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Frequency Attribute Analysis at *Euchis* Field, Niger Delta, South-Southern Nigeria for Structural and Hydrocarbon Delineation

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Abstract: - Aimed at enhancing hydrocarbon exploration in the Niger Delta, Nigeria; structural interpretation of at *Euchis* field was undertaken by analysing the frequency attribute of the reservoirs therein. *Schlumberger's Petrel 2017* software was used for data processing and interpretation of the field's Well logs. In order to facilitate the lithostratigraphic interpretation of the field, seismic-to-well tie was carried out using three dimensional 3D seismic data provided. Seismic attribute analysis and prospects identification were carried out for structural analysis. Lithostratigraphic interpretation shows that the *Euchis* field is predominantly characterized by sand-shale interbeddings. The frequency attributes map analysis indicated three distinct reservoirs with frequency ranges of ≈ -9 to 48 Hz, ≈ -9 to 51 Hz and ≈ -6 – 54 Hz respectively. Based on the inverse proportionality between the thicknesses of rock layers in the subsurface and peak frequencies of the seismic reflection, the lower frequency were delineated as indicators of hydrocarbon occurrence at the field. Lithologic correlation at the field showed that the occurrence of the Basin within the *Euchis* field fall within the depth range of 2500 m and 3360 m and the presence of intra-reservoir seals. The structural analysis revealed occurrences of normal, listric, regional and minor faults at various depths. The regional faults were observed to have cut across the three reservoirs, forming a conduit for hydrocarbon migration; whereas the minor faults serve as traps within the second and third reservoirs. The other faults were observed to have a predominant trend in northnorth-west south-south east direction.

Keywords: lithological facies, seismic frequency, amplitude, faults, hydrocarborn migration, hydrocarbon traps, hydrocarbon prospective zones

I. Introduction

The approach of seismic attributes interpretation is an integral part of seismic interpretation projects for over about five decades now. Analyses of amplitude, average reflection strength and spectral decomposition are very useful tools for locating reservoir quality, outlining their geometry and displaying lateral changes in thickness of structures (Ryan, 2007). In recent times, seismic attributes has widened its lithological and petrophysical predictions of reservoirs (reservoir characterizations). Particularly, the application to hydrocarbon exploration is broadened extensively (Brown, 2004). Frequency attributes analysis is the most vital methods involved in seismic decomposition which involves separation and classification of seismic events within each seismic signal trace based on their frequency content (Sheriff, 2002).

Basically, it is known that during the propagation of elastic waves, loses energy occur due to spherical divergence, scattering, intrinsic absorption and reflection at rocks interfaces. The loss of energy also uniquely influences variations in amplitude and frequency responses of reflected seismic waves. Particularly, the major factors which lead to the significant changes in frequency includes; geologic structures, layer thicknesses, lithology and pore fluid properties among others. Arrivals of seismic p-waves and s-waves provide the exploration Seismologist useful information about the characteristic frequency responses. The responses are utilized for delineating the stratigraphic features, rocks properties changes and fluid accumulations and properties discriminating it from their surrounding environment.

Firstly in spectral decomposition, each 1D trace from the time domain of the seismic are decomposed into their corresponding 2D representation in the time-frequency domain (time-frequency decomposition). These are achieved using short-time Fourier transform, continuous wavelet transform, Wigner-Ville distribution, matching pursuit, among many others. Once each trace has been transformed into the time-frequency domain, Next to the decomposition is band pass filter which is applied to view the amplitudes of seismic at any frequency or range of frequencies (Sheriff, 2002). Each of the band frequencies is considered as seismic attribute showing the geological patterns that may not be obvious in the other contracting frequency bands. It is known that the relationship between the thickness of a rock layers and the corresponding peak frequency of its seismic reflection is in the inverse. Hence, thinner rock layers are much more apparent at higher frequencies whereas the thicker rock layers are much more apparent at lower frequencies. The inverse proportionality is therefore applied for qualitative identification of various directions of the thinning or thickening of rock units.

In reservoir characterization and hydrocarbon detection, seismic low-frequency amplitude information plays an important role. Particularly, based on time-frequency seismic character of gas sand, frequency attribute analysis can be used as a direct hydrocarbon indicator (DHI) for the sandstone gas reservoir in the Niger Delta (Adepoju *et al.* 2013).There is direct relation between seismic low-frequency responses and the properties of hydrocarbon reservoir: the low frequency energy anomalies were directly associated with hydrocarbon reservoirs occurrence. There are numerous cases of successful applications the low-frequency anomalies of reflected p-waves which suggested hydrocarbon occurrences (Goloshubin *et al.*, 2006, 2014 and Li *et al.*, 2016). Such includes Taner *et al*. (1979) who noted the occurrence of lower frequencies beneath gas deposits and condensate reservoirs. Also, Castagna *et al.* (2003) showed that gas reservoirs could be identified by low-frequency shadows.

A combination of several attributes would significantly increases the reliability of detecting anomalies in either microtrem or wavefield which are presumably caused by hydrocarbon reservoirs (Marc-Andre *et al.* 2009), Bilal and Brown (2016) applied spectral decomposition by frequency attributes on stacked seismic traces to enable low-frequency analysis and comparison on two oil bearing reservoirs. The work revealed that the low-frequency anomalous response was strong at and below the interbedded heterogeneous reservoir.

Frequency attributes are also applied to assist in identifying low frequency AVO anomalies, which could potentially aid hydrocarbon detection. This is based on the fact that AVO is a frequency dependent technique which has been exploited to improve discrimination of fluid content from seismic data. Shengie and Ying (2019) conducted a study on seismic low-frequency amplitude analysis for identifying gas reservoirs within thinly layered media and a combination of the theoretical calculation and physical modelling results provided a reasonable explanation of the low frequency shadow. Hence, as posited from the study, actual hydrocarbon reservoirs exhibit low frequency among characteristics of fluid distributions of the reservoirs.

Some recent studies have shown that some oil wells in the area where the *Euchis Field* is located is dry owing to encounter of oil production having stopped shortly after drilling (Ibe and Iduma 2021). There is, in recent times a growing interest in new hydrocarbon prospects at Niger Delta Basin, south-southern Nigeria.

Therefore, there is need to research on the Structural Interpretation of the *Euchis* Field Niger Delta for Hydrocarbon Exploration. This is in order to minimise the rampant suspension of drilling. Low frequency attribute measurement and analyses of the field using the existing oil well logs with extrapolation, would give clues on the area's viability for hydrocarbon exploration. This study is therefore aimed at carrying out structural analysis and interpretation for hydrocarbon exploration in *Euchis* Field, Niger Delta Area, Nigeria using low frequency attribute analysis. The attribute analysis based on wireline logs shows the depositional facies, the facies correlation across available wells in the area, mapping of faults and reservoirs of interest, prospective zones for hydrocarbon production and lead ranking in the *Euchis* field.

The Study Area

Euchis Field is located within the Niger Delta Basin of south-southern Nigeria. The Niger Delta Area is one of the world's major hydrocarbon provinces; one of the world class oil provinces. The area is sitting directly on the Gulf of Guinea on the Atlantic Ocean in Nigeria in West Africa (Michael, 2013). Within the Niger Delta Area, the *Euchis* Field as indicated in yellow box under the legend is bounded by latitudes 3°N and 6°N and longitudes 5°E and 8°E; covering the an area of about 75,000 km^2 at an elevation of about 96 meters above mean sea level. The area is composed of an overall regressive clastic sequence which reaches a maximum thickness of 9,000 -12,000 m (Fatoke, 2010). Figure I shows the location of the *Euchis* Field in the Niger Delta Basin, Nigeria.

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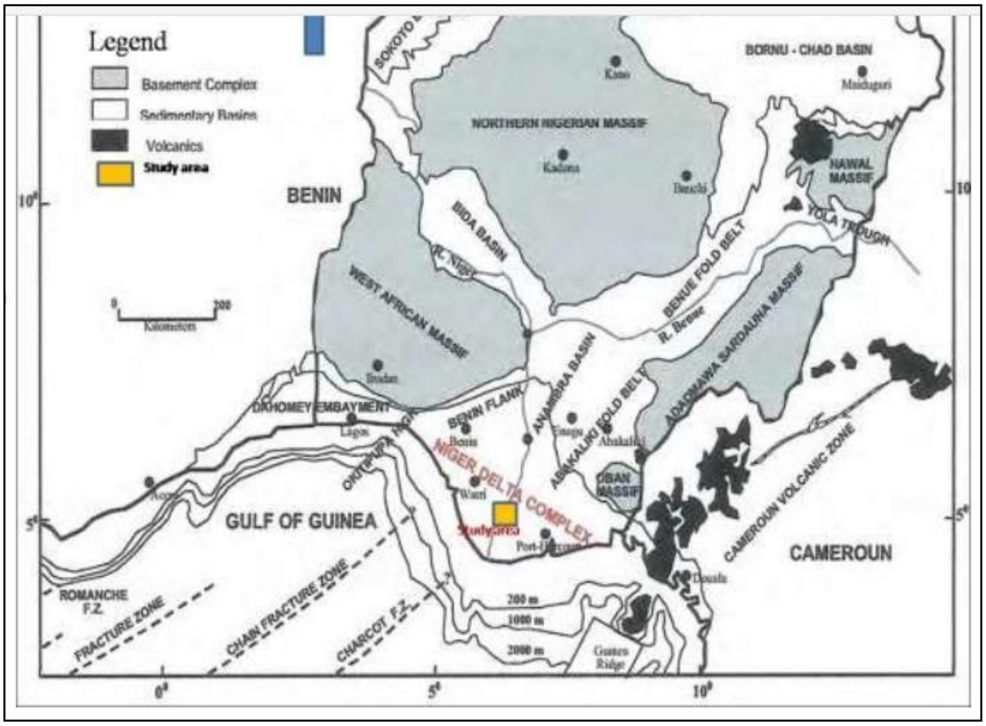

Figure I: Location of the *Euchis* Field in Niger Delta Basin, South-southern Nigeria

In the past few decades, Niger Delta Basin was known to have produced about2 million barrels of oil per day (Tuttle *et.al*, 1999). Currently, over 5000 wells have been drilled sited in the Basin (Raji and Abejide, 2013). Figure II shows the base map of the study area indicating all the drilled wells.

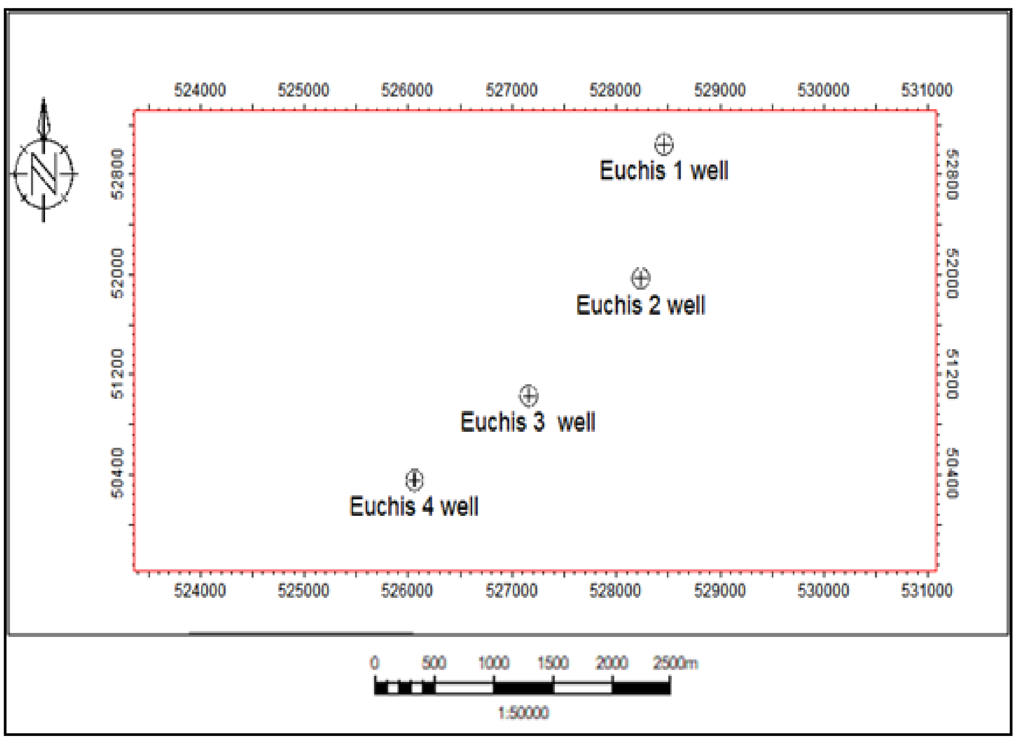

Fig. II: The base map of the study area indicating all the drilled wells

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II. Materials and Method

Data acquisition from the *Euchis* Field is composed of Well logs from four Wells namely 1, 2, 3, and 4 and three-dimensional (3D) Seismic reflection volume data of the Feild. The well log suit used for the study comprises Gamma Ray (GR) Logs, Spontaneous Potential (SP) Logs, Porosity Logs and Resistivity Logs, Density Logs, and Sonic Logs. The seismic data type is a time migrated zero phase data, with SEG normal polarity convention and the troughs (in blue colour) represent negative amplitude of the reflectivity or a decrease in acoustic impedance while the high amplitude impedance and reflectivity are represented in red colour (FigureV).

Next, seismic-to-well tie was carried out. That is; the logs data were integrated with the seismic data using time-depth data (checkshot data) and a synthetic seismogram was generated. Hence, based on established relationship between the well logs data and the seismic data the structural interpretations were carried out. The interpretations comprise that of bright spot mapping, faults and horizon mapping. Horizon mapping of the reservoirs was carried out to generate the individual surfaces of the reservoirs upon which fault modelling, time and depth structural maps were produced. The seismic section attributes were projected and viewed to enhance signal-to-noise ratio level, evaluate direct hydrocarbon indicators, enhanced for visibility of the faults and characterize them into seismic facies based on amplitude, geometry and continuity features.

III. Results and Discussion

Wireline (gamma ray) logs count which distinguishes regions of high and low natural radioactivity was obtained. Two distinct lithologic units namely; shaly facies and sandy facies were identified across the wells. The sandy facies signifies regions of low natural radioactivity were represented as the low gamma ray log readings while the shaly facies indicates regions of high natural radioactivity (Fig. III).

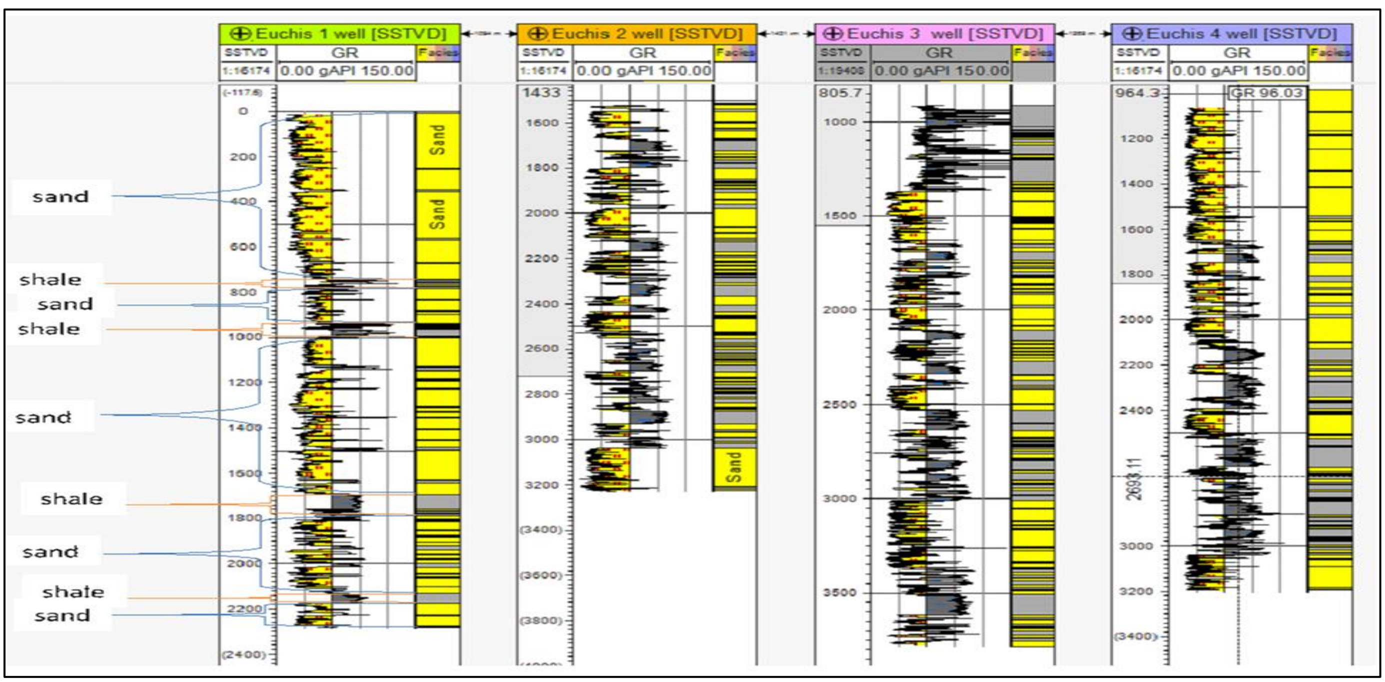

Fig. III: Lithologic Units Identified across the Four Wells

After the lithological interpretation, three reservoirs were identified and correlated across the Field in NE-SW direction in order of proximity from *Euchis* Wells namely; Well-1, Well-2, Well-3 and Well-4. Hence, it is observed that there were faults within the field indicated by the upward and downward displacement of reservoir tops, presence of a Basin of depths of 2500 m to 3360 m in the subsurface as seen between Wells-2, -3 and -4. There is intra-reservoir seals (shales) observed from the high gamma ray log reading. This agrees the findings Osaki *et al.* (2016) in the Basin. The lithologic correlation across the Four Wells is shown in Fig.IV.

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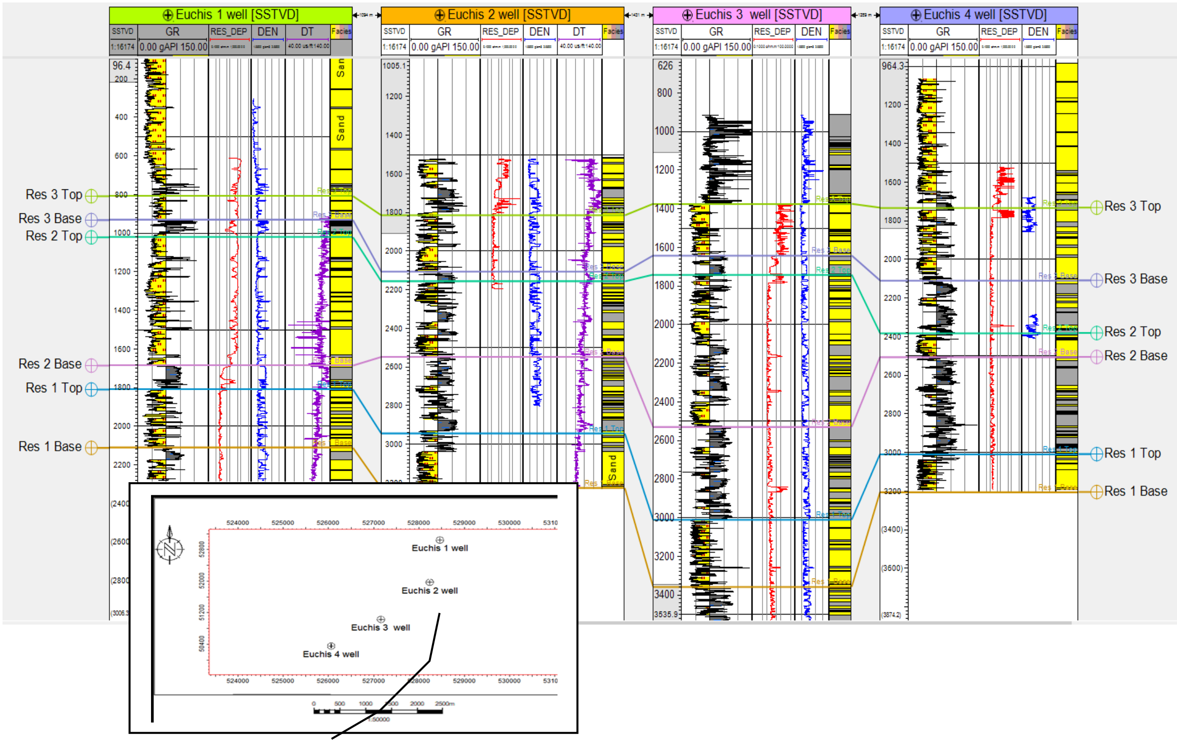

Fig. IV: Lithologic Correlation across the Four Wells

In order to establish a relationship between well log data and seismic data, seismic to well tie was done with Euchis I well checkshot data as the reference well. The acoustic impendance resulted from the product of the density log and the sonic log; the reflectivity (RC) produced from the acoustic impendence was then convolved with Ricker 25Hz to produce the synthetic seismogram. The generated synthetic seismogram showed a very good tie (Fig. VIII). The Seismic-to-well tie carried shows good density and sonic log readings which penetrate all the formations within the field. Upon convolving the the reflectivity with Ricker 25Hz wavelet, the reservoir tops such as Res 1 Top, Res 2 Top, and Res 3 Top fell on the trough which coincides with the blue reflectors while the peak coincides with the red reflectors.

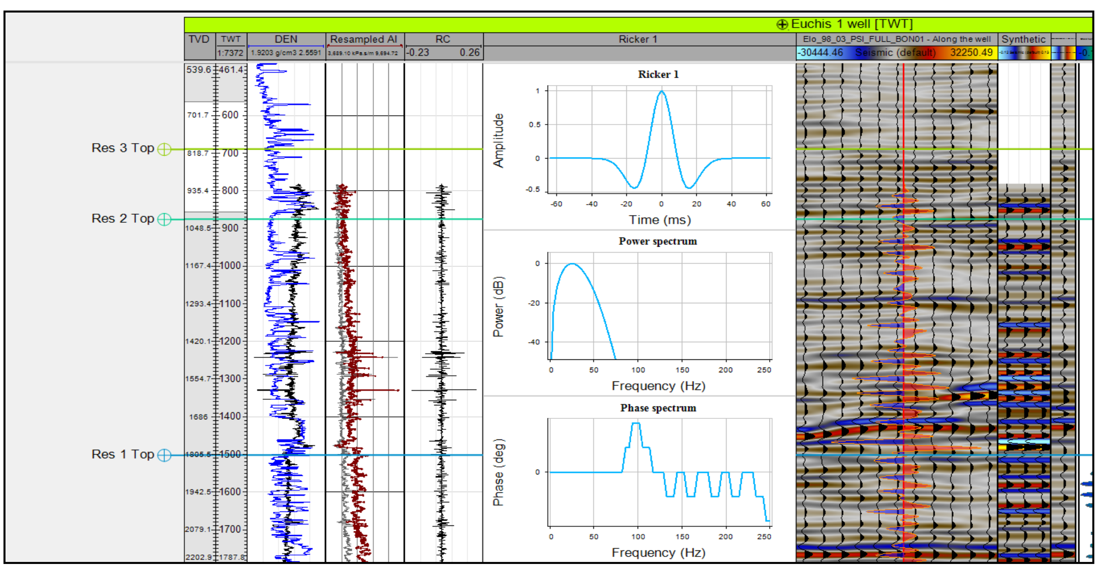

Fig. V: Display of Synthetic Seismogram used to tie the Well-logs to the Seismic Data.

After the seismic to well tie, mega faults and micro faults were all mapped in the field (Fig.VI). This is to ascertain the flow path of hydrocarbons and structural traps at the field. The mega faults mapped cut across the three identified reservoirs breaching the

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integrity of the seals. Normal faults were observed from the amplitudes of the displaced reflectors predominantly trend in NNW-SSE direction. Listric and growth faults were observed from the amplitudes of the reflectors showing decrease in dip with increasing depth in the subsurface. This is in agreement with the findings of Fazlikhani (2017) in the Basin. Regional faults were observed to have cut across the three reservoirs serving as conduit for hydrocarbon migration. This observation is most probably due to the bright spots along the plane of the faults. Minor faults were also shown serving as traps especially at the subsurface of the second and third reservoirs.

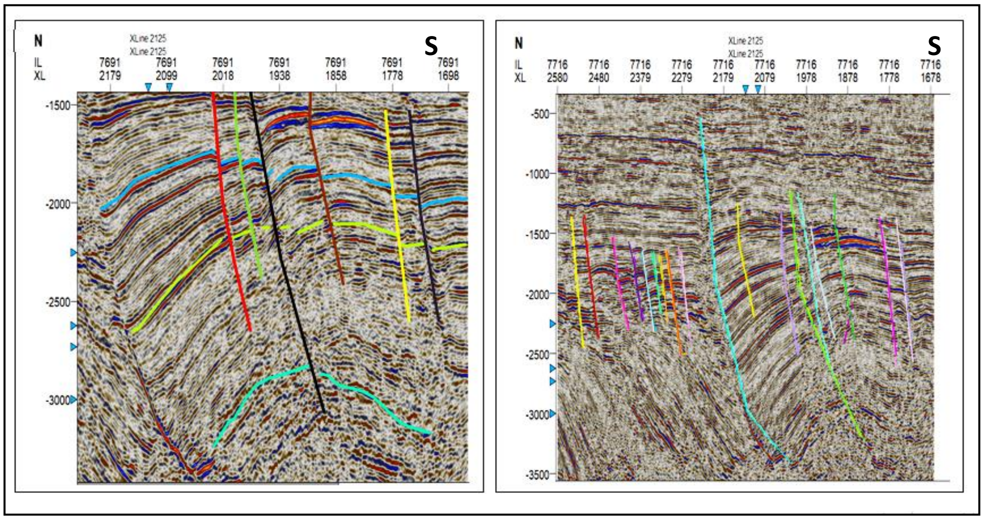

Fig. VI: Faults Mapped across Seismic Signals on Inline 7691 and 7716

Three reservoirs identified in the well logs were mapped across the seismic section (Fig. VI) according to the principles of stratigraphy. Three major reservoirs horizons tagged Res-1, Res-2 and Res-3 respectively were mapped. Res-1 depicts the oldest lithostratigraphic unit of Formation identified as to have fallen within Agbada Formation while Res-3 is the youngest of the three identified reservoirs. The delineated seismic horizons were based on the properties observed across the dip section of Inline-7866. It is observed that the Seismic Horizon 1 which corresponds to the Reservoir 1 top was observed to be discontinuous. This discontinuity was shown by the chaotic seismic reflectors which the top of the Reservoir 1 terminated abruptly. Also, the Reservoir 1 top reflector is shown to be exhibiting an upwarping pattern which could be depicted as an anticlinal fold. Reservoir 2 top which corresponds to the Seismic Horizon 2 was observed to have both upwarping and downwarping features which signify compressional tectonic activities (fold). Reservoir 3 top corresponding to the Seismic Horizon 3 was observed to exhibit both folding and faulting as shown from the geometry, continuity, discontinuity and amplitude of the seismic reflectors in the Figure X. Generally, the seismic reflectors were observed to have been deformed, discontinuous and displaced; these were attributed to faulting (extensional tectonics).

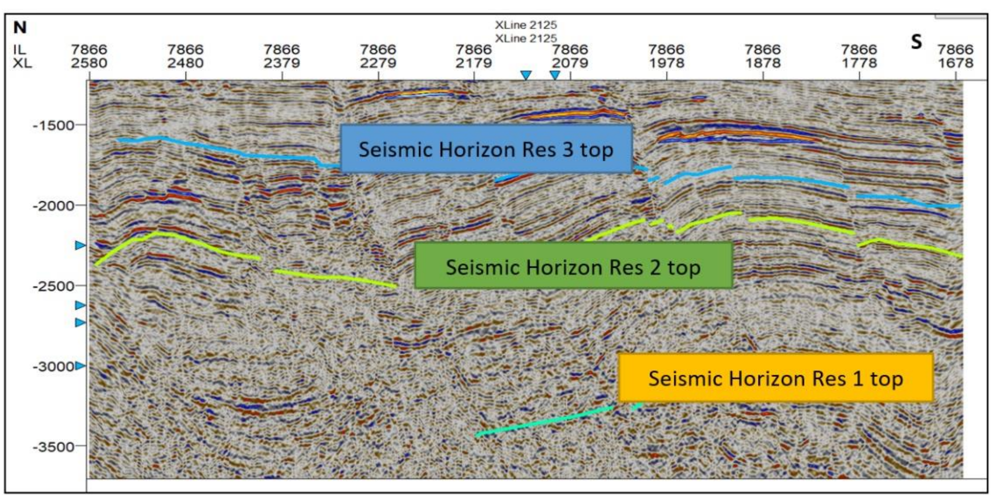

Fig. VI: Identified Seismic Horizons Serving as Reservoir Tops across Inline 7866

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Having identified the reservoirs in wells and seismic volume, Frequency attribute maps were extracted from the seismic reflection data to enhance the desired separation of seismic events within each trace based on variations in frequency values. The maps were shown in three identified reservoirs namely; Res-1, Res-2 and Res-3. The frequency ranges on the maps ≈ -9 – 48Hz, ≈ -9 – 51Hz and ≈ -6 – 54Hz respectively (Figures VII, VII1 and IX). The frequency values have inverse relationship with the thicknesses of rock layers of the seismic reflection. The thinner reservoir layers correspond with higher frequencies while the thicker reservoir layers correspond to the lower frequencies. Hence, the regions observed on the maps to have shown lower frequencies have higher chances of hydrocarbon prospectivity and this occurrences are within the thinner reservoir beds.

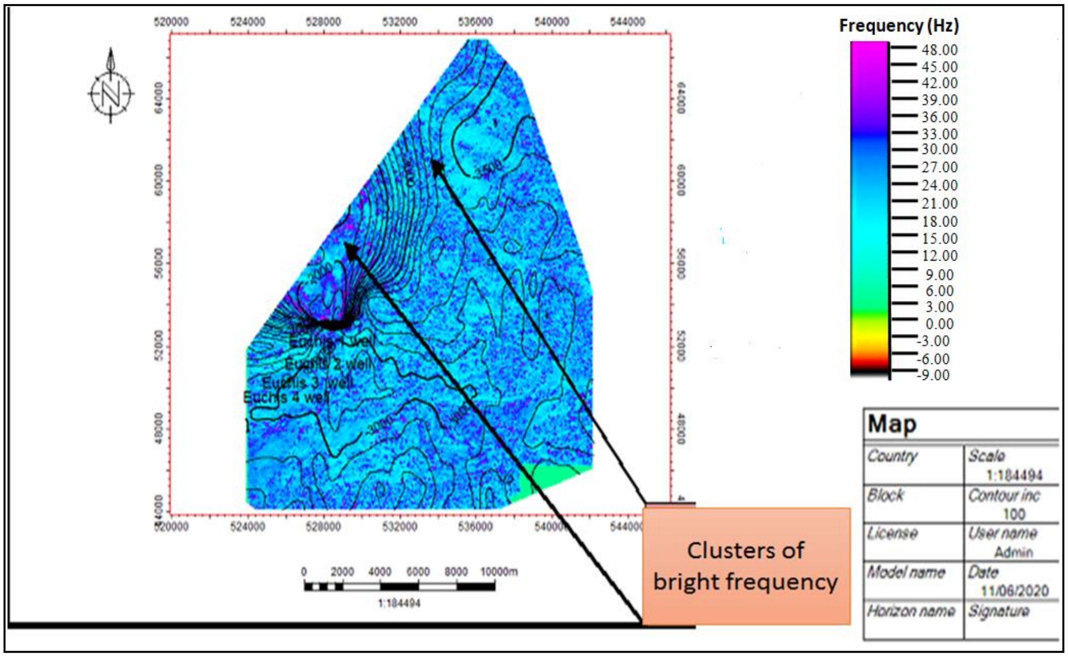

Fig. VII: Frequency Attribute Map for Res 1

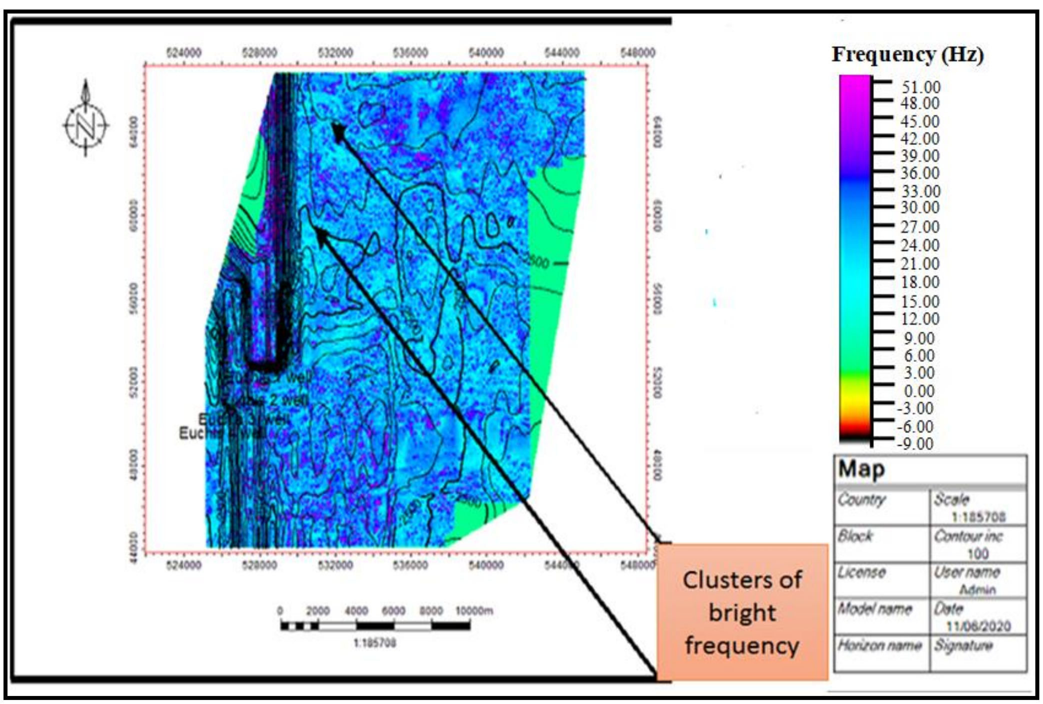

Fig. VIII: Frequency Attribute Map for Res 2

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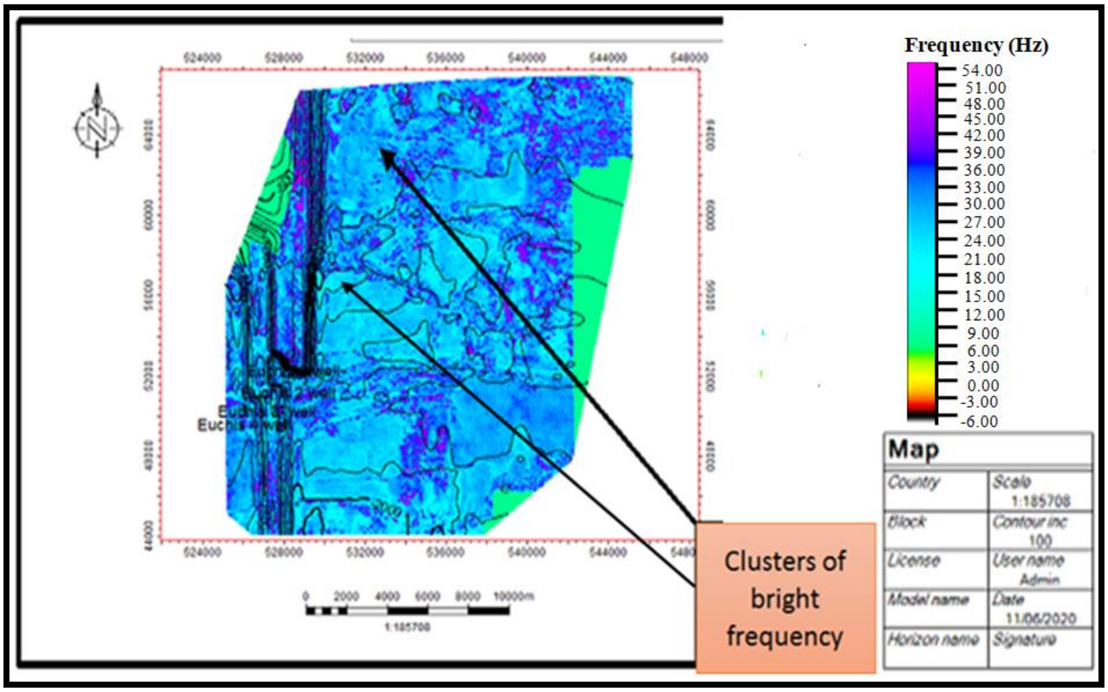

Fig. IX: Frequency Attribute map for Res 3

Time surface maps of the mapped reservoirs were generated. Fig. X shows the time surface maps for the three reservoirs which were measured in millisecond (ms). From the legends, orange colour zones are the regions with highest elevation time while purple colour zones are regions with lowest elevation time.

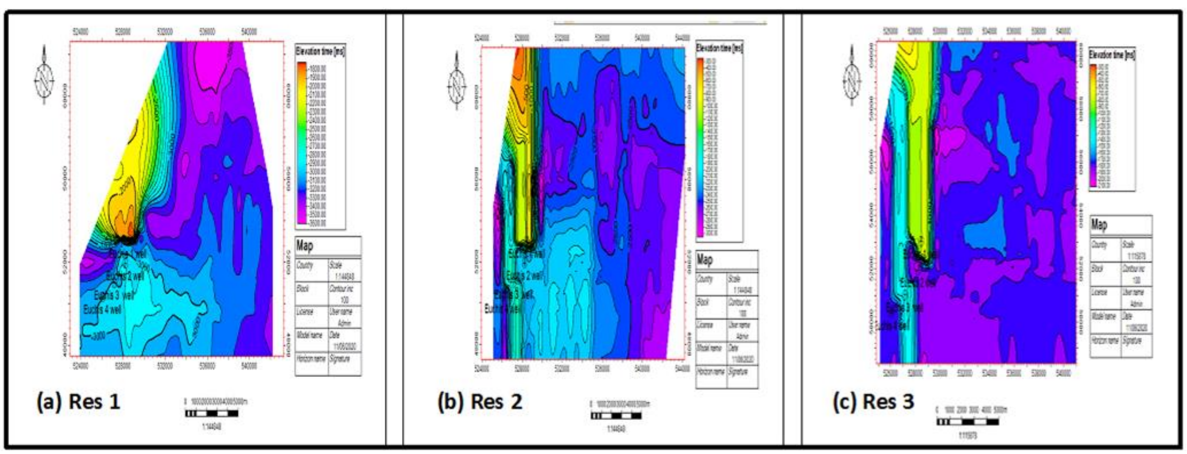

Fig. X: Time Surface Maps for the three Reservoirs

Time-depth conversion was done.Figure XI is the plot of depth Z in metres (m) against the two way travel time TWT in milliseconds (ms). It is a non-linear look-up plot invariably depicting a second order polynomial function. The look-up function was used in the time surface maps for the three reservoirs to generate the depth structure maps for the three reservoirs representing the function generated (Equation 1).

$$y = 73.0596 + 2.52965\,x + 0.000599318\,x^2 \qquad 1$$

Where y is the measured depth Z (m) and x is the two way travel time TWT (ms). Hence, the equation 1 was used for time-depth conversion.

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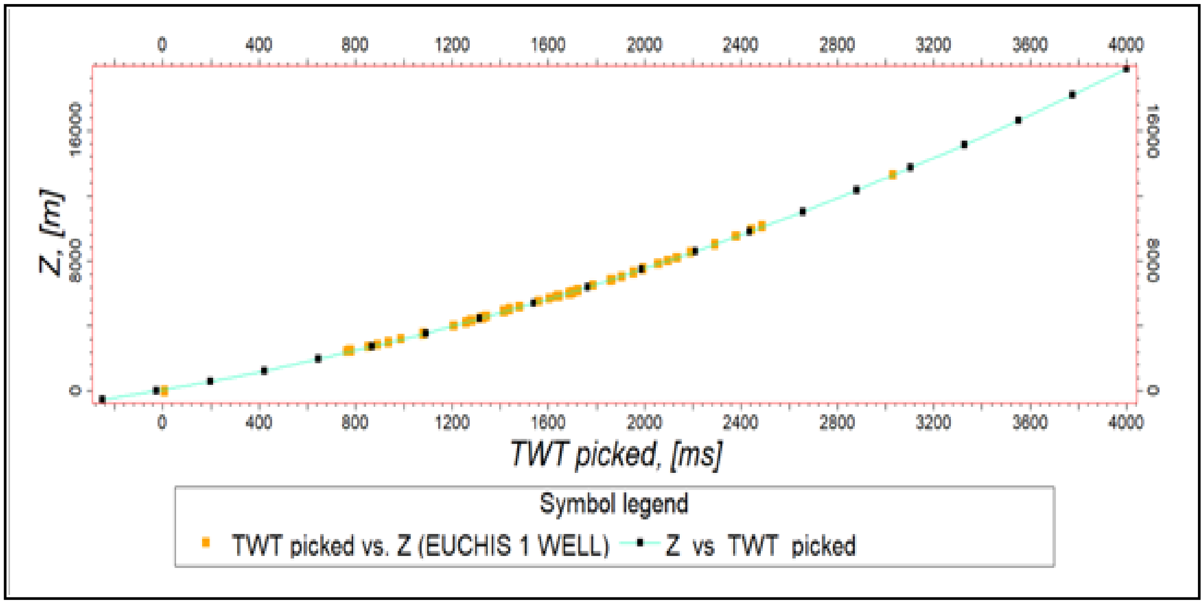

Fig. XI: A Polynomial Function (look-up) generated by the Plot of Z against TWT

The depth surface maps for the three reservoirs measured in meters (m) are presented in Figures XII (a - c). From the legends, orange colour zones are regions of highest elevation depth while purple colour zones are regions of lowest elevation depth. The time surface maps were converted to depth surface maps to enable the measurement of the depths at which hydrocarbons could be indicated.

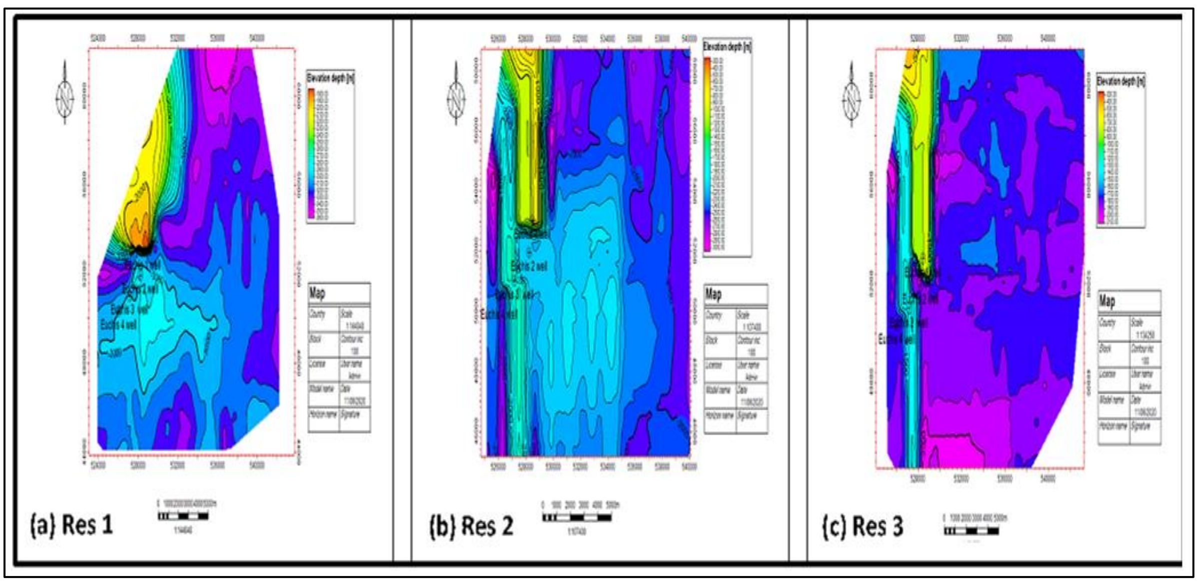

Fig. XII: Depth Surface Maps for the Three Reservoirs

Various exploration play facies were identified based on the seismic section. The *Euchis* field's seismic facies were tagged A-facies, Bh-facies, Cbh-facies, Cbl-facies, D-facies and E-facies (Figure XIII). The A-facies corresponds to the lower part of the Res-1 which is the oldest lithostratigraphic unit depicting a chaotic rotated blocks. The Bh-facies is identified at the upper section of the Res-1 indicating high amplitude discontinuity. The Cbh-facies seen at the middle part of the Res 1 signifies high amplitude convergent structure. The Cbl-facies were also observed within the Res-1 at the mid-section showing low amplitude convergent structure. The E-facies observed at the upper right section of the Res-2 corresponds to continuous low amplitude, high amplitude and Impedance structure. The D-facies were found in the upper section of Res-3 which correspond to continuous high and low amplitude. Generally, the analysis shows that the seismic facies having the best exploration play corresponding to the regions

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where the bright spots were identified; these are the Bh-facies and the E-facies. These two facies could be observed to have enhanced the behaviour of the reflectors in terms of amplitude, geometry and continuity.

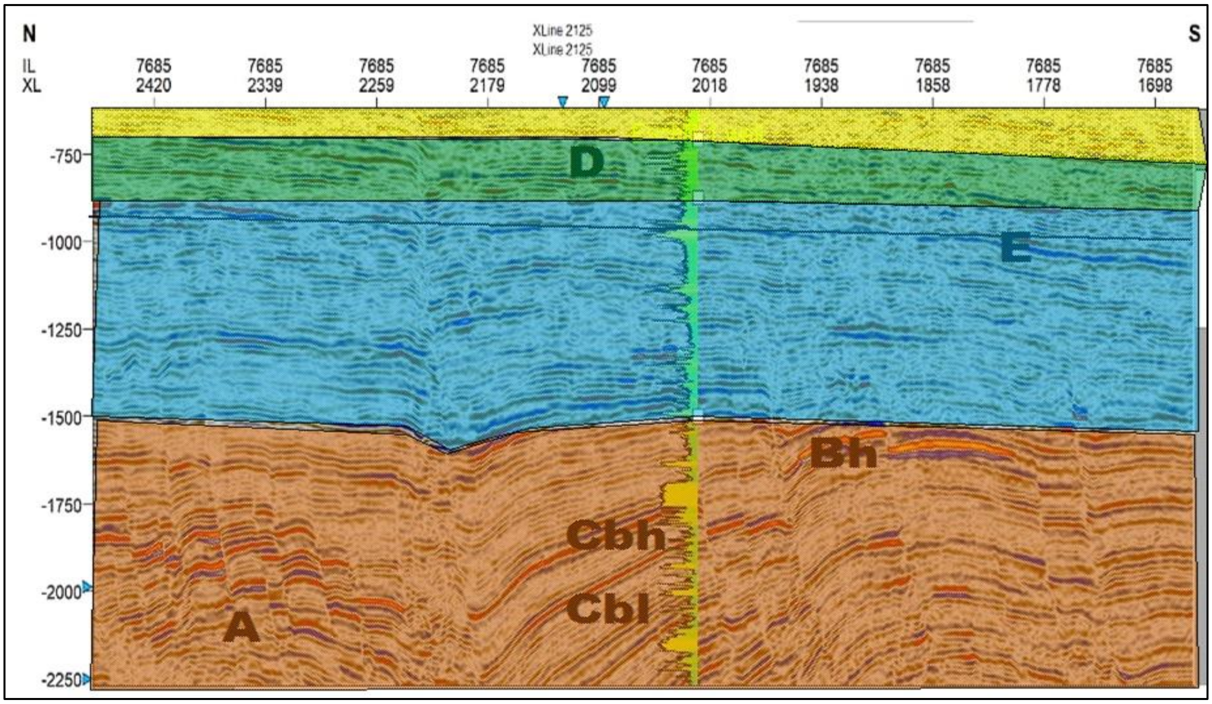

Fig. XIII: Identified Seismic Facies on Inline 7685

Figure XIVis the surface map showing the identified prospective zones on Inline 7685 in the three reservoirs. It could be inferred that one of the prospective zones occurs at Res-1 and Res-3 while two prospects exist in Res-2 occurs within the *Euchis* Fields. These prospective zones are enclosed with the red broken lines as can be observed at the northwestern part of the map.

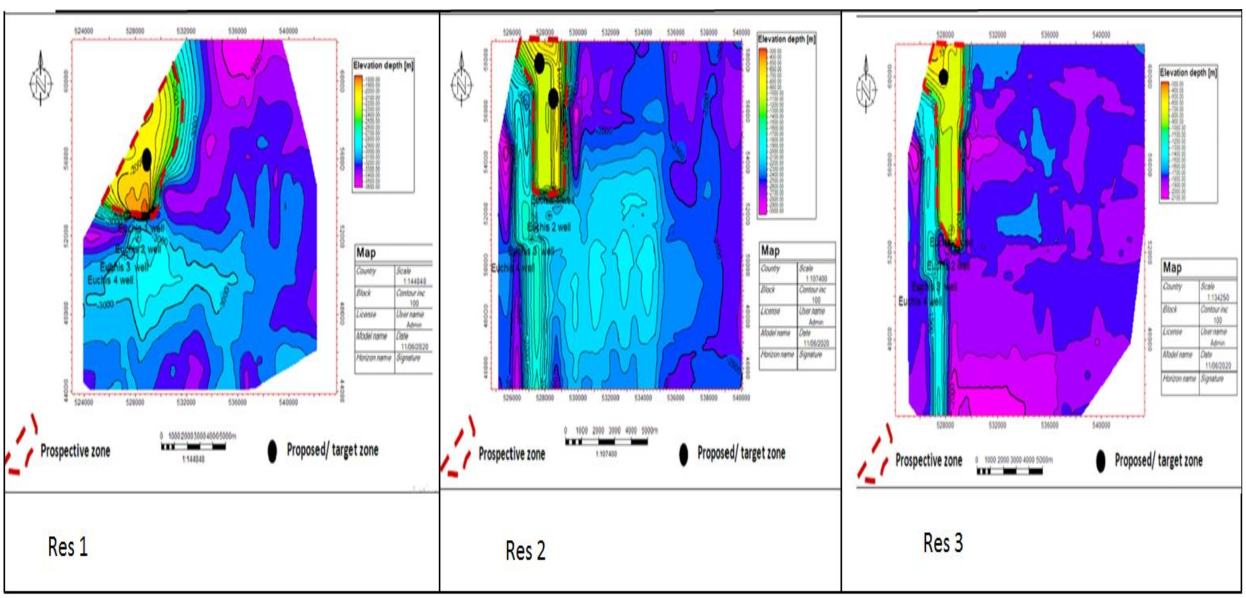

Fig. XIV: Surface Map showing Identified Prospective Zones in the Three Reservoirs

The legends attached to the three reservoir maps in the foregoing (Figure XIV) indicate that the pink and purple zones indicate regions of low elevations which correspond to the depocenters where sediments accumulated first. The light blue and green zones depict regions of high elevation and serve as the migration path for hydrocarbon to the upper regions. The yellow and red colours in the legends signify the regions of highest elevation regarded as the structural high. It was inferred that hydrocarbons at *Euchis*

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field most probably have migrated from the depocenters in the northeast, southeast and southwest to the adjacent structural high in the northeast. Hence the structural high forms the target zone (the prospective zone).

Iv. Conclusions and Recommendation

Two lithological facies namely; sandy and shaly facies have been delineated with the shaly facies intercalating the sandy facies at the *Euchis* Field. Three reservoirs characterised by seismic reflection frequency attributes of ranges; $\approx -9\ to\ 48Hz$,$\approx -9\ to\ 51\ Hz$ and $\approx -6\ to\ 54\ Hz$ respectively were delineated with the noting that the peak frequency values have inverse relationship with the thicknesses of rock layers. The three reservoirs correlated across the field in the NE-SW direction have shown the occurrence of faults within the field, the presence of a Basin at depth range of 2500 m to 3360 m and the presence of intra-reservoir seals. Four hydrocarbon prospective zones were delineated across the three reservoirs. Faults of various kinds namely; normal, listric, regional and minor were all delineated in the field. On special note, the regional faults were identified to have formed a conduit for hydrocarbon migration within the *Euchis* field. The minor faults were particularly observed to be serving as hydrocarbon traps within the field. Generally, the majority of the other faults were observed to have their trends in NNW-SSE direction predominantly. Finally, it is recommended that the future drilling for hydrocarbon within the study area should be with the consideration of the crest (zones marked by red dashes) delineated in Res-1which may be gas-bearing. This is to avoid or prevent tapping the gas cap which could lead to over pressure; causing a kick or blowout.

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