Reservoir quality derived from routine core analysis data of deep-water turbidite outcrop analogue

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Abstract. Turbidity current is a process where the fluid flows occurs as a turbulent flow where the molecules inside the fluid are moving randomly but with a net movement toward the orientation of the transport. The physical properties of turbidite deposit is highly impacted by the grain size distribution and rock texture during the deposition. The field in this study was an outcrop of Jatiluhur Formation which deposited by turbidity current on deep marine environment. The main goal of this study was to understand the correlation between the petrophysical properties of turbidite deposit with its depositional mechanism using the routine core analysis method. The samples in this study were collected from an outcrop and the routine core analysis data contains the percentage value of porosity and vertical permeability. The result of this study were the porosity was relatively equal to the permeability and depositional mechanism had a significant role in controlling the porosity and the permeability.

Keywords: Deposition, petrophysical, permeability, porosity, turbidity

1. Introduction
Turbidity current is a process where the fluid flows occurs as a turbulent flow where the molecules inside the fluid are moving randomly but with a net movement toward the orientation of the transport. Moreover, dilute mixtures of sediment and water moving as mass flows under gravity is the most important mechanism for moving coarse clastic material in deep marine environments [1]. These turbidity currents carry variable amounts of mud to gravel tens, hundreds and even over a thousand kilometers out into the deep seafloor [2]. Turbidite deposit has a specific sedimentary structure such as massive graded to parallel lamination. Other sedimentary structures can also be formed such as ripple and cross lamination [3]. Furthermore, some of these deposits are generally poorly sorted due to its high velocity transport mechanism [4]. In addition, the physical properties of turbidite deposit is highly impacted by the grain size distribution and rock texture during the deposition [5].

In the study area, the Jatiluhur Formation was deposited by turbidity current located on a slope-shelf system. This formation reflects the under unit of the mid-earliest late Miocene sedimentary layers that outcropped in the Bogor Trough. Moreover, the Jatiluhur formation was assembled all along a period of collapsing- and lowstand stages in relative sea level [6]. This deposit were outcropped on the banks of Cipamingkis River, Bogor with a form of interconnected lobe (figure 1).

The petro-physical properties of turbidite deposits that were either in subsurface condition or outcropped were hardly understood due to its limitation on modern analogues availability. Jatiluhur Formation that was perfectly outcropped was the best location to study its petro-physical properties.
There were several methods to find out the reservoir quality of turbidite deposit such as seismic method to routine core analysis [7]. The routine core analysis has a significant role during this process to understand the reservoir quality [8]. The aim of this study was to understand the correlation between the petro-physical properties of turbidite deposit with its depositional mechanism using the routine core analysis method from outcropped Jatiluhur Formation.

The initial hypothesis of this study was a process during deposition had an influence to the petro-physical properties of a sedimentary rock. Based on its character of depositional mechanism, turbidite deposits were formed by high velocity at the bottom of the turbidity current, coupled with lower velocity current on its top. Due to this character, settling velocity for a specific grain size could be expected to be higher at the bottom of a current and vice versa to its top. Bigger grain size would have the tendency to be deposited at the bottom of a turbidite deposit by a bed load mechanism, while finer grain size would be deposited later on by a suspended mechanism. This depositional pattern would trigger higher porosity and permeability value at the bottom compare to its top. Meanwhile, at the top of channel, the finer sediment would be deposited due to the particle moves in suspension (suspended load) hence it tends to have poor porosity and permeability (figure 2) [9].

![Figure 1. Outcrop of Jatiluhur Formation at Cipamingkis River, Bogor.](image)

![Figure 2.](image)

(a) The relations between flow height and sediment concentration.
(b) The relations between velocity and height above bed.
2. Data and method
The data in this study was obtained from an outcrop of Jatiluhur Formation at Cipamingkis River, Bogor, West Java Province. This outcrop was composed by fine to very-fine grained sandstone and intercalated siltstones with inverse and normal grading structure, although there were ripple-cross lamination and parallel lamination structure locally. Furthermore, there were intensely bioturbated with Thalassinoides-type burrows. The inverse-normal grading structure indicated an overall increase-to-decrease in flow rate associate with the depositional event of intermittent multiple, which may have been inferred by the currents of fluctuating bottom.[10].

Five samples (B1–B5) were used in this study. The five samples were collected from a channel or a lobe of turbidite deposit (figure 3). Each sample were collected at the midpoint and at the edge of the channel. Sample B1 and B2 were collected at the edge of the channel. Meanwhile, sample B3, B4, and B5 were collected from the midpoint of the channel. Sample B3 was collected at the middle, B4 at the bottom, and B5 at the top respectively.

The routine core analysis (RCAL) were done from the available sample to measure its petrophysical properties such as porosity and vertical permeability. The porosity was obtained by measuring helium grain volume and grain density at constant pressure of 300 psi. So, the product of pressure and volume in a closed system remains constant or \( P_1V_1 = P_2V_2 \) (Boyle’s Law). Helium was used as gas in all grain volume experiments because it is the ideal gas at ambient conditions, is inert and has a very small molecular size so that it can penetrate all the accessible pores in a rock. The permeability was obtained by injecting helium at constant pressure of 300 psi to the core plug accordance to Darcy’s equation [11].

3. Results and discussion
The differences in porosity and permeability value from samples B1 to B5 were obtained from the RCAL (table 1). Specific reservoir quality could be addressed from the relationships between the different petro-physical parameters. This relationship showed that the porosity was relatively equal to the permeability. The higher porosity resulted in the higher permeability value (figure 4). The relation had the form:

\[
y = 0.013x - 0.0375 \quad (R^2 = 0.8115)
\]

y axis is the value of permeability, x axis is the value of porosity, and the gradient (m) is 0.013 positive.

Figure 3. Sketch an outcrop of Jatiluhur Formation at Cipamingkis River, Bogor.
The porosity and permeability were affected by height above the bottom or bed during the process of deposition. The velocity and the transportation mechanism were the main control of it. The higher velocity results the coarser grain of sediment would be deposited due to its settling velocity. The coarser sediment tended to have more chaotic sortation producing higher porosity and permeability value. In contrary, the finer grain sediment would be deposited in suspensions which made it very tight. This theory was justified by the RCAL result. This relationship showed that the porosity was inversely proportional to the height above the bed (figure 5a). The lower height above bed results in higher porosity. The relationship between porosity and the height above bed has the form:

\[ y = -0.4427x + 3.9414 \quad (R^2 = 0.7549) \]

y axis is the height above the bed, x axis is the value of porosity, and the gradient (m) is 0.4427 negative.

While the relationship between permeability and the height above the bed was quite similarly inverse proportional compared to the previous equation. The relationship between permeability and the height above bed has the form:

\[ y = -25x + 2.3 \quad (R^2 = 0.5) \]

y axis is the height above the bed, x axis is the value of permeability, and the gradient (m) is 25 negative.

This relation showed that the permeability was inversely proportional to the height above the bed (figure 5b). The lower height above bed results in higher permeability. Overall, it could be concluded that the porosity and the permeability value increased when the height above bed decreased (figure 6).

![Figure 4. The relationship between porosity and permeability for an outcrop of Jatiluhur Formation.](image)

Table 1. Values of the petro-physical properties from an outcrop of Jatiluhur Formation.

| Sample | Porosity (%) | Permeability (mD) |
|--------|--------------|-------------------|
| B1     | 5.43         | 0.02              |
| B2     | 5.18         | 0.03              |
| B3     | 5.89         | 0.05              |
| B4     | 8.37         | 0.07              |
| B5     | 4.96         | 0.03              |
Figure 5. The relations between porosity and permeability to the height above bed from Jatiluhur Formation, (a) Porosity-height above the bed relationship, (b) Permeability-height above the bed relationship.

Figure 6. The relations between porosity, permeability, and the height above bed at the point of sampling for an outcrop of Jatiluhur Formation.

4. Conclusion
The study of RCAL of turbidite deposit for an outcrop of Jatiluhur Formation revealed their petrophysical properties relationship with the mechanism of turbidity current. Porosity and permeability value on a turbidite deposit had positive correlation. Increasing value of porosity tended to increase the permeability value also. While its depositional mechanism had a significant role of its petro-physical properties. Transportation mechanism of bed load and suspended load inside a turbidity current had a significant impact of their porosity and permeability value.

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