

THREE DIMENSIONAL SEISMIC, WELL LOG AND STRUCTURAL ANALYSIS OF “IGBOBI” FIELD, OFFSHORE NIGER DELTA

O. S. Hammed¹, M. O. Awoyemi², W. N. Igboama¹, D. O. Ebun³, J. O. Fatoba⁵, O. T. Olurin⁶, M. Aroyehun⁵, G. O. Badmus⁴, A. B. Arogundade², and S. C. Falade²

¹ Department of Physics, Federal University, Oye-Ekiti, Nigeria

² Department of Physics, Obafemi Awolowo University, Ile-Ife, Nigeria

³ Department of Physical Science, Ondo State University of Science and Technology, Okitipupa, Nigeria

⁴ Department of Mathematics and Physics, Afe-babalola University, Ado-Ekiti

⁵ Department of Geophysics, Federal University, Oye-Ekiti, Nigeria

⁶ Department of Physics, Federal University of Agriculture, Abeokuta, Nigeria

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Abstract

The search for Hydrocarbon as the main energy source for the development of the world economy is based on the experience from sandstone environment. Therefore, it is imperative to evaluate the targets (pay zone) within the available fields to determine the extent of the known reservoirs for assessment and development. To achieve this, three dimensional seismic, well logs and structural interpretations of Igboobi Field in the Niger Delta were carried out to characterise the reservoir. Data used were well logs, seismic section and the structural map of the sand tops. The Interactive Petrel Software was used in the Interpretation. An integration of well and seismic data in conjunction with time-depth relationship was employed to identify where the hydrocarbon bearing sands from well, post on the seismic lines. Good tie was obtained for well to seismic data. The depth converted structural maps correlated with the time structural maps. The identified prospects were viewed and evaluation of tested traps was carried out to characterise the reservoir. The correlating zones where hydrocarbon bearing sands from wells, post on the seismic lines were identified. It is therefore recommended that Igboobi field is prospective and should proceed to further stage.

Keywords: Hydrocarbon Volume; 3D Seismic; sand tops; structural interpretation; well logs.

1. Introduction

The advantage of using wells and seismic instead of just wells alone, is that the seismic data can be used to interpolate and extrapolate between and beyond sparse well control. Seismic data encompasses a wide spectrum of information from 2-D, 3-D or 4-D surveys and vertical seismic profile (VSP) studies. These data can be integrated to overcome the limitations inherent in any single data domain. For example, 3-D seismic data can sample a large aerial extent of a particular reservoir, but it provides only limited vertical resolution. This research will reveal the potential of combining seismic reflection, structural maps and wire line logs in the estimation of reservoir, since seismic sections have good lateral resolution but poor vertical resolution. And the wire-line logs on the other hand have good vertical resolution but poor lateral resolution.

The introduction of the 3D seismic revolution has made the use of amplitudes an integral part of seismic interpretation and has allowed more valuable geological information to be discerned as seismic attributes (i.e. phase, amplitude, instantaneous frequency) [1]. A seismic attribute is any measure of seismic data that helps to visually enhance or quantify features of interpretation interest. A good seismic attribute is either directly sensitive to the desired geologic feature or reservoir property of interest, or allows us to define the structural or deposi-

tional environment and thereby enables us to infer some features or properties of interest. Attributes can be defined as all parameters contained in seismic data. This “boom” of attributes came about especially after the introduction of coloured seismic sections by [2], followed by the work of Taner *et al.* [3] on complex seismic trace analysis, and lastly by the generalization of 3D seismic data and interpretation workstations [3-5]. Seismic attributes form an integral part of qualitative interpretative tool that facilitates structural and stratigraphic (channels, pinch out, meanders) interpretation as well as offer clues to lithology type and fluid content estimation with a potential benefit of detailed reservoir characterization [6]. For instance, fault structures which have been classified into seismically resolvable and sub-seismic scale (subtle) faults [7] can be interpreted more effectively with the aid of seismic attribute.

Surface and volume seismic attributes can be used in every stage of the hydrocarbon reservoir modelling process to reduce uncertainty and complement the available data. Interpretation workflows for structural geology, stratigraphy analysis and rock/pore fluid properties based on attributes derived from processed seismic data, are now daily routines in oil and gas companies [5].

2. Geology of Niger Delta and petroleum history

The geology of the Niger delta has been extensively discussed by several authors like [8-10].

The Niger Delta is situated on the Gulf of Guinea on the West Coast of Africa. It is located at the South eastern end of Nigeria, bordering the Atlantic Ocean and extends from about latitudes 4° to 6° N and longitudes 3° to 9°E [14]. The basin is bounded to east by the Calabar Flank, which is a subsurface expression of the Oban Massif. To the west, it is bounded by the Benin Basin, to the South, by the Gulf of Guinea and to the North by Older (Cretaceous) tectonic structures such as the Anambra Basin, Abakiliki Anticlinorium and Afikpo Syncline.

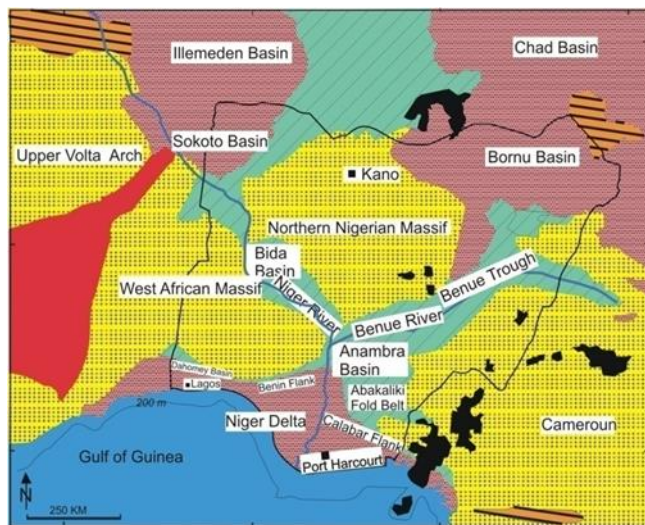


Figure 1. Simplified geological map of Nigeria showing the location of the Niger Delta and some other Nigerian basins. Modified after Stacher [15]

The Niger Delta Province contains only one identified petroleum system [11-12]. This system is referred to as the Tertiary Niger Delta (Akata –Agbada) Petroleum System. The maximum extent of the petroleum system coincides with the boundaries of the province (Figure 1). The minimum extent of the system is defined by the areal extent of fields and contains known resources (cumulative production plus proved reserves) of 34.5 billion barrels of oil (BBO) and 93.8 trillion cubic feet of gas (TCFG) (14.9 billion barrels of oil equivalent, BBOE) (Petro consultants, 1996a). Currently, most of this petroleum is in fields that are onshore or on the continental shelf in waters less than 200 meters deep (Figure 2).

The tectonic framework of the Niger delta is related to the stresses that accompanied the separation of African and South American plates, which led to the opening of the south Atlantic. The Niger Delta is the largest delta in Africa with a sub-aerial exposure of about 75,000km² and a clastic fill of about 9,000 to 12,000m (30,000 to 40,000ft) and terminates at different intervals by transgressive sequences. The Proto-delta developed in the Northern part of the basin during the Campanian transgression and ended with the Paleocene transgression.

Formation of the modern delta began during the Eocene. The onshore portion of the Niger Delta Province is delineated by the geology of southern Nigeria and south-western Cameroon. The northern boundary is the Benin flank - an east north-east trending hinge line south of the

West African basement massif. The north-eastern boundary is defined by outcrops of the Cretaceous on the Abakaliki High and further east south-east by the Calabar flank-a hinge line bordering the adjacent Precambrian [13].

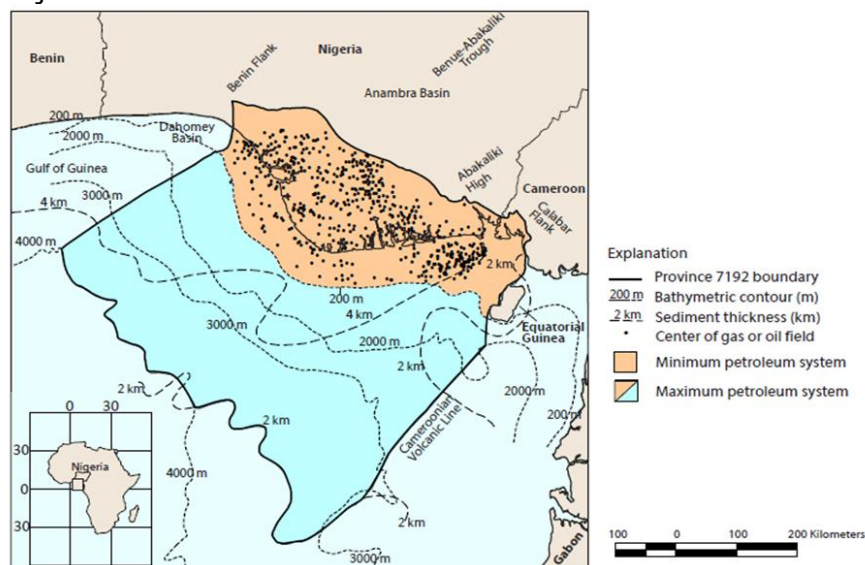


Figure 2. Map of Niger Delta showing Province outline (maximum petroleum system); and key structural features. Minimum petroleum system as defined by oil and gas field center points (data from Petroconsultants, 1996); 200, 2,000, 3,000, and 4,000m bathymetric contours shown by dotted contours; 2 and 4 km sediment isopach shown by dashed lines (From Tuttle *et al.* [16]).

The offshore boundary of the province 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, and the two-kilometre sediment thickness contour or the 4000-meter bathymetric contour in areas where sediment thickness is greater than two kilometers to the south and southwest [13].

Sedimentary deposits in the basin have been divided into three large-scale lithostratigraphic units: (1) the basal Paleocene to Recent pro-delta facies of the Akata Formation, (2) Eocene to Recent, paralic facies of the Agbada Formation, and, (3) Oligocene-Recent, fluvial facies of the Benin Formation. These formations become progressively younger farther into the basin, recording the long-term progradation of depositional environments of the Niger Delta onto the Atlantic Ocean passive margin [13].

3. Materials and method

3.1. Seismic data

The seismic data set (Figure 3) available for the study area was provided by one of the Multinational Oil companies in Nigeria. This includes a 3D post-stacked time migrated seismic data and six spatially distributed exploration well data. The coverage area of the 3D seismic grid in the field is about 52.96sq.km. There are 6200 inlines and 1700 crosslines (Figure 4). The 3D seismic data containing 7900 seismic reflection lines (1700 cross-lines shot parallel to the strike direction of dip and 6200 in-lines shot parallel to the direction of dip) were used in this project. The data were acquired and processed on an offshore area of approximately $3.1 \times 10^8 \text{m}^2$. The data were processed to improve the resolution and the details of the structure interest. Horizon picking was carried out on the seismic section by picking continuous and strong seismic reflections, which are usually due to lithological contrast, or presence of an unconformity. Usually, the interpreted lithological tops or reservoir tops picked on the well logs are posted on the seismic section, and the corresponding seismic response will be picked

as the horizon. The seismic data appears to be of good quality and characters and easy to follow across the survey area.

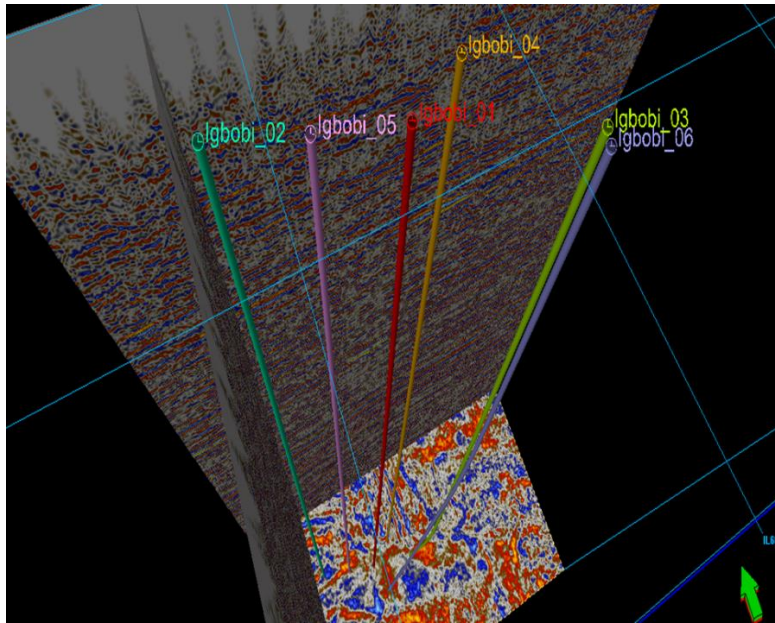


Figure 3. The 3D seismic data and all six wells

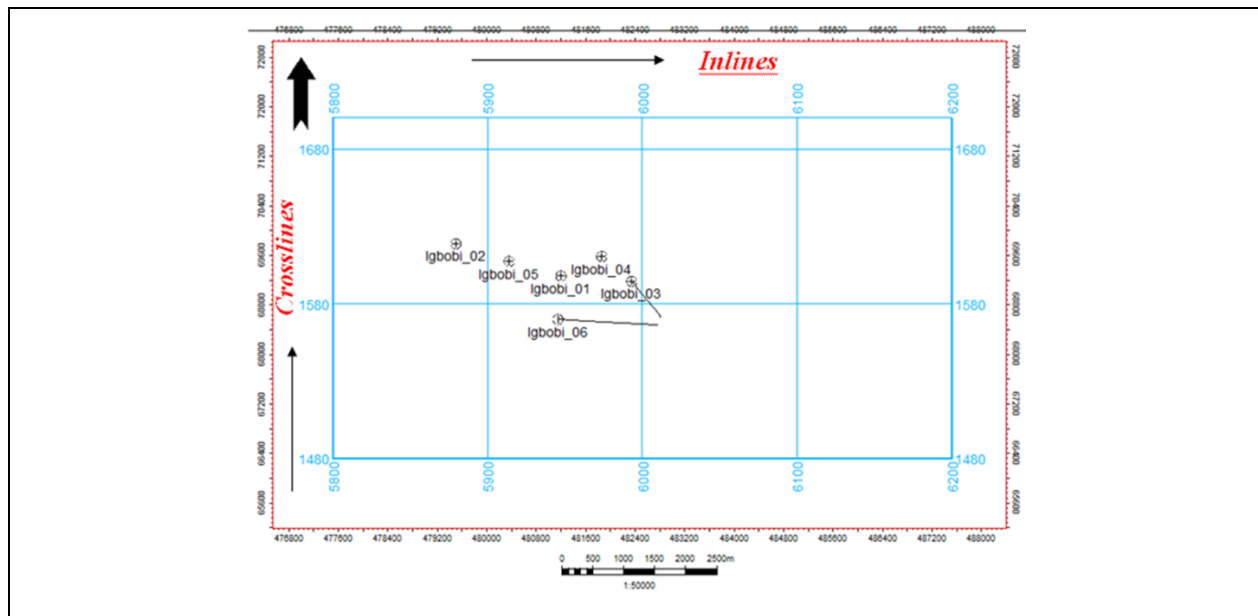


Figure 4. Base map/ seismic grid showing spatial distribution of wells, the inlines and crosslines

The essential workflow adopted for the seismic interpretations in this research are data loading and visualization; analysis of the seismic volume starting with initial scrolling through the data after loading. In order to carry out quality control by checking the type of seismic data, if it is stacked or unstacked, migrated or not migrated. This assists in the study of stratigraphy style within the field. Thereafter, the seismic volume was sliced in the area that showed the highest potential of geologic interest.

Attribute extraction was carried out on the time slices to construct attribute extraction maps for the visualization of stratigraphic and geomorphological features that may be diagnostic of specific areas of prospective interests.

3.2. Well LOG data

The data used in the study included digital suites of well logs which were imported into the interactive Petrel's software, seismic sections, base map and structure map of the study area. Out of six wells explored, wells Igbobi_1 to Igbobi_4 have composite logs suites including gamma ray, resistivity, sonic, neutron density logs and checkshot data. Wells Igbobi_3 and Igbobi_6 have deviated data. The seismic sections highlighted the fault enclosing the reservoir brought about by direct hydrocarbon indicators while revealing the horizons tracked on the reflections across the field. The relevant wire line log signatures and cut-offs were employed to identify the hydrocarbon-bearing reservoirs.

3.3. Generation of time and depth map

The mapped horizons in time were depth converted to depth map by the time-depth relationship using a velocity function and is presented in figures 11-13. The identified pay zones on seismic were mapped throughout the seismic cube on both inline and cross lines. The mapped horizons were named Sand 1 to Sand 5 as identified on wells. Seismic mis-tie was carefully observed and corrected before conversion into time maps.

The time maps were converted to depth map with the time depth relationship using a velocity function and then compared with the depth map. Contour patterns were consistent which indicates that the velocity model utilised is applicable. Fault polygons were digitised and posted on both time and depth maps.

4. Results and discussion

4.1. Seismic interpretation

3-D seismic structural interpretation comprising 6200 in-lines (Dip) and 1700 cross-lines (Strike) was carried out in "IGBOBI" Field offshore Niger Delta. Faults were mapped and correlated. Major regional faults delineated were designated as F1, F2, F3, F4 and F5 (Figure 5) where F1 and F2 are canter regional faults. Three horizons were mapped on the 3D seismic cube and were designated as Sand 1_top, Sand 2_top, and Sand 3_top, respectively (Figures 6 - 7). The top of hydrocarbon bearing reservoirs which were characterised by the sand tops using the well logs were mapped on seismic cube (Figure 8). The mapped horizons in time were depth converted to depth maps by the time-depth relationship. The depth structural maps were mapped for closures or structures that possess effective trapping system suitable for hydrocarbon accumulation, development and production which are presented in Figures 11 - 13. It can be observed that the contour patterns and structures on the time map are also represented on the depth map which further indicates that the velocity model used is applicable.

4.2. Synthetic seismogram and well to seismic tie

The seismic interpretation was carried out using Petrel software. The in-lines and cross-lines were identified. Checkshot data was used to display the Wells and Time. The Igbobi_04 and Igbobi_05 wells have both sonic and density logs from which the synthetic seismograms were generated to tie well data to seismic data.

One of the first steps in interpreting a seismic dataset is to establish the relationship between seismic reflections. It is usually necessary to be more precise and establish exactly how the top of a reservoir is related on seismic and well log. Synthetic seismograms are the bridges between geological information, derived from well data in depth and geophysical information (seismic in time). This essentially involves a two-step process; by the means of check-shot data and sonic logs, establishing time-depth relationships for the wells.

Density logs and sonic logs parameters were used to calculate acoustic impedance and reflection coefficients. These were then convolved using a zero-phased wavelet to obtain the

seismic “wobble” trace. The derived synthetic was validated statistically by observing proportion of energy in the seismic trace that is matched in the synthetic, using the coefficient of correlation method. In this case, the result is strong and positive. For consistency reasons and also to reduce the level of uncertainty, the seismic data which is in time was tied to the well data which is in depth. The synthetics provide a means of tying the well log data with the actual seismic data thereby giving geologic meaning to the seismic interpretation. The Gamma Ray log, with the top of the sand reservoirs and synthetic seismogram were all posted on the seismic sections which fall exactly on the well path. This is to aid the transfer of geologic information from well log on to the seismic.

4.3. Well to seismic tie

The check shot was used as the time to depth relationship to display the well in time so that it can be displayed on seismic which is in time. Well to seismic tie was carried out in order to calibrate the seismic data and also identify its polarity (peak or trough), a synthetic seismogram was generated to tie the well to seismic (Figure 9). The synthetic seismogram was generated using sonic and density logs. Firstly, corrected sonic and density logs were used to generate the Acoustic Impedance (Track 4) and a reflection coefficient (Track 5) parameters using Zoepritz equation. These parameters were convolved with extracted wavelet from the seismic (zero phase wavelet) to generate the synthetic seismogram (Track 6). The synthetic seismogram was compared with the seismic data (Track 7). All these tracks are shown in (Figure 10). The major events on the synthetic seismogram were correlated with those on the seismic section as shown in (Figure 9). Therefore this could be considered as a good tie. It can also be observed that the pay zones correspond to high and low amplitude events (trough and peak) on the seismic data.

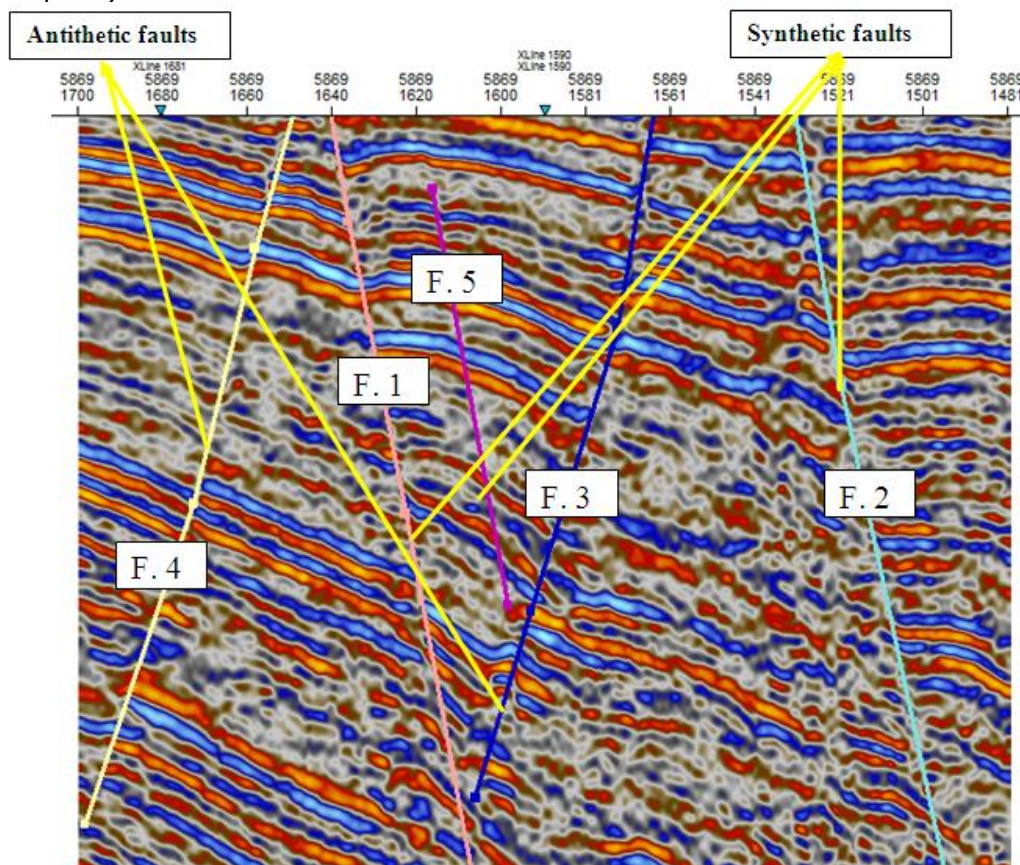


Figure 5. Major regional faults delineated showing F1, F2, F3, F4, and F5 faults

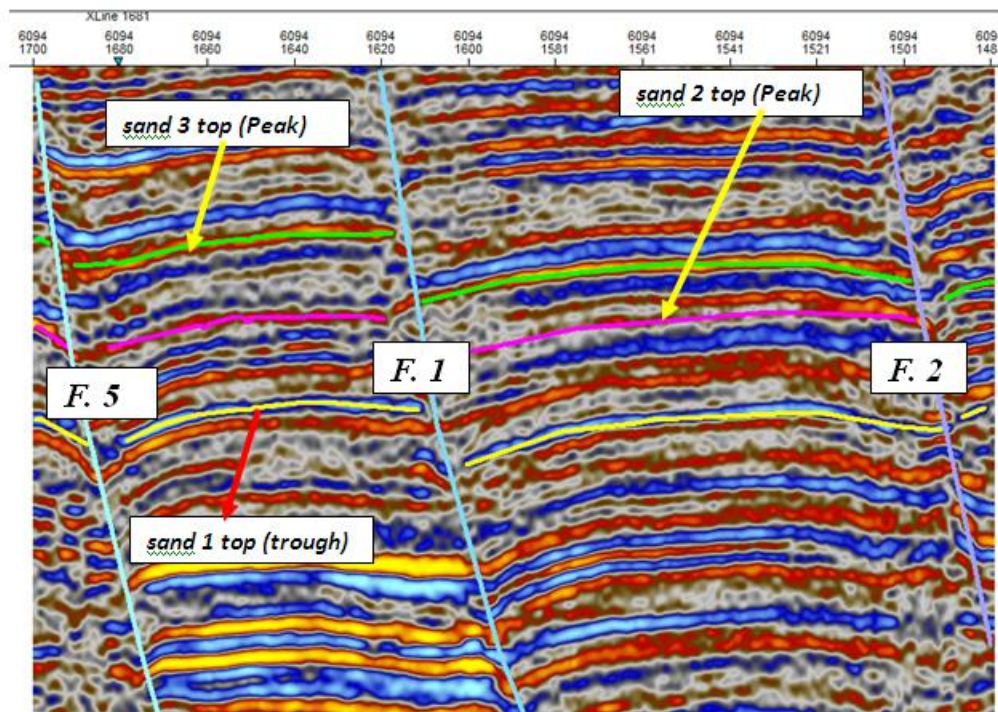


Figure 6. Mapped Horizons on inline 6094

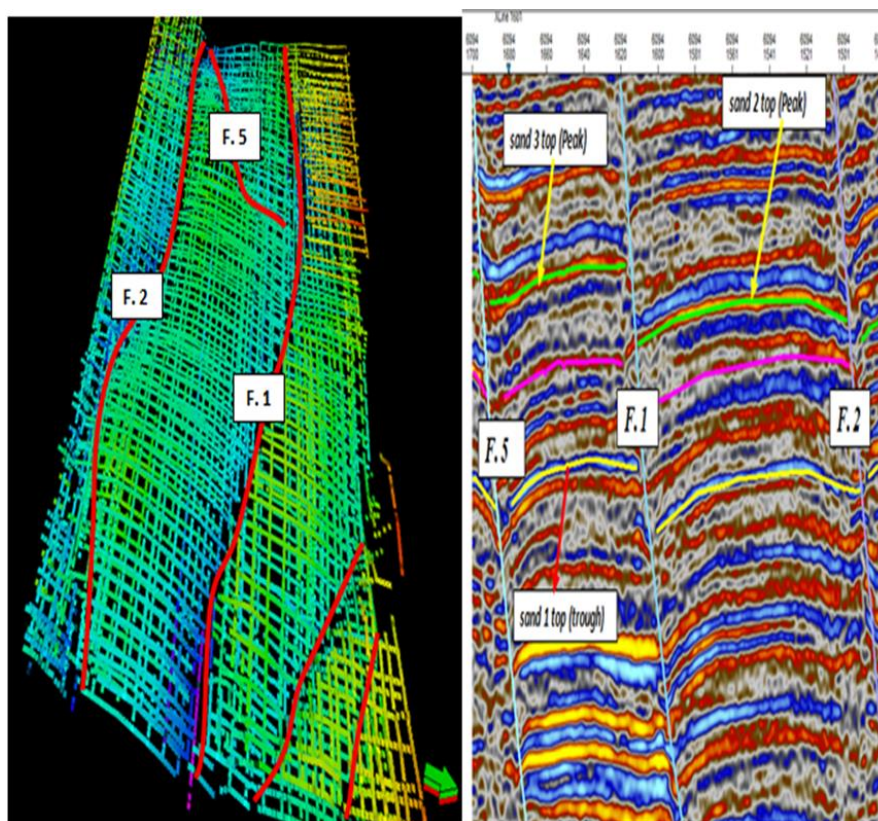


Figure 7. Mapped Horizons in 3D View on inline 6094 displaying the most prominent faults

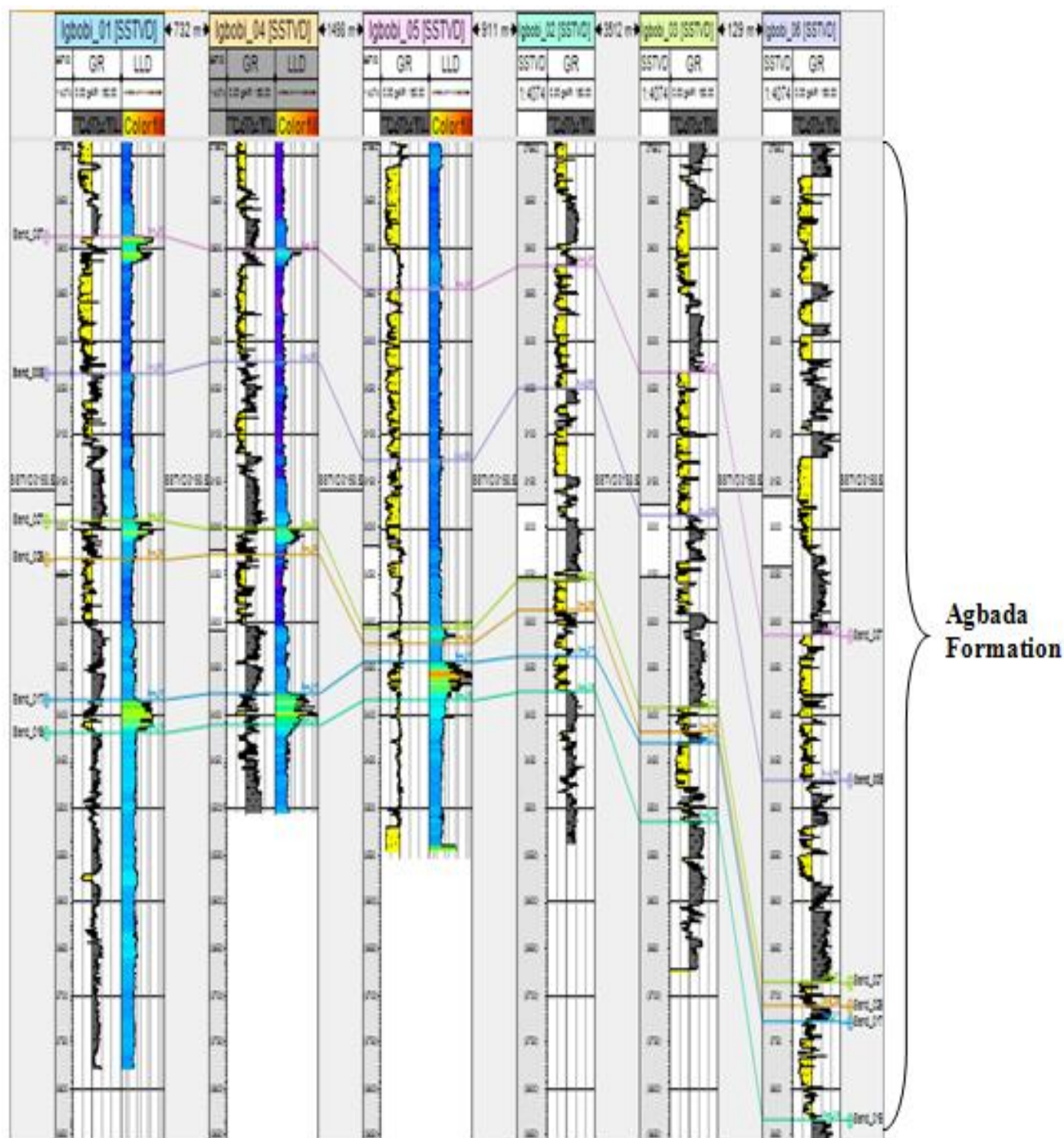


Figure 8. Well log correlation of Hydrocarbon Bearing Reservoir Sands across the Field

Well correlation: The available wells in the Field were correlated from east to west using the marker shale and sand present in relation to the three major stratigraphic column in Niger Delta.

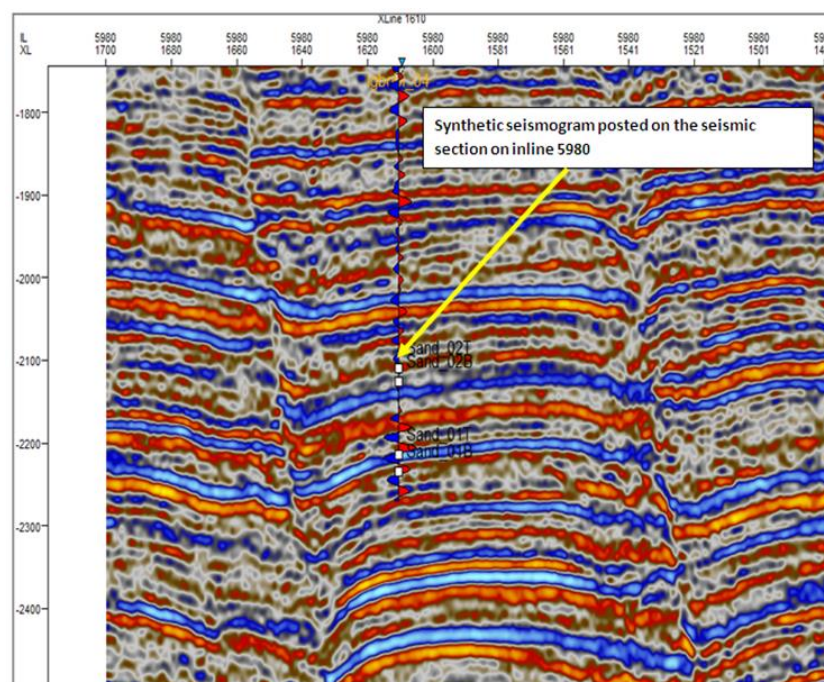


Figure 9. Overlay of Synthetic Seismogram on intersecting Inline 5980

4.4. Seismic attributes extraction

The principal objective of computing seismic attributes is to obtain accurate and detailed information on structural, stratigraphic and lithological parameters of the seismic prospect [3]. For this research, suitable attributes were chosen among others due to their strength to resolve the geological features of study. In this research, we correlated the calculated set of seismic attribute maps with each other and compare with available well information to understand and map reservoir facies heterogeneities. This section ensures the understanding of each particular attribute and its contribution to reservoir characterization

Different kinds of attributes have been applied but a few have shown convincing result. The most representative, consistent and realistic attributes used, based on reservoir geology and well control information, in this work are surface attributes. These attributes include extract value and RMS amplitude. All these were measured over a time window on surfaces interpreted from the seismic data. A surface attribute is the value of an attribute relative to a single horizon and an interval window, between two horizons or within a constant time window. Surface attributes are much more dependent on the user interpretation, and consequently dependent on the user picking of a horizon, than volume attributes computed with user-defined parameters.

4.5. Well LOG interpretation

From the geology of the region, the three formations of the basin are Akata Formation, Agbada Formation and Benin Formation. The Akata Formation is mainly transgressive marine shales and is the source rock but has not been penetrated by most wells. The Agbada Formation is an intercalation of Sand and shale of which the shale at the base may be matured enough to generate hydrocarbon (Figure 8). More importantly the intercalation of Sand and Shale in the Agbada formation forms a network of reservoir overlain by a seal which is a key to the accumulation of hydrocarbon. The Benin formation is basically Sand and is of little importance to hydrocarbon in the study area. The base of the Benin Formation has been predicted on the well log based on its gamma ray log characteristics which indicates sequence of Sand.

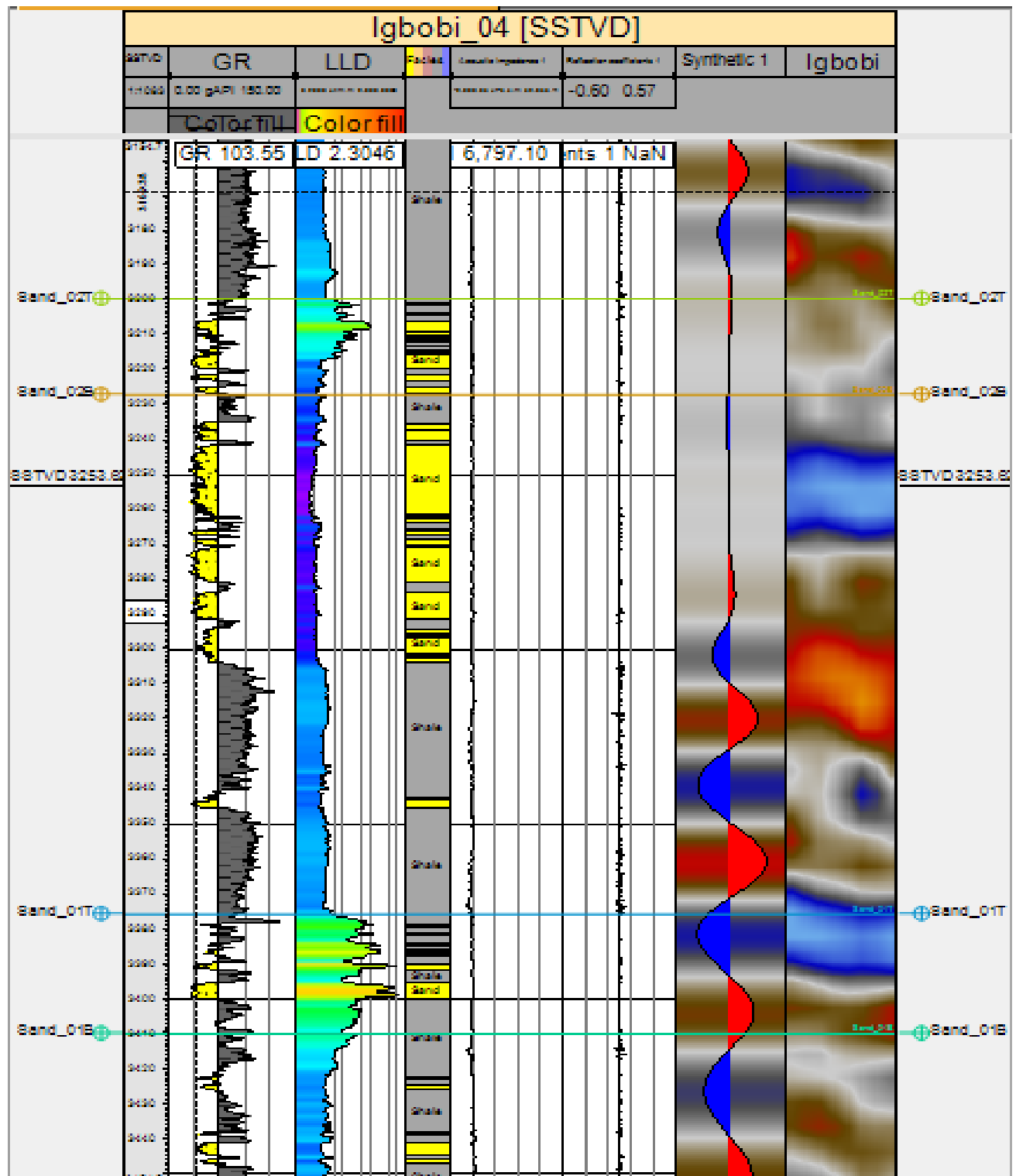


Figure 10. Well to seismic tie section: Track 4 to 7 is the AI, RC, Synthetic and Seismic section respectively

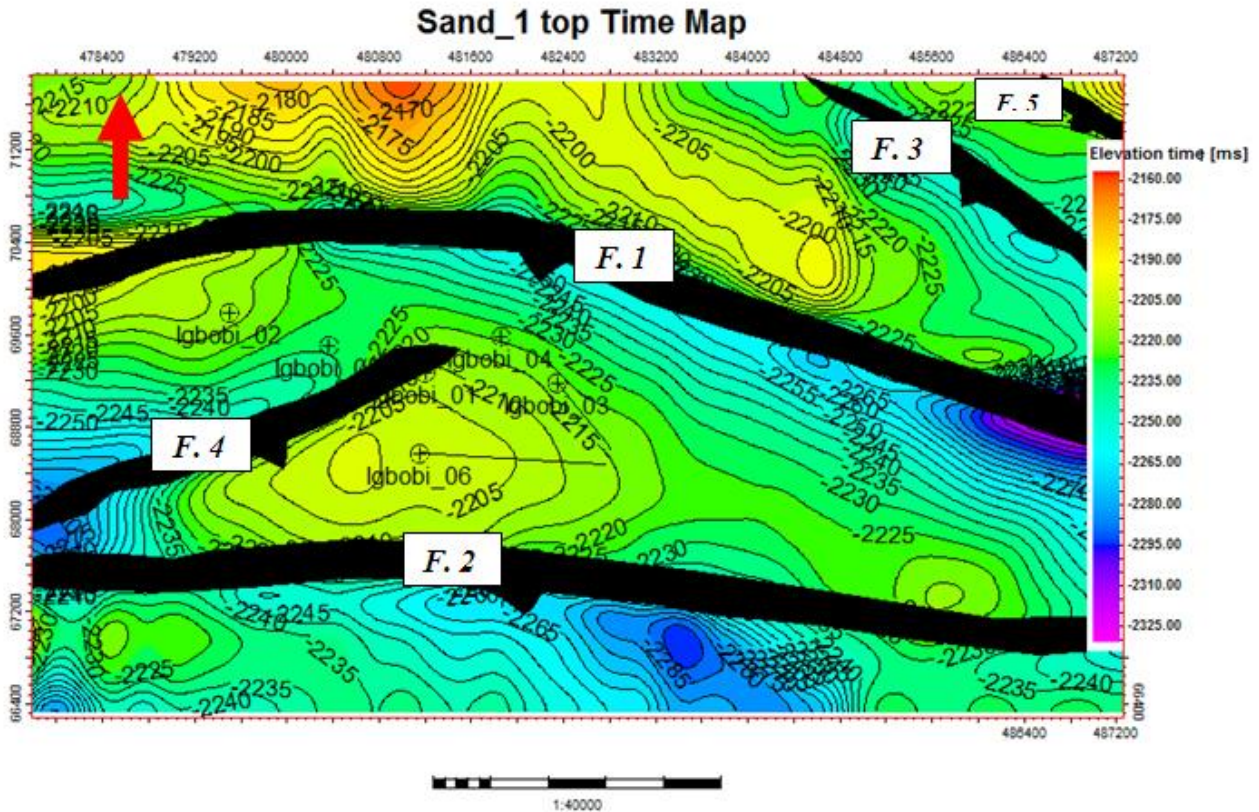


Figure 11a. Time map of Sand 1

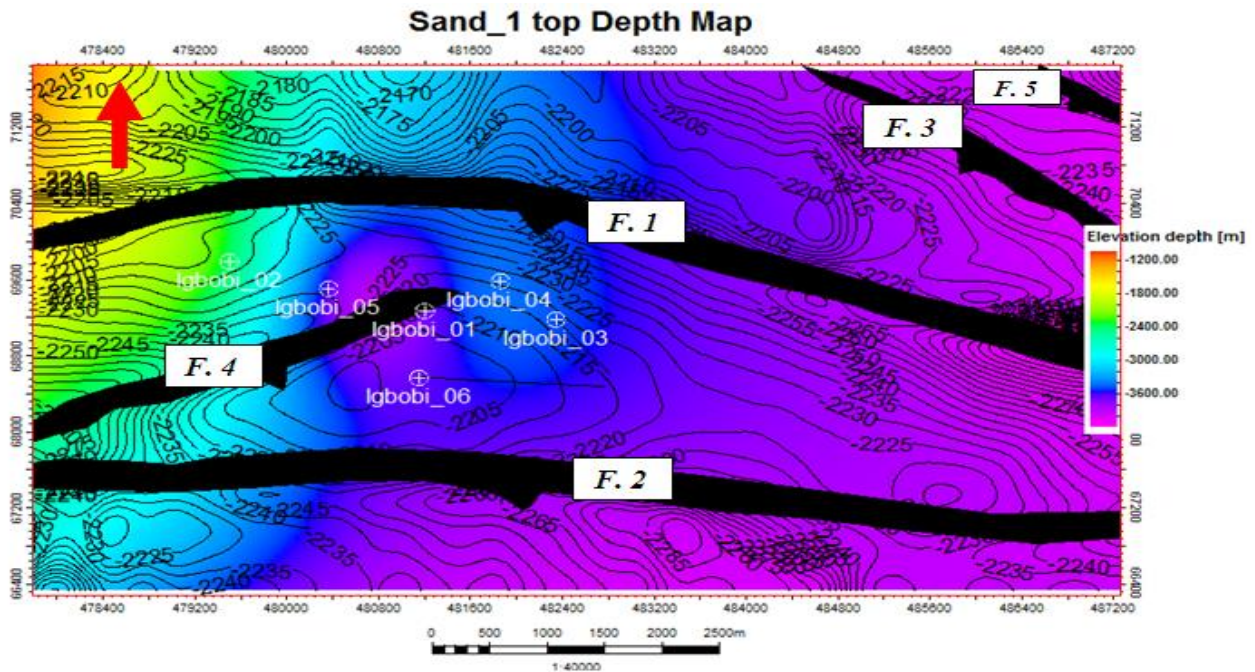
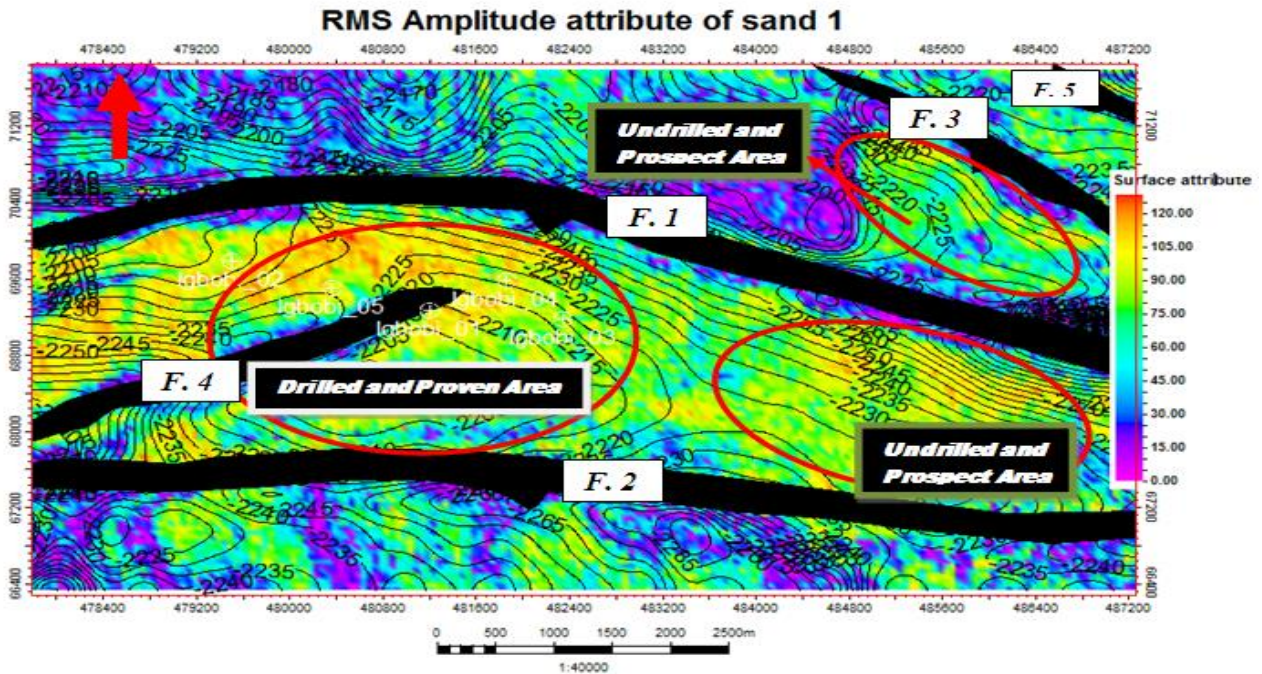
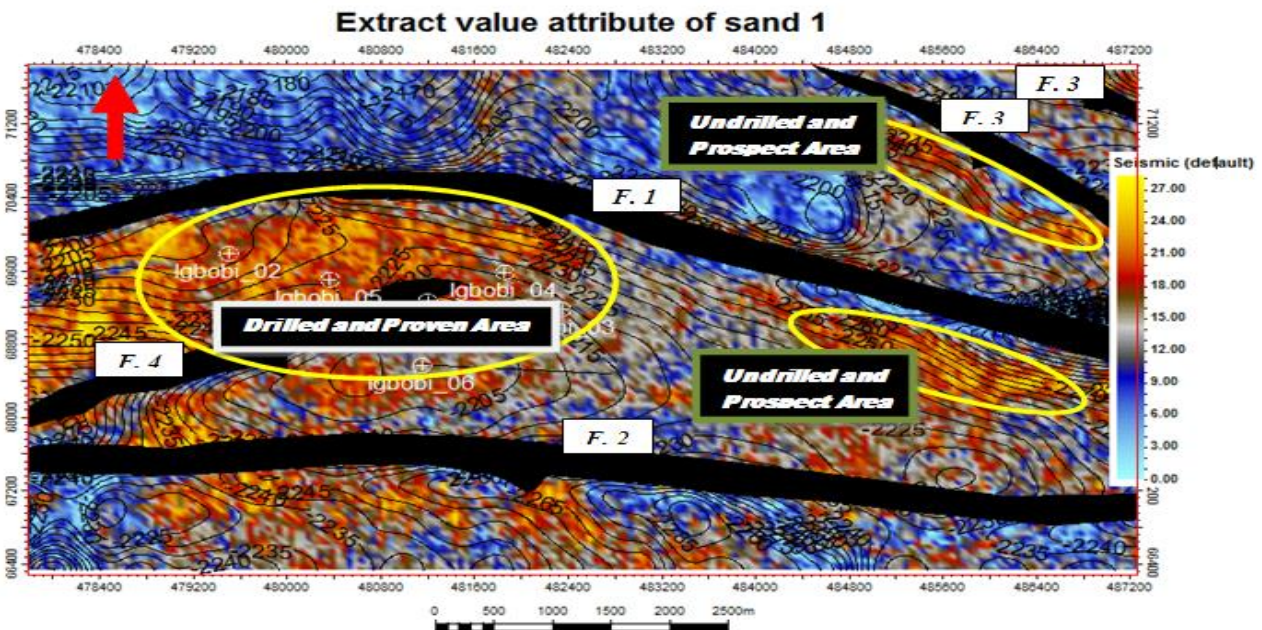


Figure 11b. Depth map of Sand 1



(11ci)



(11cii)

Figure 11c. Surface attributes extracted at 150ms window on Sand 1 showing High Amplitude event around Igbobi field wells associated with Hydrocarbon accumulation and other region with similar attribute anomaly also supported by structures in the rings

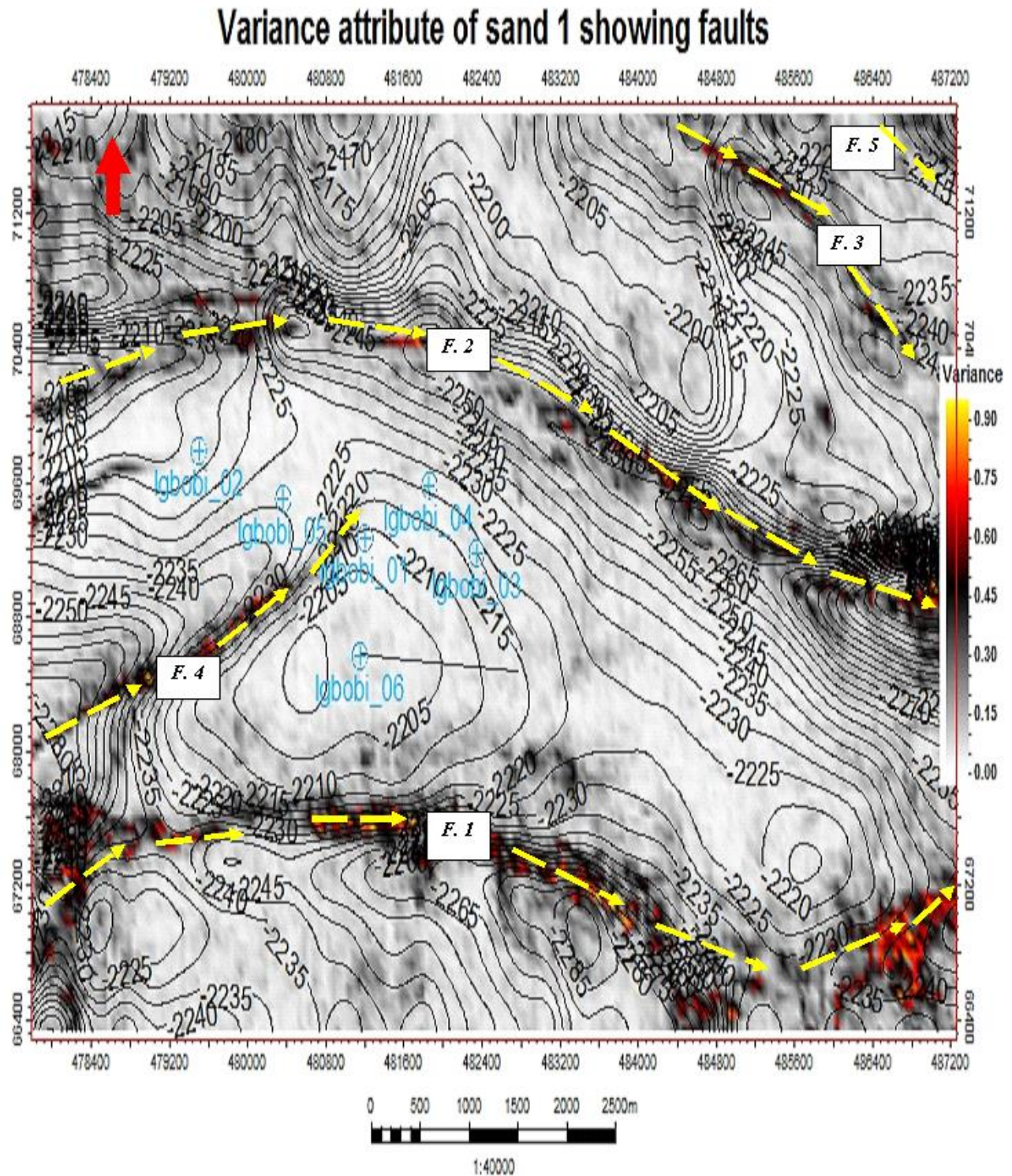


Figure 11d. Variance attribute showing the faulted area on d map of sand 1

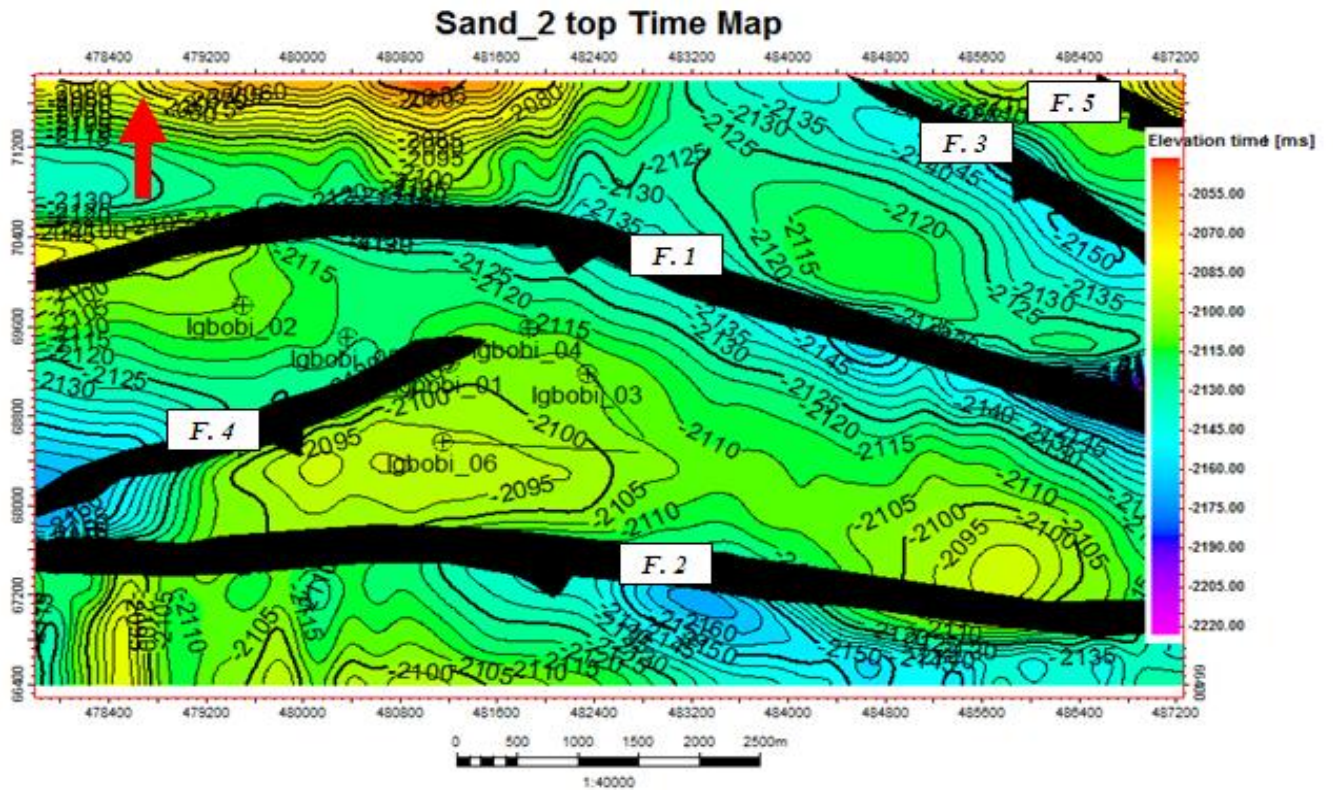


Figure 12a. Time map of Sand 2

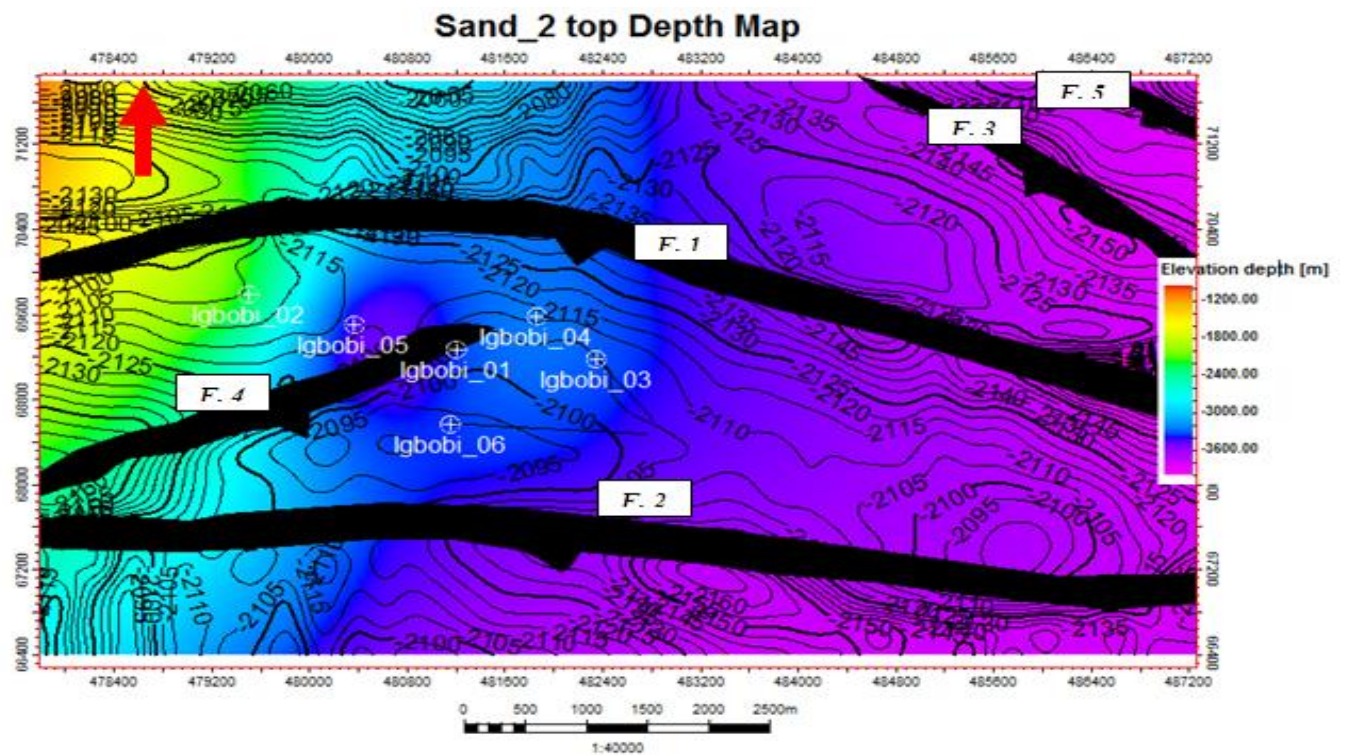
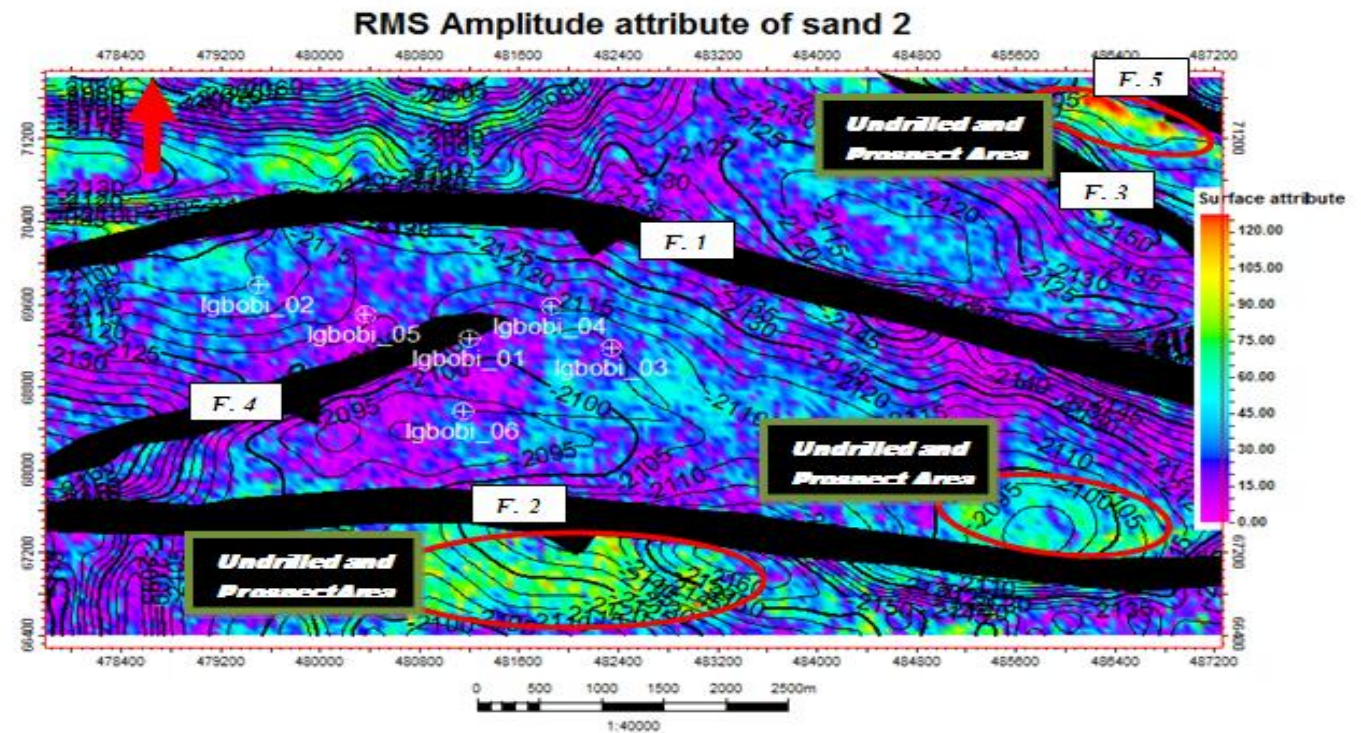
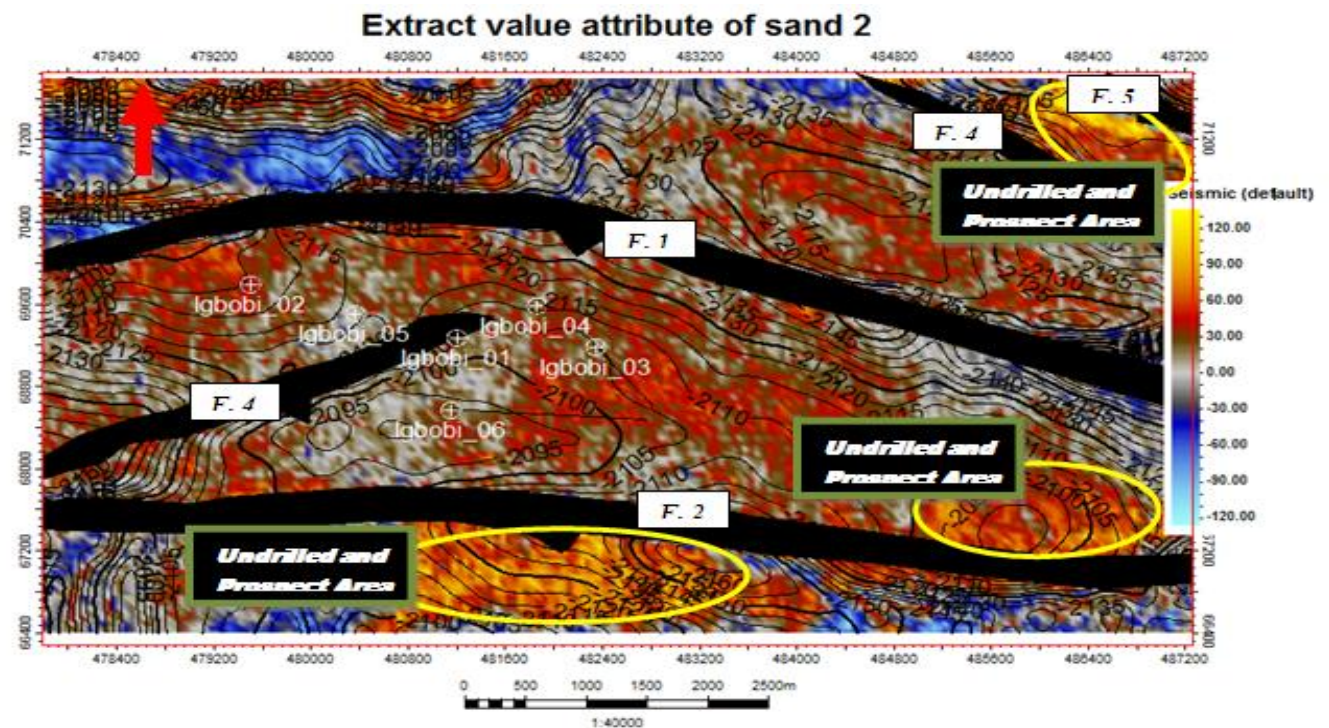


Figure 12b. Depth map of Sand 2



(12ci)



(12cii)

Figure 12c Surface attributes extracted at 150ms window on Sand 2 showing High Amplitude event around Igbobi field wells associated with Hydrocarbon accumulation and other region with similar attribute anomaly also supported by structures in the rings

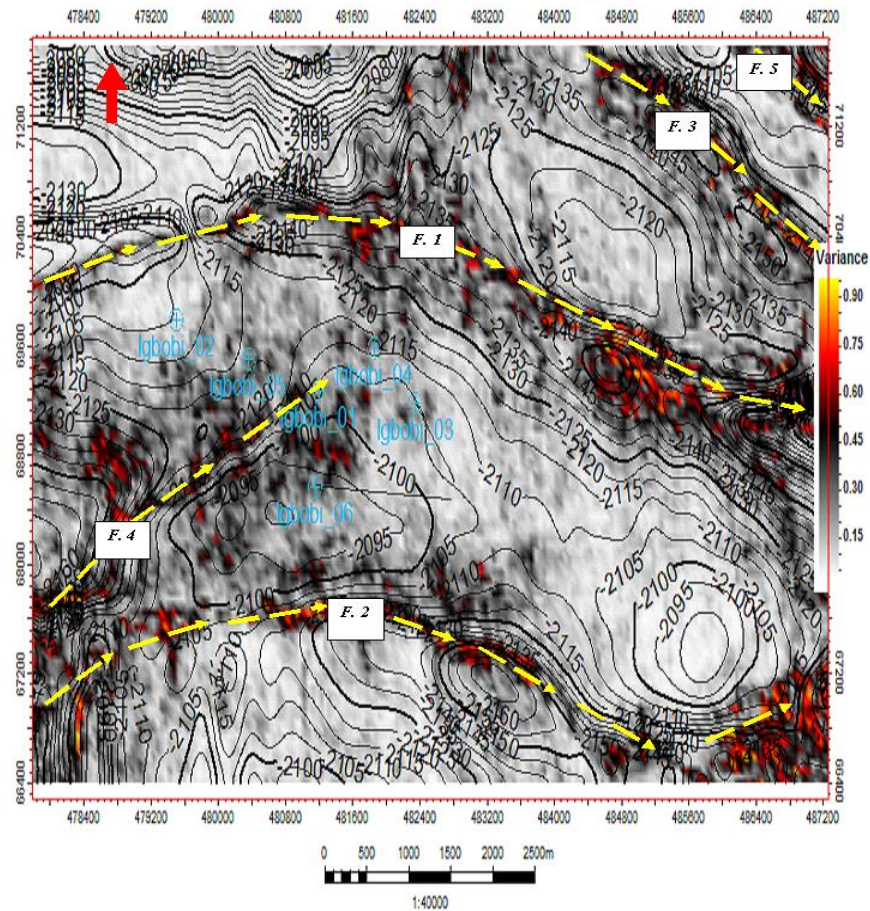


Figure 12d. Variance attribute showing the faulted area on the map of sand 2

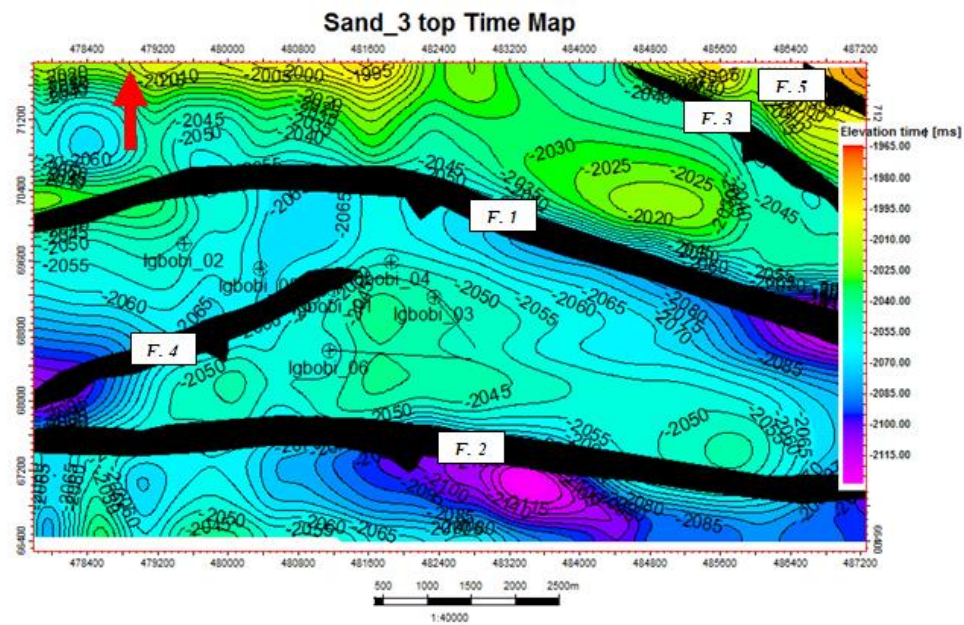


Figure 13a. Time map of Sand 3 top

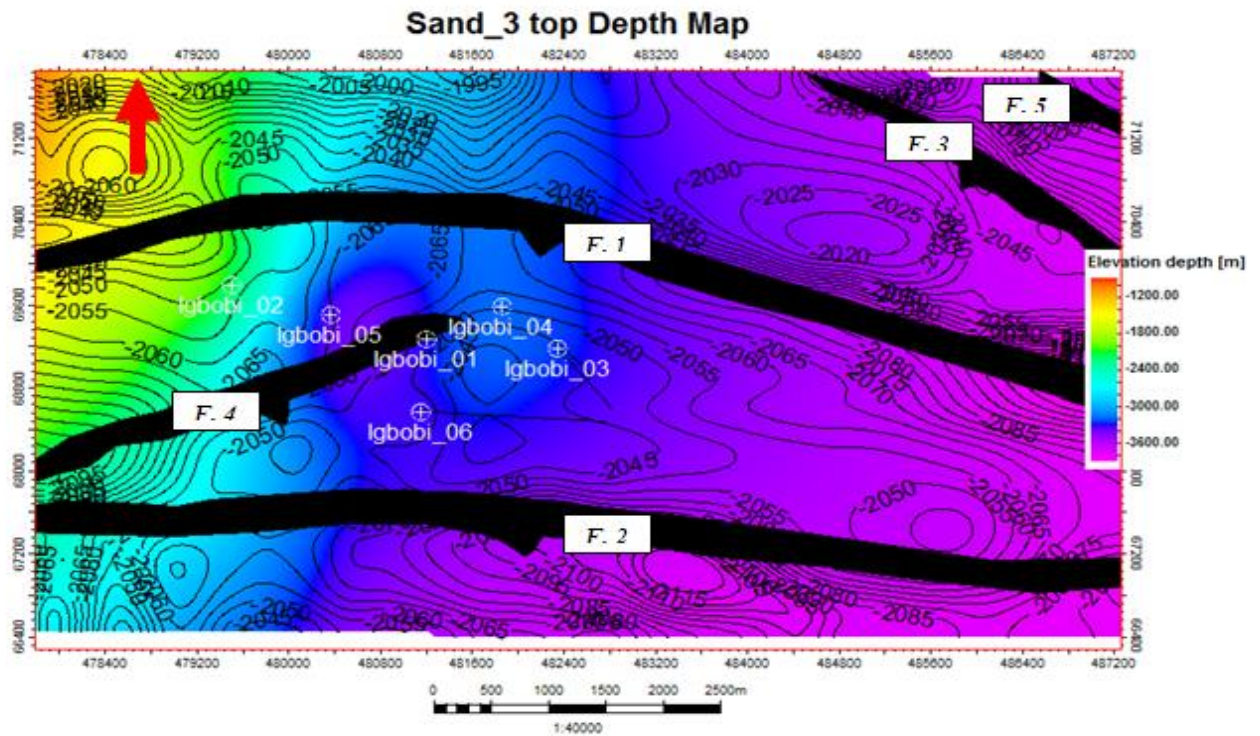
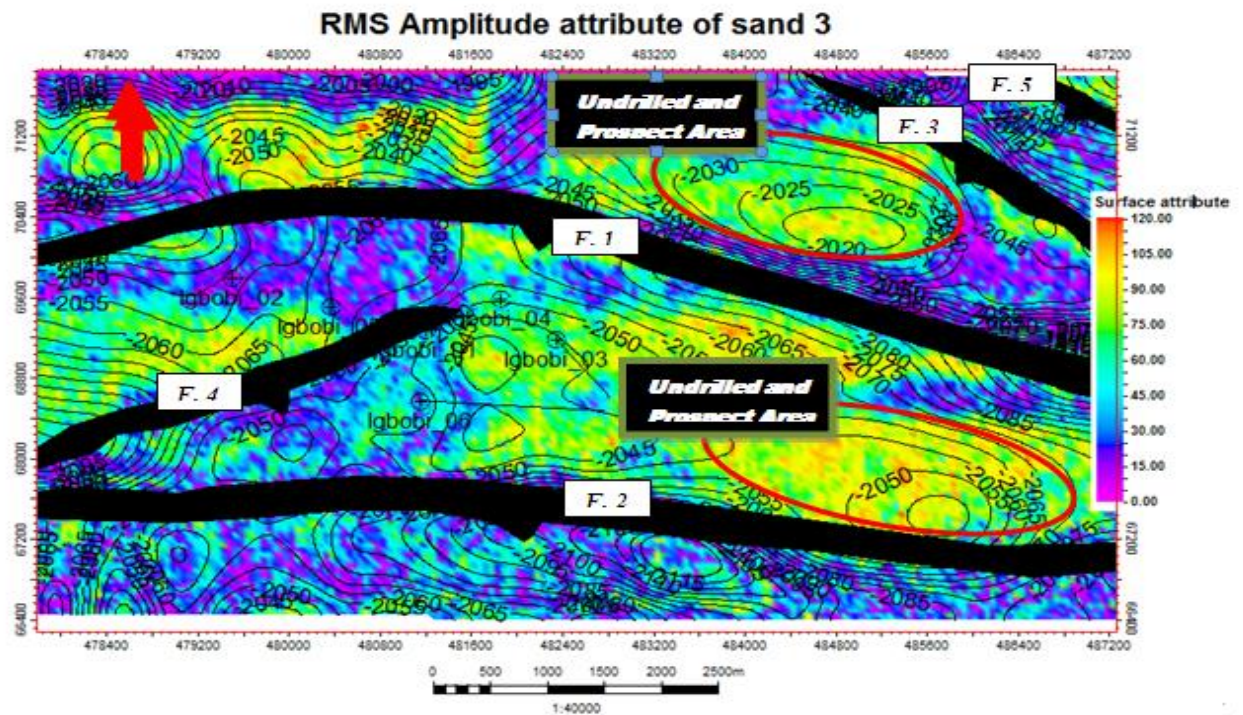
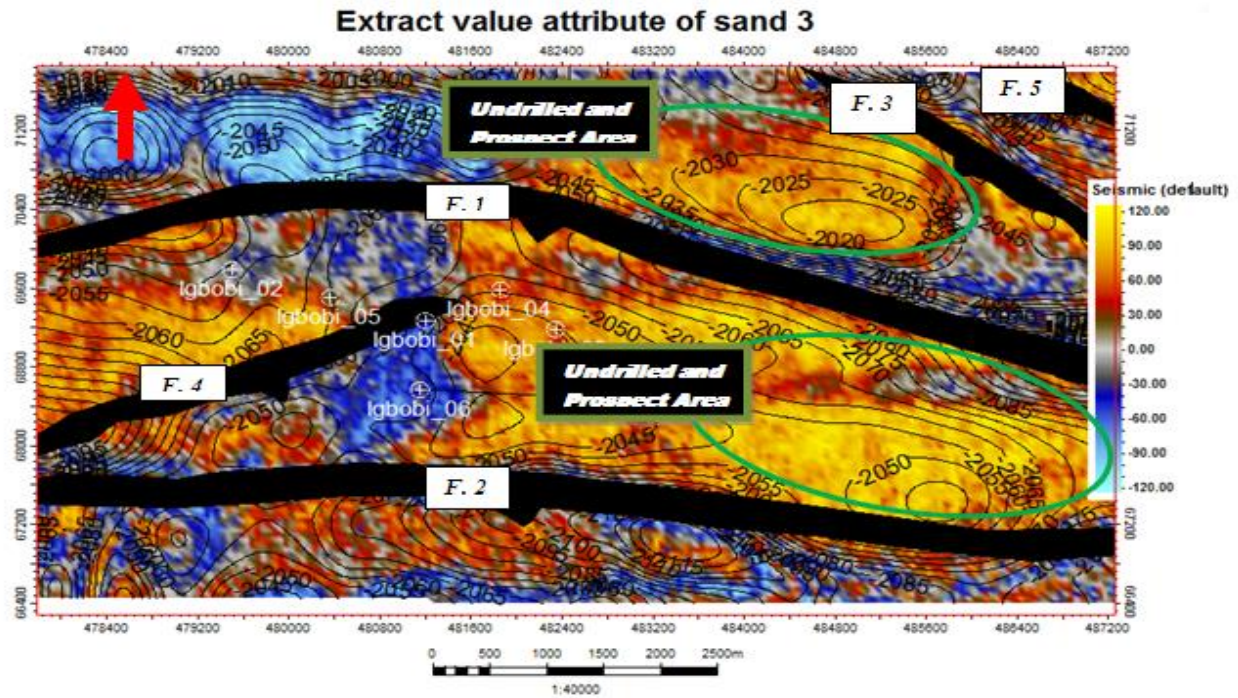


Figure 13b. Depth map of Sand 3 top



(13ci)



(13cii)

Figure 13c. Surface attributes extracted at 150ms window on Sand 3 showing High Amplitude event around Igbobi field wells associated with Hydrocarbon accumulation and other region with similar attribute anomaly also supported by structures in the rings

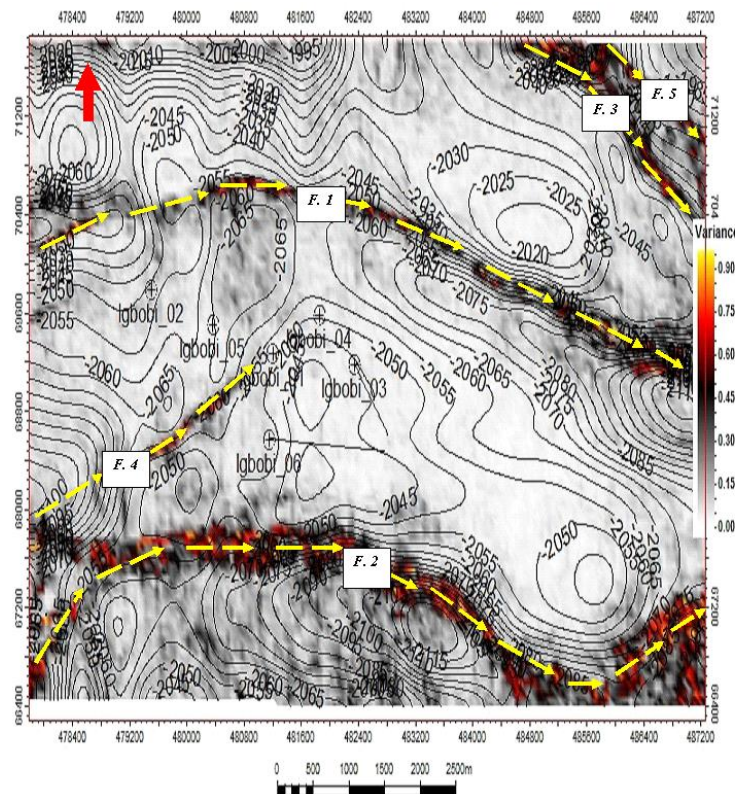


Figure 13d. Variance attribute showing the faulted area on the map of sand 3

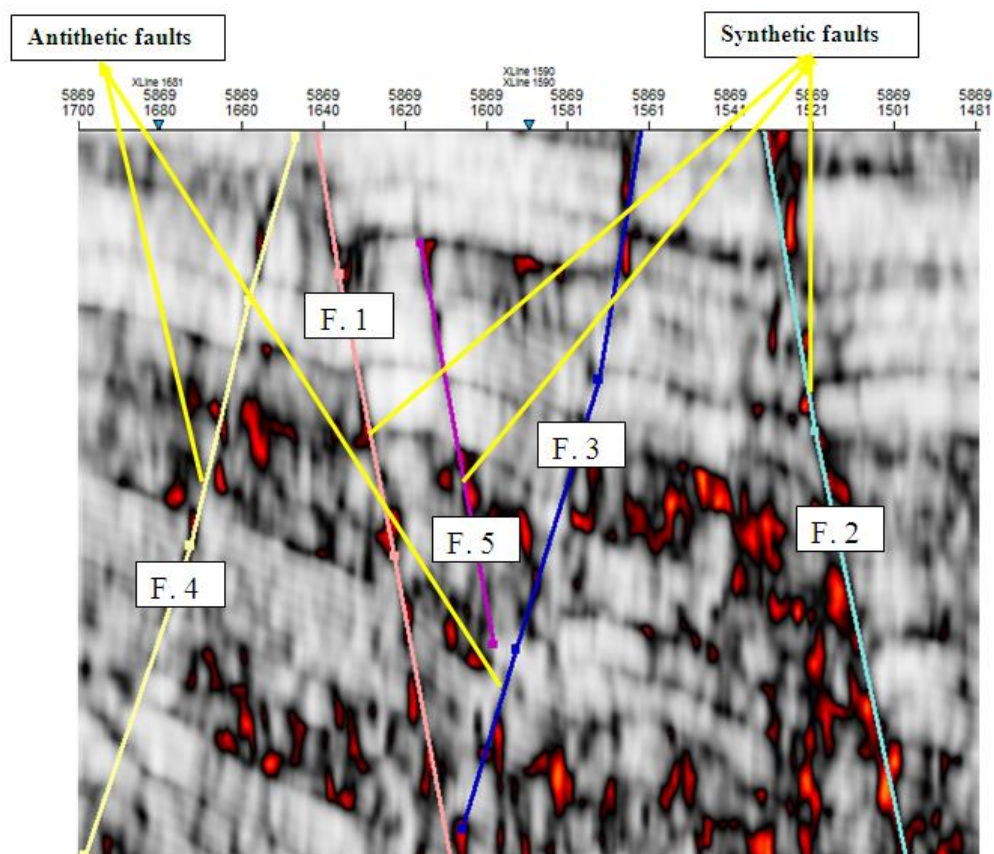


Figure 14. Inline variance attribute generated to enhanced the faults

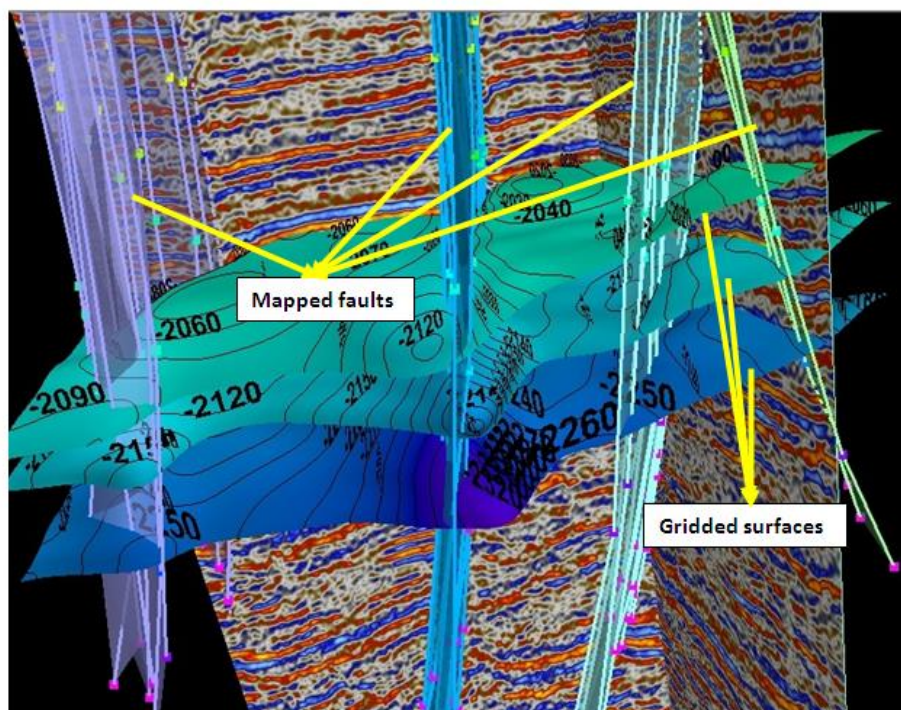


Figure 15. Gridded Surfaces from mapped Horizons and Faults on Igbobi Field

4.6. The structural interpretation

Basically, five faults (named F1 to F5) three of which are synthetic dipping South-East and two antithetic faults dipping North-West were interpreted from the inline (5869) sections (Figure 14). To reduce uncertainty in the fault interpretation and continuity across the seismic cube, variance attribute was extracted. The variance attribute is effective in comparing similarities of neighbourhood traces and hence effective in delineating discontinuities which might be masked by noise in the default seismic. It was used to determine the lateral continuity of each fault across the seismic cube.

Structural interpretations necessarily feed off stratigraphic interpretation and must be conducted somewhat simultaneously. For example, it is not possible to calculate the throw on a fault without being able to identify common horizons on either side of the structure. Conversely, to correlate a horizon from one side of a fault to the other, understanding of the fault geometry (whether it is a normal fault or reverse fault, etc.) is very essential. As with stratigraphic interpretation, vertical section, time slices and structural attributes will all be utilized together during the structural interpretation procedure and the results of interpretation on one display may be viewed and used to constrain and guide fault and horizon mapping.

4.7. Fault interpretation

Linear features related to seismic reflection truncations were assumed to be faults for significant horizons. Faults were mapped on every 10 seismic sections throughout the seismic cube (Figure 15). Faults were more prominent on the inline because they are commonly acquired in such a way that they are perpendicular to the regional fault trend. Faulted regions were enhanced with the aid of various attributes.

4.8. Identification of traps, prospects and reserve evaluation

Structural Traps were identified from the closures on the Time Structural Map generated for each Sand Top. The contour patterns were used to identify fault assisted, fault dependent and anticline traps. Most of the closures have been penetrated by wells. Therefore, identified prospects were easily viewed. However, evaluation of tested traps was carried out to estimate reserves by integrating information on both structural maps and well log interpretation and seismic sections.

5. Conclusion

An integration of three dimensional seismic, well logs and structural analysis of Igbobi Field in the Niger Delta was carried out by applying a time-depth relationship to identify where the hydrocarbon bearing sands from well, post on the seismic lines. Structural Traps were identified from the closures on the Time Structural Map generated for the Sand Tops. The identified prospects were viewed and evaluation of tested traps was carried out to characterise the reservoir. Good tie was obtained for well to seismic data. The depth converted structural maps correlated with the time structural maps. The correlating zones where hydrocarbon bearing sands from wells, post on the seismic lines were identified. It is therefore recommended that Igbobi field is prospective and should proceed to further stage.

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To whom correspondence should be addressed: Dr. O. S. Hammed, Department of Physics, Federal University, Oye-Ekiti, Nigeria