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A Confusion Matrix based approach, derived using Neutron Porosity – Compressional Slowness Overlay Technique to resolve the issue of Gas masking in Silty/Shaly Reservoirs in Mehsana & Mandhali members of Kadi Formation, Cambay Basin

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Abstract

The purpose of this study is to identify such Silty/Shaly Reservoirs having Gaseous presence difficult to spot in conventional Open-Hole Logs due to Shale contamination. Conventional Open-Hole Tool limitations to decipher such Silty/Shaly Reservoirs imposes a classic challenge for the interpreter.

This study attempts to resolve the challenge by deriving a Confusion Matrix based on Neutron Porosity – Compressional Slowness Overlay Technique and thereby assessing Accuracy and Precision which will help in predicting such shale masked Gaseous Reservoirs of Mehsana & Mandhali members of Kadi Formation in upcoming development wells in Mehsana Sub-block, Cambay Basin.

Ten wells are taken for the study in which Silty/Shaly Reservoirs of Mehsana & Mandhali members were interpreted as Hydrocarbon bearing and eventually produced Gas. Neutron Porosity – Compressional Slowness Overlay Technique by normalizing the two curves in nearby Shale Formations was applied and the Crossover in Silty/Shaly Reservoirs is corroborated as Gas producing pay-zones. The Confusion Matrix based on the mentioned Overlay Technique is used to calculate parameters Accuracy (α) and Precision (p). Based on these parameters the Overlay Technique may be conformably applied over similar Silty/Shaly Reservoirs in the upcoming development wells of Mehsana Sub-block.

Introduction:

Kadi Formation in Mehsana Fields exhibits a typical silty characteristics of reservoirs which often impose challenges in conventional log interpretation. Sand layers in Mehsana and Mandhali Member of Kadi Formation encountered in some of the fields of Mehsana Sub-Block such as Jotana, East-Linch and Langhnaj the gaseous presence are masked due to shale contamination.

Based on the conventional Log Interpretation few Shaly Sands which were evaluated as Oil bearing, have produced significant amount of Gas upon production testing.

This motivated us to take up a case study to identify such Shaly Reservoirs in Kadi formation of

Mehsana field having Gaseous presence by calculating parameters like **Accuracy (α)** and **Precision (p)** by means of deriving a Confusion Matrix, based on the predicted results obtained from Neutron – Compressional Slowness Overlay Technique and actual production testing results.

Among the set of parameters, accuracy (α) is closeness of the predicted result to the actual result, while precision (p) is the closeness of the actual and predicted results to each other. The degree to which any prediction can come closer to the actual results can be authentically decided by these two key parameters α & p.

A prediction weighted by these two parameters can be calculated using Confusion Matrix. We summarize Confusion Matrix by having all possible outcomes of predicted and actual values into four elements: True Positives (TP), False Positives (FP), True Negatives (TN), and False Negatives (FN).

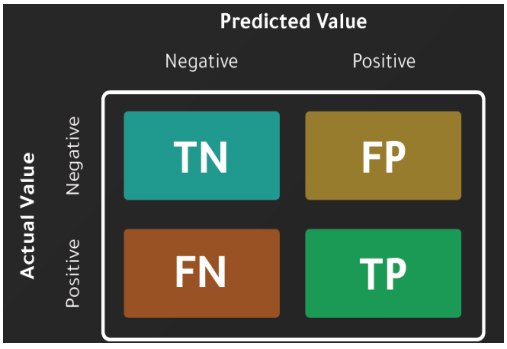
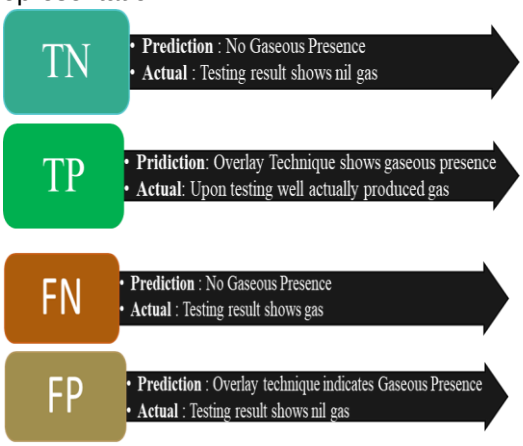


Figure: 1

In the given context these 4 elements of the Matrices can be explained by following graphical representation:



General Geology:

Mehsana sub-bl[illegible]aracterized by the presence of basi[illegible]aults in the East and West, Unawa cross trend in North and Kadi-Nandasan-Langhnaj cross trend in the South. Kadi-Nandasan cross trend bifurcates this block from Ahmedabad block. The block has a very prominent N-S trending feature, Mehsana Horst which divides block into two depressions, one to its east and other to the west, with distinctive sedimentation patterns.

Figure: 2

Stratigraphy in Mehsana Sub-Block;

- Gujarat Alluvium
- Jhagadia Formation
- Kand Formation
- Babaguru Formation
- Tarapur Shale
- Kalol formation
- Kadi formation
    - Chhatral Member
    - Upper Tongue
    - Upper Mehsana
    - Mehsana Member
    - Lower Tongue
    - Mandhali Member
- Older Cambay Shale
- Olpad Formation
- Deccan Trap

Kadi formation developed as an arenaceous facies in this block is equivalent to Younger Cambay Shale. Four members namely Mandhali, Mehsana, Upper Mehsana and Chhatral have been recognized in this formation. The Kadi and Kalol formations are separated by the Upper Tongue of the younger Cambay shale. The Kadi and Kalol formations of early to Middle Eocene age are thick clastic wedges in the northern part of Cambay Basin. Southward these formations inter-tongue with and grade into the marine Cambay shale. Mandhali and Mehsana members are separated by Lower Tongue of Cambay shale.

Methodology:

Ten wells are taken for the study in which Silty/Shaly Reservoirs of Mehsana & Mandhali member were interpreted as Hydrocarbon bearing. Neutron Porosity – Compressional Slowness Overlay Technique by normalizing the two curves in nearby shale formations was applied and the Crossover in Silty/Shaly Reservoirs is corroborated as Gas producing pay-zones.

A Confusion Matrix was formed based on the predicted results from Neutron Porosity – Compressional Slowness Overlay Technique and actual testing results obtained in each well. Elements in this matrix distribution are in accordance with the elements explained in Figure: 2 and are represented as follows:

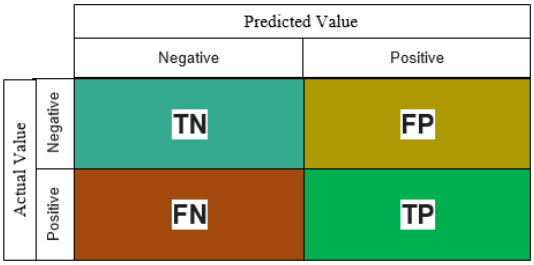


Figure: 3

Accuracy (α) is calculated using the Four Matrix elements as, $\alpha = \frac{TN+TP}{FP+TP+TN+FN}$ ..... (i)

Precision (p) is calculated using the same four matrix elements as, $p = \frac{TP}{TP+FP}$ ..... (ii)

Case Study:

Determining fluid nature of silty/shaly reservoirs in Mehsana & Mandhali members often impose challenges which at times are difficult to delineate with limited geological and reservoir inputs. Also, conventional processing techniques with established petrophysical parameters restrict the capacity in knowing only the fluid saturation and volumes. Thus, with limited Open-Hole logs following case-study of Ten wells from different fields of Mehsana Sub-block, in which silty/shaly Reservoirs of Mehsana & Mandhali members were interpreted as Hydrocarbon bearing, are taken to establish the parameters Accuracy (α) and Precision (p) from the predicted results of Neutron Porosity – Compressional Slowness Overlay Technique and actual testing results obtained in the wells.

Well-1: The development well XXLJ#18 (Figure 4) was drilled to exploit Mehsana & Mandhali member sands in Mehsana Sub-block, Cambay Basin, ONGC. Two sands MP-XA & MP-XB in Mandhali member, that are developed with silty/shaly character in the intervals XX03.5 – XX06.0m & XX20.5 – XX24.5m, exhibited contradictory behavior upon initial testing and thus leading the hypothesis to be represented in the form of confusion matrix. In the figure, it is clearly depicted that presence of gas from Conventional Log data is difficult to delineate. However, Overlay-technique plotted with Neutron-Porosity and Compressional-Slowness Logs is fairly representing Gas/High-GOR presence.

MP-XA sand in the well XXLJ#18 was tested and initially produced influx of oil with gas. On the other

hand, MP-XB sand was tested and initially produced only influx of oil.

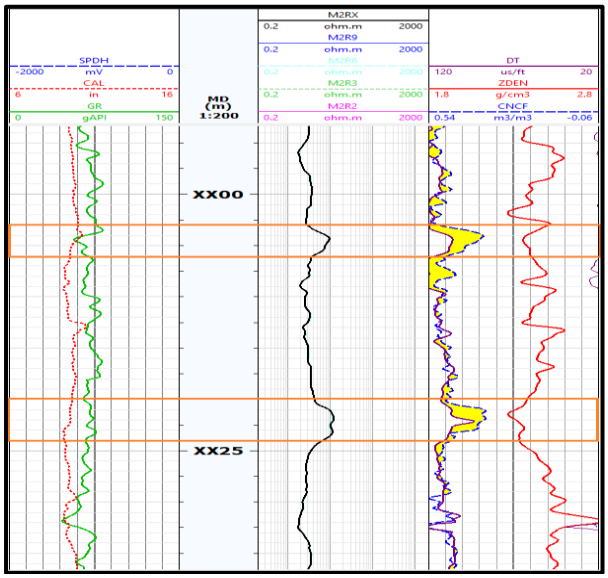


Figure 4: A case of **True Positive** & **False Negative**

Well-2: The well XXL#3 (Figure 5) was drilled targeting Mehsana and Mandhali sands in Mehsana Sub-block, Cambay Basin, ONGC. Interval XX82.0 – XX90.0m (MP-XY sand) in Mandhali member is silty/shaly in nature. No Gas presence is indicative from Conventional Log Composite. However, Overlay-technique on Neutron-Porosity and Compressional-Slowness Logs is fairly representing Gas/High-GOR presence.

Interval XX82.0 – XX90.0m was perforated and upon activation produced significant amount of Gas with rates Q_L: 6.1 m^3/d W/C: 31.1 % Q_O: 4.2 m^3/d, **Q_G: 6000 m^3/d**.

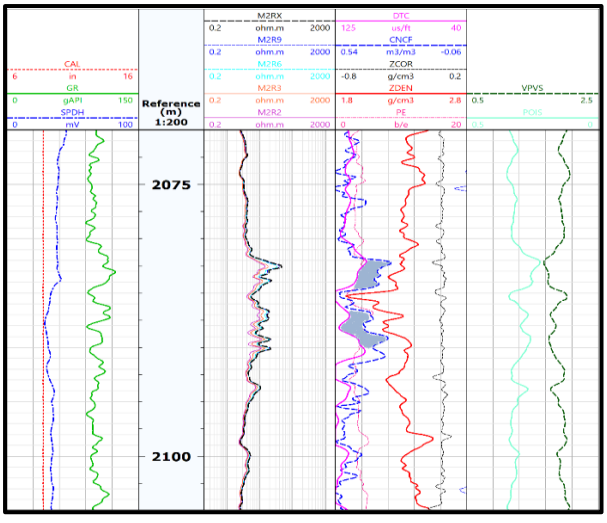


Figure 5: A case of **True Positive**

Well-3: The well XXL#5 (Figure 6) has a different story than the above mentioned case studies. This well was drilled as an Exploratory Well in Mehsana Sub-block, Cambay Basin, ONGC. Interval XX18.5 – XX25.0m (MP-ZB sand) in Mandhali member is silty/shlay with Coal intercalation. Gas presence is not indicative on Conventional Log Composite. As well as on Overlay-Plot of Neutron-Porosity and Compressional-Slowness Logs, no significant separation is seen in between DTC and Neutron Porosity Logs. Thus it is interpreted as silty/shaly reservoir with no indication of Gas. The testing results also confirmed the same.

Intervals XX19.0-XX20.5m & XX23.0-XX25.0m were perforated and on activation, did not produce significant amount of Gas with rates Q_L: 2.0 m^3/d W/C: 99.0% Q_O: 0.02 m^3/d.

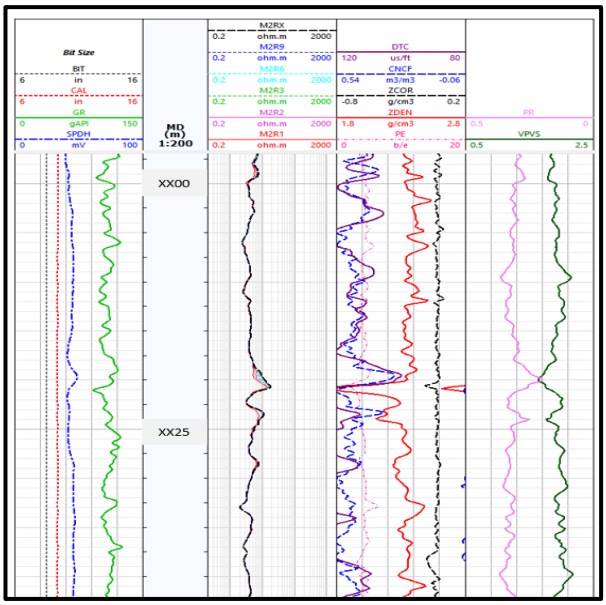


Figure 6: A case of **True Negative**

Well-4: The wells XXL#3 & XXL#6 (Figure 7 & 8 respectively) drilled to exploit Mehsana and Mandhali sands in Mehsana Sub-block, Cambay Basin, ONGC. In the well XXL#3 Interval XX00.0 - XX10.0m of MS-X sand is silty/shaly. No Gas presence is indicative from Conventional Log Composite. However, Overlay-technique on Neutron-Porosity and Compressional-Slowness Logs is fairly representing Gas/High-GOR presence.

As the testing data of this formation in the well is not available, the nearby well XXL#6 is taken into study, where in, interval XX71.0 - XX76.0m of same sand MS-X (Figure 8), with similar Log Character as that of in Well XXL#3 (with slightly higher shaliness), was perforated and Hydro-Fractured. Upon activation, in-spite of not showing any gas signature/indication on Conventional Log Composite, the well produced significant amount of Gas with rates Q_L: 2.0 m^3/d W/C: 90.4% Q_O: 0.2 m^3/d, **Q_G: 3800.0 m^3/d**.

Based on the nearby well performance and considering the structurally upper position of the sand formation in well XXL#3, the well is considered a True Positive case.

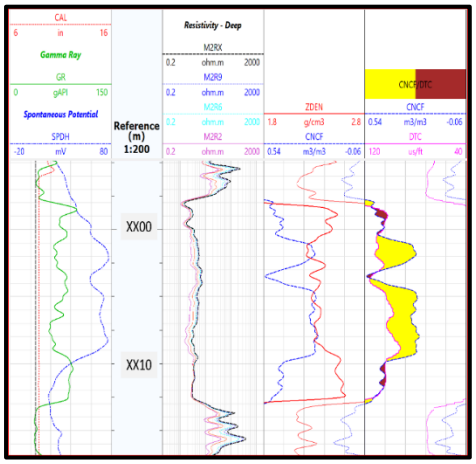


Figure 7: A case of **True Positive**

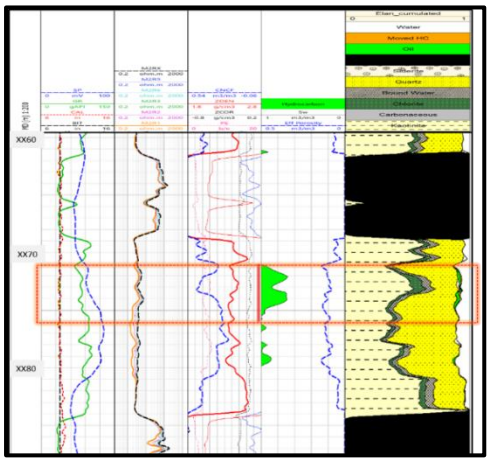


Figure 8: MS-X formation in the nearby well XXL#6

Well-5: The well XXLJ#23 (Figure 9) was drilled to exploit Mandhali sands in Mehsana Sub-block, Cambay Basin, ONGC. MP-X sand is developed with silty/shaly character in the interval XX68.0 – XX71.0m of Mandhali Formation. In the figure, it is clearly depicted that presence of gas from Conventional Log data is difficult to delineate. However, Overlay-technique plotted with Neutron-Porosity and Compressional-Slowness Logs is fairly representing Gas/High-GOR presence.

MP-X sand in the well XXLJ#23 was tested and initially produced water with little gas.

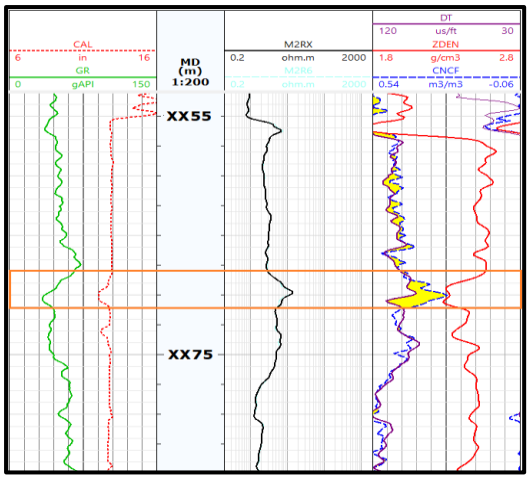


Figure 9: A case of **True Positive**

Well-6: The well XXLJ#24 (Figure 10) was drilled to exploit Mandhali sand in Mehsana Sub-block, Cambay Basin, ONGC. MP-X sand is developed with silty/shaly character in the interval XX54.0 – XX56.5m of Mandhali Formation. In the figure, it is clearly depicted that presence of gas from Conventional Log data is difficult to delineate. However, Overlay-technique plotted with Neutron-Porosity and Compressional-Slowness Logs is fairly representing Gas/High-GOR presence.

MP-X sand in the well XXLJ#24 was tested and initially flowed gas, **Q_G @ 905 m^3/d**.

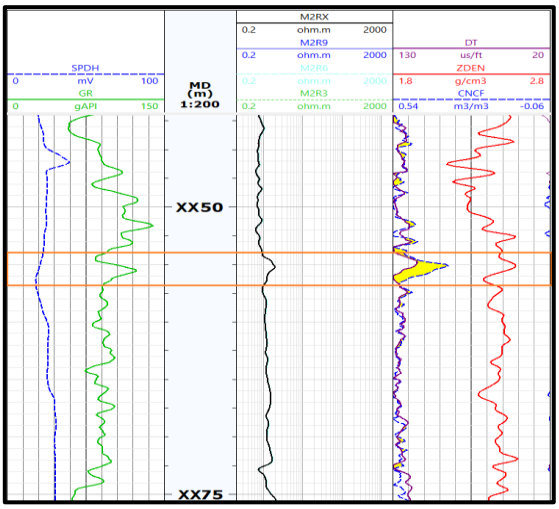


Figure 10: A case of **True Positive**

Well-7: Well XXWD#14 (Figure 11) which was drilled to exploit Kalol and Mandhali sands in Mehsana Sub-block, Cambay Basin, ONGC. MP-X sand is developed with silty/shlay character in the interval XX40.0 – XX49.0m of Mandhali Formation. Presence of gas from Conventional Log data is difficult to delineate. However, Overlay-technique plotted with Neutron-Porosity and Compressional-Slowness Logs is fairly representing Gas/High-GOR presence.

MP-X sand in the well XXWD#14 was tested with HF and initially produced Oil with Gas @ Q_o: 28.0 m^3/d and **Q_G: 11906.0 m^3/d** respectively.

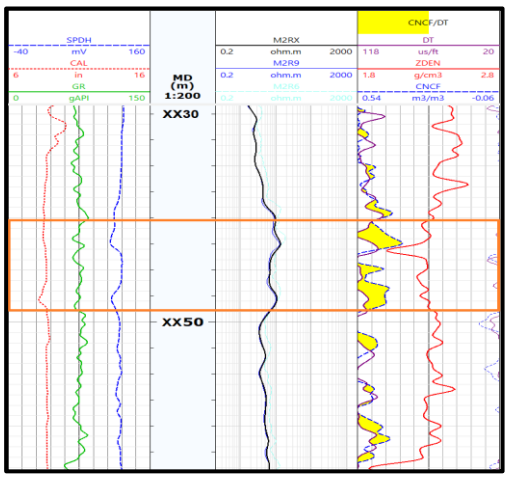


Figure 11: A case of **True Positive**

Well-8: Well XXWD#16 (Figure 12) was drilled to exploit Mehsana sands in Mehsana Sub-block, Cambay Basin, ONGC. MS-X sand is developed with silty/shaly character in the interval XX18.0 – XX25.0m of Mehsana Formation. In the figure, it is clearly depicted that presence of gas from Conventional Log data is difficult to delineate. However, Overlay-technique plotted with Neutron-Porosity and Compressional-Slowness Logs is fairly representing Gas/High-GOR presence.

MS-X sand in the well XXWD#16 was tested and initially produced Oil with Gas on self @ Q_O: 48.0 m^3/d and **Q_G: 1990.0 m^3/d** respectively.

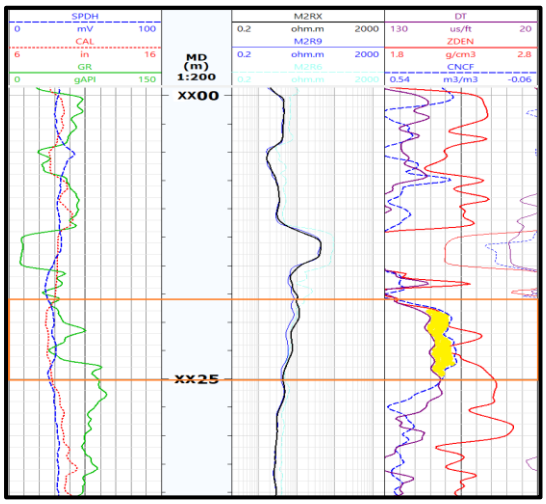


Figure 12: A case of **True Positive**

Well-9: Well XXLJ#49 illustrated in Figure 13, was drilled to exploit Mandhali sands in Mehsana Sub-block, Cambay Basin, ONGC. MP-X sand is developed with silty/shaly character in the interval XX26.0 – XX28.0m of Mandhali Formation. In the figure, it is depicted that presence of gas from Conventional Log data is difficult to delineate. However, Overlay-technique plotted with Neutron-Porosity and Compressional-Slowness Logs is fairly representing Gas/High-GOR presence.

MP-X sand in the well XXLJ#49 has produced both oil & gas upon initial testing.

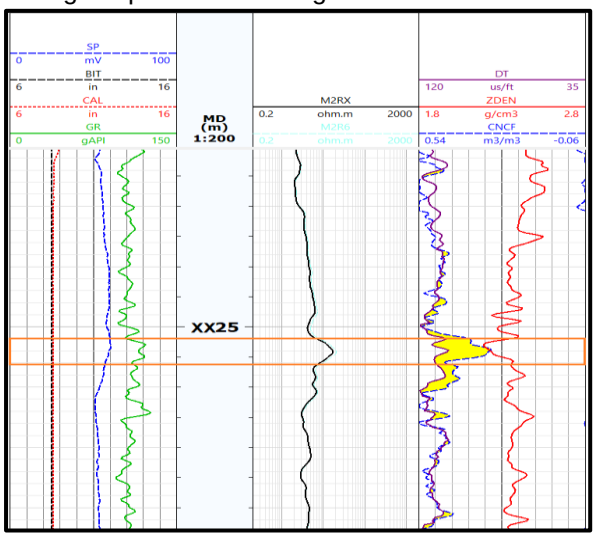


Figure 13: A case of **True Positive**

Well-10: Well XXLJ#50 illustrated in Figure 14, was drilled to exploit Mehsana sands in Mehsana Sub-block, Cambay Basin, ONGC. Interval XX46.0 – XX55.0m of MS-XC sand of Mehsana Formation is interpreted as silty/shaly. Gas presence indication is masked by the presence of shaliness on Conventional Log Composite. Whereas, clearly being represented by Overlay-Technique on Neutron-Porosity and Compressional-Slowness Logs.

Interval XX46.5 – XX50.0m was perforated and on activation, produced significant amount of Gas with rates Q_L: 1.0 m^3/d W/C: 17.1% Q_O: 0.9 m^3/d, **Q_G: 9000.0 m^3/d**.

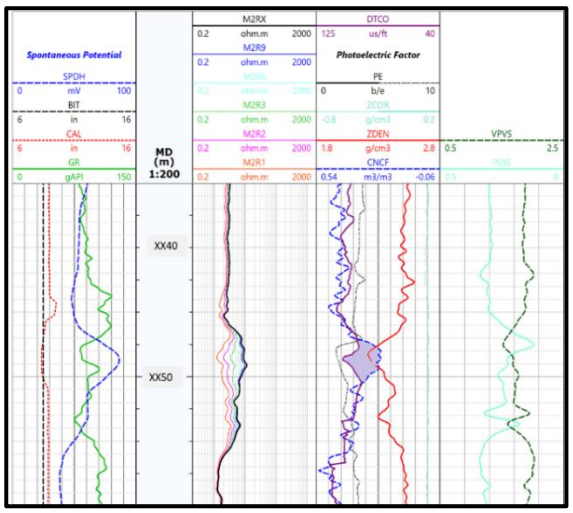


Figure 14: A case of **True Positive**

Results:

Following table summarizes all the cases in the wells discussed in the study:

Well No.	Well Name	Interval	Prediction of gaseous presence through Overlay Technique (Yes/No)	Whether gas present Actual testing Result? (Yes/No)	Category
Well-1	XXLJ#18	XX03.5 – XX06.0m	Yes	Yes	True +ve
Well-1	XXLJ#18	XX20.5 – XX24.5m	Yes	No	False -ve
Well-2	XXL#3	XX82.0 – XX90.0m	Yes	Yes	True +ve
Well-3	XXL#5	XX18.5 – XX25.0m	No	No	True -ve
Well-4	XXL#3	XX00.0 - XX10.0m	Yes	Yes	True +ve
Well-5	XXLJ#23	XX68.0 – XX71.0m	Yes	Yes	True +ve
Well-6	XXLJ#24	XX54.0 – XX56.5m	Yes	Yes	True +ve
Well-7	XXWD#14	XX40.0 – XX49.0m	Yes	Yes	True +ve
Well-8	XXWD#16	XX18.0 – XX25.0m	Yes	Yes	True +ve
Well-9	XXLJ#49	XX26.0 – XX28.0m	Yes	Yes	True +ve
Well-10	XXLJ#50	XX46.0 – XX55.0m	Yes	Yes	True +ve

10 Wells demonstrated in the study have a total of 11 number of cases in which 4 different elements can be represented in the following matrix format (Figure: 15):

		Predicted Value: Negative	Predicted Value: Positive
Actual Value	Negative	TN=1	FP=Nil
Actual Value	Positive	FN=1	TP=9

Figure: 15

Based on the above matrix and using equation (i) & (ii), Accuracy (α): $\{ \frac{TN+TP}{FP+TP+TN+FN} \}$ value of 0.909 (Equivalent to 90.9%) and Precision (p): $\{ \frac{TP}{TP+FP} \}$ value of 1.0(equivalent to 100%) in the 10 wells has been achieved. This indicates that, gas masking in such silty/shaly reservoirs of Mehsana and Mandhali members of Kadi formation can be resolved with ~ 90.9 % accuracy.

Hypothesis testing:

Based on the achieved Accuracy (α) and Precision (p) values the proposed hypothesis was tested on another well having silty/shaly formation characteristics in Mehsana Sub-block, Cambay Basin, ONGC for validation purpose.

The hypothesis was validated by implementing the overlay technique in well XXLJ#57. The well was drilled as an Exploratory Well targeting Mandhali pays in Mehsana Sub-block, Cambay Basin. Interval XX21.0-XX24.0m belonging to MP-XA sand of Mandhali Formation is of silty/shaly nature with no clear indication of gaseous presence on processed Log with conventional petrophysical parameters. This Interval was perforated and on activation, well produced Gas @ **5200.0 m³/d**.

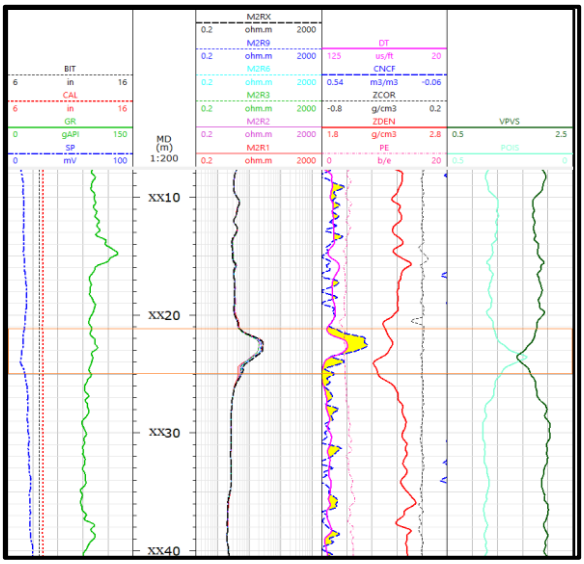


Figure-16: Well: XXLJ#57

Discussion & Conclusion:

Accurate evaluation of Hydrocarbon bearing Shaly-Sands in Mehsana & Mandhali Members of Kadi Formation is a challenge. The formation lithology are shaly which mask the 'Gas effect' seen on Resistivity, Density and Neutron logs. The main feature to note is the high Gamma ray suggesting the presence of clay content and the developed SP log also hinted the silty nature of the sand.

Conventional interpretation techniques have limitations in detecting the Gaseous presence in shaly sand reservoirs in Mehsana and Mandhali Members of Kadi Formation. Confusion Matrix based parameters Accuracy (α) & Precision (p) are key in successful validation of Neutron porosity and Compressional slowness Overlay Technique that has deciphered Gaseous presence in such reservoirs thus opening an alternative perspective over conventional interpretation provided the availability of Sonic Log data. Also, with increasing number of cases may give better insight about Accuracy (α) & Precision (p) thereby increasing confidence in the discussed Overlay Technique.

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