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Evaluation of low resistivity pay zones of Chhatral Member of Younger Camay Shale of Gamij field, Ahmedabad block, Cambay basin

Abstract

Petrophysical parameters play an important role for evaluation of low resistivity reservoirs. In the present study, an attempt has been made to understand the physical and chemical rock properties and their interactions with fluids to infer the hydrocarbon prospectivity of low resistivity rocks. The comprehensive integration of logs / cores / ditch sample cuttings provide vital information to understand the reasons of low resistivity pay zones. The mechanisms responsible for low resistivity phenomenon viz. mineralogy, grains size and clay distributions have been interpreted based on well log / laboratory data. Specialized logs viz. Lithoscanner, NMR recorded in study area indicate that the reservoir rocks of Chhatral Member consist of significant amounts of pyrite and Fe-Ti minerals, very fine grain size and high volume of clay minerals. These characters associated with reservoir rocks are responsible for lowering of resistivity. As grain size gets smaller the surface area to volume ratio increases which raise the capacity to hold water. Thus very fine grain size will have high capillary bound water resulting in lowering of resistivity. Similarly, high clay content lowers the resistivity by virtue of high bound water and high conductivity. The Chhatral Member was deposited in lower delta regime in the study area. The study will help to identify low resistivity hydrocarbon bearing zones in Gamij field.

Introduction

The Cambay Basin is one of the major hydrocarbon producing basins of India (Fig.1). This basin is an intracratonic rift graben situated in the western part of the Indian sub-continent. The basin came into existence during Late Mesozoic era with the development of major extensional faults along preexisting basement trends following widespread extrusion of Deccan Trap basalt. This basaltic floor formed the basement for the deposition of a huge thickness of Tertiary- Quaternary sediments in the basin. Based on the recognized basement fault trends, the basin has been divided into a number of blocks namely Sanchor-Patan, Mehsana-Ahmedabad, Tarapur, Broach-Jambusar and Narmada (Mathur et al. 1966; Chandra and Choudhary, 1969; Biswas 1987; Raju and Srinivasan 1993).

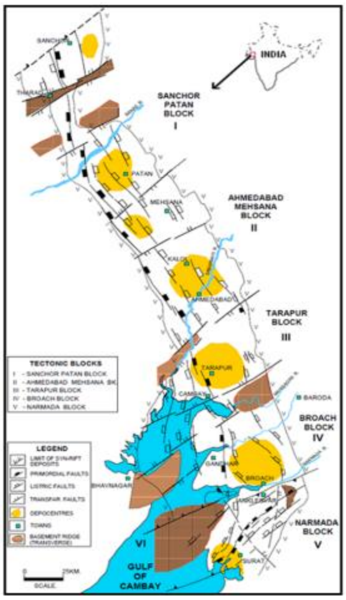

Fig.-1: Cambay Basin (Mishra and Patel, 2011)

Gamij is onshore field located in the eastern margin of Mehsana-Ahmedabad block of Cambay basin and was discovered in 1982 and put on production in 1994 (Fig.2). The generalized stratigraphy of Cambay Basin is shown in Fig. 3. The field has multilayered reservoirs in Sertha and Wavel Members of Kalol, Chhatral Member of Younger Cambay Shale (YCS) and Olpad Formations. The major producing reservoirs are sands of Sertha & Wavel Members of Kalol followed by Chhatral Member of YCS. Chhatral pay has a very wide areal distribution (in almost all the field) with a large locked hydrocarbon reserve. Chhatral is a low resistivity pay with average resistivity of producing intervals ranging from 1-3 ohm.meter. The average porosity is 15-20%. The permeability is very low ranging between <1 to 10md. Due to huge locked reserve and poor productivity (~2 m3/d/well) it is always a challenge to increase recovery from such type of reservoir. This study is carried out in order to understand the reason for low resistivity and the regional setting for deposition so that a better strategy can be developed for exploiting the reservoir.

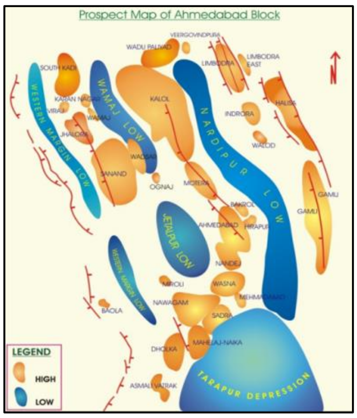

Fig.-2: Prospect Map of Ahmedabad Block

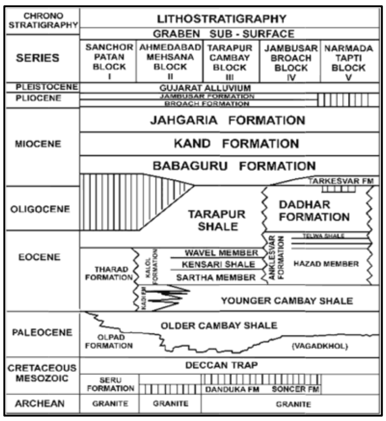

Fig.-3: Generalized stratigraphy of Cambay Basin

Identification of Low resistivity pay

The problem of identifying low resistivity pay through wireline log has been a challenge since a long time. Low resistivity pay is relative term which indicates lack of proper resistivity contrast as compared to shale portion or water bearing portion. As identification of low resistivity pay is difficult with conventional logging tools, a specialized logging program such as ECS/ Lithoscanner, NMR or EPT might be use along with conventional sidewall coring, & production logging (Chu, W.C. and Steckhan, J., 2011; Souvick, S., 2003). Electromagnetic Propagation Tool can distinguish between oil and water based on difference in dielectric constant. NMR logging is another tool used to determine the reservoir rock petrophysical properties. NMR log measures the strength and decay time of the signal generated due to relaxation of proton in an alternating magnetic field. The relaxation time varies depending on the bonds affecting the proton. This is used to identify the producibility of reservoir, lithology independent porosity and distinguish between bound and free water. ECS (elemental capture spectroscopy)/ Lithoscanner measure relative elemental yields for silica, iron, calcium, sulfur, titanium, chlorine, barium and hydrogen based on neutron induced capture gamma ray spectroscopy. Matrix properties and quantitative dry weight lithologies are then calculated from this fraction.

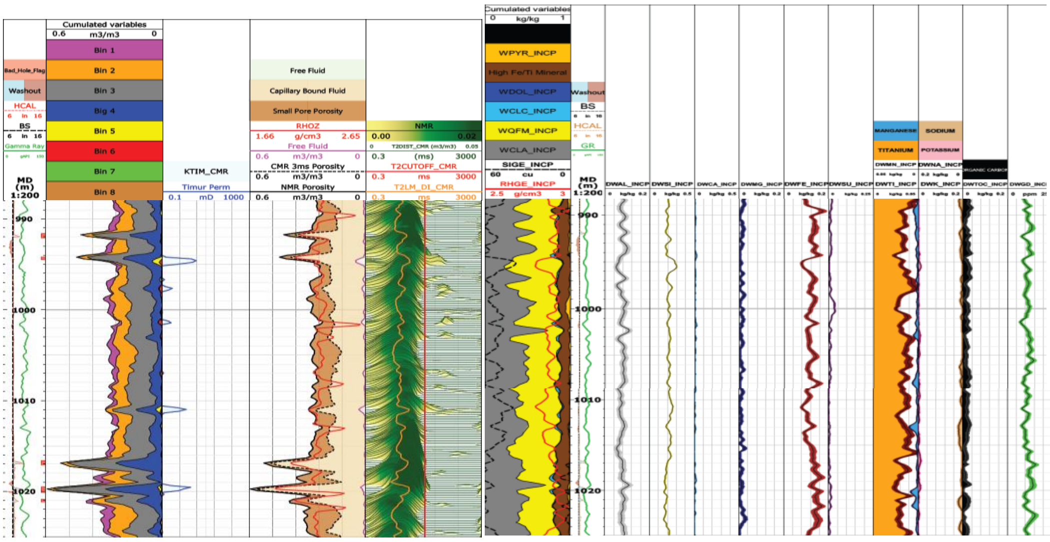

Fig.-4: NMR and Lithoscanner Log recorded in well GM-X, in Chhatral pay

Causes of Low resistivity Pay

A number of factors have been found to act on the logging tool to lower apparent resistivity, like bed thickness, grain size, mineralogy, structural dip, clay distribution, water salinity and any combination of the above (Boyd, A. et al., 1995; Worthington, P.F., 2000; Darling, H.L. et al., 1993; Zhiqiang, M., et al., 2007). In Gamij field, the following factors lead to lowering of resistivity:

- **Mineralogy:** Presence of conductive minerals such as Pyrite, Ilmenite, Glauconite, Siderite, Hematite etc. will suppress the resistivity of formation. The effects of conductive mineral vary with its morphology and distribution. In order to quantify the effect of conductive minerals, the proportion of such minerals has to be computed. In Gamij, a specialized Lithoscanner was recorded in well GM-X. It is observed that pyrite and Fe-Ti minerals were present which lead to lowering of resistivity (Fig. 4).
- **Grain size:** As grain size gets smaller, the surface area to volume ratio increases, which raises the capacity to hold water. Thus very fine grain size will have high capillary bound water resulting in lowering of resistivity. In order to understand the effect of grain size in Gamij field a specialized log NMR was recorded in well GM-X. NMR log is used to measure the bound water which ultimately indicates grain size distribution. In Gamij field it is observed that most of the Chhatral section show high bound water which lead to lowering of resistivity (Fig-4)**.**
- **Clay Distribution:** Presence of clay as dispersed, structural or laminated have impact on resistivity. High clay percentages lower the resistivity by virtue of high bound water and high

conductivity (due to cation exchange capacity). Lithoscanner recorded in well GM-X shows high volume of clays present in Chhatral section (Fig-4).

Depositional Setting

Depositional environments are important and essential not just for establishing the evolution history of the area, but also needed to properly understand and describe the reservoir behavior and properties so that proper development strategy can be formulated. To assess the depositional environment, environmental analysis was undertaken. Environmental analysis is based on properties of rocks that have environmental significances, which are sediment structures, textures, fossils and sedimentary facies associations analyzed from the core and log data. From these information, the depositional model has been envisaged. In the study area the depositional environment has been depicted based on specialized logging and core data available in well GM-X and GM-Y.

The following features relevant to sedimentary environment, as observed from the logs and core are:

1) Chhatral interval (990m-1020m) is characterized by parallel to subparallel beds dipping west at an angle of about 6°.

2) Crossbeds are seen in the zone of study, with the top unit 4m thick and the lower units varying between 2-0.5m in thickness.

3) There is a decreasing trend of the crossbed unit thickness with depth.

4) The lithology is mostly shale with intervals of siltstone about 10-20cm thick.

5) Some of the silty intervals show burrows.

6) Pyrite is not seen readily in cores of Chhatral interval. However the Lithoscanner indicates it's presence. Pyrite infilling of burrows is seen in cores of Kalol interval (below K-IX coal).

Given such, and keeping in mind that Kalol is terrestrial and Cambay shale for the most part is marine, Chhatral must therefore represent transitional facies. Given the abundance of fine sediments (represented by shale) and slopes of 4°-6°, delta environment seems to match the description of this well. Tidal influence is unlikely due to the constant dip direction (tidal environments usually show bimodal to bipolar dip directions). At the base of Kalol formation (976.7m) the appearance of coal streaks (in core cc#3, segment T22) marks the first subaerial exposures and the start of continental regime.

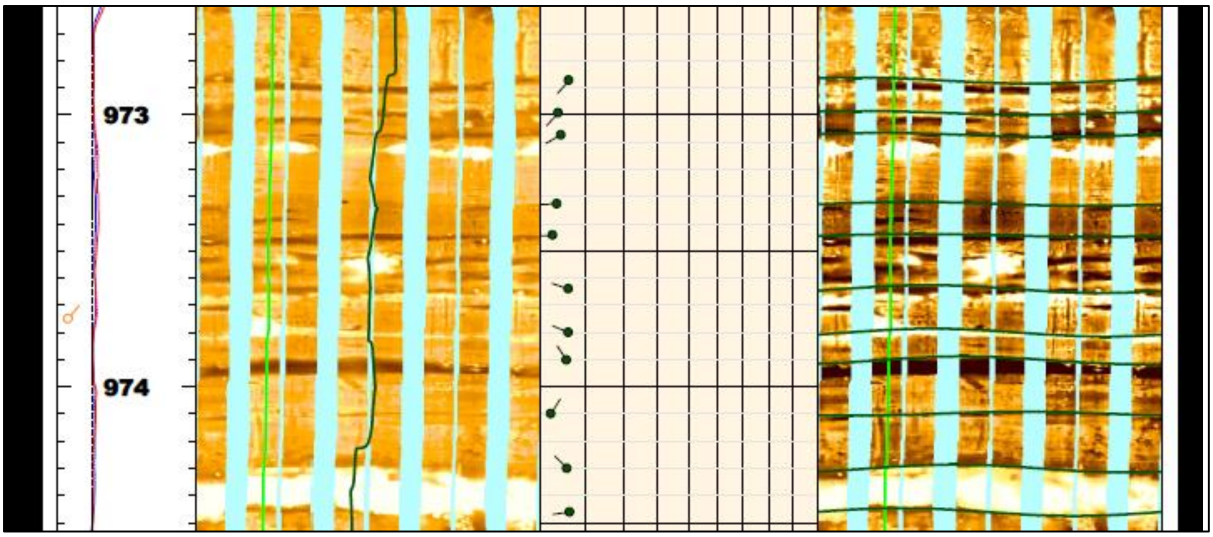

Fig.-5: FMI Log motif depicting tidal structures (rapid change of dip direction but in an ordered way, showing bimodality of dip direction)

In view of the above, the depositional environment encountered in this well in the Chhatral section is best described as lower delta slope deposits, of a delta building out to the west and gradually changing to a tidal-influenced delta top at Kalol times (bimodality of dip direction, 973-974m for example). The core images in fig. 7, depicting shales intercalated with ~15-20 cms of siltstone, support this interpretation in terms of grain-size of the sediment deposited. Given the fine grained nature of the sediment, and the

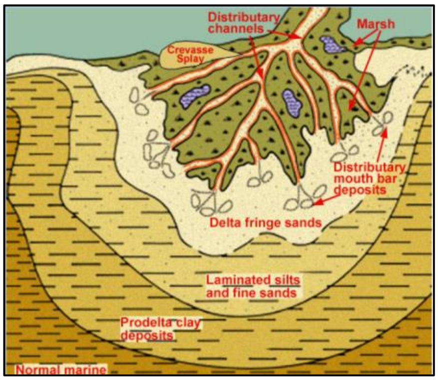

Fig.-8: Conceptual model of Delta Sub-environments

structural details as seen in the FMI log the probable situation at this locatic
from prodelta at the bottom of Chhatral, grading to laminated silts of the
visualized in fig. 8, where a conceptual model of delta has been perceived. From the correlation sections presented in fig. 9 and fig. 10, it can be seen that the pack thickness of Chhatral does not show any trend from north to south, but shows a very distinct thinning trend from west to east. This is due to Gamij being at the eastern margin of Cambay rift basin.

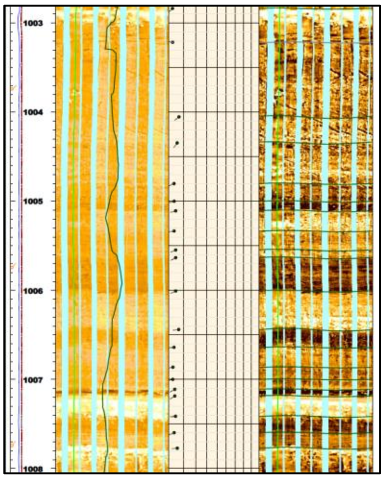

Fig.-6: FMI log motif recorded in well GM-X showing lamination in Chhatral interval

Fig.-7 Core photographs in well GM-X showing laminations and burrows

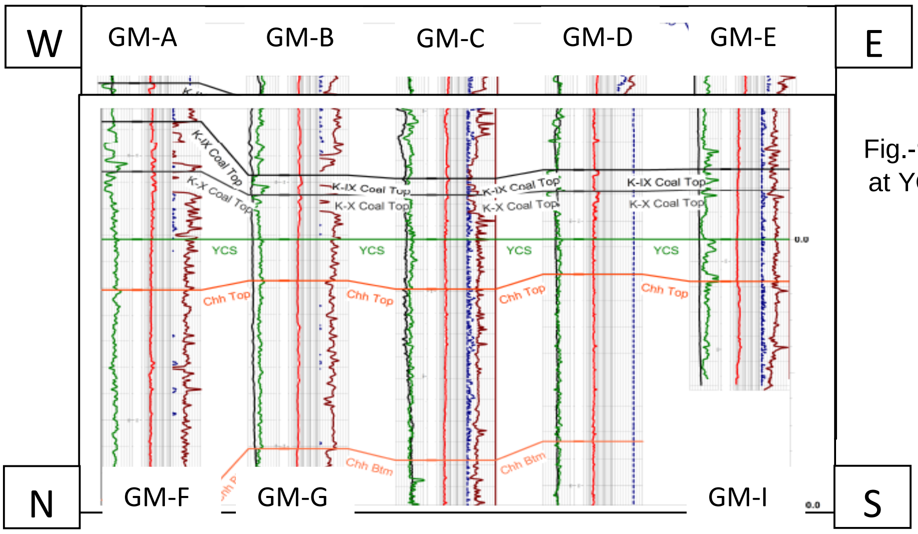

Fig.-9: EW well log cross section flatened at YCS top, showing Chhatral Formation

Fig.-10: NS well log cross section flattened at YCS top, showing Chhatral

Worldwide scenario

Low resistivity pay has been recognized as a challenge for over 30 years with documented records found in the Gulf of Mexico, Angola, Venezuela, Australia, Argentina, the North Sea, North Africa, the Middle East, India, Malaysia, Philippines and China. The Gulf of Mexico basin is the world's leading oil and gas producer from Low Resistivity Low Contrast (LRLC) clastic reservoir (Sneider, R.M., 2005). Below are some success stories from around the world:

- Successful identification of gas bearing low resistive sand using new wireline formation tester tool with the pump-out and optical fluid analyser modules and Nuclear Magnetic Resonance data- East Kalimantan Field, Indonesia (Palar, S. and Sutiyono, S., 1997).

- Interpretation of very thin gas sands from north-eastern Italy by detailed logging program using the EPT (Electromagnetic propagation tool), Micro-Resistivity Dip meter curves and attenuation curve along with standard logs (Suau, J et al, 1984).

- Surprising productivity from low resistivity Pleistocene sands of offshore Louisiana using log analysis with geological reasoning and core data. When the zone was perforated through 100 ft, the well flowed oil at 1303 BOPD, with no water. When the sidewall samples were analyzed through SEM, it was found that the clay was distributed within the sand as overgrowths on grain surfaces, and that in some pores these were completely pore-filling, leading to high bound water (Vajnar, E.A.et al 1977, Worthington, P.F., 2000).

Conclusion

- Low resistivity low contrast reservoirs are always a challenge for the geologist. For the explorationist it might become a missed opportunity and for development geologists and petroleum engineers, there is always a challenge in quantifying their volume and establishing their producibility.
- Low resistivity pay is a relative term, which indicates lack of proper resistivity contrast as compared to shaly portions or water bearing portions.
- A specialized logging program such as ECS/Lithoscanner, NMR, or EPT might be used along with conventional sidewall coring for identification of low resistivity pays.
- This study is carried out on Chhatral pay of Gamij field in order to understand the reasons for low resistivity and it's regional environmental setting for deposition so that a strategy can be developed for the exploiting the reservoir.
- Based on available data and studies in Gamij, mainly 3 factors, viz. grain size, mineralogy and clay distribution have been found to act on the logging tool to produce low resistivity.
- Based on data recorded in well GM-X, the depositional environment in the Chhatral section is best described as lower delta slope deposits, of a delta building out to the west and gradually changing to a tidal-influenced delta top at Kalol.
- A detailed study on core analysis, rock property measurements, thin sections, SEM imaging, along with inter-disciplinary effort between the geologist and petrophysicist in analyzing all the data available is required so that a robust conceptual geological model can be built. Based on such a model, a suitable development strategy can be built for the aggressive exploitation of low resistivity reservoirs.

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