



Integrated Petro physical evaluation in Deep Water Reservoirs: A case study from KG Offshore, India

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Abstract

Estimation of petro physical properties such as effective porosity, volume of shale, and water saturation using well log responses is a significant step for reservoir evaluation. The X field is a crucial chunk of the multi-billion-dollar project undertaken by State Owned Oil and Natural Gas Corp (ONGC). The paper highlights the application of Multi-component induction logging, Nuclear Magnetic Resonance, Full bore Resistivity Imager and Dynamic formation tester survey for accurate petro physical evaluation in a deep-water Pliocene turbidite formation composed of thin sand interbedded with shale. It has been suggested by many studies that, most of the time, conventional methods for petro physical evaluation (e.g. porosity and saturation calculation) in this kind of reservoir do not work properly. To reduce the uncertainty in the estimations of hydrocarbon in place and fluid contacts in clastic reservoirs, it is paramount to integrate various measurements such as log analysis, image logs, pressure data and fluid sampling results for a holistic and meaningful evaluation approach. The integrated approach and workflow that combined these independent measurement methods proved to be the key to the success for formation fluid characterization. Detailed geo mechanical analysis has been carried out and crucial reservoir parameters like pore pressure prediction, magnitude and direction of Horizontal stress, UCS, friction angle and Well bore stability model were estimated, The outputs were used in the design of gravel pack for completion and also played an important role in the production profile for the field.

Introduction

Petro physical analysis plays an important role in reservoir characterization, especially in

discriminating between the hydrocarbon and non-hydrocarbon bearing zones. Generally, petro physical analysis is performed to transform the wire-line log data into reservoir properties such as volume of shale, porosity, permeability, and water and hydrocarbon saturation. Proper analysis of these reservoir properties can significantly enhance the ability to discriminate between the hydrocarbon and non-hydrocarbon bearing zones. Complex geology of study area, inadequate reservoir characterization can cause significant amounts of hydrocarbons to remain un-recovered or to be recovered partially. Hence, proper evaluation of Petro-physical parameters plays an important role in the field development

Among the main uncertainties are the scarcity of knowledge of clay volume and volume of irreducible water in the sand, high silt index and no neutron density cross-over in hydrocarbon bearing sections. The inability to quantify these uncertainties results in water saturation computation either too optimistic or pessimistic depending heavily on the clay volume. Integrating Nuclear Magnetic Resonance logs along with the conventional logs can aid in reducing the uncertainty of petro physical evaluation. To mitigate the uncertainties of petro-physical evaluation for volumetric analysis, a clear understanding of formation resistivity anisotropy is essential. This paper describes the methodology that proved successful in establishing presence of hydrocarbon in deep water reservoirs of Krishna Godavari play.

Multicomponent Induction Tool

Worldwide 30-40% of the in-place reserves are confined within thin beds. The conventional logging tools, with low vertical resolution, are not able to characterize the thin beds. Tri-axial resistivity tools help in delineating thin sand shale sequences thereby reducing uncertainties in quantitative evaluation of thin sand shale sequence. The tri-axial resistivity tool



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(3DRI) produces a nine-element array for each transmitter and receiver pair. Shale affected resistivity in laminated layers is calculated as vertical and horizontal resistivities which plays an important role in finding the correct hydrocarbon saturation associated with thin beds, which could have easily been underestimated or overlooked in conventional resistivity logs. In Laminated Shale Sand Analysis (Figure 1), the volume of laminar shale is determined twice, i.e.; from the tensor model, and another by using the Thomas Stieber model. The Thomas Stieber model is simple with only two basic inputs, while the tensor model is more complex, relying on correct input values for horizontal and vertical shale resistivity which are to be determined on the basis of zone interval defined. The convergence of the two models in laminated intervals can be used as a check that the shale resistivity values are valid. The Laminated Shale Sand Analysis platform was used in this well for evaluation of thin-bedded sand-shale sequences using vertical resistivity along with conventional horizontal resistivity data. Authors are responsible for sizing and positioning their illustrations.

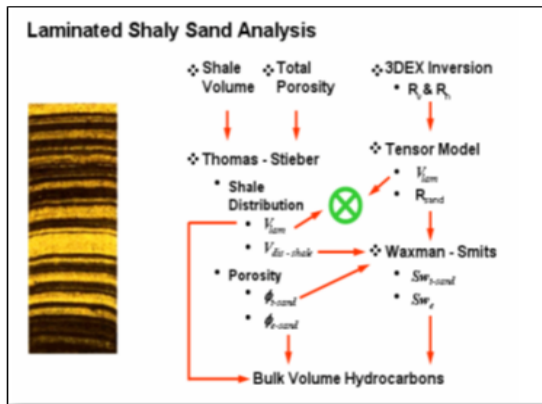


Figure 1: Generalized workflow for evaluation of laminated reservoirs.

NMR Logging Technology

Nuclear magnetic resonance (NMR) refers to a physical principle - the response of nuclei to a magnetic field. The measured quantities are signal amplitude and relaxation rates. The signal amplitude is calibrated to give porosity. Two principal relaxation times are associated with NMR measurements; the longitudinal relaxation time (T1)

and the transverse relaxation time (T2). The relaxation times, either T1 or T2, are interpreted to give pore size and/or pore fluid properties (Figure 2). NMR log is primarily used to get lithology independent porosity, pore and grain size distribution, volume of irreducible fluid and permeability. The NMR derived effective porosity helps to cross check the porosity derived from ELAN, helping in the analysis of low-resistivity pay. Gas, light oil, water, and some medium-viscosity oils exhibit significant diffusion-induced relaxation when they are in a gradient magnetic field. For these fluids, T2diffusion, the relaxation time constant associated with the diffusion mechanism becomes an important tool for their identification (Figure 3)

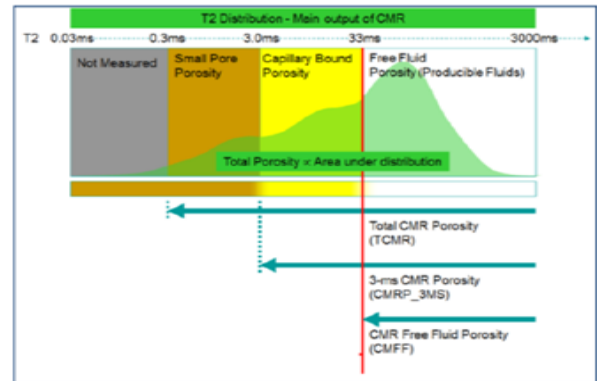


Figure 2: T2 distribution-curve from NMR

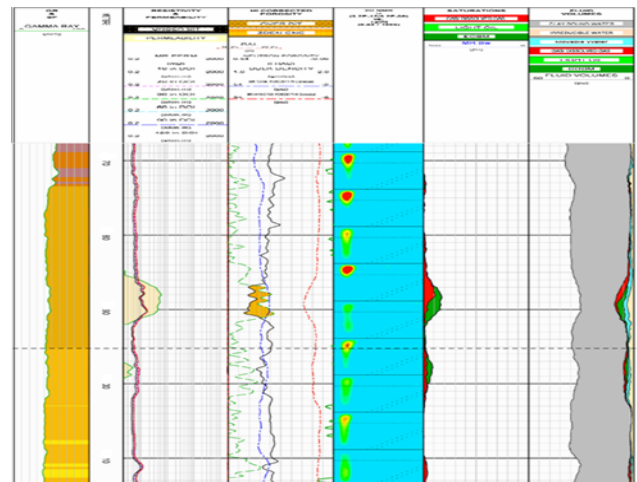


Figure 3: D-T2 fluid typing plot shows presence of Gas



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compared to the other two wells (Figure 7(b)). The pressure anomaly may be due to a geologic discontinuity like fault etc.

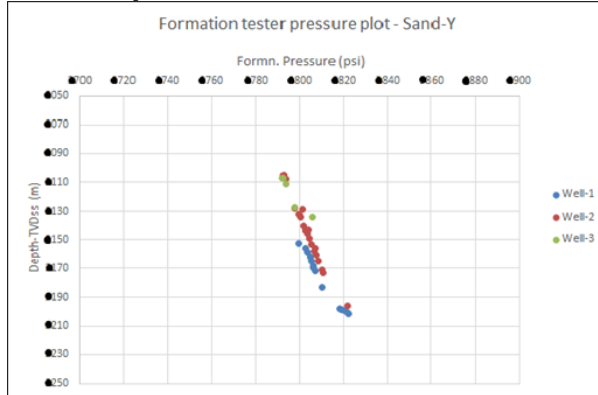


Figure-7(a): Formation pressure plot for Sand-Y

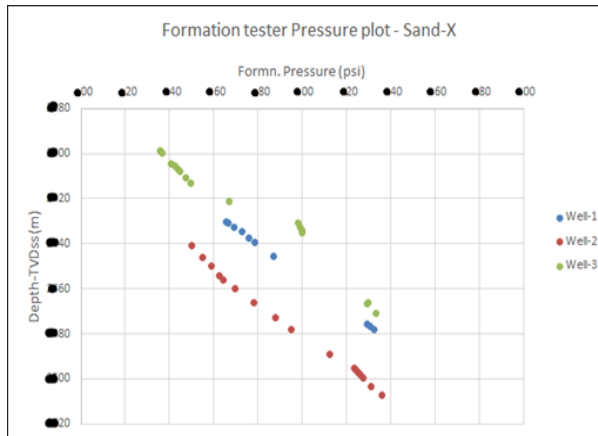


Figure-7(b): Formation pressure plot for Sand-X

Geomechanical Analysis

The Mechanical Earth Model (hereby abbreviated as MEM) is comprised of many properties, including elastic properties, rock strength, pore pressure, and in-situ stress magnitudes and direction as a function of depth, referenced to a stratigraphic column. A MEM can be used to estimate and predict the best possible methods for safety drilling and completing in a single borehole in developing a field (Figure 8(a)).

The mechanical responses and properties of grain-supported and clay-supported formations usually

differ significantly. By classifying rocks according to their mechanical stratigraphy, it is possible to apply different correlations and relations for different facies to best estimate their rock mechanical properties and geo-mechanics parameters.

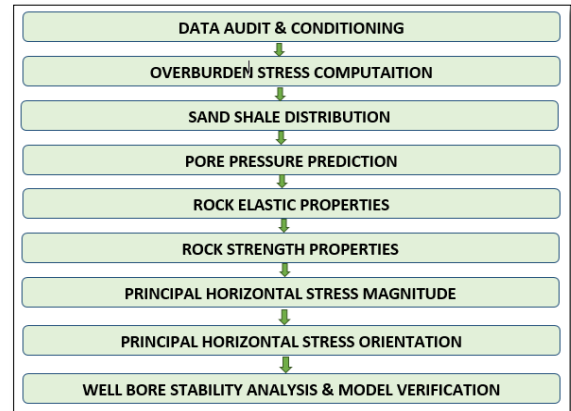


Figure 8(a): Workflow for Mechanical Earth Model

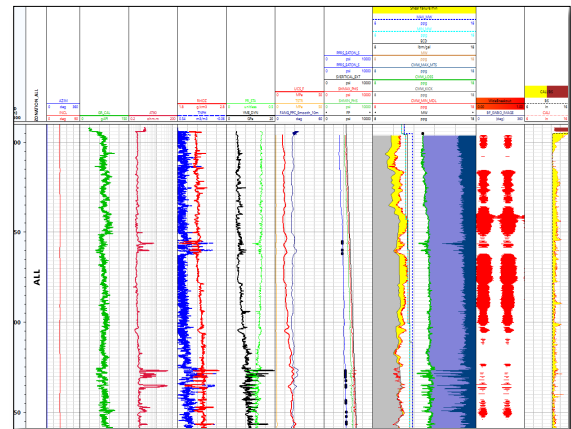


Figure 8(b): MEM and Wellbore Stability Analysis

Most pore pressure methods are vertical effective stress approaches based on Terzaghi's law. The effective stress principle states that all measurable effects of a change in stress and functions of the effective stress. The vertical effective stress is defined using Terzaghi's law.

$$P_p = (\sigma_v - \sigma_v') / \alpha$$

Where α is the Biot's coefficient that usually is assumed to be close to 1.0 for shale. The effective stress can be derived from the logs (for example, sonic slowness, resistivity logs, drilling parameter



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and seismic velocity profiles). The pore pressure is prediction using Eaton's sonic method and the output is validated with the formation pressure test data.

The Wellbore stability (WBS) analysis computes synthetic borehole failure like breakouts and drilling induced fractures based on well centric Mechanical Earth Model (MEM), Rock strength and mud weight (Static & Dynamic) data used for drilling (Figure 8(b)). The results have been validated with the actual failures seen on Image logs and Caliper logs.

The UCS of the field in the reservoir section is found to be in the range of 2000-2400 psi, suggesting unconsolidated sands with low degree of cementation between the matrix grains.

Detailed Geomechanical analysis has been carried out and crucial reservoir parameters like pore pressure prediction, magnitude and direction of Horizontal stress, UCS, friction angle and Well bore stability model were estimated. The outputs were used in the design of gravel pack for completion and also played an important role in the production profile for the field.

Conclusions

The integrated petro physical evaluation has been carried out by combining conventional logs, multi component induction, magnetic resonance, Full-bore resistivity imager and formation tester data. This integrated analysis helped in identifying laminated deep-water Gas reservoir and build a 1D MEM for smooth gravel-pack completions and production thereafter.

Resistivity Anisotropy provides better results as it takes care of the beds thinner than the resolution of Image tools. Identifying the thin zones on Image logs than applying proper petro physical parameters for resistivity anisotropy approach provides the best results. The resulting water saturation from the laminar sand resistivity and sand porosity provides better characterization of the laminar sand fraction reservoir properties.

Image logs have the unique strength of detailed visualization and more accurate reservoir characterization. Petro physical results and net pay are greatly enhanced by using micro-resistivity as a guiding factor in determining hydrocarbon saturation. Nuclear magnetic resonance logging helped in estimating volumes of hydrogen containing fluids residing within the formation. The important contributions of NMR log have been providing bound and free fluid volumes. NMR acquisition helped in analysis for permeability estimation in reservoir studies.

Formation pressure testing and sampling intervals could successfully be identified on the basis of multicomponent induction tool and NMR log. The interval was probed and found to be Gas bearing.

Integration of data should be encouraged to minimise the uncertainty within the petro physical processing and while integration with seismic.

From the combined formation tester pressure data analysis of the three wells, it is evident that Sand-Y is hydro-dynamically connected in the wells. Further production can be taken from two wells and one well can be used as a water injector in course of time to boost the recovery from the reservoir.

The outputs of 1D MEM were used in the design of gravel pack for completion and also played an important role in the production profile for the field. The present study can be utilized for optimization of drawdown to mitigate the sanding problem in the Y field.

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