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Integration of Magnetic Resonance and Routine Core Analysis for Improved Characterization in a Low Permeability Hydrocarbon Play.

Abstract:

This paper presents an integrated approach for the reservoir characterization of low permeability shaly sands of younger Kalol unit in eastern part of Cambay Basin. Integration of results obtained from conventional logs, Nuclear Magnetic Resonance (NMR) log and Routine Core Analysis data gives a holistic view of the reservoir. The reservoir facies of this unit is sandstone and based on the petrographic studies it is further classified as subarkose. The reservoir contained a significant amount of disperse clay and the size of the framework grains are also very fine, causing significant difference between total porosity (PHIT) and effective porosity (PHIE). In such type of thin reservoir, petrophysical parameters estimated through conventional suit of wireline logs are more sensitive to the lithology than the fluid present in the pore spaces. Further challenges are posed by tightness of the reservoir, which causes suppressed response of the free fluid on the electric logs. Nuclear magnetic responses are however free from these limitations, and are presumed to be more representative of the free fluid than lithology. Results can be further refined by calibrating these responses with the core data. Once, a reasonable calibration is achieved, final reservoir parameters can be obtained.

Electric logs are commonly used for characterizing the fluid response of the reservoir. Details about the clay percentage, total/effective and porosity and hydrocarbon saturation, computed from the electric logs are used for understanding of the reservoir quality. However, such resistivity based techniques are non-trivial in nature and therefore sometimes it is difficult to characterize the reservoir.

Nuclear magnetic resonance (NMR) T2 measurements provide a non-resistivity based formation evaluation technique. NMR relaxation time is sensitive to pore size distribution of the formation. Longer T2 are associated with larger pore size. The T2 response can be segmented into different bins. Each segment provides a quantitative estimate of the porosity (Lu Chi & Zoya Heidari, 2014). A shaly sand reservoir can get mineralogically complex and the resistivity based interpretation can get masked in such complexities. Since NMR measurements are independent of the lithology the T2 based interpretation are not affected because of such complexities. Integrating the standard resistivity based interpretation with the NMR enable the interpreter a complete assessment of the reservoir parameters and hence its characterization.

Description of the Study area

Study area is located in the southern part of the Ahmedabad-Mehsana tectonic block of the Cambay Basin, towards eastern basin margin (Figure-1). It is surrounded by a number of oil and gas fields. The prominent nearby fields are Indrora, Wavel, Bakrol, Sabarmati and Gamij.

Thick Cambay Shale has been the main hydrocarbon source rock in the Cambay Basin. In the northern part of the Ahmedabad-Mehsana Block, coal, which is well developed within the deltaic sequence in Kalol, Sobhasan and Mehsana fields, is also inferred to be a possible hydrocarbon source rock.

The known reservoirs are Fluvio-deltaic sands of the Kalol Formation (Middle to Late Eocene), however, in a few wells the hydrocarbons are also reported from thin layers of sand and silts within the Cambay Shale Formation (Early Eocene), The present study deals with the Kalol formation where shaly sand reservoir has been identified as hydrocarbon bearing. The thickness of drilled section of Kalol formation within the study area varies from 200m-250m.

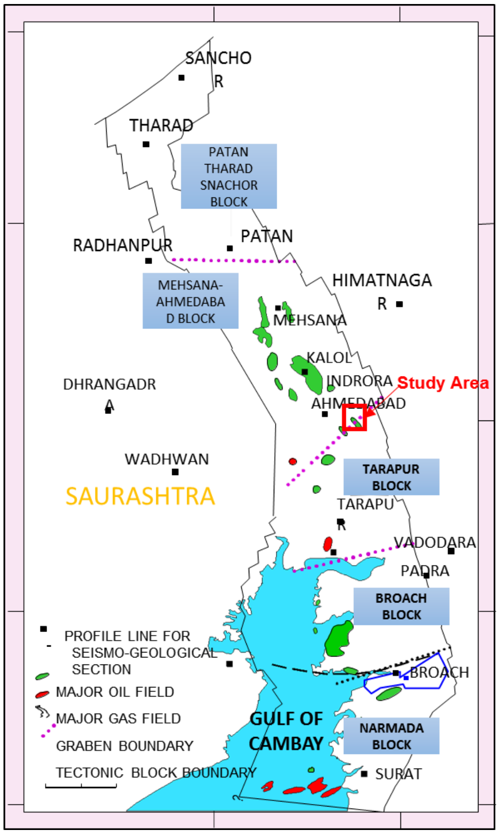


Figure.1: Location of the study area.

An attempt has been made for the reservoir characterization of low permeability shaly sands of younger Kalol unit by integrating the cutting & core data with wireline log.

Methodology:

In this study the lithology models were built based on the available cuttings, wireline logs of two wells, Well-A and Well-B. Core was acquired in Well-B, which covers around 0.5 m of the pay section. The deterministic log analysis results were compared with core analysis data. Magnetic Resonance log has been critical to calibrate the results obtained by deterministic approach with the results of Routine Core Analysis.

Younger Kalol unit has more than 70% of quartz grains with porosity ranging from 20% to 22% and high water saturations of around 40-50% and permeability typically in the range of 1md- 10md. From petrographic studies it was also evident that the reservoir contained a significant amount of disperse clay (20-25%, Kaolinite and Chlorite) as well as grain size was also very fine causing some difference between total porosity (PHIT) and effective/connected porosity(PHIE). Scanning Electron Microscope (SEM) data showed clay coating over the quartz grains (Figure 2). Resistivity logs are in the range of 3 to 5 ohm-m against the oil interval indicates the conductivity due to the shaly sands or by rock itself. These layers have tested and produced water free oil.

Porosity was calculated based on neutron-density cross plot porosity. Grain density has been derived from NMR logs using following equation;

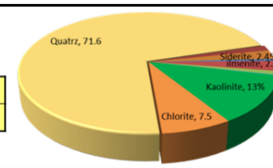
Grain Density: {(TCMR*Rho Fluid)-Rholog}/(TCMR-1)

TCMR: NMR total porosity, Rho Fluid: Fluid density (taken as 1gm/cc here), Rholog: Density value reading at each depth

There are 6 horizontals and 2 vertical plugs selected for RCA and Dean stark analysis (Table 1). Grain density data at Core-1, Sample-1 (X1030 meter) was doubtful (Table-1). So preference was given to NMR driven grain density calculation.

In figure 2, Sandstone, very fine-grained, moderately sorted, and is classified as subarkose. The grain shapes are angular to surrounded, and mainly have point contacts. The framework grains are mainly quartz grains, (white grains) with scarce of feldspars (Plate-A, potash (K-L 2) and plagioclase), rock fragments (chert, sedimentary fragments, and traces of rock fragments). Other grains are accessorries, including sporadic mica, chlorite, heavy minerals (tourmaline and zircon), opaque's (Plate A: G1; I-J 5) and phosphatic material. Patchy detrital matrix is distributed between the grains. Visible porosity is good (11.25%, blue areas). The pore system is primary intergranular and secondary pore types. The stage dissolution of grains created secondary porosity. Higher magnification SEM image (Plate-B) is a close-up view of clay minerals, which occurred as clay-coatings, pore-lining and also as pore-filling material. The clays are identified as chlorite (E-G1; A-D 9) and kaolinite (B-C 2). Ilmenite grains (Ilm) are noted. Some existence microporosity (G6, O7) are observed within the clay minerals

Quatrz	Kfelds	plag	cal	dolo	Siderite	pyrite	Ilmenite	sylvite	mixed clay	illite and mica	Kaolinite	Chlorite
71.6	1.4	0	0	0	2.45	0.55	2.7	0.95	0	0.15	12.55	7.5



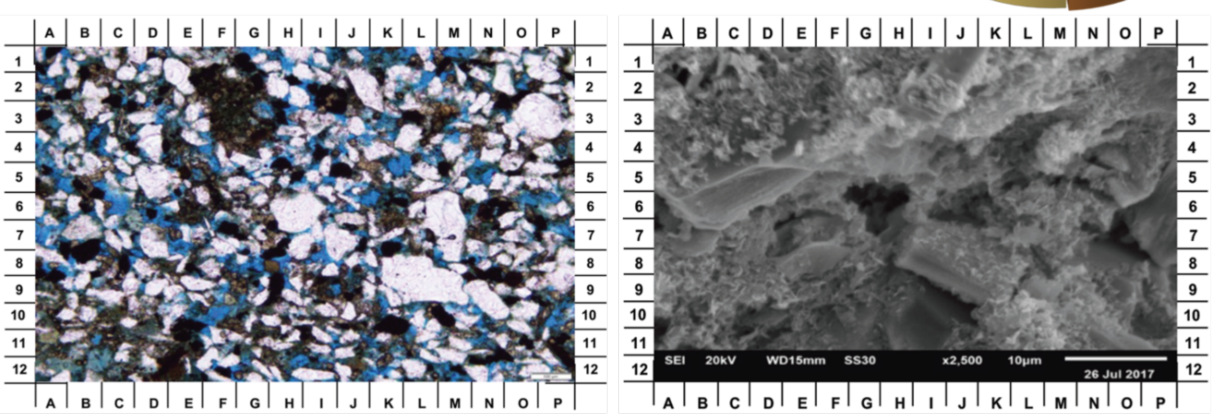


Plate-A (Magnification 10X) Plate-B (Magnification 2500X)

Figure 2: XRD, petrography and SEM results show abundance of quartz grains, dispersed clay and clay coating over sand grains.

Core No.	Sample No.	GD (gms/cc)	Porosity (%)	Kair (md)	Kair at 1 atm mean pressure (md)	Kinf (md)	Sw % PV	So % PV
1	1	2.85	31.24	1.66	195	0.70	49.64	44.12
1	2	2.78	21.37	0.19	0.28	0.11	84.68	14.56
1	3	2.81	22.77	0.20	0.27	0.14	90.34	8.43
1	4	2.79	20.65	0.12	0.21	0.03	95.24	4.19
1	5	2.78	23.85	0.22	0.44	0.03	82.02	17.63
1	6	2.88	25.88	0.25	0.34	0.16	99.17	0.00
1	1V	2.83	25.24	2.03	2.35	1.46	80.09	17.81
1	2V	2.79	20.43	0.02	-	-	98.99	0.24

Grain density doubtful or not representative as XRD reports shows 70% Quartz

Comparable to log driven PHIT

Sand

Shale

Table-1: Routine core analysis data.

Saturation Estimation using Resistivity Based Approach and Shortcomings:

Saturation models are models which relate measured resistivity to water saturation from which hydrocarbon content can be determined. Saturation models like Archie, Waxman-Smits, and other shaly sand models i.e. Dual-Water model, Indonesia Model, etc., are used to calculate the hydrocarbon saturation from resistivity log (Elvis Onovughe & Adekunle Sofolabo). In this study, for the evaluation of water saturation it was proceeded to perform various sensitivities using well logs and application of theoretical models of water saturations. For shaly sandstones there are a number of models that were determined in the past that have evolved over time. However, within this study various models of water saturation were used to compare or reproduce the most appropriate model that match with production data. In this study, the model most used is Waxman Smit.

A parallel conductance path exists in shaly sands. Some of the electrical currents will flow though the cations associated with the clay and some will pass through the salt solution in the pore system. Knowledge of the boundary between the clay associated water and the pore water is not necessarily in this model because the equation treats the two waters as a mixture. This is possible because the formation resistivity factor used in the model reflects the net conductivity from the two current paths.

The conductivity through the cation system is expressed by the terms B and QV. B is temperature and salinity dependent. QV quantifies the cation concentration per volume of formation water. The ion concentration is usually expressed in equivalents per litre. The combined term B*QV expresses the conductivity due to the presence of compensating cations in the water filling pores.

The conductivity of a wet shaly sand can be expressed as:

Co = CW/F1 + B*QV /F1

Where F1 is the formation factor for the Waxman Smits model

Because the equation treats the two conductance paths as a mixture having a common F, Sw cannot be solved in terms of the resistivity index.

Instead, Sw must be included in the body of the equation to balance the mixture relationship. Thus the Waxman-Smiths equation (Waxman M.H and L.J.M Smits) can be written in the familiar form:

CT = (PHIT^m* × SWT^n* / A) * (CW + B × QV / SWT)

Where, B: 3.63 mho.cm^2/meq

Qv: 0.91 meq/cm^3

m*: 2.25(assumed)

n*: 2.4

Parameters (B, Qv, m* and n*) are selected based on the excess conductivity (multiple salinity) and resistivity index calculation from core plugs. Other equations are also attempted (like Indonesian, Dual water) but no satisfactory results are achieved. As there are around 20% dispersed clay with in sand, most probably resistivity is suppressed due to clay conductivity though rock conductivity also cannot be ruled out. Salinity was considered as 25000 ppm (PVT sample salinity 30k ppm) considering mixing of borehole fluid (50k ppm) with formation water.

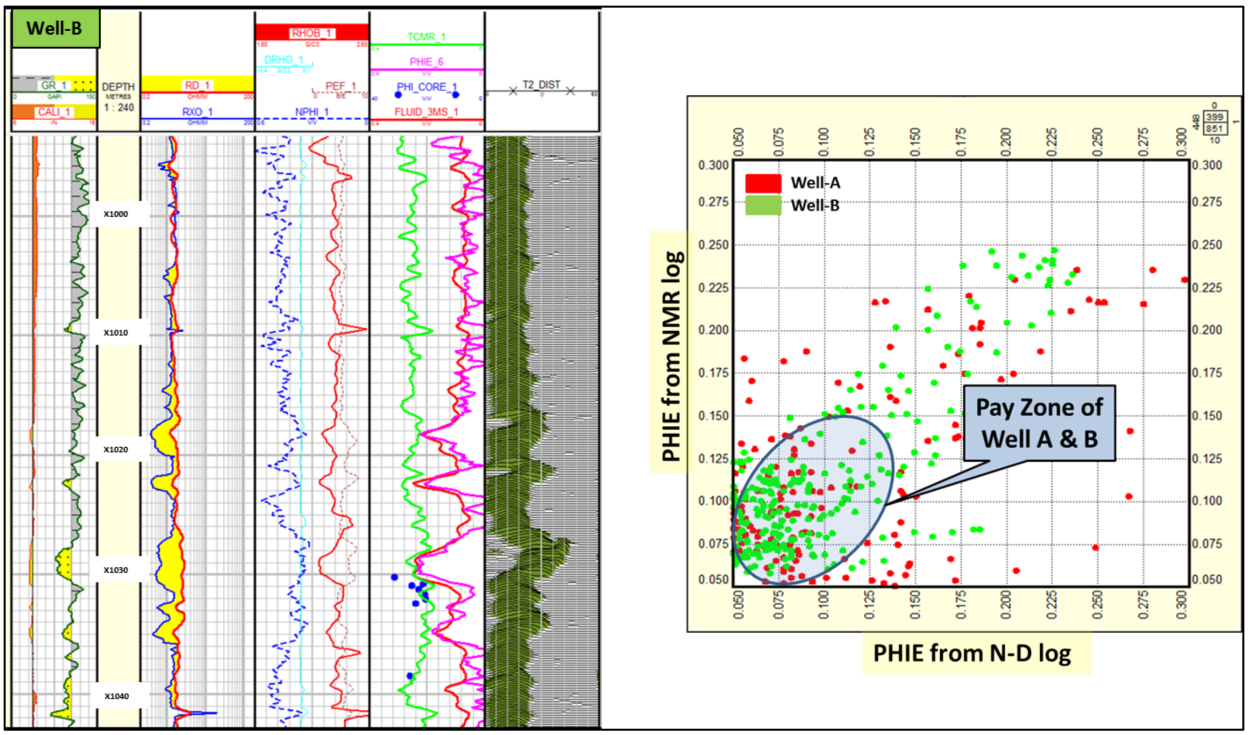


Figure 3: Comparison of porosity from neutron-density logs, NMR logs and core data. Core porosity at depth X1030 meter does not match (left figure) due to erroneous grain density measurement (Table-1). For both the wells (Well-A and Well-B)

Saturation Estimation using Integration of Magnetic Resonance and Results of Routine Core Analysis:

Irreducible water saturation (Swirr) and bulk volume irreducible (BVI) water from nuclear magnetic resonance logging are not directly measured quantities but are derived from the T2 distribution and the effective porosity. Thus, they are dependent on models and the associated parameter used in the interpretation of the T2 distribution data.

From petrographic studies, it was also evident that the reservoir contained a significant amount of dispersed clay as well as grain size was also very fine causing some difference between total porosity (PHIT) and effective/connected porosity(PHIE). In NMR results, the difference also existed between free fluid volumes (FFV) and bound fluid volume (BFV). It was decided to use 20ms cutoff to estimate the free fluid volume considering tight nature of the rock and very fine grain size. Nevertheless, this change will not affect the total as well as effective porosity. Anything above 3 ms cutoff (FLUID_3MS) was considered as effective porosity (capillary bound + free fluid) as shown in figure 3. Effective porosity from NMR was compared with effective porosity derived from neutron-density. Significant confidence was achieved after comparing phie from both NMR and standard logs.

During the testing of younger Kalol unit water free oil was produced in Well-A & B. This leads to the inference that the reservoir is well above the free water level and water in the reservoir unit has been nearly replaced by oil during migration except bound water thus it is suitable to estimate the Swirr from NMR logs using below equation.

Swirr = Bound fluid / Total Porosity

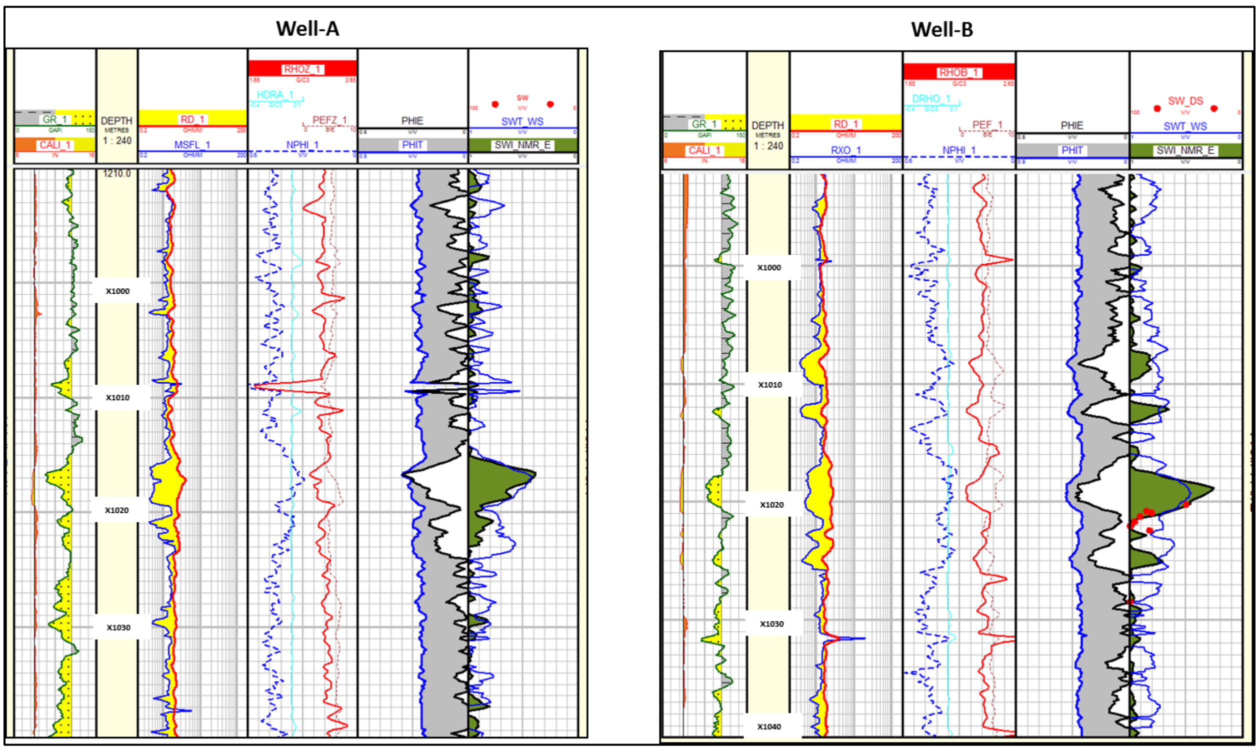


Figure 4: Comparison of saturation from resistivity logs (SWT_WS), NMR logs (SWI_NMR_T) and Dean stark data(SW_DS)

Conclusion:

Shaly sand reservoir of younger Kalol unit has been characterized by a unified methodology, making use of multiple data sets. Resistivity based approach, in presence of dispersed clay often results in underestimation of hydrocarbon saturation. Since NMR based porosities and hydrocarbon saturations are attributed to reservoir fluid and are nearly unaffected by clay minerals, integration of magnetic resonance with core data gives more representative reservoir parameters agreeing better with core results. Moreover, the NMR log is showing very small fraction of T2 distribution within the range of 3ms to 20ms, it can be inferred that the pay zone is well above the transition zone.

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