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Fingerprinting Submarine Fan Deposits using Attribute Analysis: A Case Study of "AFUN" Field, Deep Offshore, Niger Delta

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Abstract

The unique nature of submarine fans of deep offshore Niger delta, mainly in terms of its differential distribution of facies, sand to shale ratio, orientation and classification, uncertainties as regards the connectivity and continuity of the submarine fan complex reservoirs occasionally lead to unfavourable surprises like drilling well and encountering a wet sand in a known hydrocarbon discovery. Therefore, such subtle stratigraphic trap needs to be assessed using an attribute analysis technique. The aim of this work was to extract attributes of turbidite deposits and their geomorphology within the environment of deposition. Seismic attributes were conducted to image distribution of event discontinuities related to faults using the principle of seismic geomorphology. The seismic geomorphological analysis involved the extraction of seismic attributes from the generated time structure maps. This was done in order to image depositional environment and extract the attribute of submarine fans and their general morphology. The attribute of the geobody and the geometry was then used to describe the connections between the reservoirs. Amplitude analysis revealed that the mapped sands (which are overlain by the Transgressive System Tract, TST) have their amplitude randomly distributed and suggestive of lithology effect. The amplitude response could be due to the different depositional environments of the overlying shales which are characterised by their unique acoustic impedances, mineralogy and hence seismic responses. The study concluded that the distribution and type of architectural elements such as fractures within the fan system have major impact on the reservoir distribution, continuity and connectivity of sand/shale bodies.

Keywords: *Seismic attributes; Turbidite deposits; Submarine fans; Depositional environments; Architectural elements.*

1. Introduction

Seismic geomorphology, the extraction of geomorphic insights using predominantly three dimensional seismic data, is a rapidly evolving discipline that facilitates the study of the subsurface using plan view images. Many analytical techniques are employed to image and visualise depositional elements and other geologically significant features [1].

This analysis can take the form of: (i) horizon picking and subsequent illumination; (ii) amplitude extraction along specific horizons [2]; (iii) horizon slicing or stratal slicing, whereby the volume is flattened on a key horizon and then amplitude extractions are made from time slices parallel to the key horizon; (iv) proportional horizon slicing, where an interval is bound between two mapped horizons and then is unproportionally sliced between those two horizons; (v) interval attribute analysis whereby an interval that brackets the "Funny Looking Thing" (FLT) is defined and then characterised seismically; (vi) voxbody picking; (vii) extraction of horizon based attributes such as dip magnitude, dip azimuth, curvature and roughness; (viii) extraction of volume based attributes such as phase, coherence, and impedance; and (ix) volume corendering, whereby two or more volume attributes are displayed simultaneously within the same volume.

The key to each of the analyses is to look for and recognise geologically or geomorphologically meaningful patterns in plan view as well as in section view. Such patterns can take the form of fluvial or deepwater channels, slumps and slides, shelf sediment ridges, and carbonate patch reefs. For the geomorphological approach to seismic interpretation to succeed, it is essential for the interpreter to have a broad experience base with respect to seismic plan view and section view expression of a variety of depositional elements [1].

For a long time, turbidites have been considered to be barely acceptable reservoir rocks. Their thin-bedded layered characteristics makes seismic approach to individual layers impossible, and well log correlations and fluid communication between wells often encountered serious difficulties, making these deposits somewhat less attractive. In addition, economics required that several reservoirs be found stratigraphically because one submarine fan sand may be too small [3]. This study therefore intends to extract attributes of turbidite deposits of "AFUN" field deep offshore Niger Delta and their geomorphology within the environment of deposition. The case study, "AFUN" Field, lies within the deep offshore Niger Delta of water depth of about 990-1117 m (Figure 1.). The study area is entrenched within the Gulf of Guinea at the Western Inner Fold Thrust Belt of the delta toe divided into lobes by the Charcot fracture zone. The lobes are characterised by numerous fracture zones [4]. "AFUN" Field covers an area extent of approximately 812 km^2 and has six oil wells drilled. The sediments have been deposited during Early to Late Miocene [5].

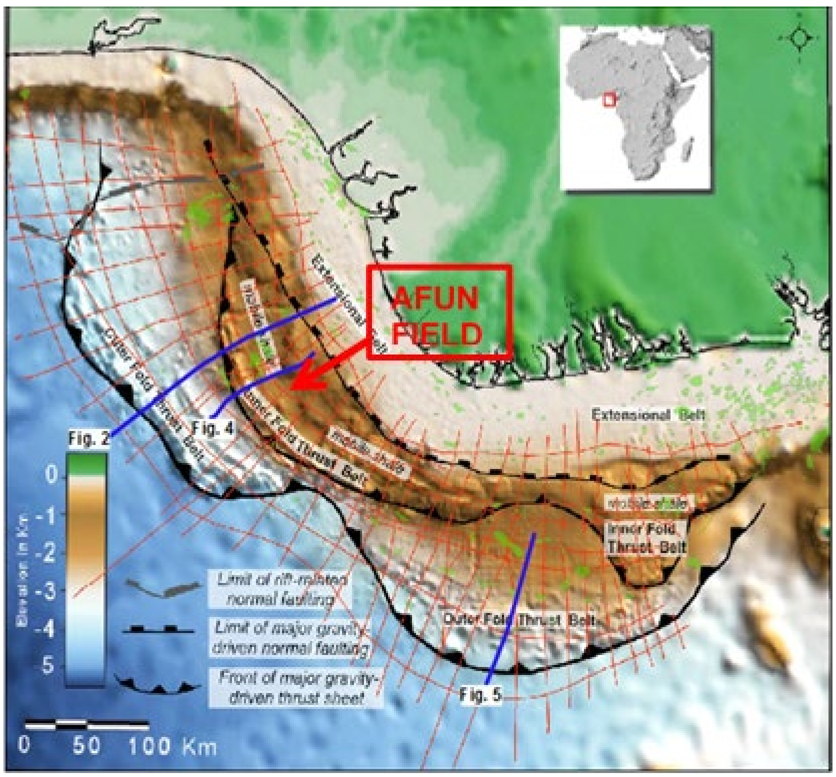

Figure 1. Map showing the location of the study area [4]

2. Geology of the study area

The Niger Delta Basin consists of Cretaceous to Holocene marine clastic strata that overlie oceanic and fragments of continental crust (Figure 2). The Cretaceous section has not been penetrated beneath the Niger Delta basin, and thus, Cretaceous lithologies can only be extrapolated from the exposed sections in the adjacent basin to the northeast, the Anambra basin. In this basin, Cretaceous marine clastics consist mainly of Albian Maastrichtian shallow marine clastic deposits [6-7]. The precise distribution and nature of correlative Cretaceous deposits beneath the offshore Niger Delta is unknown.

From the Campanian to the Paleocene, both tide dominated and river-dominated deltaic sediments were deposited during transgressive and regressive cycles, respectively [7]. In the

Paleocene, a major transgression initiated deposition of the Imo Shale in the Anambra Basin and the Akata Shale in the Niger Delta Basin. During the Eocene, the sedimentation changed to being wave dominated [7]. At this time, deposition of paralic sediments began in the Niger Delta Basin, and as the sediments prograded southward the coastline became progressively more convex seaward.

Today, delta sedimentation remains wave dominated [8-9]. The Tertiary section of the Niger Delta is divided into three formations including Akata, Agbada and Benin Formation representing prograding depositional environments. The sections of these formations are described in [10] and summarized in a many other papers [11-13, 7]. The Akata Formation at the base of the delta is of marine origin, and its thickness ranges from 2000 m (6600 ft) at the most distal part of the delta to 7000 m (23,000 ft) beneath the continental shelf [7]. In the deepwater fold and thrust belts, the Akata Formation is up to 5000 m (16,400 ft) thick because of structural repetitions by thrust ramps and the core of large detachment anticlines [14]. The Akata Formation is composed of thick shale sequences that are believed to contain source rocks and may contain some turbidite sands (potential reservoirs in deep-water environments). On seismic sections, the Akata Formation is generally devoid of internal reflections (Figure 2), with the exception of a strong, high-amplitude reflection that is locally present in the middle of the formation. This mid-Akata reflection serves as an important structural marker for defining detachment levels.

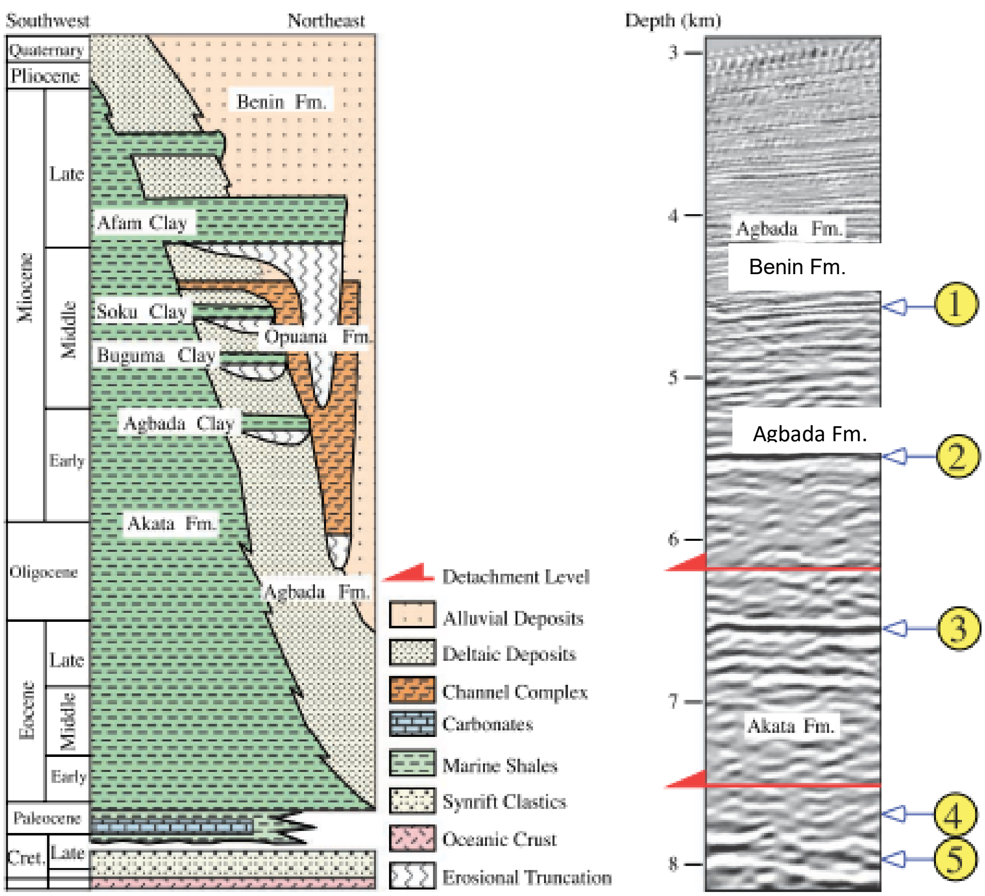

Figure 2. Schematic Diagram of the Regional Stratigraphy of the Niger Delta and Variable Density Seismic Display of the Main Stratigraphic Units in the Outer Fold and Thrust Belt and Main Reflectors, including (1) Top of The Agbada Formation, (2) Top of The Akata Formation, (3) Mid-Akata Reflection, (4) Speculated Top of the Synrift Clastic Deposits, And (5) Top of The Oceanic Crust. Main Detachment Levels Are Highlighted with Red Arrows (Stratigraphic Section is modified from [15].

The Akata exhibits low P-wave seismic velocities (2000 m/s; 6600 ft/s) that may reflect regional fluid overpressures [16]. Deposition of the overlying Agbada Formation, the major petroleum bearing unit in the Niger Delta, began in the Eocene and continues into the present. The Agbada Formation consists of paralic siliciclastics more than 3500 m (11,500 ft) thick and represents the actual deltaic portion of the sequence. This clastic sequence was accumulated in delta-front, delta-topset, and fluviodeltaic environments. Channel and basin floor fan deposits in the Agbada Formation form the primary reservoirs in the Niger Delta. Onshore and in some coastal regions, the Agbada Formation is overlain by the Benin Formation, which is composed of late Eocene to Holocene continental deposits, including alluvial and upper coastal-plain deposits that are up to 2000 m (6600 ft) thick [11].

3. Methodology

Seismic structural interpretation and seismic attributes were conducted to image the distribution of event discontinuities related to faults. The interpretation of seismic data was done so as to build a coherent three dimensional network of faults and horizons. Analysis of seismic geomorphology involved iteration between section and plan views which was a critical step in the evaluation of any seismic feature [1].

Amplitude extraction was done according to the principle of seismic geomorphology. Interval attribute extraction was carried out on the reservoir sands delineated in the study area. Interval attribute extraction was carried out within the lowstand fan of the system tract (between sequence boundary and transgressive surface). This was done in order to image depositional environment and extract the attributes of submarine fans and their general morphology. The attribute of the geobody and the geometry was then used to describe the connections between the reservoirs.

4. Discussion of results

Conventional structural map cannot explain facies changes and the entire trapping system that exist for a typical deep offshore field like "AFUN" Field. Rapid facies change were observed for the various reservoirs mapped indicating that the turbidite deposit are highly heterogeneous. The structural framework reflects an incomplete perspective of the trapping system in the offshore depobelts. Stratigraphic traps are also prevalent in the study area essentially in form of pinchouts.

Figures 3-4 display Maximum Magnitude and Root-Mean-Square Amplitude attributes extraction carried out on the three reservoir sands delineated in the study area. These attribute extractions imaged depositional environment within the lowstand fan of the system tract (between sequence boundary and transgressive surface). Hence stratigraphic facies prediction captured the heterogeneities which can be used to guide future exploration and field development activities and detailed stratigraphic analysis established the shape, orientation and lateral extent of the geobody. It was possible to distinctly map out a big submarine fan as indicated by red line of the amplitude map (Figure 5). Generally, the model reveals that AFUN Submarine Fan is of Niger Delta Ancient Basin Floor fan. It is radial in geometry. It is characterised by dendritic faulting pattern therefore contributing to reservoir complexity (Figure 6). Maximum canyon width of the submarine fan delineated is about 11.3 km with maximum fan width and length of approximately 40.2 km and 34.5 km respectively.

The amplitude analysis revealed a random distribution of high and low amplitudes which were not conforming with structures. The amplitude response is believed to suggest lithologic effect rather than hydrocarbon presence.

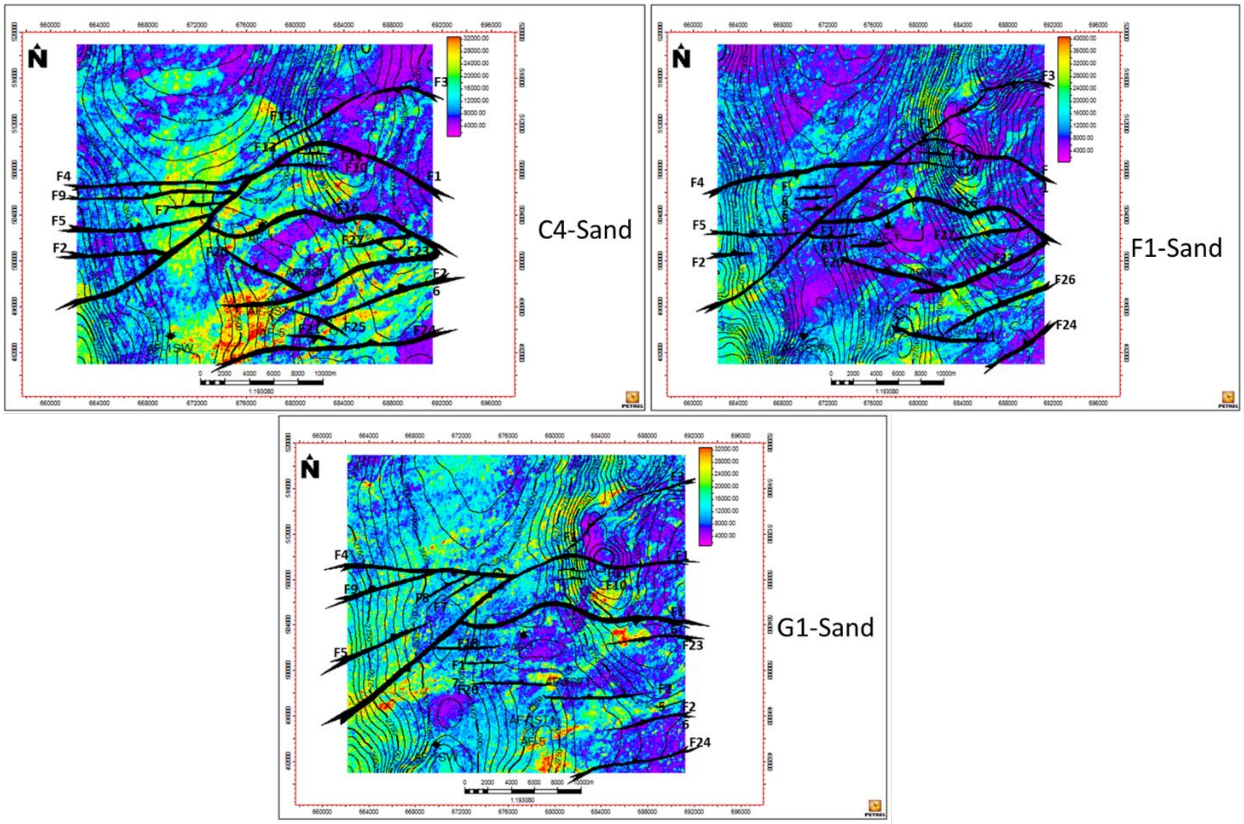

Figure 3. Maximum Magnitude Attribute Map for the Three Reservoir Sands

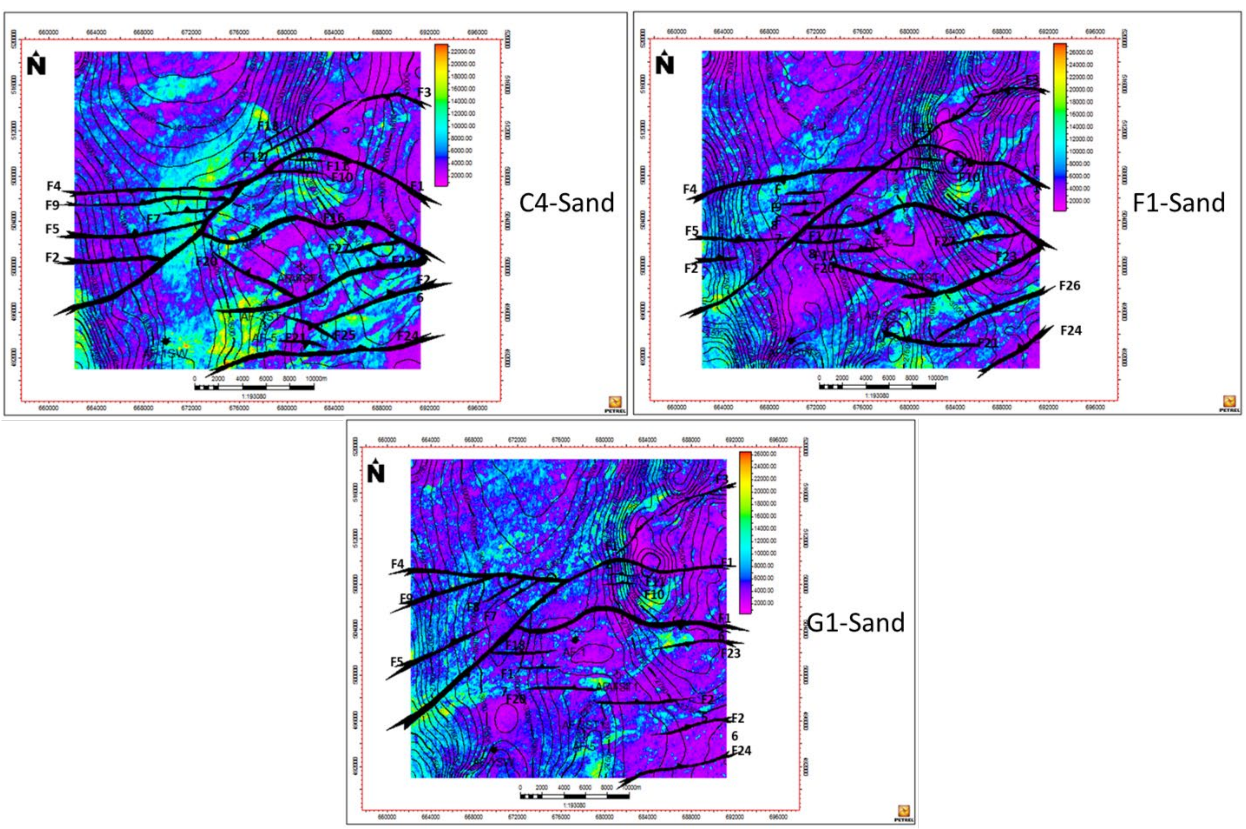

Figure 4. RMS Attribute Map for the Three Reservoir Sands

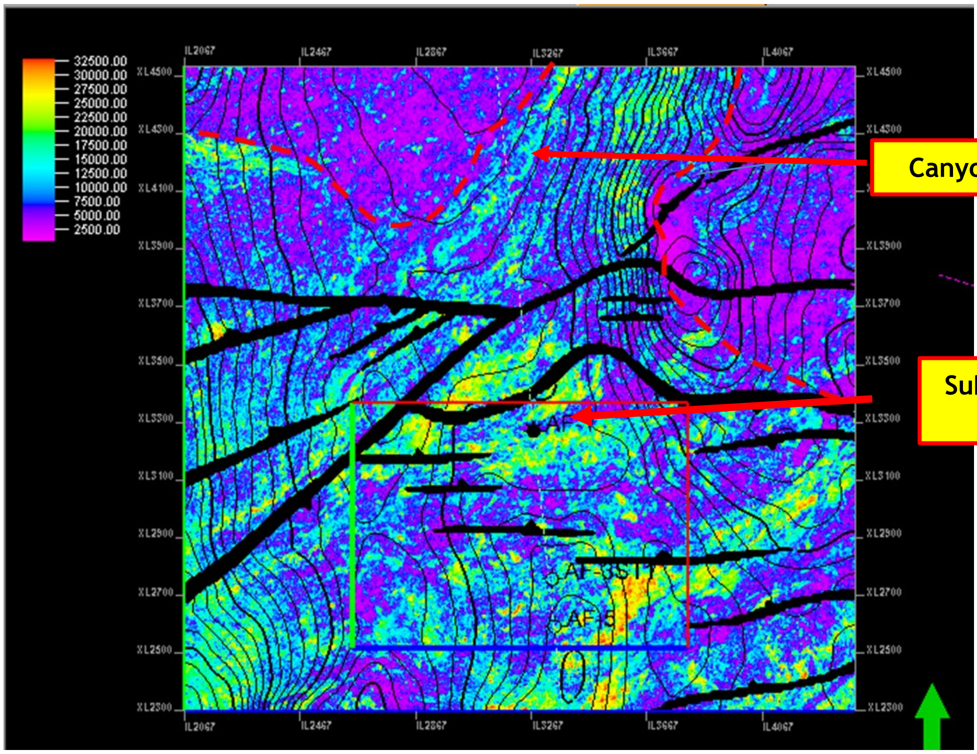

Figure 5. Representative Submarine Fan Model for “AFUN” Field

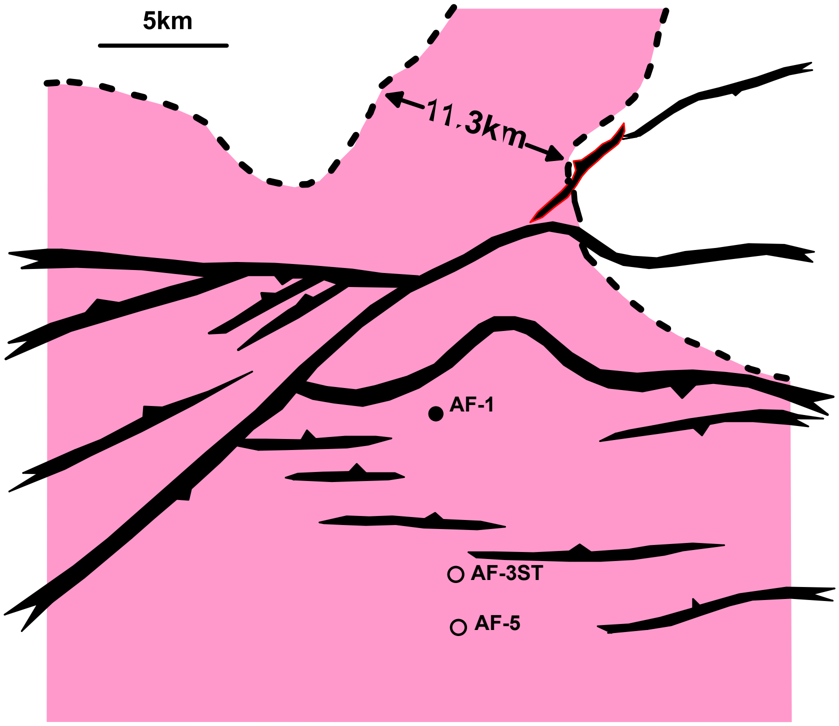

Figure 6. Annotated Diagram showing the Dimension of the Submarine Fan and Faulting System of a Representative Reservoir

5. Conclusions

The seismic geomorphological aspect involved the extraction of seismic attributes from the generated time structure maps. Amplitude analysis revealed that the mapped sands (which are overlain by the TST) have their amplitude randomly distributed, suggestive of lithologic effect. These amplitude responses could be due to the different depositional environments of the overlying shales which are characterized by their unique acoustic impedances, mineralogy and hence seismic responses. Reservoir quality was interpreted based on depositional features. These control reservoir characteristics in different facies of the reservoirs. It has also been shown that the distribution and type of architectural elements such as fractures within the fan system have major impact on the reservoir distribution, continuity and connectivity of sand/shale bodies. The results obtained will assist in guiding drill targets and enhance the economic viability of a structural complex and stratigraphic heterogeneous deepwater submarine fan deposit.

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