Qualitative Approach to Hydrocarbon Prospect Analysis within Amplitude Constrained Window: A Case Study of the Ava Field, Onshore Niger Delta

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ABSTRACT

Qualitative and quantitative study of seismic attributes is critical in hydrocarbon exploration and reservoir studies. However, due to paucity of critical dataset, quantitative studies may prove difficult; hence, the study of Ava field showcases how qualitative studies of the limited dataset can be effectively used to guide seismic attribute studies. A 90.73 sq.km 3-D seismic data, four well-log-data (Ava-1, 2, 3 and 4) and a check-shot-data from Ava-1 well was available for the study. Seismic structural interpretation, lithostratigraphic correlation of hydrocarbon bearing sands, well-to-seismic tie was carried out. Seismic-attribute analysis and amplitude extractions were done for direct hydrocarbon indicators (DHI) detection. Eleven (11) hydrocarbon-bearing sands (A, B-series, C, D-series, E, F, G, H, I, J and K sands) were correlated. Fluid discrimination studies using the neutron-density cross-plot and average-velocity plot revealed C and I-sands are gas sands which are possibly unconsolidated while others are oil-bearing sands. The deeper interval (1780ms – 1850ms) is characterized by bright amplitudes at the crest of the structure; sands E and F were associated with polarity reversals. A NW-SE major fault defines the trapping system for the central AVA structure, prospect and leads. An integration of the reservoir depth maps and extracted amplitudes using the Root-Mean-Square algorithm reveals the conformance of amplitude to structure at the central closure for only sands E and F, disproving the bright reflections at the deep prospective intervals are possible DHI. Application of qualitative seismic analysis method to attribute studies has helped in the DHI discrimination of the deep prospects in the Ava field.

Keywords: Qualitative analysis, Amplitude extraction, Seismic attributes, Hydrocarbon prospects, Direct Hydrocarbon Indicators

INTRODUCTION

Qualitative interpretation involves the conventional seismic techniques which include the marking of laterally consistent reflectors and discontinuous characteristics like faults. One of such qualitative approach to interpretation is seismic attributes.

Seismic attributes have evolved over the past three decades and have been invaluable in making far better accurate predictions and characterization of reservoir properties (Dorn, 1998). Sheriff (1999), Chambers and Yarus (2002), and Schlumberger (2009) highlighted the geological significance of seismic attributes as useful in defining lithological contrast, bedding continuity, bed spacing and thickness, depositional environment, geologic structures, gross porosity, fluid content, abnormal pressure, temperature, and polarity of seismic.

Anomalies due to variation in seismic attributes often appear in sections as Direct Hydrocarbon Indicators (DHI). DHI attributes are attributes that when observed in a seismic horizon, they indicate directly the presence of hydrocarbon to a very high degree.

Polarity reversals are DHI's that result from a change in polarity of the seismic response. It occurs when a shale (with a lower acoustic impedance) overlies a brine saturated zone (with high acoustic impedance) that becomes invaded with an oil or gas sand (with the lowest acoustic impedance of the three). Polarity Reversal is the same as local wave shape change. The changes in the acoustic impedance contrast from increase to decrease results in polarity been reversed. A change in the reflection from peak to trough is indicative of polarity reversal. (Brown, 2004).

Quantitative and qualitative analysis of DHI's are critical to hydrocarbon exploration. However, due to paucity of data, quantitative analysis - such as AVO, may seem far reaching. A combination of qualitative seismic attribute analysis techniques could equally prove useful for prospective analysis in order to effectively guide hydrocarbon exploration.

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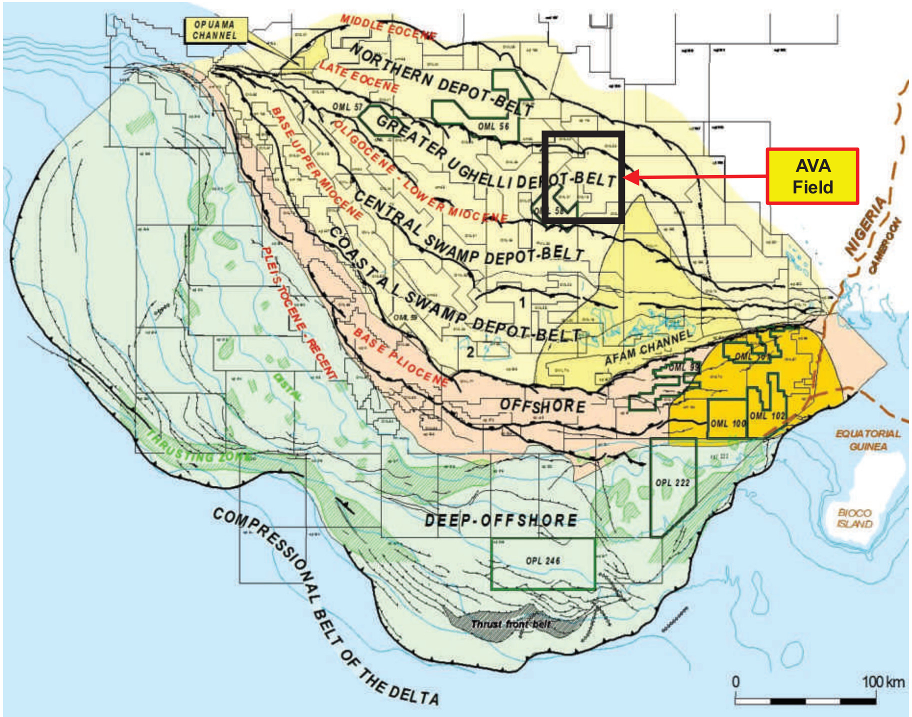

Figure 1: Map of the Niger Delta showing the location of Ava field.

STUDY AREA

The study area is located onshore, Niger Delta in the north eastern part of the basin. The Niger Delta is located in southern Nigeria, between Longitudes 3°E and 9°E and Latitudes 4°N and 6°N) and it covers an area of about 75,000km. The clastic fill of the basin is about 12 km thick (Doust and Omatsola 1990; Reijers *et al.,* 1997). The onshore portion of the Niger Delta Province is delineated by the geology of southern Nigeria southwestern Cameroon (Nwachukwu and Chukwura, 1986).

The geology of the field studied is within the Greater Ughelli depobelt (Figure 1). The depobelt is believed to be characterized by Lower Miocene – Oligocene deposits. The greater Ughelli is characterized by structure building growth fault, simple rollover anticlines, fault closures.

DATASET

The data available for the research include; Well data (LAS files) for four wells named as Ava 1, Ava 2, Ava 3 and Ava 4 (Figure 2), check shot data for Well Ava 1, deviation data for all four wells, 90.73 sqkm 3-D seismic data with poor resolution processed as 32-bit integer of the study area. The seismic volume includes cross lines

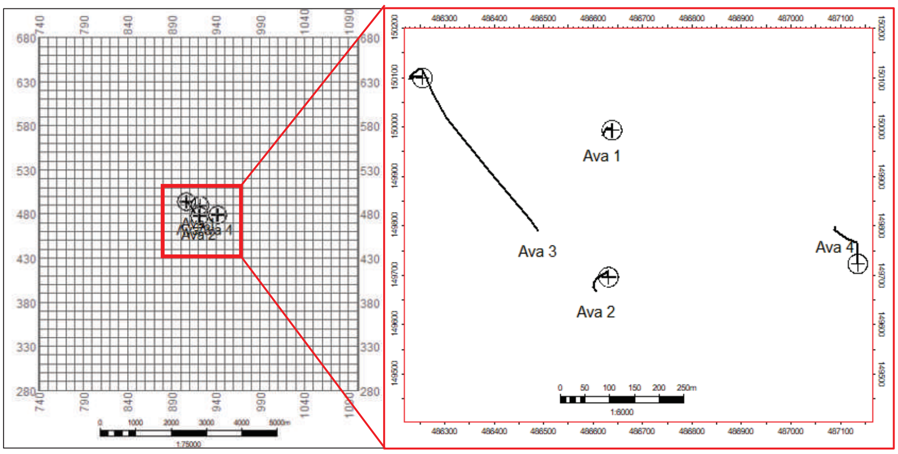

Figure 2: Base map showing the seismic survey well trajectories.

(strike line) ranging from 280 to 680 and in lines (dip line) ranging from 740 to 1100. The time data is from 0 ms to 8000ms.

METHODOLOGY

Structural reconnaissance of the seismic data was done using the variance attribute, fault interpretation, well data analysis and amplitude extractions. Hydrocarbon bearing reservoirs were correlated and the wells were integrated into seismic using the available check shot data. Further adjustment to the TWT to depth relationship was achieved by generating a synthetic seismogram in other to ensure the reservoir tops are tied to their true corresponding seismic reflections (Figure 3).

identified and delineated.

Amplitude extraction was carried out on the horizons mapped using seismic attributes such as RMS and other surface attribute that corresponds to the polarity associated with the reservoir tops e. g. Average negative amplitude at troughs, Average peak amplitudes at peaks and number of zero crossing attribute at zero crossing. Depth structure map was overlain on amplitude to qualitatively investigate if amplitude conforms to structure so as to verify if the bright reflection observed at the crest of the structure of some of the hydrocarbon reservoirs are truly DHIs.

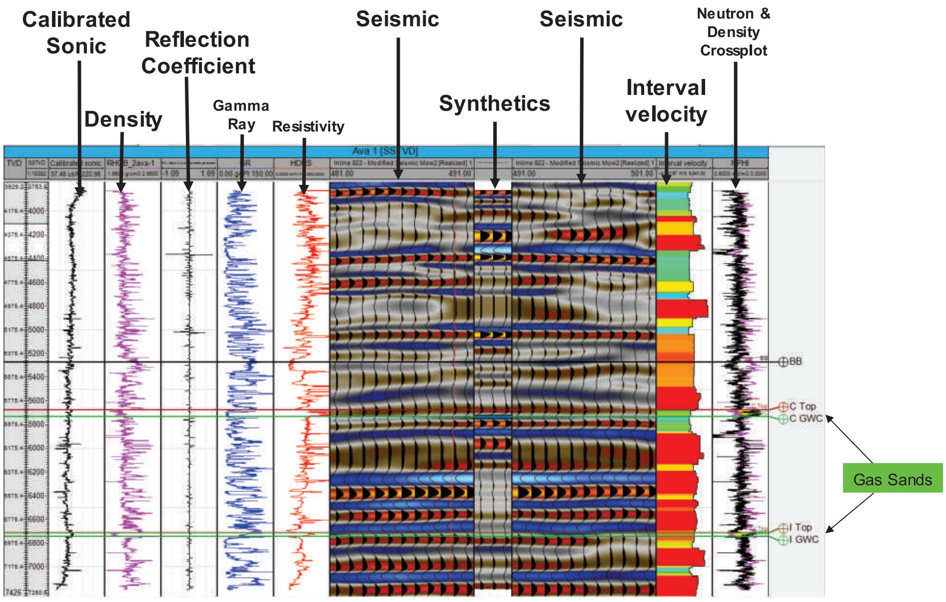

Figure 3: Synthetic seismogram along Ava-1 showing the gas sand intervals.

For fluid discrimination, perspectives were integrated from all suites of well logs which includes the Gamma ray, resistivity, neutron, density and sonic log. A significant deflection in the resistivity beyond the resistivity of water, within a sand body, is suggestive of hydrocarbon. Also, neutron and density crossover aided the discrimination between an oil or gas bearing reservoir.

A reconnaissance study of the seismic lines and time slices was carried out in other to visually investigate structural closures for possible DHIs. A strike line correlation of all identified hydrocarbon bearing sands was carried out and reservoirs were chosen based on their hydrocarbon type and possible DHI response.

The five (5) selected surfaces/horizons (reservoir tops) were carefully mapped and depth structure map were generated. Explored and prospective intervals were

RESULTS

Reservoir Correlation & Fluid discrimination

Eleven (11) hydrocarbon bearing reservoirs (A, B series, C, D series, E, F, G, H, I, J and K sands) were correlated across the four (4) Ava wells. A 307ft thick marine shale encountered by Ava-2 separates the shallow reservoirs (A to J) from the deep reservoir K. Such thick marine shales are typically aerially extensive and can serve as good regional markers and seals (Figure 4).

Reservoir C and I were interpreted as gas reservoirs due to their large contrast in the neutron and density response while other reservoirs with lesser contrast were interpreted as oil bearing sands (Figure 5). For a hydrocarbon bearing reservoir, an observable increase in contrast between the neutron and density log is indicative of gas while a relatively lower contrast is suggestive of oil.

A plot of the average velocity vs depth obtained from the synthetic seismogram shows several sharp decrease in average velocities within the Benin and Agbada formation (Figure 6). Within the Benin formations, two zones - Benin Sand-1 (BS-1) at -4336ft and Benin Sand- (BS-2) at -4973ft were picked. These two intervals correspond to clean sands with blocky gamma ray signature. At the Agbada formation, two low velocity intervals were identified within reservoir C (gas reservoir) and reservoir J (Oil reservoir).

Tuttle *et al.,* (1999) inferred that petroleum in the Niger Delta is produced from sandstone and unconsolidated sands predominantly in the Agbada Formation. Relatively, the velocity anomaly is due more significant in the Benin formation than the Agbada formation. The presence of this velocity anomaly in both formations, irrespective of their varying fluid type, suggest a lithological effect, possibly unconsolidated sands.

The anomalous zones observed in the average velocity plot has no preference for fluid type or formation but associated with their lithology. The anomalous low velocity zones were recognized within sands in both the Benin and Agbada formations and hydrocarbon bearing sands within the Agbada formation. This anomaly is possibly due to the unconsolidated nature of the sand.

Ava Structure

Variance attribute was employed to visualization and to guide the faults mapping within the subsurface intervals of Ava field. A total of five synthetic faults were mapped and labeled Cyan, Purple, Brown, Blue and Green faults (Figure 7). The faults are listric faults (Figure 2) which are typical of the Niger Delta growth structures and forms the major structural trap types identified in the Niger Delta (Doust and Omatsola,1990). The Cyan fault is the major fault within the field which trends in NW-SE direction while the other faults are relatively minor faults. The Ava central closure is at the hanging wall of the Cyan faults

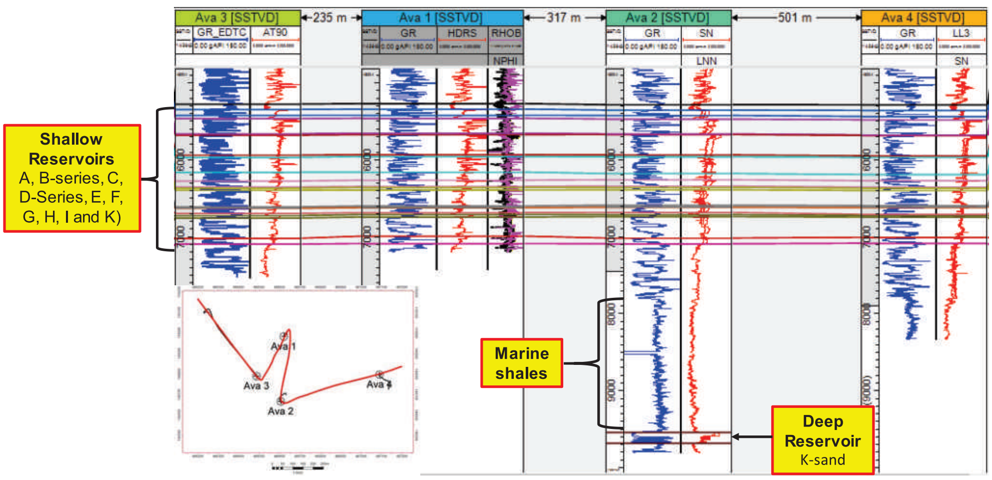

Figure 4: Strikeline correlation of Ava-3, Ava-1, Ava-2 and Ava- 4 wells showing the shallow and deep reservoirs.

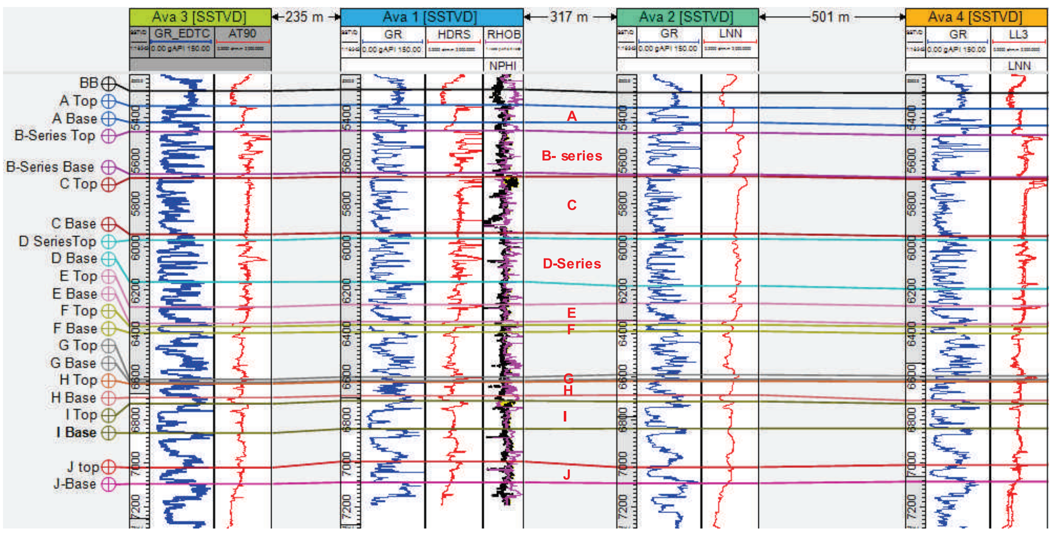

Figure 5: Strikeline correlation of Ava-3, Ava-1, Ava-2 and Ava- 4 wells showing the shallow reservoirs.

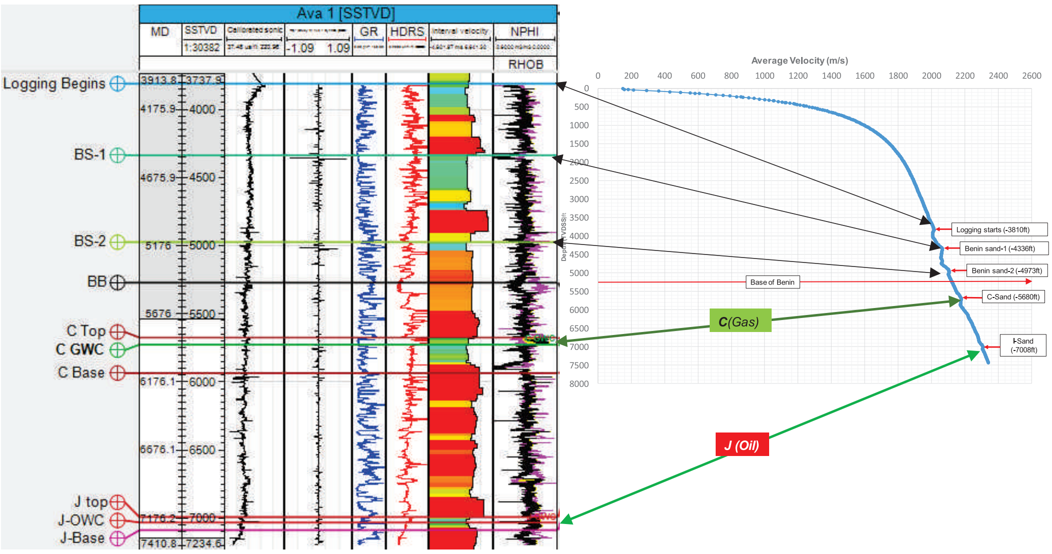

Figure 6: A relationship between the Ava-1 well logs and the average velocity anomalous zone.

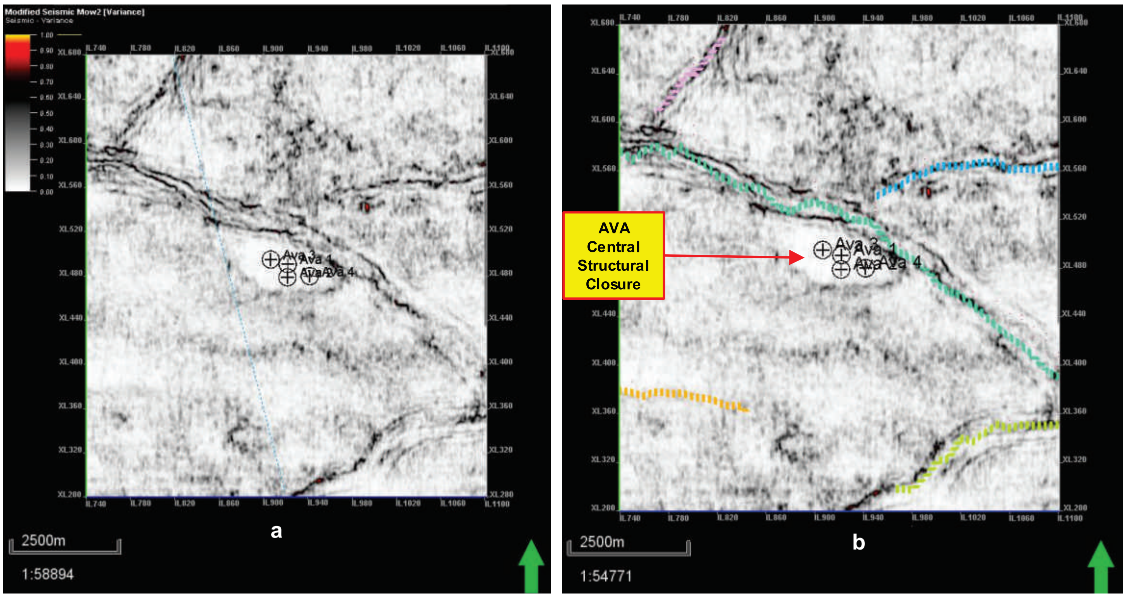

Figure 7: Variance attribute time slice 1720ms showing the structural framework within Ava field. (a) uninterpreted time slice (b) time slice showing the interpreted faults.

and has been penetrated by all the Ava wells.

Seismic section along Ava-1 further shows that polarity reversals were observed at the reservoir E and F only while G, H and I are characterized by bright reflections. There is a noticeable change from a trough to peak polarity downdip for reservoir E. On the contrary, a change from peak to trough was observed for reservoir F downdip (Figure 8).

Reconnaissance study of the time slices within the reservoir intervals shows that amplitudes are restricted within the oval shaped Ava structure for reservoir E and F but are absent in reservoir C, H and I intervals (Figure 9). In summary, polarity reversals are associated with amplitude restriction within structural closures.

Reservoir mapping and Attribute Analysis

Five (5) reservoirs within a time window of 1650ms - 1840ms were mapped. Reservoir C and I (Gas sands), reservoir E and F (polarity reversal) and reservoir H (bright reflection) were mapped in other to study the amplitude responses within the Ava closure and other prospective areas within each reservoir (Figure 10).

The depth structure map revealed a prospect NW of the Ava central closure. Two leads were identified and delineated at the west and east of the Ava central closure. This leads are potential structural closures whose full extent has not yet been completely defined due to the

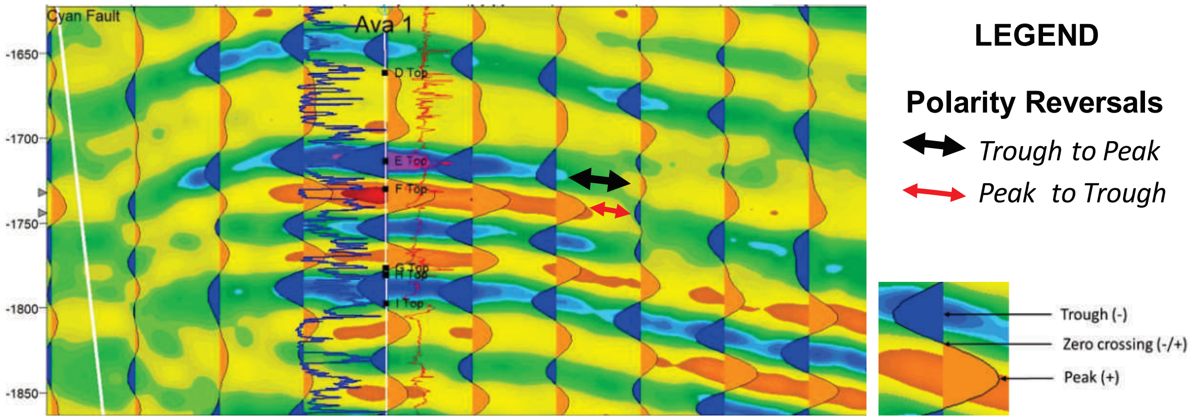

Figure 8: Polarity reversals associated with the reservoir E and F.

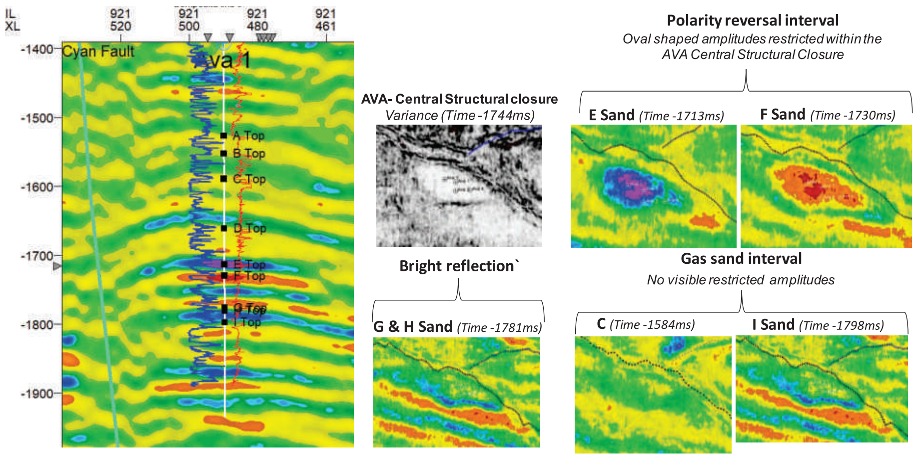

Figure 9: Time slices at reservoir intervals using a dB cycle color display showing the amplitude responses to hydrocarbon presence during the reconnaissance study prior to horizon mapping.

limited extent of the seismic coverage.

Horizon based amplitude extraction was carried out for all the horizons mapped. The windows used for this extraction is restricted to the time window that corresponds to the reservoir gross thickness (Table 1).

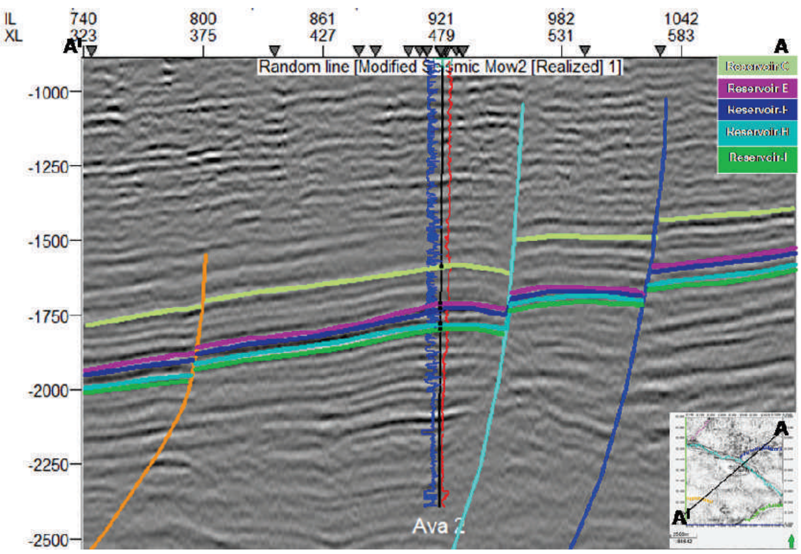

Figure 10: Seismic section showing all the horizons mapped.

Using this time window, the RMS, amplitude extraction was carried out for all the reservoirs. In addition, average positive, average negative and number of zero crossing attributes analysis was carried out for the horizon based on their polarity type.

Table 1: Showing the average sand thickness for each of the reservoir and their corresponding TWT time window. Amplitude extraction for each of the horizons was constrained within their respective time window.

Reservoir	Average Thickness (ft)	TWT Window (ms)	Polarity at top of reservoir
C Sand	260ft	69	Zero crossing (-/+)
E Sand	79ft	15	Trough
F Sand	32ft	5	Peak
H Sand	63ft	12	Zero crossing (+/-)
I Sand	34ft	6	Zero crossing (+/-)

The structure map was overlain on the various attributes extracted in other to investigate if amplitude conform to structure. Amplitude conform to structure at the Ava central closure and Ava West Lead, for oil bearing reservoirs E and F which are characterized by polarity intervals (Figures 11, 12, 13, 14 and 15). Amplitude does not conform to structure for both the gas sands (C and I) and reservoir H bright reflection (Figure 16).

The oil-bearing reservoir E and F are characterized by polarity reversals and amplitude conformance to structure at the Ava central closure. This polarity reversal is due to the two reservoirs being overlain by a shale with a low acoustic impedance. Reservoir E and F contains brine which has a high acoustic impedance and was later invaded by oil (with a relatively low acoustic impedance than the overlying shale and brine) consequently, resulting in the polarity of the reservoirs being reversed.

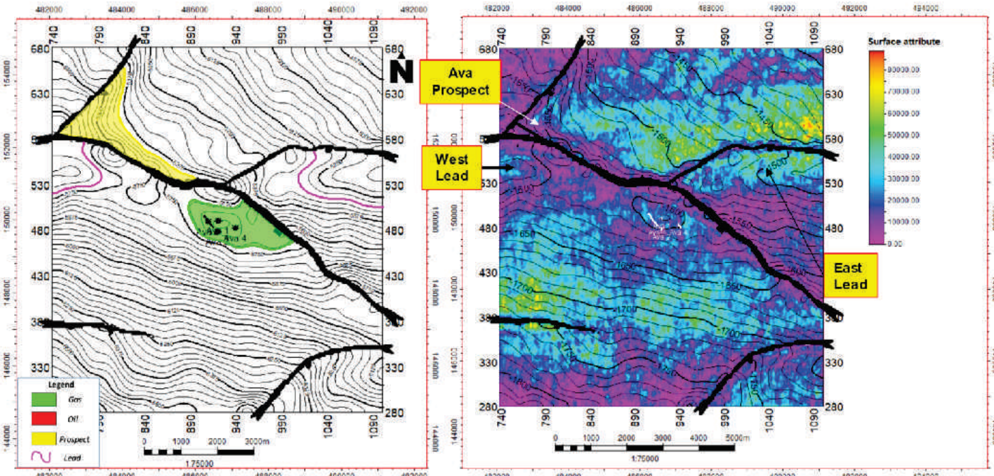

Figure11: Reservoir C depth structure map and RMS amplitude map showing the amplitude responses to the explored Ava central closure and its surrounding prospect and leads.

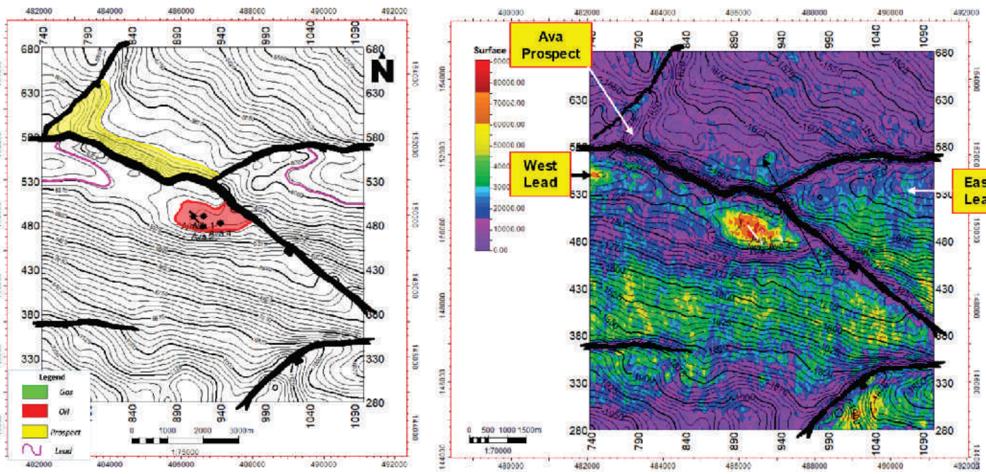

Figure 12: Reservoir E depth structure map and RMS amplitude map showing the amplitude responses to the explored Ava central closure and its surrounding prospect and leads.

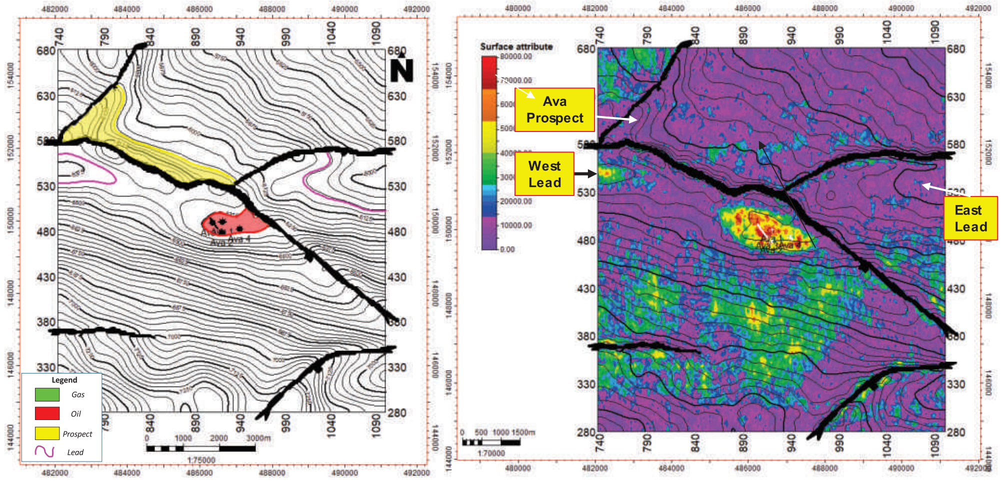

Figure 13: Reservoir F depth structure map and RMS amplitude map showing the amplitude responses to the explored Ava central closure and its surrounding prospect and leads.

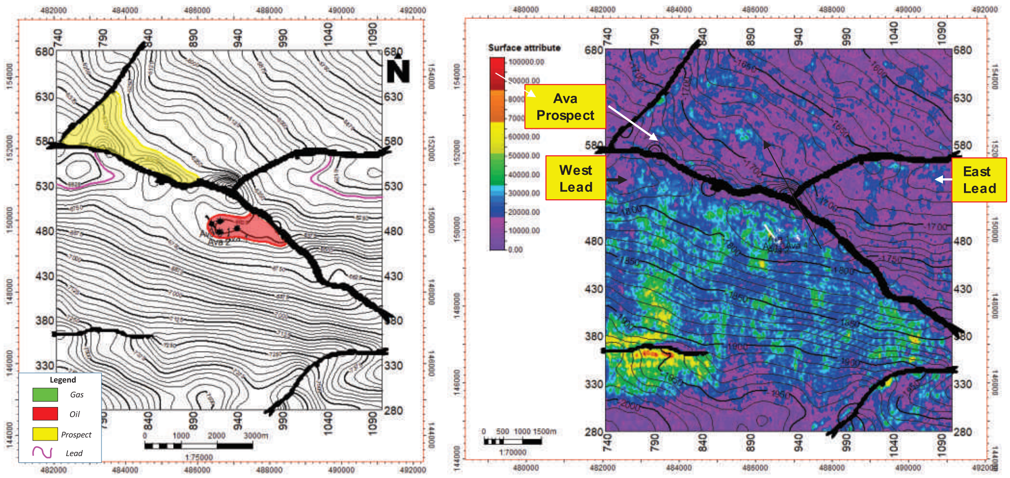

Figure 14: Reservoir H depth structure map and RMS amplitude map showing the amplitude responses to the explored Ava central closure and its surrounding prospect and leads.

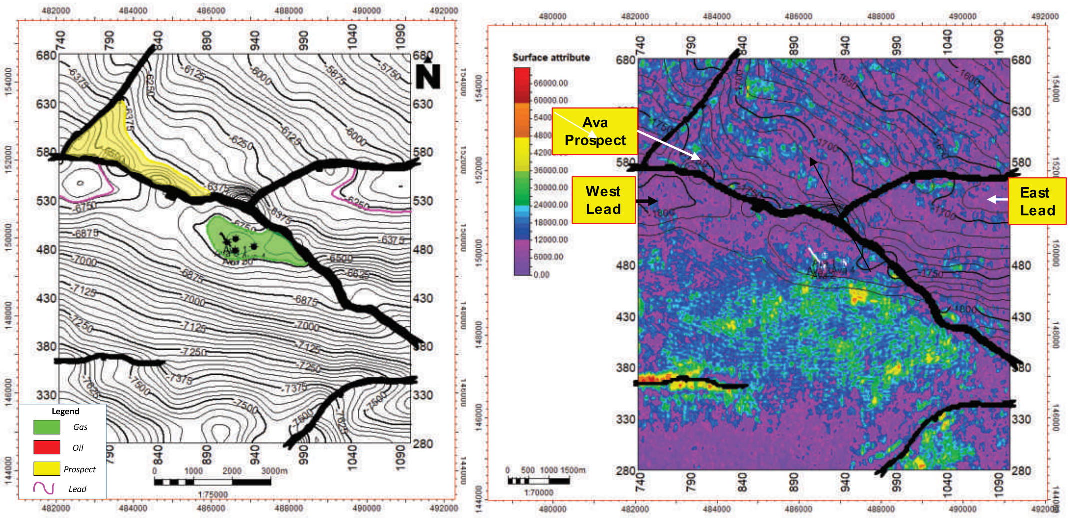

Figure 15: Reservoir I depth structure map and RMS amplitude map showing the amplitude responses to the explored Ava central closure and its surrounding prospect and leads.

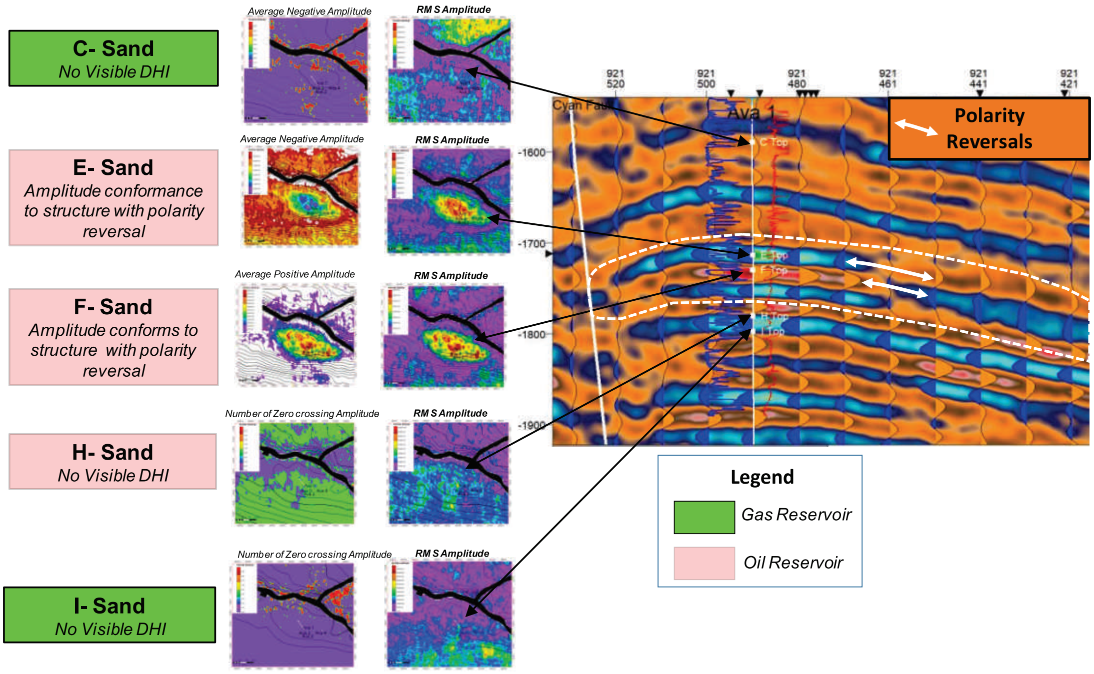

Figure 16: Amplitude maps and seismic sections showing the DHI's in all the reservoirs mapped. Amplitude conforms to structure for reservoirs associated with polarity reversals.

The bright reflection observed at the crest of reservoir H are not bright spots, but are rather bright reflections suggestive of lithological effect.

One of the critical pitfalls during seismic interpretation is the misinterpretation of zones of polarity reversals as faults. Some interpreters may feel inclined to identify both these phase changes as faults antithetic to the main faults (Brown, 2011).

CONCLUSIONS

In the midst of paucity of data, qualitative seismic attribute analysis was carried out for Ava field Niger Delta. The seismic attribute study provided insights to the structural framework, nature of reservoir and DHIs within the subsurface of Ava field.

The qualitative analysis of the seismic attributes within the subsurface interval of Ava field Niger Delta has assisted in amplitude discrimination, DHI investigation and prospect analysis.

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