Application of Seismic Facies and Attributes in Delineating Hydrocarbon Prospective Zones in the "Ebowei Field", Offshore Niger Delta Basin

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ABSTRACT

The Niger Delta Basin is a prolific hydrocarbon basin and has been explored both onshore and offshore. However, there are a few challenges facing the exploration of the frontiers. It ranges from the complexities of facies to depositional and structural architectures of the lithostratigraphic units. This work presents a better way to tackle some of the challenges through the integration of seismic and well-log data to analyze the structural patterns, seismic facies, and attributes types. Attribute analysis performed on the mapped reservoir tops gave clues to the petrophysical properties of the identified reservoirs. The seismic facies analysis was done using the Prather et al., 1998 model. Reservoir one corresponds to the A facies deposited in a prograding marine environment, and reservoir two corresponds to the D and E facies also deposited in a prograding marine environment. Reservoir three corresponds to the B facies deposited in a delta front and tidal channel environment while reservoir four corresponds to the Cbl and Cbh facies deposited in a tidal channel environment. The sum of negative amplitude and Root Mean Square (RMS) seismic amplitude was performed on the surfaces. From the analysis, reservoir one has the lowest clusters of amplitude and is ranked the least, while reservoir three has a better bright amplitude than reservoir one. Reservoir 2 has the second-best, and reservoir four has the highest clusters of bright amplitude. The results indicate that reservoir four has excellent petrophysical properties, while reservoirs two and three have good petrophysical properties. Reservoir one has poor petrophysical properties as observed from the little amplitudes. It further confirms that the amplitude of a reservoir has a direct relationship with its petrophysical properties. The presence of 4, 3, and 2-way closures in reservoirs four, two, and three points the way forward for exploration activities within the "Ebowei field".

Keywords: Seismic facies, Seismic Attribute, Prospective zones

INTRODUCTION

The Niger Delta Basin is a prolific hydrocarbon basin and has been explored both onshore and offshore. The Niger Delta Basin is located on the passive continental margin of the Gulf of Guinea in Equatorial West Africa between Latitudes 3° to 6° N and Longitudes 5° to 8° E. Its estimated oil and gas reserves are huge, available technology is constantly improving and a large infra-structure system is available. The exploration of this province has taken place almost exclusively during the past forty-five (45) years (Anomneze *et al.,* 2015). Furthermore, the identification, evaluation and description of these subsurface attributes of various reservoir packages, structural styles, and stratigraphic analysis from conventional interpretation of seismic data is always challenging because the complexity of the subsurface to seismic wave propagation (Chopra and Marfurt 2005; Nasser 2020).

The Ebowei field was discovered in 1986 by an exploratory well and by appraised 2 wells (1996 and 2006), it is located offshore, southeast of the Niger Delta Basin as shown in fig.1 below. This field, displays one of the best examples of prolific hydrocarbon field due to the plays and prospects inherent in the subsurface lithostratigraphic units. Structural closures have been identified within the field which have paved way exploitation activities. Exploration wells drilled within this field a showed great commercial prospects but structural complexity, cases of bright spots on identified seismic section but dry wells sadly encountered after drilling has triggered the study and reassessment of the seismic attributes and facies of the Agbada Formation. Another factor consider was the steady decline in production.

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The objectives of the study present ways to tackle some of the challenges through the integration of seismic and well-log data to analyze the closures, seismic facies, and attributes types. Attribute analysis performed on the mapped reservoir tops gave clues to the petrophysical properties of the identified reservoirs.

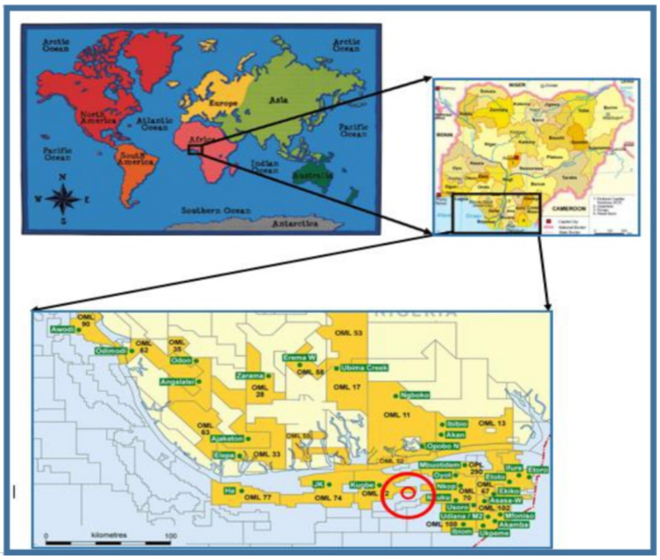

Figure 1: Location map showing the study are in red circle modified after (Ejadawe *et al.,* 2007).

GEOLOGIC AND STRUCTURAL SETTING

The Niger Delta Basin is an extensional rift basin where rifting occurred from the Late Jurassic to the Late Cretaceous. Cretaceous fracture zones, expressed as trenches and ridges, control the tectonic framework of the delta and separate the margin into individual sub-basins, which form the boundary faults of the Cretaceous Benue-Abakaliki trough (Doust and Omatsola, 1990). The Niger Delta Basin is the youngest and most southern sub-basin (located at the southwest boundary) in the Benue-Abakaliki trough. The Benue-Abakaliki trough represents a failed arm of a rift triple junction associated with the opening of the South Atlantic (Short and Stauble, 1967).

The Niger Delta is dominated by a complex structural evolution that triggered a step-wise progradation during a massive regressive phase which is continuous to this present day (Tuttle *et al.,* 1999). The Niger Delta is subdivided into various distinct structural zones which are characterized by an extensional tectonic regime onshore and a compressional tectonic regime basinwards (Anomneze *et al.,* 2015).G

Three macrostructures have been identified over the study area in the Greater Ughelli depobelt. Each macrostructure is characterized by a sandy sequence in the north which becomes shalier to the south (Anomneze et al., 2015). The Akata Formation at the base of the delta is predominantly under-compacted, over-pressured sequence of thick marine shales, clays and siltstones (potential source rock) with turbidite sandstones (potential reservoirs in deep water). It is estimated that the formation is up to 7,000 meters thick (Bouvier *et al.,* 1989; Doust and Omatsola, 1990; Chiadikobi *et al.,* 2012). The Agbada Formation, the major petroleum-bearing unit about 3700m thick, is alternation sequence of paralic sandstones, clays and siltstone and it is reported to show a two-fold division. (Etu-Efeotor, 1997; Tuttle *et al.,* 1999). The Agbada Formation is within the hydrocarbon generative windows, a gradient range of 0.014 to 0.02°C/100m (Akpunonu *et al.,* 2012) has been reported for both swamps and onshore Niger Delta. Uko *et al.,* 2002, have also observed a geothermal gradient ranging from 1.5 to 3.4°C/100m for South-East Niger Delta. The upper Benin Formation overlying Agbada Formation consists of massive, unconsolidated continental sandstones as shown in the stratigraphic chart in figure 2.0 below.

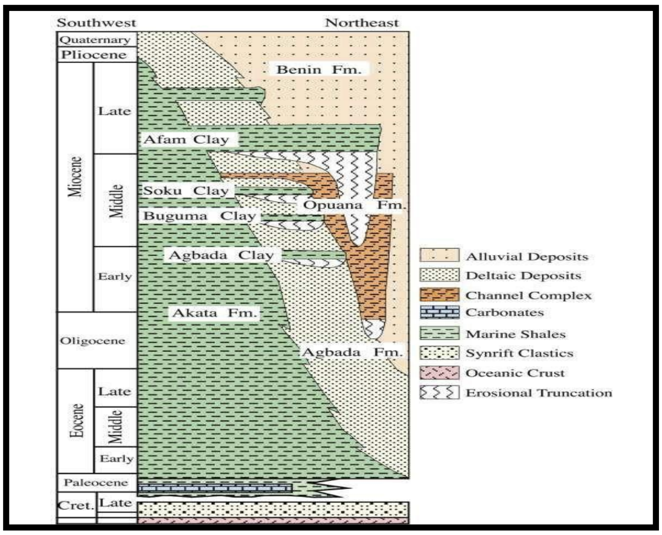

Figure 2: Stratigraphic chart of the Niger Delta Basin (after Ozumba, 2013).

DATABASE AND METHODOLOGY

The dataset made available for this work consists of 55.38 km2 3-D seismic volume; log suites for four wells, deviation data for two wells and check-shot data for the four wells. Interpretation of the well-logs and seismic data was done using Petrel 2017 "seismic-to-simulation" interpretation software. The software was used to carry out a detailed well-log correlation, seismic data interpretation, generate synthetic seismogram, surface, and attribute maps. Four wells (EBI-1 to EBI-4) were correlated in the NE-SW direction. Four reservoirs (RES 1 to RES 4) were identified in the process as shown in fig. 3 .

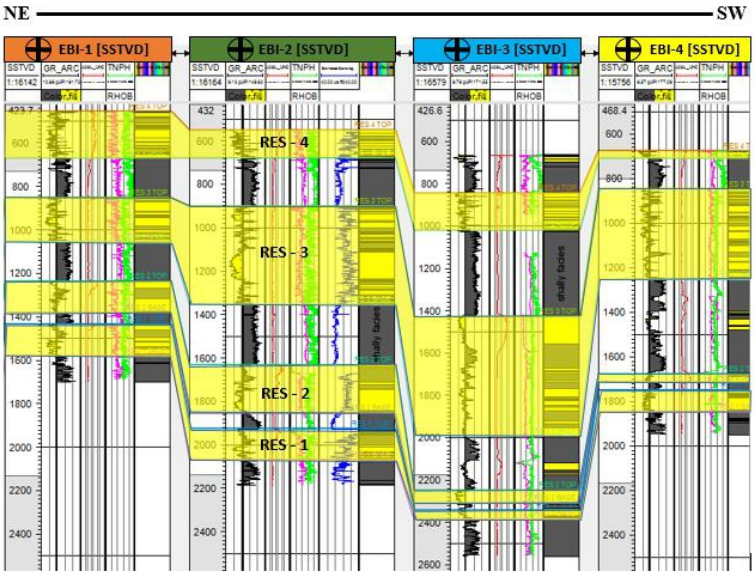

Figure 3: Reservoir correlation across four wells in the NE-SW direction.

The paper encompasses the various methods adopted for the well log, seismic facies and seismic attribute analysis in an effort to uniquely classify plays. Okeke et al., 2021, applied seismic attributes in fault identification, horizon mapping, direct hydrocarbon indicator (DHI) enhancer in the Soedinc field, offshore Norway.

SEISMIC FACIES ANALYSIS

The seismic facies interpretation was done with the aid of (Prather *et. al.,* 1998; Okeke *et al.,* 2021) template as shown in fig. 4.0 below. It also played a significant role in identifying the exploration play facies of interest associated with the reservoirs and helped in ranking the reservoir with the best facies prevalent within the Ebiowei field. Furthermore, seismic attribute analysis was performed after the various surfaces were mapped 3D seismic lines (cross-lines and Inlines). Surface maps were then generated from these mapped reflectors. These generated seismic attributes were used to produce various time attribute maps, frequency maps and amplitude maps to assist in the structural identification, delineation of prospects and leads.

SEISMIC ATTRIBUTE ANALYSIS

Many research in this field have shown that it could be used in seismic processing, frequency attenuation, and seismic stratigraphy and in the evaluation of some petrophysical properties (Okeke et al., 2021). Many people in geosciences have realized that there are advantages provided by 3D seismic data which improves stratigraphic interpretation of data; seismic interpreters however, ceased this new insight by conducting detailed studies of objects, which are of different geologic origins and ages including temporal (time) and spatial (space) events (Okeke et al., 2021). Seismic attributes have shown to be useful for detecting stratigraphic features; others are quite useful in identifying structural features such as faults and fractures (Hart, 2013). In this study two unique and significant attributes (Root Mean Square amplitude and sum of negative amplitude) were utilized effectively in characterizing the reservoirs. The Root Mean Square (RMS) amplitude is a surface attribute that measures the amplitude of a signal based on the magnitude of the signal strength (either positive or negative) between two surfaces and it is useful in identifying reservoir extent and geometry (Anomneze et al., 2015). More so, seismic attributes show reservoir

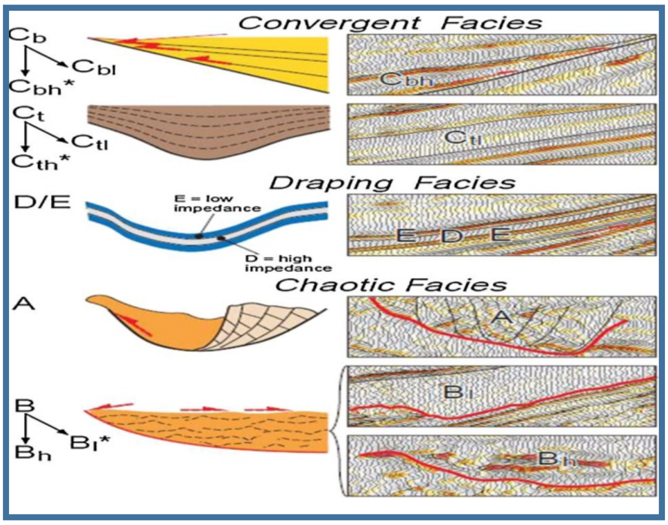

Figure 4: Various Seismic facies types (Prather *et al.,* 1998 and Okeke *et al.,* 2021).

properties by giving derivatives of quantities which are extracted from the original seismic data (Chen and Sidney 1997) and then try to relate the seismic wave's event directly or indirectly to geology.

Furthermore, the analysis of seismic attributes brings a clearer pictures of the heterogenic nature of seismic events in the subsurface by describing its geomorphology (Chen et al., 2020; Fengming *et al.*, 2018; Karbalaali *et al.,* 2018; Schneider *et al.,* 2016), facies changes (Bueno *et al.,* 2014; Wang *et al.,* 2017) and physical properties (Dupucy *et al.,* 2016; Ogiesoba *et al.,* 2019; Nawaz *et al.,* 2020) in terms of qualitative analysis, quantity analysis, and area extent. Seismic attributes analysis has been efficient, over the years, for geomorphology analysis (Bailey et al., 2016; Karbalaali et al., 2018) qualitative and quantitative interpretation (Torrado et al., 2014; Ngoc et al., 2014; Bhattacharya and Verma 2020; Malik et al., 2020) of hydrocarbon fields. The works of Chopra and Marfurt (2005, 2008), Cuesta et al., (2009), Vohs et al., (2015), Roden et al., (2016), Zhao et al., (2016), Jie et al., (2017), Othman et al., (2018), Adekunle et al., (2020) gave detailed emphasis on the application and efficiency of seismic attributes for stratigraphic and structural features identification and characterization.

RESULTS AND DISCUSSION

The seismic facies analysis was done using the Prather et al., 1998 model. The Calculations of percentage and net-to-gross ratio of sand was done to check and understand reservoir rock potentials giving room for an unbiased ranking of these reservoirs. Our studies showed that exploration play facies with higher sand percentages should be where our interests lie and be targeted during exploitation. From our research, six (6) major exploration play facies were identified as shown in fig. 5.0 below. Reservoir one corresponds to the A facies which was deposited in a prograding marine environment, and reservoir two corresponds to the D and E facies also deposited in a prograding marine environment. Reservoir three corresponds to the B facies deposited in a delta front and tidal channel environment while reservoir four corresponds to the Cbl and Cbh facies deposited in a tidal channel environment. The best exploration play facies identified across the seismic dipline was the B facies found in reservoir three which coincides with its high percentage net-to-gross ratio. The D and E facies are ranked the second best play facies while the Cbl and Cbh facies are ranked third and associated with reservoir four. The least exploration play facies (A facies) is found in reservoir one and has a low net-to-gross ratio.

SURFACE MAPS

From the depth surface map generated, it could be observed that 4-way, 3-way, and 2-way closures exists in the field. In reservoir one, 2-way and 3-way closures are present. In reservoir two, 2-way and 3-way closures were also confirmed. In reservoir three, the presence of 2-way and 3-way closures are prominent while reservoir four has 2-way, 3-way and 4-way closures. The presence of these closures point the way forward for exploration activities within the Ebowei field.

SEISMIC ATTRIBUTE ANALYSIS

In Seismic attribute analysis, geomorphological features identification is an essential element in seismic interpretation (Karbalaali *et al.,* 2018). The major reason for this is because geomorphological features control hydrocarbon accumulation in a reservoir by serving as

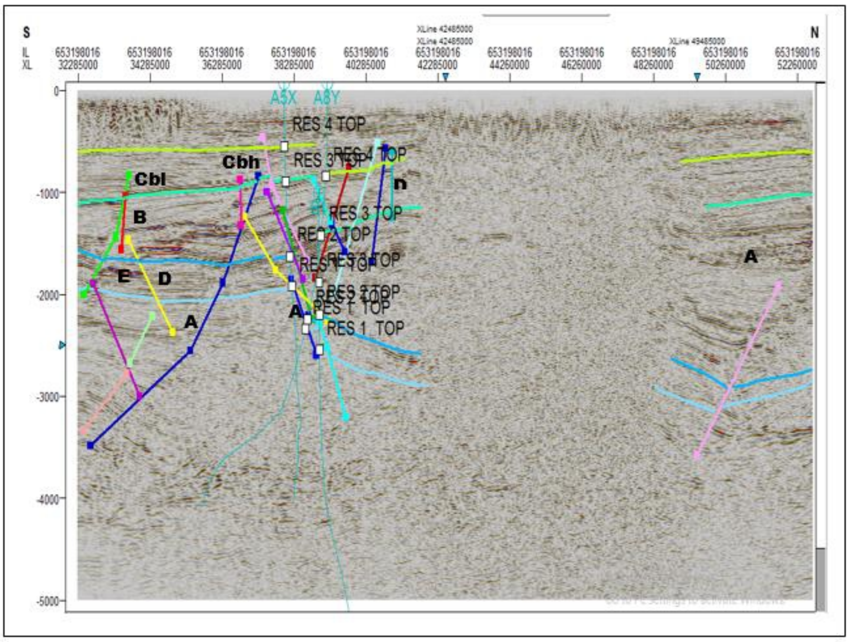

Figure 5: Seismic facies identified across Inline 653198016.

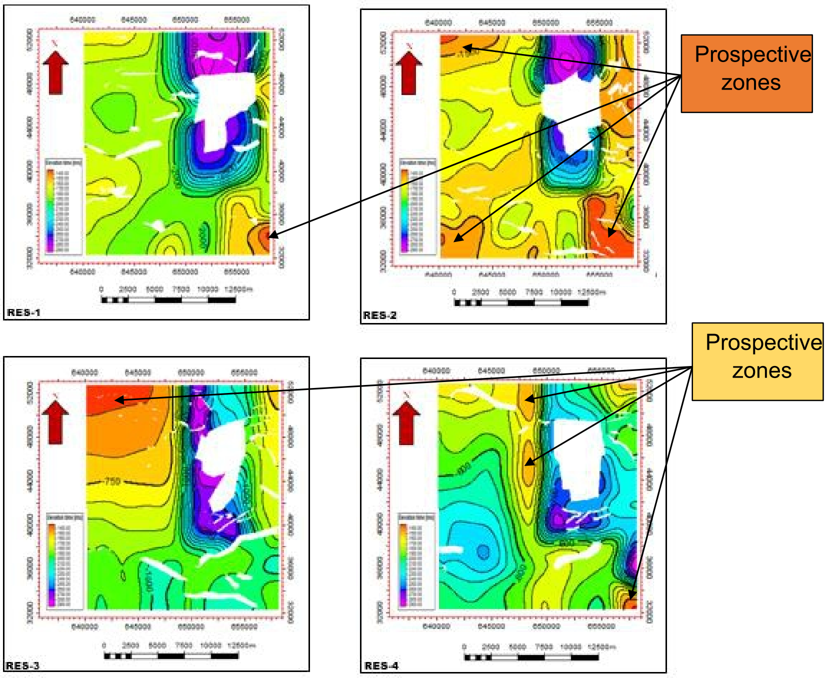

Figure 5: Closures identified on surface maps for the four reservoirs.

hydrocarbon traps or cap rocks. Seismic data coherence property is great in highlighting these features and most widely used alongside sum of negative amplitude and RMS amplitude attributes (Feng *et al.,* 2018). The work of (Okeke *et al.,* 2021), also shows that seismic attributes are useful for detecting stratigraphic features. It also plays a good role in detecting some tectonic features such as faults and fractures (Hart, 2013).

In the Ebowei field interpretation, two unique and significant attributes (Root Mean Square amplitude and sum of negative amplitude) were applied so as to characterize the various reservoirs. The Root Mean Square (RMS) amplitude is a surface attribute that measures the amplitude of a signal based on the magnitude of the signal strength (either positive or negative) between two surfaces and it is useful in identifying reservoir extent and geometry. From the RMS amplitude analysis, reservoir one has the lowest clusters of amplitude and is ranked the least, while reservoir three has a better bright amplitude than reservoir one. Reservoir 2 has the second-best, and reservoir four has the highest clusters of bright amplitude as shown in fig. 6.0 below.

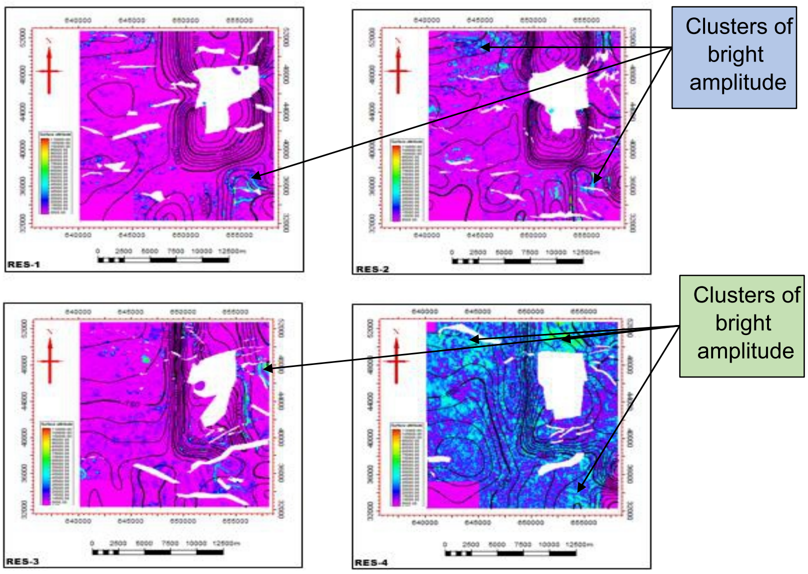

Figure 6: Root Mean Square (RMS) Amplitude map for the four reservoirs.

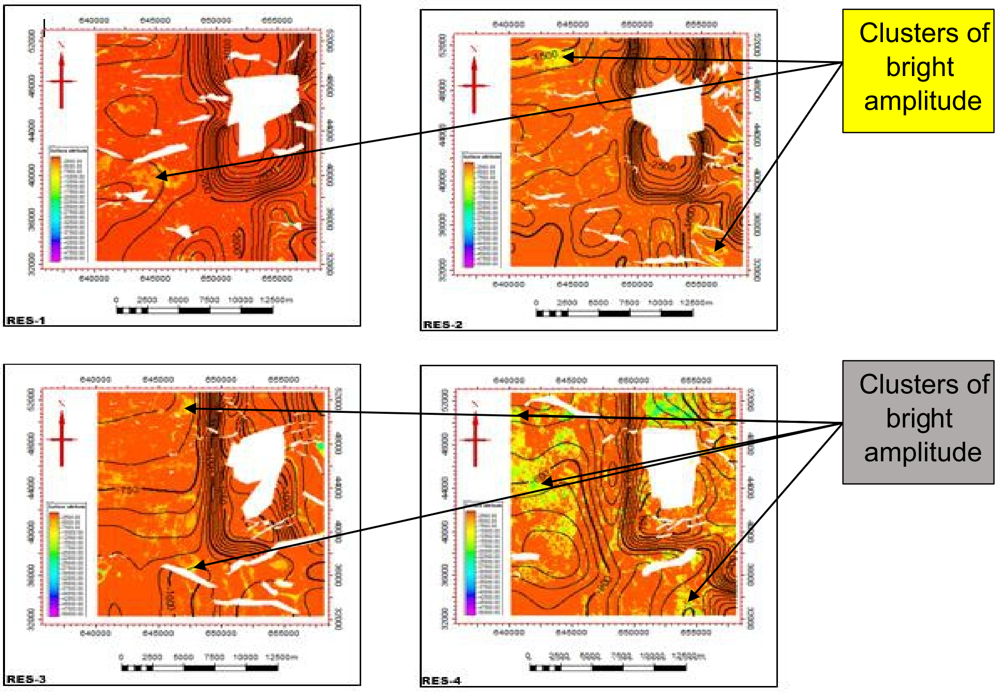

Figure 7: Sum of Negative Amplitude maps for the four reservoirs.

The sum of negative amplitude analysis interpretation showed that reservoir one has the lowest clusters of amplitude and is ranked the least, while reservoir three has a better bright amplitude than reservoir one. Reservoir 2 has the second-best, and reservoir four has the highest clusters of bright amplitude as shown in fig. 7.0 below. The results indicate that reservoir four has excellent petrophysical properties, while reservoirs two and three have good petrophysical properties. Reservoir one has poor petrophysical properties as observed from the little amplitudes. This further confirms that the amplitude of a reservoir has a direct relationship with its petrophysical properties."

SUMMARY AND CONCLUSION

The integration of multiple dataset resulted in the identification of four (4) reservoirs and six (6) major exploration play facies of interest. Reservoir one (1) has the lowest clusters of amplitude and is ranked the least, while reservoir three has a better bright amplitude than reservoir one. Reservoir two (2) has the second-best, and reservoir four has the highest clusters of bright amplitude. These results indicate that reservoir four has excellent petrophysical properties, while reservoirs two and three have good petrophysical properties. Reservoir one has poor petrophysical properties as observed from the little amplitudes. It further confirms that the amplitude of a reservoir has a direct relationship with its petrophysical properties. The presence of 4, 3, and 2-way closures in reservoirs four, two, and three points the way forward for exploration activities within the "Ebowei field".

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