Deciphering the causes of Low Resistivity Low Contrast (LRLC) silty pay for production enhancement through Integrated Petro-physical studies for Mandhali Pay of Cambay Basin, India

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Keywords

Low Resistivity Low contrast (LRLC), NMR logs, XRD, SEM, P-half method

Abstract

Identification and evaluation of low resistivity, low contrast (LRLC) bypassed pay is a challenge. The interpretation of these pay using integrated log evaluation approach can have significant production and reserve implications, especially in mature fields. In the past, it was assumed that these intervals were either tight or water bearing based on conventional log evaluation.
Understanding the causes of low resistivity log response is important when evaluating these zones. Some of the more prevalent causes for misinterpreted low-resistivity zones are: Inter bedded or laminated sand/ shale intervals, dispersed and structural clays, other conductive minerals such as pyrite, glauconite, and other members of the mica family, altered framework grains and finer grain sizes.
In Mandhali Pay of Jotana Field located in Cambay Basin , a new detailed interpretation and formation evaluation analysis have been done to reevaluate and investigate the tight and shaly sandstone layers having low resistivity reading values. Pay was identified by investigating various resistivity water saturation models, Phalf method and correlating the results with production data.
After validating the petrophysical analysis and making integration with available core measurements and production data , the potential of the LRLC pay zones in Mandhali reservoir of Jotana filed was confirmed and quantified using petrophysical attribute .

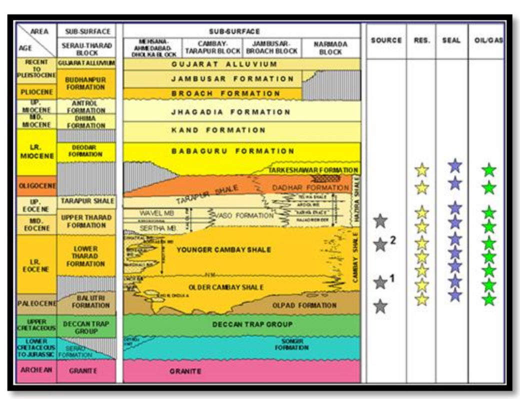
Introduction

About 30% of the world's estimated hydrocarbon reserves are entrapped in low resistivity low constraint reservoirs like laminated shaly sand and shaly sand formations. Many a times these are either considered uneconomical or don't even draw the attention of petroleum geo-scientists.
This paper presents an overview of integrated studies carried out for identification and evaluation of LRLC reservoirs of silty/shaly Mandhali formationof Cambay Basin , India. It includes analysis of basic and advance logs like Nuclear Magnetic Resonance (NMR), Resistivity Image, full waveform sonic and laboratory studies like KPHI, NMR T2 Cut-off, capillary pressure, XRD, SEM, static rock mechanical and strength parameters obtained through tri-axial studies.
Jotana Field is a major fault built structure, has multi-layered reservoir with producing sands of Eocene age. This reservoir has a high degree of vertico-lateral heterogeneity. In Jotana Field, few Mandhali sands having poor reservoir character on basic logs has shown fair producibility after being tested on strong cut observed on Side wall core and cutting data .Few vintage wells were tested against poor reservoir facies . The results have been encouraging. Due to low contrast features in the available basic logs, petrophysical analysis of such complex and heterogeneous reservoirs tends to overlook the potential zones.

Geology of the Study Area

Cambay Basin is a narrow, elongated, NNW-SSE trending "intra-cratonic aborted rift" evolved due to separation of Greater India from Seychelles towards the end of Cretaceous. The Deccan Trap forms the technical basement over which about 8km of Tertiary sediments were deposited during syn-rift and post-rift phases of basin development. The The lithostratigraphy of Cambay Basin is given in Figure-1. Jotana field falls in the prolific Cambay-Kadi Petroleum system. The principal source rocks of this system are the shales of the Cambay Group, while the principal reservoir is sand / silt layers found within Mandhali and Mehsana members of Kadi Formation forming the multi–layered reservoirs as evidenced in wells drilled in the area.

Figure 1: Generalized Statigraphy of the study area



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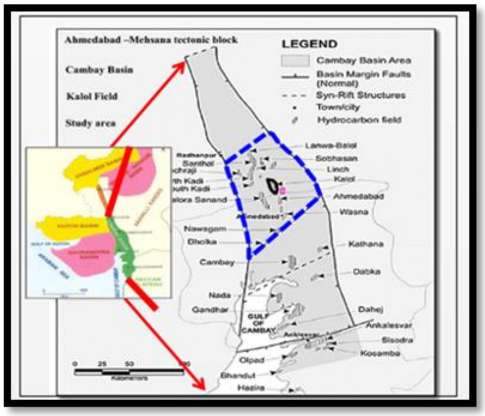

Figure 2: Map of the study area

Fig 2 shows the map of the study area which lies in Ahmedabad –Mehsana block of Cambay basin, India.

Methodology

Well log data of key wells have been considered in order to generate different type of cross-plots to arrive at mineralogy and formation water resistivity (Rw) of the studied silty pay. XRD, SEM and petro-graphic information along with different cross plots have been integrated to arrive at robust petro-physical model for the study area

Understanding the reasons for LRLC

To develop an understanding for the Low Resistivity Low Contrast Reservoirs (LRLC) in the study area, laboratory studies like XRD, SEM and petrographic studies has been carried out. XRD & SEM studies are of great help in understanding the mineralogical composition of the rocks.

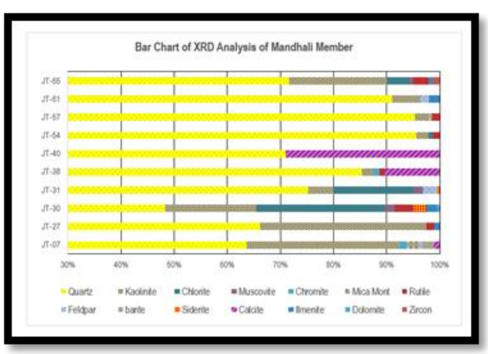

Figure 3 XRD bar chart of Mandhali unit

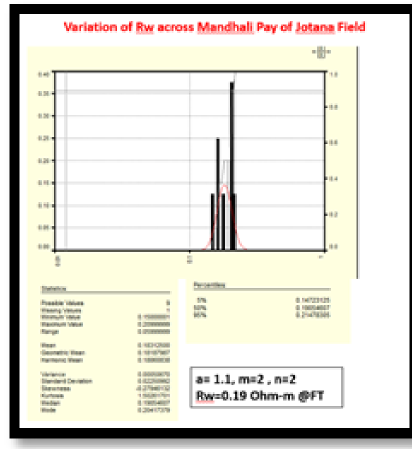

Figure 4 Variations in Rw across the field

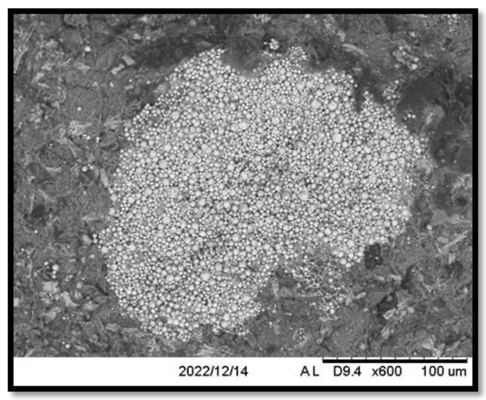

Figure 5 SEM Image showing pyrite

Figure 3 is the graphical representation of mineralogical analysis based on XRD studies for wells JT-A, JT-B, JT-C, JT-D , JT-E and JT-F. From the figure, it is clear that Quartz is the main frame work mineral, Kaolinite and Chlorite are dominant clay minerals. Siderite and Pyrite are also seen in SEM Image (Fig 5), however the percentage of both of these minerals are less than 3 % as observed on XRD data. Hence, mineralogy may not be the main reason for lowering of resistivity of the silty pays.

High formation water salinity can also be responsible for lowering of resistivity. However, in the studied area the formation water resistivity across the Mandhali pay is varying between 0.15-0.2 Ohm-m (12-15gpl salinity) at formation temperature which doesn't seem to be the reason for lowering of resistivity of pay sands of the studied area (Fig 4)

Sand shale laminations can be responsible for lowering of resistivity of pay sands. In the key wells of studied area, Thomas –Stieber plots and other analysis from scarcely

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available hi-tech data do not indicate possibilities of typical thin bed setup in the study area. However more detailed acquisition/ analysis needs to be carried out to know the thin bed nature of reservoirs.

Fig 6 shows the capillary pressure curve studies carried out on core plugs against Mandhali and OCS formations in wells JT-B and JT-F respectively. From Pc Vs Sw curve it is evident that high Swirr (Swirr>70 %) exists in the studied samples. However, there is scarcity of core plugs against silty formations and more plugs needs to be taken against such formation to better characterize the formation.

NMR T2 distribution has been processed in the wells JT-G and JT-H to obtain pore size distribution. From Fig.7 it is evident that lot of micro and meso pores are present against the silty pay.

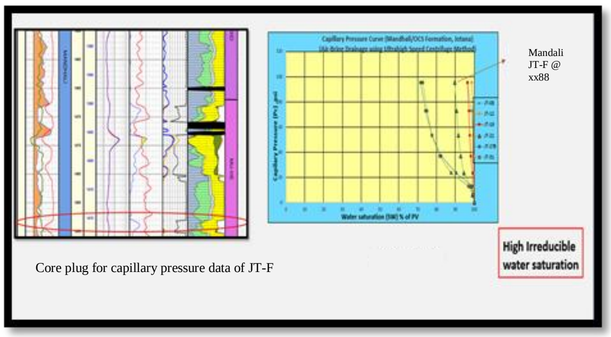

Figure 6 Capillary pressure data showing high Swirr

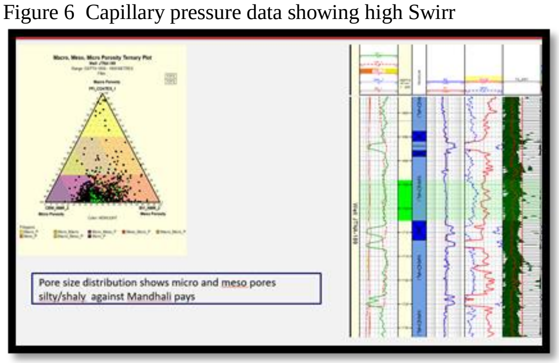

Figure 7 NMR data showing pore size distribution

In conclusion high capillarity of fine grained silty facies of Mandhali pays is found to be the most prominent reason for the Low Resistivity Low Contrast in these facies . Some clay coated grains are also seen on SEM Image and ferruginous cementation is also seen on polarizing microscope. This may cause further lowering of resistivity against silty pays .

Identification & Evaluation of LRLC pay

Cross-plots are useful technique to identify data trend and reduce multi-dimensional problem to 2 dimensional. Neutron-Density and N-D difference plot have been used to visualize the variations in silty facies in the key wells of the study area.

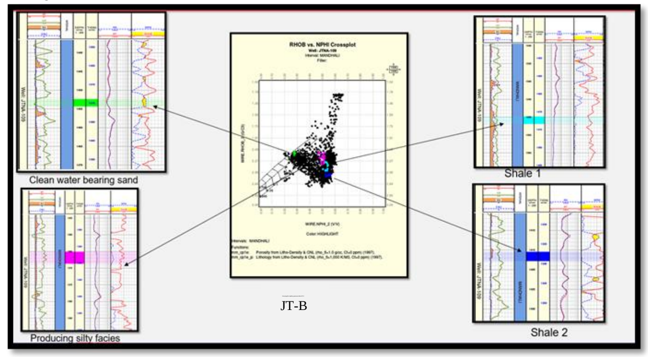

Figure 8 N-D cross plot showing different facies

Fig 8 shows Neutron Density cross –plot for well JT-B. Clean water bearing sands is marked as green color. Cyan and blue color highlighted shows two different types of shales. Producing silty facies is marked as purple colour. N-D cross plot gives a clear trend for all three facies and is a useful technique for identifying the producing facies.

Fig. 9 shows the log motif and processed output for the well JT-B . Multi-mineral processing for Sw and PHIE has been carried out for the silty facies. P-Half method has also been used to compute saturation. Interval 1362.5-1363.5 m & 1365-1369 m against Mandhali Unit has been perforated and hydraulic fracturing has been carried out. The interval gave Ql =14 cu.m per day with 20 % water cut.

Sw computed using Multi-mineral model (Sw in orange colour in Fig 9), Indonesian equation is giving Sw around 60% and PHIE ~19 %. Sw has also been computed using P-Half method. There is good correlation between Sw computed from P-Half (Sw in blue colour) and Multi-mineral model(orange colour). P- Half method gives some unwanted saturation at places, which can be ruled out by taking support from SP log and N-D difference log.

In nut shell, P-Half method for computing saturation seems to work well for the study area in conjunction with SP & N-D difference log.

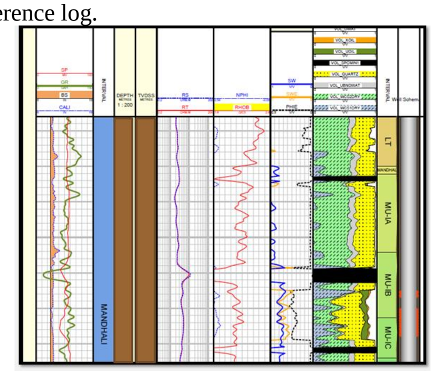

Figure 9 Multi-mineral and P-half output for well JT-B

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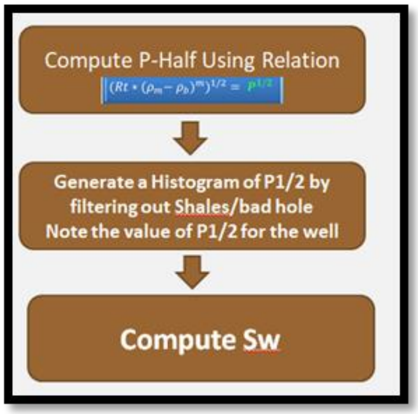

Figure 10 Methodology to evaluate Sw using P-Half

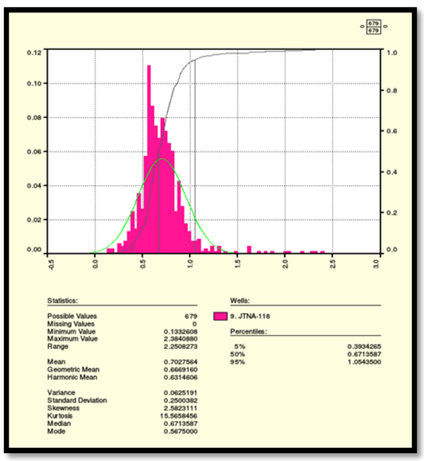

Figure 11 Histogram of P-half for well JT-B

To evaluate the silty pay, multi-mineral and P-half method has been used in the current study.

P-Half method is an independent statistical evaluation method. This method is based on the 'Pattern Recognition approach' proposed by G.R. Pickett (Ref. SPWLA Fourteenth Annual Logging Symposium, May 6-9, 1973). The basic advantage of the pattern recognition approach is that the resistivity index (a measure of water saturation) can be derived without having a calibration for the porosity device (i.e., grain density, matrix Δt, etc.), without a knowledge of m, Rw, or Rmf, and in the presence of many types of logging 'calibration'-type errors.

The methodology for computing saturation using P-half method is shown in the figure 10 and histogram of P-half in fig 11.

The basis for the pattern recognition approach is the realization that a plot of resistivity versus any of the available 'porosity tool' responses (Acoustic, Neutron, Density etc.) will produce an identifiable graphical pattern for water saturated zones and that this pattern will be distorted in a particular way if any of the zones contain hydrocarbons. Values of water saturation are determined using a parameter 'P'. This parameter is a function of formation resistivity and porosity tool response. It has been found empirically that P has a square-root-normal distribution for zones 100% saturated with water. Hydrocarbon zones deviate from this distribution. By determining the mean value of P at a water saturation of 100 percent, it is possible to evaluate the resistivity index, I, for hydrocarbon zones and, hence, the values of water saturation.

Conclusion

An understanding for the reasons for low resistivity , low contrast silty pays of Mandhali sands of Jotana field has been developed by integrating logs, laboratory and other geo-scientific data. The analysis of all available dataset point to fine grained nature and capillarity to be the prominent cause of LRLC in the study area. Some clay coated grains are seen on SEM Image and ferrogenous cementation are also seen on polarizing microscope. This may cause lowering of resistivity against silty pays

Since, most of the wells have basic logs only, crossplot techniques, RHOB-NPHI, N-D difference vs N/D Ratio have been utilised to analyse the facies. Most of the silty zones which have produced hydrocarbon on testing have been found to be clustering on the upper edge of the sand-shale trend on RHOB-NPHI cross plot thereby indicating possible pull of carbonaceous material & nil influence of heavy minerals. These trends have been used to identify prospective silty facies across studied wells.

It was observed that multi-mineral processing has been able to identify prospective zones in tested wells. Statistical technique P-half was also used to compute saturation against these pays, and was found to provide similar estimates of Sw.

The study has provided good insight in terms of developing an understanding for the reasons for low contrast pay and identify/prioritise these pays for better exploration and exploitation. More data in terms of Lab Studies & hitech data particularly CMR is recommended to be acquired for improved quantitative evaluation of tight Mandhali reservoirs.

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Acknowledgement

The authors express their sincere gratitude to Smt. Sushma Rawat, Director(Exploration) , ONGC for her kind permission to publish the paper. The authors thank all the CEWELL colleagues for their valuable support.
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