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Prospect Validation Using Geological Expression in an Existing Gas Discovery, Offshore Mozambique

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SUMMARY

This study attempts to gain a better insight into the controls on an under-saturated gas discovery, offshore Mozambique, using Geological Expression techniques such as High Definition Frequency Decomposition (HDFD) and multi-attribute classifications with synthetic wedge modelling being used to better understand the results. HDFD highlights known hydrocarbon bearing sands as high magnitudes and shows that structural processes are dominant in controlling their distribution. Observations from the Chaos divided by Envelope attribute lead to gas chimney interpretations and show that faults may be acting as migration pathways for hydrocarbons into and out of the reservoir. The Interactive Facies Classification tool confirms preconceived ideas of a later stage inversion, shows potential deposition fairways and sand-sand juxtaposition across faults confirming that faults are not acting as baffles to fluid flow. Finally synthetic wedge modelling of the reservoir provides an explanation for similar colour responses of the HDFD RGB blend above and below the gas-water contact. We observe that, even though thickness is a dominant controlling factor on the colours in the RGB blend, pore fill plays a role and allows a single stratigraphic layer to be divided based on it. These techniques aided in better understanding and risking the reservoir.

Introduction

This study focuses on the use of Geological Expression techniques, in addition to standard AVA analysis, in evaluating a present day relatively under-saturated gas reservoir in the Sofala Concession, offshore Mozambique. Geological Expression is a data driven-interpreter guided approach to interpretation where the aim is to give the interpreter insights that may not be achieved through traditional interpretation methods (Henderson, 2012).

The Sofala Concession is located at the eastern margin of the north-south trending Urema-Chissenga Graben which represents the southern extent of the major East African Rift System (Figure 1a). The Urema-Chissenga Graben is a buried rift within the greater Mozambique Basin and the coastal extension of the Chissenga Graben passes through the Western flank of the Sofala Concession. The sedimentary fill of the Mozambique Basin is related to the breakup of Gondwana, the formation of the Indian Ocean and the Antarctica drift with respect to Africa. Initial rifting was followed by two distinct phases of continental separation, one beginning in the mid-Jurassic and the other in the mid-Cretaceous. The Mozambique Basin is not considered to be a conventional passive margin but a 'volcanic margin' (where basin development had been strongly influenced by mantle plume impingement) which had developed in an extensional regime in the early phase and was subjected to shearing stresses in the late phase (E.N.H., 2000). Renewed continental break-up in the Late Cretaceous and Early Tertiary, which led to the development of the East African Rift System, have left a structural overprint. The sediment fill comprises a rifted Permo-Jurassic overlain by a marine influenced passive margin sequence of Lower Cretaceous to Tertiary age clastics with isolated Cretaceous and Tertiary age carbonates.

The Nemo-1 well drilled in 1969 targeted a four way structural closure at the Domo Sandstone level in the present day Sofala Concession (Figures 1b and 1c). The well tested both gas and water at the Domo Sandstone level and DST results indicated the reservoir to be partially gas saturated. Using the 2012 acquired 3D PSTM data the initial aims of the project was to look for internal heterogeneities within the Domo interval, to test the presence of additional prospective zones and to better understand the structure and stratigraphy within the 3D area especially around the Nemo-1 discovery. The discovery was evaluated using High Definition Frequency Decomposition, multi-attribute classifications and synthetic wedge modelling techniques.

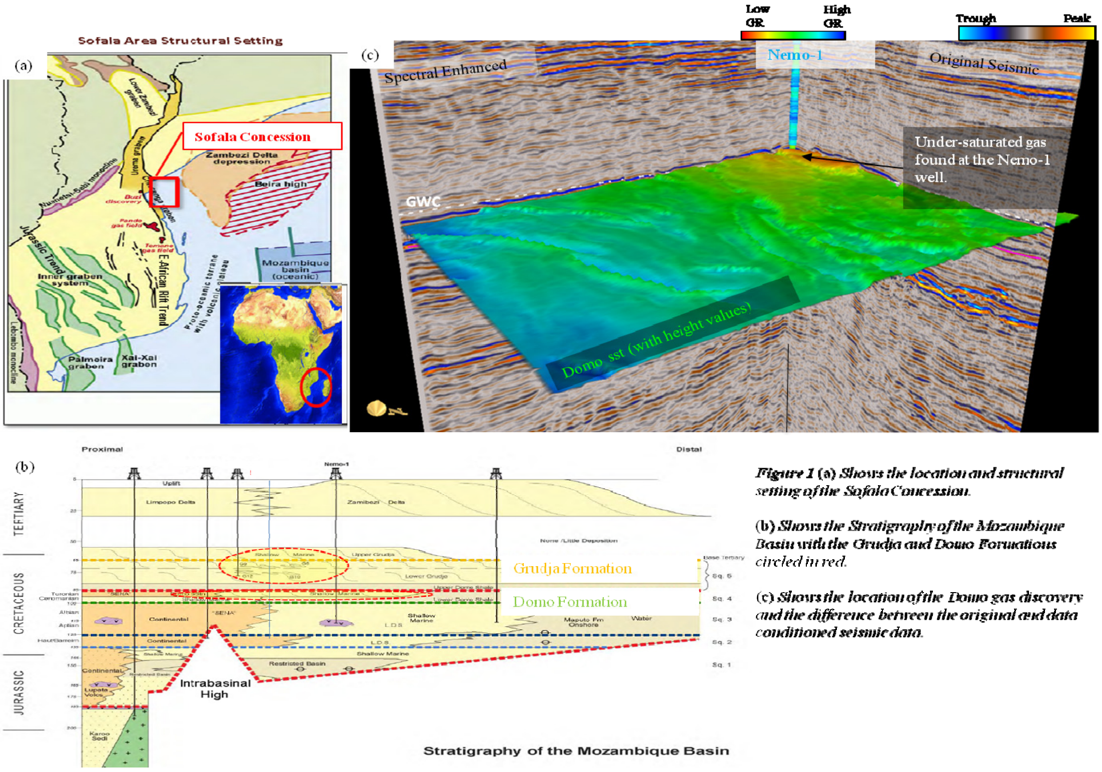

Figure 1 (a) Shows the location and structural setting of the Sofala Concession.

(b) Shows the Stratigraphy of the Mozambique Basin with the Grudja and Domo Formations circled in red.

(c) Shows the location of the Domo gas discovery and the difference between the original and data conditioned seismic data.

***Figure 1** Shows the geological setting for the Sofala Concession and the gas discovery at the Domo level.*

High Definition Frequency Decomposition

High Definition Frequency Decomposition (HDFD) is a technique based on a matching pursuit algorithm, whereby each seismic trace is decomposed into a number of individual wavelets whose sum equates to the original trace. After decomposition into wavelet responses, a trace can be reconstructed at any given frequency (McArdle & Ackers, 2012). HDFD magnitude volumes with dominant frequencies of 15 Hz, 35 Hz and 55 Hz were blended using an RGB colour space. The result is a HDFD RGB blend which shows a variety of colours caused by the response and interference of the different frequencies, predominantly due to changes in bed thickness, lithology and pore fill. The HDFD RGB blend showed that the boundaries of the reservoir are delineated by faults which led to the interpretation of a dominant structural control on the distribution of hydrocarbon filled sands within the Domo Sandstone interval (Figure 2a). It also showed high magnitude, low frequency responses around the Nemo-1 well at the Domo Sandstone level which match the reservoir extents observed on the RMS amplitude of the Far Stack seismic data (Figure 2b). High magnitude, low frequency responses were also observed down-dip and to the east of the reservoir, below the gas-water contact. This response is explained later in the synthetic modelling section.

Chaos divided by Envelope

The Envelope attribute calculates the instantaneous amplitude while the Chaos attribute uses gradient structural tensor calculations to highlight structurally chaotic areas relative to a background mean. When Chaos is divided by Envelope the result is an attribute which highlights chaotic, low reflectivity areas. In the Sofala 3D, below the Domo interval, these areas correspond to volcanic vents while at and above the Domo interval they occur around faults and are relatively confined within a zone above the Domo Sandstone but below shallow prospects at the Grudja level (Figures 2c and 2d). These 'seismic distortions' were interpreted as being associated with gas chimney effects with gas migrating out of the reservoir and into the sands above. This interpretation provided a reason for the reservoir being relatively under-saturated at present and also demonstrated that the faults in the area may not be acting as baffles to fluid flow but instead may be behaving as 'leaky faults'.

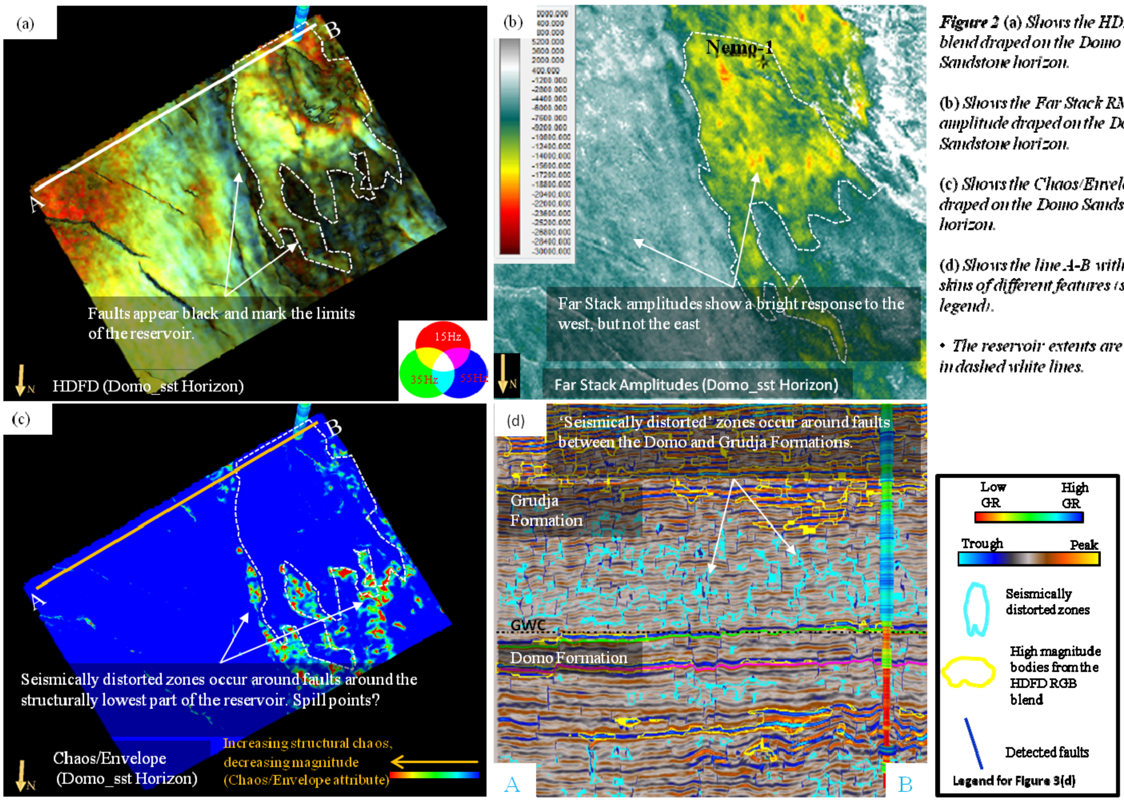

Figure 2 *(a) Shows the HDFD RGB blend draped on the Domo Sandstone horizon.*

(b) Shows the Far Stack RMS amplitude draped on the Domo Sandstone horizon.

(c) Shows the Chaos/Envelope draped on the Domo Sandstone horizon.

(d) Shows the line A-B with the skins of different features (see legend).

- *The reservoir extents are outlined in dashed white lines.*

Figure 2 *Shows the results from HDFD, Far Stack RMS amplitudes and Chaos/Envelope attributes.*

Interactive Facies Classification

The Interactive Facies Classification tool (IFC+) uses a Hierarchical Clustering and Gaussian Mixture Model optimisation to segment seismic attribute/s into statistically different facies. The IFC+ was used to simplify the information from the HDFD blend, Terrace Thickness attribute (which blocks the wavelets on a trace by inflection points and measures the time thickness within each block) and Fault Detect attributes into a single volume. The resulting volume was used to help interpret the interplay between structure and stratigraphy at the Domo Sandstone level (Figure 3). The shallow marine facies in the Domo Sandstone would have originally been deposited in a north-south graben with the basin to the south. The classification results showed that the Nemo-1 well was drilled into the thickest sands which were present on top of a structurally higher area to the south while thinner shallow marine systems were present in structurally lower areas to the north. This confirmed the interpretation of structural inversion along the faults probably due to late stage shear stresses in the Late Cretaceous – Early Tertiary. The classification results also showed potential depositional fairways and sand-sand juxtaposition across faults.

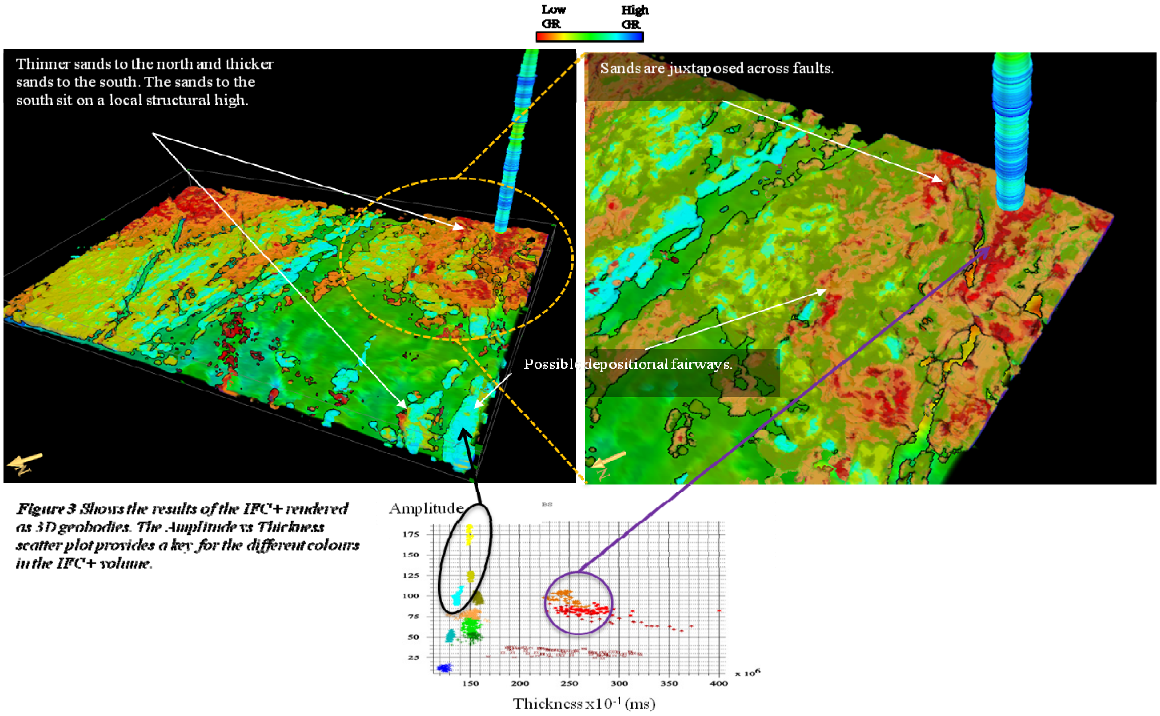

***Figure 3** Shows the results of the IFC+ rendered as 3D geobodies. The Amplitude vs Thickness scatter plot provides a key for the different colours in the IFC+ volume.*

***Figure 3** Shows the results from the IFC+ tool.*

Synthetic wedge modelling

Synthetic modelling of seismic events is a well-known method for investigating tuning effects in seismic data (Widess, 1973). Used in conjunction with spectral re-composition techniques these synthetic models can be very useful in understanding the colour response from frequency decomposition RGB blends. A simple synthetic wedge model was created using velocity, density and thickness values from the Nemo-1 well (Figure 4a), convolved with Ricker wavelets of different frequencies and then recomposed to match the frequency spectra of the real seismic data (Figure 4b). A HDFD RGB blend, with dominant frequencies of 15 Hz, 35 Hz and 55 Hz respectively, was generated from the recomposed synthetic seismic data (Figure 4c). Colour responses observed above and below the GWC in the synthetic seismic HDFD RGB blend mimicked the colours observed on the west and east at the Domo Sandstone horizon. Frequency decomposition colour blend responses are typically affected the most by thickness variations with the brightest magnitudes occurring around the tuning point (McArdle & Ackers, 2012). From our synthetic HDFD RGB blend we observe that even though gas and water are present in the same stratigraphic layer, they can be treated as individual wedges with the tuning point in each wedge having similar colour responses. This explained the similar colours at the reservoir and to the east, where the Domo Sandstone lies below the GWC (Figures 4c and 4d).

Conclusions

The HDFD RGB blend showed that the dominant control on the hydrocarbon sand distribution may be due to structural rather than stratigraphic influences. The Chaos/Envelope volume provided an explanation for the reservoir being relatively under-saturated at present as it shows 'seismically distorted' zones occurring along the major faults which may be due to gas chimney effects as gas migrates out of the Domo Sandstone into the overlying section. Interplay between the structure and stratigraphy in the area were interpreted from the IFC+ volume which supports ideas of a late stage inversion and sand-sand juxtaposition across faults, implying that faults and fractures may not be acting as baffles to fluid flow. Finally, the synthetic modelling showed why there are similar bright colour responses at the reservoir and to the east in the HDFD blend. It highlighted the non-uniqueness of colour response within the HDFD RGB blend and showed that while thickness may be the dominant factor in the colour response, pore fluid does play a role as well. Geological Expression techniques aided in risking the area by confirming the location and extents of the reservoir, the environment of deposition and the 'leaky fault' idea which led to the conclusion of either poor trapping mechanisms (seal breach by tectonic activity) and/or unfavourable timing of charge leading to low saturations in the Domo Play.

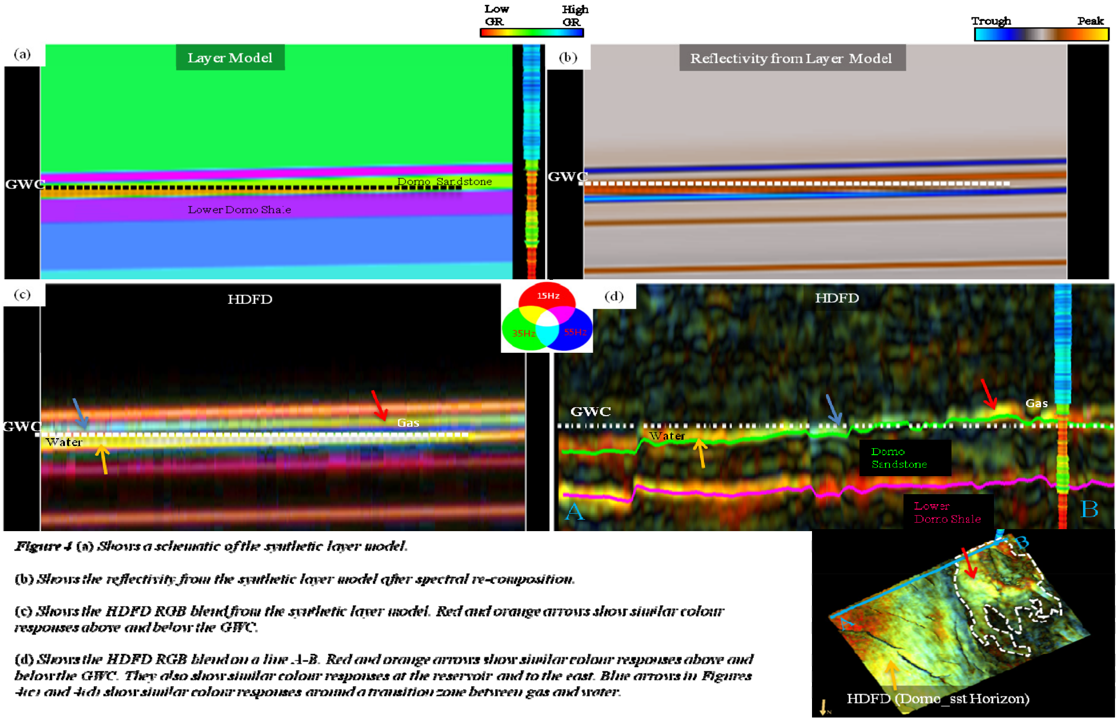

***Figure 4** (a) Shows a schematic of the synthetic layer model.*

(b) Shows the reflectivity from the synthetic layer model after spectral re-composition.

(c) Shows the HDFD RGB blend from the synthetic layer model. Red and orange arrows show similar colour responses above and below the GWC.

(d) Shows the HDFD RGB blend on a line A-B. Red and orange arrows show similar colour responses above and below the GWC. They also show similar colour responses at the reservoir and to the east. Blue arrows in Figures 4(c) and 4(d) show similar colour responses around a transition zone between gas and water.

***Figure 4** Shows the results from synthetic modelling of the reservoir.*

References

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