Three-Dimensional Facies Modeling of Deepwater Fan Sandbodies: Outcrop Analog Study from the Miocene Kerek Formation, Western Kendeng Zone (North East Java Basin)

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ABSTRACT

Kendeng Zone is well known as the main depocenter in the North East Java Basin. It developed as a back arc basin related to Oligo-Miocene volcanic arc and was subsequently filled with thick pelagic and volcanogenic sediments.

This article emphasizes on determination of facies, geometry and distribution of sand bodies within the Miocene Kerek Formation that comprises the western Kendeng Zone. Sedimentological logs and rock samples were collected from outcrop data along river traverses in the study area. The samples were described and characterized by using petrography, paleontology and sedimentology analyses. Three depositional facies were identified, which consist of massive sandstone of submarine lower fan, a lobe of submarine lower fan and pelagic mud deposits.

Statistical analysis was also used to characterize and describe identified depositional facies within the Kerek Formation. Statistically, the geometry consists of (1) pebbly massive sandstones of submarine lower fan (mean distribution of sands bodies: 4.58 km, mean thickness: 0.6 m, length from 3D modeling: 1.58 km); (2) sandstone sheets of submarine lower fan (mean distribution of sands bodies: 2.85 km, mean thickness: 0.08 m, length from 3D fence diagram: 1.26 km); (3) pelagic mud, which is composed solely of thick mudstone lithofacies. In term of reservoir potential, the massive sandstones that have significant amount of porosity would be considered as having the highest potential.

INTRODUCTION

The study area is located in Kedungjati region, Purwodadi, Central Java (Figure 1). Stratigraphically, the area is comprised of four lithologic units (formations) that include (in younger order) Calcareous-sandstone of Kerek Formation, Tuffaceous-sandstone of Banyak Member (Kalibeng Formation), Calcareous-claystone of Kalibeng Formation and Limestone of Kapung Member (Kalibeng Formation) (Figure 2).

North East Java basin, particularly the Kendeng Zone, is located between volcanic arcs at present. The Kendeng Zone was the main depocenter for Eocene-Miocene sediments that are composed of thick turbidite and pelagic sequences (De Genevraye and Samuel, 1972; Smyth et al, 2003 & 2005). The turbidites are recorded in the Miocene age Kerek Formation.

The objectives of this article are to unravel the depositional model, then subsequently construct an understanding of relation between turbidite and reservoir sand bodies based on geometry and distribution pattern of the Kerek Formation. This article emphasizes on outcrop-based study in order to get a comprehensive understanding about deepwater play characteristics in an active margin setting.

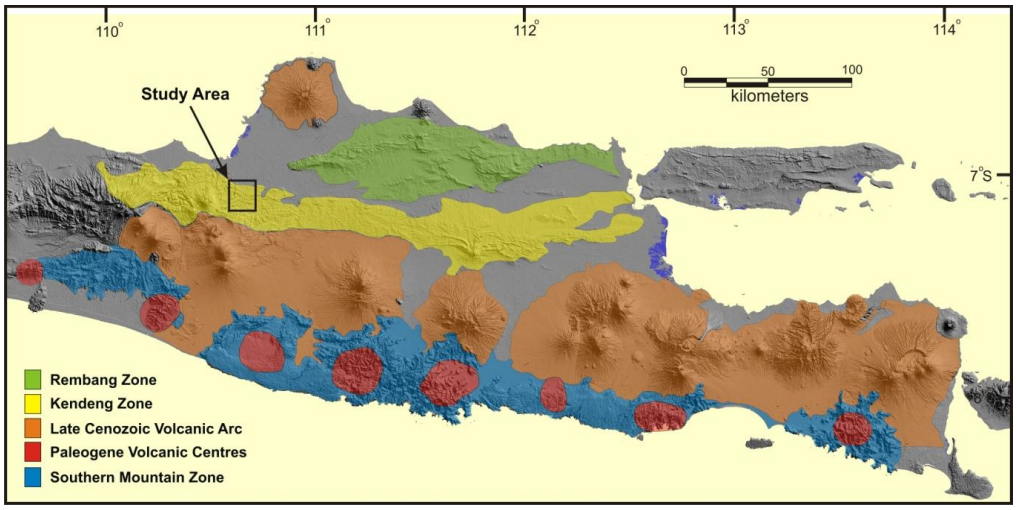


Figure 1. *Digital elevation model (Shuttle Radar Transect Mission) overlain by schematic zonation of East Java. The study area is bounded by black square (modified from Smyth et al, 2003).*

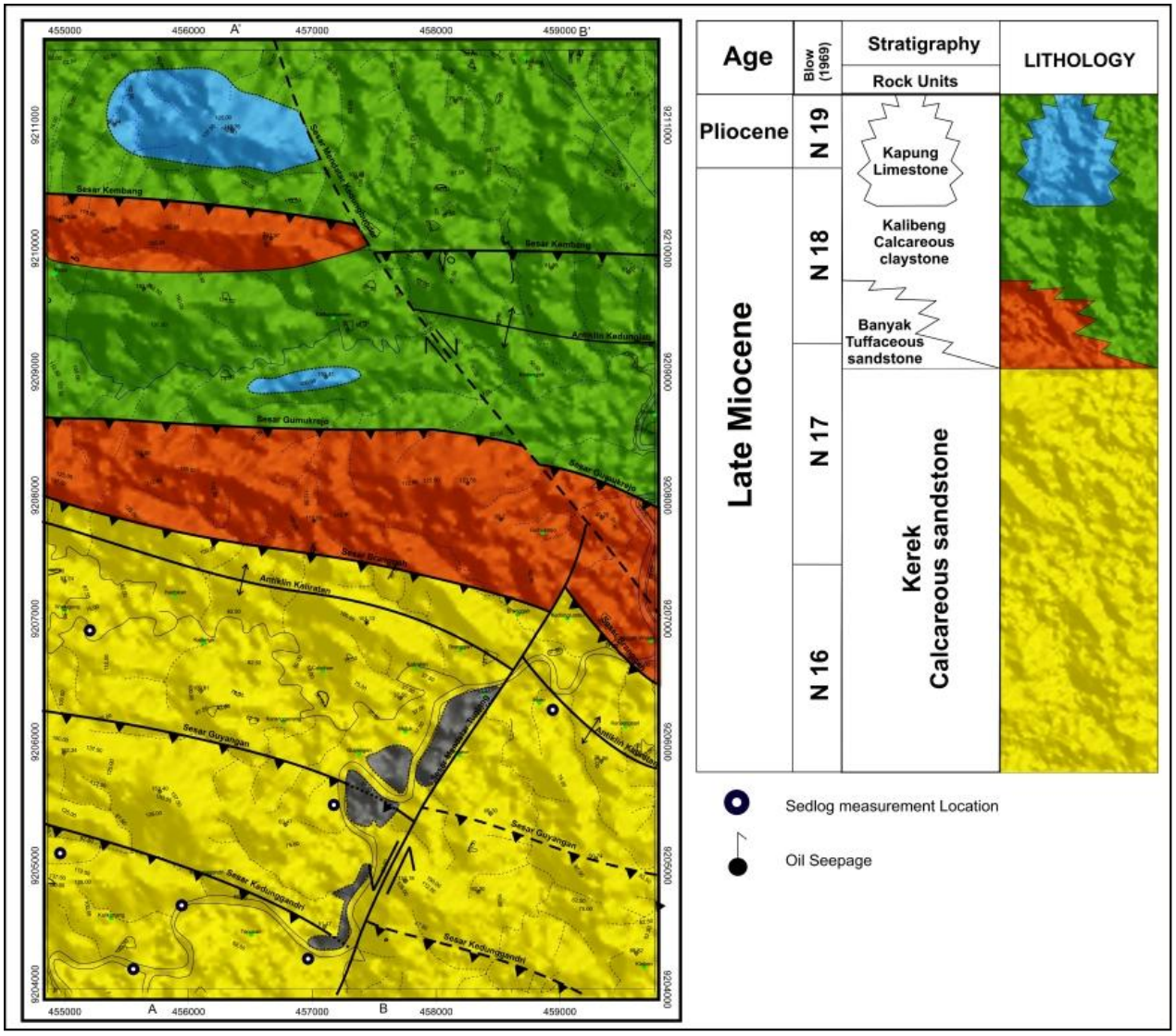


Figure 2. *Simplified geological map of the study area shows four lithostratigraphic units. The calcareous sandstone of Kerek Formation is shown in yellow colour.*

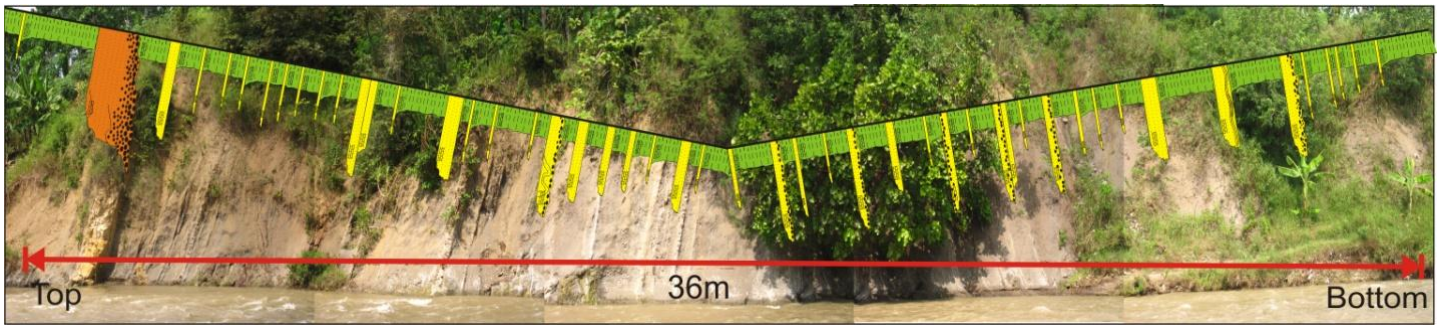


Figure 3. *Outcrop of Kerek Formation with representative KJ 98 sedimentological log along the Tuntang River, Kedung Jati Village.*

METHODS

The study includes outcrop visits to produce sedimentological logs (Figures 3 and 4), geological map and acquire rock samples for laboratory analyses. The laboratory analyses are comprised of petrographical and paleontological analyses. Outcrop data and lab results were then used in geological modeling. The turbidite sandbodies model (Figures 5 and 6) was built by correlating the sedimentological sections (chronostratigraphic correlation), then gridding and layering vertical horizon of sandbodies without involving fault model. All of these steps were done by using standard 3-D geological modeling software package.

FACIES & ARCHITECTURAL MODEL

Interpretation of sedimentological logs taken from the outcrops revealed that their depositional facies are of fan complex, particularly of lower fan system. The lower fan system was formed by accumulation of individual lobe fans and pelagic deposits, which are products of high and low density turbidity current.

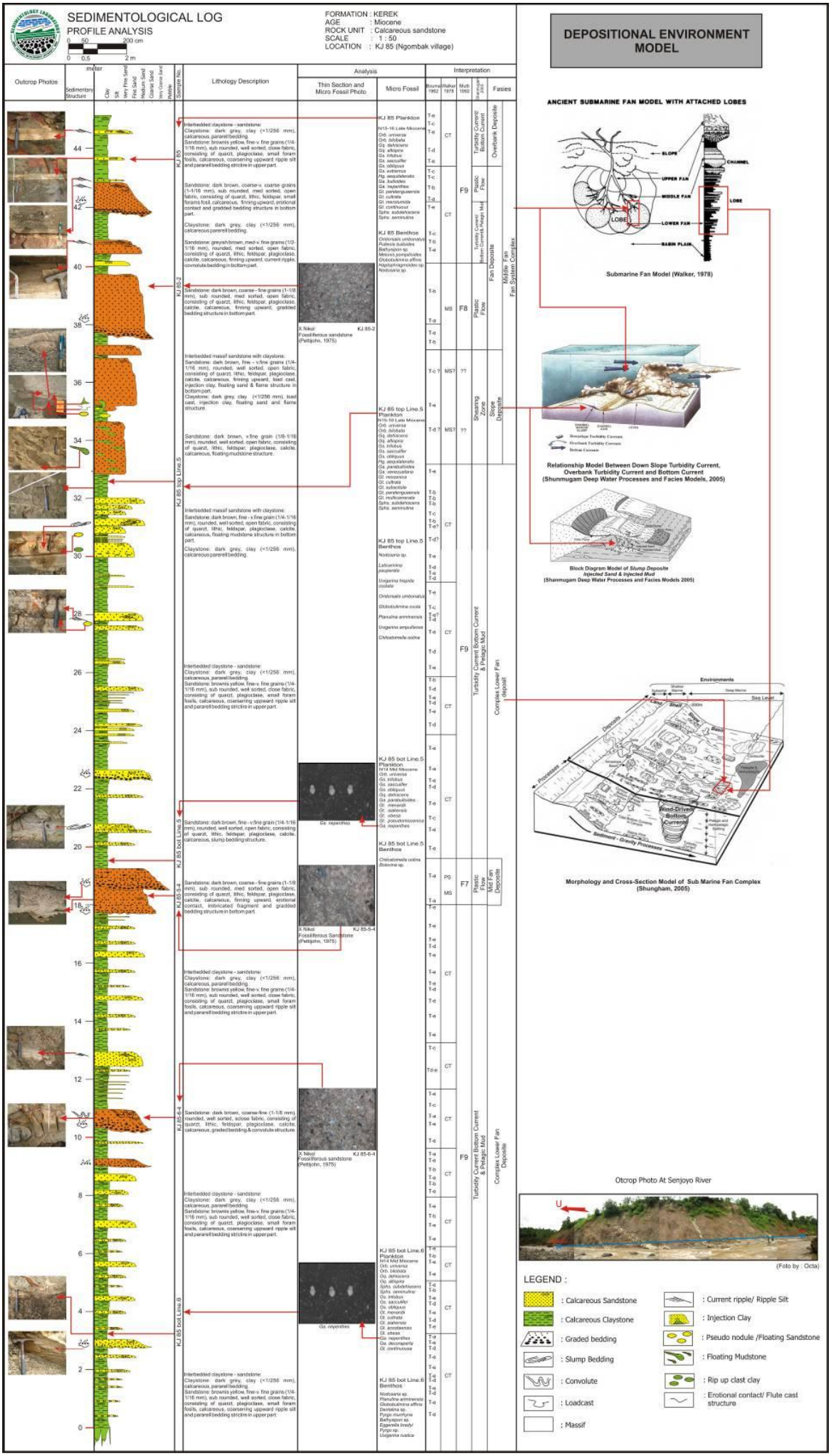


Figure 4. *Sedimentological log of KJ-85 that is composed sheet sandstone of fan lobe in the lower section and gradually change to massive sandstone in the upper section.*

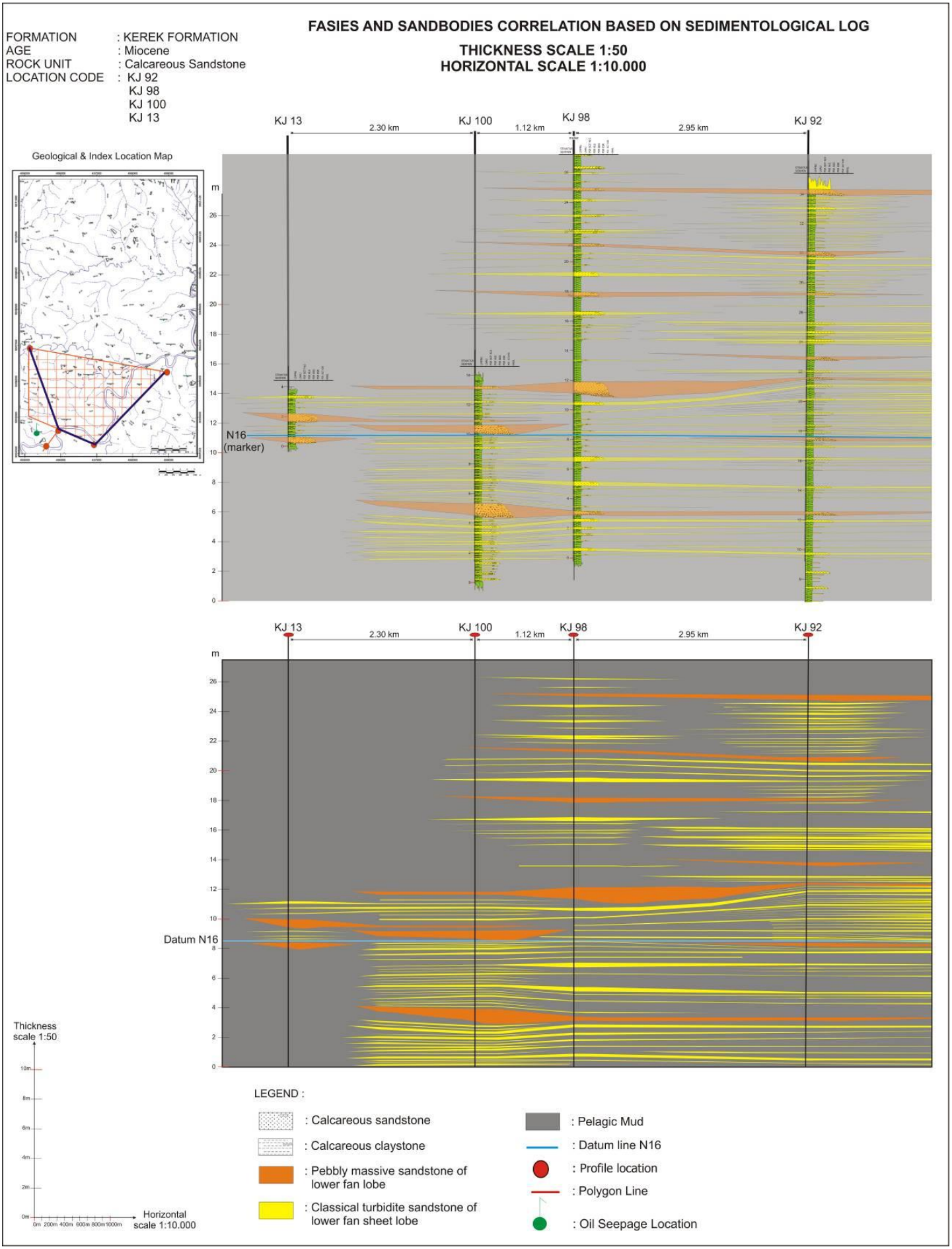


Figure 5. *Correlation section of the sedimentological logs. The section is flattened on N16 marker.*

The characteristic lithofacies comprised in each depositional facies of the lower fan system and its geometry are described below:

a. Pebbly massive sandstone of submarine middle fan

The massive sandstone of lower fan deposit typically consists of some lithofacies that combine together. Massive coarse sandstone with erosional base contact dominates the lower portion of the deposit. Gradually normal graded sandstone and stratified pebbly sandstone occur on several places as a remark of temporary hydraulic change of the current. Stratified medium-grained sandstone cap the upper part of the deposit. The entire package shows a fining upward stacking pattern. Such combination of features is interpreted as the result of high density turbidity current that occurs on a fan. The process began with initial high density and velocity of the current allowed for the transportation and deposition of coarse-grained materials. As the current kept distributing the materials to another part of the system, finally on the upper part of the deposit, finer-grained (stratified medium-grained sandstone) are more dominant. The results of 2D correlation and 3D modeling show that the mean thickness and sand body distribution are 0.6 m and 4585.6 m, respectively. The minimum thickness and distribution of sand bodies are 0.25 m and 1403 m, respectively. The length of the fan as inferred from a single representative lobe is 1580 m (Figure 8).

b. Sandstone sheets of submarine lower fan

This deposit consists of several lithofacies that can be easily classified by using Bouma sequence classification (Ta-Te) [Bouma, 1962]. Intercalation of graded sandstone with erosional contact (Ta), convolute sandstone (Tc), parallel laminated siltstone (Td), and stratified mudstone (Te) occur monotonously all over the deposit. Thin bed of convoluted lamination sandstone also occurs simultaneously with another lithofacies, which provides evidence for low density turbidity current. This is due to the current become less dense and the velocity of the current become less unable to distract semiplastic sediments (Bouma, 2000). It has been widely accepted that convoluted lamination is the result of distraction of current on semiplastic sediments, therefore low density turbidity current produce thin or even no convolute structure (Shanmugam, 2005). The result of 2D correlation analysis shows that the mean thickness and distribution of sand bodies are 0.08 m and 2855.4 m, respectively, with the minimum thickness and deployment of sand bodies being 0.02 m and 1011 m, respectively. The length of the fan, as inferred from a single representative middle fan is 1264 m.

c. Pelagic mud

This deposit consists solely of thick mudstone lithofacies. Pelagic mud is the result of suspension process that occurs in almost all deep sea setting.

PALEOCURRENT ANALYSIS

Paleocurrent direction can be identified from a variety of erosional structures such as tool mark, grove cast and flutecast. In the study area, paleocurrent direction was analysed from flute cast structures. The flute cast structure measurements indicate that the main trend of sediment supply moving from north to south with average direction of N 144o E (NW-SE) (Figure 6).

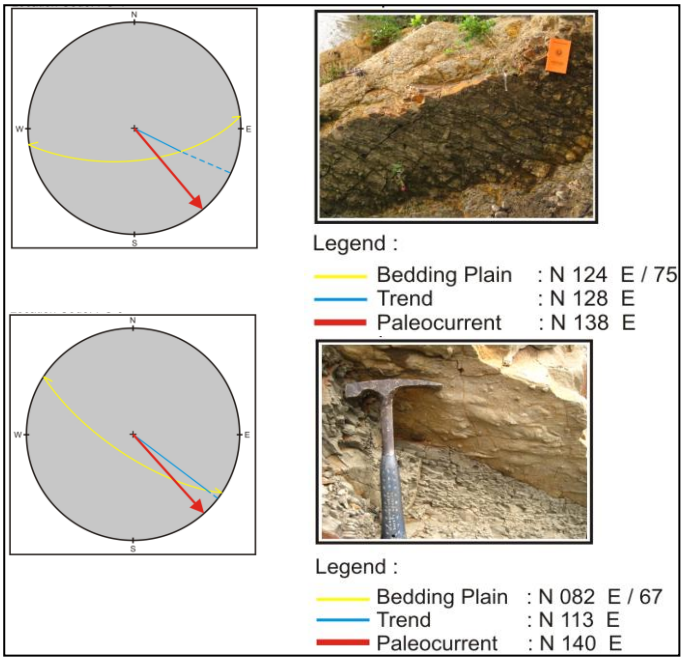


Figure 6. *Paleocurrent analysis as measured from grove (top) and flute cast (bottom) structures yielded NW-SE depositional trend.*

DISCUSSIONS AND CONCLUSIONS

The unique characteristic possessed by turbidite sediments in the Western Kendeng Zone is that they are part of fan lobe complex and encompasses mixed sand and mud with overall coarsening upward stacking pattern. Tectonically, turbidite deposits within the Kendeng Zone and its vicinity are quite different due to the active margin and volcanic arc setting. Kendeng zone as the main depocenter received a lot of sediment contribution from Southern Mountain Zone to the south and Rembang zone to the north.

Therefore these turbidite sequences predominantly composed mixed of siliciclastic, volcaniclastic and even carbonate content (Smyth et al, 2005; Subroto et al, 2007). Paleocurrent analysis shows that sand supply came from the NW towards SE, most likely from Rembang High and was deposited into Kendeng low. The 3D modeling could depict the architectural element of deep water fan complex, focusing on sandy facies formation that

has a significant implication to reservoir geometry (Figure 7). Middle fan sandstones are rarely found in the study area, as only 10 out of 130 sand bodies were identified as middle fan deposit whose thin section results showed that they are wacky sandstones. The thickness slice of 3D modeling yields the mean thickness-width ratio of massive sand bodies 1:1300 m, with porosity of around 0.03 to 0.15. Therefore, it is mostly considered to be a precisely analog of turbidite reservoir in the Western Kendeng. There are 120 existing sand bodies in the study area which are interpreted as part of the lower fan lobe. They are composed of a thin sheet sands interbedded pelagic mud with mean thickness-width ratio analyses from horizontal slice of 3D sandbodies modeling 1 : > 2000 m. However, lower fan sands have not been considered eligible to be reservoir analog due to poor rock property values (porosity ranges from 0.01 to 0.05), quite thin sand and rich in clay mineral (Figure 8).

Deep water processes in western Kendeng Zone has produced a variety of stacking turbidite sands. Two-dimensional correlation reveals fan lobes switching in this area. They have compensational stacking character which fans are vertically migrated due to high accommodation space with balanced sedimentation rate (Mutti and Davoli, 1992). Meanwhile the sheet sands are significantly retrogradely-stacked in lower Kerek Formation, which are continuously-distributed to overall area, and they represent lower fan lobe sands, although in some place only a half part of the lobes is discovered. It probably proves the lobe geometry is greater than expected during study. Beside in the upper part of the Kerek Formation, the sand lobes tend to be thinner and smaller. This study might be useful to provide turbidite reservoir analogue model for subsurface application and for future hydrocarbon exploration in the western Kendeng Zone.

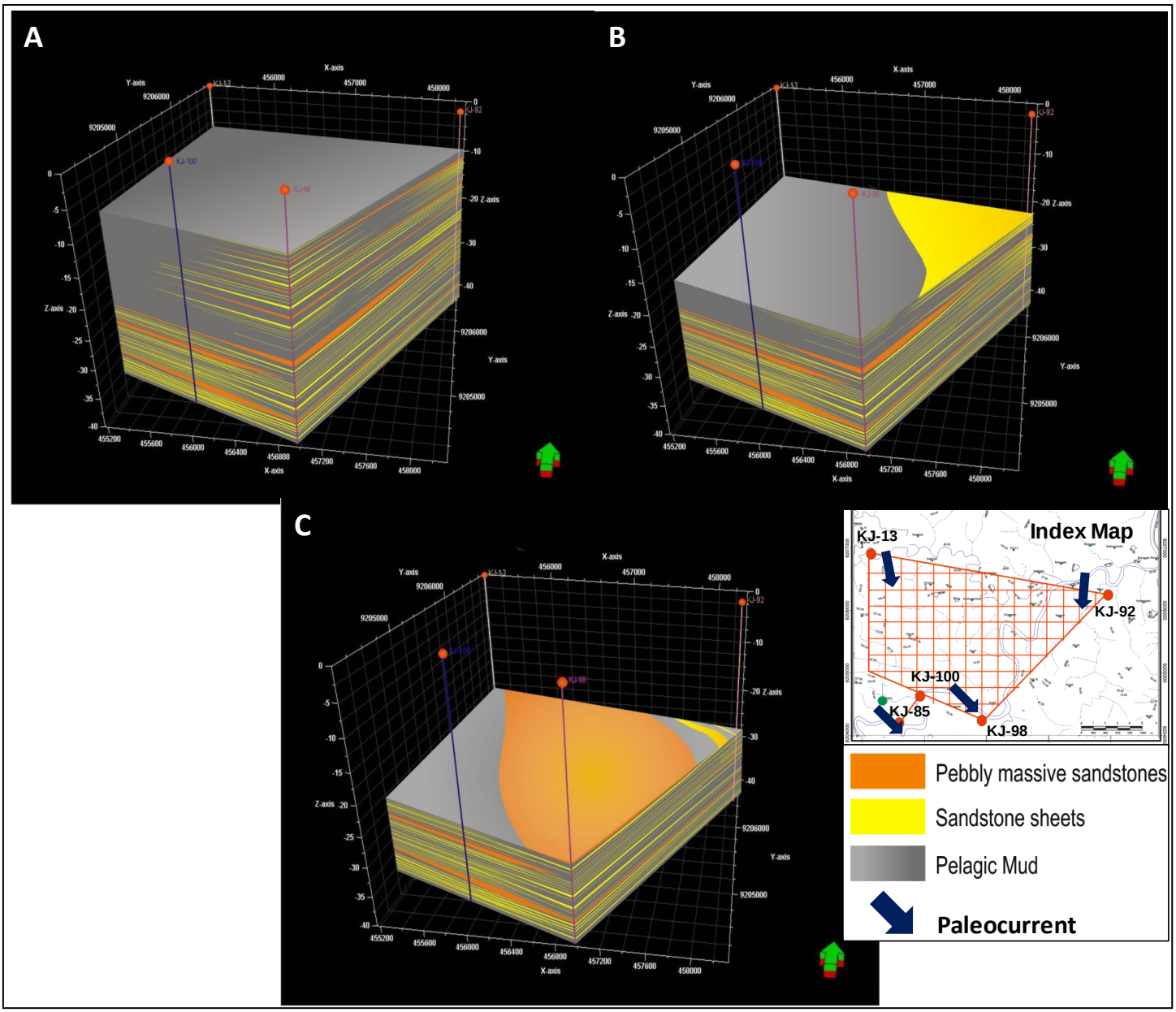
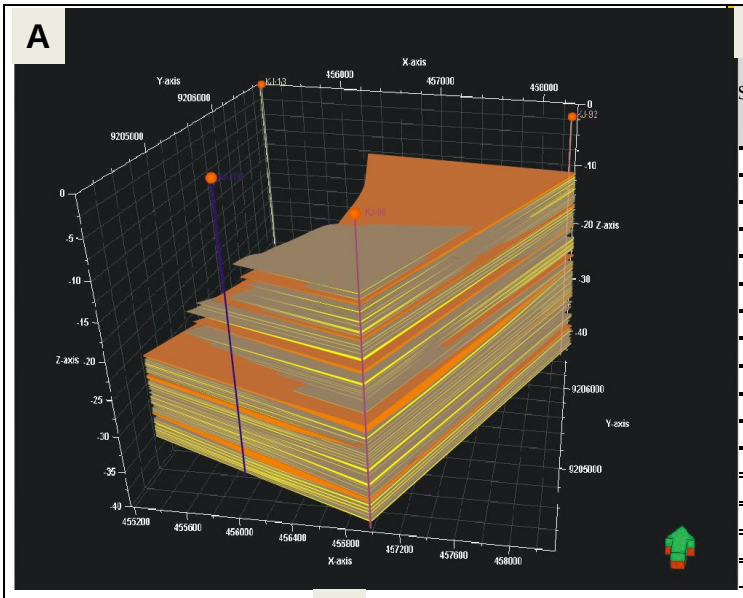


Figure 7. *A) 3D model showing the succession of deepwater fan facies sandbodies. B) Thickness-oriented slice within sandstone sheets of lower fan lobe and C) Thickness-oriented slice of pebbly massive.*



B

Massive Sandstone Fasies Geometry

Sandstone Layer	Based on 2D Corelation		Based on 3D Fance Diagram
	Thicknes (m)	Distribution of sands bodies (m)	Length (m)
1	0.5	5800	
2	0.46	5310	
3	0.45	5316	
4	0.35	3645	
5	1.2	7310	
6	0.65	3950	
7	0.68	2845	1580
Datum N16			
8	0.53	1403	
9	0.25	3012	
10	1	7265	
Mean	0.607	4585.6	
Median	0.515	4630	
Modus	-	-	
Max	1.2	7310	
Min	0.25	1403	

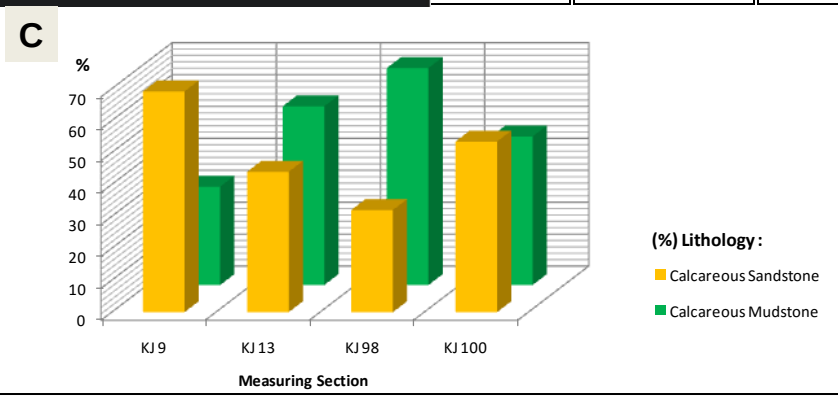


Figure 8. *A) 3D sandbody modeling. B) Example statistics of massive sandstone facies sandbodies. C) Sand-shale percentage from several sedimentological logs.*

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