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An Integrated Formation Evaluation Approach for Maximizing the Value of Mature Shaly Sand Reservoir- A Case Study from Ravva Middle Miocene Reservoir

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Summary

Middle Miocene reservoir of Ravva field, Krishna Godavari offshore basin, India has been producing hydrocarbon for the last ~20 years. To increase production and extract hydrocarbon from by-passed zones, an integrated field development project including comprehensive petrophysical evaluation was instigated. Petrophysical analysis of the field was challenging due to the presence of both dispersed and laminated clays as well as the requirement for specific petrophysical parameters for individual fault block compartments. Additional challenges to the analysis came from a sparsity of log and core data as well as different vintages of data which required normalization. Although there are deficiencies in each data set, integration of the data sets leads to a synergy resulting in accurate petrophysical results for input to the volumetric estimation.

Keywords: Krishna-Godavari Basin, Formation Evaluation

Introduction

The Middle Miocene reservoirs are the most prospective zones of Ravva field, Krishna Godavari offshore basin located on the eastern coast of India. This mature field has been producing hydrocarbon for the last 20 years. The field has produced more than 253 million barrels of crude and sold 317 billion cubic feet of gas. To increase production and maximize recovery, operator has initiated an integrated cross-functional field characterization study. The main objective of the study was to identify the bypassed hydrocarbon through robust static and dynamic model. The work was commenced with qualitative and quantitative 4-D seismic interpretation *(Kondal et al. 2013)* together with fault seal analysis and detailed sequence stratigraphic modeling. A comprehensive petrophysical evaluation followed and was aided by the application of modern techniques and high-tech logs.

Method

Fault seal analysis and formation pressure data suggest the presence of several fault blocks with different pressure regime and variable fluid and matrix properties in the Middle Miocene interval of Ravva field. Petrophysical analysis is challenging in the reservoir due to the presence of both dispersed and laminated clays as well as the requirement for specific petrophysical parameters to be applied to each of the individual fault block compartments. Additional challenges to the analysis came from a sparsity of log and core data as well as different vintages of data which required normalization to enable accurate comparisons from well to well. Some wells within the field have been affected by insufficient well log information over the reservoir intervals either due to the poor borehole condition or tool failure. This does not allow complete quantitative analysis in reservoir zones. Analysis done by integrating the limited available log data (open hole data affected by poor borehole condition and cased hole data), dynamic data indicating performance of the wells and correlation from near-by wells are applied to generate petrophysical properties in these wells. In some well, cased hole log data like neutron, gamma and specially pulsed neutron capture (PNC) data is used to compute the lithology, porosity and fluid saturation in the absence of open hole log data. This provides more confidence to populate the petrophysical properties in those regions and also for history matching in dynamic modeling.

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Shale volumes are estimated from neutron-density difference responses for this shaly sand intervals as it provides better vertical resoulution. Although Vsh from gamma ray is determined, it is not preferred over Vsh determined from Neutron-Density logs. The main reason is the presence of considerable amount of K-feldspar and Illite in sand section (as evident from XRD results). Appropriate fluid corrections are made on neutron density logs in gas intervals. Depending on the poor borehole condition and data quality, Vsh determined from Gamma ray has been used in certain intervals.

Total and effective porosity values are derived from the density response in combination with the estimated shale volume. Total porosity is estimated by means of the density log method, and then discounted (as a function of estimated shale volume) for clay effects in order to achieve clay-corrected effective porosity *(Fertl, 1987)*.

An estimate of in situ permeability from log data is needed as input for geo-cellular modeling. A model for permeability estimation from log data has been constructed based on the core and petrophysical log analysis results. If the poro-perm transform is solely based on total porosity data, it will provide a good match in reservoir section but also show high amount of perm in shale section as shales here has very high porosity. The routine core porosity and permeability data suggest that porosity alone is not likely to be a good predictor of permeability. The model presented here is a regression estimate of the logarithm of core Klinkenberg corrected permeability at net overburden pressure as a function of the corresponding core derived values of total porosity and log derived shale volume. The result suggests that permeability in this rock is actually more sensitive to variations in clay content than to variations in porosity *(Wong et al. 1998)*. Core calibrated log derived permeability is matched with the limited mobility and well test analysis data.

Major uncertainty in formation evaluation of this reservoir comes from the water saturation determination, as core measured saturation (Dean Stark) data is unavailable from core plugs. All the efforts to acquire vertical core plugs for water saturation determination at the field are in vain due the extremely friable nature of sediments. Absence of Dean-Stark saturation data makes it impossible to calibrate the water saturation determined from log based method as well as saturation height function.

In post–production wells where fluid contacts have been affected by the production, saturation computed from resistivity logs is applied to know possible position of contact *(Archie, 1942)*. Water samples collected from wireline pressure testing and production is analyzed for their salinity and matched with the log based Pickett plot derived salinity to increase the level of confidence for formation water resistivity determination. Electrical properties like cementation factor (m) and saturation exponent (n) are also measured in SCAL tests (Special Core Analysis test) using the formation water equivalent brine in lab at NOBP condition *(Klein et al., 1997)*. In this shaly sand reservoir where significant variation exists between total water saturation (Swt) and effective water saturation (Swe), Cation Exchange Capacity (CEC) is computed in the lab to consider the conductivity associated with clays and its role in water saturation computation *(Waxman & Smits, 1968, Fertl & Hammack, 1971, Worthington, 2002)*.

Capillary pressure (Pc) tests were conducted on more than 50 core plug samples collected from different wells using centrifuge tests with variety of laboratory systems, like airoil, air-water, and water-oil systems. All of these laboratory data were re-calculated to reflect assumed reservoir conditions. The calculations of the Pc data at assumed reservoir conditions utilizes standard values of interfacial tension and contact angle ("Special Core Analysis", Core Laboratories, 1982), along with values of fluid gradients obtained from pressure tests and compositional analysis. The result is an estimate of in situ reservoir water saturation (oil-water system) for each Pc sample as a function of height above zero capillary pressure. Inspection of the capillary pressure data leads to the subjective conclusion that (as is often the case) the single rock parameter most responsible for the variation in Pc response between plugs is the rock permeability.

Saturations computed from log based method and height function is showing significant variation. Absence of any core saturation data makes it difficult to choose the right one for volumetric calculation. The hydrocarbon saturation computed from resistivity log based methods is showing pessimistic values than the saturation height method. This is because the resistivity values are affected by thin shale laminations present within the reservoir section (observed in core photos). In laminated shaly sand intervals the basic wireline resistivity log is compared to modelled sand resistivity and micro-resistivity log derived from image logs. This comparison indicates the pessimistic readings of resistivity values from wireline response. In thick clean reservoir section, saturation values computed from log based method and saturation height function are matching well (Figure 1).

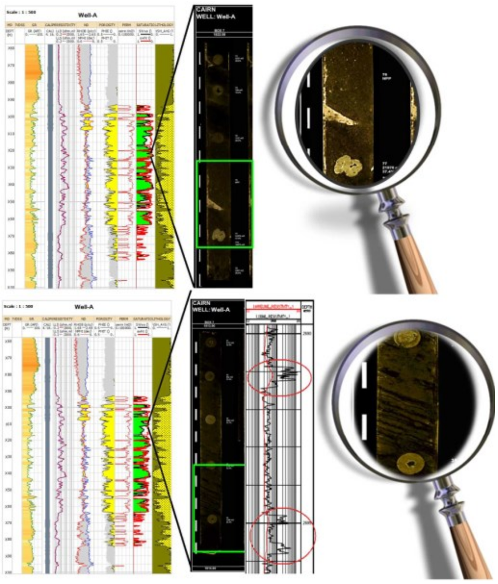

Figure 1: Comparison between height function and resistivity based saturation.

To prove the effect of fine shale laminations on the conventional resistivity logs with more confidence, triaxial induction resistivity tools had been run in some of the wells. Sand resistivity obtained from the triaxial induction tools shows conventional resistivity values are getting subdued due to the presence of fine shale laminations (Figure 2) in the reservoir.

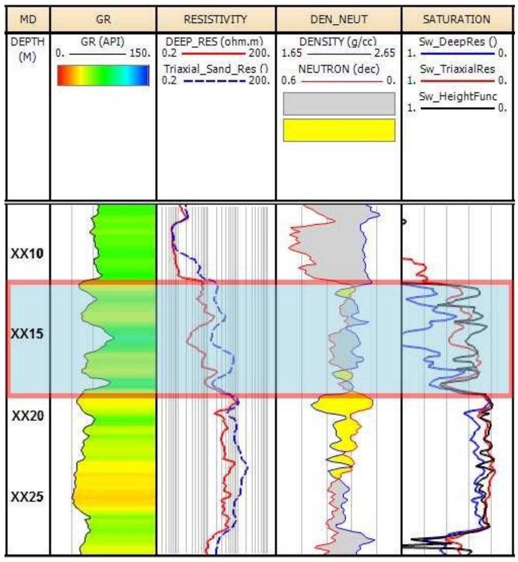

Figure 2: Comparison between conventional and triaxial induction resistivity shows saturation values computed from conventional resistivity is subdued because of fine shale laminations

Although there are deficiencies in each data set, integration of the data sets leads to a synergy resulting in accurate petrophysical results for input to the estimation of STOIIP (Stock Tank Oil Initially in Place) and EUR (Estimated Ultimate Recovery) *(Woodhouse & Warner, 2005).*

Conclusion

The objective of this paper is to summarize the challenges faced during the comprehensive formation evaluation for this complex shaly sand reservoir. The petrophysical work flow that is presented through the paper can be applied to other mature, complex shaly sand reservoir for formation evaluation.

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