Bulletin of Earth Sciences of Thailand

RESERVOIR POTENTIAL USING SEISMIC ATTRIBUTES AND DEPOSITIONAL ENVIRONMENT ANALYSIS OF THE EOCENE SUCCESSION SOUTHERN ROVUMA BASIN, MOZAMBIQUE

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Abstract

This study examined depositional environments and sand distribution in the Eocene of the southern Rovuma basin using well data and seismic attributes. The succession was deposited in deep water by a major progradational event that occurred in the Tertiary because of a huge influx of sediments and shelf edge collapse which generated turbidity currents that transported shallow water sediments down slope. Seismic amplitude data cannot fully delineate detailed stratigraphic or structural features, so it is important to consider a number of seismic attributes that can help to easily identify those features. Beyond of many available attributes, RMS, spectral decomposition, variance and coherence were selected due to their proven abilities to delineate stratigraphic, structural discontinuities and bed thickness. Seismic attributes were extracted from a conventional 3D Pre Stack Time-Migration seismic volume. Two main horizon slices were analyzed within the interval. Shallow slice Top Sand RMS and Variance better enhance the sand distribution and the lateral continuity associated with the channels and depositional lobes, whereas the deeper slice Base Sand can be imaged more efficiently by using Spectral Decomposition, Coherence and Variance. Nevertheless, the base of the channel are filled by mud. Channel widths vary from 800 m to 2.2 km. These channels are NW-SE oriented. Depositional environment analysis was carried out on the basis of seismic geomorphology supported by well log data. The study interval was divided into 4 units based on well logs and comprise proximal to distal fans. Potential reservoir targets in this interval might be located where there are high amplitudes on RMS combined with Variance, however, the presence of carbonate cement must be considered. Attributes effectively demonstrate lateral continuity and geomorphology of the channels.

Keywords: Reservoir potential, Depositional environment, sand distribution seismic geomorphology, offshore Mozambique

1. Introduction

Rovuma Basin is located in the north of Mozambique and covers approximately 29,500 sq/km, including onshore and offshore. Since discoveries of natural gas in the northern offshore of the basin many studies have been done to evaluate the prospectively of the entire Basin. The natural gas discoveries range from Eocene to Miocene in a combination of stratigraphic and structural traps with sandstones and shale providing a series of thick reservoirs. The study area is located in the southern Rovuma Basin (Figure 1), where there is only one well drilled, and the main problem seems to be whether there is reservoir potential. The drilled well encountered potential sands in two intervals, Eocene and Mid-Cretaceous (Late Albian). The focus of this study is the Eocene interval to reduce uncertainties and generate better understanding of reservoir distribution and geometry in the southern Rovuma Basin, using a combination of well data and seismic data analysis.

The main objectives of this study are:

- To determine the depositional environment of potential reservoirs by integrating seismic geomorphology and well data.
- Determine the controls in sand distribution and geometries of the potential reservoirs and to forecast areas of high reservoir potential

2. Results and Interpretation

2.1 Well log interpretation and Synthetic Seismogram

The zone of interest in this study lies in deep water depositional units. The lithological difference between the water depths and

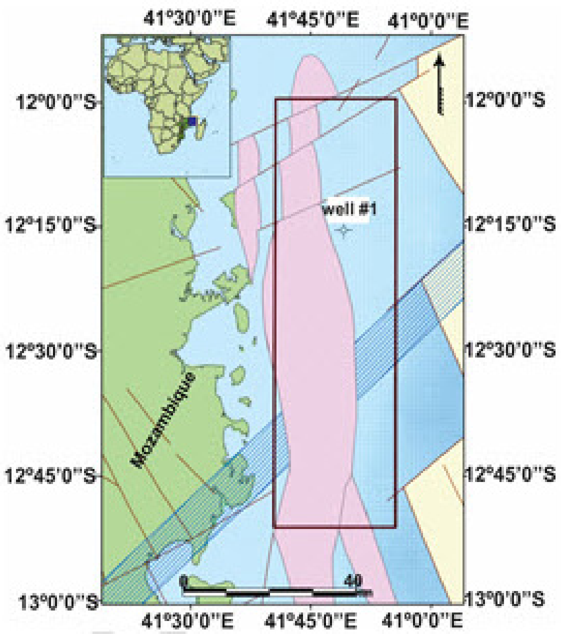


Figure 1: Location map of the Southern Rovuma basin

biostratigraphy interpretation suggest that shelf forams are in sands and bathyal forams in mud so that the background sedimentation is mainly mud. This suggests collapse of the shelf edge and down slope transport of forams introducing shallow water sediments via turbidity currents.

The interval was divided into 4 units based on the lithology variation and they are characterized by proximal (middle fan) and distal (Outer fan) deposition that may due either by lobe switching or water depth changes (Rider, 1996). In the seismic section, progradation seismic reflections can be seen in the interval.

The seismic data is of normal polarity as seabed (increase in acoustic impedance) is represented by peak. The synthetic seismograms of well#1 show reasonable cross correlation coefficients (greater than 55%) when compared with seismic data. acoustic impedance of the sands is comparatively higher than shale. Consequently, the amplitudes are positive for sands on the synthetic and seismic data. Within the interval, there are also carbonate cemented sands with relatively high values of acoustic impedance than sands.

2.2 Thickness Variation

Interpretation of the seismic data indicates that the interval consist of broadly sub-parallel and continuous reflectors that were produced by progradation. Three (3) key horizons and horizon slices were interpreted throughout the interval. However, the Top Sand and Base Sand were not possible to interpret seismically because the interval is too thin 38 m and the reflectors are discontinuous. For that reason were mapped on seismic for the Top Sand the upper reflector TS (Top seismic) which shows a positive and continuous amplitude and the Base Sand that ties to a strong positive amplitude within the section. Mapped the positive seismic amplitude associated with the base of this sand because it was more regionally mappable BS (Base seismic). The deepest horizon has a significant amount of erosion associated with local truncation and onlaps, this was considered the main unconformity in the study area which separates the post-rift and passive margin places.

The structural configuration of the study interval is dominated by a major NW-SE normal faults.

The isopach maps of the interval indicates that the thickness is greatest along the shelf and thins towards the basin. The main sediment transport direction was NW-SE (Figure 2).

2.3 Lateral Distribution

Sand distribution and geometry of the channels are controlled by deep water processes and are illustrated on combined seismic attribute maps and seismic cross sections with their interpretative geological drawings. The RMS TS+10 attribute map has 3 distinct channel-shape and 4 fan shaped amplitude anomalies located in the eastern and central parts of the study area (channels A, B and C, and fans A, B, C and D; Figure 3). According to its fan shaped geometry, divergent to prograding reflection patterns, seismic cross section geometry, and location on aslope, this feature is interpreted as a submarine fan (Figure 4).

In detail, slice TS+10 of the fan, in particular channels B and C, have both chaotic

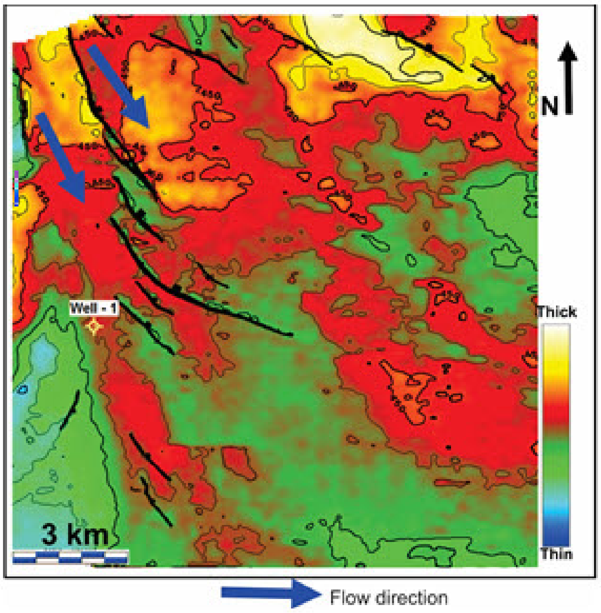


Figure 2: Isopach map of TS_BS, showing the main sediment transport direction

and moderate amplitude reflectors. Channel A ends on the down east part in a fan shaped amplitude anomaly up to 5 km wide and 10 km in length (Figure 3). Based on its fan shaped plan view geometry on the RMS map, its relationship to submarine fans on the Variance map (Figure 4), and the internal sheet to channel like reflectors, the fan shaped A, B and C anomalies are interpreted as sheeted to channelized fans. The most interesting feature of the TS+10 slice is the feature that has a bowl shape, and is bounded by low values of variance (Figure 4), which indicate a clear fan shape. The channel is filled by high amplitude material that runs NW-SE (Figure 4).

Based on the channel geometries on the variance slice TS+10, and vertical seismic sections these are interpreted as levee deposits.

Major channel-shaped amplitude anomaly immediately landward, and at a slightly lower stratigraphic level (TS+20), than the fans

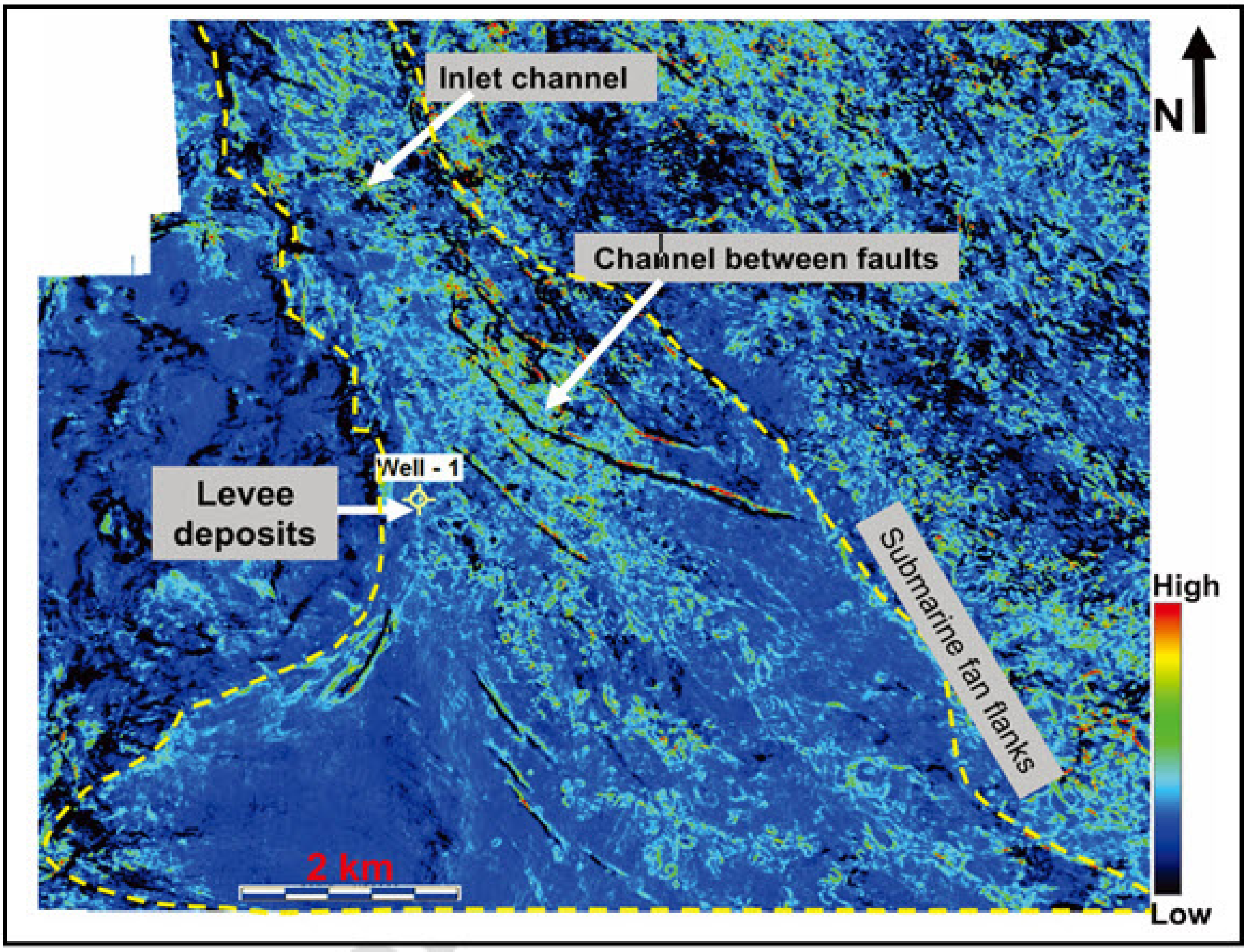


Figure 4: Variance attribute at horizon slice TS+10 show clearly the submarine fan morphology and high amplitude channels oriented NW to SE

described above (Figure 5). This channel fan has high amplitude anomalies which are 2.5 km wide and 12.5 km long trending NW to SE. From the seismic cross section of the slice TS+20, the amplitude anomaly has internally complex packages of low to high amplitude reflectors up to 85 ms (approximately 85 m) thick that display a The seismic sections perpendicular to the depositional systems indicate the development of low amplitude features at the northeast part of the lowermost slice (BS-20), both in RMS extraction and Spectral decomposition.

These amplitude anomalies are related to two channels visualized by low Variance values, which emphasize the edges of the channels (Figure 6).

These anomalies are typically 70 ms or 70 m.

In the central part of slice BS-20, the Variance attribute indicates low amplitude features that are interpreted as channels (Chopra and Marfurt, 2007). The GR pattern is serrated and the thickness of the sand observed in Well-#1 in the corresponding interval is in the range of 2 m.

High amplitudes occur in the Variance, RMS and spectral decomposition maps associated with sand in Well #1

Similarly, low amplitudes are related to a shale-dominated. Therefore, high amplitude anomalies are related to sands deposited by turbidity currents. Some sinuous channels are seen on the attribute map. Two channels occur near the center of the slice (Figures 6). Channel width ranges from 1 – 1.2 km and the general trend of the channels is northwest–southeast.

2.4 Integration of Seismic Attributes

In this study different seismic attributes were effective within each layer of the study interval. The horizon slices extractions of the RMS amplitude, spectral decomposition, coherence and similarity Variance successfully image different elements of the submarine fan deposits systems (Figure 4), but at deeper levels these three attributes have limited discrimination capability (Figure 6). The essence of running

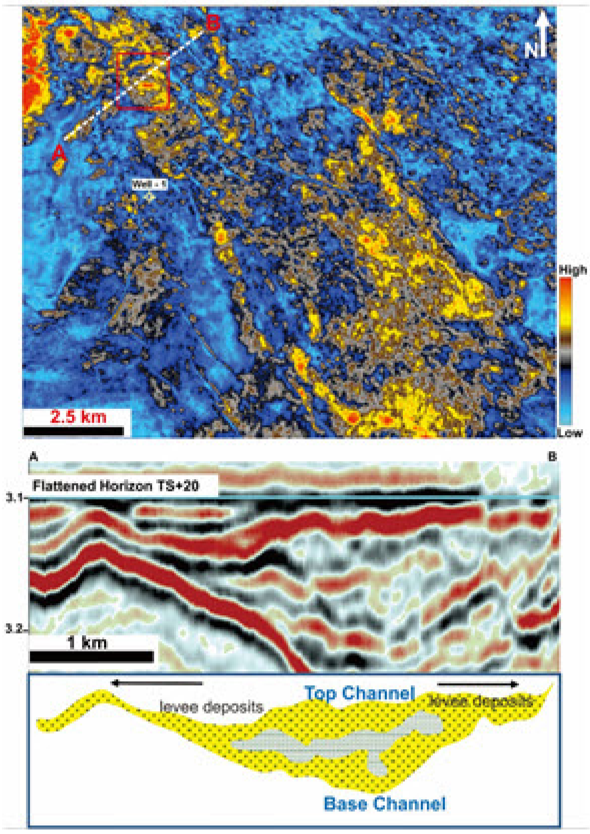


Figure 5: RMS TS+20 b) Representative seismic section though the slice showing high amplitude features and interpretative geological drawing.

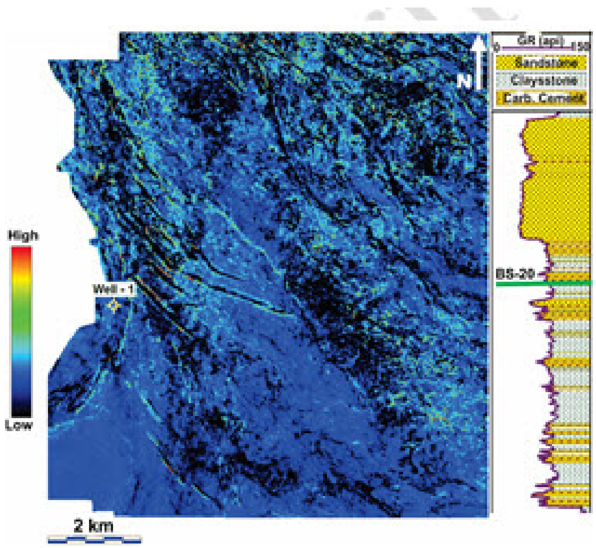


Figure 6: Variance horizon slice in BS-20 show low amplitudes oriented NW-SE. The low amplitude are interpreted as mud filled channels.

of running RMS attributes on horizon slice TS and BS was to identify higher proportion of channel sands or better reservoir facies. Figure 7a shows high RMS regions within the TS horizon slice map indicating characteristically high amplitude sand units. The Variance seismic attribute correlate well with faults and channels within the study area.

Faults signatures and deeper features were enhanced through calculating the Coherence within the seismic data volume and the horizon slice.

from the TS/BS depth structure maps and channels with seismic attributes. The slope was generated by major tectonic events at the base of the study interval on the regional unconformity that separates the Cretaceous and Tertiary. There was a structural high to the northwest, suggesting NW – SE sediment supply (Key et al., 2008).

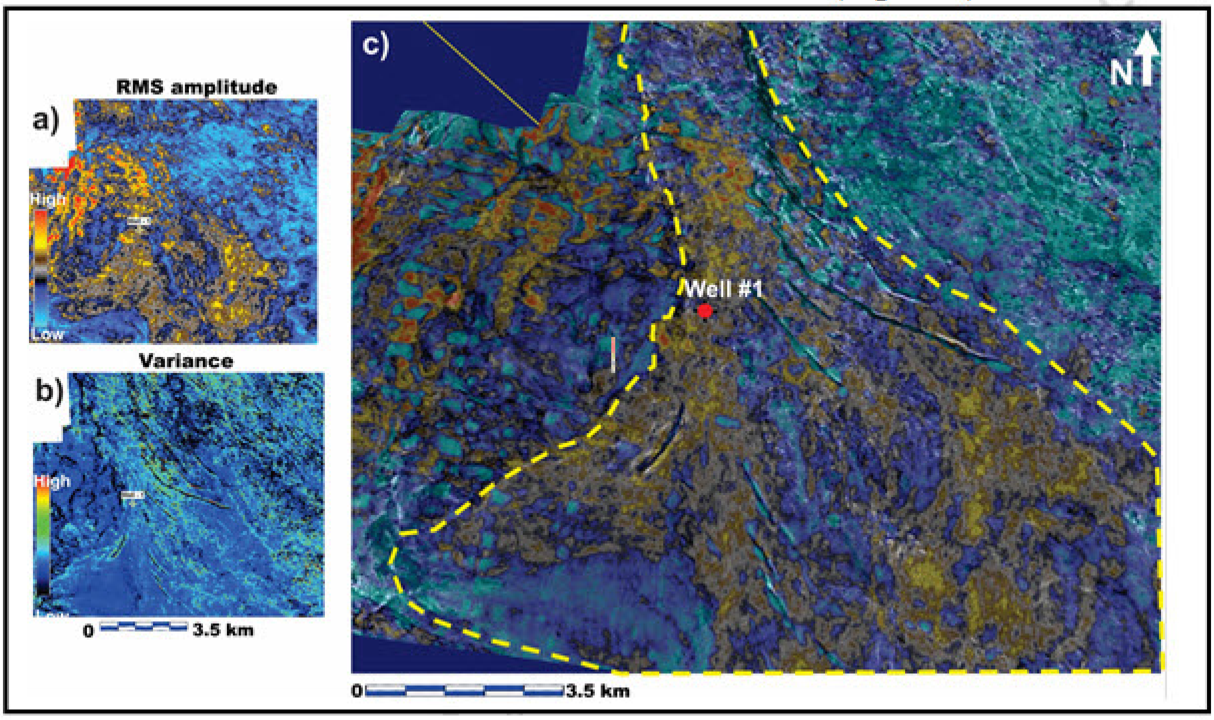


Figure 7: Integration of RMS and Variance at horizon slice TS+10. a) RMS, b) Variance. c) Combination of RMS and Variance. Attributes show good match and emphasize the lateral distribution and main submarine fan morphology

The horizon based on RMS and spectral decomposition map extractions provide better imaging of sand distribution at deeper levels. Moreover, variance horizon slices further improves the resolution of depositional geometry and morphology of the subsurface channel (Figure 7).

The integration of maps produced by all attributes highlights the value of each technique for prediction of sand distribution. Most attributes observed and interpreted show high amplitudes with same NW-SE trend for the depositional channel sands (Figure 7).

2.5 Depositional Setting

Depositional setting was interpreted

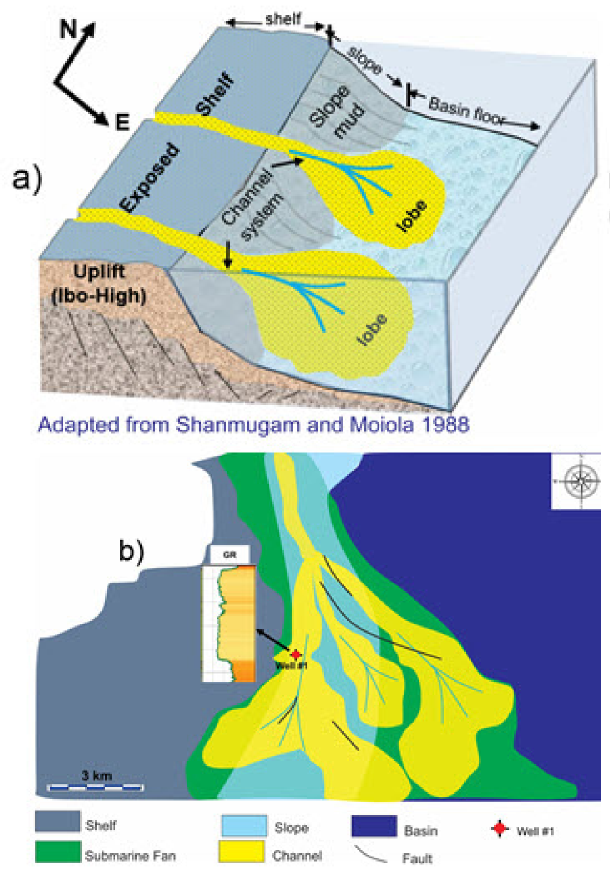
The sand rich unit 2 was deposited on a fan (Figure 8). The sands were transported as turbidity currents and deposited as thin bodies, Figure 8a is model proposed to explain the mechanisms of filling observed in the succession. Unit 1 and Unit 3 are intercalated sand and shale facies, indicates a more distal, possibly mid-fan setting (Figure 8).

Seismic cross sections across the study area indicate that the channels are characterized by unconfined sheet sandstones and shale beds, probably deposited on a fan (Figure 8).

3. Discussion

3.1 Reservoir Potential

The landward end of the channel is



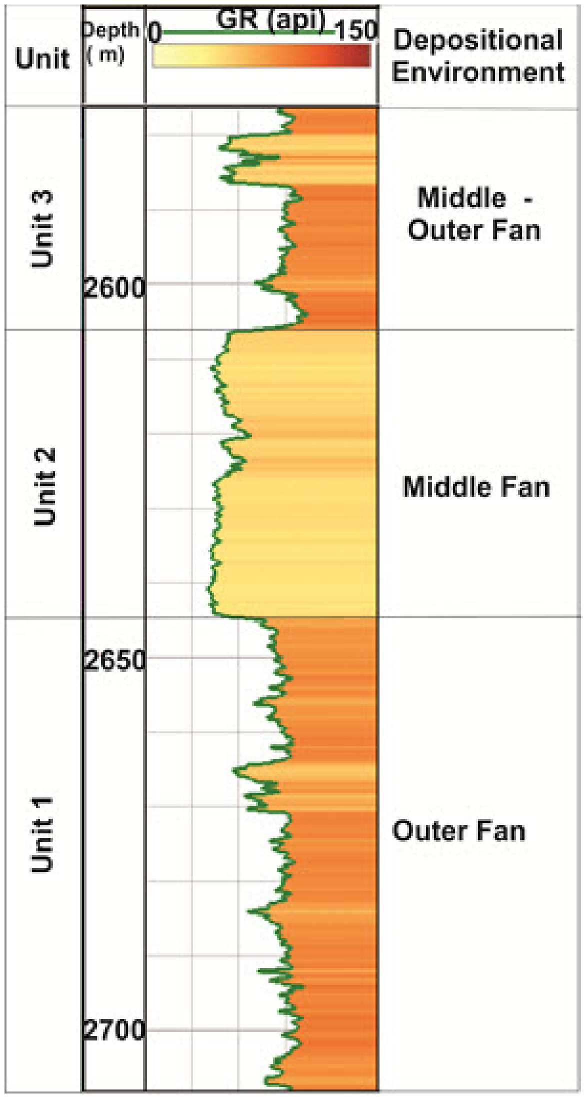


Figure 8: Eocene depositional model of sandy submarine fan. a) Conceptual depositional model, b) Present day depositional model. Depositional environment interpreted according to lithology variation due to lobe switching. Note Uplift – increase the sediment supply rate and change the drainage direction of rivers (Stankiewicz et al., 2006)

narrow and has a series of low to medium amplitude reflection packages, with dimensions in the range of 0.8 – 1.2 km wide and 50 – 80 m deep. These areas have irregular seafloor topography. Downslope, the channel merges with other tributary channels of varying dimensions. Submarine fan models predict that reservoir potential is characterized by proximal channelized facies and more distal depositional lobes (Figure 8; Reading and Richards, 1994). Sands are transported to the end of the fan by turbidity currents and may even spill over the walls, depositing levees (Figures 4).The superposition of levee turbidite deposits above sheet-sand turbidites is related to a lateral shift of the fan lobes. The system is mud rich asdefined by the channel shape and depositional lobes (Shanmugam and Moiola 1998).

The best reservoir potential in this type of depositional system is in the middle – distal fan (Figure 9). However, carbonate cement may have degraded some of the sands. Many of the sands are not heavily cemented, although they have thin cemented intervals that may influence the response of the attributes.

The highest amplitude anomalies have a NW-SE direction which aligned with the channel orientation. Carbonate cements are related to sandstone with good original porosity. Nevertheless, they are relatively thin. Thus, RMS combined with Variance that is related to carbonate cements can define reservoir potential in the study area. Sandstones have enhanced amplitudes but not as high as carbonate cements.

Overlaying of RMS with Variance is effective in highlighting the middle – distal fan which suggests that there is a good match with the depositional model as most sands occur where they expected (Figure 9).

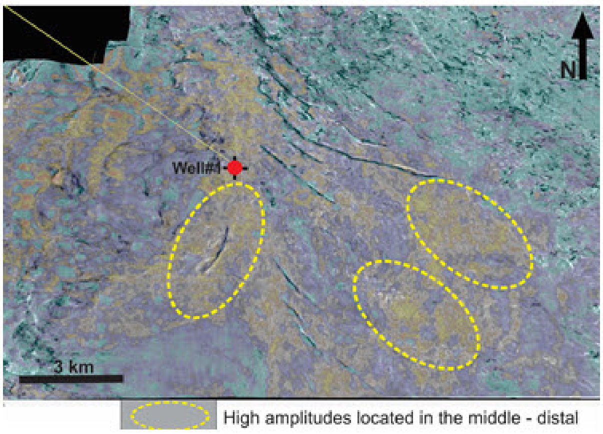


Figure 9: RMS extraction 50 % transparency overlay on the Variance attribute showing amplitudes related to lithology variation and sand distribution.

4. Conclusions

Integration of well log analysis and multi-seismic attributes were used to generate a 3D seismic geomorphology and map the Eocene sand distribution in the southern Rovuma Basin. From this study the following conclusions were drawn:

- Sediments in this interval represent a passive margin succession that was deposited in response to the East African uplift during the Tertiary. The steep slope angle created by the Ibo-high structure influenced sediments to be deposited in deep water. The direction of turbidite channels changed from an initial W-E direction to NW-SE direction
- The sand distribution and geometry of the succession was controlled by turbidity currents that brought sands into a deep water environment with muddy background sedimentation.
- Two major depositional environments have been identified in the zone of interest. They proximal and distal, characterized as channel facies and distal depositional lobes, respectively.
- Attribute maps were useful to determine the seismic geomorphology and lateral distribution of the high amplitudes. However, they can't discriminate if those high amplitudes are related to sand or carbonate cement.
- The attributes indicate that the lower level is comprised of channels filled by high amplitude sandy sediment, while the deeper levels have mud-filled channels.
- A combination of the RMS and Variance attributes provides more confidence for predicting reservoir potential than either attribute alone.

5. ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor Prof Dr. Joseph J. Lambiase, for his warm support and suggestions, and also Mr. Angus John Ferguson and Dr. John Warren for their knowledge through the Petroleum Geoscience Program. I would like to express my appreciation to PTTEP and INP for offering me the opportunity to pursue this degree. Many thanks to all staff for precious support. Lastly, I am very thankful to my family, my colleagues and my friends for their encouragements and c heerfulness.

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