A Systematic Approach used for Wellbore Placement in Deep-seated Radioactive Sandstone Reservoir: Case Study- Onshore, Niger Delta

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ABSTRACT

Well-44H was planned to drill through a deep-seated radioactive sandstone reservoir body directly overlain by a thin bed of calcite, which itself is underlain by a thick column of shale. The objective was to land the wellbore in an optimal position within the target reservoir maintaining an offset of about 6 feet below the calcite roof while avoiding reservoir exits. The targeted reservoir contains radioactive minerals, thus making gamma ray interpretation unreliable, because the total gamma ray response in shale and radioactive sandstone are similar on the well logs. While drilling, depth uncertainties were observed in our prognosis generated from the post stacked time migrated (PSTM) and post stacked depth migrated (PSDM) 3D seismic volumes. The challenge was how to delineate the top of the target reservoir during landing combined with depth and bed dipping uncertainties. This paper demonstrates the systematic approach deployed to mitigate these challenges. The methodology used included the systematic integration of reliable rotary steerable system, improved formation evaluation tools, real-time shale volume modeling, real-time geological model from reservoir navigation service (RNS), mud logging samples and effective communication protocols. Some of the formation evaluation tool suites deployed had At-bit Resistivity, Gamma ray, Multiple Propagation Resistivity (MPR), Density and Neutron sensors. The vshale model was developed using density and neutron data from the offset wells and updated in real-time as the actual data came in. This approach resulted in the landing of the well at an optimal position of about 6 feet below top of the reservoir at 88.9 degrees hole inclination. The horizontal section was successfully drilled and geosteered to 1000 feet length as planned. 100% of the lateral hole section was in the target reservoir. The well has been completed and is currently producing in excess of 1500 barrels of oil per day.

Keywords:

INTRODUCTION

Geological Setting:

The studied area lies within 10 to 15 feet of water depth in the swampy portion of the Niger Delta oil field, Nigeria (Figure 1). The Tertiary Niger Delta is one of the major regressive deltaic sequences of the world, and it is situated in the Gulf of Guinea on the west coast of Central Africa, north of the equator between latitudes 4°N and 6°N and longitudes 3°E and 9°E, in the southern part of Nigeria (Orajaka et'al, 2015). Thus, the onshore portion of the Niger Delta Province is delineated by the geology of southern Nigeria and southwestern Cameroon.

The basin is believed to have witnessed varying degrees of both syn- and post- depositional deformation with gravity tectonism as a primary deformation process (Ajakaiye and Bally, 2002). Two episodes of folds and thrust belts that accommodate slip of up-dip, gravity-driven extension on the continental shelf have been recorded in the basin. These folds and thrust belts were initiated during the early Tertiary and parts of them remain active today. Stratigraphically, the studied area is consistent with the typical Niger Delta tripartite stratigraphy; Benin, Agbada and Akata Formations. The deep seated Akata Marine Formation is the predominant Niger Delta source rock. It consists mainly of marine shale deposits and is overlain by the paralic Agbada Formation which contains the Niger Delta reservoir intervals. The paralic sequence consists of shore face, beach and tidal channels sandstones interbedded with marine and interdistributary-bay shales. High sediment supply rates in a large- scale deltaic system resulted in the formation of growth faults and rollover anticlines; both of which combine to provide the primary hydrocarbon migration path and the structural trap mechanism. The Agbada Formation is overlain by the massive, sandy, fluvial dominated Benin Formation.

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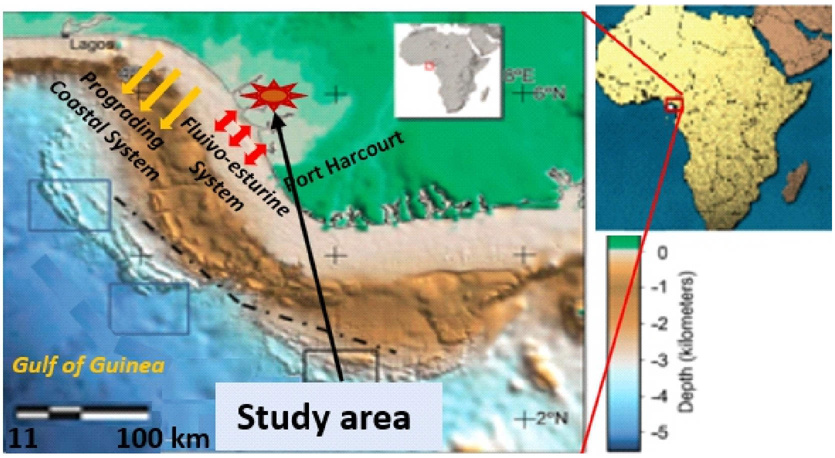

Figure 1: Study Location (After Corredor *et al.,* 2005 and Onyeji *et al.,* 2017).

All the wells drilled in the studied area to date have only penetrated the top Benin and Agbada formations with all the hydrocarbon pool discovered restricted to the paralic Agbada Formation (Onyeji et'al, 2020). The field consists of a series of fault assisted closures against the two major structural building faults in the area. The trapping mechanism of the reservoir cored is formed by a combination of rollover anticlines, canyon incision and fault closure (Onyeji et' al, 2017). Well-44H is the deepest well drilled in the studied area targeting B15 reservoir. The reservoir consists of moderately to well sorted, sub-rounded, very fine grained, poorly consolidated deep-seated radioactive sandstone body directly overlain by a thin bed of calcite, which itself is underlain by a thick column of shale (Figure 2).

Log patterns suggest the sand as being predominantly lower to middle shore face deposit originated from wave and tidal dominated deltaic complex during the Miocene age. The objective was to land the wellbore in an optimal position within the target reservoir maintaining an offset of about 6 feet below the calcite roof while avoiding reservoir exits. The targeted reservoir as earlier stated contains radioactive minerals, therefore making gamma ray interpretation unreliable, since gamma ray response in shale and radioactive sandstone are similar on the well logs, see figure 2 above. Also, depth uncertainties were observed in pre-well prognosis generated from the post stacked time migrated (PSTM) and post stacked depth migrated (PSDM)) 3D seismic volumes. The challenge was how to delineate the top of target reservoir during landing, combined with factors that includes depth uncertainty, radioactive reservoir sand, and bed dip. This paper demonstrates the systematic approach deployed to mitigate these challenges.

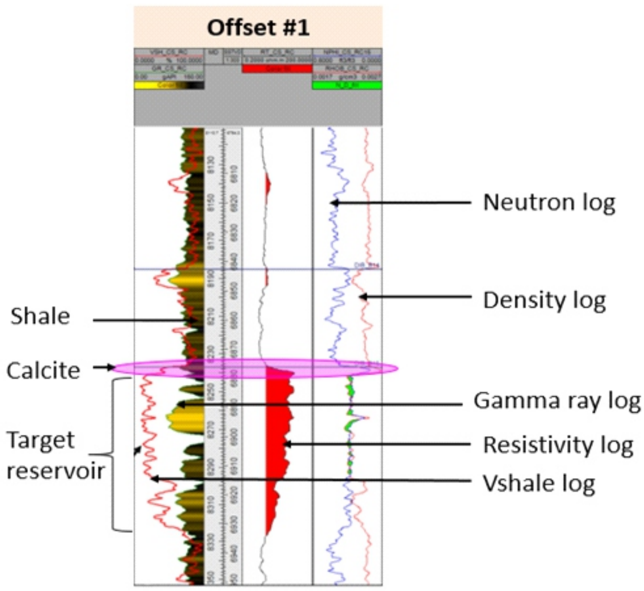

Figure 2: Target Reservoir Type Log showing deep-seated radioactive sandstone unit.

MATERIALS AND METHODOLOGY

The materials deployed for success of the project were not limited to the following;

- Geological software (Petrel, Geolog, Microsoft excel)
- Reservoir Navigator Service (RNS)
- 3D seismic data
- Mud log data (cuttings and gas counts)
- Improved formation evaluation tools (At-bit resistivity, Gamma ray, Multiple Propagation Resistivity (MPR), Density and Neutron data).

The methodology used to mitigate the challenges narrated in the previous section include the systematic integration of improved formation evaluation tools with the closed-loop rotary steerable system, good communication protocol and good drilling practices. However, Formations tops/ prognosis and depth structural map of the target reservoir were generated from the post stacked time migrated (PSTM) and post stacked depth migrated (PSDM)) 3D seismic volumes using Petrel. The prognosis was generated from the two seismic volumes based on experience to minimize depth uncertainties. Considering the quality of the targeted reservoir, shale endpoint was generated from neutron and density porosity data from the offset well using Geolog v7.5 to build real-time vshale computation algorithm. The algorithm was loaded into the Petrel to compute shale volume in real-time since neutron and density data will be acquired in the new well (44H) to delineate the top of the sand. Additionally, At-bit resistivity tools allowed the early detection of formation changes for geo-stopping during landing phase. The azimuthal resistivity tool provided real-time distance-to-bed (D2B) data, target boundary direction and signal strength used to indicate the position and proximity of the nearest bed boundary. Gamma ray and Density image logs gave the structural trends and the stratigraphic direction of wellbore movement while drilling. Multiple propagation resistivity (MPR) aided in performing a real-time petrophysical evaluation. The reservoir navigation software forward modelling provides 2D geological modeling and real-time correlation with offset wells and visualization of the structural trends in the reservoir during horizontal drilling.

Result and Discussions

Development of shale endpoint from the offset well and Realtime Vshale computation; Prior to the drilling of the well, shale end point was generated from the offset well to determine the appropriate algorithm that will predict the true representative of the volume of shale in the deep-seated radioactive reservoir. Some geological consideration was put in place while generating the shale endpoint, it includes;

- The total gamma ray response in shale and radioactive sandstone are similar on the well logs, thus making gamma ray interpretation unreliable.approach deployed to mitigate these challenges.
- Radioactive minerals have no effect on the combined density and neutron counts on the well logs, therefore shale volume computation using neutron and density logs in combination is more reliable in computing shale volume especially in immature environments (Onyeji *et al.,* 2009).

  Based on the above considerations, neutron porosity (NPHI) and total density porosity (PHIT_den) from the offset well were used to generate shale end point of target reservoir see figure 3.

The target reservoir (B-15 series) shale end point generated from neutron and density data of the offset well were NPHI_SH=0.40597 and PHIT_DEN_SH=0.12683 respectively. These values were incorporated into the real-time shale volume model developed to compute real-time Vshale as density and neutron porosity data is being acquired on Well-44H. The model is updated as data come in via WITSML feed into Petrel see figure 4.

Well Landing in the target reservoir and drilling of the horizontal section of the well; In the landing phase, the target reservoir top was found to be much deeper than prognosis generated from the 3D seismic volumes (depth difference of about 40ft). It was observed that the post stacked depth migrated (PSDM) seismic volume was correlating with the actual tops at the shallower section of the well, while the post stacked time migrated (PSTM) was better at deeper section. However, there was depth uncertainties with both seismic volumes. Then we switched to isopach method using the offset well logs, this method presented a better picture of the true behaviour of the subsurface between Well-44H and the offset well. Also, prior to landing point, two internal markers (B13 and B14) close to the target reservoir were identified in the offset well and correlated to the Well-44H, this aided to accurately project to the target top reservoir (figure 4). Real-time Vshale computed from Neutron/Density data helped in differentiating the top of deep-seat radioactive sandstone from the overlying shale. At-Bit resistivity measurement aided in landing the well into the radioactive reservoir at the targeted inclination. Meanwhile, Image

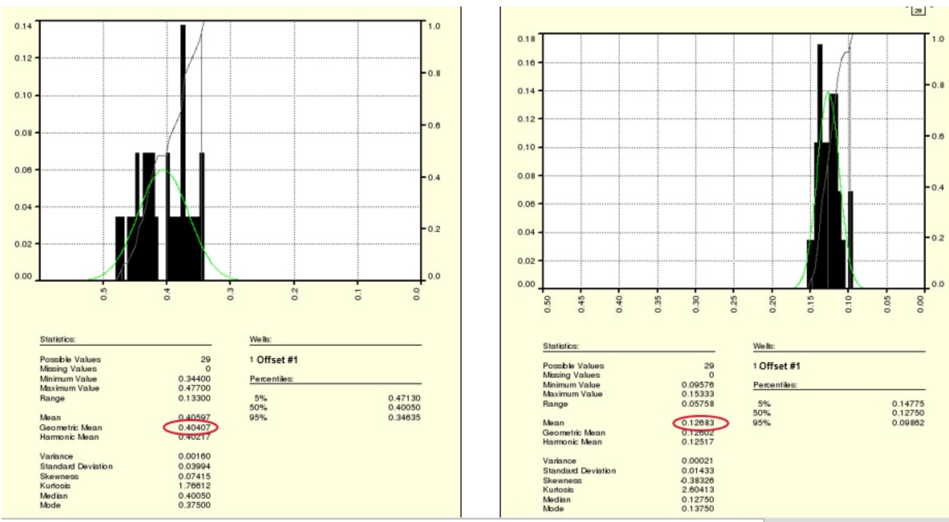

Figure 3: B-15 Reservoir Histogram Plots showing (A) Neutron porosity shale endpoint, and (B) Density porosity shale endpoint.

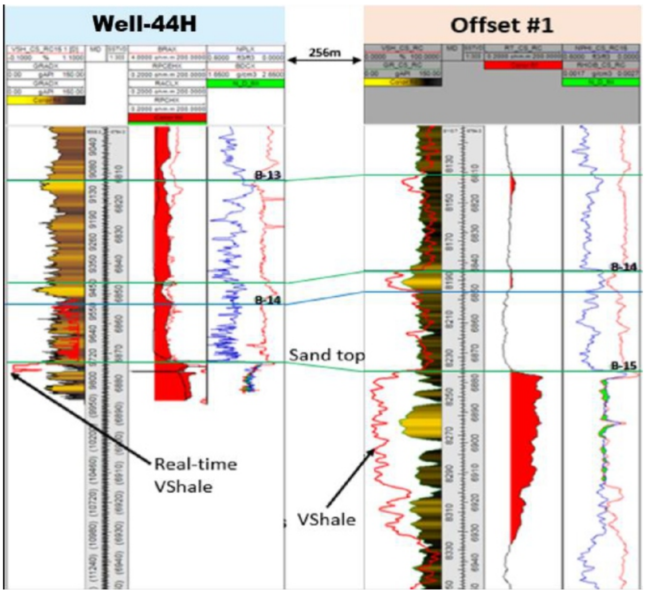

Figure 4: Well Log Correlation panel showing real-time Vshale in the new well (44h).

logs confirms cutting down structure. The dips picked from the borehole image logs (gamma ray and density) in real-time confirmed that reservoir structure dipped more than expected (2.0 degrees) to 4.5 degrees (Figure 5).
Gamma ray and Neutron/Density Logs confirms further change in dip which made bit to drill to the top of the calcite from 9600 ft MD. Also, change in inclination at 9720 ft MD was observrd from 85 5 degrees to 84 degrees took effect to counter the bed dip and bit went back into calcite and into the sand.
After placing the wellbore optimally into the target reservoir about 7 feet away from the calcareous base, the horizontal section was successfully drilled keeping the well 100% in the target reservoir. This was achieved with aid of reservoir navigation service platform, which included and not restricted to distance-to-bed boundary calculation used in anticipation of intra-reservoir zone within the drain hole section, a radial lithological mapping around the wellbore (figure 6).

While fluid typing was carried out with the use of real-time resistivity, neutron porosity and bulk density measurements. Further confirmation of lithology type and fluid characteristics was done with mud logging data during drilling. A total of 1000 feet drain hole length was achieved at cost effective manner.

Lessons learnt, Best practices and Challenges

Lessons learned;

- Proper planning and the use of technology were key to successful execution of the project.
- Real-time shale volume computation, near-bit resistivity, and mudlog cuttings sample were crucial in determining the top of the radioactive reservoir for proper landing.
- Isopach map presented a better picture of the true behavior of the subsurface between Well- 44H and the offset well, as the prognosis were coming deeper while approaching the landing point.
- Spectral gamma ray or elemental captured spectroscopy (ECS) tools should be incorporated into the logging tools when drilling through radioactive sand to determine the type of radioactive mineral presence in the sand.
- Effective communication protocol and teamwork were vital.

Best practices;

- Define geologic markers (main and internal) for detailed stratigraphic correction prior to landing the

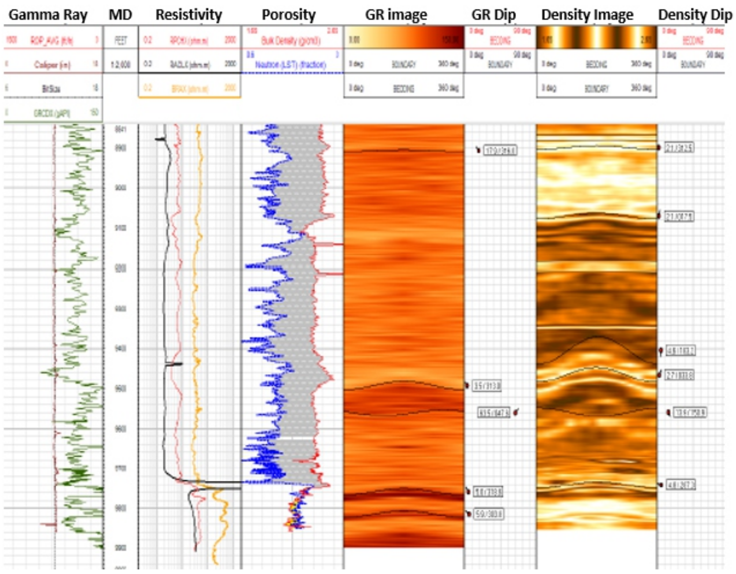

Figure 5: Well Log plot showing real-time dip analysis from image logs.

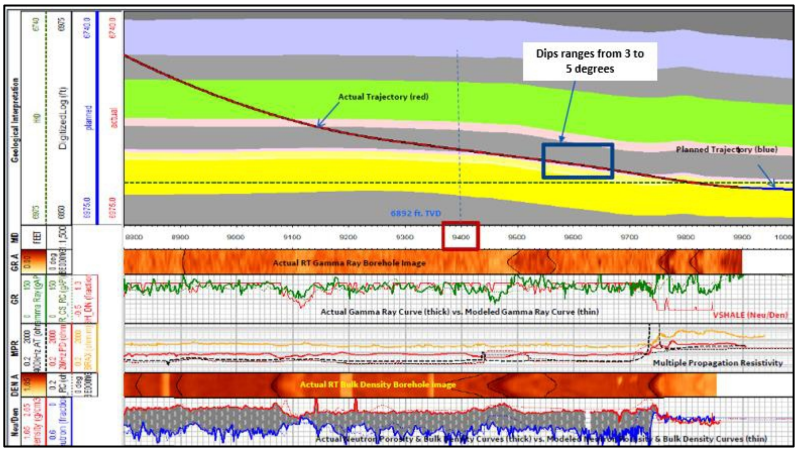

Figure 6: RNS Geological model showing actual versus planned trajectory, image logs and real-time Vshale.

well.

- Adjust reservoir navigation service (RNS) geological model accordingly with correctly correlated formation tops for proper landing.
- Understanding the geology of the area is critical to successful field development. The radioactive reservoirs, calcite presence may not be considered initially
- Integration of borehole image logs to real time drilling analysis was valuable for more accurate interpretations of the structural dips
- Effective communication and geologic protocols put in place by the teams during well execution.

Challenges

- Inability to differentiate the radioactive reservoir from the overlying shale using the logging while drilling (LWD) GR tool in real time
- Determination of real time shale end point for Vshale computation.
- The seismic vintages were to help quantify the depth uncertainties.
- Subsurface structural uncertainty as regards to general dipping of the reservoir structure.
- Time delay (5 minutes) in real-time data transmission to the base office due to poor network at the rig-site.

CONCLUSIONS AND RECOMMENDATIONS

The use of Isopach presented a better picture of the true behaviour of the subsurface between Well- 44H and the offset well. Dips picked from the borehole Image logs in real-time confirms structural behavior (Dip of about 4 to 5 degrees). Real-time Vshale calculated from density and neutron data and at-bit resistivity were very helpful and instrumental in delineating the actual top of the radioactive sand. Further confirmation of the reservoir lithology was done through mud log cuttings samples. Formation tops were correctly correlated and RNS model was adjusted accordingly, allowing accurate landing of the well at an optimal position of about 7 feet into the reservoir, at 88.9 degrees hole inclination. The horizontal section was successfully drilled to 1000 feet length and keeping the well 100% in the target reservoir. The systematic approached deployed along side with effective communication among the office real-time well monitoring and rig-site teams aided in the successful execution of the project at cost effective manner and incident free. Thus, we recommend the application of the above-mentioned processes/methodology in drilling any similar reservoir within the Niger Delta oil province.

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