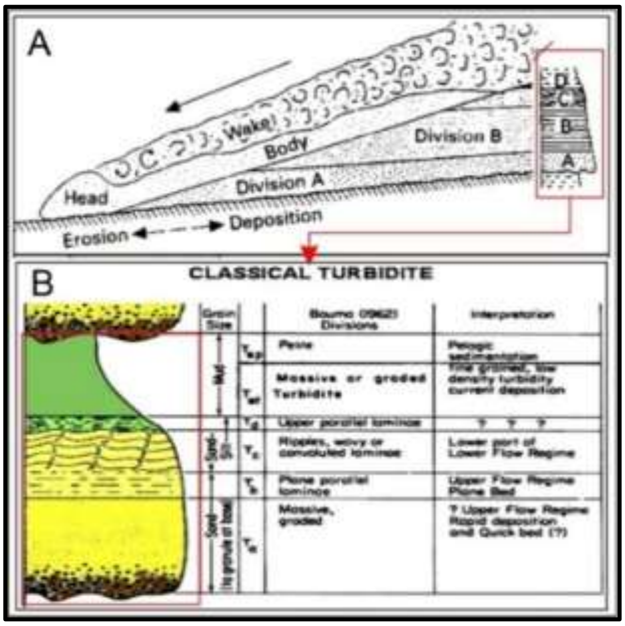

Figure 3. Interpretation of turbidite deposits in the study area (Bouma, 1962)

C. Lithofacies

Lithofacies that make up the Serang River measuring section of the research area consist of 9 lithofacies (Figure 4 and Figure 5). The division is based on the description of the characteristics of the outcrops in the field, consisting of facies 1 (Pebbly Sandstone), facies 2 (Massive Sandstone), facies 3 (Bedded Sandstone), facies 4 (Parallel Laminated Sandstone), facies 5 (Wavy, Cross-Laminated, and Convoluted Sandstone), facies 6 (Interbedded Sandstone and Mudstone), facies 7 (Massive Mudstone), facies 8 (Interbedded Sandstone and Siltstone), and facies 9 (Slump Deposits).

Figure 4. Lithofacies of the research area (Facies 1-4, Facies 6-7)

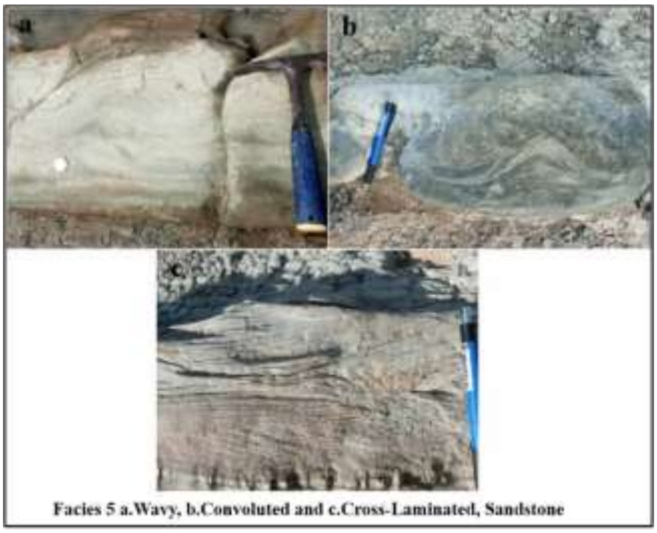

Figure 5. Facies 5 Wavy, Convoluted and Cross-Laminated Sandstone

1. Facies 1 (Pebbly sandstone)

Massive pebbly sandstone consists of a very coarse sand matrix and gravel-sized andesite fragments, light brown gravelly sandstone, poorly sorted, open-packed, carbonate cement. The thickness of this facies ranges from 7 m. This facies is interpreted as a sequence of pebble sandstones (PS) facies (Walker, 1978). The interpretation of this facies is that the transportation process occurs due to high-density flow and increased sand-carrying flow. The deposition process is that the grains are deposited collectively and quickly, consisting of a mixture of gravel and sand because the flow slows down.

2. Facies 2 (Massive sandstone)

Composed of massive sandstone and graded bedding sandstone consisting of very fine-very coarse sand, brownish cream in color, well sorted, closed packing, carbonate cement, and bioturbation structures. The thickness of the sandstone ranges from 80cm-5m. This facies is interpreted into the sequence massive sandstones (MS) facies (Walker, 1978). This facies interpretation includes a depositional mechanism caused by high turbidite current density due to the rapid deposition process so that tractional cannot form, grain-by-grain sedimentation influenced by suspension with gradual sedimentation according to the transport forces acting on the layer.

3. Facies 3 (Bedded sandstone)

A layered sandstone consisting of medium-coarse sand, brownish cream in color, well sorted, close packed, carbonate cement. The thickness of the sandstone ranges from 50cm-4m. This facies is interpreted as part of the Tb interval of the Bouma sequence, 1962. Interpretation of the depositional mechanism into low-density or high-density turbidite currents. The high density of turbidite currents is due to the rapid depositional process so that tractional cannot form, deposition is gradual in accordance with the transport forces acting on the layer.

4. Facies 4 (Parallel Laminated Sandstone)

Parallel laminated sandstone consisting of very fine to very coarse sand, brownish-cream in color, well sorted, close packed, carbonate cement, and flute cast structures beneath the layers. The sandstone thickness ranges from 40 cm to 1.4 m. Traction sedimentation from low-density turbid currents. The transport process results from turbidite currents, which in the Bouma sequence are included in Tb, while the deposition process is rapid and repeated.

5. Facies 5 (Wavy, Convoluted and Cross-Laminated Sandstone)

This facies consists of coarse-to-very coarse sand, brownish-cream in color, well-sorted, tightly packed, carbonate cement, and contains structures. The sandstone thickness ranges from 50 cm to 70 cm. This facies is interpreted as part of the Tc interval of the Bouma sequence (1962). The sedimentation mechanism is interpreted as traction from low-density turbid currents. The transportation process occurs due to turbidite currents or also due to strong undercurrents. The sedimentation process is due to grain flow.

6. Facies 6 (Sandstone and Mudstone Interbedded)

This facies consists of alternating sandstone and claystone with interbedded sandstone. The sandstone has a fine-to-very coarse sand size, brownish cream in color, and the claystone is brownish gray, well sorted, close packed, carbonate cement. The thickness of the sandstone ranges from 10cm-40cm, with less occurrence and is located between the claystone with a thickness of 20cm-2.6m. The sandstone is interpreted as part of the Ta, Tb, or Tc interval while the claystone is Te from the Bouma sequence, 1962. According to Walker, 1978, the alternation of sandstone with claystone is a classic turbidite facies (CT). Therefore, it can be interpreted that this facies is included in the turbulent flow mechanism with low concentration.

7. Facies 7 (Massive Mudstone)

Massive mudstone facies and bioturbation structure, brownish gray, well sorted, closed packing, carbonate cement. Thickness 50cm-1m. Interpreted as part of the Te interval of the Bouma sequence, 1962. Claystone sedimentation in deep-sea sedimentary systems can be formed by mechanisms other than turbid currents, namely by pelagic suspension deposition mechanisms.

8. Facies 8 (Sandstone and Siltstone Interbedded)

This facies consists of interbedding sandstone and siltstone and there are sandstone interbeds of siltstone. The sandstone has a medium-coarse sand size, brownish cream color, and the siltstone is brownish gray, well sorted, close packed, carbonate cement. The thickness of the sandstone ranges from 10cm-40cm, there are fewer and are between siltstone with a thickness of 60cm-3.1m. The sandstone is interpreted as part of the Ta, Tb, or Tc interval while the siltstone is Td from the Bouma sequence, 1962. Deposited by traction current mechanisms with siltstone contacts indicating different depositional phases and higher energy. The dominance of siltstone can be interpreted as deposited in the distal phase of the turbid current. Siltstone sedimentation in deep-sea sedimentation systems can be formed by mechanisms other than turbid currents, namely by pelagic suspension deposition mechanisms and is a classic turbidite facies (CT) whose mechanism can be interpreted as turbulent flow with low concentration.

9. Facies 9 (Slump Deposits)

This facies consists of sandstone with medium to very coarse sand size, brownish cream color and carbonate cement. The thickness of this facies ranges from 60 cm to 2.2 m. This facies is interpreted as part of the Tc interval while the siltstone is Td from the Bouma sequence, 1962. The slump transport process results from its deposition that overloads sedimentary rocks. The deposition process is the cessation of movement on the lower slope due to gravitational forces.

D. Architectural Elements

Interpretation of architectural elements is based on the description of the facies arrangement, succession patterns, which refer to previous researchers regarding the deep sea turbidite fan model (Stow and Piper, 1984). So that the lithofacies formed in the Serang River can be used as a description of the genesis of its formation in the past to interpret the depositional environment. The facies association model used is the Stow and Piper classification (2013), from the results of the previous lithofacies analysis, the facies association of the research area can be grouped into 6 groups, they are distal levee, silty-sandy distal lobes, sandy lobes, mud-filled channels, distributary channels and Mid-fan/slope channels.

1. Distal levee

Consisting of several lithofacies, namely facies 5 (wavy, cross-bedded, and convoluted laminated sandstone), facies 6 (interbedded sandstone and mudstone), and facies 8 (interbedded sandstone and siltstone). The transport mechanism of turbidite currents that carry fine material with decreasing concentration and velocity, with grain-by-grain sedimentation influenced by suspension. This facies association is in the form of classic turbidite deposits deposited on the upper fan of the levee or middle fan that forms a levee (natural embankment) see Figure 6.

2. Silty-sandy distal levee

This facies association consists of several lithofacies, namely facies 3 (bedded sandstone), facies 4 (parallel laminated sandstone), facies 6 (sandstone and mudstone interbedded), facies 7 (massive mudstone), and facies 9 (slump deposits). This facies association was formed due to the transition of a weakened current and transported quite far from its source so that the sandstone is still present, which distinguishes it from other facies associations due to the relatively equal thickness of the sandstone and mudstone. The transportation mechanism is a current shift from density flow where sediment deposition slows and stops to turbidity flow which carries fine sediment material quite far from its source. This facies association was deposited in the middle fan as a fan deposit (lobe) see Figure 7.

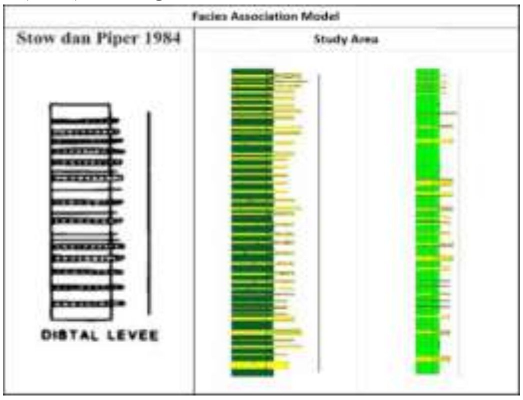

Figure 6. Distal levee facies associations of the research area (Stow and Piper, 1984)

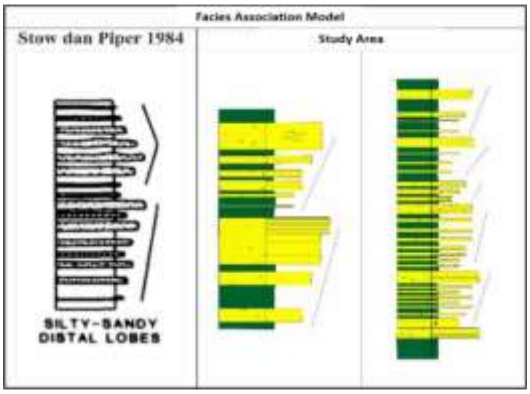

Figure 7. Silty-sandy facies association of distal lobes of the research area (Stow and Piper, 1984)

3. Sandy lobes

Consisting of several lithofacies, namely facies 1 (gravelly sandstone), facies 3 (bedded sandstone), and facies 6 (sandstone and mudstone interbedded). The transport mechanism is in the form of a shift in high-density currents that carry sediment supplies close to the source, so that coarse particles are still carried and deposited, changing into turbidity currents with low concentration and speed so that mud is deposited. Formed in the middle fan as lobe deposits and associated as channel deposits (Figure 8).

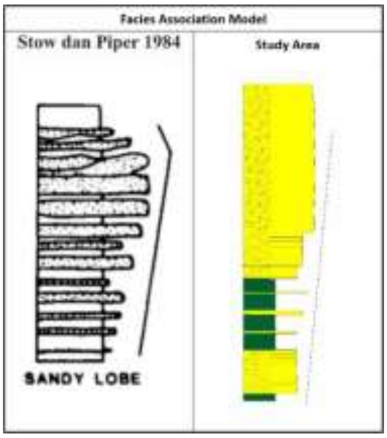

Figure 8. Sandy lobe facies association in the research area (Stow and Piper, 1984)

4. Mud-filled channels

This facies association consists of several lithofacies, namely facies 2 (massive sandstone), facies 4 (parallel laminated sandstone), facies 5 (wavy, cross-laminated, and convoluted sandstone), facies 6 (sandstone and mudstone interbedded), facies 7 (massive mudstone), and facies 8 (sandstone and siltstone interbedded). The depositional process is dominated by muddy turbidity current, this is characterized by the dominance of mudstone. This facies association was probably deposited in the upper fan to the middle fan, Walker (1978) see Figure 9.

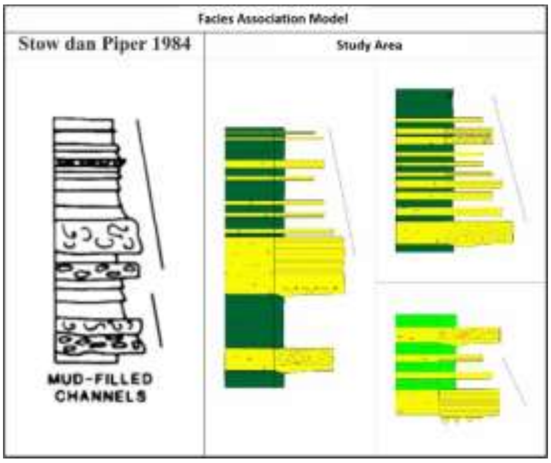

Figure 9. Mud-filled channel facies association in the research area (Stow and Piper, 1984)

5. Distributary channels

Consisting of several lithofacies, namely facies 2 (massive sandstone), facies 5 (wavy, cross-laminated, and convoluted sandstone), facies 6 (sandstone and mudstone interbedded), and facies 7 (massive mudstone). In this facies association, there are many fairly thick sandstones characterized by turbidites with very coarse to fine sand grains and many scoured contacts. Mudstone in this facies association is quite small (Figure 10).

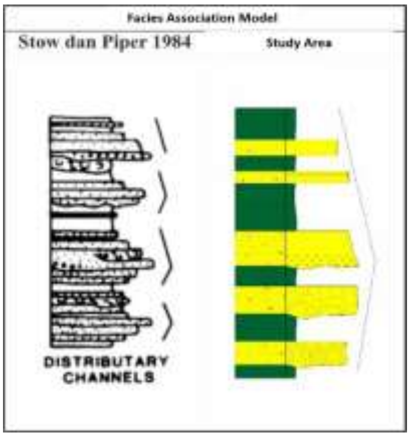

Figure 10. Distributary channel facies association in the research area (Stow and Piper, 1984)

6. Mid-fan/slope channels

This facies association consists of several lithofacies, namely facies 2 (massive sandstone), facies 5 (wavy, cross-laminated, and convoluted sandstone), facies 6 (sandstone and mudstone interbedded), facies 7 (massive mudstone), facies 8 (sandstone and siltstone interbedded), and facies 9 (slump deposits). The characteristics of turbidite deposits with a fining upward pattern indicate a weakening of the turbidite current, the presence of slumps after the sandstone indicates a change in current on the slope. Interpreted deposited in the supra fan near the natural embankment, in the valley between the upper fan and the middle fan (Figure 11).

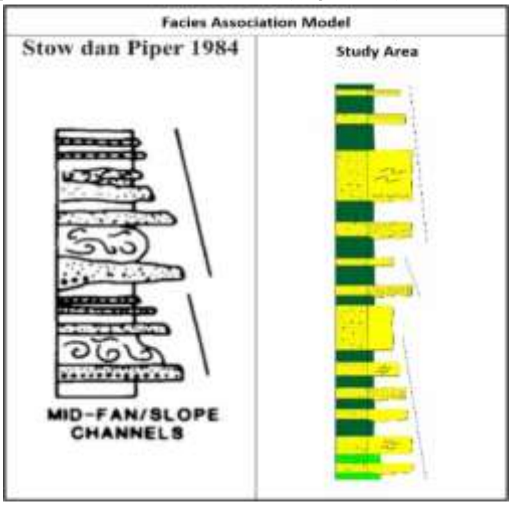

Figure 11. Mid-fan/slope channel facies association in the research area (Stow and Piper, 1984)

E. Depositional Environment

Based on the lithological characteristics and interpretation of the depositional mechanism in the measured stratigraphic cross section, see Figure 19, with reference to the facies model proposed by Walker (1978). The lithology in the exposed Serang River section falls into the classical turbidite (CT), massive sandstones (MS), and pebble sandstones (PS) facies deposited in the middle fan system in the channelled sub-depositional environment - smooth portion of suprafan lobes (Figure 12).

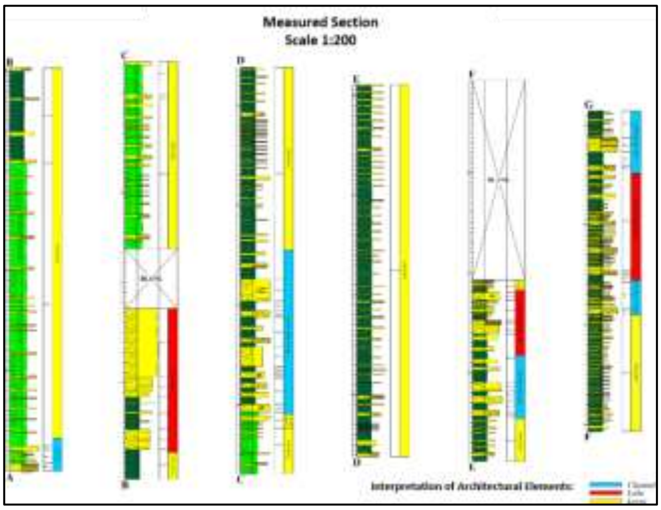

Figure 12. Measured section of research area

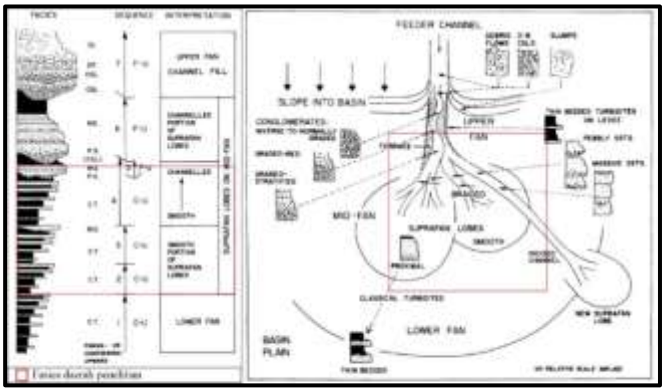

Figure 20. Interpretation of progradation sequences and submarine fan depositional models in the research area (red box) based on Walker, 1978

F. Architecture Model of Research Area

The following is an interpretation of the deep sea environmental architecture model (Walker, 1978) and the location of the deep sea environmental architecture model in the research area (Figure 13).

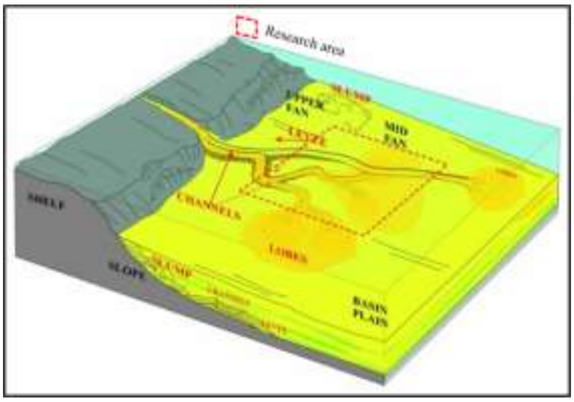

Figure 13. Illustration model of marine depositional environment in the research area (Modified from Walker, 1978).

CONCLUSIONS

The architectural elements obtained from the measured stratigraphic cross-section analysis of the Serang River trajectory consist of 6 facies associations. Each architectural element has a different lithofacies so that the sedimentation process of the facies association of the architectural elements is interpreted to be different but the same deposition in the middle submarine fan depositional environment in the channelled-smooth portion of suprafan lobes.

The results of the analysis and interpretation of measured stratigraphic data are found in the Serang River track of the alternating carbonate sandstone and Kerek carbonate claystone units. The sedimentation process in the research area has two types of deposition processes, namely mass transport deposition (MTD) and turbidite currents in the form of slump and Bouma sequences of the Ta-Te interval. Nine lithofacies were found, namely facies 1 (Pebbly Sandstone), facies 2 (Massive Sandstone), facies 3 (Bedbed Sandstone), facies 4 (Parallel Laminated Sandstone), facies 5 (Wavy, Cross-Laminated, and Convoluted Sandstone), facies 6 (Sandstone and Mudstone Interbedded), facies 7 (Massive Mudstone), facies 8 (Sandstone and Siltstone Interbedded), and facies 9 (Slump Deposits). The architectural elements of the research area include six facies associations consisting of distal levee, silty-sandy distal lobes, sandy lobes, mud-filled channels, distibutary channels, and mid fan/slope channels. In the facies model by Walker (1978), the research area falls into the classical turbidite (CT), massive sandstones (MS), and pebble sandstones (PS) facies which were deposited in the middle fan system in the channelled-smooth portion of suprafan lobes sub-depositional environment.

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REFERENCES

1. Bemmelen, R.W. 1949. *The Geology of Indonesia.* v. IA. The Hague. Gov. Printing Office. Martinus Nijhoff. Amsterdam.
2. Boggs. S., 2006, *Principles of Sedimentology and Stratigraphy Fourth Edition*. University of Oregon
3. Bouma, A.H., 1962, Sedimentology of some flysch deposits: a graphic approach to facies interpretation, Elsevier, Amsterdam, p.48-83.
4. Darman, H., Ralanarko, D., Suryono, S. S., Hartono, H. G., Dwiharso, Syavitri, D., dan Abdurrokhim, 2023, Sandi Stratigrafi Indonesia. IAGI, Jakarta.
5. Martodjojo, S., dan Djuhaeni, 1996, Sandi Stratigrafi Indonesia. IAGI, Jakarta.
6. Nichols, G., 2009, *Sedimentology and Stratigrafi Second Edition*. Wiley Blackwell. United Kingdom.
7. Shanmugam, G., 2012. New Prespective of Deep-Water Sandstone, Amsterdam: Elsevier, Petroleum Exploration Development, 40(3), 316-324.
8. Shanmugam, G. dan Miola, R. J., 1988, Submarine fans: characteristics, models, classification, and reservoir potential. Earth-Sci. Rev., 24: 383-428.
9. Stow, D. A. V., dan Piper, D. J. W., 1984, Deep Water Fine Grained Sediment : Facies Models, Geological Society, London, Special Publications.
10. Sukardi dan B. Budhitrisna, 1992, Peta Geologi Lembar Salatiga 1408-6 skala 1:100.000, Pusat Penelitian Daerah dan Pengembangan Geologi, Bandung.
11. Walker, R.G., 1978, Deep-Water Sandstones Facies and Ancient Submarine Fans: Models for Exploration for Stratigraphic Traps. AAPG. Bulletin., v. 62, p.932-966, Tulsa, Oklahoma.