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Sequence Stratigraphy Analysis of “Unik” Field, Onshore Niger Delta, Nigeria

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Abstract: *The sequence stratigraphic analysis of “Unik” Field located in the Coastal Swamp area of Niger Delta Basin has been carried out. Geophysical wire-line logs from nine wells and a 3-dimensional seismic data in SEGY format were utilized. In the study, the lithologies were identified, the potential reservoirs detected and the reservoir characteristics of the field predicted. Also, sequences, systems Tracts and facies were generated on seismic volume. Ten electrofacies characterizing the main facies of the depositional environments were interpreted within correlative well log depth range of the “Unik” field. These electrofacies includes: floodplain, transgressive shoreline, point bar, channel fill, multistory channel, tidal flat, barrier bar, barrier foot, stream mouth bar and prograding wedge. Six depositional cycles (sequences) comprising of the lowstand systems tracts (LST), transgressive systems tracts (TST) and highstand systems tract (HST) were identified on the geophysical wire-line logs. These sequences were tied to sequences interpreted on seismic data to give a good tie. Seismic facies analysis of each sequence reveals that the reflection configuration patterns is generally of parallel to sub-parallel, divergent with sheet or wedge shaped external form typical of a shelf environment characterized by a high-energy sedimentation environment with high to medium reflection amplitudes.*

Keywords: *Sequence Stratigraphy, Amplitude, Seismic, Niger Delta*

I. Introduction

The increase in the demand for energy necessitates the need for sophisticated subsurface reservoir studies for optimizing the hydrocarbon exploration and development in existing fields as well as pre-explored areas around the world. As structural traps have become depleted for petroleum companies to explore in Niger Delta Basin due to long-term hydrocarbon production, an attempt to increase hydrocarbon exploration to meet the global demand for energy is necessary. In doing this, the need for critical study of evolution of the sedimentary basin is required. Therefore, emphases have shifted from delineating structural prospects to stratigraphic prospects.

Sequence stratigraphy is based on the assumption that eustatic sea-level is the most important control on stratigraphic geometries and facies distribution and therefore on the distribution of reservoir sands and sealing shales (Aitken and Howell, 1996). Therefore, sequence Stratigraphy techniques involve the careful evaluation of the interaction between eustacy, subsidence and sediment supply as equally important controls on changes in accommodation space, which in turn controls depositional geometries and successions.

Figure 1: Location map of Niger Delta Province (After Owoyemi, 2004 and Microsoft Encarta, 2006)

The flexibility of sequence stratigraphy in resolving various practical issues related to petroleum exploration and production differentiates the method as an essential tool in the geoscience activities within the industry. The work of Olowokere (2008) integrated multiple seismic attributes and strata-surface techniques to evaluate seismic stratigraphy facies in "Terry" Field and showed that contemporaneous structural deformation controlled the thickness of each sequence, the geometries of the delta lobes at the shelf margin and directions of progradation in the study area. In recent time, Nauman *et al.,* (2010) opined that seismic stratigraphy together with attribute analysis have proved to be a major tool in studying and analyzing the geology and petroleum system of an area. In this study, 3-D seismic data were integrated with well logs to define the sub surface stratigraphy of "Unik" field, onshore Niger Delta.

II. Location Of Study Area And Geology

The study was carried out in a field situated in the onshore Niger Delta, Southern Nigeria. (Fig.1). It is in the Coastal Swamp Area of Niger Delta Basin.

The Niger Delta basin is situated on the continental margin of the Gulf of Guinea in equatorial West Africa between latitudes 3° and 6°N and longitudes 5° and 8°E (Ehinola and Ejeh, 2009). The onshore portion of the Niger Delta is delineated by the geology of southern Nigeria and southwestern Cameroon (Tuttle *et al.*, 1999). The northern boundary is the Benin flank. The northeastern boundary is defined by outcrops of the Cretaceous on the Abakaliki High and further east-south-east by the Calabar flank. The offshore boundary of the basin is defined by the Cameroon volcanic line to the east, the eastern boundary of the Dahomey basin (the eastern-most West African transform-fault passive margin) to the west (Tuttle *et al.*, 1999).

The Cretaceous section of Niger Delta Basin has not been penetrated (Reijers *et al*., 1997), but the tertiary section has been divided into threefold diachronous lithostratigraphic units by the work of Short and Stauble (1967) and Doust and Omatsola (1990). These units are the Akata Formation (marine origin) at the base, overlain by the Agbada Formation (Deltaic Facies) and finally the Benin Formation (Alluvial and upper coastal plain sands). The three Formations extend throughout the delta with deposition beginning from Palaeocene/Eocene and through the Recent. Structurally, Niger Delta is affected by large scale synsedimentary features, which includes the growth faults, the rollover anticlines and the shale diapirs (Doust and Omatsola, 1990; Stacher, 1995).

III. Materials And Methodology

The materials used for this study are from Shell Petroleum Development Company Ltd (SPDC), which include quality 3-Dimensional seismic data covering approximately 245 square Kilometres, 697 In-lines (dip) and 546 Cross-lines (strike); geophysical wire-line log data (gamma-ray log, spontaneous potential log and resistivity log); check shot data and a base map (Fig. 2). The analysis of the geophysical wire-line logs and the seismic data were done using PETREL™ (2009) Software.

Lithology was interpreted using the combination of the gamma ray and spontaneous potential logs of each well, followed by the lithostratigraphic correlation of the wire-line logs, using the well tops information of the sand bodies across the wells along the X-line (strike) direction and also along the In-line (dip) direction.

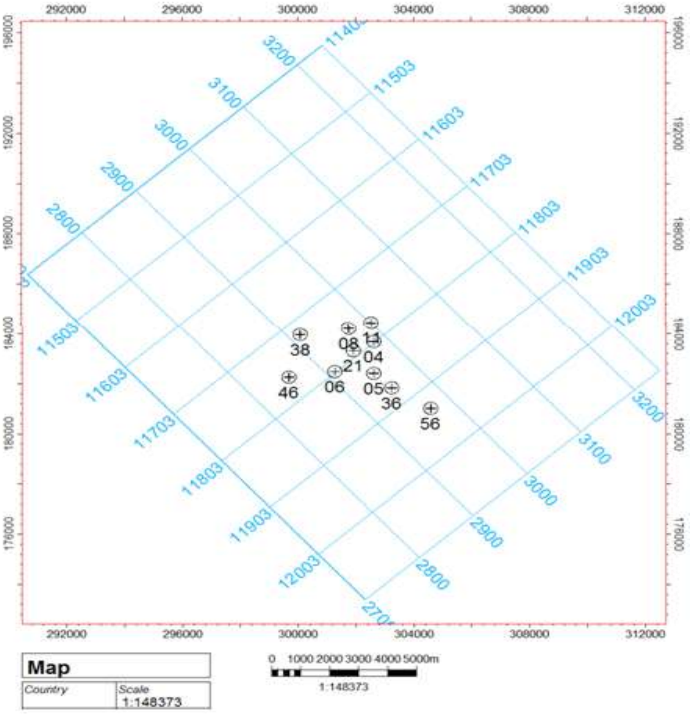

Figure 2: Base map of "Unik" Field, Onshore Niger Delta (After SPDC, 2006).

Interpretation of the facies cycles, sequences and system tracts from wire-line logs through log pattern identification was also carried out. Facies interpretation was done using the gamma-ray log motifs (electrofacies) within the field of study. Different gamma-ray log motifs were identified on the field of study (Fig. 3). From these identified gamma-ray log motifs, using the classification of Schlumberger (1985) of the gamma-ray log motif, different distinct electrofacies were interpreted.

Stratigraphic interpretation by mapping sequences and systems tracts was carried out on the 3-Dimensinal seismic data by identifying discontinuities from reflection terminations. Well-to-seismic tie was done using check-shot data to tie well log depth information to seismic time information. The seismic facies analysis of the study area was done by examining and interpreting different seismic facies unit within the study area based on the seismic reflection attributes (reflection configuration, amplitude, frequency and continuity), in view of interpreting all possible variations of the seismic parameters within each seismic sequences and systems tracts in order to determine lateral lithofacies as well as the fluid type changes.

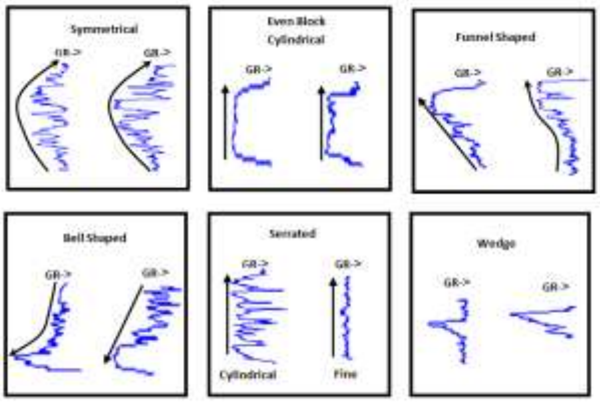

Figure 3: Examples of the Gamma- ray Log Motifs of the Study Area

IV. Results And Discussion

4.1 Lithology interpretation

For lithology interpretation, the shale baseline and sand baseline for both Spontaneous potential and gamma ray logs were determined. Thereafter the bed boundary was picked at a point midway between the maximum (shale baseline) and the minimum (sand baseline) deflection of the anomaly. Using the gamma-ray threshold of 70 out of 150 as the bed boundary, the lithology of the study area was interpreted to be shale and sand. These correspond to the types of rock present in the area. The interpreted lithologic units for each well were then correlated. Figure 4 shows the in-line correlation form Southwestern to the Northeastern part of the study area. It was observed that shale carries a higher percentage of sediments within the interpretation interval in the study area compared to sand and the sand to shale ratio decreases depth-wise in the correlated wells within the field. Also, from the correlation of the wells, it was interpreted

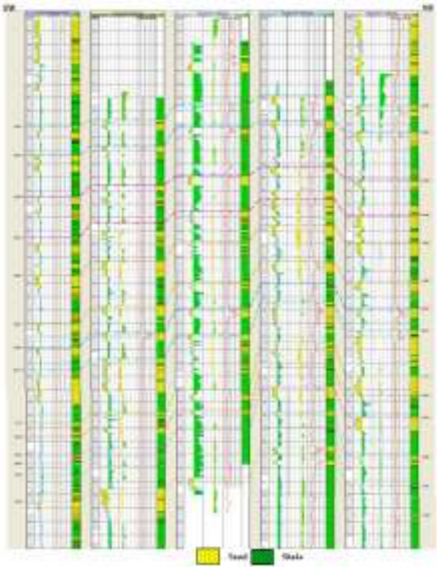

Figure 4: Well Correlation panel from Southwest to Northeast

structurally that the area is block faulted towards the Southwestern part of the study area.

The log motifs of the gamma ray response to grain sizes were used in the prediction of the depositional environment (Fig.3). Symmetrical pattern indicating a progressive high energy deposition passing gradually into declination in energy level with time; even blocky suggesting a constant energy level high in clastic deposits; a gradual shift towards a high energy depositional environment was denoted by a coarsening upward (funnel-shaped) pattern; Fining upward indicating shift in shoreline towards the coastal environment, therefore energy level reduction with time. A serrated cylindrical log motif implies an alternation of high and low energy level but high in clastic deposits, while fine serrated suggests seasonal flood plain in the coastal settings. Notwithstanding that the different depositional environment may present similar log motifs, the overall stacking of the gamma-ray log pattern was used in predicting possible depositional environment of the field.

Interpretation of the major transgressive and regressive cycles from each well and then correlation of the interpretation across the available wells was done, to interpret the facies distribution across the study area. The interpretation was done using the gamma-ray log motifs (electrofacies) within the field of study. Transgressive facies cycles were made up of retrogradational sequences depleting landward shift of sediment during relative sea-level rise, therefore fining upward trend of the gamma-ray log motif. The regressive facies were composed of the progradational sequence interpreted as relative sea-level fall and the consequent coarsening upward trend of the gamma-ray log motif. Five major transgressive/regressive facies cycles; comprising of progradational, retrogradational and aggradational parasequence were interpreted. From the interpretation, it is indicative that the depositional environment is composed mainly of the building up (Aggradation) and building-out (Progradational) facies. These lead to the general coarsening upward trends of the gamma-ray log. Therefore, the sediment could be interpreted to have been deposited during a relatively high accommodation space. According to Schlumberger (1985), this type of parasequence stacking patterns and electrofacies are typical for deltaic environment.

4.2 Facies Interpretation

Different distinct electrofacies were interpreted (Fig. 5) for facies distribution within the Field and also to map out the sand facies that could serve as good hydrocarbon reservoir. These cycles were correlated across well in the study area to give the electrofacies distributions across the field. It is important to mention that most of the interpreted facies of the field are of good correlation between the wells, representing lateral extent of the facies deposited by lateral migration and also corresponding to minimal change in grain size and even deposition of the sediments.

Ten electrofacies characterizing the main facies of the depositional environments were interpreted within correlative well log depth range (1250-2150 m) of the field. Theseelectrofacies includes: floodplain, transgressive shoreline, point bar, channel fill, multistory channel, tidal flat, barrier bar, barrier foot, stream mouth bar and prograding wedge.

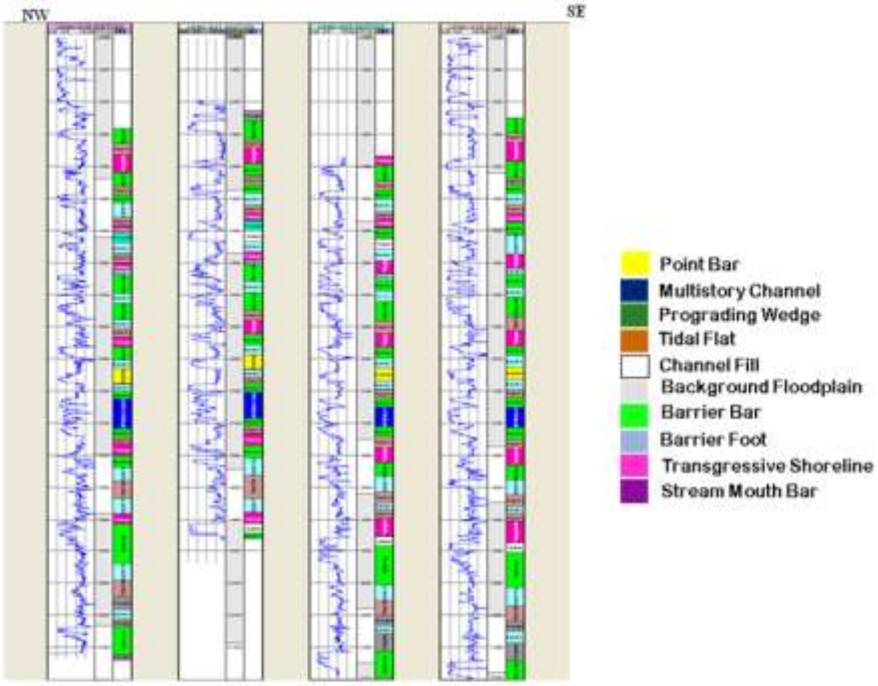

Figure 5: Electrofacies Distribution of the study area.

4.3 Systems Tract and Key Surfaces on Logs

Five sequences were identified and interpreted on the wire-line log (Fig. 6), using the pre-defined methodology of Vail and Wornardt (1990). Each sequence comprises both the Transgressive and Highstand System Tracts. Each sequence comprises of both the Transgressive System Tracts and Highstand System Tracts. It was observed that the Transgressive System Tracts are thin compared to the Highstand System Tracts in all the five sequences and it thickens towards the Southern part of the area of study. The Highstand System Tracts is the dominating Systems Tract within the sequences. Lowstand System Tract (Prograding Wedge) was interpreted within sequence 5 with approximate thickness range between 20 m and 30 m.

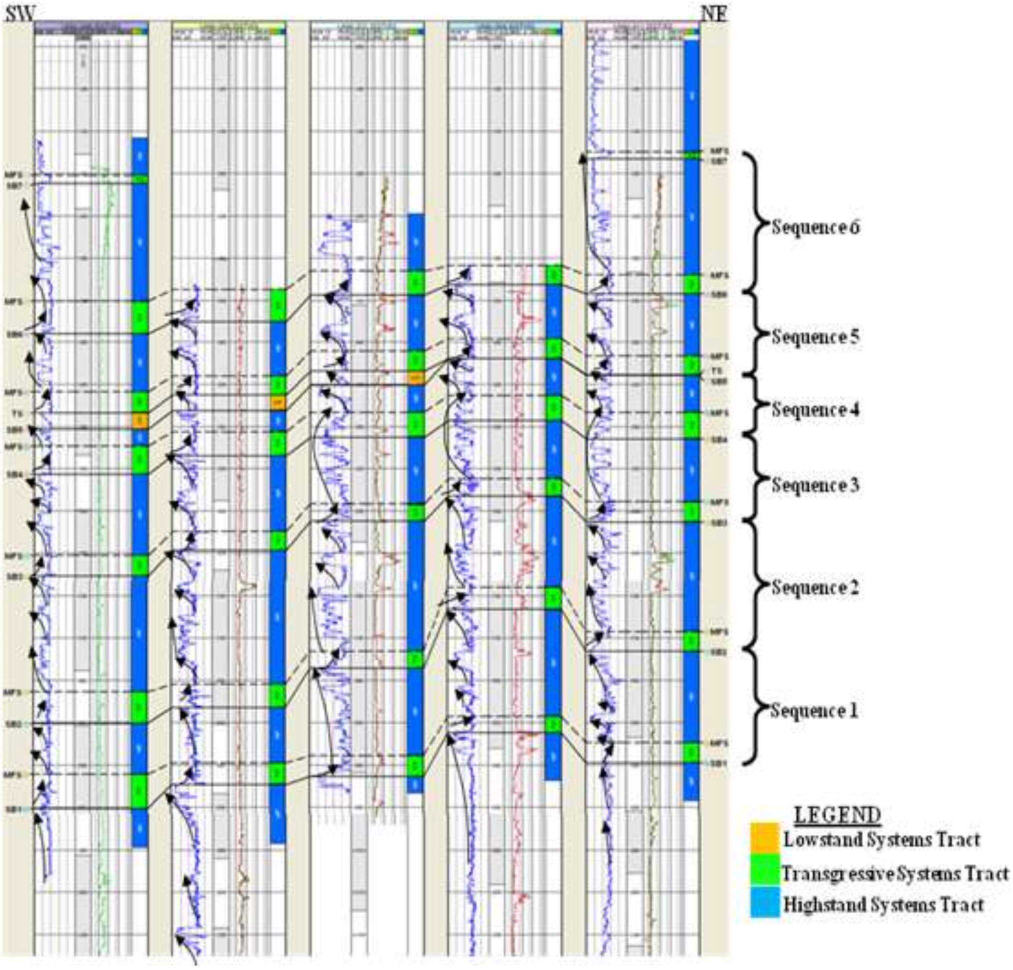

Figure 6: Sequences, Maximum Flooding Surface and System tracts Interpretation of “Unik” Field from Southwest to Northeast through Well “Unik”-46 to “Unik”-11.

4.4 Seismic sequence analysis

The objective of seismic sequence analysis was to interprete the depositional sequences and systems tracts on the seismic sections of the field of study by identifying discontinuities on the basis of reflection terminations. In some cases were the depositional surfaces were conformable, they were recognized by the lateral changes in the seismic reflection attributes (especially, reflection amplitude) within the interpreted Agbada Formation, since lateral changes in reflection attributes corresponds to changes in lithology and/or depositional processes. Figure 7 shows the detailed vertical facies sequence subdivision based on the key surfaces and units that are traceable across “Unik” field of Niger Delta Basin, in recognizing the sequential depositional regime. The analysis of strata termination patterns, within Agbada Formation, present on the seismic sections of “Unik” field resulted in the identification of seismic sequences 1 – 6, bounded above and below by sequence boundaries SB1 - SB7. SB1 was recognized by its characteristic onlap and erosional truncation pattern. The unconformity surface above SB1 is characterized by downlaps at the top and toplap below. This represents the maximum flooding surface (MFS) for sequence 1, which may be associated with the main condense section of the depositional sequence. In some cases were the depositional surfaces were conformable, they were recognized by the lateral changes in the seismic reflection attributes (especially, reflection amplitude) within the interpreted Agbada Formation, since lateral changes in reflection attributes corresponds to changes in lithology and/or depositional processes.

4.5 Seismic facies analysis

Seismic facies analysis makes use of different seismic parameters in order to get other than structural information. Parameters that were taken into consideration in the seismic facies analysis of "Unik" Field are reflection amplitude, reflection continuity, reflection configuration, abundance of reflection and geometry of seismic facies. Figure 8a shows the result of a seismic section from the study area with different seismic reflection attributes (reflection configuration, amplitude, frequency and continuity). It was interpreted that the general reflection amplitude of "Unik" Field varies from low in the northern part to high as it moves gradually towards the southern part of the field. A low amplitude indicates more similar lithology on both sides of the interface while a high amplitude reflection character generally points to vertical alternation of contrasting lithology.

Continuity is expressed in geologic terms as lateral changes in acoustic impedance and hence in lithology. It also gives information on the energy level of the deposits. From Figure 8a, the reflection continuity varies from very discontinuous for deposits below the interpreted sequence 1, and its continuity improves down the sequences to deposits above the interpreted sequence 6. It was also generally observed that the reflection continuity improves from discontinuous from the northern part to continuous for deposits down the southern part of "Unik" Field. Continuous reflections are characteristic of depositional environments where uniform conditions are laterally extensive while discontinuous reflections indicates rapid changes in energy level (rapid lateral facies changes).

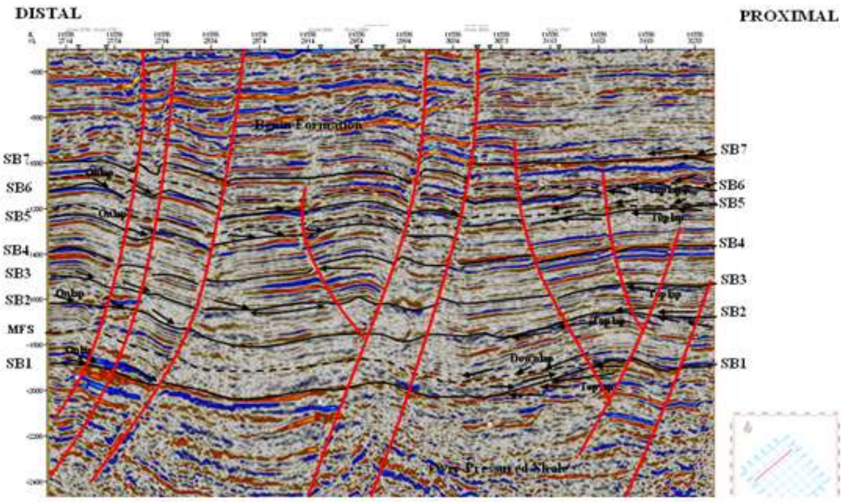

Figure 7: Illustration of Sequence Boundaries and Maximum Flooding Surfaces on seismic section of "Unik" field.

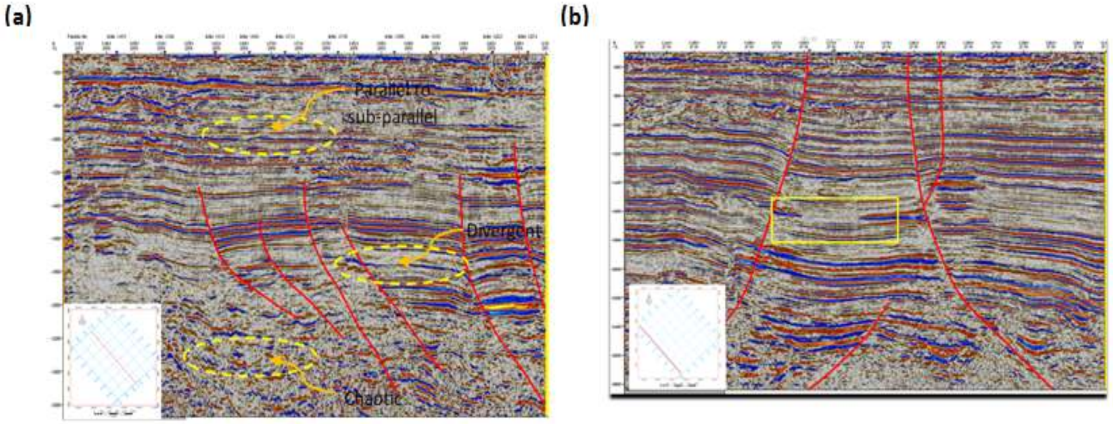

Figure 8: (a) Seismic Reflection Attributes of "Unik" Field; (b) Reflection geometry of channel units in the study area.

The reflection configuration of the "Unik" Field (Fig.8a) varies from parallel and/or sub-parallel reflection, indicating uniform rates of deposition; to divergent reflection, suggesting syn-depositional differential tectonic movements. The divergent reflections are prevalent in the older sequences and it becomes sub-parallel to parallel towards the younger depositional sequences. Chaotic reflection configuration comprising of discontinuous discordant reflections of variable amplitudes and frequency was observed at deposition below the interpreted sequence 1 of "Unik" Field. The chaotic reflection configuration of "Unik" Field was interpreted to represent over-pressured shales. Seismic facies analysis in terms reflection geometry was interpreted. Figure 8b shows a reflection geometry of a channel. The channel was confirmed by a time slice along the geometry both on seismic unit and iso-frequency volume attribute (Fig. 9), used for isolating frequency dependent changes. This channel is evident on the Southwestern part of the study area. The facies have low sinuosity with a high width of about 1000 m.

4.6 Interpretation of the Depositional Environment

From the integrated interpretation of wireline logs and 3-dimensional seismic data of the study area, there are variations in the developed and preserved facies along strike as well as along the dip. For instance, in the eastern part of the study area is mainly aggradational and comprised of stacked shelf-margin deltas, the central and the western part of the study area in contrast are mostly progradational and dominated by shelf-margin deltas and submarine channel sand fills, pinch-outs and collapsed slope sediments. The variation in facies along the strike was interpreted to be as a result of variation in fault controlled accommodation on the shelf-margins and slope environment of the field.

V. Conclusion

From the sequence stratigraphy approach applied to the study of "Unik" Field using an integrated wire-line log and seismic data, it was interpreted from both wireline log and seismic sections that the primary control of accommodation in the field is the sand dispersal patterns resulting from rollover topography associated with growth faulting. Seven sequences and Maximum Flooding surfaces were identified. Six depositional sequences were interpreted comprising of lowstand prograding wedge, the retrograding transgressive systems tracts and the highstand systems tracts which area predominantly progradational. The lowstand prograding deltaic complex is composed of interbedded sandstones and shales interpreted to have been deposited as a wedge along deltaic distributaries. The transgressive system composed of shale interpreted to be as a result of the retrogradation of sediments. The highstand system is sandy and has predominantly blocky wire-line patterns, probably indicating sand channels.

"Unik" Field comprises discontinuous event packages, directly resting on chaotic over-pressured shale, the highstand and transgressive systems tracts are characterized by highly continuous seismic event. The continuity of the deltaic facies is great, leading to a good correlation of sandstone packages between wells

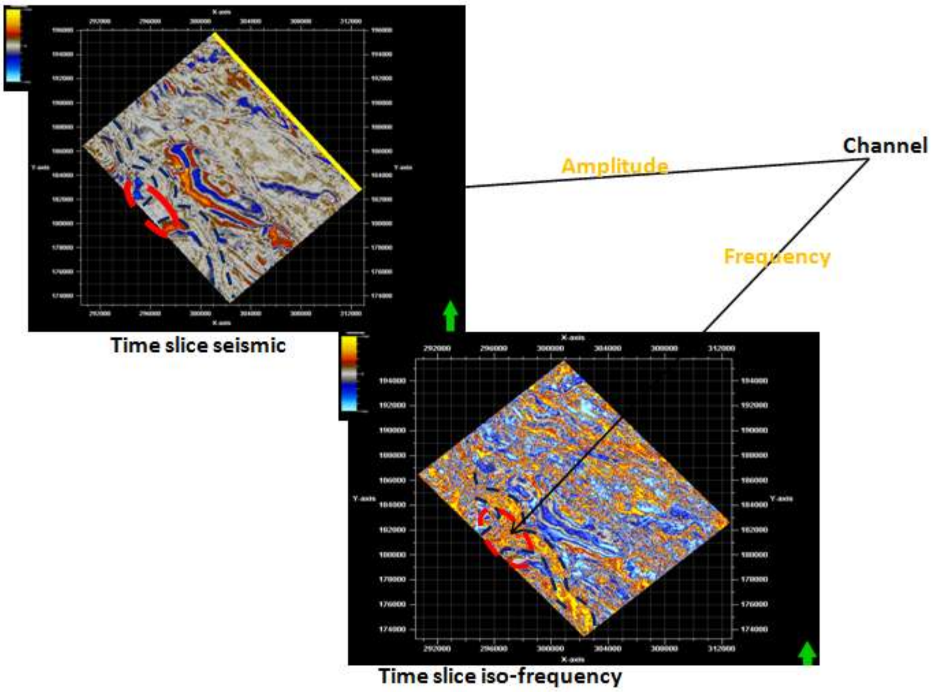

Figure 9: Time slice along a channel (position of the channel in broken red line).

and increased seismic continuity. The alternation of highstand sands and transgressive shales provide an association of reservoir and seal rock, essential for hydrocarbon accumulation and stratigraphic traps in the area respectively.

From the integration of the available data set and seismic facies analysis, it was deduced that the possible resource areas are the onlap above the interpreted over-pressured shale, and the pinch-outs, channel sand fills within the identified sequences with the “Unik” Field. However, this study has aided the accurate recognition of genetic packages and general stratigraphic architecture of the potential reservoirs of “Unik” Field; and also created a better understanding of the subsurface geology in the field of study.

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