Petrophysics Analysis for Reservoir Characterization of Cretaceous Clastic Rocks: A Case Study of the Arafura Basin

Analisa Petrofisik untuk Karakterisasi Reservoar Batuan Klastik di Umur Kapur: Studi Kasus Cekungan Arafura

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Abstract- This study presents petrophysics analysis results from two wells located in the Arafura Basin. The analysis carried out to evaluate the reservoir characterization and its relationship to the stratigraphic sequence based on log data from the Koba-1 and Barakan-1 Wells. The stratigraphy correlation section of two wells depicts that in the Cretaceous series a transgression-regression cycle. The petrophysical parameters to be calculated are the shale volume and porosity. The analysis shows that there is a relationship between stratigraphic sequences and petrophysical properties. In the study area, shale volumes used to make complete rock profiles in wells assisted by biostratigraphic data, cutting descriptions, and core descriptions. At the same time, porosity shows a conformity pattern with the transgression-regression cycle.

Keywords: petrophysics, reservoir characterization, Cretaceous, transgressive-regressive cycle

Abstrak- *Studi ini menunjukkan hasil analisis petrofisik untuk dua sumur yang berlokasi di Cekungan Arafura. Analisa dilakukan untuk mengevaluasi karakterisasi reservoar dan hubungannya dengan sekuen stratigrafi berdasarkan data log dari sumur Koba-1 dan Barakan-1. Penampang korelasi sekuen stratigrafi dari kedua sumur tersebut menggambarkan bahwa pada seri berumur Kapur menunjukkan adanya siklus transgresi-regresi. Parameter petrofisika yang akan dilakukan perhitungannya adalah volume serpih dan porositas. Analisis menunjukkan bahwa adanya hubungan antara sekuen stratigrafi dan properti petrofisik. Pada daerah penelitian, volume serpih dapat digunakan untuk membuat profil batuan pada sumuran secara lengkap yang dibantu oleh data biostratigrafi, deskripsi batuan dari data potongan batuan pemboran, dan batuan inti. Sedangkan porositas menunjukkan adanya pola kesesuaian dengan siklus transgresi-regresi.*

Katakunci: petrofisik, karakterisasi reservoar, Kapur, siklus transgresi-regresi

INTRODUCTION

First record of log data in 1927 of an oil well in France (Schlumberger, 1999). Reservoir descriptions based on well-logging data crowded between the late 1970s and early 1980s (Schlumberger, 1999). The petrophysical analysis is to evaluate rock physics parameters as it provides data for the integrated reservoir characterization (Moore *et al.*, 2011). Generally it is to determine raw log data into petrophysical parameters value such as volume of shale (Vsh), porosity ($\emptyset$), and net reservoir (Asquith and Krygowski, 2004).

The study area located in the Arafura Basin where the Koba-1 well located at 006 52 '56.334" S and longitude 133 20' 58.740" E and the Barakan-1 well located at latitude 007 17 '29.127" S and longitude 132 40' 17.761" E. Administratively, the area situated in three regencies, i.e., the Southeast Maluku, Aru island, and West Southeast Maluku, Maluku Province (Figure 1).

STRATIGRAPHIC STUDY AREA

The study areas have mapped into the 1:250,000 scales of Aru Sheet (Hartono and Ratman, 1992), Tanimbar Sheet (Sukardi and Sutrisno, 1989), which outcrops of Miocene-Quarter Age Formation:

Tanahmerah Formation

Brownish white-reddish, fine-medium quartz sandstone; well sorted, less compact, bedded (2-2.5 m); locally clayey; with conglomerate and carbonaceous siltstone intercalations.

Wasir Formation

Marl, calcareous mudstone, locally sandy, light grey, less compact, poorly bedded (1-1.5). Fine bioclastic limestone brownish yellow-greyish brown, bedded (5-10 cm), less compact, rather hard interbedded with marl and calcareous mudstone, found also intercalation of coarsed grained calcarenite, hard and compacted, bedded, grey-yellowish grey.

Manumbai Formation

Marl, light-brownish grey, less compact, rather hard, bedded (25-30 cm), locally sand, with fine-medium clayey bioclastic limestone intercalations.

Coquina limestone, light brownish grey, less compacted, porous, thick bedded (1-5 m).

source: Hartono and Ratman (1992), Sukardi and Sutrisno, (1989), Panggabean and Pigram (1989), and Achdan and Turkandi (1994)

Figure 1. The study area (red block) situated as a part of the Arafura Basin.

Koba Formation

Chalky and marly calcarenite, light grey-greyish-white, fine-medium grained, less compact-compact, unbedded; locally thick bedded 3 m, with flute marks. Locally intercalated by yellowish white sandy marl.

Kai and Tayandu Islands Sheet (Achdan and Turkandi, 1994) have outcrops of Eocene and Oligocene Age Formation:

Meduar Formation

Reef limestone, chalk, calcarenite and marl with abundant of coral, benthonic foraminifera and molluscs. Marl contains some small foraminifera. Reef limestone are vuggy, mostly found in the upper part. Crossbedded are common in calcarenite. Benthonic foraminifera: Lepidocyclina sp., Cycloclypeus sp., and small foraminifera: Globorotalia mayeri, G. Menardii, Orbulina suturalis, Globigerinoides subquadratus, the age of this formation is Mid. Oligocene-Mid. Miocene with the environment of deposition of outer neritic to litoral and regresive, interfingers with Tamangil Formation and unconformably overlies Elat Formation. Thickness 500 m.

Tamangil Formation

Limestone composed of benthonic foraminifera in matrix of micrite. Upward the micrite fewer. Fosil: Lepidocyclina stigteriv.d., L. (Nephrolepidia) sp., L. (Eulepidina) dilatata, L. Gigantea, Spiroclypeus sp, age of Mid. Oligocene to Late Oligocene, 50 m thick, neritic deposition environment, interfingers with lower part of Meduar Formation and unconformably overlies Elat Formation.

Elat Formation

Marly limestone with marl intercalation. Upward the calcarenite is coarser and the beds thicker, reaching up to

1 m thick and marl become disapear. Locally, graded bedding, cross-bedding, convolute lamination, chert concretion and clast. Calcarenite contains benthonic foraminifera, bryozoa, algae, echinoid spines, fish scale imprints, mollusc fragment and corals. The benthonic foraminifera: Lacazinella wichmani, L. reicheli, Discocyclina sp., D. dispansa, Discocyclina pratti, Nummulites, Alveolina. Planktonic foraminifera: Globorotalia cerroazulensis, G. centralis. Age P10-P17 Early Eocene-Mid. Eocene. Deposited in, neritic environment and regresive, interfingers with Yamtimur Formation. 700 m thick.

Yamtimur Formation

Marl with calcarenite intercalation, well bedded, bed thickness is up to 6 m. Upward, the calcarenite interbeds become more common, and marl layers become fewer and thinner. Planktonic foraminifera: Globorotalia spinulainflata, G. aragonensis, G. broedermani, Globigerina boweri, G. graveli, Pseudohastigerina micra, P. wilcoxensis, age of Mid. Eocene Globorotalia bulbrooki zone, neritic depositin environment, 200 m thick.

Of the four geological maps, only the Waghete Sheet (Panggabean and Pigram, 1989) have outcrops of the Jurassic-Cretaceous Age Formation, which are the Kembelangan Group:

Kopai Formation

Glauconitic quartz sandstone, siltstone, calcareous mudstone.

Micaceous sandstone; minor conglomerate, calcarenite, calcilutite, glauconitic sandstone.

Woniwogi Sandstone

Orthoquartzite; minor siltstone, mudstone.

Piniya Mudstone

Micaceous mudstone, glauconitic mudstone, muddy glauconitic quartz sandstone, and siltstone.

Ekmai Sandstone

Glauconitic quartz sandstone, quartz siltstone; minor carbonaceous siltstone, sandstone, mudstone, and shale.

Koba-1 Well was drilled Kembelangan group from 3750 ft (marked by the presence of fine grained to silty sandstone) to approximately 5350 ft (Promet Arafura Limited, 1984). Description of this interval is interbedded claystone, siltstone and sandstone with minor limestone/dolomite stringers. The sandstone is light grey, medium to fine grained, firm, friable, subangular to subrounded, well to very well sorted, occasionally argillaceous but generally has good visual porosity and with trace carbonaceous fragments. No significant gas peak or oil show was recorded. Claystone here is vari-coloured with shades of light grey, greenish grey, dark grey and brownish grey, soft to firm, blocky, soluble in parts, subfissile and grading to shale with depth, calcareous, silty in parts with trace glauconite and pyrite. Siltstone is generally light brown, moderately hard to hard, brittle, calcareous, fine sandy in parts with carbonaceous laminations and trace disseminated pyrite.

This study focuses on identify petrophysical properties of sequence stratigraphy from the Cretaceous series.

Embry and Johannessen (1992) have defined the T-R (transgressive-regressive) sequence. The subaerial unconformity used as a sequence of unconformable portions. Whereas, a maximum regressive surface used as a conformity correlation. This methodology maintains subaerial unconformity as a sequence boundary and also provides conformity correlations that can be objectively determined. It thus avoids the fatal flaws of previously defined types. The T-R sequence divided into two, namely a TST (transgressive systems tract) and a RST (regressive systems tract), with the application of maximum flooding surfaces as a mutual boundary. Figure 2 shows a scheme for a T-R sequence, where The maximum regressive surface is used as a comfortable surface so as to the correlation boundary for T-R sequences can be attracted accordingly (Embry, 2002).

Catuneanu (2006) sequence stratigraphy is a method for recognizing deposited rock unit packages in the same cycle, which is controlled by a combination of changes in

Event	T-R
Start Transgression	SB
Start B.L. Rise	RST
Start B.L. Fall	
Start Regression	
	TST
Start Transgression	SB
	RST
Start B.L. Rise	

source: Embry (2002)

Figure 2. Scheme for a T-R sequence. T-R: Transgressive-Regressive; SB: Sequence Boundary; RST: Regressive System Tract; TST: Transgressive System Tract.

base level, accommodation space, and sediment supply.

METHODOLOGY

The study mainly based on the petrophysical analysis of Barakan-1 and Koba-1. Nowadays, logging tools and interpretation methods are developing in accuracy and a more modern way, which plays an essential role in the geological decision-making process. At present, the interpretation of logging data is one of the most useful and vital tools in petroleum geologists for determining the petrophysical parameters (Asquith and Krygowski, 2004). The purpose of this study to depict petrophysical parameters of the reservoirs, which included volume of shale, and porosity by computing. The steps for the determination of these properties are as follows:

Shale volume (Vsh) calculation

The log data used to calculate the Vsh in this study is the gamma-ray log (GR). Gamma-ray record used because it is a tool that is very sensitive to changes in the radioactive content of a rock. A high GR value indicates a high shale content due to the presence of potassium ions and a low GR value indicates a low shale content or also called a clean layer due to the absence of potassium ions (Asquith and Gibson, 1982).

$$I_{GR} = \left(\frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \right) \qquad (1)$$

Many approach modes to calculate Vsh from GR log data. First, look for the GR index (I_{GR}) value from the GR log data with the following relationship:

Where:

GR_{log} = the gamma ray reading at the depth of interest

GR_{min} = the minimum gamma ray reading. (Usually the mean minimum through a gamma ray reading)

GR_{max} = the maximum gamma ray reading. (Usually the mean maximum through a gamma ray reading)

Schlumberger (1972) Vsh has a linear relationship with IGR so that Vsh = IGR. Some researchers show that sometimes Vsh has a nonlinear relationship with IGR, as shown in Figure 3. So to approach solution will use on the two wells in the study area that needs to be determined for each method. The nonlinear

responses as the diagram given by Soto, *et al.,* (2015) are:

$$Vsh = 0.083(2^{3.7 I_{GR}} - 1) \qquad (2)$$

Larionov (1969) for Tertiary rocks:

$$Vsh = \frac{I_{GR}}{3 - 2 \times I_{GR}} \qquad (3)$$

Steiber (1970):

$$Vsh = 1.7 - [(3.38 - (I_{GR} + 0.7)^2]^{\frac{1}{2}} \qquad (4)$$

Clavier (1971):

$$Vsh = 0.33(2^{2 I_{GR}} - 1) \qquad (5)$$

Larionov (1969) for older rocks:

In this study, the Vsh calculation method that will use is the linear Vsh method due to the absence of XRD (X-Ray Diffraction) analysis results to determine the shale volume of rock samples (cutting & Side Wall Core (SWC)).

Porosity calculation

Porosity is the volume of the part of rock not filled with solids divided by the total volume of rock (Mamaseni *et al.*, 2018). porosity will tend to be lower in deeper and older rocks due to the effects of cementing and excessive pressure on the rock (Rider, 1996).

Porosity divided into two main types: total porosity (Øt) and effective porosity (Øe). Total porosity defined as the entire pore space in a rock divided by the volume of all rocks (Nnaemeka, 2010) or porosity obtained from direct log measurements without being corrected for their shale contents. Effective porosity represents the pore space filled with fluid and bound water (Nnaemeka, 2010). Effective porosity produced after removing the shale effect from total porosity. In a clean interval, effective porosity is equal to total porosity. The porosity of the log can be calculated from a single porosity log (density, neutron, and sonic) or several log porosity combined.
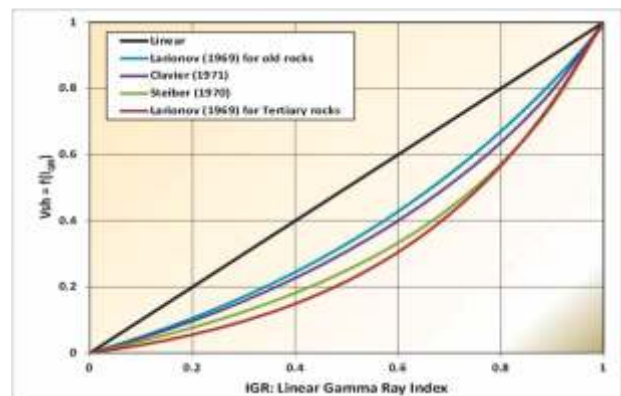
source:Soto, et al (2015)

Figure 3. Relation between the Vsh with IGR. Vsh: Shale volume; IGR: Gamma Ray Index.

Correlation of total porosity and effective porosity can be approached from the following relationships:

$$\emptyset_t = \emptyset_e + V_{sh} \times \emptyset_{sh} \qquad (6)$$

Where, $\emptyset_{SH}$ = shale porosity

Porosity can calculate from a single density log by approaching the relationships of formation bulk density (?b), formation matrix density (?ma), and formation fluid density (?f) as:

$$\emptyset_d = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \qquad (7)$$

The porosity of the density log ($\emptyset_d$) is also called the total porosity. Whereas, to obtain effective porosity of the density log ($\emptyset_{de}$) needs to be corrected for shale derived from Eq. (6) as:

$$\emptyset_{de} = \emptyset_d - V_{sh} \times \emptyset_{dsh} \qquad (8)$$

Where, $\emptyset_{dsh}$ = shale porosity from density logs.

The neutron log porosity ($\emptyset_n$) measures the amount of hydrogen present in the formation fluid, and this is repose the mass of the neutron adjacent to the mass of hydrogen. Atlas (1979) conveys that porosity for neutron logs needs to be correct for shales content such as:

$$\emptyset_{ncorr} = \emptyset_n - (V_{sh} \times \emptyset_{nsh}) + Lithology\ correction \qquad (9)$$

Where, $\emptyset_{nsh}$ = shale porosity from neutron logs and Lithology correction = 0.04.

Density-neutron logs ($\emptyset_{dn}$) are useful for reading porosity directly (Islam *et al.*, 2017) If among the two logs there is a difference in reading porosity then a combination of density-neutron logs (Schlumberger, 1999) needs to be done to obtain the corrected porosity. That has given below:

$$\emptyset_{dn} = \sqrt{\frac{\emptyset_{ncorr}^2 + \emptyset_{de}^2}{2}} \qquad (10)$$

Sedimentary rocks will affect the velocity of the sonic. Rock with high dense will have higher velocities. From this approach, the sonic log can be used to calculate log porosity; one formula that is Dresser, 1979:

$$\emptyset_{s-sh} = \left(\frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}\right) - Vsh\left(\frac{\Delta t_{sh} - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}}\right) \qquad (11)$$

where; tma = 44.4 μsec/ft, ? tf = 185 μsec/ft, ? tsh = 70 μsec/ft .

RESULT OF STUDY AND DISCUSSION

Wire logs data (Table 1) is used to identify petrophysical properties in the study area are as follows GR log, Neutron log, and Density log. Identify this property; other supporting data is needed, such as biostratigraphic data, cutting descriptions, core description, and other data that can be gained in well report.

Lithology profile

The wells in the study area have a complete GR log, neutron log, density log, and sonic log data. These data are primary data for petrophysics analysis, but to confirm the results of the analysis need to assisted with other data.

The lithology information in Koba-1 Well obtained from the description of cutting data during drilling. This data can be found in the Koba-1 exploratory well report and Koba-1 final well report (Promet Arafura, 1984). Furthermore, for information on age and depositional environment obtained from the results of biostratigraphic analysis (Promet Arafura, 1984). The summary of these data is presented in Figure 4.

Whereas, lithology for Barakan-1 Well obtained from the description of cutting data during drilling (Union Texas (KAI), 1995). While for information on age and depositional environment is obtained from the results of biostratigraphic analysis (Robertson Utama Indonesia, 1995). The summary of these data is shown in Figure 5.

The subject of the study will focus on the Cretaceous series by analyzing the petrophysical properties of shale volume and porosity. This analysis will much help out by the existence of lithology description and biostratigraphy data.

Shale volume calculation can be identified layers that have high and low radioactive content (Asquith and Gibson, 1982), where low shale content indicates having low radiation levels or also referred to as clean layers. Based on this, shale volume can be used to detail the lithology profile of a well. The results of shale volume calculations is displayed in Figures 6 and 7, which complete with lithological descriptions of cutting and SWC data on the Cretaceous series.

Table 1. Well logs data.

Wireline	Koba-1		Barakan-1	
	Top (ft)	Bottom (ft)	Top (ft)	Bottom (ft)
Gamma Ray (GR)	1460	6100	1900	9914
Neutron	1481	6098.5	6822.5	9906
Density	1481	6098.5	6822	9906
Sonic	1460	5000	3800	9900

source: Promet Arafura Limited (1984)

Figure 4. Lithology profile of Koba-1 Well.

source:Union Texas (KAI) (1995)

Figure 5. Lithology profile of Barakan-1 Well.

Figure 6. Detail lithology profile at Creataceous Series based on SWC, lithology description, and linear shale volume of Koba-1 Well.
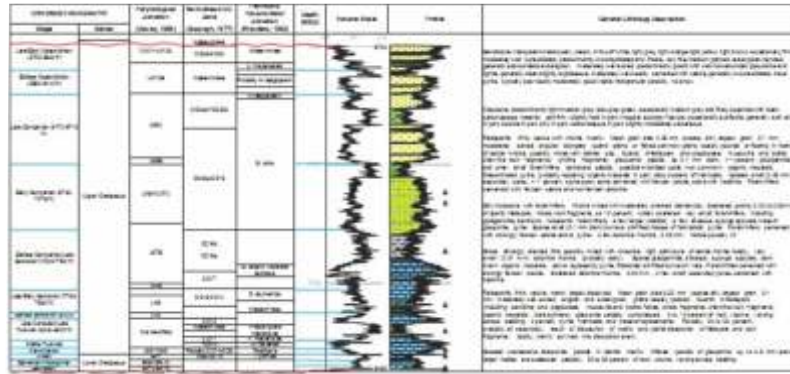
Figure 7. Detail lithology profile Creataceous Series based on cutting lithology description and linear shale volume of Barakan-1 Well.

Porosity log

After calculating the shale volume, the porosity calculation can be performed. The Koba-1 Well has laboratory analysis data for porosity data from SWC samples. Consequently, for porosity analysis of log data and validating, it can be resolved at this well.

Porosity analysis in the Koba-1 Well can be used neutron log data, density log data, and density log data. To find out the utilization of log data to be applied, it is necessary to first analyze the validity by comparing the results of the porosity analysis of some log data with the porosity data from SWC.

Five SWC porosity data of Cretaceous series intervals evaluated for validation can see in Table 2

Based on the availability of log data for porosity analysis, namely neutron log, density log, and sonic log, six methods can be applied to obtain a porosity log (Figure 8). The first method used single neutron log data, where derived this method corrected with shale factor to obtain porosity log neutron corrected Øncor. The second method used density log data, where derived this method corrected with shale factor to obtain porosity log density corrected Øde. The third method used sonic log data, where derived this method also corrected with shale factor to obtain porosity log sonic corrected Øs-sh. In contrast, the fourth method to the sixth method is a combination method of the neutron log, density, and sonic log. The fourth method is a combination of sonic log and neutron log Øs-sh ncor. the fifth method is a combination of sonic log and density log Øs-sh de, and the sixth method is a combination of neutron log and density log Ødn.

In order to be able to find out which porosity log is closer to the SWC porosity data as validation, a comparative test is carried out on the six porosity log calculation methods (Table 3). Comparative tests have been carried out using Average Relative Error (ARE) and Average Deviation from 1:1 Line (Yogi, 2018).

ARE is the quality of the average error aspect relative to SWC data. Relative error is a portion of measurement uncertainty of porosity log compared to porosity SWC. This ARE method uses the equation:

$$ARE = \frac{1}{n}\sum \left| \frac{\phi_{swc} - \phi_{log}}{\phi_{swc}} \right| \qquad (12)$$

Comparison of each of the following methods uses the average deviation from 1:1 line method, where this method calculates the number of aspects of the average deviation from the SWC data with the following equation:

$$average\ deviation\ from\ 1{:}1\ line = \frac{1}{n}\sum |\phi_{swc} - \phi_{log}| \qquad (13)$$

From the comparative test results, it can be seen that the first method using a neutron log is the method that produces the smallest error value and the smallest deviation as well. So for further analysis will use the porosity log of the neutron log for petrophysical analysis in the Arafura Basin. Therefore, porosity analysis on the Barakan-1 Well of Cretaceous series will use the Neutron log method.

Table 2. SWC core analysis results of Koba-1 Well.

Sample Number	Depth ftmd	Porosity Percent	Grain Density gr/cc
5	3945	34.8	2.67
6	4120	35.1	2.68
7	4175	33.6	2.75
8	5202	16.6	2.77
9	5446	29.9	2.66

Table 3. Comparison of each method using Average Relative Error and Average Deviation from 1:1 Line.

Method	Average Relative Error (ARE)	Average Deviation from 1:1 Line
Neuton $\varnothing_{ncor}$	0.157	0.049
Density $\varnothing_{de}$	0.192	0.056
Sonic $\varnothing_{s-sh}$	0.454	0.146
Sonic-Neutron $\varnothing_{s-sh\,ncor}$	0.306	0.098
Sonic-Density $\varnothing_{s-sh\,de}$	0.306	0.096
Neutron-Density $\varnothing_{dn}$	0.175	0.053
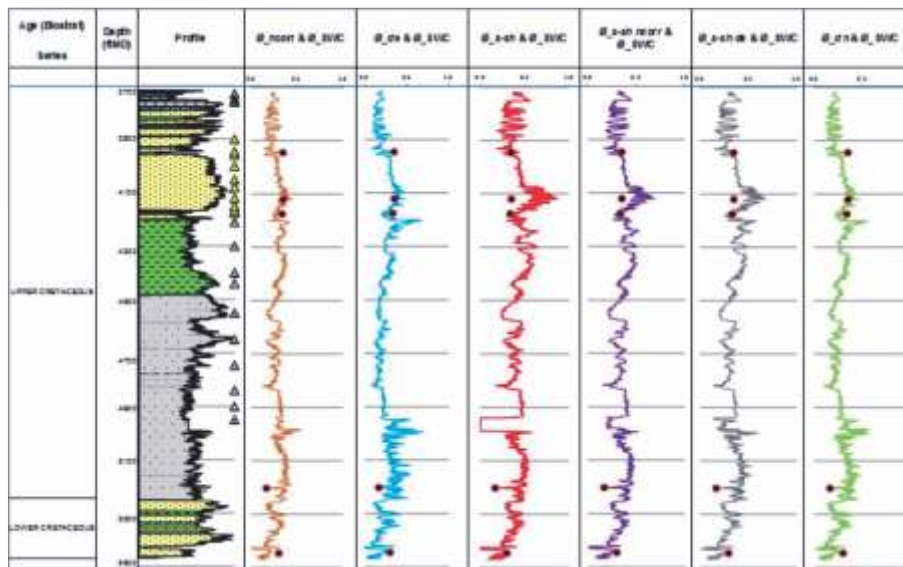
Figure 8. Comparison of porosity log and porosity SWC of Koba-1 Well.

T-R event and porosity log

Fakhruddin *et al.,* (2018) identified that at the Cretaceous series, both of Koba-1 and Barakan-1 Wells had a Transgressive and Regressive (T-R) cycle (Figure 9). From the T-R event, it indicates the distribution of petrophysical properties, especially the porosity.

The T-R event is then plotted side by side with the results of the porosity analysis on the Koba-1 Well. The result (Figure-10) shows that when the transgression event, the porosity value generally increases, and vice versa, when the regression event, the porosity value generally decreases. It reveals that there is a relationship between the T-R event with petrophysical properties in the study area. However, these results need to test on other wells, namely Barakan-1 in the Arafura Basin.

In the Barakan-1 Well, unfortunately, the neutron log data only exists at 6822.5 ftmd - 9906 ftmd intervals, so for porosity calculations at 5700 ftmd - 6822.5 ftmd intervals will use sonic logs. Figure-11 shows the porosity calculation results compared with the T-R event; the results show comparable feature as in the Koba-1 Well where during the transgression event, the porosity value generally increases, and when the regression event, the porosity value generally decreases.

source:Fakhruddin, et al (2018)

Figure 9. T-R event Jura-Cretaceous. T-R: Transgressive-Regressive; SB: Sequence Boundary; MFS: Maximum Flooding Surface.
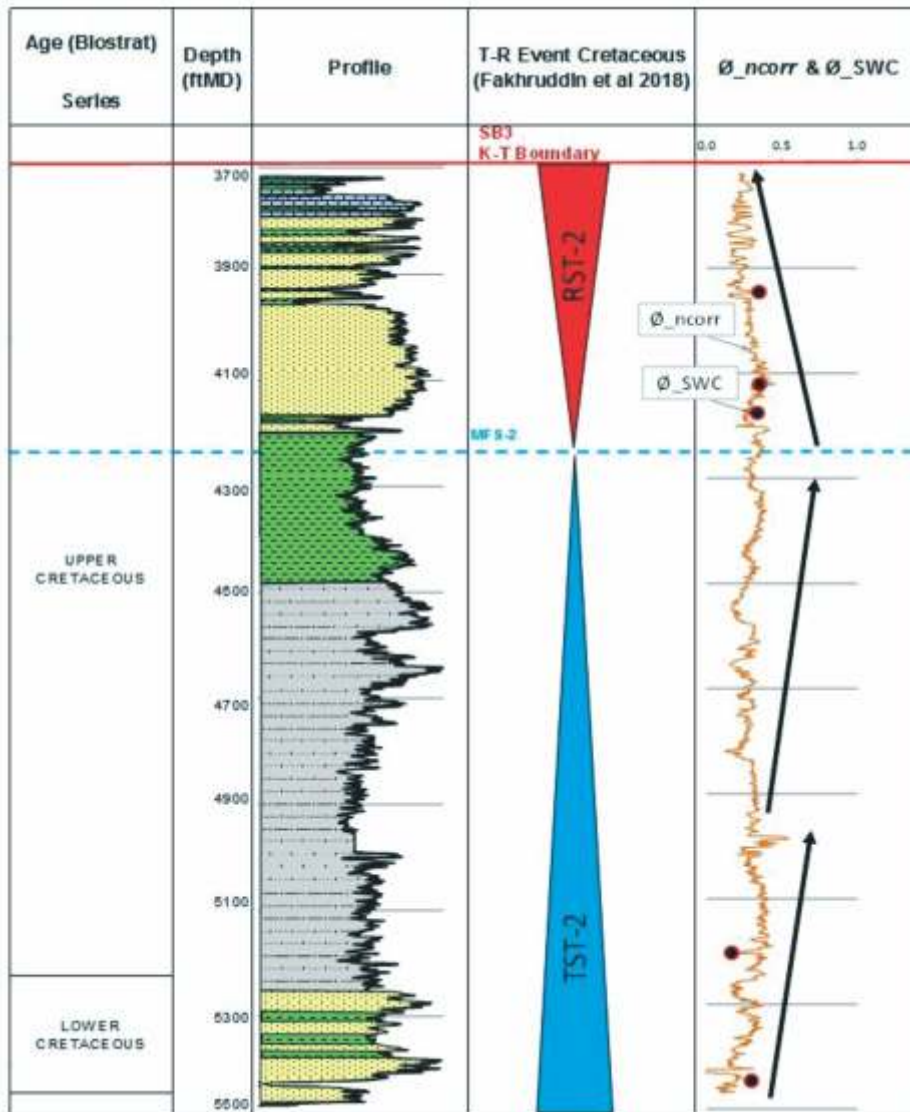

Figure 10. Comparison of porosity log and T-R Event at the Cretaceous series (Fakhruddin *et al.*, 2018) of Koba-1 Well. T-R: Transgressive-Regressive; SB: Sequence Boundary; RST: Regressive System Tract; MFS: Maximum Flooding Surface; TST: Transgressive System Tract.
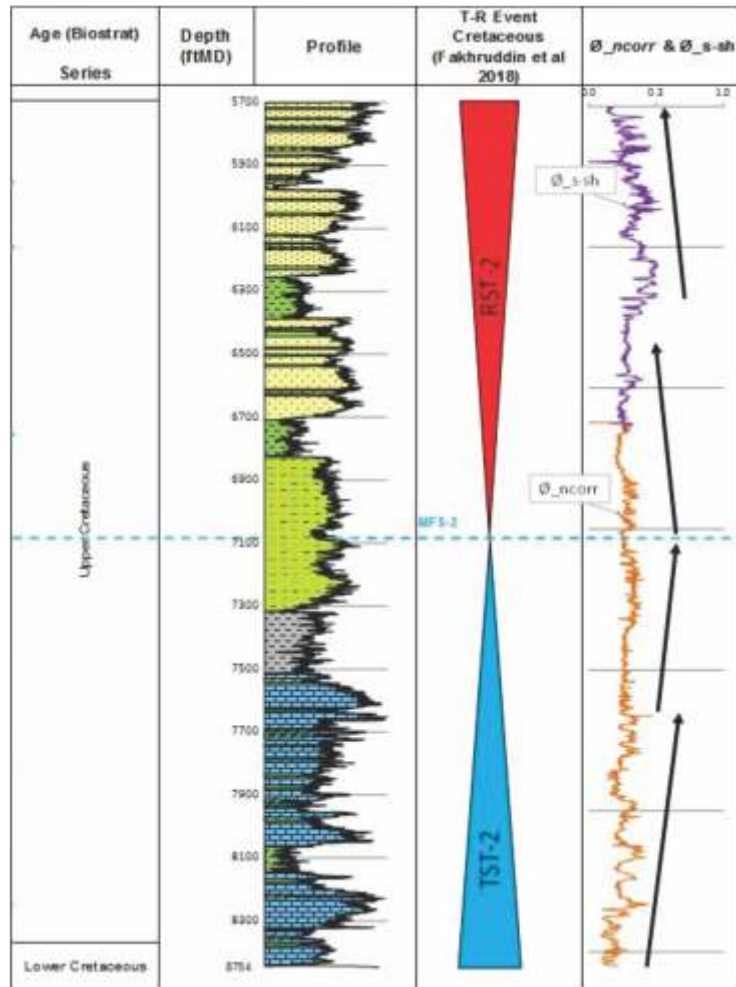
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Figure 11. Comparison of porosity log and T-R Event at the Cretaceous series of Barakan-1 Well (Fakhruddin *et al.*, 2018). T-R: Transgressive-Regressive; RST: Regressive System Tract; MFS: Maximum Flooding Surface; TST: Transgressive System Tract.

CONCLUSIONS

In addition to porosity analysis, shale volume can also be used to assist to be more detailed well lithology profiles.

With the availability of three log data for porosity analysis, namely neutron log, density log, and sonic log, six methods can be applied to obtain porosity log in Koba-1 Well. Neutron log is the method that produces the smallest error value and the smallest deviation as well based on Average Relative Error (ARE) and Average Deviation from 1:1 Line.

In both Koba-1 and Barakan-1 Wells, the porosity calculation results compared with the T-R Event in Cretaceous series, the results show that during the transgression event, the porosity value generally increases and whereas the regression event, the porosity value generally decreases.

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