Laser Particle Size Analysis (LPSA) approachment for Depositional Environment and Hydraulic Flow Unit (HFU) determination in Keutapang Formation, Rantau Field (North Sumatera Basin) and Air Benakat Formation, Tempino Field (South Sumatera Basin)

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Abstract: Keutapang Formation deposited in North Sumatra Basin at the mid to late miocene on regression phase. Air Benakat Formation deposited in South Sumatra Basin, has similar characteristic with Keutapang Formation which deposited in the regression & compressional phase near the same age. The purpose of this study is to know the relationship between Laser Particle Size Analysis (LPSA) and Depositional Environment to include Hydraulic Flow Unit (HFU) in each Formation to help reservoir characterization process and rock type determination. Laser Particle Size Analysis results show that both formations have grain size from 11 to 160 μm in other words is very fine sand (wentworth scale). Sorting ranges from 1.5 to 2.4Ø which is classified as poorly sorted to very poorly sorted. Skewness ranges from -0.091 to 0.658 Ø grouped into near symmetrical, fine, and very fine skewness. Kurtosis ranges from 0.686 to 1.102 Ø grouped into very platy kurtic, platy kurtic, and mesokurtic. Based on the Linear Discriminate Function (LDF) method, by evaluating the values of Y1, Y2, Y3 and Y4, it describes that both formations are deposited on the Deltaic Environment with Shallow Agitated Water and dominated by traction currents.

1. Introduction
Air Benakat Formation in South Sumatra basin and Keutapang in Sumatra Basin have similar age, which was deposited in the regression & compressional phase near the same age. Although both Formations have different basin, but regionally, both Formations has the almost same depositional environment.

1.1. Grain Size Analysis
Grain Size is important properties at siliciclastic sediment that geologist have to identify first to understand depositional process & environment to include hydrodynamic process. This analysis is used to characterize sediment properties, classify, depositional environments and also make some clues for transportation mechanism.
Laser Particle Size Analysis is a technology for identifying grain size of clastic sedimentary rock. Laser diffraction measures very small particle (0.5 – 1000 microns), when laser beam passes a dispersed particle, it could measure angular variation of particle. Rock Size can be categorized by Wenworth Scale below.

**Table 1. Wenworth Scale**

| Diameter (mm) | Diameter (μm) | phi | Wenworth size class   | Rock type            |
|---------------|---------------|-----|-----------------------|----------------------|
| 4995          |               | 12.0| Boulder               | Conglomerate/Breccia |
| 256           |               | 8.0 | Gravel               |                      |
| 64            |               | 6.0 | Pebble               |                      |
| 4             |               | 4.0 | Granite              |                      |
| 2.50          |               | 2.0 | Very coarse sand     |                      |
| 1.00          |               | 1.0 | Coarse sand          |                      |
| 0.50          |               | 0.5 | Medium sand          |                      |
| 0.25          |               | 0.25| Fine sand            |                      |
| 0.10          |               | 0.10| Very fine sand       |                      |
| 0.0625        |               | 0.0625| Very coarse silt   |                      |
| 0.0311        |               | 0.0311| Coarse silt        |                      |
| 0.0166        |               | 0.0166| Medium silt        |                      |
| 0.0156        |               | 0.0156| Fine silt           |                      |
| 0.0078        |               | 0.0078| Very fine silt      |                      |
| 0.0039        |               | 0.0039| Coarse silt        |                      |
| 0.0017        |               | 0.0017| Fine silt           |                      |
| 0.00096       |               | 0.00096| Very fine silt    |                      |
| 0.00096       |               | 0.00096| Coarse silt       |                      |
|               |               | 0.00096| Fine silt            |                      |
|               |               | 0.00096| Very fine silt      |                      |
|               |               | 0.00096| Coarse silt        |                      |
|               |               | 0.00096| Fine silt           |                      |
|               |               | 0.00096| Very fine silt      |                      |
|               |               | 0.00096| Coarse silt        |                      |
|               |               | 0.00096| Fine silt           |                      |
|               |               | 0.00096| Very fine silt      |                      |
|               |               | 0.00096| Coarse silt        |                      |
|               |               | 0.00096| Fine silt           |                      |
|               |               | 0.00096| Very fine silt      |                      |
|               |               | 0.00096| Coarse silt        |                      |
|               |               | 0.00096| Fine silt           |                      |
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|               |               | 0.00096| Fine silt           |                      |
|               |               | 0.00096| Very fine silt      |                      |
|               |               | 0.00096| Coarse silt        |                      |
|               |               | 0.00096| Fine silt           |                      |
|               |               | 0.00096| Very fine silt      |                      |
|               |               | 0.00096| Coarse silt        |                      |
|               |               | 0.00096| Fine silt           |                      |
|               |               | 0.00096| Very fine silt      |                      |
|               |               | 0.00096| Coarse silt        |                      |
|               |               | 0.00096| Fine silt           |                      |
| Mean is the average value of grain size. In general, this grain size is expressed in phi or in mm. Median is the size of the particle right in the middle of the population, which means that half of the overall weight of the particle is finer while the other half is rougher than the grain size. Median can be seen directly from the cumulative curve, ie the value of phi at the point where the cumulative curve cuts the value of 50%. Sorting is the standard deviation value of grain size distribution (distribution of values around the mean). Kurtosis shows the comparison value between the centering of the section on the edge of a curve. To determine the value of Kurtosis, the formula proposed by [2] is used. Skewness states the degree of inequality of a curve. If Skewness is positive, the sediment has more coarse grain numbers than the fine numbers of grain and vice versa. To process the data for analysis, combining data to several curves can show the relationship and characterize facies of reservoir using Linier discriminate function (LDF) method as described on Materials and Methods.

1.2. Hydraulic Flow Unit

The Hydraulics Flow Unit, according to [3], can be defined as a volume that represents the total volume of reservoir rock which includes geological properties, whereas this property controls the flow of fluid that is internally different and can be estimated with other physical rocks. So, the flow unit is distinguished based on petrophysical properties and certain geological parameters. The primary parameter that influences fluid flow is the pore geometry attribute. In turn, the pore geometry is influenced by its mineralogy (type, location and overflow) and texture of the rock (grain size, grain shape, sorting and packing)[4]. The approach by using the concept of average hydraulic radius (mean hydraulic radius, rm) becomes a model to correlate porosity, permeability, and capillary pressure with the equation shown below.

Eq-1: $R_{hm} = \frac{\text{Surface Area Wet Parameters}}{\text{Water Volume Wet Surface Area}}$

For the pore throat is cylindrical tube model can use the equation:

Eq-2 $R_{hm} = \frac{r}{2}$

By developing this concept, Kozeny and Carman wrote the following permeability equations:

Eq-3 $0.0314 \sqrt{\frac{K}{\phi}} = \frac{2e}{1-6e} \left[ \frac{1}{\sqrt{535\phi v}} \right]$

Based on the concept above, it deliver equation of Reservoir Quality Index,

Eq-5 $RQI = 0.0314 \sqrt{\frac{K}{\phi}}$

Porosity-Z or pore-volume to grain-volume ratio is described by equation,
\[ \varnothing z = \left[ \frac{\varnothing e}{1 - \varnothing e} \right] \]

Flow Zone Index (FZI), could be described by equation below,
\[ FZI = \left[ \frac{1}{\sqrt{\varnothing FSI \varnothing qv}} \right] = \frac{RQI}{\varnothing z} \]

Then, Hydraulic flow units can be computed by equation below,
\[ HFU = \text{Round}(\ln(FZI), 2 + 10.6) \]

The relationship between HFU and Grain Size could be described by simple cross plot of them.

2. Materials and Methods

Samples that used in this study consist of two different fields, there are Rantau and Tempino Fields. Each of them was deposited in two different basins, but still deposited in the same tectonic phase, and the same relative age. Number of samples from Rantau Field is 22 samples from 2 different wells, while for Tempino Field are 26 samples from 3 different wells.

Figure 2 show that both of formation sample have poorly to very poorly sorted and different in sizes sediment that lead to interpretation of near source and deposited quite fast. Most of the Air Benakat Formation and Keutapang sandstones formation are very fine grained and poorly sorted, it show a long time in transporting and change in sizes because of the grain interaction. The plot of sorting vs mean shows clustering of samples in smaller size of the grains (Figure-02). With this samples plot, grain size and sortation of samples as result of traction and suspension in sedimentary environment

The plot of kurtosis vs skewness of samples population is a useful tool for describing depositional environments. Kurtosis vs skewness graphic plot shows that Keutapang and Air Benakat Formation samples are very platykurtic to mesokurtic with mostly fine symmetrical (Figure-03). Values differences in kurtosis which is out of population imply that sortation was achieved from different source in a high energy environment. Populated samples from both formation in the normal curve area show as picture of sand-silt mix and nearly pure sand texture (Figure-03).

2.1. Linier Discriminate function (LDF)

Depositional environment and processes seems to have a good correlation with variation of energy and fluidity factors during/prior to sediment deposition using statistical analysis for interpretation. To discriminate processes and depositional environment, linier discriminate function was used where Y1 describing shallow agitated water - beach, Y2 for beach - shallow marine, Y3 for shallow marine, deltaic or lacustrine and Y4 to describe turbidity and deltalic.

For shallow agitated water (SA) and beach (B), equation below was applied:
\[ Y_1(\text{SA:B}) = -3.5688M + 3.7016r^2 - 2.0766SK + 3.1135KG \]

If \( Y_1 < -2.7411 \), it represent “shallow agitated water” and if \( Y_1 > -2.7411 \), would be “beach” environment.
Equation below was used to separate beach (B) and shallow marine (SM).

\[ Y_{2(B:SM)} = 15.6534M + 65.7091r^2 + 18.1071SK + 18.5043KG \]

If \( Y_2 < -63.3650 \), it represents “beach” and if \( Y_2 > -63.3650 \), it show “shallow marine”. To separate shallow marine (SM), deltaic or lacustrine (L), equation below was applied:

\[ Y_{3(SM:F)} = 0.2852M - 8.7604r^2 - 4.8932SK + 0.0482KG \]

If \( Y_3 > -7.4190 \), it represents “shallow marine” and if \( Y_3 < -7.4190 \), it shows that the environment is “deltaic or lacustrine”.

To separate deltaic (D) and turbidity current environment, equation below was applied:

\[ Y_{4(F:T)} = 0.7215M - 0.4030r^2 + 6.7322SK + 5.2927KG \]

If \( Y_4 < 9.8433 \), it represents turbidity current deposition and if \( Y_4 > 9.8433 \), it shows deltaic deposition.

\( M, r, SK, \) and \( KG \) as variable of mean grain size, sortation, skewness and kurtosis.

As result of mentioned linear discriminate functions (\( Y_1, Y_2, Y_3 \) and \( Y_4 \)) for the Air Benakat Formation and Keutapang Formation, we can conclude that the depositional environment for both formations were influenced by Beach or Shallow Agitated water as described in crossplot of \( Y_1 \) and \( Y_2 \) below:

![Figure 3. Y1 and Y2](image)

![Figure 4. Y3 and Y4](image)

Based on the \( Y_3 \) and \( Y_4 \) crossplot, all the samples from Air Benakat and Keutapang Formations are deposited on deltaic system. According to both crossplot it describes that both formations are deposited on the Deltaic Environment with Shallow Agitated Water and dominated by traction currents.

2.2. Relationship between Grain Size and Hydraulic Flow Units

As we state in introduction, Hydraulic flow unit can be defined as a volume that represents the total volume of reservoir rock which includes geological properties, whereas this property controls the flow of fluid that is internally different and can be estimated with other physical rocks. To calculate the HFU, we use the equation at Eq-5 to Eq-8 that mentioned.

Difficulties in geological modeling process comes when there is no relationship between log analysis properties (which will be distributed) with HFU (from core data analysis). With LPSA data, we can obtain a linear (indirect) relationship between grain size and the shale volume on the same rock geometry. This relationship can be used to distribute HFU values by using a plot of grain size with HFU or Flow Zone Index. Figure-06 and Figure-07 show that the grain size on Air Benakat and Keutapang Formation have relationship to Vshale. This is a good clue to solve the relationship problem to distribute the Hydraulic Flow Unit in the geological model. The relationship between Vshale anda Grain Size was shown in Eq-12 and Eq-13.
Fig. 5. V shale vs Grain Size of Air Benakat Formation Sample

Eq-12:  Grain size = -97.6 (V shale) + 132.4

Eq-13:  Grain size = -96.4 (V shale) + 79.6

To make a further solution, we try to make a crossplot the Grain Size with Hydraulic Flow Unit & Flow Zone Indicator (FZI) properties that have calculated by equation at Eq-7 and Eq-8.

Fig. 7. FZI vs Grain Size of Air Benakat Formation Sample

Eq-14:  HFU = 0.015 (Grain Size) + 9.95

Eq-15:  HFU = 0.0107 (Grain Size) + 10.195

According to crossplot of FZI and HFU vs Grain Size above, shows that the Hydraulic Flow Unit have a relationship with grain size of Air Benakat Formation follows the equation Eq-14 and crossplot FZI and HFU vs Grain Size below, shows that Hydraulic Flow Unit have a relationship with grain size of Keutapang follows the equation Eq-15.

Fig. 9. FZI vs Grain Size of Keutapang Formation Sample

Fig. 10. HFU vs Grain Size of Keutapang Formation Sample

Equations in Eq-12 to Eq-15, could be used to make a HFU model using Vclay Modeling, Grain Size Modeling and finally the HFU modeling. This workflow might more explainable and
useful to determine properties rock type and permeability transform. And this relationships could be used to another field in the same formation targets with Keutapang and Air Benakat Formation, if there are no data about the grain size.

3. Conclusion
   a. Keutapang Formation deposited in North Sumatra Basin at the mid to late miocene on regression phase. Air Benakat Formation deposited in South Sumatra Basin, has similar characteristic with Keutapang Formation which deposited in the regression & compressional phase near the same age.
   b. Laser Particle Size Analysis results show that both formations have grain size from 11 to 160 µm in other words is very fine sand (wentworth scale). Sortation from 1.5 to 2.4Ø which is classified as poorly sorted to very poorly sorted. Skewness ranges from -0.091 to 0.658 Ø grouped into near symmetrical, fine, and very fine skewness. Kurtosis ranges from 0.686 to 1.02 Ø grouped into very platyurtic, platyurtic and mesokurtic.
   c. Based on the Linear Discriminate Function (LDF) method, by evaluating the values of Y1, Y2, Y3 and Y4, it describes that both formations are deposited on the Deltaic Environment with Shallow Agitated Water and dominated by traction currents.
   d. There is a relationship between Hydraulic Flow Unit and Grain Size that we could use to several fields that have same formations or ages. With LPSA data, we can obtain a linear (indirect) relationship between grain size and the shale volume on the same rock geometry. This relationship can be used to distribute HFU values by using a plot of grain size with HFU or Flow Zone Index as discribed below.

   **Table 2. Vclay vs Grain Size and Grain Size vs HFU of each formation**

   | Formation          | Vclay vs Grain Size | Grain Size vs HFU |
   |--------------------|---------------------|-------------------|
   | Air Benakat Formation | $\text{GS} = -97.6 \ (\text{Vshale}) + 132.4$ | $\text{HFU} = 0.015 \ (\text{GS}) + 9.95$ |
   | Keutapang Formation | $\text{GS} = -96.4 \ (\text{Vshale}) + 79.6$ | $\text{HFU} = 0.0107 \ (\text{GS}) + 10.195$ |

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