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Delineation of stratigraphic sequence of adez off-shore field for adequate oil yield from 3-d seismic and well log data in Niger Delta, Nigeria

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ABSTRACT

Adequate knowledge of the structural presentation of an offshore field is a veritable tool for the determination of the yield and viability of the oil wells. To achieve this maximally several studies need to be done before drilling wells in a field but current studies hold that the most scientific approaches include the integration of seismic analyses and well log data. Hence, 3-D seismic and gamma ray logs were employed in the delineation of the stratigraphic sequence of Adez off shore field in the lower Niger Delta region. The 3-D Seismic sections in this study delineated eight faults from which four horizons were mapped out while the stratigraphic sequence analyses of the well logs established a chrono-stratgraphic framework of the study area. The reflection seismic sequence varies laterally and are characterized by low-medium to high amplitude discontinuities indicating lateral facies changes typical of sand-shale inter-beddings deposited in the environment giving insight into the basinal stratification and energy regimes that prevailed during early sedimentation. These results in the Adez field are indicative of high petroleum yield.

Keywords: Strtigarphic Sequence, Adez Off Shore field, amplitude discontinuities, basinal stratification, high petroleum yield

INTRODUCTION

Growth fault systems are important sites for petroleum exploration in extension basins. They play major roles in the passage of hydrocarbon from source to reservoir rock and act as seals when the fault plane is smeared with shale. They are also potential sites for thick sediment accumulation especially around the hanging wall [1]. Various forms of trapping systems of diverse geometry are associated with the faults. They are therefore structural complexities and reservoir heterogeneities which are often responsible for intra-reservoir entrapment of bypassed oil. Consequently, integrated multidisciplinary approach is necessary to unravel the structural development, sequence stratigraphic history, paleo-depositional environments and hydrocarbon reservoir potential of fields [2]. Hence, integrated multidisciplinary stratigraphy sequence was applied in in order to facilitate the identification of major progradational sedimentary sequences which offer the main potential for hydrocarbon generation and accumulation. Thus, 3-D seismic reflection data were integrated with well logs so as to define the hydrocarbon trapping mechanism and depositional architectural sequence of "Adez" field, situated in the off-shore Niger Delta. The seismic sequence and log sequence stratigraphy were employed to map the depositional characteristics and structural complexities of the reservoirs in the area of study in line with [3] for the enhancement of reservoir yield.

MATERIALS AND METHODS

Location and Geological Setting of the Study Area

The study area lies offshore Niger Delta in southern Nigeria and situated within shallow marine environment of the continental shelf (Figure 1) which covers an area of about 102 km^2 of migrated seismic sections (Figure 2). It is located within latitude 4^0 00'N to 6^0 00'N and longitude 3^0 00'E to 9^0 00'E. It is bounded in the East and West by the Calabar and Benin flanks respectively, in the South by the Gulf of Guinea and the older (Cretaceous) tectonic elements such as the Anambra Basin, Abakaliki uplifts and the Afikpo syncline in the North [4]. It extends into the Atlantic Ocean from the Crossriver in the East with Rivers Niger and Benue as the main source of sediments [5]. The offshore Niger Delta has the characteristic shelf slope break of growth fault modified ramp margins [6]. Trap configurations in the offshore Niger Delta are controlled by gravity driven systems of linked extensional growth faults and compressional toe thrusts initiated during the Paleocene when the modern Niger Delta was formed [7] & [8]

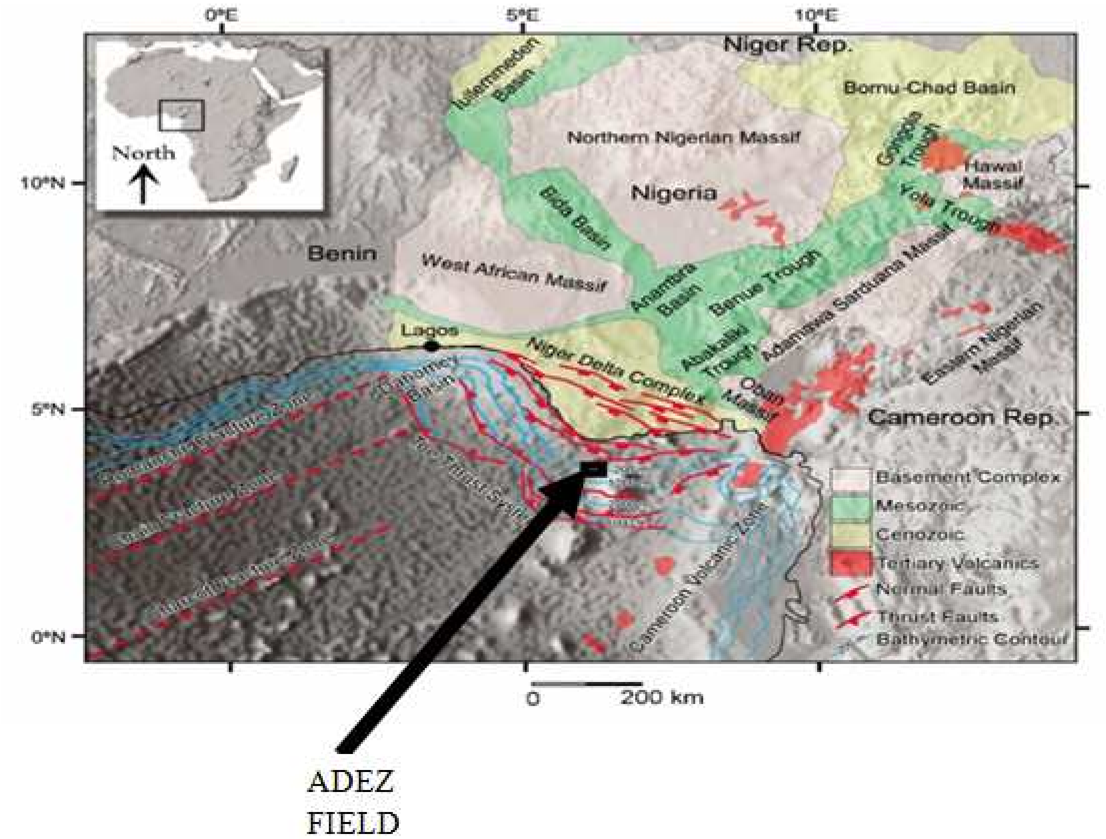

Figure 1: Map of Niger Delta showing the study location, Adez Field (After Corredor et. al., 2005)

The base map of the area comprises 637in-lines and 595cross-lines in an area of 102 sqkm was studied. A three pronged approaches were used to unravel the structural sequence and stratigraphy of 'ADEZ' field in the Niger Delta. These interdisciplinary approaches include structural interpretation of the field, well log interpretation of some wells (wells 1, 2 and 3) and interpretation of seismic sequence from the seismograph data. Thus, well behaved 3-D seismic sections from the field were analyzed and the resistivity and gamma ray logs obtained from three logged wells in the field were also analyzed [9]. The outcome of the analyses were then imported into an interactive Petrel^{TM} workstation. While, the gamma ray log was used to identify different lithologies penetrated by the well, the resistivity log was used to delineate the hydrocarbon bearing zone (Figure 3). The reservoirs identified from the well logs were tied against the reflection events from seismic sections (Figure 4). Depth structural maps were then produced from the time-depth curve generated from the check shot data (Figure 5).

RESULTS AND DISCUSSION

The data was critically examined and analysed for seismic sequences using criteria such as toplap, erosional truncation, onlap and downlap.

The interpretations were in three sections in line with the trend of analyses

(a) Structural Interpretation

The time structures map **(**Figures 6 and 7) depict the time structures map of horizons $H_{1,}$ $H_{2,}$ H_3 and $H_{4.}$ The time structural maps had their two ways travel time (TWT) ranging from 1650-2150 ms, 1680-2250 ms, 1800-2400 ms and 1800-2520 ms. The time variations within the study location were due to the structural deformation that had occurred in the area.

The Depth structural maps in the study area **(**Figures 8 and 9) depict horizons H_1, H_2, H_3 and H_4 with depths ranging from 1650-2150 m, 1680-2250 m, 1800-2400 m and 1800-2520 m which indicates severe structural deformations in the area.

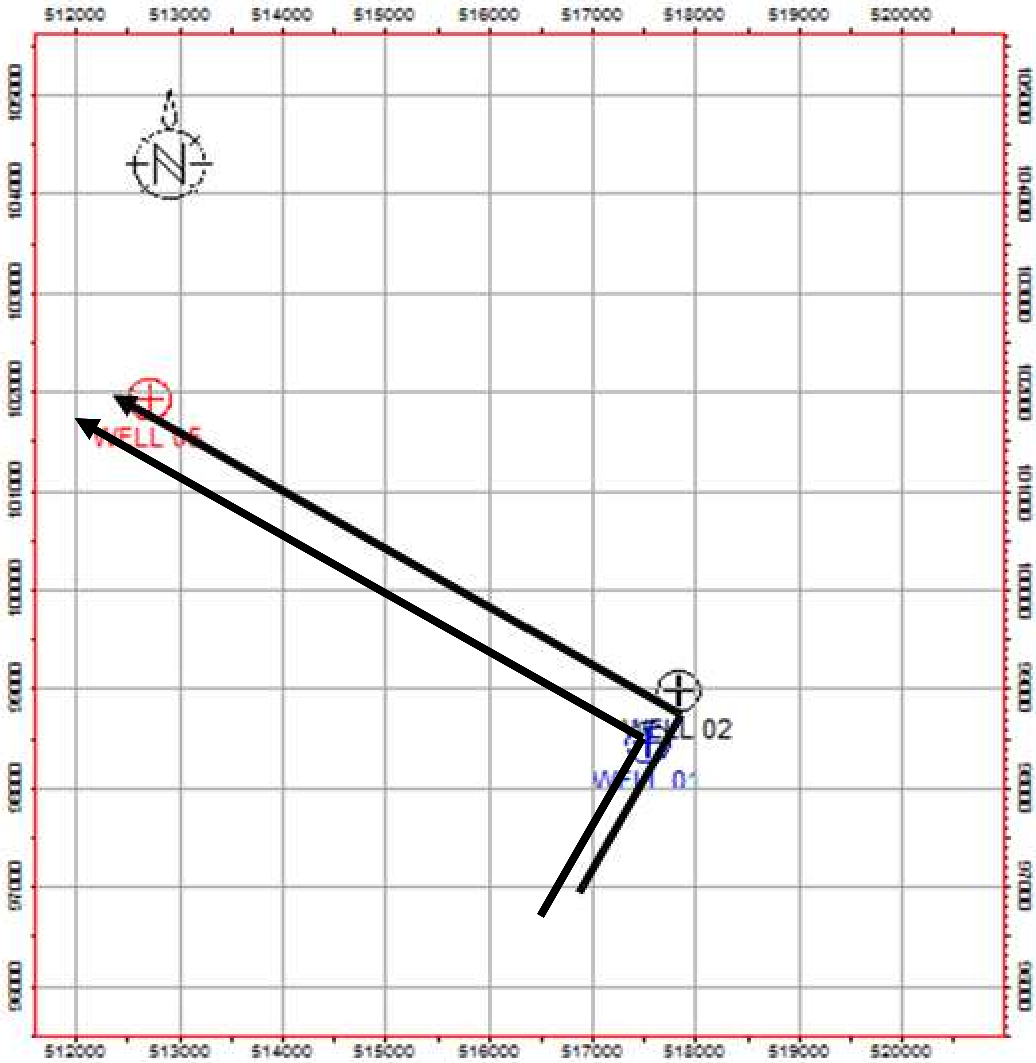

Figure 2: Base map showing the locations of logged wells and S-N direction of correlation

Four major structural building faults were delineated. While Faults (F_1 and F_2) are trending in east-west direction, fault F_4 is trending approximately northwest-southeast direction. Fault (F_6) on the other hand is a reverse fault to fault F4 as it is trending approximately northeast-southwest direction [10].

(b) Well Log Interpretation

The analysis of well-log sequence proposed by [11] & [12] was adopted. This involved the evaluation of the stacking patterns of para-sequence sets within the interval of interest (Figure 14). Depositional sequence, system tracts, sequence boundaries stratigraphic surfaces and para-sequence stacking patterns of pro-gradational, retro-gradational and agradational formations were identified based on their diagnostic characteristics log patterns in the wells.

From the Log Sequences, Well 1 (Figure 10), covers a subsea depth interval of 304.8 m – 3175.10 m but was only logged from 1831 m to 3036 m; well 2 covers a subsea depth interval of 609.6 m – 3040.68 m but was only logged from 1803 m to 3172 m and well 5 covers a subsea depth interval of 1676.4 m – 3078.48 m but was only from 1676 m to 3074 m. The lithologic units penetrated in the wells by the gamma ray and resistivity logs are alternating sand and shale. The shale units are thicker with depth, while the sand units disappear with depth. On the gamma ray log, the sands exhibit both saw teeth and upward coarsening motifs which are characteristic pattern of lowstand system tracts while the upward fining log motif indicates the transgressive system tracts (Figure 10). Two maximum flooding surfaces at 2474 m and 1831 m with two sequences boundaries at 3036 m and 2450 m and two transgressive surfaces at 2800 m and 1903 m were delineated in well 1 while three maximum flooding surfaces at 2529 m, 1962 m and 1803 m; three sequences boundaries at 3172 m, 2490 m, and 1908 m and two transgressive surfaces at 2900 m and 1980 m were delineated in well 2 In well 5, three maximum flooding surfaces at 2430 m, 2056 m and 1970 m; three sequences boundaries at 3074 m, 2403 m, and 2030 m and two transgressive surfaces at 2540 m and 2123 m were also delineated based on the diagnostic characteristics log patterns.

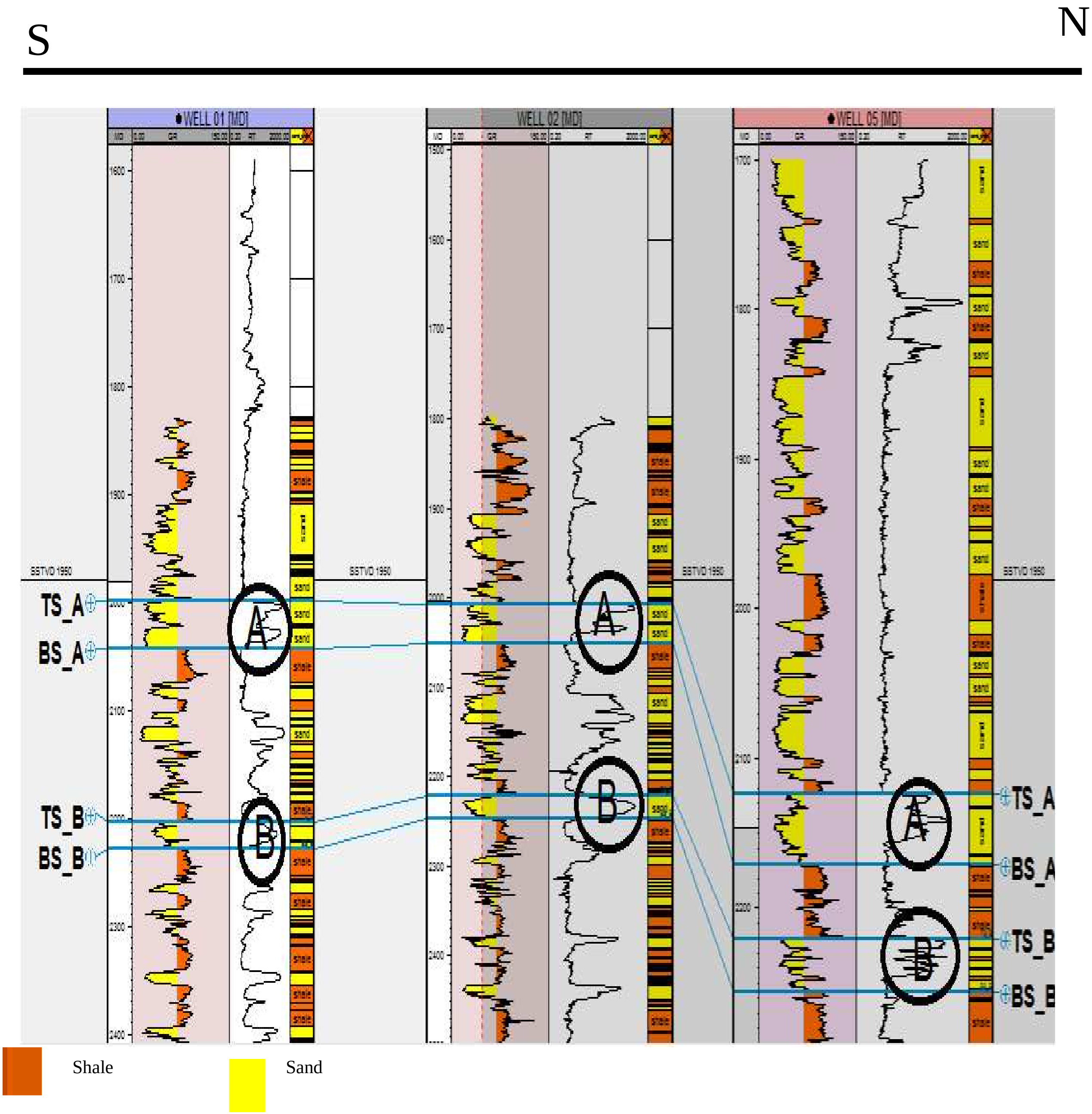

Figure 3: Correlation panel of wells 1, 2 and 5 showing the mapped reservoirs A and B

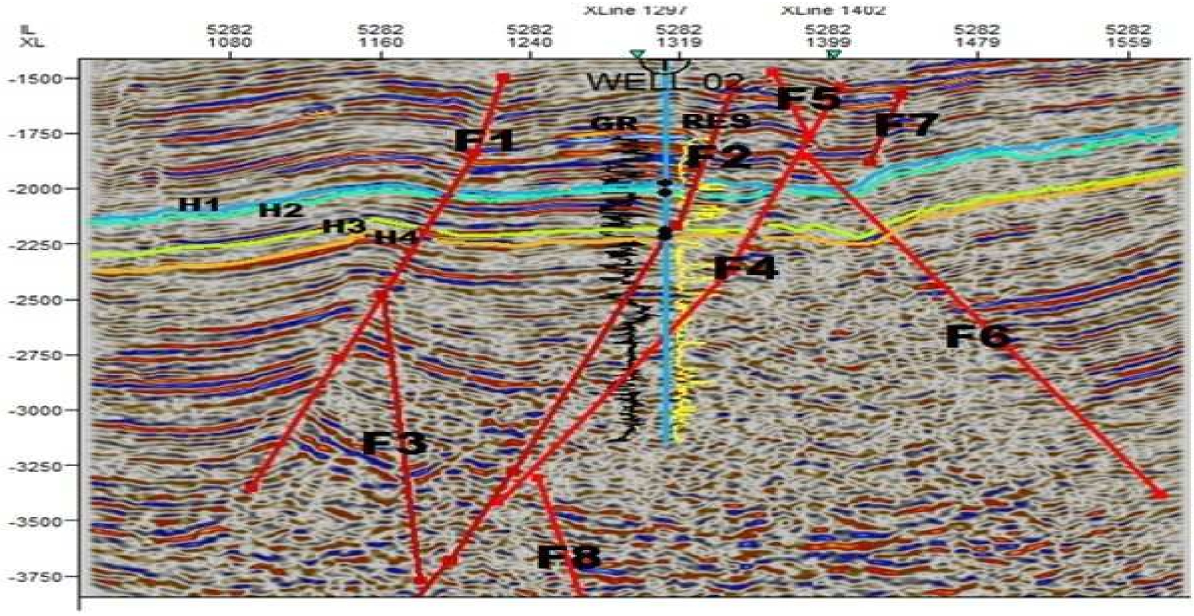

Figure 4: Seismic section of inline 5282 showing faults and mapped horizons

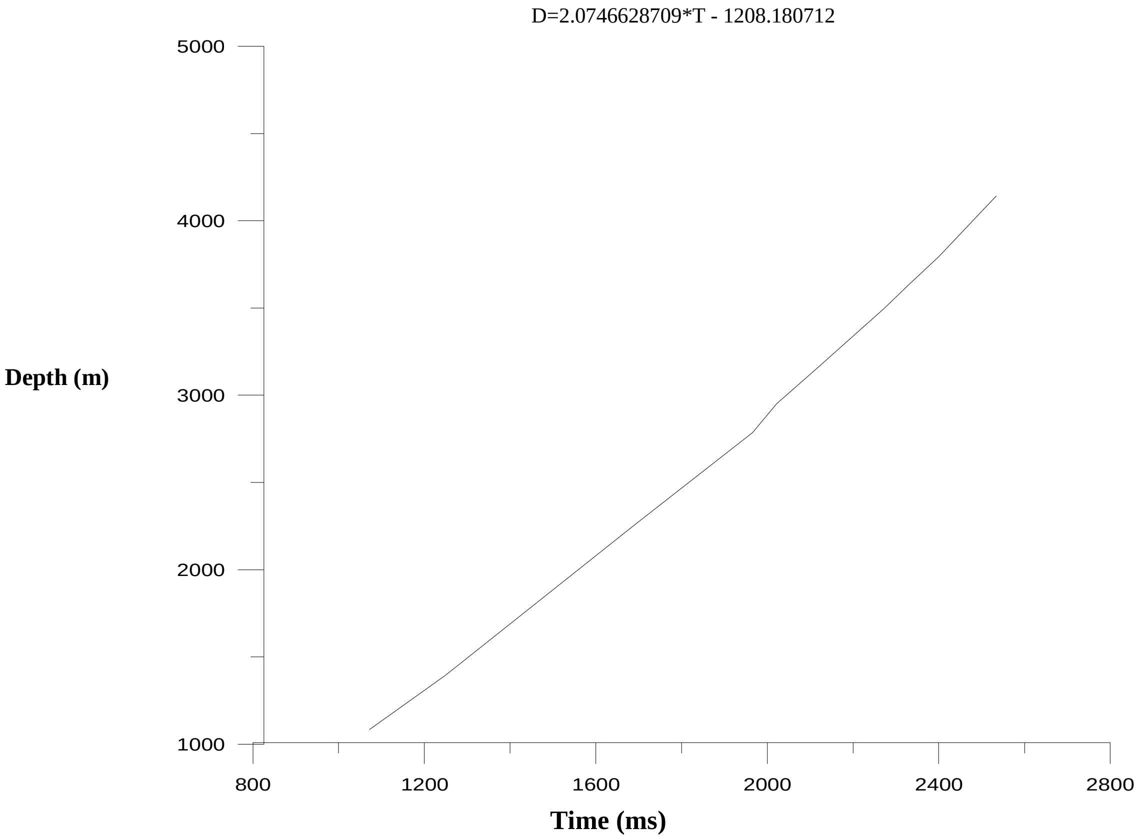

Figure 5: Time to depth conversion curve for well 1

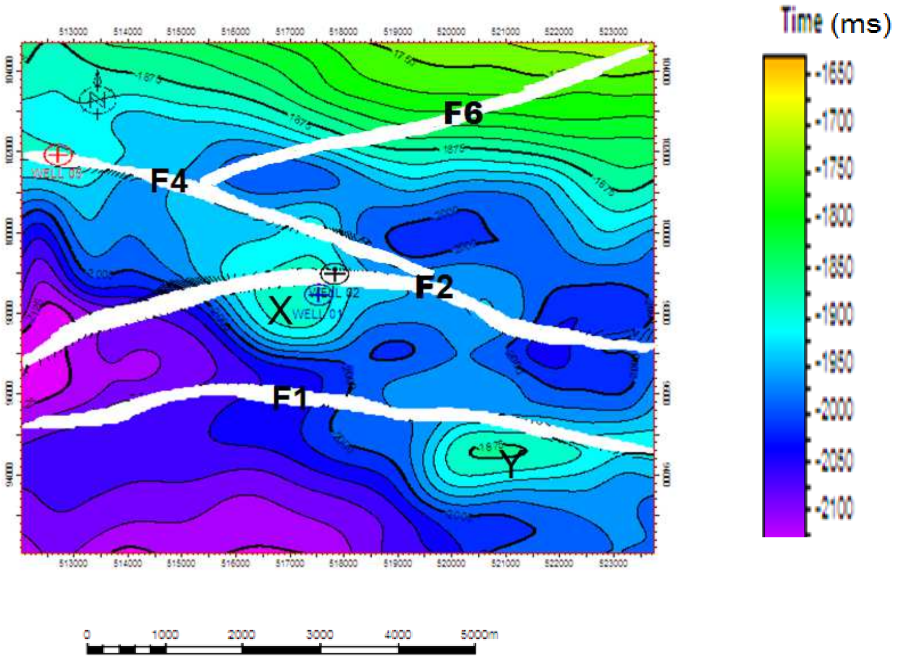

Figure 6: Time structure map of horizon 1

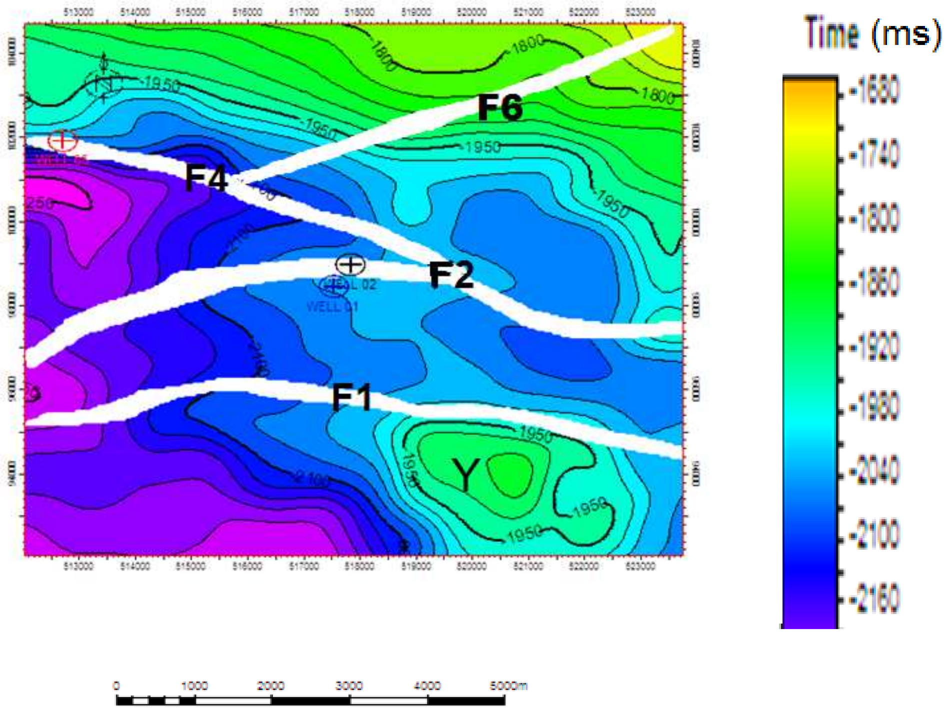

Figure 7: Time structure map of horizon 2.

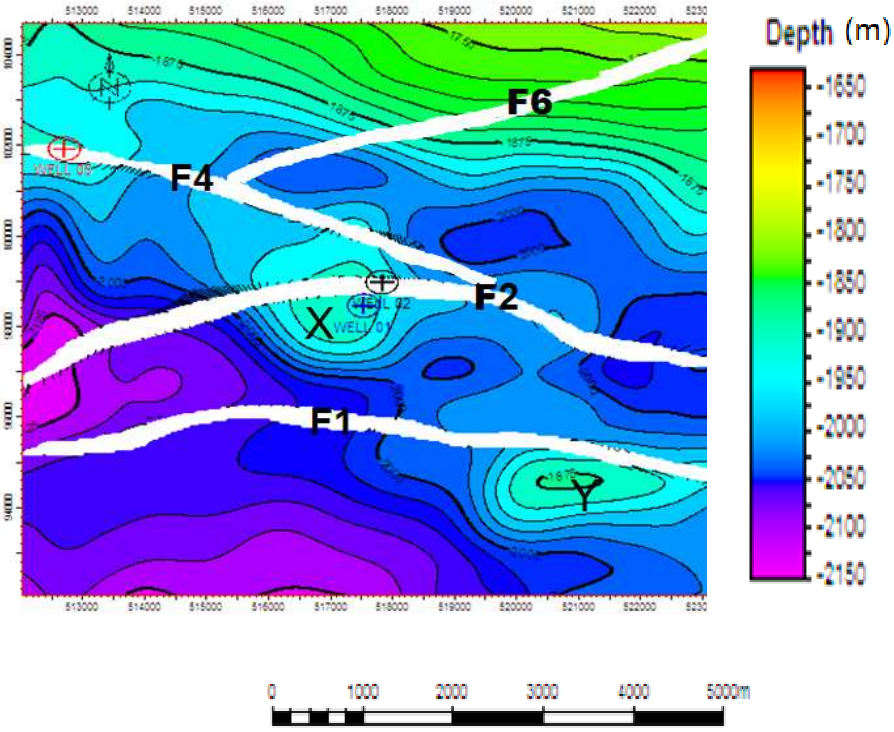

Figure 8: Depth structure map of horizon 1

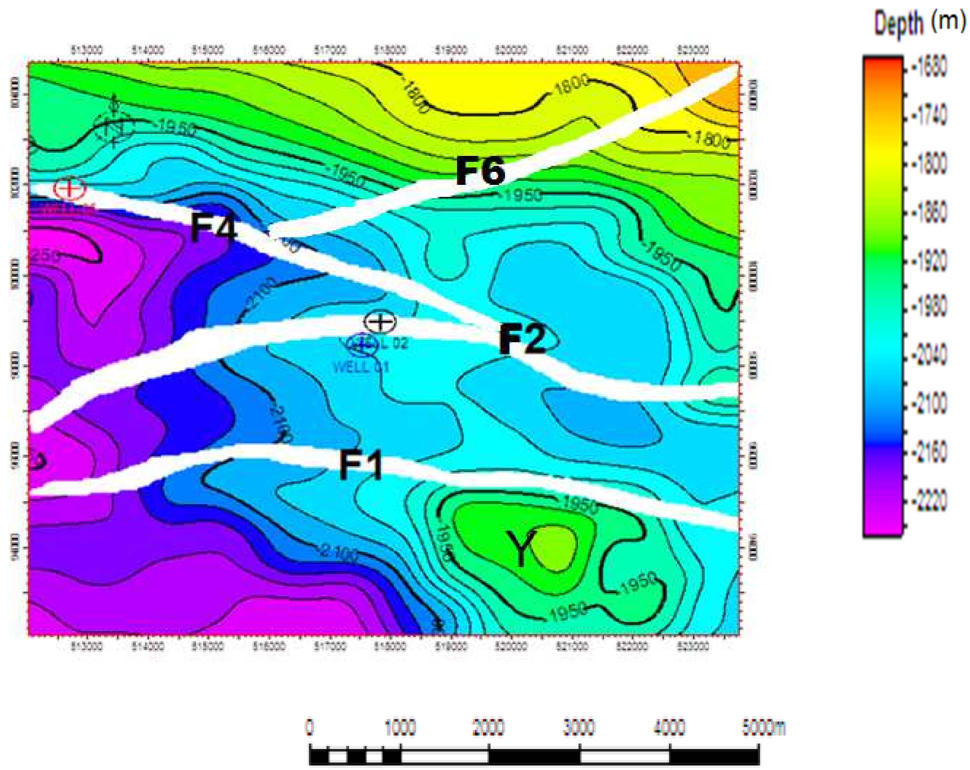

Figure 9: Depth structure map of horizon 2

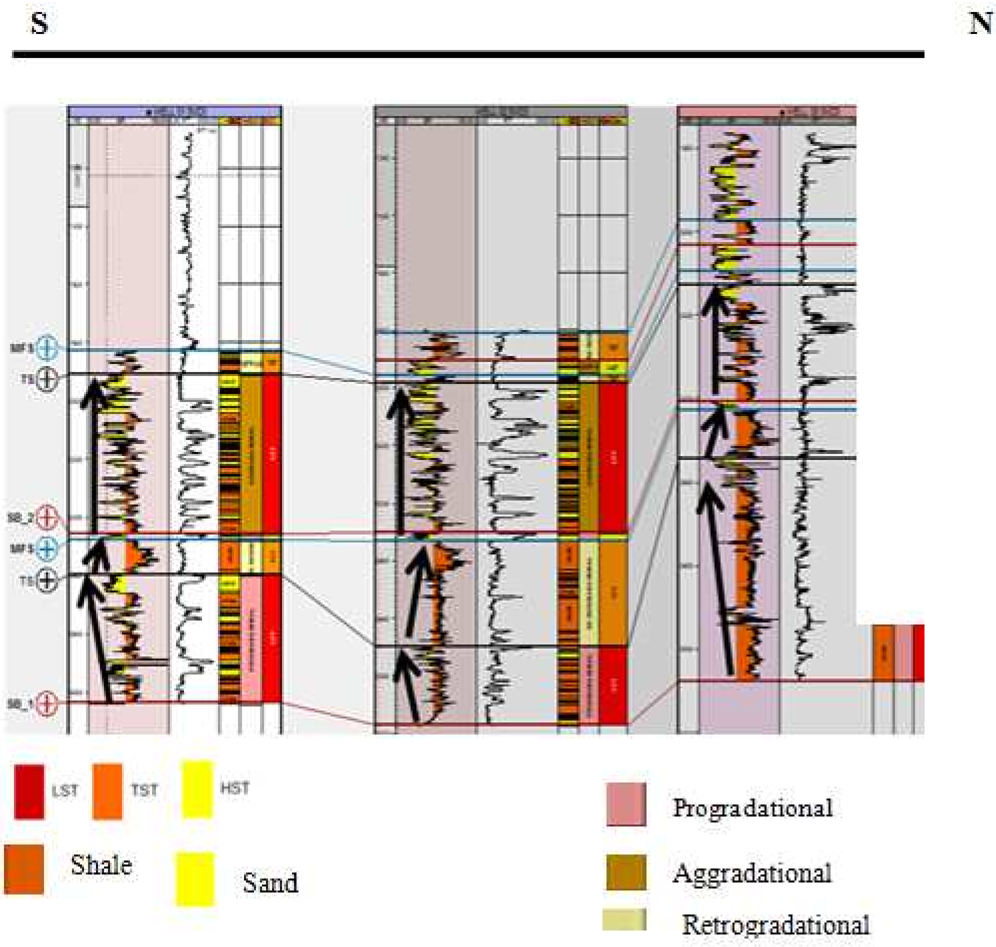

Figure 10: Correlated panel showing stratigraphic framework for wells 1, 2 and 5

(c) Seismic Sequence Interpretation
Two depositional sequences (Lower and Upper sequences) were mapped within a time window of 2000 ms to 3167 ms throughout the study area. The sequences were mapped from discordant relationship of rock units at the sequence boundaries (Figure 11). These intervals were defined primarily on the basis of seismic reflections patterns, configurations and lithofacies. Sequence boundaries are laterally extensive and conformable in stratigraphic order from the oldest (S2) to the youngest (S1). The Lower Sequence (S2 sequence) is located within a shale diapiric structure (Figure 12).

The seismic facies is characterized by a parallel and wavy, discontinuous and high amplitude reflection patterns. They are chaotic, discontinuous reflection of variable amplitudes ranging from medium to high amplitude reflection patterns. While parallel wavy, high amplitude discontinuous reflection patterns are present at the southern end of the field, divergent, medium to high amplitude reflection patterns occur at the northern end. On the other hand, chaotic, discontinuous discordant reflection of variable amplitude is predominant at the centre indicating the presence of deformed over-pressured shales resulting from improper de-watering during rapid burial of the sediments. The study showed that the Upper Sequence (S1 Sequence) overlies the top of Akata surface throughout the study area (Figure 12) and the sequence boundary is a regional unconformity that truncates steeply dipping Akata reflection.

These geometries can be due to variations in sedimentation rates, subsidence and/or burial effects (differential compaction) indicating syn-depositional differential tectonic movements. Moreover, divergent facies are formed in wedge shaped sedimentary bodies, where the sediments thickness distribution is asymmetric. These depositional settings are typical of continental shelf in a marine environment.

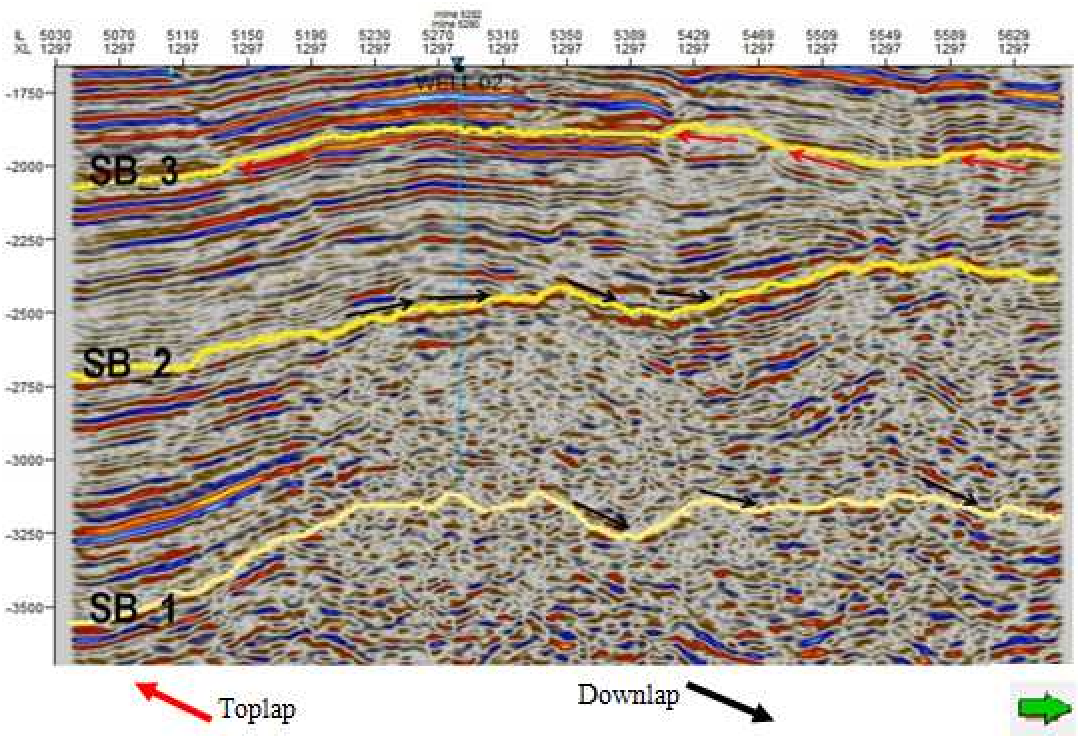

Figure11: Seismic sequence interpretation of crossline 1297

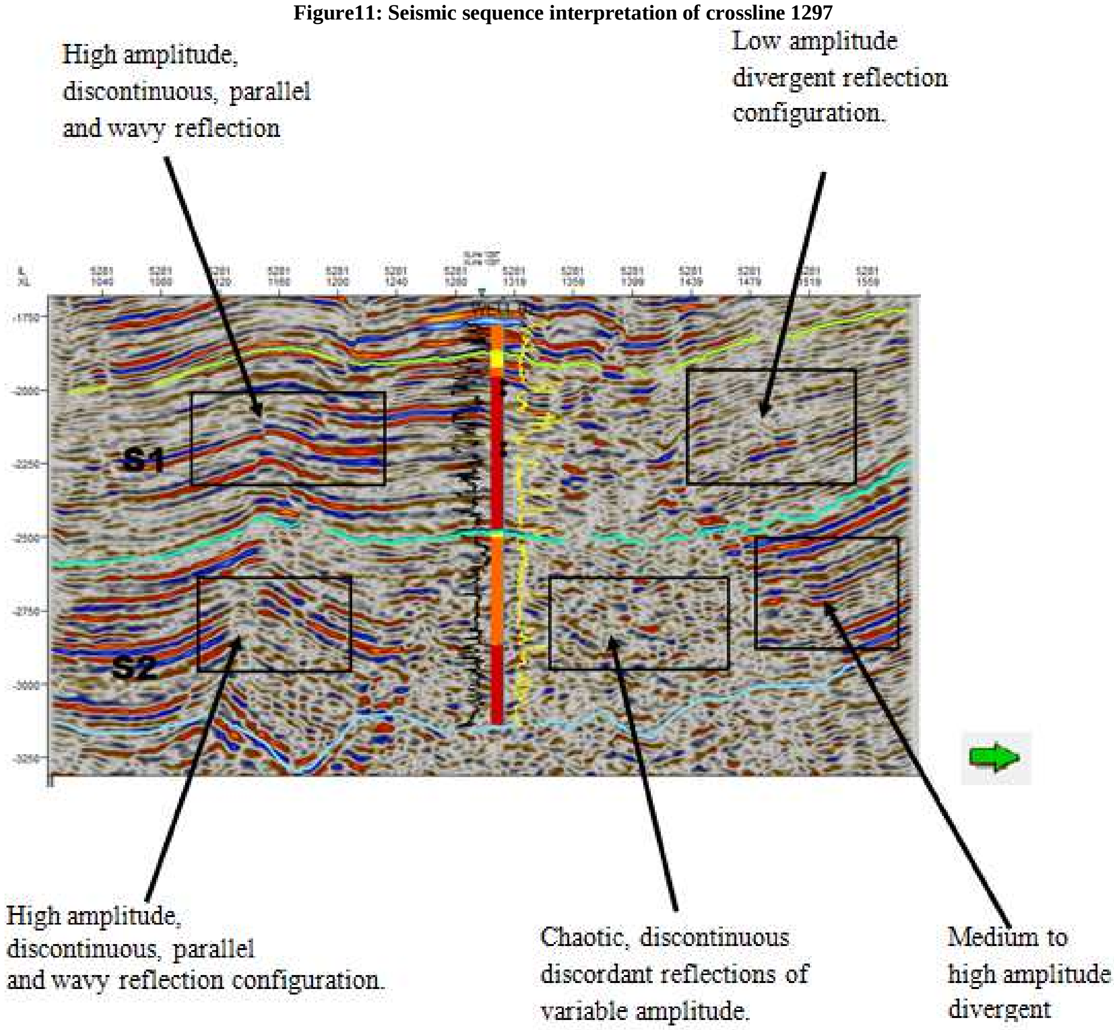

Figure12: Seismic facies interpretation of inline 5281

CONCLUSION

In this study, eight faults labelled F_1, F_2, F_3, F_4, F_5, F_6, F_7 and F_8 were delineated and mapped. F_1, F_2 and F_4 are growth faults; F_3, F_6 and F_8 are reverse faults, while F_4 and F_7 are both antithetic and synthetic faults. Four horizons located within a time window of 2076-2376 ms two way travel times were also mapped. The time structural maps generated had two ways travel times ranging from 1650-2150 ms, 1680-2250 ms, 1800-2400 ms and 1800-2520 ms. Two depositional sequences characterized by type 1 sequence boundary and composed of low-stand transgressive and high-stand system tracts were delineated. Seismic sequence analysis from reflection termination patterns such as top-lap, on-lap and down-lap were treated and used to map the sequence which lies between 2000-3167 ms two-way travel time. The seismic facies exhibit parallel and wavy, discontinuous reflection geometries with high amplitudes in the southern part. This geometry could probably connote a disruption in lateral continuity of the beds in the southern part of sequence 1. The depositional settings suggest a continental shelf environment. Divergent facies exhibits low amplitude to medium-high amplitude both in the upper and lower sequence. These geometries can be due to variations in sedimentation rates, subsidence and/or burial effects (differential compaction). This geometry indicates syn-depositional differential tectonic movements. The depositional setting is the continental slope of the marine environment and it is observed at the northern part of both sequence 1 and 2. Stratigraphic traps of paleo-channel fills, regional sand pinch-outs and truncations, crested accumulations below nonconforming surfaces were delineated. Chaotic exhibitions of discontinuous and discordant reflection patterns were also obtained which suggest the occurrence of disordered arrangements of reflection surfaces due to the presence of deformed over-pressured shales resulting from improper de-watering during rapid sedimentations. The lateral facies changes are typical of sand-shale inter-beddings deposits giving insight into the basinal stratification and energy regimes that prevailed during early sedimentation. These delineated prominent features are indicative of the existence of anticlinal structures (which are the necessary requirements for high petroleum yield) in the central and southeastern parts of the study field. Hence, the Adez field is a prolific environment for high petroleum yield.

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