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Synergetic Approach for Comprehensive Petrophysical Evaluation of Low Resistivity Pays Integrated with High-tech Logs of KGDWN- 98/2 Area, KG offshore - A Case Study

Abstract

Low resistivity pays has been challenging problem in formation evaluation in many years. Identification and estimation of the petrophysical parameters using the conventional logs for low resistivity reservoirs is very difficult. The LRP (Low Resistivity Pays) are existing in nature and may be due to laminated sands and shales, fresh waters, electronic conduction, fine grains, internal and superficial micro-porosity. In the present study, low resistivity pays were developed due to presence of thinly laminated sand shale sequences. The standard logging tools are unable to identify them because of their low vertical resolution.

In the present paper, an attempt has been made for identification and petrophysical evaluation of low resistivity pays developed in Pleistocene-Pliocene reservoirs in Godavari clay formations in KG-DWN-98/2 area, KG deep water. Low resistivity pays was unable to identify in the study area using the conventional logs. The conventional resistivity tool reads a very low value (less than 1 ohm-m) in hydrocarbon bearing reservoirs and unable to differentiate oil and water sands in the key wells. The high-tech logs like borehole electrical imaging tool (FMI), resistivity anisotropy measurement tool (RT scanner), dipole shear sonic (DSI) and combinable magnetic resonance tool (CMR) were integrated through synergetic approach to identify/characterize low resistivity pays in the study area. High vertical resolution imaging tool FMI having vertical resolution of about 0.2 inch (5mm) seems to be better tool for identification of thin sands developed in Godavari clay formations. The anisotropy based resistivity measurements tool RT scanner measured the horizontal (Rh) and vertical (Rv) component of resistivity which used for computation of the laminated sand tensor resistivity (RSS) in the studied wells. The computed sand resistivity (RSS) is in the range of 8-20 ohm-m compared to conventional resistivity of 1 ohm-m and leads to identify the low resistivity pays. CMR tool is also helpful to assess the producibility of these reservoirs through estimation of permeability and free fluid porosity in laminated sand shale sequence.

The present study has brought out methodology and workflow as suggested by Thomas stieber (Thomas and Stieber, 1975) for petrophysical evaluation of hydrocarbon bearing low resistivity sands developed in the study area. The comprehensive petrophysical evaluation comprising of robust multi-mineral model with sand resistivity (RSS) have been successfully applied in the key wells for computation of effective porosity and realistic water saturation. The petrophysical processed outputs were validated with production testing results in the key well. The proposed methodology and workflow may be further used for petrophysical characterization of low resistivity pays in up-coming locations in development plan or exploratory phase of KGDWN-98/2 area.

Introduction

KGDWN-98/2, NELP-1 block, covers an area of 7294.6 sq km. It is located off the coast of Godavari delta in the east coast of India (Fig. 1).Hydrocarbons have been established by ONGC and other operators in Plio-Pleistocene levels in the basin. It is youngest petroleum system in the basin which belongs to post rift tectonic stage of evolution with hydrocarbons occurring in structurally and/or stratigraphically controlled traps in Pleistocene to Miocene reservoirs. These reservoirs have been deposited under marine conditions and source rock is thought to be Eocene to Oligocene marine shale.

Major Challenges in Petro-physical Evaluation of Low Resistivity Pays

Numerous authors have described the challenges associated with the evaluation of a low resistivity, low contrast laminated sand-shale reservoir. When the thickness of the laminations is significantly less than the vertical resolution of conventional logging instruments, The petrophysical model for interpreting sand-shale reservoirs is based on the concepts of the volumetric shale distribution model (Thomas and Stieber,1975) and a tensor resistivity model to determine laminar shale volume and laminar sand resistivity. The resistivity tensor utilizes macroscopic electrical anisotropy defined by the combination of the horizontal parallel and vertical series resistivity equations (Hagiwara, 1997, Klein et al., 1997; Popta et al., 2004).

Computation of Sand Resistivity (RSS)

The identification and realistic water saturation of hydrocarbon bearing intervals in thinly laminated shaly sand reservoirs are very difficult using conventional logs. Due to presence of thin shale or clay layers in reservoirs make the low resistivity even though when hydrocarbon bearing sands are present within. This is due to because the current passing through conducting clay layer and making low resistivity in tool response. The effect on decrease in resistivity in presence of volume of laminated shale may modelled as seen in Fig-2.

Anisotropy based Resistivity Measurements

The first multicomponent induction instrument available to the industry provides vertical and horizontal resistivity data for an improved delineation and evaluation of low resistivity, low contrast pay zones. This instrument surveys the formation in three dimensions with multicomponent transmitter-receiver induction coil arrays to derive the true horizontal and vertical formation resistivities. The effect of laminar shale in the reduction of resistivity may be modelled by the methodology proposed by (Thomas and Stieber, 1975) using the horizontal (Rh) and vertical resistivity (Rv) recorded by the RT scanner tool. Sand layer resistivity (RSS) can be computed by solving the equation-1.

Identification of thin laminations from Image Logs

The composite log of well: A consisting of conventional logs Gamma ray(GR) in track-1, deep resistivity (AT90) in track-3, density& neutron log in track-4 and compressional time in track-5 is shown in Fig-3A & 4A. It is very difficult to identify the interesting sand layers from hydrocarbon point of view in the well-a using these conventional logs. The high vertical resolution image log FMI is recorded in the well which confirmed the presence of sand shale laminations in the reservoir in the well-A (Fig.-3B & 4B). The high gamma ray is observed in both sand and shale sections both in the well. The high gamma may be attributed to presence of feldspar as confirmed by thin section & core analysis in nearby wells.

Petrophysical Evaluation:

The petrophysical evaluation was carried out in the key wells, few of them viz. wells-A & B have been discussed here. A robust multi-mineral model consisting of four minerals quartz, feldspar, silt & clay haven veen taken for computation of effective porosity and water saturation.

Well: A

The composite log of well: A is shown in Fig- 3A&4A. The composite log consisting of conventional logs GR (in track1), Resistivity(in track 2), Density & Neutron(in track 3) and compressional travel time (in track4). It is very difficult to identify the interesting sands from hydrocarbon point of view. Since the formation having many thin sand laminations within the reservoir interval which couldn't be picked by conventional log due to vertical resolution of tools. FMI tool having high vertical resolution able to see these thin sands developed in reservoir.(Figs. 3B & 4B).

The processed output of well: A is shown in Fig.-5 & 7. The composite logs along with anisotropy resistivity logs Rh (green color)and Rv (blue color) in track-4, processed outputs Sw, Phie & volume of clay in tracks 7,8 & 9). The RSS sand resistivity is computed using Rh & Rv and displayed in red color in track-4.

For example, at depth 2451.8m, the recorded conventional resistivity (AT90) is 0.8 ohm-m where as Rh & Rv are 0.8 & 5 ohm-m. The computed Sw from conventional resistivity (AT90) is 80-90%, showing water bearing zone where as values of Sw 40-50% from the proposed model and interpreted as hydrocarbon bearing.

The reservoir has been developed in the interval 2448-2481 m is a thin laminated sand shale sequence in nature as confirmed by both FMI and RT scanner tool. It is interpretated as low resistivity reservoir. The computed Sw from proposed methodology is 65-40 % and interpreted as hydrocarbon bearing. The OWC (oil water contact) is observed at 2470 m. CMR tool also indicating the good permeability (0.8-200 mD) with higher T2 also exihibit the presence of hydrocarbon as in Fig-6. During testing of 2448-2465 m, it flowed oil@2370 barrel/day and Gas@62,254 m3/day.

Another hydrocarbon bearing reservoir has been observed in the interval 2349-2361 m in the same well (Fig-7). The computed sand resistivity (RSS) is 8-10 ohm-m compared to recorded conventional resistivity of 0.8-1.0 ohm-m. The present workflow helped to estimate realistic water saturation of 50-60% and interpretated as hydrocarbon bearing. The CMR tool indicating good amount of effective porosity and permeability in the shaly sands laminations. (Fig-8). During testing it flowed oil@985 barrel/day and gas@49,294 m3/day.

Well:B

The same methodoly and work flow has been applied in another well:B. The low resistivity ihydrocarbon bearing sands have beenpetrophysically evaluated in the interval 1826-1840 m as in Fig-9 & 10. The sands have been characterized with computed effective porosity & water saturation in the range 25-30 pu, 40-65% respecively. The intervals have been recommendated for testing.

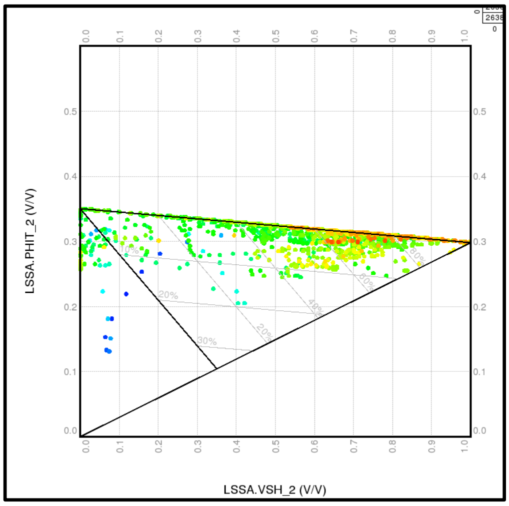

Fig.-9 Well: B, Integrated interpretation results for a laminated shaly-sand formation

Fig.-10 Well:B, X-plot between total porosity and volume of clay

Conclusions

- The combination of horizontal and vertical resistivity measurements from the multi-component induction tool integrated with high vertical resolution micro resistivity imaging tool (FMI) have been successfully used to for identification and interpreting the low resistivity pays developed in laminated sand shale sequences in Godavari clay formations in KG-98/2 area.

- The innovative methodology and workflow based on anisotropy resistivity measurements is found to be suitable for computation of the laminated sand tensor resistivity (RSS) in the key wells. The sand tensor resistivity is the key parameter for estimating the realistic water saturation and thus identification hydrocarbon bearing intervals in the studied wells.

- The present study has brought out comprehensive petrophysical evaluation work flow was successfully applied for computation effective porosity and realistic water saturation in low resistivity pays the key wells. The petrophysical processed outputs were validated with production testing results in the key wells.

- The proposed methodology and workflow may be further used for petrophysical characterization of low resistivity pays in up-coming locations in development plan or exploratory phase of KGDWN-98/2 area.

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