Using Regional Geology and High-End Geophysical Methodologies for Effective Subsurface Risk Assessment: Case Studies from Shallow Water Offshore, Nigeria

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ABSTRACT

High-end geophysical workflow has been successfully deployed in Shallow Water Offshore Nigeria for effective subsurface risk assessment. In this paper, we demonstrate this workflow for two business critical evaluations: 1) the identification and maturation of High-Pressure gas exploration opportunities and 2) evaluation of sand connectivity for a gas-bearing reservoir, called the H2, to support proper placement of appraisal/development wells. Ocean Bottom Nodes (OBN) seismic datasets were uploaded and enhanced by using high-end geophysical workflow to highlight subtle structural and stratigraphic features and visualized on interpreted events using the stratigraphic attributes. The results show that consistent late-stage lower Net-to-Gross (NTG) sand fairways exist between Well-002 and Well-001. The results were integrated with quantitative interpretation work to further optimize the location of the planned appraisal/development wells and unlock significant gas resources in the block. The workflow was also used to enhance the imaging of a deep high-pressure (HP) footwall exploration prospect within the lower shelf depositional environment in Shallow Water Offshore Nigeria. The results show that the crestal part of a reservoir-seal-pair (RSP) is sand-prone and that another is highly channelized and has relatively lower NTG. These results were used to optimize the reservoir chance factors of the RSPs. These high-end methods are used to enhance seismic imaging and enable seismic interpreters to iteratively interrogate seismic data on-the-fly. The products are used to produce credible subsurface models that underpin quality decisions key to successful exploration and field development in Nigeria.

Keywords: Seismic Interpretation, Subsurface Imaging, Risking, Reservoir Connectivity, Well placement.

INTRODUCTION

Critical business decisions are founded on credible technical evaluations. The objective of this paper is to demonstrate how robust geological models and high-end geophysical tools were deployed to assess the subsurface risks in two valuable projects in the Shallow Water Offshore, Nigeria (Figure 1). The assessments highlighted the subsurface risks in the projects and informed the business decisions made for the projects.

The first example is a near field exploration (NFE) project to identify and mature deep high pressure (HP) gas opportunities in support of Nigeria Liquefied Natural Gas (NLNG) Train 7 (T7) aspirations. The prospect is attractive being situated beneath an existing discovery. The plan is to test the prospect by deepening one of the planned development or appraisal wells for the discoveries, thus, reducing capital expenditure (CAPEX). Ocean Bottom Node (OBN) seismic data acquired in the area has indicated a faulted dip footwall closure beneath the field. However, the well section shows that the thickness and interval Net to Gross (NTG) of the Lower Messinian stratigraphic sequence significantly depreciates laterally and vertically in the area (Figure 1). Thus, reservoir presence and quality are the key risks for the deep exploration objectives and relevant high-end geological and geophysical workflows were used to de-risk the prospect.

The second example is the evaluation of H2 gas-bearing reservoir that straddles two adjacent fields. H2 reservoir is within the Lower Shelf Gross Depositional Environment of the Upper Messinian. It is made up of mostly channels, heteroliths and shoreface sands. Pressure data from two adjacent wells (~3km apart) penetrating H2 reservoir suggests ~120psi depletion observed in both gas and water legs of the reservoir. Thus, it was necessary to properly

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assess H2 sand distribution and connectivity for the placement of appraisal/development wells.

DATASET & METHODOLOGY

Ocean Bottom Node (OBN) seismic data acquired in 2019/2020 and processed in 2020/2021 was used for the assessments. The anisotropic velocity model of the PSDM volumes were iterated multiple times to achieve optimal imaging of the subsurface. Post-processing filtering was applied to the data to improve the signal to noise ratio. Various sub-stacks of the data were decomposed and uploaded to an advanced seismic interpretation platform to highlight useful structural and stratigraphic features.

Near stack seismic data (0 to 15-degree angle stack) was used for H2 reservoir continuity/distribution assessment being the data with the best imaging of the seismic stratigraphic facies and minimal hydrocarbon fluid imprint.

The regional geological framework of the area was established using the integration of the control wells, revalidated maximum flooding surfaces (MFS), interpreted regional markers, available petrophysical well logs and validated formation pressure data.

Spectral decomposition attribute (with emphasis on waveform analysis) was used to assess the reservoir-seal-pairs (RSPs) of the exploration objective and the H2 reservoir in the appraisal/development scope. The attribute was extracted from the top to base of H2 at 20ms window to evaluate H2 internal stratigraphic architecture.
The Gross Depositional Environment (GDE) map was derived using a combination of the interpreted maximum flooding surfaces, interval net to gross (NTG), seismic facies and biostratigraphy.

RESULTS AND DISCUSSION

The GDE map (Figure 1) shows that H2 reservoir and the exploration objectives are within the lower shelf in the Middle Messinian. The well correlation section shows increase in the interval gross thickness from Well-003 to Well-001 and from Well-1A to Well-001. It also shows a decrease in the interval NTG from Well-003 to Well-001 and from Well-1A to Well-001. The interval NTG of the Upper Messinian stratigraphic sequence significantly depreciates from Well-003 to Well-001. This is attributed to the distal nature of Well-001 & Well-002 relative to Well-003. Moreover, Well-001 & Well-002 partially penetrated the Upper Messinian in the distal blocks.

Figures 2a-2d show the depositional model of the block of interest. The depositional model is calibrated by Well-001 that tested the footwall of the structure. The figures clearly show the ponding of the deposits against the green fault and general progradation to the blue fault especially within the upper shelf and upper part of the lower shelf. The high contrast events are sand-prone seismic facies and the low contrast events are the shale-prone seismic facies. Evidence of channelization is clearly seen in the figures and Mass Transport Deposits (MTDs) are seen close to the bottom of the section near the upper slope.

Figures 3a & 3b show the seismic correlation section from Well-003 to Well-001. These figures further highlight event continuity within the macrostructure. The section also shows that the crestal part of RSP 3 target is risky and shale-prone due to evidence of intense channelization.

The isopach map of the Upper Messinian (Figure 4) further shows that the depocenter of the macrostructure is close to the green fault. It also shows that the crest of H2 reservoir is at the flank of the depocenter in Play 3. Well-

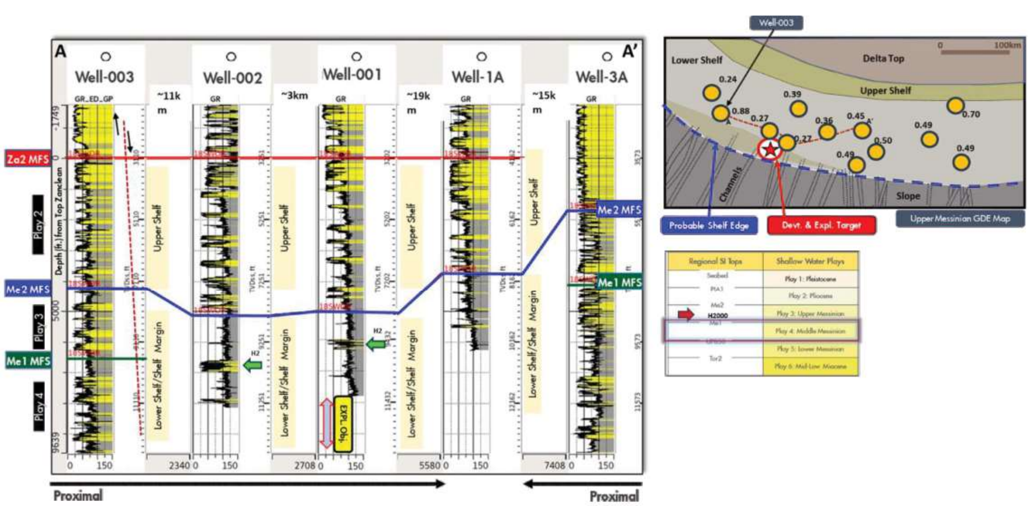

Figure 1: GDE map of the Middle Messinian & well correlation section flattened on Zanclean 2 Maximum Flooding Surface (MFS). The interval NTG of the Upper Messinian stratigraphic sequence significantly depreciates from Well-003 to Well-001.

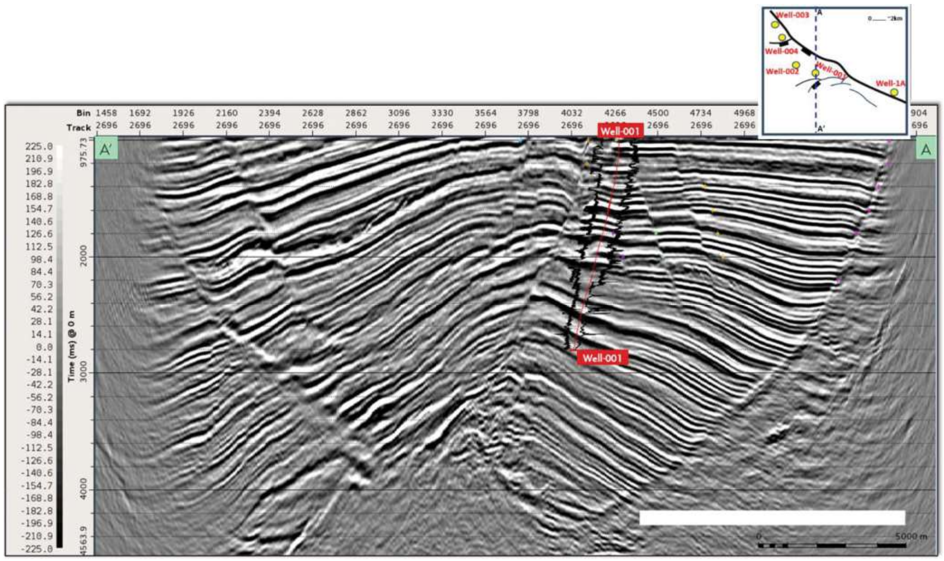

Figure 2a: Depositional model of the block of interest.

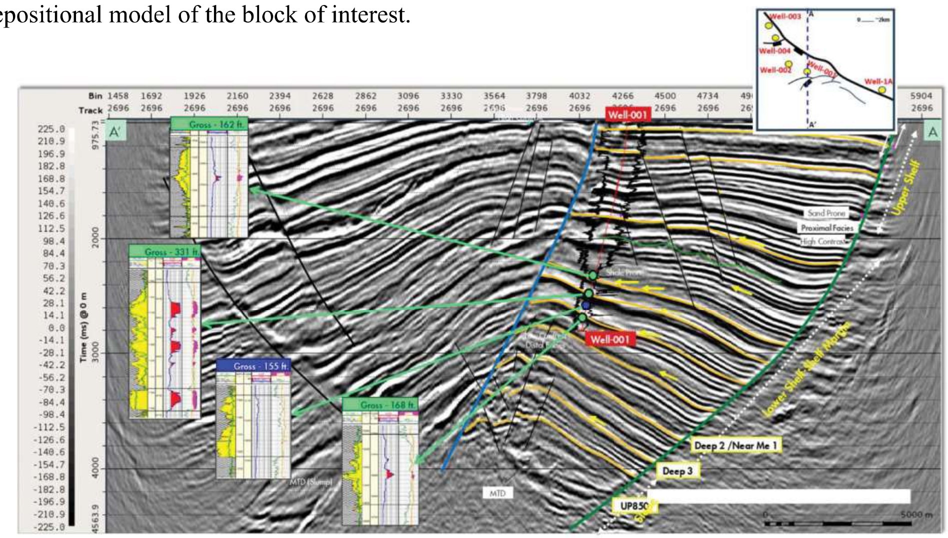

Figure 2b: Depositional model of the block of interest.

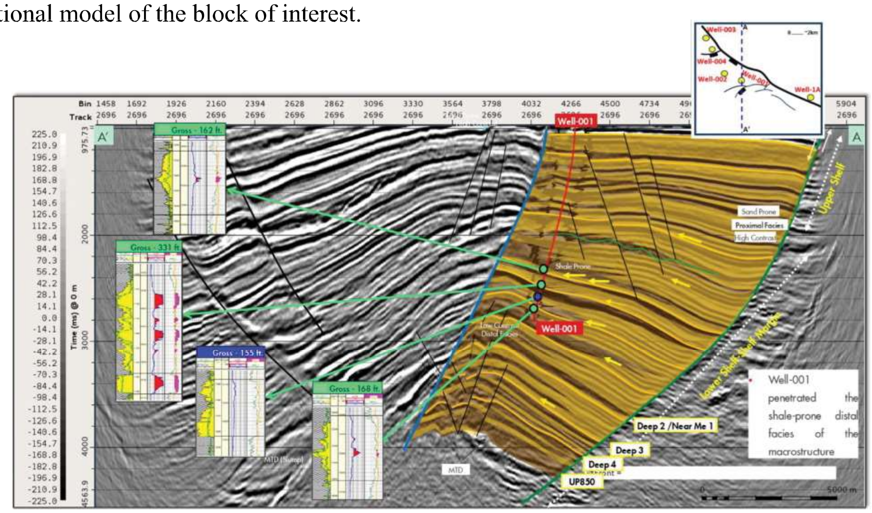

Figure 2c: Figure 2b: Depositional model of the block of interest.

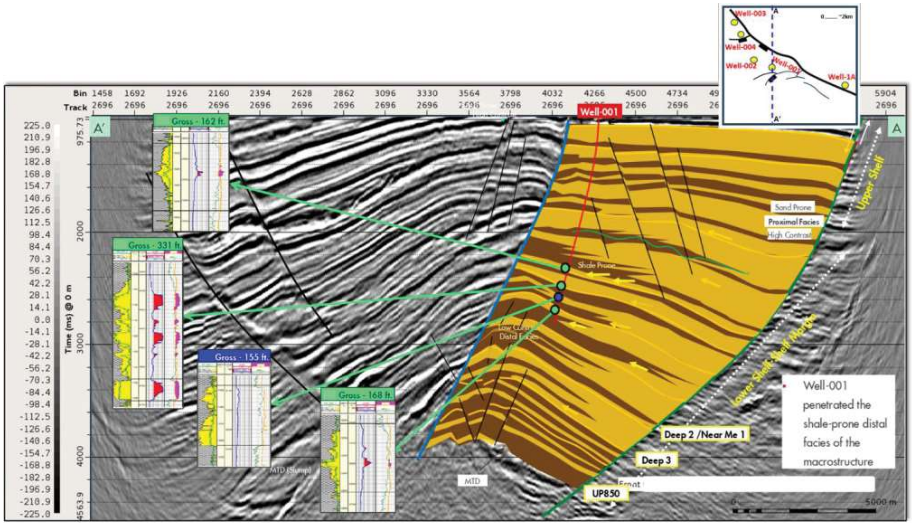

Figure 2d: Depositional model of the block of interest. Orange color shows sand-prone facies and brown color shows shale-prone facies.

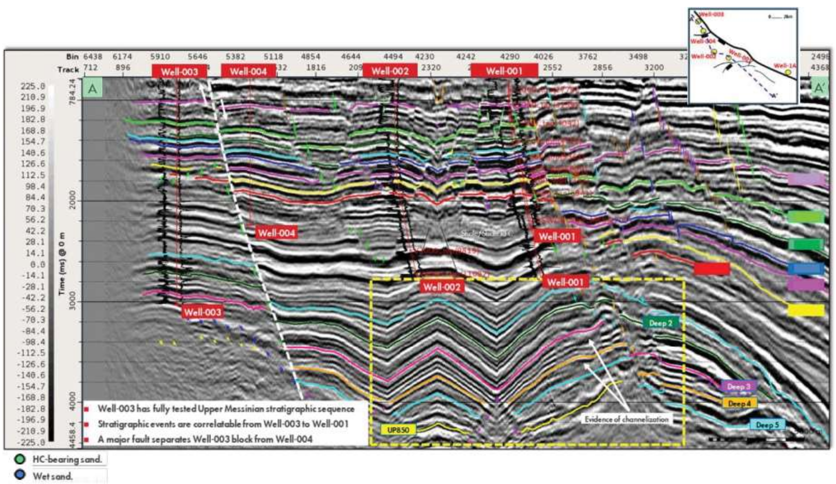

Figure 3a: Seismic correlation from Well-003 to Well-001.

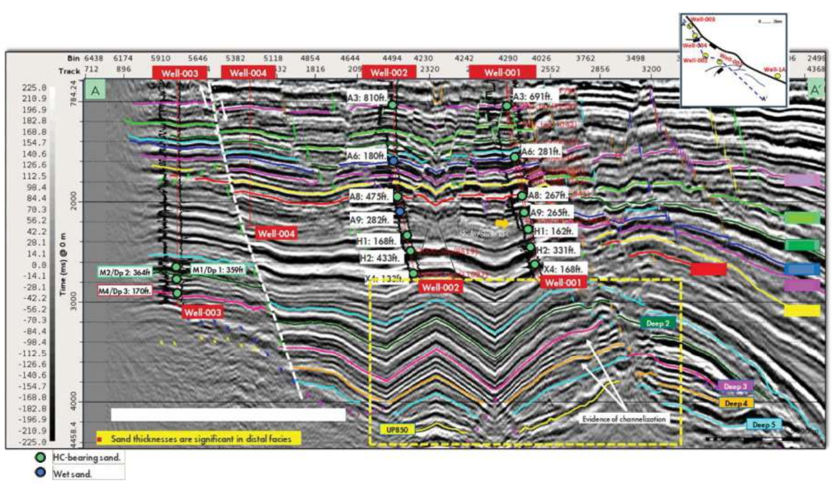

Figure 3b: Seismic correlation from Well-003 to Well-001.

002, Well-004 & Well-001 tested the distal part of the depocenter.

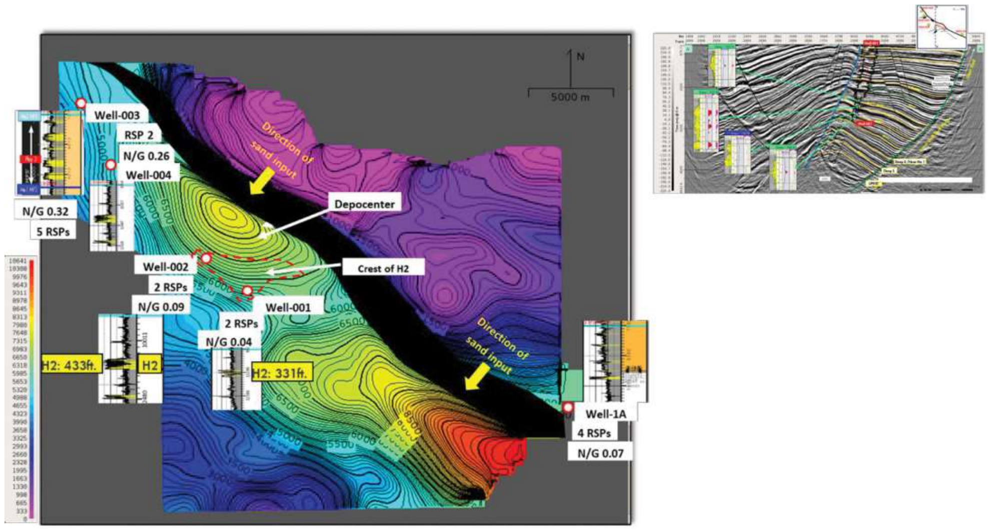

Figure 4: Isopach map of the Upper Messinian (Me. 1 – Me. 2).

The seismic attribute maps of the deep exploration targets (Figure 5) show that Deep 2 Reservoir-Seal-Pair (RSP) is reservoir-prone & the crestal part of Deep-3 RSP is

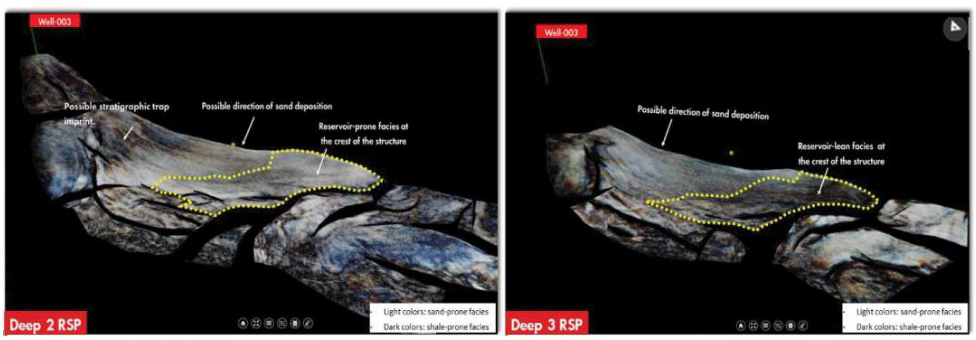

Figure 5: Seismic attribute maps of deep exploration targets.

channelised and shale-prone.

The 3D seismic sections (Figure 6a & 6b) show the interpreted H2 top and the evidence of channelization. Multiple channels are clearly seen between Well-002 and Well-001.

The H2 sand/NTG development & connectivity maps (Figures 7a & 7b) show that the late-stage NE-SW trending fairways are lower NTG facies. It also shows that late-stage N-S trending lower NTG fairways exist between Well-002 and Well-001. The degree of heterogeneity between Well-002 and Well-001 within ~3km is significant.

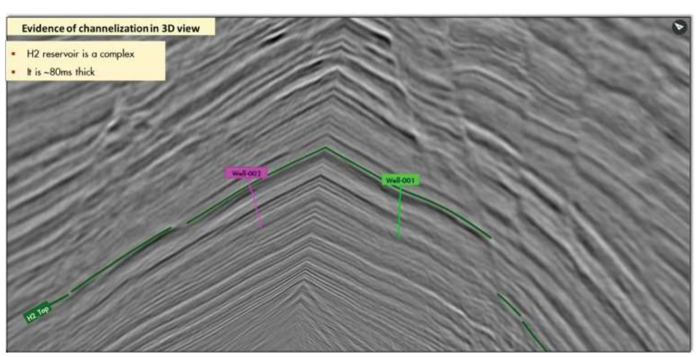

Figure 6a: 3D seismic sections showing the interpreted H2 top and the evidence of channelization.

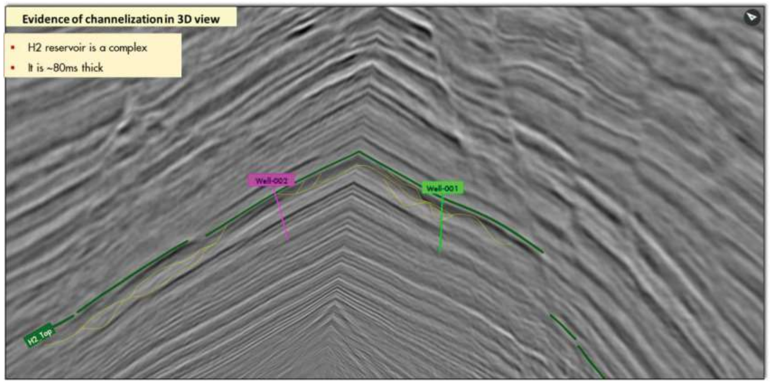

Figure 6b: 3D seismic sections showing the interpreted H2 top and the evidence of channelization.

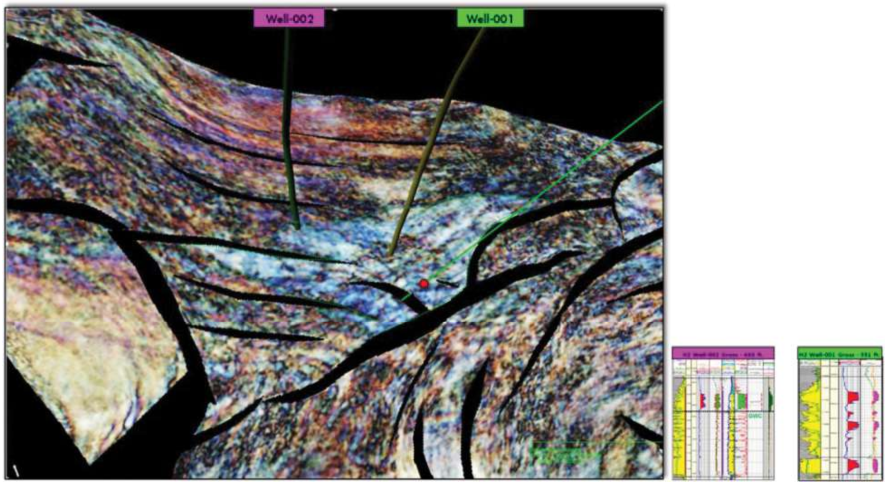

Figure 7a: H2 sand/NTG development & connectivity. Bright smooth colours signify sand-prone facies probable higher NTG. Dark colours signify shale-prone facies with probable lower NTG.

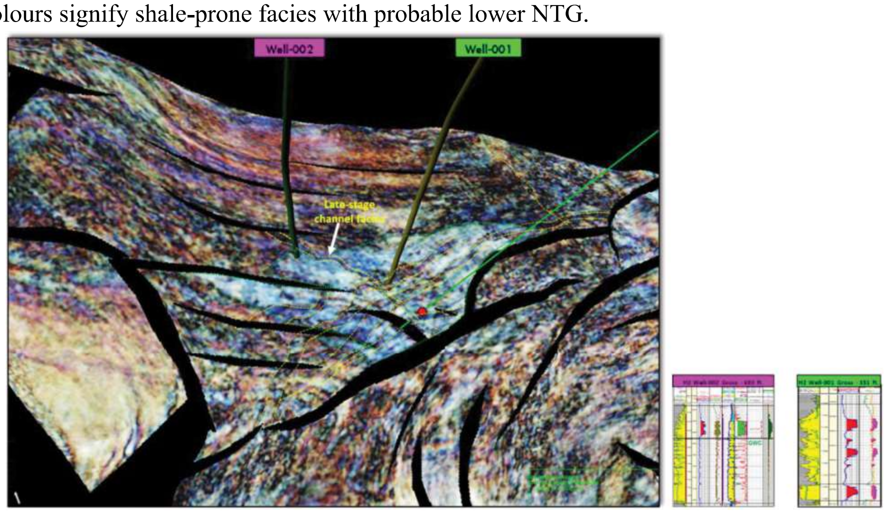

Figure 7b: H2 sand/NTG development & connectivity. Bright smooth colours signify sand-prone facies probable higher NTG. Dark colours signify shale-prone facies with probable lower NTG.

SUMMARY OF BUSINESS IMPACT

High-end geophysical workflow has been successfully deployed in Shallow Water Offshore Nigeria to de-risk reservoir presence/quality of an exploration target in the Middle Messinian and the placement of the appraisal/development wells for a gas-bearing reservoir in the Upper Messinian. The assessments were underpinned by a robust regional geological model, high-quality seismic data, control wells for calibration/ground-truthing and high-end geophysical workflows for stratigraphic attribute generation.

The summary and business impact of the work is:

· Reduction of subsurface uncertainty - results highlighted consistent late-stage lower NTG fairway between the two key wells that tested H2 reservoir. The planned appraisal/development wells were further optimized.

· Enabled sand fairways identification, understanding of reservoir distribution, and supporting well connectivity assessments.

· De-risked/upgraded Deep 2 RSP and downgraded Deep 3 RSP exploration targets: Results show probable areas of viable hydrocarbon reservoirs by assessing the reservoir-prone and reservoir-lean facies within the deep exploration targets in the Middle Messinian.

· Focused staff capabilities and skills on interpreting and validating various subsurface concepts/models.

· Eliminated the guesswork in choosing the right sets of seismic sub-stacks to combine into enhanced seismic images and reduced time to achieve this by up to 95% by enabling staff to iteratively interrogate the uploaded seismic data on-the-fly.

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