INTEGRATING PETROGRAPHY WITH CORE-LOG-WELL TEST DATA FOR LOW PERMEABILITY SANDSTONE RESERVOIR CHARACTERIZATION: PRELIMINARY RECOMMENDATION FOR PRODUCTION OPTIMIZATION

By: Junita Trivianty Musu[(1)], Hadi Prasetyo[(2)] and **Bambang Widarsono[(1)]**
Researcher[(1)] at "LEMIGAS" R & D Centre for Oil and Gas Technology
Jl. Cileduk Raya Kav. 109, Cipulir, Kebayoran Lama, Jakarta Selatan 12230, INDONESIA
Tromol Pos: 6022/KBYB-Jakarta 12120, Telephone: 62-21-7394422 ext.1420, Facsimile: 62-21-7246150,
Email: jmusu@lemigas-core.com
Badan Pelaksana Hulu MIGAS (BPMIGAS)[2)]
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ABSTRACT

Integrating petrographic core information into combined core petrophysics, log, and well test data for understanding facies and environmental deposition in rock characterization has proved itself useful to improving quality and reliability of the required conclusions. This integrated approach has specifically shown its use in the cases of complex reservoirs such ones characterized as low-permeability sandstone reservoirs. It is in this spirit that this paper demonstrates how this virtually cost efficient analysis provides preliminary recommendations for the exploitation of such reservoirs. As case study, two types of producing reservoirs (Bekasap, Bangko, Pematang, and Tanjung Formations) have been taken in 2009. The first type is strongly controlled by depositional environment. It is found in the upper part of Bekasap and Bangko formations (1900 - 2300 ft-ss), deposited in estuarine system, and made of very fine to fine grained sand with low to moderate bioturbation. This mostly feldspathic and lithic greywackes have permeability of up to 200 mD. The second type is strongly dominated by diagenesis process and is mainly found in the Upper Pematang and Tanjung Formations (6200 - 7400 ft-ss). This reservoir type is characterized by its coarse-grained and conglomeratic sandstones resulted from fan-delta and braided channel depositional system. Diagenetic events such as compaction, recrystallization of matrix into microcrystalline clay minerals, precipitation of authigenic minerals in pore system are also well identified from the performed petrographic analysis. This is dominated by sublitharenite and litharenite sandstones exhibit horizontal permeability of up to several dozens mD. The two producing reservoir types have undergone carefully planned exploitation and stimulation operations, and the horizontal drilling and fracturing job for the type-1 and type-2 reservoirs, respectively, are acknowledged as two success stories of their own. These successes would not prevail without application of well integrated core-log-well test approaches in reservoir characterization, in which information from core petrography plays an important contribution.

Keywords*: reservoir characterization, sandstone, low permeability, petrography*

I. INTRODUCTION

Indonesia's oil and condensate reached its maximum production in 1977 and 1995 of about 1.5 BOPD. Indonesia's oil production has declined in recent years, mainly due to maturation of its existing fields. Recently the oil production is about 950 thousand BOPD[1]. One of the available techniques in increasing oil recovery rates is by production optimization in

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low permeability reservoirs; therefore integrated approach in detailed reservoir characterization is needed.

Several studies have been accomplished in describing the controlled of geological factors in production of hydrocarbons. According to Davies[2] geological factors such as structural position, lithology, grain size, sorting, shaliness, pore-geometry play important roles in controlling the fundamental reservoir parameters including porosity, permeability, and saturation. Pettijohn *et al.*[3] found out that the relationship between rock characteristic and reservoir quality in term of porosity, especially permeability is highly influenced by textures and sedimentary structures. Textures include grain size, sorting, compactness, and packing of the reservoir framework grains, whereas sedimentary structures comprise of bioturbation, cross lamination and parallel laminations, and ripple marks. Pittman[4] based on petrographic study has determined the relationship between the type of porosity and reservoir quality and potential log calculation problem and well completion. Syed[5] and Civan[6] have both described that the development of clastic reservoir quality is influenced by depositional environment. According to Cade *et.al.*[7] permeability increases with the increased of grain size and grain sorting coefficient. Evans *et al.*[8] has also explained the correlation of type and size of porosity, grain size, sorting and diagenesis and porosity and permeability enhancement.

This paper demonstrates that the application of integrated petrographic analysis and petrophysic, log and well-test data would produce major advances in giving preliminary recommendation for exploitation development strategic and also production optimization. Integrated petrographic data is very useful for evaluating the relationship between depositional environment, mineralogy composition, pore geometry, diagenesis, and reservoir quality, which lead to better perspective in reservoir modelling. Therefore, the reservoir model can be applied in other reservoirs with similar characteristics. Two types of producing reservoirs including Tanjung Formation in Barito Basin, East Kalimantan and Pematang and upper part of Bekasap and Bangko Formations in Central Sumatra Basin were the objects in the study.

II. METHODS

Thin section petrographic supported by scanning electron microscope (SEM) and x-ray diffraction (XRD) analysis were the main techniques in reservoir characterization. The results of the analysis were then combined with data from the megascopic core description, log, and well-test. The integrated petrography study was performed in LEMIGAS in 2009.

Thin sections prepared and taken from the conventional cores were cut 2 cm thick and impregnated with blue-dyed epoxy resin to maintain the existing natural porosities of the rock samples and to recognize porosity under the microscope. Petrographic point-count analysis of the thin section was carried out to quantitatively determined grain compositions (both primary and secondary origins) and visual porosity percentages. An average of 400 grains, including grain composition and porosity percentages were counted per thin section. Pore geometry, types and its distribution and type of sensitive minerals and their occurences and distribution (especially clay) were also observed using SEM. SEM analysis was applied to examine the geometry of the pore systems and to determine the type and distribution of sensitive minerals, especially for understanding mode of occurrences of the authigenic minerals pattern such as clays and cements within pore systems. XRD analyses were prepared for all samples to semi-quantitatively-quantitatively determine the whole rock (bulk analysis) and clay mineralogy in terms of weight percent of the whole rock.

III. RESULTS

Based on lithology characteristic, the Bekasap and Bangko Formations are differentiated into upper and lower parts. The upper part known as low permeability reservoir, strongly controlled by the depositional environment, so called reservoir type-1. On the other hand, the lower part with thicknesses varied from 10 to 20 ft shows better reservoir quality, composed of cross bedded and massive sandstones with slight bioturbation, conglomeratic fine grained sand.

The lower parts of the Bekasap and Bangko Formations generally show distinct or erosional boundaries with fining upward trend (Figure 1a and 1e). Gamma-ray log is 58 API and resistivity is 80 ohm and 60 API and resistivity of 30-60 ohm respectively. However, cased hole resistivity formation (CHRF) logs show resistivity is 20 ohm. This is an indication that the lower part of the formation is a depleted oil zone. According to logs data and routine-core analysis the amount of V_{shale} is 18% and horizontal perme-

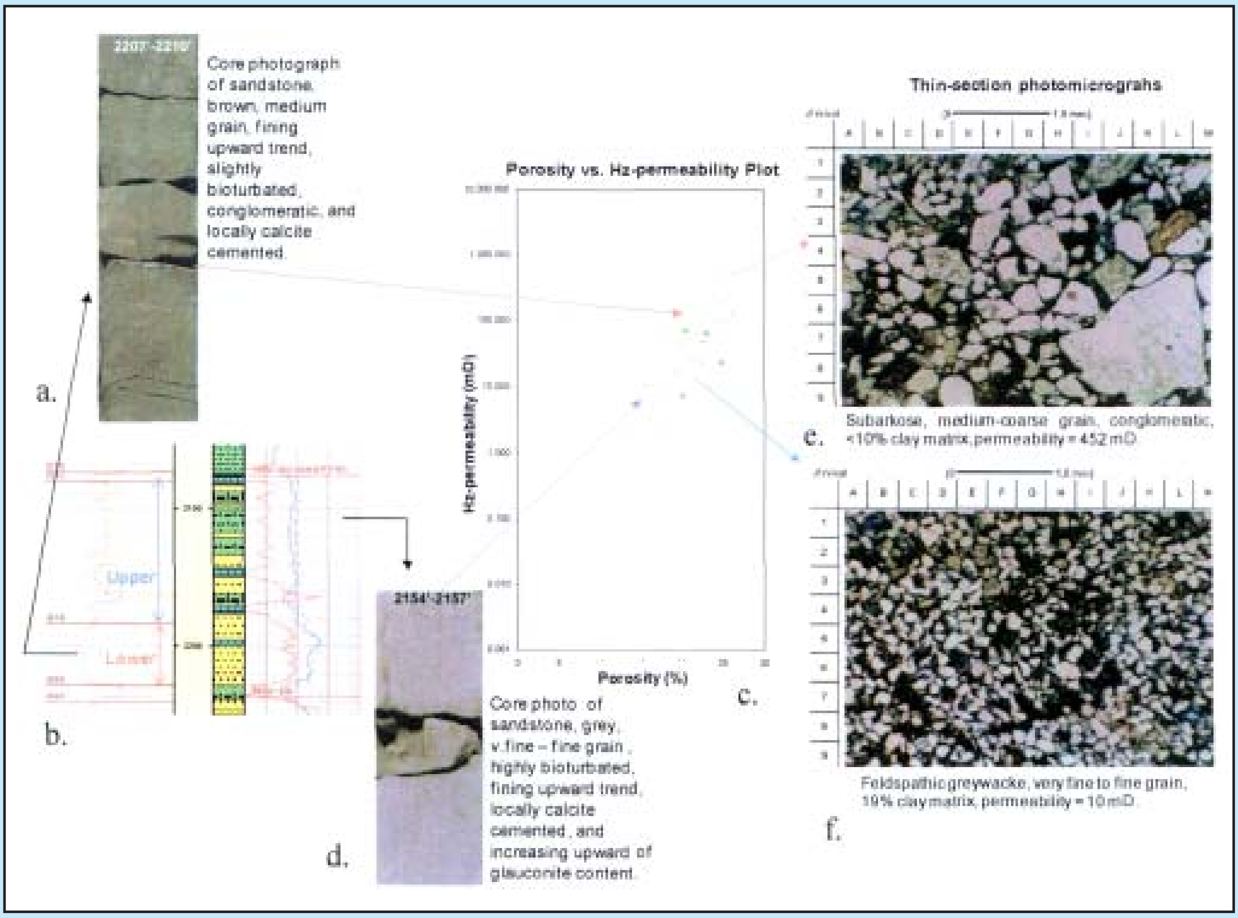

Figure 1
Reservoir characterization of the upper part of the Bekasap Formation.

ability reached up to 1900 mD (Figure 1b). Cross plot porosity against permeability shows higher trend (red line) compared to the upper line (blue line) as in Figure 1c. Vertical well-test data shows that the oil production reached up to several hundreds barrel per-day.

Thicknesses of the upper part of the two formations reached up to 40 ft, dominated by very fine to fine bioturbated sandstone, gamma-ray logs read at 60-90 API and show low resistivity of 8-12 ohm (Figure 1d and Figure 1f). Logs data and routine-core analysis revealed the amount of V_{shale} is 24-42% and permeability varied from tens up to 550 mD (Figure 1b). Resistivity value based on CHRF logs is relatively similar to the open hole resistivity, indicating that the upper part of the two formations are unswept zones. Cross plot porosity against permeability shows lower trend (blue line) compared to the lower line (red line) as in Figure 1c. Vertical well-test data at the upper part of the formations show that the oil production is around tens barrel per-day, whereas horizontal drilling well could produce oil ten times higher compared to vertical well.

Integrated petrographic analysis combined with core description and routine-core data shows that the reservoir quality development in reservoir type-1, especially horizontal permeability is strongly controlled by the depositional environment. Permeability is strongly affected by grain sizes and sedimentary structures. The decreased of grain sizes and the increased of the amount of bioturbation will reduced permeability. Very fine to fine sandstone (0.1 to 0.16 mm) with high bioturbation intensity has permeability up to 200 mD, and fine sandstone (0.2 mm) with low bioturbation intensity has permeability reached up to 600 mD. On the other hand, coarser sandstone with medium grained sandstone (0.22-0.26 mm) and cross bedded structures has permeability up to 3000 mD (Figure 2).

Figure 3 demonstrates that permeability is also controlled by the amount of matrix and sedimentary structures. The increased of matrix and bioturbation would decrease permeability values. The increased of matrix (>20%) and bioturbation would decrease permeability up to 50 mD. Sandstones with matrix content of about 5-10% with slight bioturbation would have permeability values around 200-500 mD. Comparison was made on sandstone with matrix content less than 5% and cross bedded structures which has higher permeability value up to 1900 mD.

Other example is reservoir tipe-2 namely Pematang and Tanjung Formations. Low permeability from few to 30 mD of the two formations are mainly controlled by diagenesis factor aside from depositional environment factor. Generally, the lithology characteristic of the two formations consisted of conglomerate, conglomeratic sandstone and coarse to very coarse sandstone with gamma ray values read at reach up to 105 API due to high amount of feldspar content and logs resistivity varied from 10 to 20 ohm. Figure 4 shows comparison of porosity against permeability. It relatively shows weak correlation, shown by the rela-

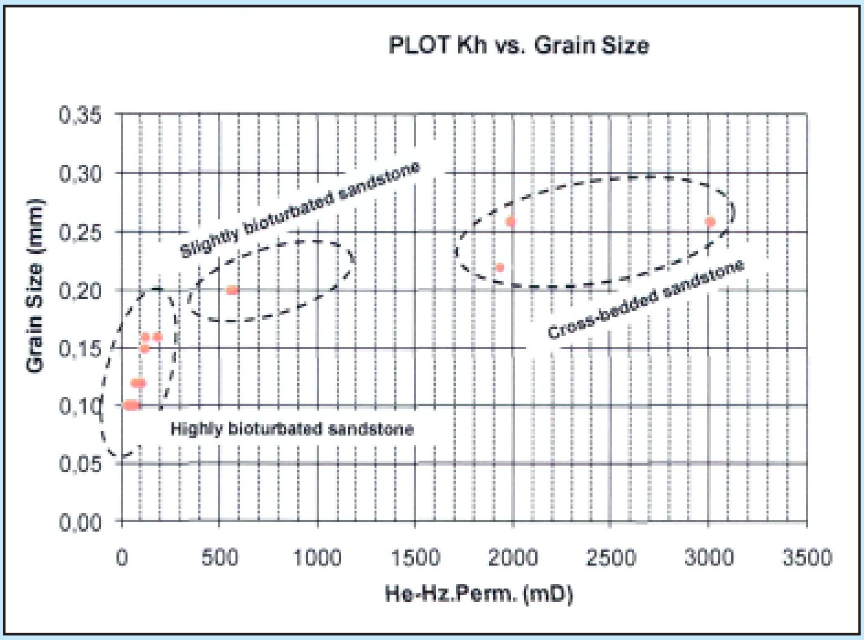

Figure 2
Relationship between permeability and depositional environment including grain size and bioturbation
(He-HZ. Perm: Helium horizontal permeability)

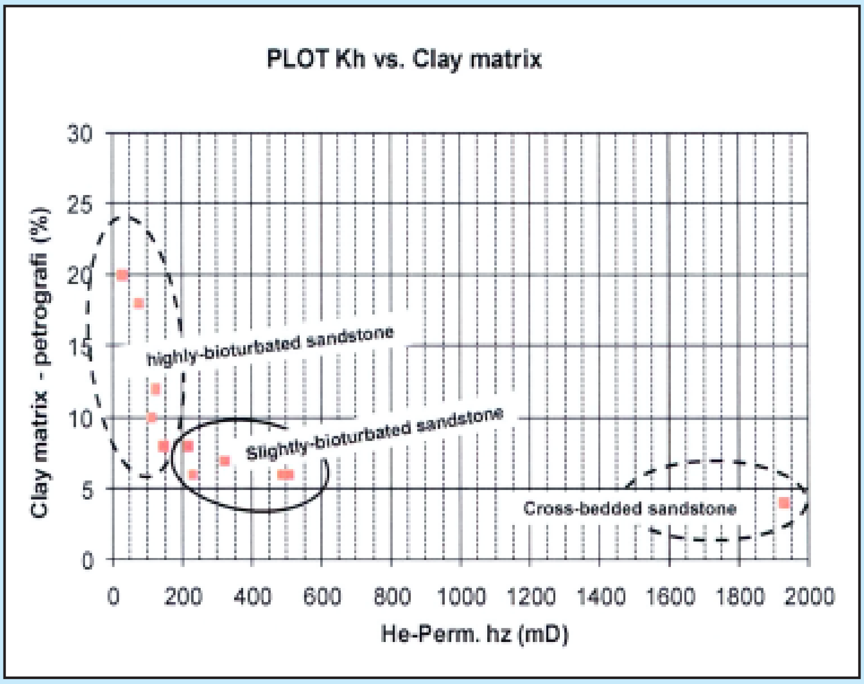

Figure 3
Relationship between clay matrix and bioturbation and permebaility
(He-HZ. Perm: Helium horizontal permeability)

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tively scattered plot, but it demonstrates distinct trend. The vertical development shows the assemble of fining upward parasequences.

Petrographic analysis shows the reduction of porosity especially permeability in reservoir type-2 is also controlled by diagenesis process including compaction, as shown by planar, semi-sutured and even sutured grain boundaries, and cementation including kaolinite, smectite, illite and zeolite (Figure 4).

Exploitation and simulation operation shows the production optimization of low permeabilty reservoirs caused by diagenesis process have succesfully done by fracturing job. In general, fracturing jobs in several wells in Pematang and Tanjung Formations have increased oil rate production ten times higher from 10 BOPD to 60-100 BOPD. Detailed knowlegde and understanding geological controls and reservoir characteristics in micro-mezo scales as mentioned previously, would comprehend the correlation between lithology characteristics of the reservoirs and hydrocarbon production efficiency and also in recommending and planning strategic and technology to be used in production optimization, especially in low permeability reservoirs.

Geological factors controlling low permeability need to be identified, that is controlled by the depositional environment or diagenesis or combination of both. This study revealed that there is a correlation between geological factors controlling low permeability with the technology used for the production optimization. Based on drilling and production data for the reservoirs type-1 and type-2, the production optimization strategy for low permeability reservoir mainly caused by the depositional environment is achieved by horizontal drilling. On the other hand, the fracturing job is the optimum technique to increase

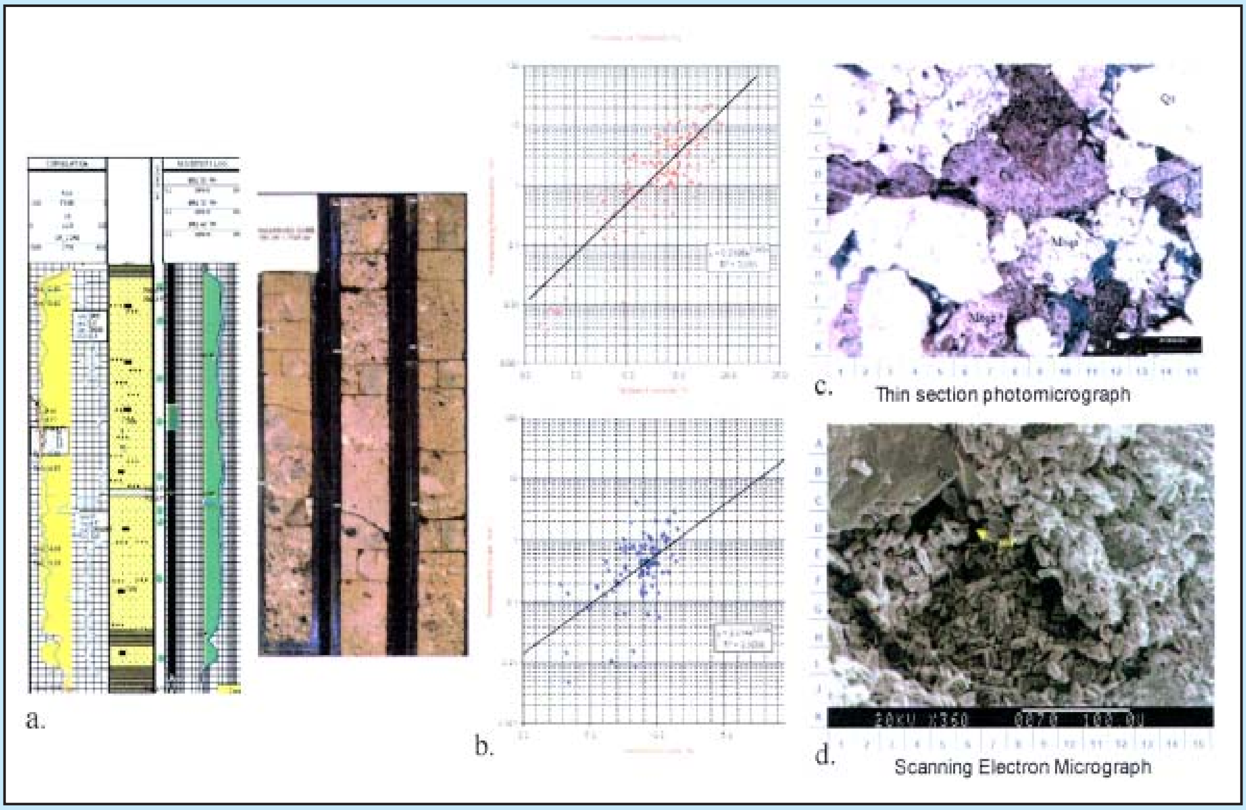

Figure 4
Reservoir characterization of conglomeratic sandstone of low permeability Pematang Formation.
a. Logs and conventional core, b. Cross plots of porosity against permeability,
c. Diagenetic process including compaction, shown by planar and semi-sutured grain contacts,
d. Kaolinite cementation

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production in low permeability reservoir controlled by diagenesis process.

IV. CONCLUSIONS

Integrating petrographic analysis with core information, log, and well-test data for reservoir characterization prove itself useful for preliminary recommendation on planning and determining strategy and techniques to increase production. The optimum strategy for low permeability reservoir caused by depositional environment could be accomplished by horizontal drilling, whereas low permeability reservoir caused by diagenesis process could be done through fracturing jobs. It is also ascertained that integrated petrographic analysis can be used as an aid in reaching engineering as well as geological conclusions.

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