Scientific Contributions Oil & Gas, Vol. 45. No. 3, December 2022: 169 - 181

SCIENTIFIC CONTRIBUTIONS OIL AND GAS
Testing Center for Oil and Gas
LEMIGAS

Journal Homepage:http://www.journal.lemigas.esdm.go.id
ISSN: 2089-3361, e-ISSN: 2541-0520

Uncovering The Potential of Low Resistivity Reservoirs Through Integrated Analysis: A Case Study from The Talang Akar Formation in The South Sumatra Basin

Fiqya Fairuz Zaemi[1], Rian Cahya Rohmana[1] and Widi Atmoko[2]

[1]Tanri Abeng University
Jl. Swadarma Raya No.58 Ulujami Pesanggrahan South Jakarta, Indonesia

[2]Patra Nusa Data
Taman Tekno BSD Tangerang, Indonesia

Corresponding author: fiqya.fairuz@student.tau.ac.id

Manuscript received: December 05th, 2022; Revised: January 10th, 2022
Approved: December 19th, 2022; Available online: January 24th, 2023

ABSTRACT - The study area is an oil and gas field that has a low resistivity reservoir zone in the Talang Akar Formation, South Sumatera Basin. The reservoir zone is composed of siltstone and sandstone that was deposited in a shallow to transitional marine environment. The aim of this study is to identify and determine the potential of low resistivity reservoirs in the study formation. The data used in the study include well log, mud log, core data (porosity, permeability, petrography), formation water analysis, and biostratigraphy. The methodology includes qualitative analysis to determine reservoir potential zones (quick look interpretation) and the reason for low resistivity reservoirs, as well as quantitative analysis to calculate petrophysical parameters. The results of the quick look analysis showed 77 low resistivity reservoir zones, but the petrophysical analysis identified 25 low resistivity reservoir zones as potential candidates for drill steam test (DST). Factors causing low resistivity reservoirs in the study area include clay mineral content (kaolinite and illite), conductive minerals (pyrite and siderite), high salinity formation water (>10,000 ppm), very fine to medium sand grain size (0.063 - 0.5 mm) distribution of clay minerals (laminated and dispersed clay), and thin laminates. The results of the petrophysical analysis show that shale volume is less than 30%, porosity is greater than 14%, permeability is greater than 10 mD, and water saturation is less than 70%.

Keywords: Formation Evaluation, Low Resistivity, Petrophysics, Talang Akar Formation.

How to cite this article:

Fiqya Fairuz Zaemi, Rian Cahya Rohmana and Widi Atmoko, 2022, Uncovering The Potential of Low Resistivity Reservoirs Through Integrated Analysis: A Case Study from The Talang Akar Formation in The South Sumatra Basin, Scientific Contributions Oil and Gas, 45 (3) pp., 169-181. DOI.org/10.23327/SCOG.45.2.33172.

INTRODUCTION

The decline in Indonesia's oil and gas production over the years can be attributed to the natural condition of the wells. Out of the 60 sedimentary basins in the country, 38 have undergone exploration (ESDM, 2021). Exploration is a crucial aspect of the oil and gas industry, and one of its components is formation evaluation. This process involves examining the characteristics and properties of rocks below the surface using wellbore measurement results. The purpose of formation evaluation is to locate a reservoir, gauge hydrocarbon reserves, and predict the amount of hydrocarbons that can be extracted. One method of formation evaluation is well logging, which involves analyzing the response of logging tools, presented in a triple combo log curve (gamma ray log, SP log, caliper log, resistivity log, neutron log, density log, sonic log, and photoelectric factor log). Generally, reservoirs that can be produced have sandstone lithology with low gamma ray values, high resistivity values, and the presence of crossover between density logs and neutron logs. However, there are several cases of reservoir production resulting from low resistivity values. This is the case for several formations in Indonesia, one of which is the Talang Akar Formation.

The Talang Akar Formation in Indonesia has been demonstrated to produce a low resistivity reservoir with a significant production value. Holis et al (2016) conducted a study on low resistivity in the Talang Akar Formation and found that the low resistivity reservoir in the formation is characterized by low gamma ray values, the presence of crossover between the neutron log and density log, evidence of hydrocarbons in total gas and oil, and has a cut-off value with very low resistivity (< 5 ohmm). The primary objective of this study is to conduct a comprehensive analysis of the potential of low resistivity reservoirs within the Talang Akar Formation. Furthermore, the research aims to examine and comprehend the underlying causes that contribute to the formation of these low resistivity reservoirs. Through this examination, the study hopes to provide valuable insights and information on the subject matter.

Theoretical Basis For Low Resistivity Reservoir

Low resistivity is a layer of oil and gas contained in a reservoir with low resistivity values from 0,5 to 10 ohmm (Ming, 2013 & Melfi, 2017), which can be difficult to accurately assess as a water layer due to the complex geological origins of the layer and the limitations of the resistivity log tool in identifying it (Ming et al., 2013). Identifying low-resistivity layers in formation evaluation has been difficult because the complex pore structure and minerals in the reservoir reduce the sensitivity of fluid in pores to conventional logs (Chu and Steckhan, 2011). Low-resistivity oil layers frequently have low resistivity contrast between brine-water bearing reservoirs and oil-bearing reservoirs (Gandhi et al., 2011).

According to Boyd et al., (1995), factors that affect low resistivity reservoirs include:

- Clay mineral content, such as illite, glauconite, kaolinite, and chlorite. The Cation Exchange Capacity (CEC) of clay minerals allows them to adsorb water on their surfaces within pores. The range of CEC values associated with different clay minerals emphasizes the necessity of accurately evaluating the total volume of clay as well as identifying the type of clay mineral present, as it significantly affects the increase in formation conductivity when clay is present (Evdokimova. 2013).
- Conductive mineral content, such as pyrite and siderite. Pyrite ($FeS2$) has a significant impact on formation resistivity, as has been demonstrated by numerous field and theoretical examples (Evdokimova. 2013).
- Salinity of formation water, formation water that has a high saline value (highly saline water) with a value of 10,000 ppm – 35,000 ppm.
- Microporosity, the presence of microporosity can cause trapped formation water so that it can increase rock conductivity.
- The thickness of the rock layer, the depositional environmental factors are the most important things in influencing the claystone layer. Formations that are thinly bedded often have resistivity anisotropy, meaning that resistivity measured perpendicular to the bedding is significantly higher than resistivity measured parallel to the bedding. Average resistivity calculated using these tools' vertical resolution can be misleadingly low and result in an overly pessimistic estimate of computed water saturation (Oifoghe, 2014).

Rohmana et al., (2017) conducted research on low resistivity reservoirs in the Gumai Formation, Jambi Sub-Basin with the aim of evaluating the causes of low resistivity and conducting petrophysical analysis. The study found that several factors can affect low resistivity: grain size (very fine sand – medium sand), clay mineral content (kaolinite, glauconite, illite, and chlorite), distribution of clay minerals (laminated clay and dispersed clay), moderate to highly saline water, and the presence of microporosity.

One of the main challenges in low resistivity reservoirs is identifying and characterizing the hydrocarbon interval, which is often difficult to discern due to the lack of resistivity contrast between hydrocarbon and water. Accurate identification and characterization of low resistivity pay is crucial for re-developing mature assets and increasing oil recovery (Rajput et al., 2019). The accuracy of current logging interpretation is not sufficient to accurately identify low resistivity reservoirs. In addition, the coexistence of low resistivity gas layers and high resistivity water layers makes it difficult to interpret well logs, which can have a significant impact on production (Su-juan, 2009). To improve the accuracy of porosity estimates, it is necessary to consider the effect of shale content and study the relationship between core porosity and logging data (Gai et al., 2015). Investigating the nature of the gamma ray response can help with lithology identification. Petrography and XRD data are also valuable in the identification of low resistivity reservoirs, as they can reveal information about the development of clay minerals (Lander et al., 2016).

There is currently no method that has been proven effective for identifying low-resistivity reservoirs (Bai et al., 2019). Various fluid identification methods have been suggested for identifying low-resistivity oil pay, including the overlap method, cross-plot method, nuclear magnetic resonance (NMR) logging method, and mathematical and statistical methods. The overlap and cross-plot methods are the most used and require the establishment of effective fluid identification parameters for success (Fan et al., 2015; Das and Chatterjee, 2018). In this study, authors using some methods from Holis et al (2016), including petrophysical analysis, core and cutting description, petrography analysis, petrophysical cross plot and cut-off analysis, and data analysis validation. This approach was used to gain a better understanding of the petrophysical role of low resistivity.

Regional Geology

The South Sumatra Basin is divided into four sub-basins: the South, North, Central Palembang, and Jambi sub-basins (LEMIGAS, 2001 in Julikah, et al., 2015). Regional physiography of the South Sumatra Basin divides the South Sumatra Basin into three parts, namely the southern Palembang sub-basin, the central Palembang sub-basin and the Jambi sub-basin (Figure 1).

During the Paleogene period, the formation of the South Sumatra Basin was influenced by NW-SE trending dextral strike-slip faults, which caused the region to develop as a pull-apart continental rift basin. The basin is divided into four sub-basins based on its paleo-structural orientations of NE-SW, WNW-ESE, N-S, and NW-SE: the Jambi Sub-basin, the North Palembang Sub-basin, the Central Palembang Sub-basin, and the South Palembang Sub-basin. In the Late Miocene, the subduction of the Indo-Australian plate under the Eurasian plate led to the compression of the Sumatra region, causing the inversion of the basin and the uplift of the Barisan Mountains. This uplift continues today and has also resulted in the creation of northwest-southeast faults and folds that later became significant hydrocarbon traps.

The stratigraphy of the South Sumatra Basin consists of a sedimentation cycle starting with the transgression phase and ending with the regression phase. The initial cycle begins with a non-marine cycle in the Lahat Formation in the Early Oligocene, followed by the Talang Akar Formation, which is unconformably deposited above it. The Talang Akar Formation consists of fluvial sediment in the lower part and delta environmental and shallow marine sediment in the upper part (Aryanto, et al., 2014). The transgression phase lasted until the Early Miocene in the Baturaja Formation, and was followed by the Gumai Formation, which was deposited above the Baturaja Formation. The regression phase begins with the Upper Gumai Formation being deposited, followed by the Air Benakat Formation in harmony with coastal and deltaic depositional environments. The Early to late Pliocene deposited the Muara Enim Formation.

The South Sumatra Basin is known for its production of oil and gas, which is indicated by the presence of many oil and gas seeps connected by anticlines. These seeps suggest the existence of hydrocarbons beneath the surface and can be used as a sign of potential exploration opportunities based on the petroleum system (Adiyat, 2018).

METHODOLOGY

The study was conducted on five wells in the Talang Akar Formation in the South Sumatra Basin. The data used included well log, mud log, core analysis (porosity, permeability, and petrographic description), and formation water analysis to determine low resistivity reservoirs, analyze the causes of low resistivity, and perform petrophysical analysis in potential zones.

The research for this study utilized a combination of qualitative and quantitative analysis (Figure 2). The qualitative analysis focused on identifying the potential zone of low resistivity reservoirs using a quick look interpretation method and determining the cause of low resistivity within those layers. The quantitative analysis was used to calculate the petrophysical parameters in the low resistivity reservoir layer zone. The petrophysical analysis was validated using core data, specifically porosity and permeability, to confirm its accuracy. The steps in this research are:

- Conducting literature study on the evaluation of formation and low resistivity
- Collecting the necessary data, such as well log data, mud log data, core data and formation water analysis for petrophysical analysis and analysis of the causes of low resistivity.
- Performing quick look interpretation to determine the low resistivity reservoir zone with values of GR, Rt, RHOB, and NPHI.
- The analysis of the causes of the low resistivity reservoir is seen in the core data, mud log data, and petrographic data (to determine the grain size of the rock, the presence of clay minerals and conductive minerals). Formation water analysis data is used to determine the salinity content of the formation water. And biostratigraphy data to determine the depositional environment of Talang Akar formation.
- Performing quantitative analysis to determine the value of clay volume (VCL), porosity, water saturation (Sw), and permeability (K) in low resistivity zone. The values that are used as cutoffs are VCL, effective porosity (PHIE), and water saturation (Sw).
- Validate the productive zone with core and mud log data, then create reservoir lumping to obtain the final results.

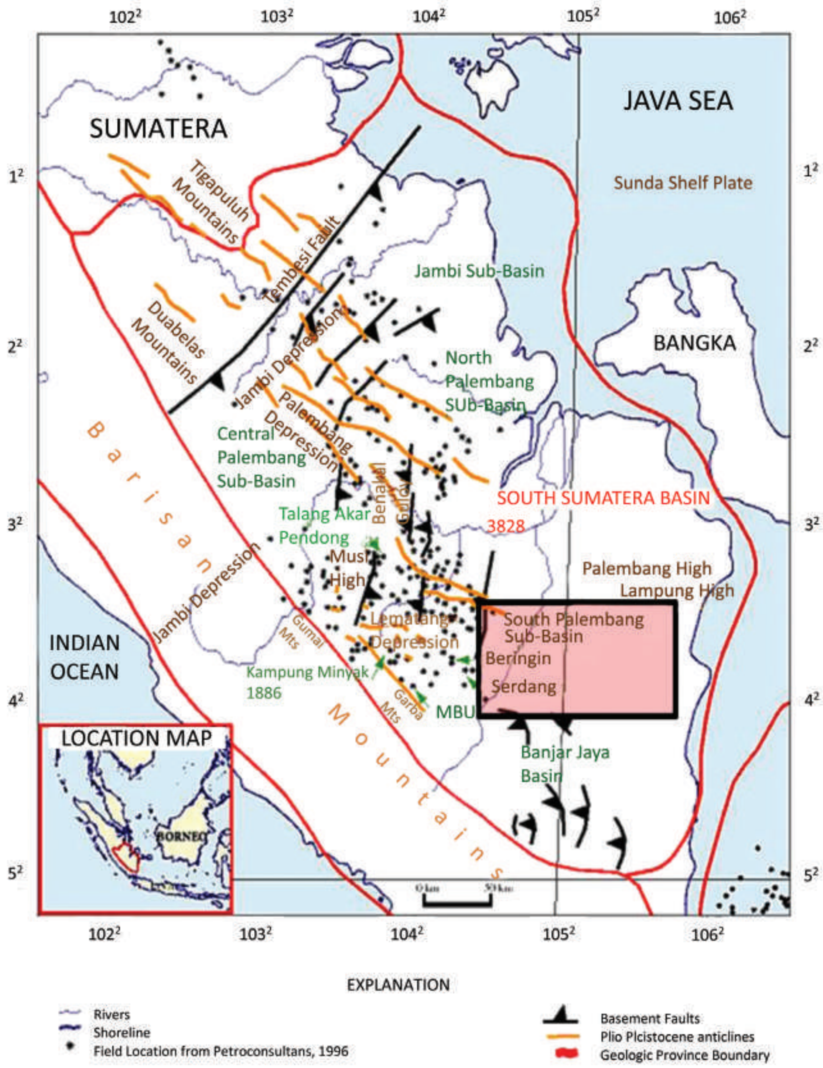

Figure 1
Study area (red box) in the South Sumatra Basin (Bishop, 2001).

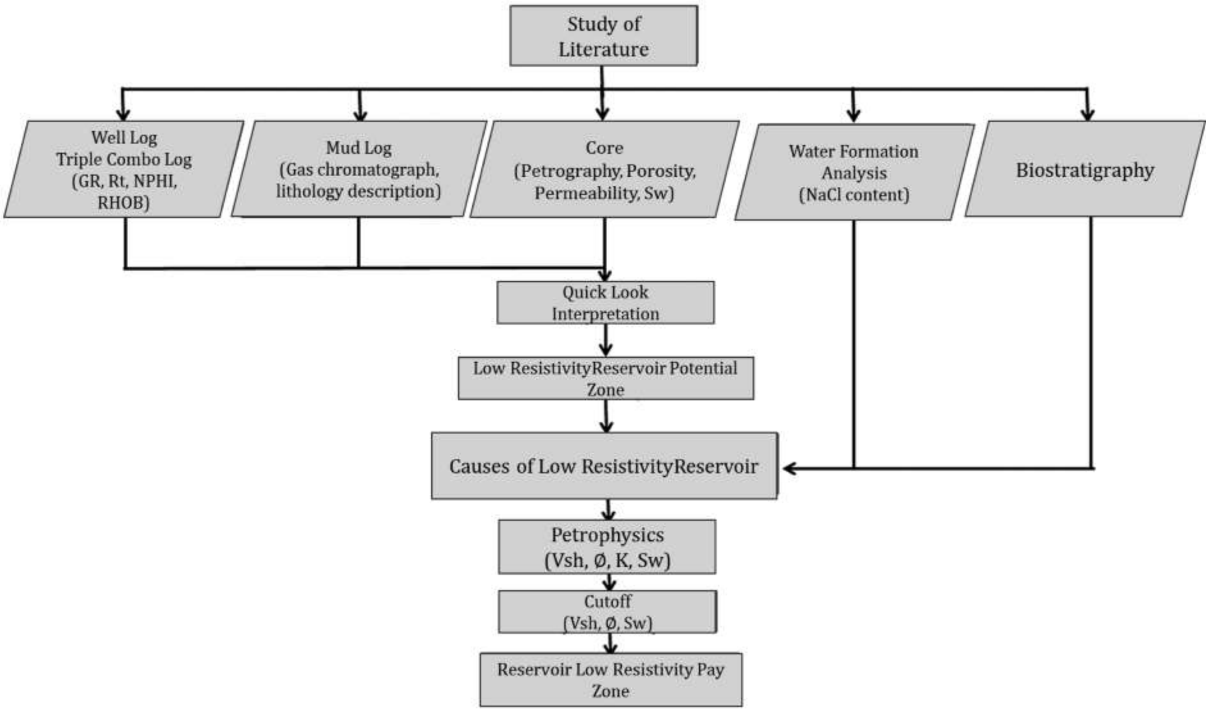

Figure 2
Research flowchart

RESULTS AND DISCUSSION

Determination of Potential Zone

The potential low resistivity reservoir zone was identified through a quick look interpretation analysis of triple combo log data (gamma ray log, resistivity log, density log, neutron log) using petrophysical software, the master log and well final report. The master log was used to measure the concentration of gas chromatograph (C1 – C5) at different depths. Data from five wells revealed the presence of potential hydrocarbon-bearing zones in the FIQ-1, FIQ-2, FIQ-3, FIQ-4 and FIQ-5 wells.

- The FIQ-1 well had 16 potential zones with sandstone lithology and resistivity values between 3 and 8 ohms, as well as gas chromatograph results showing C1 to C4.
- The FIQ-2 well had 19 potential zones with sandstone lithology and resistivity values between 1 – 8.9 ohms, as well as gas chromatograph results showing C1 to C3.
- The FIQ-3 well had 6 potential zones with sandstone lithology and resistivity values between 4 – 9 ohms, as well as gas chromatograph results showing C1 to C5.
- The FIQ-4 well had 15 potential zones with sandstone lithology and resistivity values between 1 – 7 ohms, as well as gas chromatograph results showing C1 to C5 (Figure 3a).
- The FIQ-5 well had 21 potential zones with sandstone lithology and resistivity values between 2 – 10 ohms, as well as gas chromatograph results showing C1 to C5 (Figure 3b).

Causes of Low Resistivity Reservoir

The low resistivity in the Talang Akar Formation is likely caused by the presence of very fine to medium grain sizes (0.063 – 0.5 mm) in the five studied wells, as indicated by the results of core data, mud log data, and cutting descriptions (Table 1). Sand with finer grain sizes can hold more formation water (irreducible water), which can lower the resistivity value reading.

The presence of conductive minerals, such as pyrite and siderite, in the rock can affect the resistivity value reading. In this study, four wells do not have complete core analysis, and only well FIQ-5 has enough data to study the composition and volume of clay minerals. The FIQ-5 well exhibits the presence of these minerals, as indicated by petrographic analysis. The FIQ-5 well has several potential zones with varying depths that contain these minerals, including the TA-1 zone at 2092 m (Figure 4) with pyrite, the TA-2 zone at 2307 m with pyrite, the TA-5 zone at 2436 m with pyrite, the M-13 zone at 2767 m with siderite, the TA-14 zone at 2856 m with pyrite, and the TA-17 zone at 2954 m with pyrite. Clay minerals such as illite, glauconite, kaolinite, and chlorite can contribute to the low resistivity reservoirs. The FIQ-5 well contains kaolinite and illite clay minerals, as shown by the petrographic data. The kaolinite mineral present in the FIQ-5 well has a percentage below 10%, while the illite mineral has a percentage below 2% (Table 2). Clay minerals in sandstone reservoirs can bind water, leading to low resistivity values when measured with a resistivity log tool due to the clay mineral content.

Table 1
Grain size classification on the data core in the FIQ-5 well

Depth (m)	Lithology	Grain Size (mm)	Wentworth Scale
2001.5	Sandstone	0.075 – 0.5	Very fine sand – Medium sand
2092	Sandstone	0.1 – 0.65	Very fine sand – Medium sand
2184	Sandstone	0.09 – 0.7	Very fine sand – Coarse sand
2307	Sandstone	0.1 – 1.0	Very fine sand – Coarse sand
2316	Sandstone	0.7 – 2.0	Coarse sand – Very coarse sand
2377	Sandstone	0.7 – 2.0	Coarse sand – Very coarse sand
2436	Sandstone	0.1 – 0.6	Very fine sand – Coarse sand
2478	Sandstone	0.05 – 1.0	Very fine sand – Coarse sand
2644	Sandstone	0.1 – 1.12	Very fine sand – Very coarse sand
2792	Sandstone	0.1 – 0.82	Very fine sand – Coarse sand
2856	Sandstone	0.05 – 0.75	Very fine sand – Coarse sand
2954	Sandstone	0.2 – 1.85	Fine sand – Very coarse sand

Clay minerals in well FIQ-5

Zone	Depth (m)	Clay Mineral (%)	
		Kaolinite	Ilite
TA-1	2092	4.50	-
TA-2	2307	6	1
TA-7	2436	4	2
TA-9	2478	8.50	-
TA-14	2644	7.50	-
TA-15	2767	5.5	1.3
TA-16	2856	4	-
TA-17	2901	8.75	0.75
TA-19	2954	7	-
TA-20	3012	5.5	1.25

 | DOI.org/10.23327/SCOG.45.2.33172

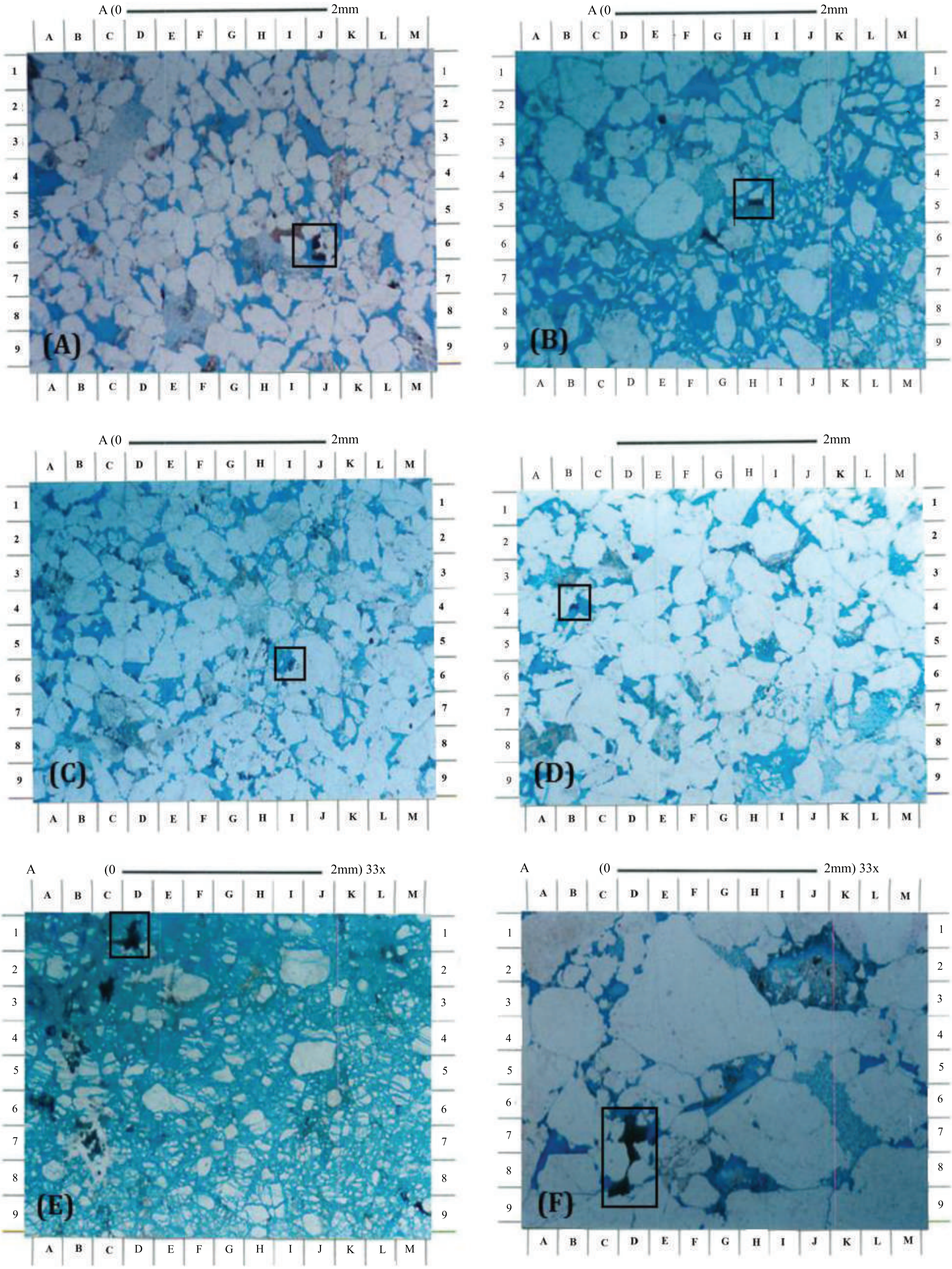

Figure 4
Petrographic data in parallel polarized light, conductive mineral pyrite (black color) in Well FIQ-5, pyrite shows in blac box; (A) Potential Zone TA-1 with a depth of 2092 m; (B) Potential Zone TA-2 with a depth of 2307 m; (C) Potentia Zone TA-5 at a depth of 2436 m; (D) Potential Zone TA-13 at a depth of 2767 m; (E) Potential Zone TA-14 at a depth of 2856 m; (F) Potential Zone TA-17 at a depth of 2954 m

The formation water in the research wells shows a high NaCl content, with a salinity of >10,000 ppm (USGS, 2018). Based on the analysis of formation water from five wells, the salinity of the formation water, as determined by the NaCl content, was classified as Highly Saline Water (> 10,000 ppm). The higher the salinity of the formation water, the lower the resistivity value, as the reservoir is likely bound to clay or shale, which can cause low resistivity values. Low resistivity values can conduct electric current (high conductor) due to the presence of water fluid.

The distribution of clay minerals was analyzed using the Thomas-Stieber Cross plot method, which included the value of total porosity versus clay volume (VCL). This analysis was conducted on five wells with low resistivity potential zones (some cross plots can be seen in Figure 5). The results showed that the FIQ-1 well has a dispersed clay zone, the FIQ-2 well also has a dispersed clay zone, the FIQ-3 well has a dispersed grain replacing zone, the FIQ-4 well has a laminated clay zone and dispersed pore filling, and the FIQ-5 well has a laminated clay and dispersed clay zone. Laminated clay minerals occur when clay minerals fill the pores of the reservoir rock, resulting in an effective porosity value of 0. Dispersed clay minerals occur when clay occupies a larger pore space than sand, decreasing the porosity value in the reservoir rock. These clay minerals in the rock can lead to low resistivity readings.

The thickness of the rock layers can impact the resistivity log reading, and this thickness is influenced by the depositional environment. According to the biostratigraphic data, the FIQ-1 well has a depositional environment of the lower upper delta

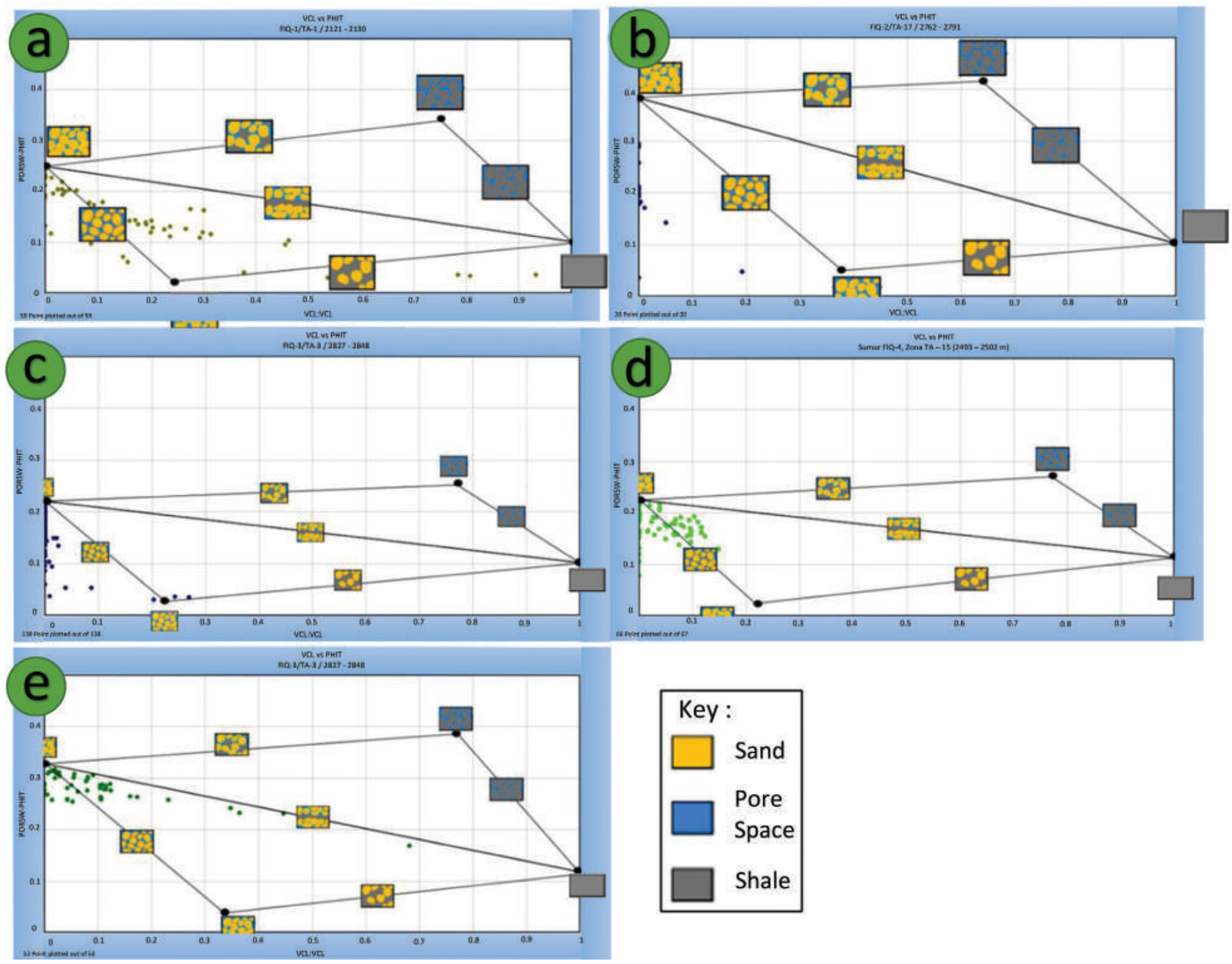

Figure 5

a) Analysis of clay mineral distribution in TA-1 zone (2121 - 2130 m) FIQ-1 well, show dispersed pore filling, b) Analysis of clay mineral distribution in TA-17 zone (2762 – 2791 m) FIQ-2 well, show some of dispersed pore filling, c) Analysis of clay mineral distribution in TA-3 zone (2827 – 2848 m) FIQ-1 well, show dispersed pore filling, d) Analysis of clay mineral distribution in TA-15 zone (2493 – 2502 m) FIQ-4 well, show dispersed pore filling, e) Analysis of clay mineral distribution in TA-1 zone (2090 – 2098 m) FIQ-5 well, show dispersed and laminated clay zone plain - the upper lower delta plain in the Talang Akar formation. The FIQ-2 well has a depositional environment of the supralittoral – neritic (upper delta plain – delta front). There is no biostratigraphic data available for the FIQ-3 and FIQ-4 wells. The FIQ-5 well has a depositional environment of the supralitoral (upper delta plain) according to its biostratigraphic data. The Talang Akar Formation in the South Sumatra Basin has a supralitoral depositional environment, namely the upper delta plain to the lower delta plain. The depositional environment of the delta has a thin complex of rocks, predominantly sandstone with interspersed with limestone and the presence of coal, thus allowing for rock lamination in the research well due to the thin layer of limestone between the sandstones.

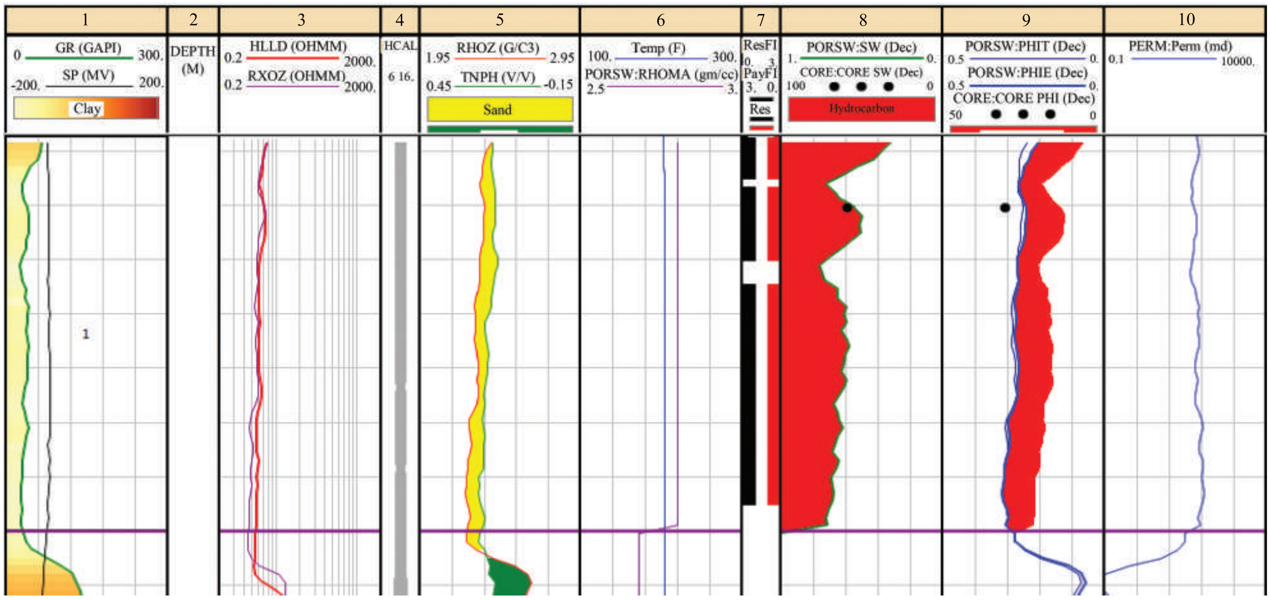

Figure 6
Results of petrophysical analysis of TA-1 zone (2090 – 2098 m) FIQ-5 well, talang akar formation, South Sumatra Basin

Petrophysical Analysis

Petrophysical analysis was conducted using petrophysical software, including the analysis of shale volume (VSH), porosity, permeability, and water saturation (SW). The shale volume for the five wells ranges from 9% to 82.7%. The porosity values, which range from poor to excellent (9-26%), with the highest porosity being found in the FIQ-5 well. Permeability analysis was conducted and showed permeability values ranging from 1 mD to 152 mD (tight to very good). The water saturation analysis was performed using the Simandoux method and the RW value on a Pickett plot. The results of the analysis showed that the water saturation values ranged from 45% to 80%. The smaller the water saturation value, the greater the hydrocarbon content (Figure 6). The results of the petrophysical analysis, including porosity, permeability, and water saturation, have been validated using core property data in several potential zones. A total of 25 DST candidates have been suggested based on the analysis of the five wells. The FIQ-5 well has the most candidates with 9, while the FIQ-1, FIQ-2, FIQ-3, and FIQ-4 wells have 8, 4, 2, and 2 candidates, respectively. These candidates were chosen from a range of potential zones, with the FIQ-2 well having the most at 19 and the FIQ-3 well having the least at 6. The results of the petrophysical analysis for each well and low resistivity reservoir zone are attached in appendices 1 through 5.

CONCLUSIONS

A quick look interpretation shows that there are 77 potential zones among the 5 wells that were studied. The FIQ-1 well has 16 potential zones, the FIQ-2 well has 19 potential zones, the FIQ-3 well has 6 potential zones, the FIQ-4 well has 15 potential zones, and the FIQ-5 well has 21 potential zones.

There are five causes of low resistivity reservoirs at the research site: the influence of grain size in rocks (very fine sand to medium sand), the presence of clay minerals in rocks, the presence of conductive minerals in rocks, the high salinity of formation water (>10,000 ppm), and the thickness of rock layers due to the influence of the depositional environment.

The results of the petrophysical analysis show that the low resistivity reservoir of the five wells has 28 DST candidates after the cutoff value (10% porosity, 39% shale volume, and 70% water saturation). Most of the DST candidates are in the FIQ-5 well. In the FIQ-1 well, there are 9 DST candidates out of 16 potential zones, the FIQ-2 well has 4 DST candidates out of 19 potential zones, the FIQ-3 well has 2 DST candidates out of 6 potential zones, the FIQ-4 well has 3 DST candidates out of 15 potential zones, and the FIQ-5 well has 10 DST candidates out of 21 potential zones.

ACKNOWLEDGEMENT

The authors would like to thank Patra Nusa Data and ESDM for supporting all data in this study. We are thankful for the numerous support from Qosha Baihaqie and all Petroleum Engineering, TAU lecturers. Lastly, we thank the Scientific Contributions Oil & Gas (SCOG LEMIGAS) reviewer and committee for published this paper.

GLOSSARY OF TERMS

Symbol	Definition	Unit
DST	Drill steam test	
mm	Millimeter	
m	Meter	
ppm	Parts per million	
mD	millidarcy	
Ohmm	Ohm meter	

REFERENCES

Adiyat, R. M. (2018). Paleogeographic stratigraphic sequence analysis in the RMA field based on log and seismic data of the Talang Akar Formation, South Sumatra Basin. Universitas Indonesia.

Aryanto, M. D., Darsono, D., Julikah, J., & Purba, H. (2014). Reservoir Characterization Using Simultaneous Inversion to Delineate Hydrocarbon Reservoir. Scientific Contributions Oil and Gas, 37(3), 185-194.

Bai, Z., Tan, M., Li, G., & Shi, Y. (2019). Analysis of low-resistivity oil pay and fluid typing method of Chang 81 Member, Yanchang Formation in Huanxian area, Ordos Basin, China. Journal of Petroleum Science and Engineering, 175, 1099-1111.

Bishop, M. G. (2001). South sumatra basin province, indonesia: the lahat/talang akar-cenozoic total petroleum system. Denver, Colorado, USA: US Geological Survey.

Boyd, A., Darling, H., Tabanou, J., Davis, B., Lyon, B., Flaum, C., Klein, J., Sneider, R. M., Sibbit, A., & Singer, J. (1995). The Lowdown on Low-Resistivity Pay. Oilfield Review 7, no 3.

Chu, W.C., Steckhan, J. (2011). A practical approach to determine low-resistivity pay in clastic reservoirs. SPE Annual Technical Conf. and Exhibition, Denver, Colorado, USA.

Das, B., Chatterjee, R. (2018). Well log data analysis for lithology and fluid identification in Krishna-Godavari Basin, India. Arab. J. Geosci. 11 (10) 1866-7511.

Evdokimova E. (2013). Log Evaluation in Low Resistivity Formation of Tomsk Region Oil Fields. SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, USA.

Fan, Z.Q., Yang, G.P., Ding, X., Yang, L., Zhou, W., Zhu, Y.J., Yang, Q.W., Sun, J.W. (2015.) The well fluid identification method and its application for tight sandstone gas reservoir of Shan 2 reservoir in Zizhou gasfield. Natural Gas Geoscience 26 (6), 1113–1119.

Gai, S., Liu, H., He, S., Mo, S., Lei, G., Huang, X., Yang, Y. & Liu, R. (2015). Reinterpreting the Low-resistivity Reservoir by Using New Logging Model: A Case Study from a Block in Sulige Tight Gas Field. SPE Middle East Oil & Gas Show and Conference.

Gandhi, A., Kubik, P., Termina, J.J., Rocque, T., Volkmar, M. (2011). Low resistivity petrophysical mapping expands the terry (sussex) play in Wattenberg field. Colorado SPWLA 52nd Annual Logging Symp, pp. 14–18.

Holis, Z., Prayogi, A., Purwaman, I., & Damayanti, S. (2016). The Petrophysic Role of Low Resistivity Pay Zone of Talang Akar Formation, South Sumatera Basin, Indonesia. Society of Petroleum Engineers. SPE-182448-MS

Julikah, J., Sriwidjaya, S., Hadimuljono, J. S., & Panuju, P. (2015). Hydrocarbon Shale Potential In Talang Akar And Lahat Formations On South And Central Palembang Sub Basin. Scientific Contributions Oil and Gas, 38(3), 213-223.

Melfi, F. M., Setyowiyoto, J., Wintolo, D., & H, M. Y. H. (2017). Evaluasi petrofisika low-resistivity pada potensi reservoir hidrokarbon formasi gumai cekungan sumatera selatan. Seminar Nasional Kebumian Ke-10, September, 590–599.

Ming, L., Haimin, G., Jun, L., Hong, Y., En, X., & Yun, Y. (2013). A method to identify low resistivity reservoir for the N1 reservoir of Shizigou oilfield of northwest Qaidam. Proceedings - 2013 International Conference on Computational and Information Sciences, ICCIS 2013,1257–1260.

Oifoghe S. (2014). Challenges in Identifyng and Quantifying Hidrocarbons in Thinly Bedded, Laminated, and Low-Resistivity Pay Zones. OTC Asia held in Kuala Lumpur, Malaysia.

Rajput, S., Bt Abdullah, I., Roy, A., B Khalid, A., Onn, C., & Khalil, A. (2019). Characterizing Thinly-Bedded Low Resistivity Reservoirs in Mature Fields. In SPE Annual Technical Conference and Exhibition.

Rohmana, R. C., Setyowiyoto, J., Husein, S., Indra, Y., & Ramadhan, A. (2017). Evaluasi dan perbandingan reservoir low-resistivity formasi cibulakan atas, cekungan jawa barat utara dengan formasi gumai, sub-cekungan jambi. Seminar Nasional Kebumian Ke-10, September.

Su-juan, Jing (2009). The well log interpretation research of low resistivity gas zone in the Sulige eastern area. Chang'an University, Xi'an, China.

United States Geological Survey. (2018). Saline Water and Salinity. From: https://www.usgs.gov/special-topics/water-science-school/science/saline-water-and-salinity#overview.

Appendix 1
Low resisitivity reservoir lumping in FIQ-1 well.

Well	Zone	Depth (m)	Thickness (m)	Rt (ohmm)	Average Vsh (%)	Average Porosity (%)	Average Permeability (mD)	Average Sw (%)	Pay (m)
FIQ-1	TA-1	2121 – 2130	9	6.3	27.7	14.8	23.4	68	5.64
	TA-2	2201 – 2208	7	6.9	21.5	21.5	124.5	70.8	5.74
	TA-3	2238 – 2242	4	8.1	31.9	16.8	61.3	68	3.02
	TA-4	2373 – 2380	7	2.4	11.3	18.6	11.8	80	0.15
	TA-5	2411 – 2419	8	3.8	10.4	22.3	75.3	56	5.23
	TA-6	2434 – 2440	6	4.3	82.7	13	10	52	1.89
	TA-7	2460 – 2466	6	3.5	12.8	18.5	15	68	2.74
	TA-8	2476 – 2491	15	3.4	15.1	16.1	12.7	69.1	7.62
	TA-9	2557 – 2567	10	5.2	31.9	9.3	2	64.2	4.92
	TA-10	2678 – 2682	4	5.3	14.3	15.8	18.1	61.8	3.05
	TA-11	2691 – 2694	3	4.9	14.6	17.3	10.8	63.6	1.98
	TA-12	2825 – 2840	15	6.2	9.1	14.6	8.4	64	8.69
	TA-13	2853 – 2861	8	3.4	15	16	5.4	68.2	2.44
	TA-14	2868 – 2877	9	3.9	14.4	15.7	7.5	64.2	7.62
	TA-15	2918 – 2927	9	4.4	15.1	14.1	3.8	72	2.13
	TA-16	3018 – 3025	7	5.9	14.1	16.7	12.7	61	4.41

Appendix 2
Low resisitivity reservoir lumping in FIQ-2 well.

Well	Zone	Depth (m)	Thickness (m)	Rt (ohmm)	Average Vsh (%)	Average Porosity (%)	Average Permeability (mD)	Average Sw (%)	Pay (m)
FIQ-2	TA-1	2167 – 2179	12	1.6	25.6	18.5	14.1	74.3	0.61
	TA-2	2245 – 2248	3	2.4	20.5	19.3	69	60.2	1.37
	TA-3	2257 – 2263	6	2.4	17.3	20	152.7	65.3	1.77
	TA-4	2294 – 2307	13	1.9	10.1	18.6	12.3	74.5	0.61
	TA-5	2320 – 2329	9	2	32.9	15.3	6.8	71.8	2.35
	TA-6	2372 – 2380	8	2.3	24.7	16.5	20.9	65.2	2.94
	TA-7	2283 – 2391	8	2.4	17.3	16.1	7.9	69.8	1.6
	TA-8	2426 – 2432	6	3.2	22.9	15.9	70.5	57.5	1.45
	TA-9	2481 – 2494	13	3.1	17.4	14.7	6.8	62.6	5.49
	TA-10	2520 – 2525	5	3.8	11.4	14.4	4.8	68.6	2.55
	TA-11	2556 – 2562	6	3.3	14.1	14.4	5.1	69.4	1.98
	TA-12	2592 – 2602	10	4.5	16.3	13.2	4.9	62.2	7.01
	TA-13	2606 – 2616	10	4.3	17.3	12	3.4	63.3	5.18
	TA-14	2669 – 2675	6	3.8	31.7	10.4	1.4	73.7	0.46
	TA-15	2690 – 2696	6	4.5	12.9	13.6	4.9	61.6	4.42
	TA-16	2731 – 2740	9	6	14.2	11.5	2.9	61.1	5.56
	TA-17	2762 – 2791	29	7.6	11.6	11.5	3.1	53.5	24.84
	TA-18	2865 – 2870	5	6	32.8	11	5.6	48.8	2.82
	TA-19	3001 – 3011	10	8.9	19	10	2.2	50.8	6.25

Appendix 3
Low resisitivity reservoir lumping in FIQ-3 well.

Well	Zone	Depth (m)	Thickness (m)	Rt (ohmm)	Average Vsh (%)	Average Porosity (%)	Average Permeability (mD)	Average Sw (%)	Pay (m)
FIQ-3	TA-1	2708 – 2718	10	9.4	11.5	19.1	27.3	54.1	8.99
	TA-2	2754 – 2759	5	7.1	25.2	13.8	8.9	68.5	1.83
	TA-3	2827 – 2848	21	7.4	18.7	15.9	13	54.6	17.68
	TA-4	2862 – 2870	8	4	15.1	16.1	7	73.3	1.07
	TA-5	2877 – 2886	9	4.4	11.4	15.3	4.7	75.7	0.46
	TA-6	2927 – 2938	11	6.1	45.7	9	3.8	66.9	2.29

Appendix 4
Low resisitivity reservoir lumping in FIQ-4 well.

Well	Zone	Depth (m)	Thickness (m)	Rt (ohmm)	Average Vsh (%)	Average Porosity (%)	Average Permeability (mD)	Average Sw (%)	Pay (m)
	TA-1	2244 – 2256	12	1.7	18.2	17.8	11	79.5	5.4
	TA-2	2267 – 2275	8	1.8	14.5	17.4	9	83.3	6.17
	TA-3	2279 – 2285	6	2.2	42.2	11.1	7.1	88.5	2.23
	TA-4	2289 – 2295	6	1.4	19	18.5	12.1	84.4	3.52
	TA-5	2302 – 2306	4	1.7	30.8	16.1	20.2	83.1	2.25

	TA-6	2310 – 2325	15	1.7	12.3	19.8	17	72.8	9.75
	TA-7	2337 – 2342	5	1.7	14.7	19.1	17.3	74	4.33
FIQ-4	TA-8	2348 – 2361	13	2.2	10.6	17.9	12.4	70.4	9.75
	TA-9	2366 – 2371	5	2	18.5	16.4	10.7	79.2	2.57
	TA-10	2383 – 2391	8	2	10.4	18.7	13.7	68.7	7.20
	TA-11	2432 – 2438	6	7.7	29.1	9.8	38.5	64.6	3.77
	TA-12	2449 – 2459	10	2.7	28.8	12.3	4.3	76	5.53
	TA-13	2475 – 2479	4	2.4	32.5	12.4	6.4	81.1	1.57
	TA-14	2482 – 2488	6	5.4	38.1	9.9	3.8	73.3	1.48
	TA-15	2493 – 2503	10	3.7	14.8	15.7	16.1	57.2	9.07

Appendix 5
Low resisitivity reservoir lumping in FIQ-5 well.

Well	**Zone**	**Depth (m)**	**Thickness (m)**	**Rt (ohmm)**	**Vsh (%)**	**Porosity (%)**		**Permeability (mD)**		**Water Saturation (%)**		**Pay (m)**
						Calc.	***Core***	**Calc.**	***Core***	**Calc.**	***Core***	
	TA-1	2090 – 2098	8	2.2	13.4	26	30.62	72.5	85	58.8	59.12	6.3
	TA-2	2305 – 2309	4	3.3	10.5	24.6	32.8	68	127	56.6	51.14	3.73
	TA-3	2314 – 2317	3	6.5	26.9	22.5	14.57	38.1	0.12	58.3	65.91	2.77
	TA-4	2375 – 2380	5	4.5	13.8	19.5	33.12	37.6	182	49.1	49.26	4.35
	TA-5	2383 – 2391	9	3.5	76.8	20.1	-	28.8	-	55	-	7.48
	TA-6	2411 – 2417	6	9	53.7	16.3	-	32.4	-	67.4	-	1.8
	TA-7	2429 – 2438	9	6.8	40.7	19.2	26.39	40.4	49	50	55.1	3.62
	TA-8	2444 – 2452	8	3.6	24.1	19.2	-	18.4	-	65.3	-	5.25
	TA-9	2474 – 2496	22	4.8	14.5	19.2	21.89	23.2	74	58.4	62.86	16.5
	TA-10	2504 – 2509	5	5.5	34	15.3	-	12.9	-	72.3	-	3.3
FIQ-5	TA-11	2510 – 2513	3	5.8	16.1	16.5	-	8.2	-	67.5	-	1.35
	TA-12	2521 – 2550	29	6.4	13	17	-	10.9	-	63.4	-	15.75
	TA-13	2553 – 2567	14	4.2	16.4	16.8	-	8.3	-	75.8	-	2.55
	TA-14	2629 – 2652	23	6.7	18	20.1	30.64	44.8	105	45	50.53	19.35
	TA-15	2762 – 2776	14	6	20.6	15.4	-	6.8	-	66	-	7.2
	TA-16	2854 – 2859	5	6.5	15.4	16.7	26.42	12.1	-3	75	57.11	1.35
	TA-17	2897 – 2915	18	6.5	15.5	15.7	-	6.3	-	67.5	-	10.95
	TA-18	2933 – 2940	7	5.2	18.7	14.1	-	6	-	76.8	-	1.95
	TA-19	2950 – 2957	7	7.2	18	20.9	30.98	42.7	-3	54.1	51.8	5.85
	TA-20	3010 – 3017	7	10.8	12.5	13.5	-	3.1	-	74.1	-	1.65
	TA-21	3092 – 3098	6	8.5	60	12.2	-	29.6	-	76.3	-	0.43