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INSIGHT ON IDENTIFYING LOW RESISTIVITY PAY ZONES FOR SANDSTONE RESERVOIR IN SOUTH SUMATRA BASIN AND SANGA SANGA BLOCK, INDONESIA.

DWIHARSO NUGROHO*[1], ALFEND RUDYAWAN[1], HILMI AMMARSYAH PUTRA[2]

1. Geodynamics and Sedimentology Research Group, Faculty of Earth Sciences and Technology, Institut Teknologi Bandung (ITB), Jl. Ganesha No.10, Bandung, Jawa Barat, Indonesia.
2. Lembaga Afiliasi Penelitian dan Industri (LAPI) - Institut Teknologi Bandung (ITB), Jl. Dayang Sumbi No.7, Bandung, Jawa Barat, Indonesia.

*Correspondence: nuki.dnugroho@geodin.net

Abstract - Low resistivity pay zones (LRPZ) are not the primary targets in most development fields. The challenge is to identify it and define its reservoir petrophysical properties besides the classic analysis of the genetics of the LRPZ. It is important to note that most LRPZ is caused by reasons directly linked to the petrophysical parameters as main constraints on defining the reservoir (petrophysical) properties. It has consequences that the petrophysical parameters for LRPZ should be defined separately from picking the parameters for normal high resistivity on the other part of the wells. This paper proposed simple methods to predict the LRPZ using the primary well logs data. It also shares some decisions made in South Sumatra, and Sanga Sanga Block results in a pretty successful story relatedly. The first method is a simple petrophysical analysis using primary wireline log data which is done by applying a particular cutoff that has been exercised on some wells in the basin-wise well test data to get field references in the same basin/subbasin (in this case is South Sumatra Basin). The second method is identifying and analyzing LRPZ using well-known MRGC (Multi-Resolution Graph-Based Clustering), commonly used on electro facies and rock type analysis and has never been used to define LRPZ. This study proved that these two methods performed well as LR pay zone prediction and significantly added new pay zones to increase the chance of getting additional reserves and production.

Keywords: Low Resistivity Pay Zone, petrophysics analysis, Multi-Resolution Graph-Based Clustering (MRGC), South Sumatra Basin, Sanga Sanga Block

Sari - Pada pengembangan suatu lapangan migas, Zona Pay Resistivitas Rendah (ZPRR) umumnya bukanlah merupakan target utama. Tantangan pada pengembangan ZPRR pada suatu lapangan migas adalah dalam mengidentifikasi kehadiran ZPRR dan kemudian menentukan nilai properti petrofisiknya, selain yang saat ini lebih lazim dibicarakan dalam artikel-artikel tentang ZPRR adalah tentang analisis proses penyebab terjadinya ZPRR. Dalam prespektif analisis petrofisika reservoir, penting dicatat bahwa terbentuknya ZPRR umumnya disebabkan oleh hal-hal yang terkait dengan parameter-parameter petrofisikanya. Parameter petrofisika, seperti densitas matrik (Rhoma), densitas fluida (RhoF), resistivitas air formasi (Rw), dan lain-lain, adalah variabel penting dalam penentuan properti petrofisika reservoir. Karena terkait secara langsung maka pemilihan parameter petrofisika untuk ZPRR harus dilakukan secara terpisah dari pemilihan parameter untuk zona pay hidrokarbon normal yang beresistivitas tinggi. Paper ini terutama bertujuan untuk mengusulkan metoda sederhana dalam memprediksi kehadiran ZPRR dengan memanfaatkan data log tali-kawat dasar yang terdapat pada hampir semua sumur pemboran. Tulisan ini juga bermaksud untuk berbagi pengalaman yang telah dikerjakan di Cekungan Sumatera Selatan dan Blok Sanga Sanga yang cukup berhasil membuktikan kehadiran hidrokarbon di interval ZPRR. Metoda pertama adalah analisis petrofisika sederhana menggunakan data log tali-kawat dasar dan dilakukan dengan mengaplikasikan nilai ambang tertentu (untuk mengidentifikasi ZPRR) yang dianalisis dari hasil uji sumur pada beberapa ZPRR (yang terbukti menghasilkan hidrokarbon) pada skala cekungan (dalam studi ini Cekungan Sumatera Selatan) agar dapat dijadikan referensi tentang nilai ambang yang dapat dipakai dalam identifikasi ZPRR di suatu lapangan (yang umumnya tidak memiliki cukup data teruji pada interval ZPRR). Metoda kedua mengidentifikasi ZPRR dengan menggunakan metoda MRGC (Multi Resolution Graph-Based Clustering) yang lazimnya digunakan dalam analisis fasies-elektro dan belum pernah digunakan dalam analisis ZPRR sebelum ini. Studi ini telah mencatat pembuktian (dengan uji sumur) bahwa kedua metoda dapat digunakan dengan baik untuk mengidentifikasi ZPRR dan secara signifikan menambah jumlah zona pay dan meningkatkan jumlah cadangan dan produksi migas pada kedua area studi.

Katakunci : Zona Pay Resistivitas Rendah, Analisis Petrofisika, *Multi Resolution Graph-Based Clustering (MRGC)*, Cekungan Sumatra Selatan, Blok Sanga-Sanga

1. INTRODUCTION

A Low Resistivity pay zone (LRPZ) is an interval that lacks positive contrast in measured electrical resistivity that contains a commercial quantity of Hydrocarbon (Worthington, 1997) (**Figure 1**). LRPZ is not the primary target in most development fields, yet the study shows that hydrocarbon in place volume (OOIP/OGIP) from these pay zones is significant. Usually, this oversight is because the typical petrophysical analysis for these zones is done along with "normal" pay zones (high resistivity pay zone) using the same petrophysical parameters (i.e., RhoMa, RhoSh, RhoF, Rw, etc.), which undermines the chance to appraise these intervals (LRLC pay zones) and estimate their applicable petrophysical properties (such as Porosity, Water/HC Saturation, etc.).

It is important to note that most LRPZ are caused by reasons that are directly linked to the petrophysical parameters themselves, such as dispersed and/or laminated shale sand reservoirs, freshwater content reservoirs, fine-grained reservoirs, superficial microporosity, microporosity, and conductive minerals (Boyd, 1995; Worthington, 1997; Worthington, 2000). These *petrophysical parameters* (i.e., RhoMa, RhoSh, RhoF, Rw, etc.) should be defined before applying petrophysical mathematical equations and using log data to estimate the *petrophysical properties* (i.e., Porosity, Permeability, Water/HC Saturation, etc.). For instance, to calculate porosity density (PhiD), the density matrix (RhoMa) and density fluid (RhoF) as petrophysical parameters should be defined prior to performing the calculation. The petrophysical parameters, in general, relate to the mineralogy of the matrix, fluid chemistry within the formation, and other textural and/or diagenetic condition of the reservoir. These combinations of factors imply that the LRPZ should be analyzed in a different cluster distinguished from the "normal" high resistivity pay zones to get petrophysical parameters that are different from the "normal" high resistivity hydrocarbon (HC; oil and/or gas) pay zones.

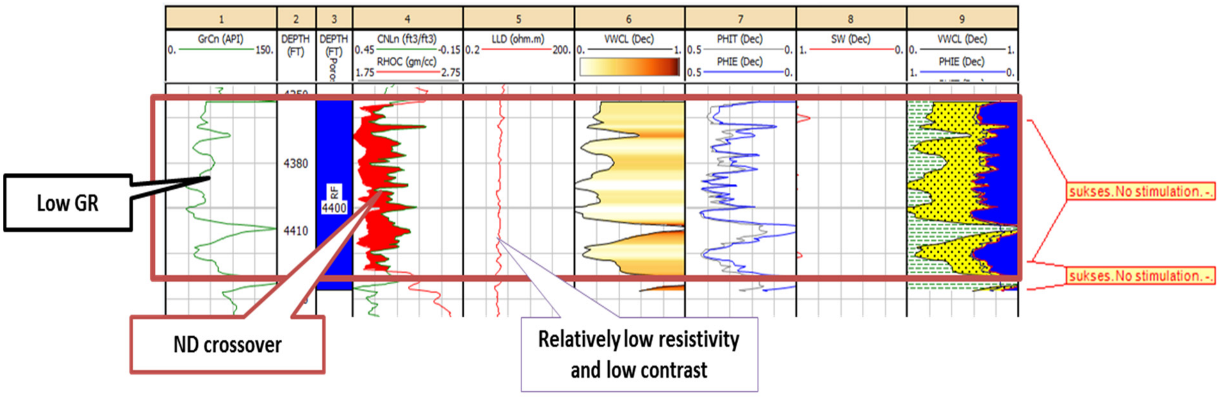

Figure 1. An example of a Low Resistivity pay zone (LRPZ) in the South Sumatra Basin is an interval that lacks positive contrast (low contrast) and/or low measured electrical resistivity (low resistivity), yet it contains a commercial quantity of hydrocarbon.

As mentioned before, on most HC field development strategies, a LRPZ is counted as an upside potential, not a primary target. That makes it common for the LRPZ to have limited data outside of the usual petrophysical data (wireline and mud log) that are almost always provided with every well-bores. Simple and quick methods for evaluating LRPZ are needed, and even critical, to find the multi causes for these pay zones in certain fields. The challenge, then, is how to predict (previously) the zones using the basic well log data since, in most cases, there are no analyzed rock samples taken from the LRPZ to identify the genetic aspect controlling the zones regarding as it is not the primary target.

This paper proposes simple methods to predict the LRPZ using the basic well logs data and shares some decisions made in South Sumatra and Sanga Sanga Block (using data from LAPI ITB – Vico Indonesia, 2015 and PT. Gada Energi – SKK Migas, 2016) that result in a quite successful story.

1. THE FIRST METHOD: QUICK LOOKED LRPZ ANALYSIS (SOUTH SUMATRA BASIN CASE)

The first method of identifying the LRPZ is by applying a certain cut-off and exercising the cut-off on some wells in the basin (South Sumatra Basin) that, for some reason, have had well test data on LRPZ. The main idea is to use basin-wide well test data to generate specific field references within the basin. The comparable former method of using cut-off resulted in a linear and single wireline log basis cut-off that needed some random well tests on that field itself (to ensure consistency and reliability, resistivity cut-off, Vshale cut-off, etc.). That is usually hard to do since LRPZ are not the primary targets (the amount of well tests taken for the LRPZ is limited or even absent in most fields). Collecting basin-wide tested LRPZ expands the number of tested intervals and makes the cut-off function more representative and robust. The most important fact is that the cut-off, in this case, is not linear but a multi-log curves function.

The procedures for defining and analyzing LRPZ using Quick Looked LRPZ Analysis Method are as follows:

1.1. Inventorying tested LRP Zones in the South Sumatra Basin.

The first step in Quick Looked LRPZ Analysis Method is inventorying all tested LRPZ available in the same basin/sub-basin or fields cluster. In this case, ten wells in South Sumatra Basin have been tested as hydrocarbon pay zones and show relatively low resistivity value or low contrast compared to wet zones or non-reservoir zones above and below (**Table 1**).

Table 1. List of wells in the South Sumatra Basin that have been tested (DST) as pay zone in low resistivity and low contrast intervals.

Well name	Sub-Basin	Interval Formasi	GR GAPI	Rt Ohm.m	NPHI v/v	RHOB gr/cc	TG units
AKT-1	Jambi	Lower TAF	~60	3-3.5	0.16	2.3	363.5
SLG-1	Jambi	Lower TAF	~70	3-3.5	0.22	2.3	20
PU-1	Jambi	Lower TAF	-85	4-5	0.18	2.3	10
KAG-24	South Palembang	BRF	37– 53	3.9-4.1	0.25	2.27	12
GRH-1	South Palembang	BRF	51-60	5.3-5.6	0.14	2.40	-
FZ-2	South Palembang	BRF	35-50	2.4-3.1	0.20	2.23	-
SK-4	South Palembang	BRF	31-34	2.5-3.3	0.06	2.33	-
GDR-1	South Palembang	U TAF	61-66	2-4	0.16	2.44	17.6
HBS-1	South Palembang	U TAF - L TAF	27-33	2.8-3.1	0.24	2.26	120
GNY-1	South Palembang	Lower TAF	57-68	5.4-6.7	0.14	2.43	144
AKV-1	South Palembang	Upper TAF	85-96	1.8-3	0.26	2.26	36

Thomas-Stieber Vsh-Phie plot (1975) and petrographic analysis on those ten wells show that at least two conditions cause most LRPZ of the Talang Akar Formation in the South Sumatra Basin. First, the LRPZ interval predominantly contains *dispersed-laminated shale* (Figure 2), which indicates the possibility that LRPZ is caused by the presence of *fine-grained reservoirs* or *superficial porosity* refers to LRPZ categories by Boyd (1995)

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(**Figure 2**). Secondly, a significant amount of pyrite, siderite, and glauconite minerals is suspected as a mineralogical factor causing conductivity increase (lowering resistivity) in this formation (**Figure 3**).

All LRPZ analysis available on tested (DST) wells (**Figure 4**) will be used as data on defining cut-off function steps, as explained in the next paragraph. Tested LRPZ intervals also will be used as a validator for identifying LRPZ using this first method in this paper.

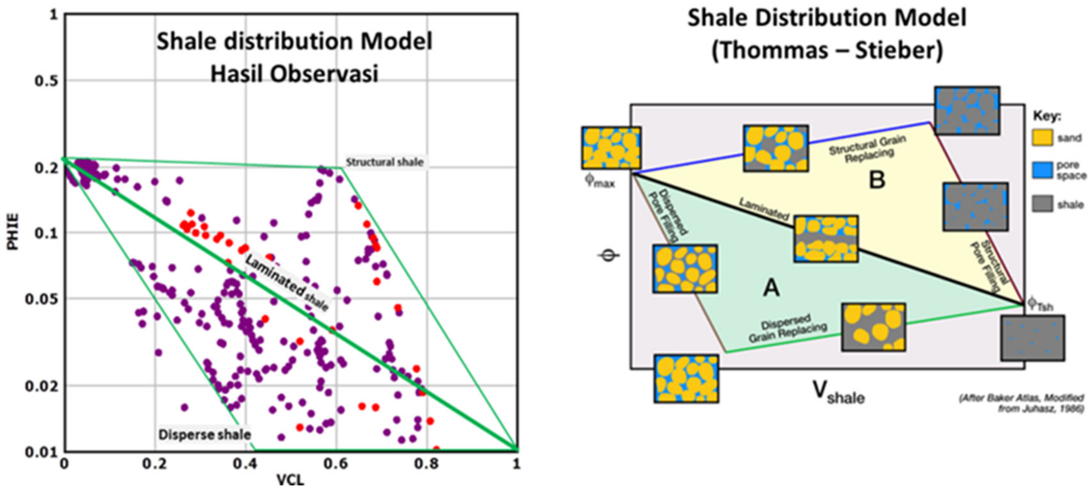
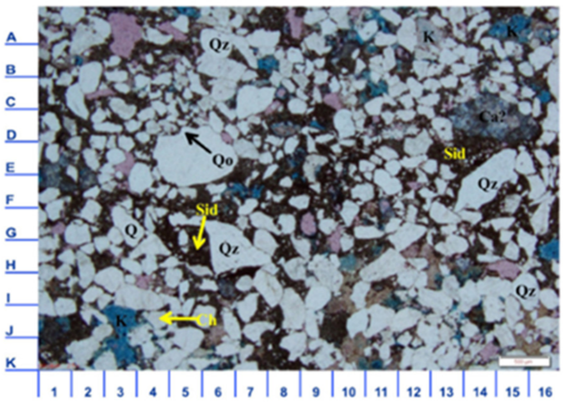


Figure 2. Thomas-Stieber plot (1975) showing the presence of significant *dispersed-laminated shale* in the LRPZ interval indicates that the emergence of LRPZ in the South Sumatra Basin can be caused by *fine-grained reservoirs* or *superficial porosity* refer to Boyd (1995).



GRAINS		55.2%	CEMENTS/REPLACEMENTS		40.8%
Quartz		53.6%	Overgrowths		2.0%
K-feldspar		0.4%	Quartz	2.0%	
Rock fragments		1.2%	Carbonate		24.0%
Chert	0.4%		Calcite	1.6%	
Metaquartzite	0.8%		Dolomite	1.2%	
Carbonaceous Organic material		Trace	Siderite	21.2%	
Bioclasts		Trace	Pyrite		Trace
Other grains		Trace	Kaolinite		13.2%
			Clay coatings		1.6%
MATRIX		**0.4%**	**VISIBLE POROSITY**		**3.6%**
Detrital clay		0.4%	Intergranular		0.8%
			Secondary [Dissolution]		2.8%
			Intraparticle		Trace

TEXTURE					
Grain Size [mm]			Sorting	:	Moderate
Minimum	Mode	Maximum	Roundness	:	Angular to subrounded
0.04	0.20	0.40	Grain contacts	:	Point>planar
Silt	Fine sand	Medium sand	Texture	:	Massive

Figure 3. The presence of significant siderite minerals (21.2%) and traces of pyrite in the GDR-1 well on the Lower Talang Akar Formation (LTAF) interval increased formation conductivity.

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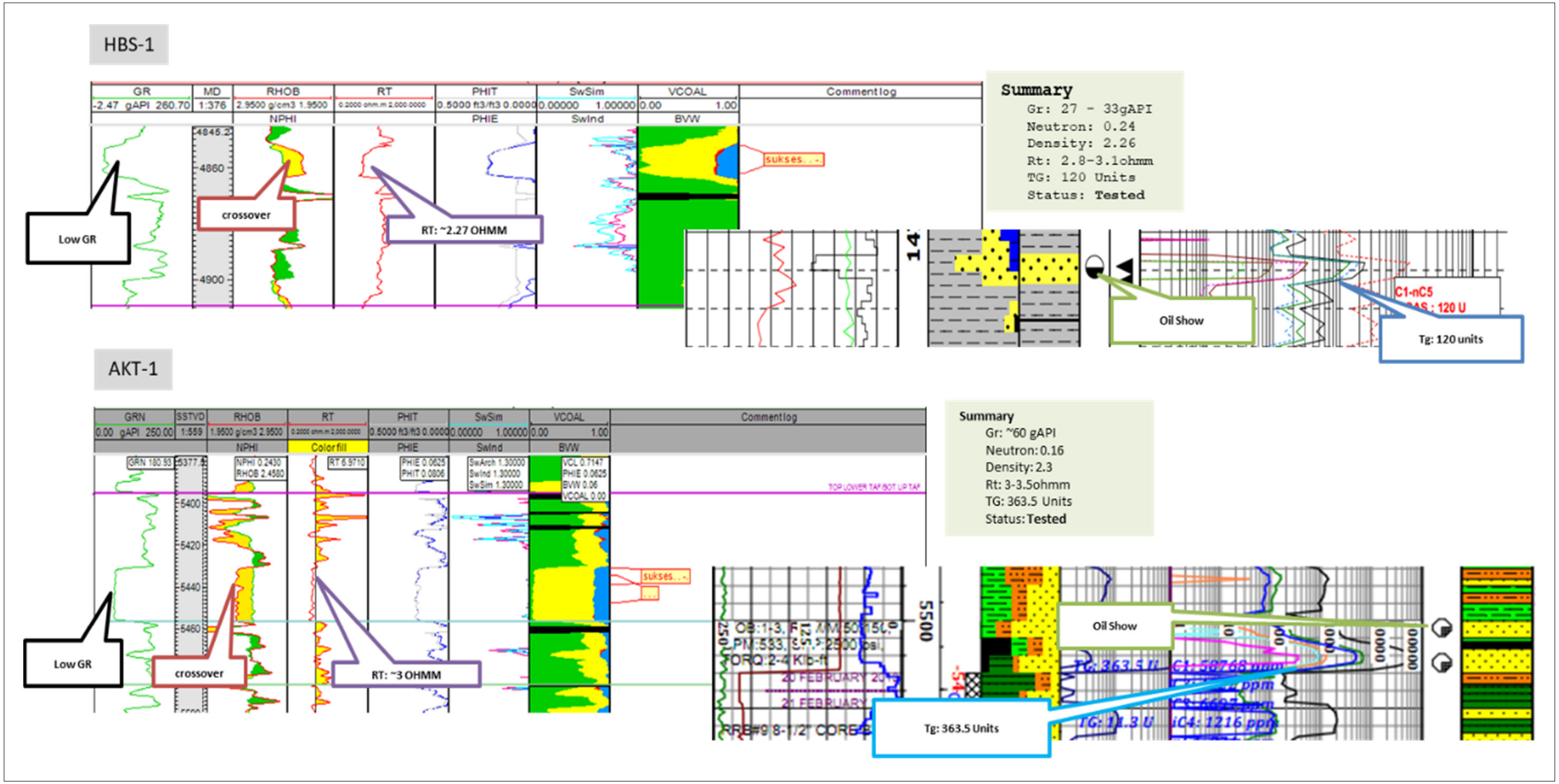

Figure 4. LRPZ on LTAF in AKT-1 well of Jambi Sub Basin, South Sumatra Basin.

1.2. Tested data interval filtering.

The second step of this procedure is to test data interval filtering by using the RPD (Relative Porosity Difference) and Resistivity log (Rt) cross-plot (**Figure 5**). RPD is the difference between density porosity (PHID) and neutron porosity (NPHI) (Holis *et al*., 201). A positive value indicates a neutron-density crossover (reservoir containing hydrocarbons), while a negative value indicates a reverse crossover (possible shale interval). RPD (Relative Porosity Difference) is made using the following equations:

RPD = PHID - NPHI *Equation (1)*

PHID = (Rho_matrix - RHOB)/(Rhoma - Rho_fluid) *Equation (2)*

RHOB, NPHI : log data

Wireline log data (Rt and NPHI) and analysis result (PHID) on tested data interval are cross plotted into a semi-log chart (**Figure 5**). Only the wireline log data and analysis with low resistivity and positive RPD with DST to confirm the significant hydrocarbons contained would be brought to the next step.

1.3. Define cutoff function on Rt vs. PHIT chart.

All the LRPZ intervals and wells that pass the first filtering method (above) are plotted into a PHIT-Rt logarithmic cross-plot in this step. The interpreted function is produced by evaluating the minimum value for both variables (**Figure 6**).

The cut-off function results for LRPZ in LTAF is:

$$Rt = 10^{1.07 - 3.29 * \mathrm{PHIT}} \qquad \textit{Equation (3)}$$

1.4. Applying the cut-off function to observed wells and intervals.

A pseudo log is generated according to the functions in the previous step and applied to all wells available. This step estimates probable LRPZ intervals in all wells with no well test (DST). The predicted LRPZ is the interval where the Rt (true/deep resistivity) value exceeds the curve generated from the function (Rt_cu) (**Figure 7**).

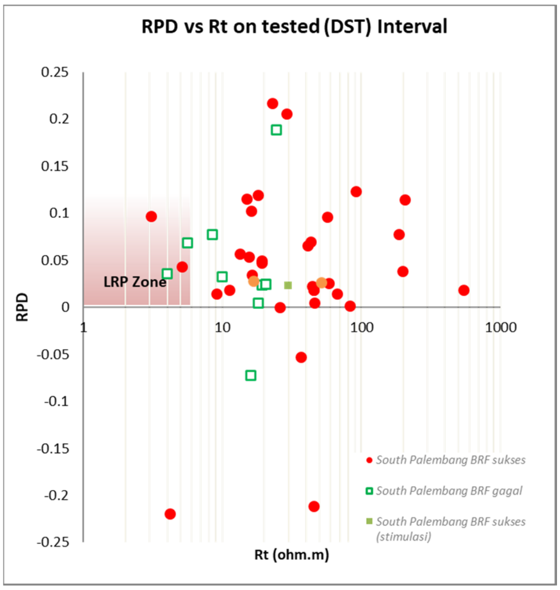

Figure 5. ND crossed over (RPD) vs. Rt on tested/DST interval as first step filtering.

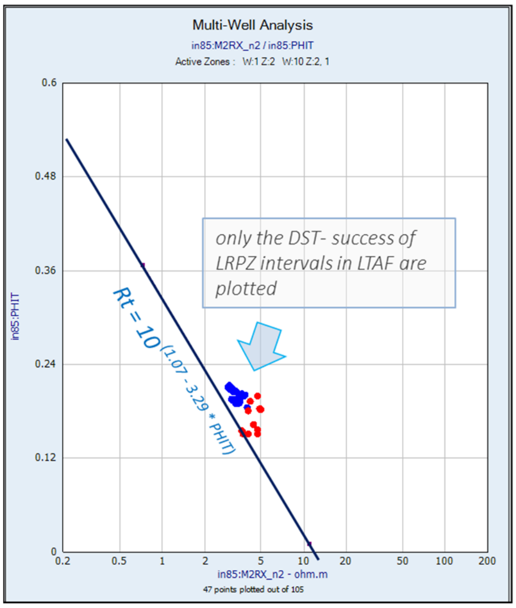

Figure 6. Rt (True/deep resistivity) vs. PHIT (Total Porosity) cross plot for defining **cut-off function.** Data plotted (in the cross-plot) are only the DST-success intervals for the Lower Talang Akar Formation (LTAF) in South Sumatra Basin (multi-wells).

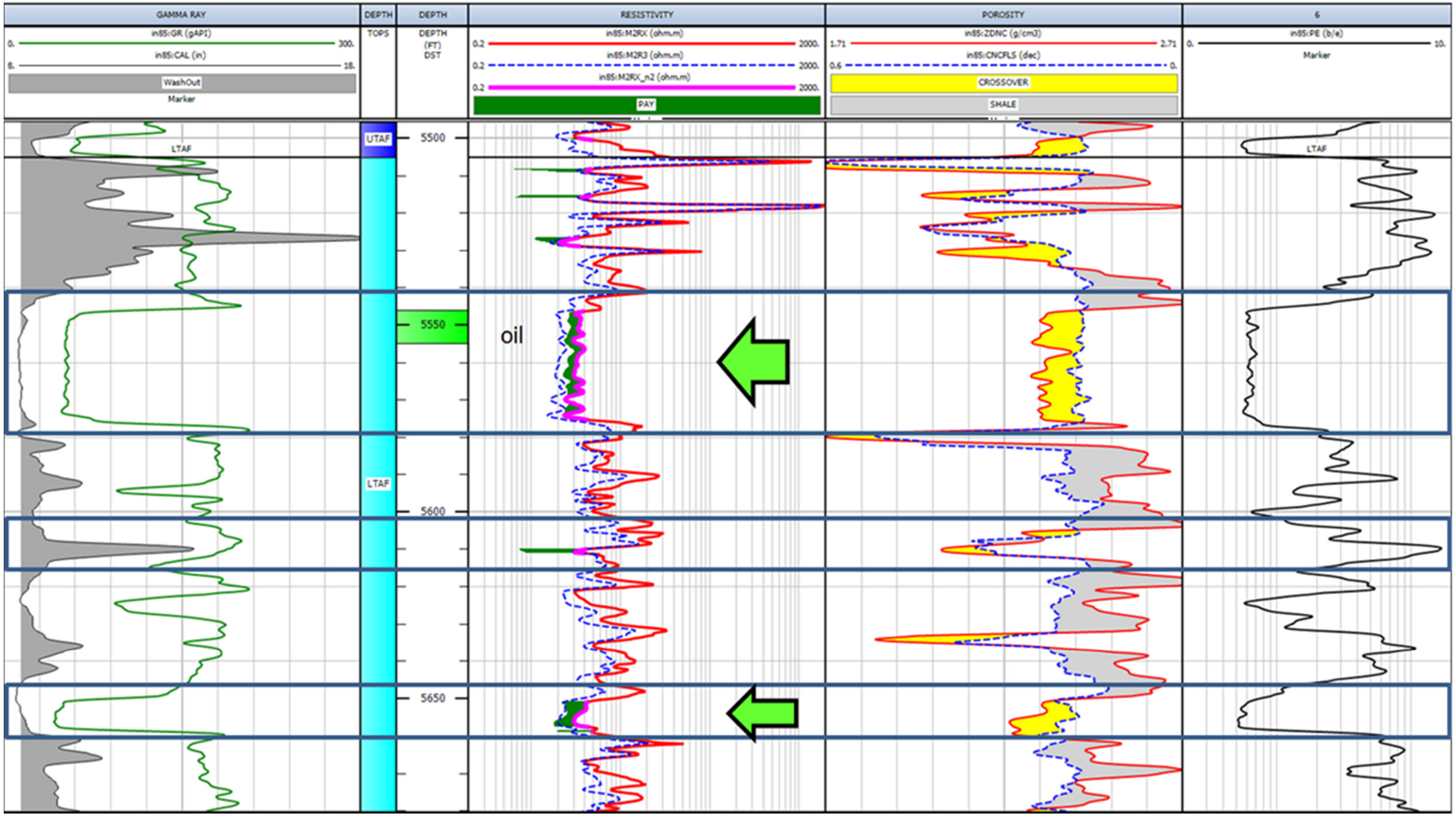

Figure 7. Predicting LRPZ by applying the Rt - PHIT function. Green shading is when **Rt** exceeds **Rt_cu**. This shading tells an intervalpossible Low resistivity pay zone sitting above the Rt = 10 $^{(a - b * PHIT)}$ line (on Rt vs. PHIT plot).

2.5 Define petrophysical parameters for well log analysis on predicted LRPZ

After the LRPZ interval is defined, the petrophysical parameters (Rho MA, Rho Sh, Rw, etc.) are evaluated exclusively for the LRPZ intervals (**Figure 8**).

2.6 Perform Well Log analysis on predicted LRPZ

The petrophysical properties (PHIT, PHIE, Sw, etc.) are then calculated using the parameters evaluated in the previous step (**Figure 9**).

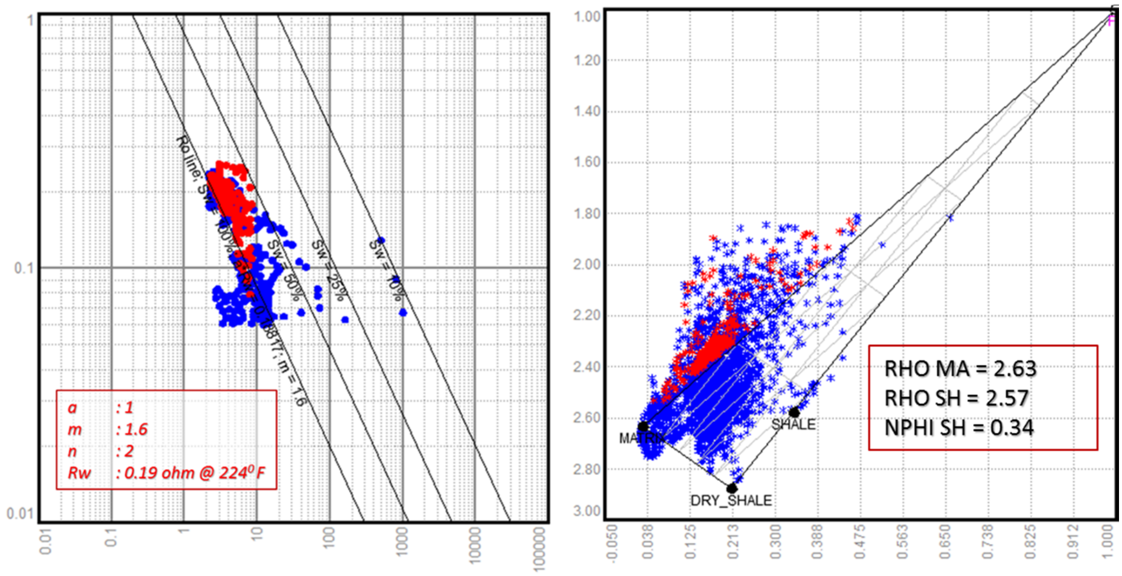

Figure 8. Defining petrophysical parameters for LRPZ of LTAF in South Sumatra Basin.

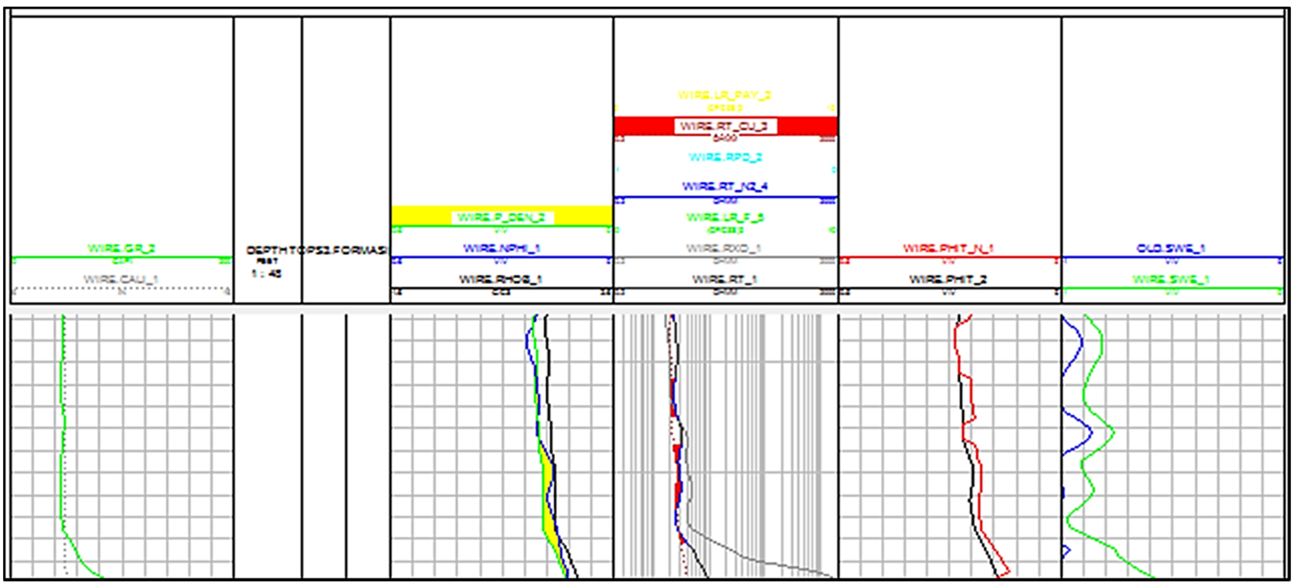

Figure 9. Well Log analysis on example well with LRPZ. The blue curve on the rightmost column is the previous analysis result, while the green one is the new interpretation which is quite optimistic yet proven in some blind tests.

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2. SECOND METHOD: MULTI-RESOLUTION GRAPH-BASED CLUSTERING (MRGC) FOR LRPZ ANALYSIS (SANGA SANGA BLOCK CASE)

The second method for identifying and analyzing LRPZ is based on well-known MRGC (Multi-Resolution Graph-Based Clustering), is typically used on electrofacies and rock-type analysis, and has never been used on defining LRPZ in untested intervals before. MRGC is a multi-dimensional dot-pattern recognition method based on nonparametric "K-nearest neighbor" and graph data representation (Ye and Rabiller, 2000). Depth log samples are characterized by two indexes, Neighboring Index and Kernel Representative Index, which describe the neighboring relationship. The underlying structure of the data is analyzed, and natural data groups are formed that may have very different densities, sizes, shapes, and relative separations. MRGC automatically determines the optimal number of clusters yet allows the user to control the level of detail needed to define the facies. The MRGC analysis workflow is divided into 2 phases; there training phase and the application phase. The training phase is used to generate and build models, and then the application phase is used to propagate the models. Representative data are selected as 'training data' to generate models, which may be used in facies propagation.

2.1. Inventorying tested LRP Zones in Sanga Sanga Block

The first step of this method is the same as with the first method, where all tested LRPZ available in Sanga Sanga Block are compiled. There are 17 wells available in this block that have been tested as hydrocarbon pay zones and show relatively low resistivity value or low contrast compared to wet zones or non-reservoir zones above and below (**Table 2**). Eight of those wells are used as model wells, while the rest are blind well tests.

Table 2. Seventeen wells in this block with conclusive well test analysis results in LRPZ.

NO	WELL NAME	ZONE TYPE	INITIAL RATE (MMSCFD)	MRGC
1	M-X1	GAS	2.7	model log
2	M-X2	GAS	1.15	model log
3	M-X3	GAS	1.95	model log
4	M-X4	GAS	0.7	model log
5	M-X5	GAS	0.2	blind test
6	M-X6	GAS	0.6	blind test
7	M-X8	GAS	0.7	blind test
8	M-X9	GAS	0.4	blind test
9	M-Y1	OIL	4.6, 30 BOPD	model log
10	M-Y2	OIL	0.3, 232 BOPD	model log
11	M-Y3	OIL	0.17	blind test
12	M-Y4	OIL		blind test
13	M-Y5	OIL		blind test
14	M-Z1	WATER		model log
15	M-Z2	WATER		model log
16	M-Z3	WATER		blind test
17	M-Z4	WATER		blind test

2.2. . MRGC Analysis to predict LRPZ in untested wells/intervals.

2.2.1. Training phase

The wireline log data were taken from selected logs, wells, and tested LRPZ intervals (so-called Model Logs). The most matched clusters and logs are defined by exercising the Model Logs, Clusters, and range values (**Figure 10** and **Figure 11**). A similar procedure is normally done on electrofacies or rock types analysis.

The resulting clusters (22 clusters; **Figure 11**) are then re-clustered with specific criteria according to the objective of estimating the LRPZ. Re-clustering results, in this case, are 5 clusters, with the first as the LRPZ cluster (**Figure 12**). Blind wells test is used to ensure that the result is quite matched and robust.

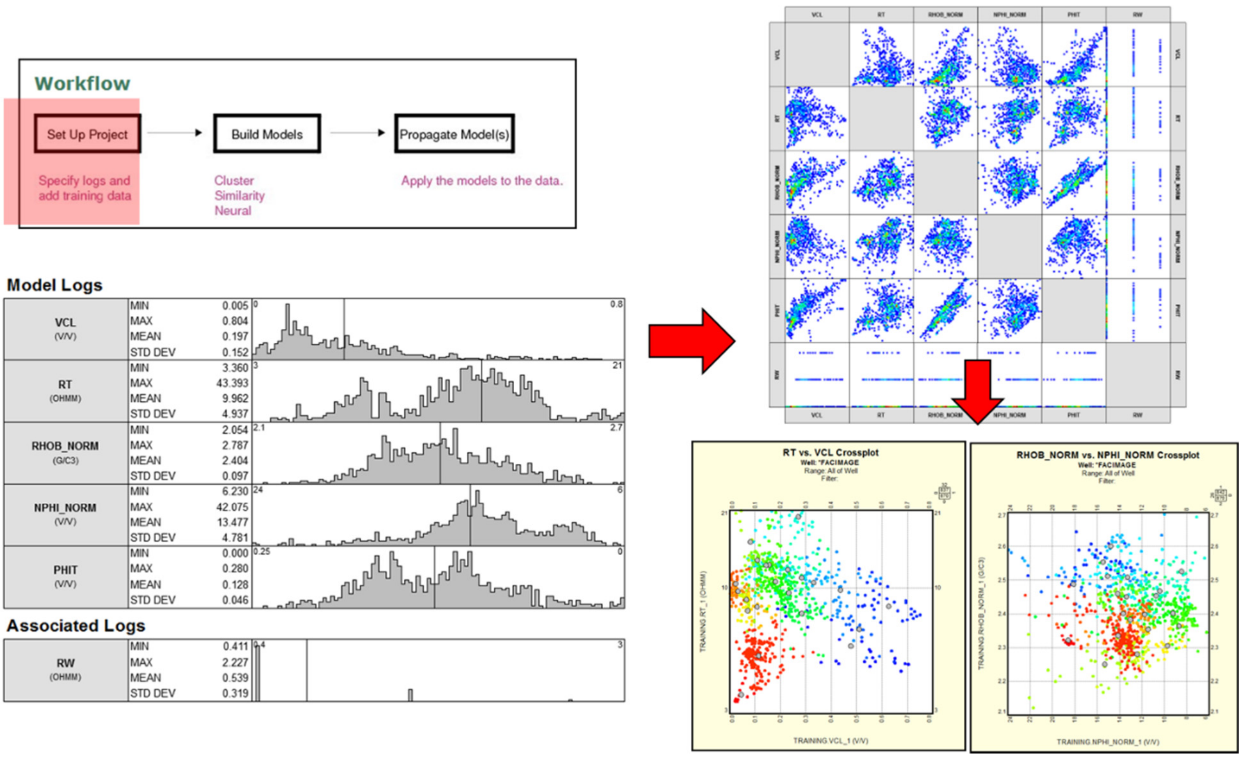

Figure 10. Training phase on MRGC analysis as part of clustering process that honors multi logs cross-plot at once. Model logs that have been used are Vcl (volume of clay), Rt (true/deep resistivity), RHOB (density log), NPHI (neutron porosity), and PHIT (total porosity).

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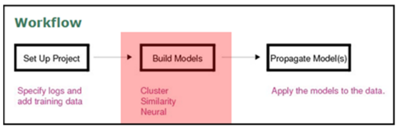

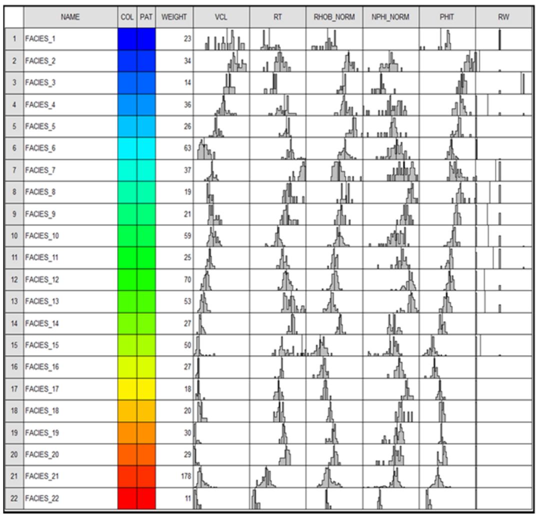

	FACIES	WEIGHT	VCL	RT	RHOB_NORM	NPHI_NORM	PHIT
1	5	23	0.48	5.73	2.33	35.49	0.15
2	4	34	0.63	8.38	2.55	15.48	0.03
3	4	14	0.51	6.73	2.49	18.13	0.06
4	4	36	0.44	9.78	2.51	15.06	0.07
5	3	26	0.33	10.52	2.60	14.79	0.08
6	3	63	0.16	12.45	2.51	13.29	0.11
7	1	37	0.27	19.75	2.45	10.74	0.09
8	3	19	0.23	11.89	2.53	8.47	0.06
9	1	21	0.28	11.02	2.47	10.41	0.08
10	3	59	0.28	7.83	2.45	13.37	0.10
11	1	25	0.23	9.54	2.40	11.75	0.12
12	1	70	0.18	10.61	2.40	9.24	0.11
13	1	53	0.14	12.41	2.36	8.69	0.13
14	1	27	0.11	13.04	2.46	14.19	0.15
15	1	50	0.08	15.53	2.25	15.33	0.20
16	1	27	0.07	8.94	2.28	12.44	0.18
17	1	18	0.07	8.04	2.31	9.73	0.16
18	1	20	0.11	8.34	2.35	11.45	0.15
19	1	30	0.03	9.68	2.38	13.04	0.15
20	1	29	0.02	10.40	2.40	13.67	0.14
21	2	178	0.11	5.22	2.34	14.13	0.17
22	1	11	0.05	3.60	2.32	18.60	0.21

Figure 11. The training phase results in clusters that each have typical logs values. In this case, the most reliable cluster number is 22 (Facies 1 – Facies 22).

	NAME	COL	PAT	WEIGHT	VCL	RT	RHOB_NORM	NPHI_NORM	PHIT	RW
1	PAY			418						
2	WATER			178						
3	TIGHT SAND			167						
4	SHALE			84						
5	FACIES_1			23						

Figure 12. The previous cluster (22 clusters; in Figure 11) is rearranged to get the cluster that is biased to the objective of the analysis, which is estimating the LRPZ (cluster #1; called "PAY" on this figure/table).

2.2.2. Application Phase

The resulting clusters (5 clusters including the LRPZ cluster) are then propagated into the other wells to get the LRPZ estimation on untested wells or intervals of this field in the Sanga Sanga Block. The initial propagation is done on blind wells/interval tests to evaluate the process. In this case, the result of the blind well test is 76 % matched (**Figure 13**).

2.3. Petrophysical Analysis.

With the LRPZ intervals identified, the following steps on this 2nd method are the same procedures performed on the 1st method, such as defining petrophysical parameters and completing the well log analysis (defining petrophysical properties) of the LRPZ.

Figure 14 shows the result of well log analysis for LRPZ in Zone N-1 Well M-ZA1 that formerly interpreted as a non-pay zone. The well test result in the N-1 Zone of Well M-ZA1 is 1.3 MMSCFD. It is proved that the LR pay zone prediction using this method is performed well and has a chance to contribute additional reserves and production.

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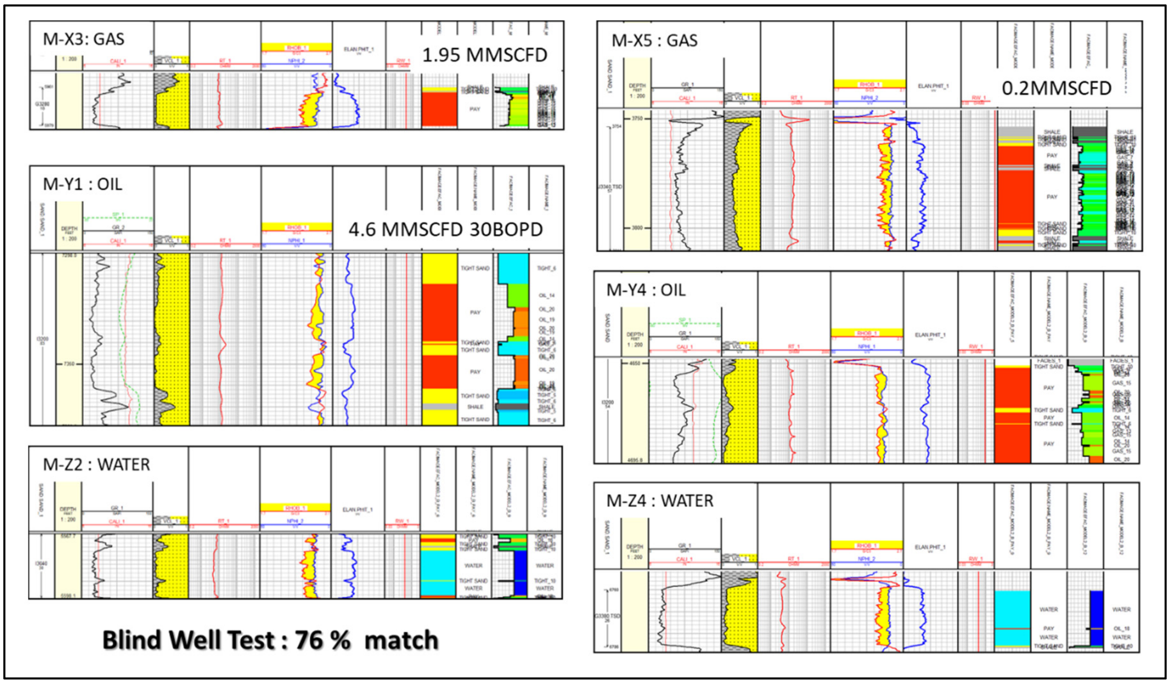

Figure 13. Propagation clusters (including the LRPZ) to blind wells/intervals test.

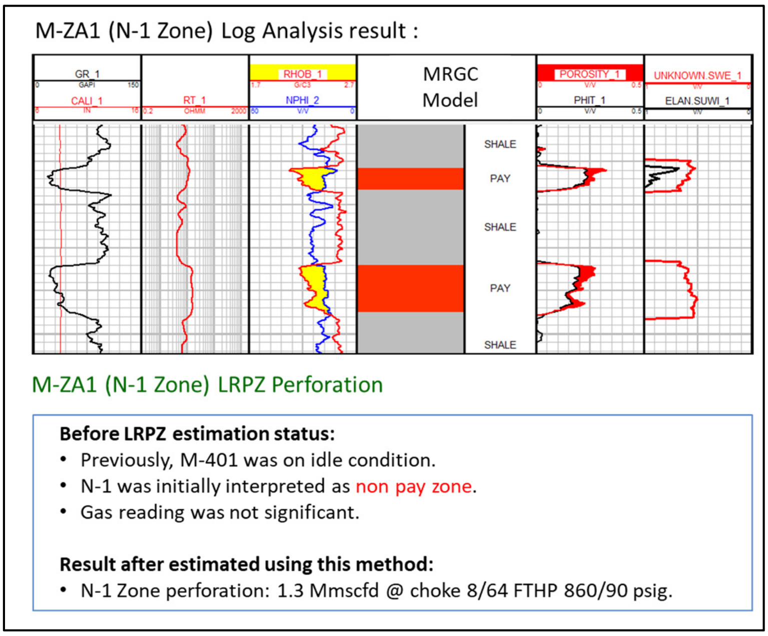

Figure 14. Well-log analysis on Zone N-1 Well M-ZA1 uses the petrophysical parameters defined exclusively for LRPZ.

One of the most promising results of applying this method comes from perforation decisions based on the results of 55 (fifty-five) production LRPZ intervals that equate to 5 – 6 new wells average economic cut-off without performing any new drilling (and additional costs relatedly). The success story and ratio in the production/flow test of LRPZ that have been done following the LRPZ prediction using this method in Sanga Sanga Block is in **Figure 15.** In contrast, **Figure 16** compares LRPZ statistics with normal pay high resistivity zone on this field in Sanga Sanga Block.

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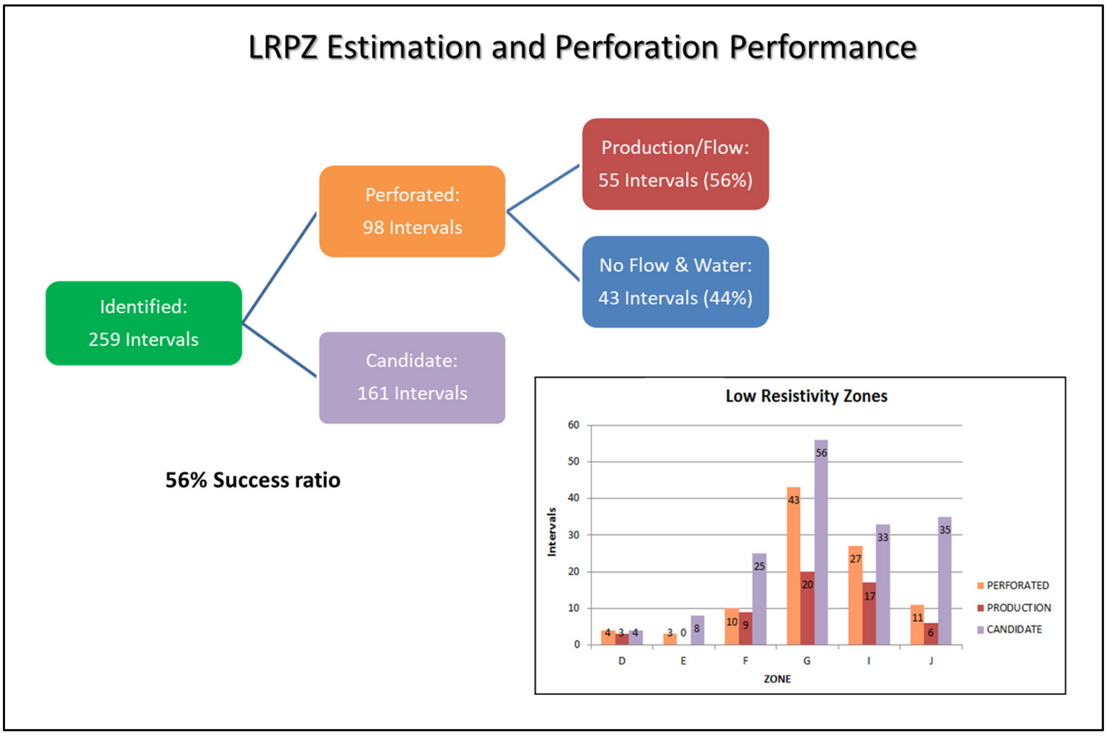
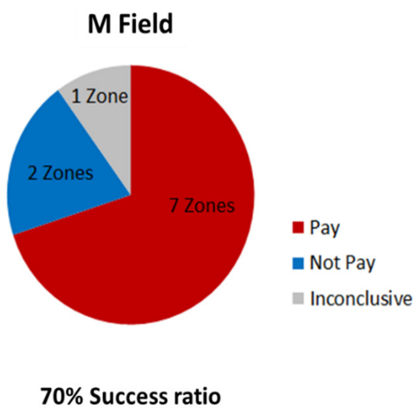


Figure 15. Success story and ratio in production/flow test of LRPZ that have been done following the LRPZ prediction using this method.

Non-LRPZ Perforation Performance



ZONE	STATUS	RESULT	FLUID	INITIAL RATE (MMSCFD)
N-1	Perforated	Flow	GAS	1.3
N-2	Perforated	Flow	GAS	0.3
N-3	Perforated	Flow	GAS	1.95
N-4	Perforated	Flow	GAS	well died before tested
N-5	Perforated	Flow	GAS	1.9
N-6	Perforated	Flow	GAS	1.53
N-7	Perforated	Flow	GAS	0.76
N-8	Perforated	flow	WATER	
N-9	Perforated	flow	WATER	
N-10	Perforated	Inconclusive		

Figure 16. Success story and ratio in production/flow test of LRPZ that have been done, for comparison to Figure 15.

3. CONCLUSION

By performing these two methods in this study, some concluding remarks can be declared as follows:

1. Petrophysics analysis for LRPZ should be performed exclusively, separated from the typical high resistivity pay zone, due to the different petrophysical parameters between those two types of resistivity zones, even if both appeared in a similar formation (stratigraphic unit).
2. The Quick Looked LRPZ Analysis method performance depends on the number of tested wells/intervals in the similar genetic type of LRPZ. This

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method performed well in a single genetic variety of LRPZ. The cut-off function result for LRPZ in LTAF is $Rt=10^{(1.07 - 3.29 * PHIT)}$.

3. The MRGC Analysis method performed well when there are a lot of wells that also represent a variation in logs value in accordance with variations in genetic types of LRPZ. The most critical approach on MRGC is deciding the number of clusters that should be biased to the prediction of variation in genetic types of LRPZ. This method can handle multi-genetic types of LRPZ.
4. LRPZ can significantly contribute additional reserve, especially in some siliciclastic brownfields.

4. ACKNOWLEDGEMENT

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