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Facies and Reservoir Rock Type Analysis of Kujung Unit-I Formation in "Betta" Field, East Java Basin, Indonesia

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Abstract
Kujung Unit-I formation in Betta field is proven to have produced 1.4 – 9.1 MMCFGPD gas which is confirmed to be 100% C1. Where the condition makes kujung Formation Unit I as a secondary target of the reservoir observed. Given the reservoar carbonate rocks are known for their high degree of complexity. So, to understand it requires more detailed attention. Therefore, this study aims to find out the relationship of qualitative analysis (analysis of deposition fasies) and quantitative (reservoir rock type) of carbonate rock reservoirs. Analysis of deposition fasies at research intervals (SB-4 to MFS-4), resulted in fasies associations in the form of interior carbonatreef mound platforms, lagoons/open shelf, barriers (sand shoals – reef shoals), slopes, and deep shelf. The direction of deposition is known to be getting deeper to the Southwest (basinal). Of the three wells, which show the best porosity value of 30-35% are ASA-2 and ASA-3. Then a good permeability value is shown in the ASA-4 well (22 – 32 mD). From the analysis of reservoar rock type (RT) with property value parameters, four groups of rocks produced which are the best (RT-1) showed interconnected pore size (R35) 2.62 – 3.17 µm with flow unit (FZI) 1.7 – 2.7. Then the worst reservoar rock type shows (R35) 0.7 – 0.9 µm (FZI) 0.006 – 0.01. The intervals that produce gas 1.4 – 9.1 MMCFGPD on asa-3 wells are filled by wackstone limestone litofasies – packstones deposited in the open shelf zone, and classified as 4th type rock reservoar (RT-4).

Introduction
Kujung Formation in East Java basin and Ngimbang Formation are oil and gas producing zones that has been proven to produce 9.1 MMCFGPD (limestones in Kujung Unit I), 430 BOPD from Kujung Limestone Unit III, and 16.5 MMCFGPD from the sandstone layers of Ngimbang Formation. Sandstones reservoir at Kujung Formation Unit III is the main target of each drilling of several exploration wells located in field "Betta" while limestone in the Kujung Unit I Formation status is still secondary target. Therefore, it is necessary to conduct further studies related to reservoir characteristics and hydrocarbon potential in the formation. The field "Betta" is located in the East Java Basin, geographically located in the Northern part of Madura Island.
Kujung Formation is the result of stable sea level conditions which support the growth of reefs in the shelf depositional environment, inner to middle neritic. In characterizing reservoirs, carbonate rocks need more detailed attention. Moreover, the lithofacies of carbonate rocks have lots of varieties and are influenced by secondary deformation which will then affect the value of the properties, which are

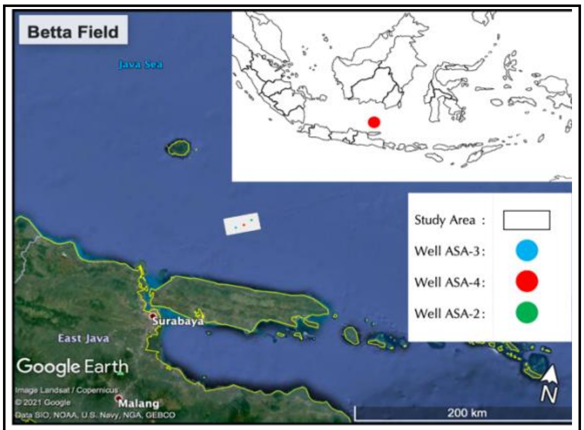

Figure 1. The research location is on the North of Madura Island, part of East Java Basin. This research is supported by three exploration wells (colored points).

porosity and permeability. Based on the value of property measurements on core samples that are often used as a reference, sometimes it still causes errors in the modeling results and actual circumstances. Therefore, it requires a method that can connect between qualitative analysis (depositional facies) and quantitative (property values). This study was conducted by utilizing several data, including three well data along with wireline log, routine core analysis (RCAL), geology final drilling report, biostratigraphy, core, and sidewall core description. All the data are combined to analyze the characterization of reservoir on petrel software.

Data and Method
In characterizing the reservoir, the researchers will combine two methods of analyses, which are qualitative analysis used to interpret the depositional facies of a reservoir and quantitative analysis used for grouping the reservoir property values. The first step that must be done before entering into qualitative and quantitative analysis is to do quality control of the data, as previously mentioned above. After data control stage is completed, it will then be analyzed to create a new project on Petrel software. Furthermore, the determination of marker horizon based on sequence stratigraphy method to divide the zone by the depositional events that has the same age, or usually being named as parasequences. In determining the parasequences, the researchers utilize the rule of electrofacies based on log type. After that, the process is continued by determining the depositional environment of these zones with biostratigraphy data, core and lithology description as the references.
The quantitative analysis divides reservoir groups based on the value of its properties (reservoir rock typing). Reservoir

properties are obtained from RCAL data either sidewall core or conventional core. In this study, the reservoir rock typing that will be applied is by using the R35 Windland method (1972) and also the hydraulic flow unit (HFU) method by Amaefule *et al.* (1993).

It can be explained that Windland (R35) method is to divide the group of reservoir rocks based on the similarity of pore-throat size (in µ) which forms a curve of 35^{th} percentile on mercury intrusion capillary pressure (MICP) on the permeability (*k)* in md vs porosity (φ) in cm^3/cm^3 plot with the following equations:

$$\log(r_{35}) = 0.732 + 0.588\log(k) – 0.864\log(100\phi) \quad (1)$$

Then, Amaefule (1993) describes the equation for reservoir rock typing based on hydraulic flow unit (HFU) method that can expressed by those equations below:

$$RQI = 0.0314\sqrt{\frac{k}{\phi}} \quad (2)$$

$$PMR = \phi_z = \frac{\phi}{1-\phi} \quad (3)$$

$$FZI = RQI/PMR \quad (4)$$

RQI is a reservoir quality index, whereas PMR is matrix pore ratio or commonly referred to normalized porosity index. (*k* in md and φ in cm^3/cm^3). The reservoir rock typing is determined based on the plot on a chart between the RQI vs PMR value, where the plot point that is within one straight slope line are group that have the same hydraulic unit value and rock type. Each hydraulic unit is represented with a unique value of FZI (flow zone unit).

Result and Discussion

Facies and Depositional Environment

The information obtained from the sidewall core report describes ASA-3 wells (Figure 2) where there are variations of lithofacies: packstone, wackstone, mudstone (Dunham classification, 1962), and shale that form a relative pattern fining upwards. As seen in Figure 2 the intervals of 4,350ft - 3,920ft is dominated by shale with thin interbeds of light brown limestones (wackstone, mudstone, and a few packstones at the bottom). After that the interval of 3100 – 3920 ft is dominated by limestones and characterized as blocky pattern where the packstone is at the bottom of the interval and the texture fining increasingly upwards (wackstone and mudstone). The iteration occurred at intervals of 2970 – 3100 ft but with finning upward pattern. After identifying lithofacies based on drilling report data, the information can be led to interpret its deposition environment where it refers to facies associations. Four depositional environment zones were obtained in the study areas which were developed based on description data, fossil analysis of sidewall cores and interpretation processes. Depositional environment in this study area are lagoon and open shelf. Kujung Unit-I formation is deposited in shallow marine deposition environment where the result of sedimentation is very typical due to the influence of eustasy.

Stratigraphy

Stratigraphic correlations connecting between the three wells in the field "Betta" using the principle of sequence stratigraphy method, the markers are determined based on the presence of visible shale and vertical changes in succession of lithofacies in the well data. The area were divided into several 13 parasequence zones based on marker flooding surface boundary (Van Wagoner *et al., 1988)* in this area. In correlation with the three wells (Figure 3), it can be understood that the results of interpretation showed a difference in facies succession at the top of the sequence body. The ASA-3 to ASA-4 well is in the open shelf environment that filled by clastic carbonate, while the closer the NE (ASA-2 well) approaches lagoon zone, which is supported by the presence of thicker shale and depletion of limestones lithofacies.

Rock type identification

In this study, rock typing analysis was conducted using two different methods, Windland method (1972) and hydraulic flow unit method by Amaefule (1993). In determining the classification of rock type using Windland method (R35), done by plotting the value of R35 from 23 data spread from Kujung Unit-I to Kujung Unitt-III Formation based on the order from the smallest to the largest (Figure 4.a). Based on the information, it was then interpreted that in this study area is divided into four rock types, yellow (RT-4), green (RT-3), blue (RT-2), and orange (RT-1). To prove it, the researchers did a plot to classify the four rock types based on MICP curve (Figure 4.b). of the four iso pore-throat curves that have been identified which are 0.5 µm, 0.9 µm, 1.11 µm, 2. 1 µm.

Classification of rock type using HFU method which determines how many rock types to choose, the first step is the same as rock typing with Windland method which is plotting the FZI calculation value (from RQI divided by PMR value) based on the order from the smallest to the largest of its value, as illustrated in (Figure 5. a). The diagram showed the results of interpretation of four rock types. According to Amaefule, (1993) sample rocks plotted on the diagram RQI vs PMR and its position in a slope line is interpreted as a group that has similar flow units. In this study based on rock typing using HFU method obtained sequences based on the bad to the best are: Yellow (HFU-4), green (HFU-3), blue (HFU-2), and red (HFU-1) (Figure 5.b).

Reservoir characterization

The combination of quantitative and qualitative analysis will provide answers on the quality of reservoir where the parameters are large porosity, permeability, pore throat, FZI, and litofacies. In this study the quality of reservoir was divided into four groups (Figure 4C and Figure 5C) into the following:

Excellent reservoir group (Red) based on pore throat 2.14 m µm dominated by wackstone lithofacies and sandstone mouth bars. Where the property has a range of 17-26% porosity and 14.5-1042 mD permeability. Based on flow unit 1.7-2.7 this group is filled by lithofacies similar to large pore throat, namely wackstone and mouth bar sandstone, with a range of 17-22% porosity and 14.5-1042 mD permeability.

Good reservoir group (Blue) based on pore throat 1.3 – 2 µm dominated by lithofacies packstone, wackstone and sandstone. Where the property has a range of 7-31.6% porosity and 0.1 - 13 mD permeability. Based on flow unit 0.07 – 0.3 this group is filled by lithofacies equal to large pore throat, namely wackstone and sandstone, with a range of 1.3 – 8.4% porosity and 0.1 - 0.4 mD permeability.

Poor reservoir group (Green) based on pore throat 1µm dominated by lithofacies mudstone, wackstone, packstone, and sandstone. Where the property has a range of 1.3 - 31.3 % porosity and 0.04 – 0.5 mD permeability. Based on the flow unit 0.03 – 0.07 this group is filled by lithofacies equal to the size of pore throat, namely wackstone and sandstone, with a range of 1.4 – 31.6% porosity and 0. 01 - 13 mD permeability.

Very poor reservoir group (Yellow) based on pore throat 0.7 – 0.9 µm dominated by lithofacies mudstone and wackstone. Where the property has a range of 1. 4 – 29.7 % porosity and 0.01 – 0. 2 mD permeability. Based on the flow unit 0.006 – 0.01 this group is filled by lithofacies that are equal to the large pore throat, namely wackstone and sandstone, with a range of 22 - 31. 3% porosity and 0.2 – 0.5 mD permeability.

Conclusions

There are several lithofacies in the research area in Kujung Unit-I: mudstone, wackstone, packstone, and shale, where the vertical succession is dominantly finning upwards and blocky at the top with the environment of deposition lagoon to open shelf, where dominated by eustasy influence. Succession in one sequence where equivalent to Kujung Unit-I formation is at the age of Upper Oligocene to Lower Miocene and has 13 parasequences divided by the period of rising sea level. The target zone on the "Betta" field has four groups of reservoir rock type: excellent reservoir group, good reservoir group, poor reservoir group, and very poor reservoir group.

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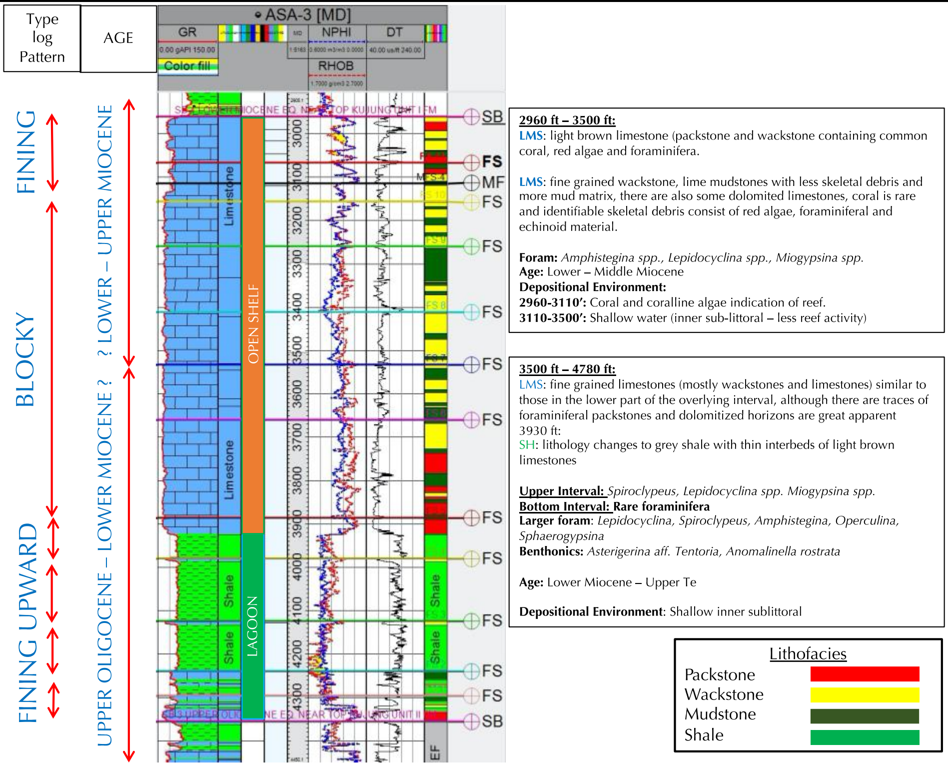


Figure 2. Sidewall core description of ASA-3 well.

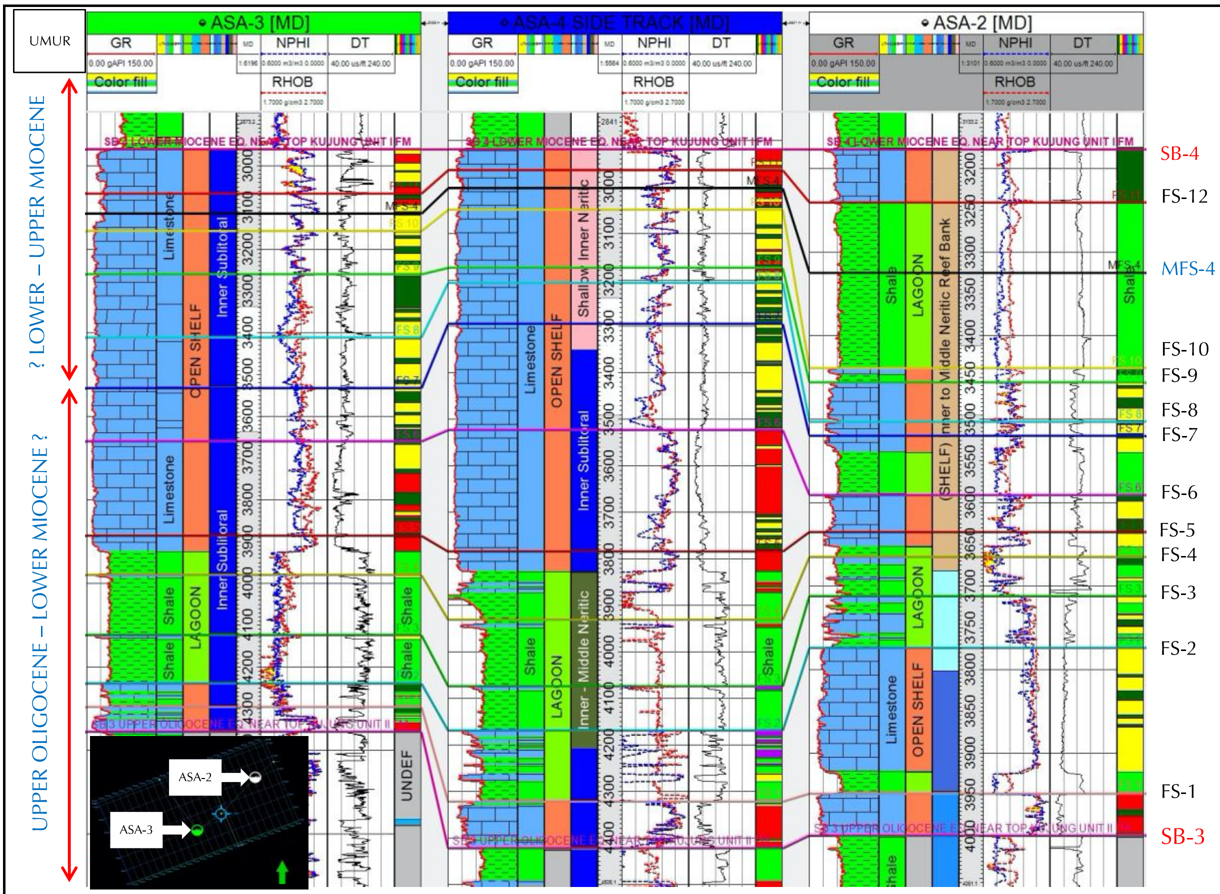
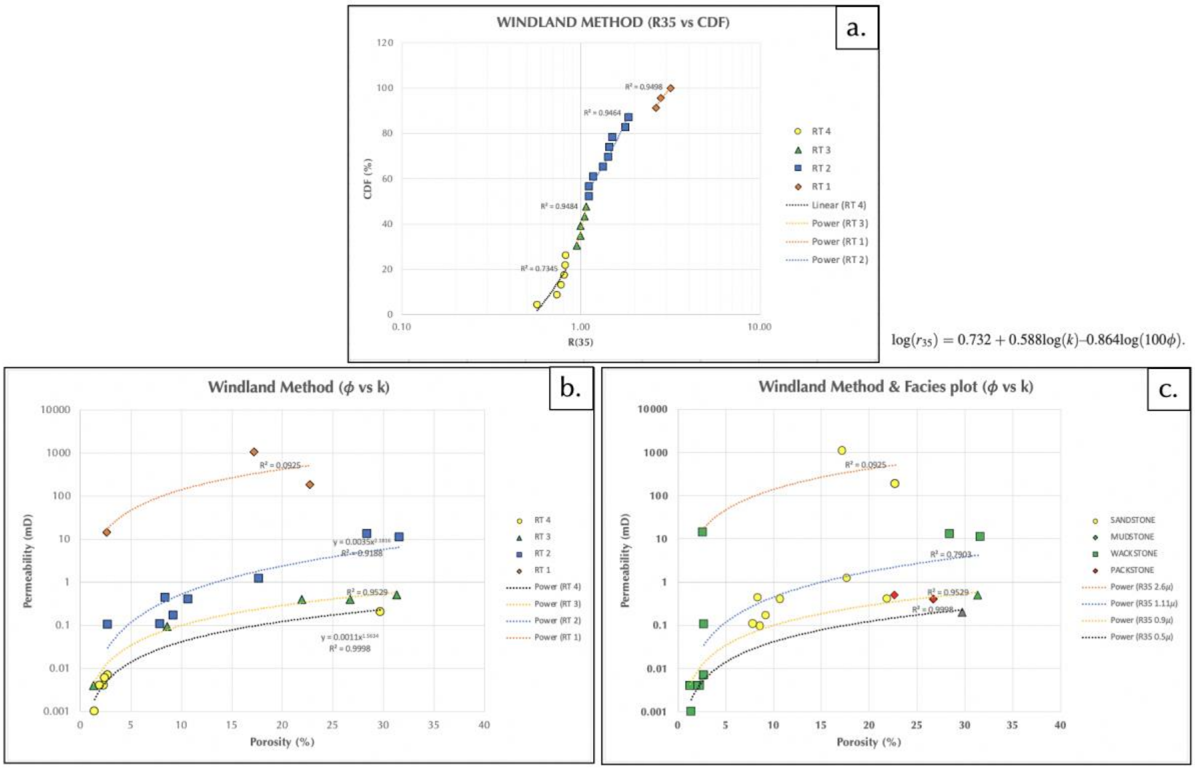


Figure 3. Sequence stratigraphy correlation logs in study area



$$\log(r_{35}) = 0.732 + 0.588\log(k) – 0.864\log(100\phi).$$

Figure 4. Rock typing by Windland R-35 method

$$\text{RQI} = 0.0314\sqrt{\frac{k}{\emptyset}}$$

$$\text{PMR} = \emptyset z = \frac{\emptyset}{(1-\emptyset)}$$

$$\text{FZI} = \frac{\text{RQI}}{\text{PMR}}$$

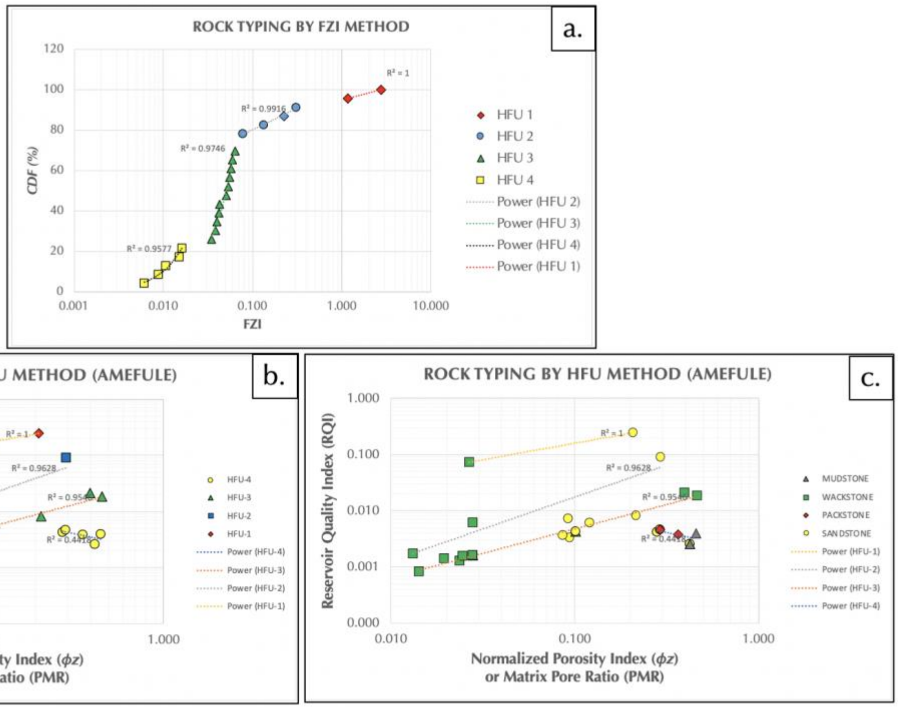


Figure 5. Rock typing by HFU method.