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SEQUENCE STRATIGRAPHY ANALYSIS USING SEISMIC SEDIMENTOLOGY AND ATTRIBUTES TO IDENTIFY POTENTIAL RESERVOIR IN SOUTHERN ROVUMA BASIN, OFFSHORE MOZAMBIQUE

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Abstract

Understanding sequence stratigraphy by applying seismic attributes can contribute for a better knowledge of the basin evolution and to predict possible hydrocarbon bearing zones, over the southern Rovuma Basin Mozambique offshore. The study comprises sequence stratigraphic analysis to determine stratigraphic architecture within 3 to 5 seconds of the 3D seismic. The seismic reflections in the 3D volume can be used to map structures and amplitude patterns that are interpreted to determine the prospective areas of having hydrocarbon bearing potential zones. The 3D seismic cube observations and analyses were integrated with one well data located approximately 80 Km to the North East direction. The well was matched with the 3D seismic by using 2D regional seismic lines to improve the well tie to the seismic. Analysis of the stratigraphic sequences in the study interval identified 3 megasequences S2, S3 and S4, bounded by SB1, SB2, SB3 and SB4 respectively. Significant potential hydrocarbons bearing zones for exploration successes in the study interval were identified on isolated carbonates buildups ICB's described as having developed a during transgressive when accommodation was greater than sediment supply. This resulted in a retrogradational coastal trajectory at the base of S4, and progradational features that indicate highstand deposits and sediments supply from North direction on the top of sequence 4. Migration pathways are related to faults that act as likely fluids conduits from lower to upper sequences. Sequences 3 and 4 are the potential reservoirs, source rock are associated to the deepest sequence. Good quality sand reservoirs are focused to paleo-geomorphologic features identified by seismic attribute analysis integrated with depositional environment studies to predict the spatial distribution and quality of these reservoirs.

Keywords: Reservoir potential, Sequence Stratigraphy, Carbonates Buildups, Offshore Mozambique

1. Introduction

The study area is located in the South end area of the Rovuma Basin which in Northern part of the Mozambique offshore (Figure1) that is an extension of the East African passive margin. Rovuma Basin has a recent huge commercial gas discovery in Tertiary progradational lowstand (LST) sequences in the Northern part (Chiulele, 2016). Oil and gas shows were found in Cretaceous Albian LST progradational sequence at onshore as well as offshore. Good quality reservoir gas discoveries in stacked sand were found in nearby study area. The sand reservoirs are reported as high amplitudes response of seismic data.

The study comprises sequence stratigraphic analysis to determine stratigraphic architecture within 3 to 5 seconds of the 3D seismic. This interval is where the seismic shows most likely prospective zones of having hydrocarbon bearing potential zones due to the structures and amplitude patterns. The 3D seismic cube observations and analyses were integrated with one well data-located approximately 80 Km and was correlated using 2D regional seismic lines to improve the well tie to the 3D seismic data.

Understanding sequence stratigraphy by applying seismic attributes would contribute a better knowledge of the basin evolution and to predict possible hydrocarbon bearing zones. Those zones can help to promote exploration over the study area and attract oil companies.

The study identified possible isolated carbonate buildups, which were developed during transgressive deposition, as well as progradational features that indicate possible highstand deposits.

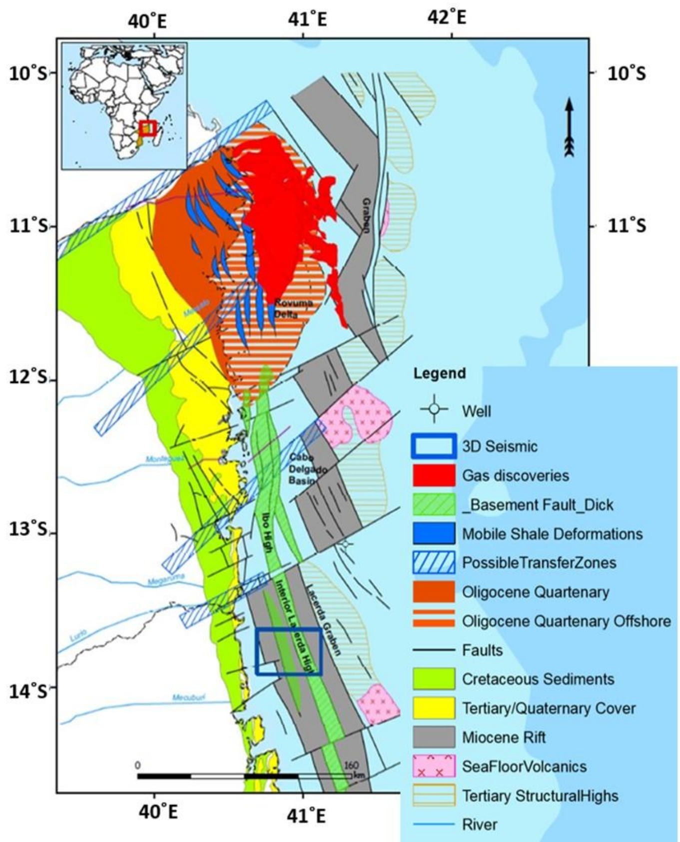

Figure 1: Location map of the Southern Rovuma basin

The main objectives of this study are:

- Identify potential reservoir that may contain hydrocarbons bearing by using concept of sequence stratigraphy and seismic attributes.

The secondary objectives are:

- Recognize and characterize the sequence stratigraphic surfaces that represent changes in depositional trends of sedimentary packages through geological time.
- Identify geological features such as carbonates buildups or channel systems based on seismic interpretation by seismic attributes.

2. Methodology

The present project relied mainly on seismic interpretation from 3 to 5 seconds (TWT) of a 3D cube, based on reflection surveys, and to identify top horizon sequence boundary 4 (SB4) and the base horizon SB1 which are calibrated by 2D seismic to tie to the nearby. This is used to determine the stratigraphic architecture within the study interval of Rovuma Basin.

Stratigraphic Characterization

Interpretation was based on seismic stratigraphy, where identification of major unconformities was based on seismic termination patterns, followed by delineation of seismic sequences. The stratigraphic framework of sequences was built in consideration of stratigraphic indicators, prominent on seismic records such as onlap, toplap, truncation and erosional surface, which are the key surfaces for seismic interpretation. According to Van Wagoner et al. (1988), sequence boundaries are defined as subaerial unconformity and correlative conformity.

Three phases for seismic sedimentology interpretation were selected: Seismic facies observation, mapping and attribute analyzing such as cosine phase which helps to see the bedding that are useful for identification of the package of sediments inside to defined sequence, the Root Mean Square (RMS) amplitude extraction from sweetness attribute which were useful to identify the features such as channels, fans, faults, for possible reservoir accumulation indicator and for carbonates buildups.

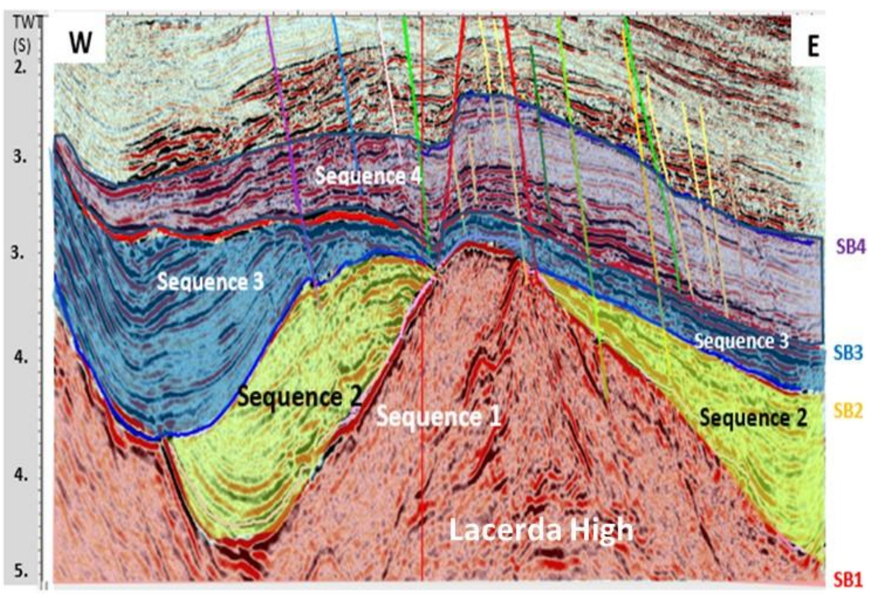

Figure 2. Shows all sequence identified within the interval study 3 to 5 seconds, and their respective associated boundaries named sequence boundary (SB).

3. Results And Interpretations

Seismic Sequence Stratigraphic Analysis

The study section is from transition post rift sediments which is distinguished by horizon SB1. There are 3 main megasequences (sequence S2, S3 and S4) identified in the study interval which are bounded by 4 sequence boundaries, namely SB1, SB2, SB3 and SB4 (Figure 2).

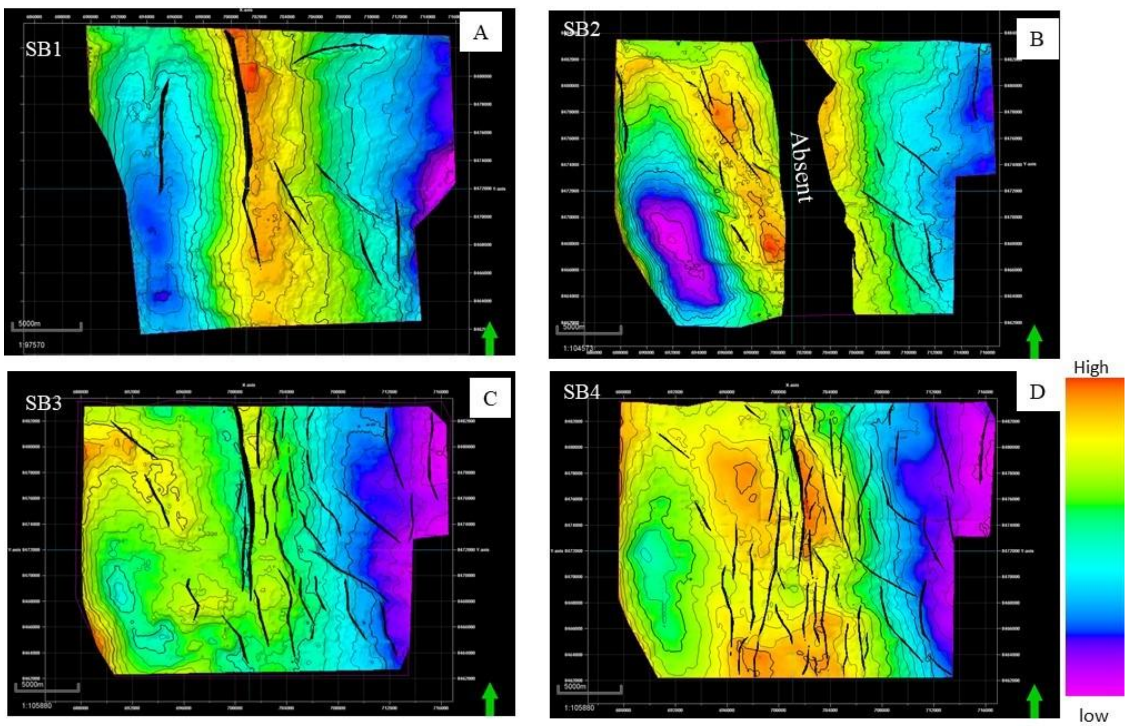

Figure 3. Structural map of all sequences boundaries identified in the study interval. (A) for SB1, shows high structures North-South oriented in the middle side, deep side tend to East; (B) SB2 shows no deposition on the middle side splitting the area in two sub basins East and West, Basins deepest side on the Western part; (C) SB3 shows deep trend to East and intensive faults to the Central part of the study interval, on the Lacerda high; (D) SB4, shows deep trend to East and faults tend to be intensive more concentrated in the middle part on the Lacerda high;

Sequence Boundaries SB

The SB1 is the lowest part of the study section, represented by strong amplitude reflection surface, which has the reflection termination, onlapping on the strong reflections, the basement uplift structure (Lacerda high) in the middle of the study area (Figure 2). It is splitting the area in two sub-basins, one in the Western side and another at the Eastern side. The reflection termination is onlapping on both flanks sides of the uplifted structure. The deepest zone is towards Eastern part of the basin as seen in the structural maps, Figure 3(A).

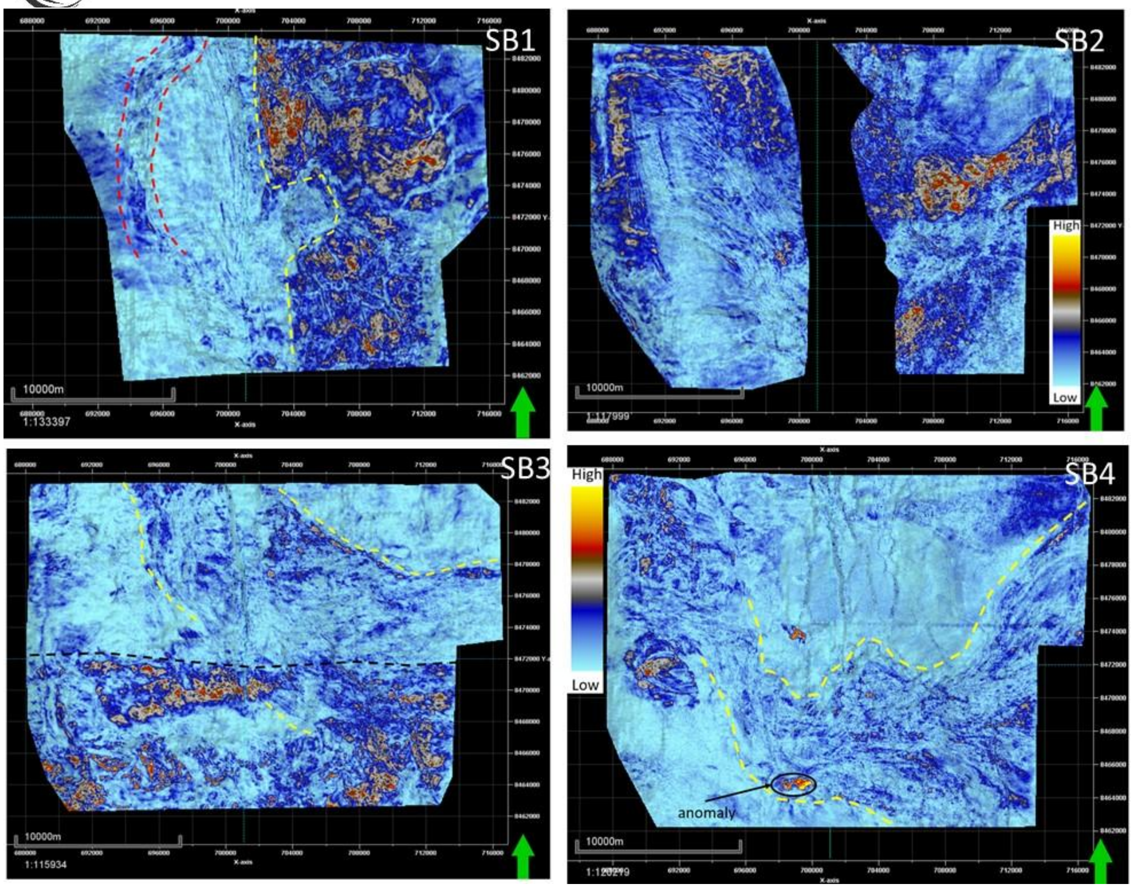

Figure 4. RMS amplitude extracted from sweetness attribute map all SB at +20ms window, (A) SB1 shows a general trend of high amplitude on the East delimited by yellow dashed line, and West side shows a "channel" features between red dashed lines; (B) SB2 shows a general trend of high amplitude on the East and also in the West and East flank of the Lacerda high; (C) SB3, shows a general trend of high amplitude on the South and also a channel belt shape without any flow direction or channel inside the belt.(D) SB4 shows a lobe complex channel shape yellow dashed, trending flow direction NW to the East direction, bright spot on the South high amplitude black circle more noticeable on the flow of channel shape.

The RMS extracted from sweetness attribute map +20ms shows a strong amplitude to Eastern side of the all section (Figure 4A). On the Western side it shows a linear structure that looks like a channel which come from North side downwards to the SE that might be a depo-center of that section. Depo-center occurs in basins with rapid subsidence and multiple sediments supply.

SB2 is distinguished by toplap seismic reflectors on the base which indicate an erosional truncation surface and conformable reflection on the top which indicates the startup of sequence 3. The surface is characterized by strong amplitude, and the reflection terminations onlapping on the SB1 both sides West and East as represented in Figure 2. The structural map represented on the Figure 3B, shows an absence of deposition in the middle of the horizons which is the top of basement Lacerda high oriented North South (N-S). A possible erosional event occurred and eroded the top of the uplift, and the fault system is intense close to the central part. The high structure also divides the zone in two sub-basins, West and East side. RMS extracted from sweetness attribute map at +20ms window for the SB2, shows some strong amplitude reflection in the both sides of the flank of Lacerda high structure Figure 4B.

There is a possibility of being reservoirs, even though the onlapping termination can be related to the trapping system, but due to the location on the flank of Lacerda high, another possibility is that it might be related to possible volcanic lavas seen by strong amplitude reflection, taking account that it is located on the base of sedimentary section.

SB3 is the strongest amplitude reflectors in the study interval mainly in the Western side (Figure 2), and shows truncated or eroded surface. It is best picking on trough due to the strong amplitude reflection, the structural maps show changes comparing to the SB1 and SB2, that in this SB3 the uplifted process probably ended, because it shows a deep trend only in one direction to East of the study interval represented in Figure 3C, although the main fault systems in the central remains. RMS extracted from sweetness attribute map shows strong amplitude reflection from half middle to the South end part of all area black dashed lines on the Figure 4C. Zones of high amplitude reflection suggesting to be the end of uplift system and also a channel belt shape where observed in the yellow dashed line (Figure 4C), even though inside of the belt shape is not clear to see flow direction.

The SB4 is the upper part of the study interval, is characterized by strong reflections with terminations ending on as a toplap and conformable reflections on the top (Figure 2), the picking on this horizon were also best on trough. The structural maps show dipping to Eastern side represented on Figure 3D, is the most faulted SB on the interval study area mainly the E side possible affected by the 2nd drift event, the faulting due to post-break drift (ECL and ENH, 2000). RMS extracted from sweetness map shows evidence of possible lobe complex due to the evidence of tongue shape, showing a possible flow direction from Western to the Southeast direction which follows the trend of high amplitude direction (Figure 4D).

Sequences (S)

Three distinguishable mega sequences namely S2, S3 and S4 that comprise a full sedimentary package from 3 to 5 seconds were identified within the interval study area.

Sequence S2

The lowest post breaks up sequence unit, between regional stratigraphic SB1 at the base and SB2 at the top (Figure 2), might have been strongly influenced by the basement Lacerda high structure and geomorphology. The seismic facies show tilting mainly on the uplifted structure which divide the area into two sub-basins where the one on the West is an isolated basin. It might have experienced several influences linked to tectono-stratigraphic evolution, that occurred after break up phase to the first drift and the area was uplifted and the major erosion occurred on the top of uplift which ends up with those two sub-basins onlapping on the high structure. The isolated Western basin is approximately 1000 ms thick while the Eastern side inside the study interval tend to be thinning possible because it was controlled by different faults, and those faults were active in different times. By observing the regional trends, there is an increasing in thickness towards the main fault from Davie ridge. Internal seismic character is not homogeneous in all of the area, comprising parallel and sub-parallel, continuous to discontinuous facies and chaotic facies are also present. Therefore, it could be related to several depositional processes and variations of depositional environment energy that might have contributed facies distribution in the first stage, afterwards the section was affected by faulting structures during the drift phases.

The sub-basin in the Western side is mainly characterized as a subsided package due to the block tilting. Parallel and sub parallel reflection variation are present in the northern part of Western sub-basin, and the package is sub parallel to chaotic reflection dominated by semi-transparent facies. The middle of Western sub-basin package shows some strong reflectors that cut the package perpendicularly such as inversion reflectors on the SB1. The onlap is not obvious in the Northern side, meanwhile the onlapping is observed towards the Southern side where the sub-basin tends to tilt dipping to the Western part. The perpendicular reflections that cuts reflectors in the middle of package remains, the toplapping facies are present on the westerly side of the western package. Fault systems were observed as intensive on the Northern part of this sub-basin and tends to decrease towards to South, all the faults are intense on the West flank close to the Lacerda high structure.

The Eastern sub-basin is an onlapping package, to the Lacerda high structure variations on sub-parallel and discontinuous reflectors alternated to chaotic as indicative of rapid changes in depositional energy level (Veeken, 2013). This may be significant as it corresponds to the different deposition time between East and West, with possible younger sediments in the West sub-basin. These seismic facies are onlapping against the high structure to the West from East, over the subaerial unconformity SB1 (Figure 2). The chaotic characters are dominant within this part and can be associated with high energy deposits in this sequence.

Western and East side may not be deposited at same time because they have different geomorphologic shapes and have very different sequence thicknesses.

Sequence S3

This is the second post-break up to second drift sequence unit bounded by high amplitude regional seismic surfaces, SB2 at the base and SB3 on top, Figure 2. This sequence is conformable with the underlying SB2 in the Eastern part while truncation is observed on SB3 in the Western part associated to strong amplitude reflection, then changes to conformable in the Eastern part of the area. S3 package is the strongest amplitude reflection to transparent and parallel reflection in the Western part, and the thinnest layer in the Eastern Side. The Western side, the package also subsided. The western side maybe has experienced one more tectonic event causing the small ridge in the West side of the study interval. The ridge in the West side probably resulted in subsidence and sediments then filled the sub basin forming an isolated basin. The sequence comprises of a package characterized by high amplitude reflections mainly on the top SB3 and within the Eastern part. Isochron map and seismic inline shows the relatively high thickness on the western part and thin layer on the Eastern Area.

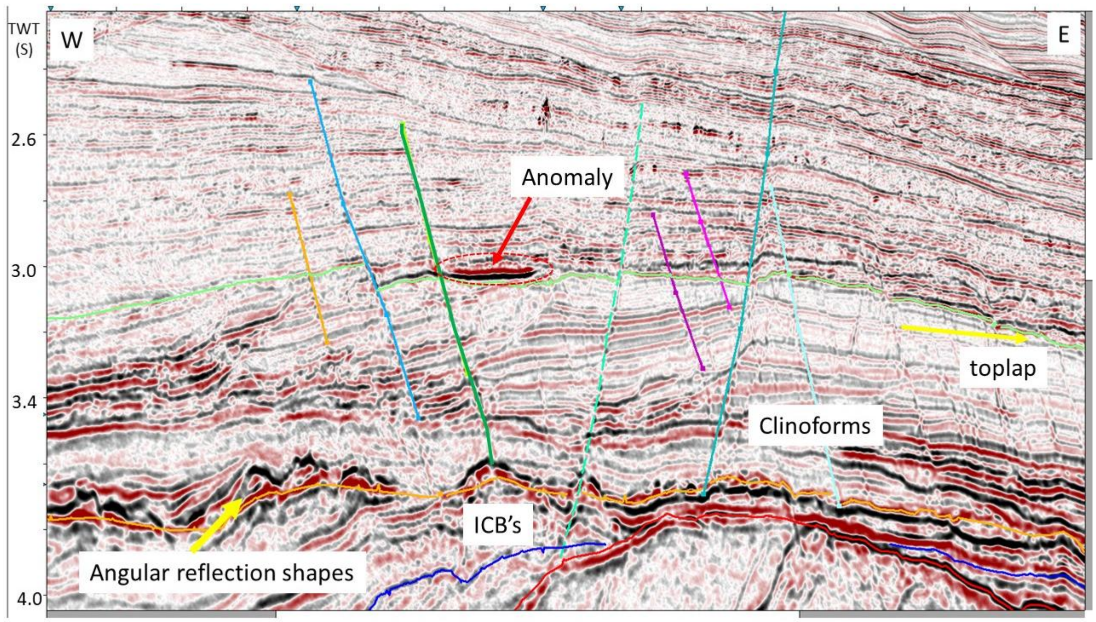

Figure 5. S4, the Western side showing angular shape that indicate possible ICB's accumulations, and Eastern characterized by toplap on the top of SB4, the anomaly detected on the RMS amplitude extracted from SB4 and fault system from ICB's, indicates possible fluids migrated from faults.

Sequence S4

This is the third post-rift stratigraphic unit and is a possible transition from the second drift and end on the base of passive margin, is bounded by high amplitude regional seismic surfaces SB3 and SB4 (Figure 2). The western part is overlaying an unconformity identified by prominent truncation, then grades to conformable in the central and eastern part on the bottom with strong amplitude reflection. The top sequence is characterized by toplap with sigmoidal features on the eastern part clearly identified on the base with downlaps and toplaps on the top. The top of S4, is delimited by sequence boundary SB4 that is characterized by an unconformity across the slope and is conformable at the base. This is a more confident sequence to interpret and the thickest sequence in all the study interval.

Seismic package comprises bottom and upper sections, where the bottom section is characterized by strong amplitude reflections, within both West and East parts. Some reflectors with angular shape suggest possible Isolated Carbonates Builds up (ICB's) or even other features such volcanos or erosional remnants. For this study, the features are assumed and described as ICB's (Figure 5). The upper part is characterized by strong amplitude in the Western part, low to moderate amplitude on Eastern part, with parallel to sub-parallel, chaotic and semi-transparent facies.

The package shows an ending of topset grading to gently dipping clinoforms thinning upwards one of the characteristic of highstand deposit (Figure 5). This suggests stacking patterns of sediments, most likely related to high sedimentation rate and low accommodation space. It is suggestive of sediment prograding to the slope that outpaced the accommodation space and the sediment prograded in a seaward direction.

Observations on seismic profile and thickness maps show thinning in the Western part while the center are thicker, that reveal changes on sedimentation patterns.

4. DISCUSSION

For the current study, discussion was constrained on sediment supply, subsidence and eustatic sea level changes, all seen as major factors that directly influence stratigraphic patterns and architecture of the sedimentary fill within the basin.

The study recognized three main sequences S2, S3 and S4, nevertheless in the lower sequence S2 and S3 were not clear to identify evidence of sediments supply and eustatic sea level changes or even possible system tract, due to the tectonic events highly affected those sequences. There is no evidence on seismic related to high reflectivity that could be source beds. Although there are several authors from regional geology that reports marine, lagoon environments when associated and correlates to the nearby basins of East African margin.

The S2 is the lower part of the sedimentary section that was deposited after the break up to the 1st drift. It was controlled with the appearance of Lacerda high uplift making the layer's subsidence in the West, and create the difference of tilting block comparing the Southern and Northern part of the West sub-basin. The South were inclined due to possible intensification of the tectonic events with possible incidence in the South.

S3 may also be deposited before the second drift due to the evidence of subsidence block on the Western side. The depositional reconstruction or system tract in this study were not seen clearly, there is no evidence on seismic but it has been reported as marine fans complex, and channels according to the regional geology.

The S4 is the thicker package in the study interval and it is possible to predict system tract involved in a depositional environment. It has had intense faulting activity mainly in the Eastern side, possible due to the event of the 2nd drift or even other recent tectonic events that may cause the reactivation of some faults as they reach the seafloor surface. Considering the features in the eastern part, they are progradational and on top of them it is possible to identify HST deposit that in combination with a reservoir can be a good seal that impedes hydrocarbon migrations making the trapping system more effective. In the western part the possible ICB's can be associated to a possible transgressive system tract (TST), and transgressive surface (TS) followed by maximum flooding surface (MFS). The bright spots identified in the attributes from Figure 4D, are possible fluids accumulations considering that, seismic profile of that section shows faults presence that depart from the ICB's to the top SB4. This suggests possible migration pathways to potential reservoirs in the ICB's as represented in Figure 5. Future investigations can help in the reconstruction of the depositional environments in the lower sequence that may improve the understanding of basinal evolution.

5. CONCLUSION

Understanding sequence stratigraphy by applying seismic attributes can contribute for a better knowledge of the basin evolution and to predict possible hydrocarbon bearing zones, over the southern Rovuma Basin Mozambique offshore. The study interval comprises 3 to 5 seconds of the 3D seismic, where the seismic shows most likely prospective and probability of having hydrocarbon bearing potential zones due to the structures and amplitude patterns

For the present study, analysis of the stratigraphic sequences in the study interval identified 3 megasequences, S2, S3 and S4, bounded by SB1, SB2, SB3 and SB4 respectively. The tectonic history played a very important role in this zone since for the lower sequences there was a difficulty to describe sediment supply and eustatic fluctuations with clarity.

Sedimentology of S2 and S3 in the study interval may have been controlled by the development of ridges that are present in the area. Those ridges seem to trend towards the Western side resulting in subsidence and then sediment infill. Due to the lack of well control the resulting basins might be deposited at different times. The S4 is the most complete section and it can be seen as the present stratigraphic reconstruction and the respective system tract.

Significant potential hydrocarbon bearing zones for exploration successes in the study interval can be found on the ICB's Isolated carbonates builds up, at the base S4 although they are imaged as a small area of occurrence. Within this sequence sub-parallel to sigmoidal internal reflection pattern is a combination of reservoir and the seal that impedes hydrocarbon migration and makes the trapping system effective. Migration pathways can be related to faults that are likely fluids conduits from lower to upper sequences.

Sequences 3 and 4 are the prolific reservoirs, source rock can be associated to the deepest sequence. S2 can be considered as the location according to regional geology and stratigraphy. The lack of exploration well within the 3D cube makes the study to be limited and full of uncertainties especially in the lower sequences.

Considering the direct relationship of high amplitudes with good quality sand reservoirs, the future exploration activities may be focused to paleo-geomorphologic features that can be identified by seismic attribute analysis integrated with depositional environment studies to predict the spatial distribution and quality of these reservoirs.

Seismic interpretation revealed that the study area consists predominantly of normal faults and is mainly controlled by the Lacerda high which divide the study interval in western and eastern parts making different layouts for some sequence. In sequence 2, the western part subsided and the sediments where deposited and compacted and controlled by the tectonic events, while the eastern part has minor activity. The southern section has more structural control of reservoirs and is influenced by extension of Lacerda high, which might create structural closure. It also is more affected by normal faults with Northwest-Southeast trend.

6. References

Baetzel, M.; Franke, D.; Heyde, I.; Schreckenberger, B.; Jokat W.; The Davie Ridge, Northern Mozambique: The Crustal Structure from Wide-angle Seismic Data. American Geophysical Union, Fall Meeting 2015, abstract id. T51F-2984

Burgess, P.; Winefield, P.; Minzone, M.; and Elders, C.; (2013) Methods for Identification of Carbonates Buildups from seismic reflection data. APPG Bulletim, V.97, N.7 (July 2013) PP.1071-1098.

Chiulele S.; Middle Cretaceous Reservoir Characterization and Depositional Environment of Central Rovuma Basin, Offshore Mozambique, Using Seismic Attributes and Well log Analysis (2016).

Chopra, Satinder and Marfurt, K.J (2007).; Seismic attributes for prospect identification and Reservoir Characterization.

ENH and ECL, 2000.; The Petroleum Geology and Hydrocarbon Prospectivity of Mozambique (2000) Volume 1

Mahanjane E.; 2014. The Davie Fracture Zone and adjacent basins in the offshore Mozambique Margin - A new insight for the hydrocarbon potential; Marine and Petroleum Geology Research paper No. 57 (2014) 561-571; Elsevier.

Mahanjane E.; 2014 The Rovuma Delta Deep_Water Folded-and-Thrust Belt, Mozambique offshore. Elsevier Tectonophisics 614 (2014) 91-99.

Salman, G.; and Abdula, I,; 1994. Development of Mozambique and Rovuma Sedimentary Basins, Offshore Mozambique. Elsivier Sedimentary Geology 96 (1995) 7-41

Veeken, J.; and Van Moerkerken, B.; 2013. Seismic Stratigraphy and Depositional Facies models: EAGE and Elsevier Scientific Publisher. P. 107-213.

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