Evaluation of Prospective Hydrocarbon Zones in Soedinc Field, Offshore Norway

Okeke Solomon & Didi Chekwube
Department of Geological Sciences
Nnamdi Azikiwe University, Awka, Nigeria
solomonekene.o@gmail.com, didichekwube@gmail.com,

Ngene Tochukwu & Oyekola Peter
Applied Physics and Mechanical Engineering
Papua New Guinea University of Technology, Lae, Papua New Guinea
Tochukwu07@gmail.com, Petertosin@gmail.com

Abstract

The challenges of operational cost have increased as the Norwegian operations expand the searches of deep-water horizons, However, a better understanding of the sequences stratigraphic elements within the Soedinc Field can help us predict some of the petroleum system elements and their depositional sequences. Therefore, Attribute analysis performed on the mapped reservoir tops gave clues on the petrophysical properties of the identified reservoirs. The study integrates 3D seismic data and log suites adopting the depositional sequence II model to classify the genetically related strata and their bounding surfaces. Two depositional sequences were identified with their allied systems tracts, nine bounding surfaces and parasequence such as (aggradation, retrogradation and progradation) were also identified. The analysis of the seismic facies indicates that some of the formations correspond to the High and Low Amplitude Convergent (Cbhl) facies and the High Amplitude Convergent (Cbh) respectively showing reservoirs with best porosity and permeability.

Keywords

Sequence stratigraphy, Seismic facies and Seismic Attributes.

1. Introduction

The Soedinc Field is an offshore field which lies within Latitude 710-720 N and Longitude 240-330E. The field is found in the Southern part of the Barents Sea, and occupies an aerial extent of approximately 20km2. A proper understanding of the Upper Paleozoic succession of the Barents Sea is derived from seismic and well data and from outcrop sections at Svalbard and Bjamelland plates, along the northwestem margin of this roughly 1.5 million km2. The lithostratigraphic units of the Basin is best described by a combining process, with alternate climates, distinct depositional pattern or system (Worsley, 2008) (Smelror et al., 2009) (Henriksen et al., 2011). The study are have undergone four tectonic phases which includes, the Timanian, Caledonian, and Uralian orogenies; the proto-Atlantic rifting; finally the splitting and opening up of the northern part of the North Atlantic found in the westernmost edge of the study area (Doré, 1991) (Tsikalas et al., 2012).

This paper therefore encompasses three main sections which are the application of sequence stratigraphy to delineate bounding surfaces, system tract, and parasequence, identification of various seismic facies, and finally the use of seismic attributes to characterize the identified reservoirs. The seismic facies analysis indicates that the Roye Formation was deposited on the carbonate shelf and corresponds to the High and Low Amplitude Convergent (Cbhl) facies, the Isbjorn Formation was also deposited on the carbonate shelf and corresponds to the High Amplitude Convergent (Cbh) facies, the Havert Formation. was deposited in a shallow marine shelf and corresponds to the Cbh facies while the Oern Formation was deposited on the shoreface environment corresponds to the cbhl facies. The best exploration plays facies identified in the Finnmark Platform is the Cbh2 and the Cbh1 which invariably corresponds to the Isbjorn and Roye Formation respectively. The attributes extraction also showed that the reservoir with the best porosity and permeability is the Roye and Isbjorn reservoirs respectively.

1.1. Regional setting

The tectonic evolution and basement complex episodes of the Barents Sea are quite ambiguous. However, the main part is somewhat established to the Paleoproterozoic (Karelian) orogeny. In the Pre-Devonian, the Baltica plate and the Laurentia Plate was separated from the Baltica and Avalonia Plate by the Iapetus Ocean while the Baltica Plate was separated from the Avalonia Plate by the Tonquist Sea. During the Late Ordovician to Early Silurian, the Baltica Plate collided with the Avalonia Plate to close up the Tonquist sea and formed the Caledonian deformation front. These two plates in a three-plate collision collided with the Laurentia Plate to form the Laurasia Continent. This led to the formation of a north-south trending fold belt referred to as the Iapetus Suture. The Timanian orogeny evolved as a result of extensional and compressional tectonic regimes along the northeastern continental margin of Baltica plate and the Barents Sea in the Vendian (Ediacarian) time (Roberts & Olovyanishnikov, 2005). At about 400 Ma, the Caledonian orogeny was initiated, this resulted in the stabilization and cratonization of the Laurentian and Baltic plates into the Laurasian continent and closing up of the Iapetus Ocean heralding the Iapetus suture regarded as a fold belt (Roberts, 2003) (Gee et al., 2006) (Gee et al., 2008) (Gasser, 2014).

The Soedinc field is a site for extensional tectonics and progradation of the Mid-Jurassic to Early Cretaceous rifting distorts the western flank of the Shelf thereby initiating a build-up of a marine condition all through the Barents Sea (Brekke et al., 2001) (Gernigon et al., 2014) (Tsikalas et al., 2012). However, the northern part of the Barents Sea experienced a major uplift during the Early-Mid Cretaceous which led to the erosion of sediment from the elevated region along the northeast, transportation, deposition and accumulation of these sediments in the subsiding basin (Gernigon et al., 2014) (Klitzke et al., 2015).

1.2. Lithostratigraphic units

The Soedinc field is accumulation of thick deposits of sediments which are Devonian siliciclastics to Quaternary glacial sediments. Prather et al (Prather et al., 1998) identified nine different lithostratigraphic units (Lithostratigraphic unit-one to Lithostratigraphic unit-nine), identifying seven major depositional sequences (Sequence-one to Sequence-seven) and various smaller transgression and regression events as a result of sea level changes. However, new lithostratigraphic nomenclature have been suggested for the Upper Paleozoic sediments by Rafaelsen (Rafaelsen et al., 2020), including the Billefjorden Group, which is made up of the Soldogg Formation, the Tettegras Formation and the Blaererot Formation, Gipsdalen Group which is made up of the Ugle Formation, Falk Formation and Oern Formation through the Bjarmeland Group which is made up of Polarrev Formation, Ulv Formation, and the Isbjorn Formation and the Tempelfjorden Group which is made up of the Roye Formation and the Orret Formation. The Harvert Formation make up the Triassic while the Klappmyss Formation comprises the Quaternary unit which is said to be the youngest of all the lithostragraphic units in the Soedinc field. The region enclosed in brown polygon shows the Soedinc Field, in the Barents Sea in figure 1 below.

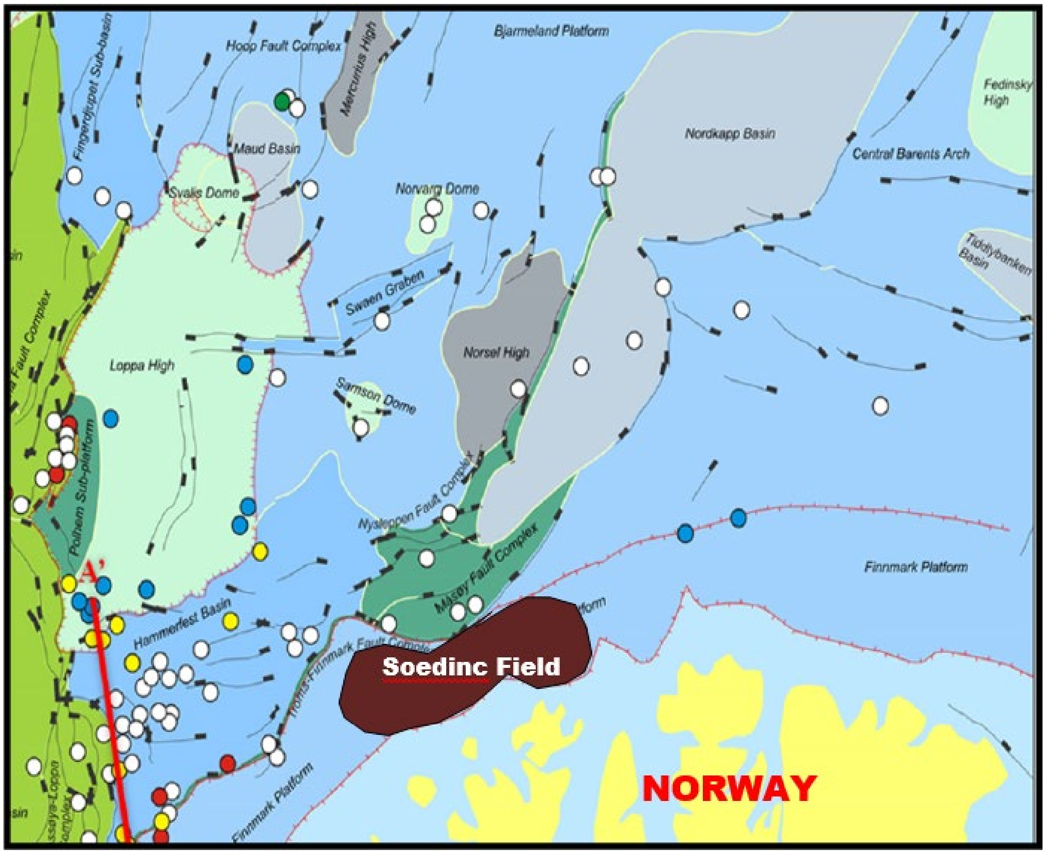

Figure 1. Map of the Barents Sea showing the Finnmark Platform (Norwegian Petroleum Directorate, 2019) modified

2. Materials and Methods

The dataset provided for this research were sixty-eight (68) 2D seismic lines, 3D seismic-reflection data, four wells (DOCS-1, DOCS -2, DOCS -3, DOCS -4) with log suites, checkshot survey for four wells, and deviation data for four wells. The datasets were quality checked and imported into Petrel 2016 working environment with together with their associated file formats. The paper encompasses the various methods adopted for the well log facies, sequence stratigraphic and seismic attribute analysis in an effort to uniquely classify plays.

Sequence stratigraphic analysis was carried out on Gamma Ray log using sequence depositional model. Various system tracts, bounding surfaces, as well as the parasequences were also identified. The associated system tracts include the Lowstand System Tract (LST), Transgressive System Tract (TST), and Highstand System Tract (HST) guided us in identifying the source rocks, reservoir rocks and the sealing units across the wells. Sequel to that, the seismic facies (Figure 2) interpretation was done with the aid of Prather et.al (Prather et al., 1998) template This also played a great role in identifying the various facies associated with the reservoirs and helped in ranking the reservoir with the highest exploration play facies prevalent within the Finnmark Platform. Finally, seismic attribute analysis was performed after the various reservoir tops identified have been mapped across the 2D and 3D seismic lines (Xlines and Inlines). Various surfaces were generated from these mapped reflectors. Over the past two decades, there have been several applications of seismic attributes in seismic processing, fault identification, horizon mapping, direct hydrocarbon indicator enhancer, seismic frequency attenuation, seismic stratigraphy as well as evaluation of some petrophysical properties. Consequently, geoscientists especially geophysicists 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. Seismic attributes have shown to be useful for detecting stratigraphic features; others are quite useful in identifying structural features such as faults and fractures (Odoh et al., 2014). 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. The sum of the negative amplitude attributes was generated for the four identified reservoirs within the Soedinc field.

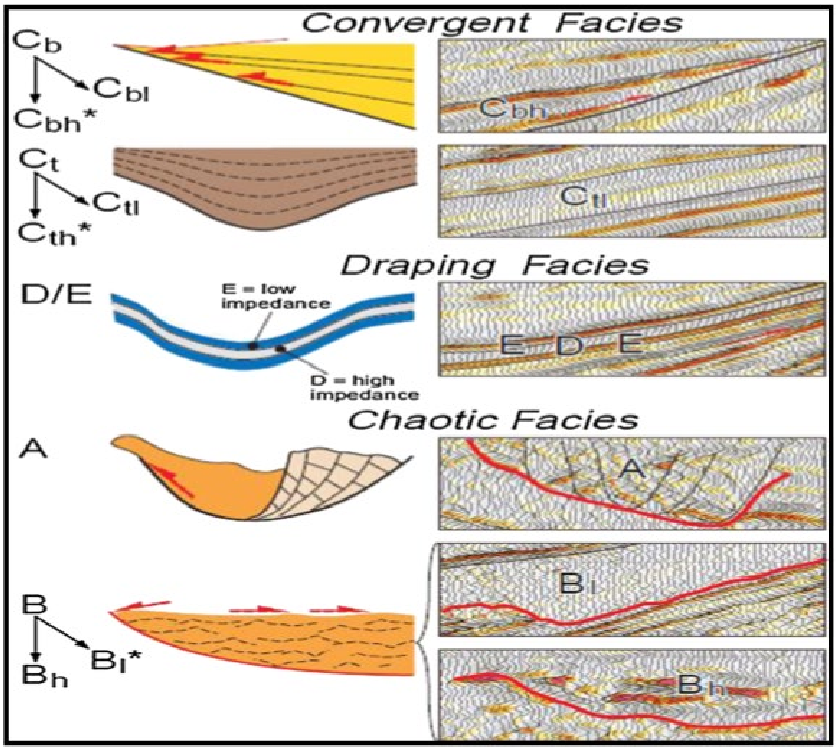

Figure 2. Various Seismic facies types (Prather et al., 1998) (Anomneze et al., 2015)

3. Results and Discussion

One of the aims of exploration is to understand the buildup of sediments within a basin. These accumulated sediments comprise play elements such as potential source rocks, reservoir rocks and sealing units and also points way for further to identification of these elements. Nine horizons correspond to the maximum flooding surfaces (MFS), transgressive surface of erosion (TS) and sequence boundaries (SB) were interpreted from the available well logs. Maximum flooding surfaces (MFS) of interest were picked from the spike in shaly signatures which invariably indicates a peak in marine transgression. While the sequence boundaries (SB) were picked from the base of the thickest sand, as shown in the gamma ray logs in figure 3 below. The transgressive surface of erosion was picked from the top of thick accumulated sand deposits and base of shale. The absence of biofacies made the interpretation more daunting and tasking.

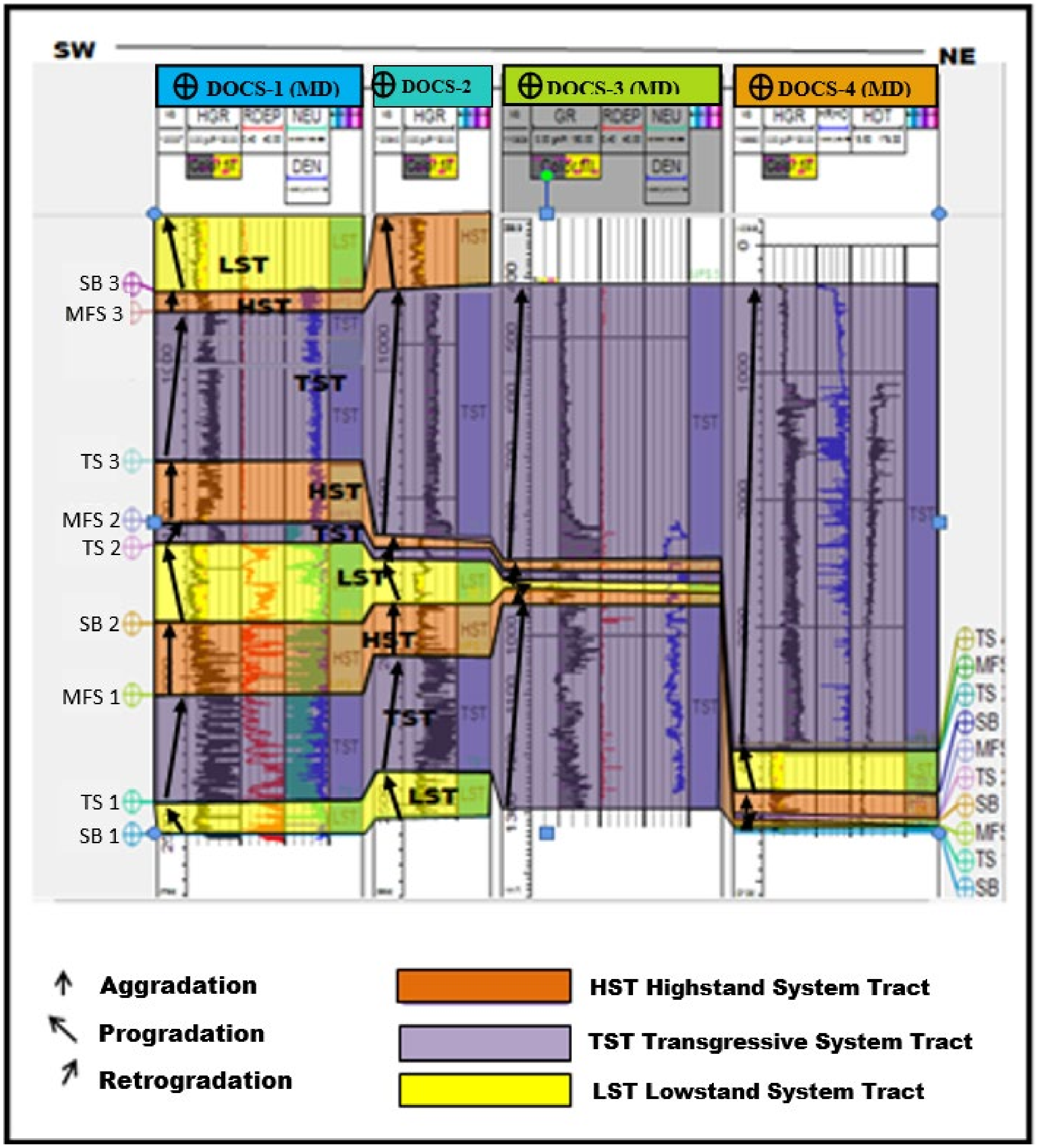

Figure 3. Sequence stratigraphic interpretation using depositional sequence II model

The sequence stratigraphic analysis was done using four wells provided for the research. Due to lack of biostratigraphic data to accurately interpret the depositional facies, sequences and also identify sealevel changes and boundaries between different genetic types of deposits. In other to classify the genetically related strata, and their bounding surfaces, we adopted depositional sequence II model for our analysis. From figure. 3 above, two depositional sequences were identified with their associated systems tracts such as the (Lowstand System Tract (LST), Transgressive System Tract (TST) and Highstand System Tract (HST)), bounding surfaces such as (sequence boundaries, transgressive surface of erosion and maximum flooding surface) and parasequence such as (aggradation, retrogradation and progradation). In the four wells (7128/4-1, 7128/6-1, 7131/4-1 and 7229/11-1), the LSTs corresponds to the Roye Formation, the Isbjorn Formation and sands of the HSTs which corresponds to the Havert Formation and Oern Formation consitutes the reservoirs. While the TSTs corresponding to the Tettegrass Formation and shales of the HSTs corresponding to the Roye and Havert Formation constitute the source and seal units.

The bounding surfaces includes the three sequence boundaries, the four transgressive surfaces of erosion and four maximum flooding surfaces. In well DOCS-1, three prograding sequnces which corresponds with the LST's indicating a regressive phase were identified. Sequel to that, two retrograding sequences (transgressive phase) and three aggrading sequences corresponding to the TST's and HST's respectively were also identified. In well DOCS -2, two prograding sequences corresponding to the LST's, three retrograding sequences and aggrading sequences corresponding to the TST's and HST's respectively were also identified. Moving forward, in well DOCS -3, one prograding sequence which corresponds to the LST and three retrograding and aggrading sequences corresponding to the TST's and HST's respectively were interpreted. We also took a step forward in well DOCS -4 to identify three prograding sequences which also tallies with the LST's, four retrograding and two aggrading sequences correspond to the TST's and HST's respectively.

More so, we observed that the sequence boundary 1 (SB 1) is an unconformity surface owing to the fact that it overlies the Caledonian Basement unconformably (nonconformity). Furthermore, The TST 3 which bounds the HST and TST indicates that the genetic package (LST) must have been eroded during the Triassic before the deposition of the Marine Klappmyss Formation.

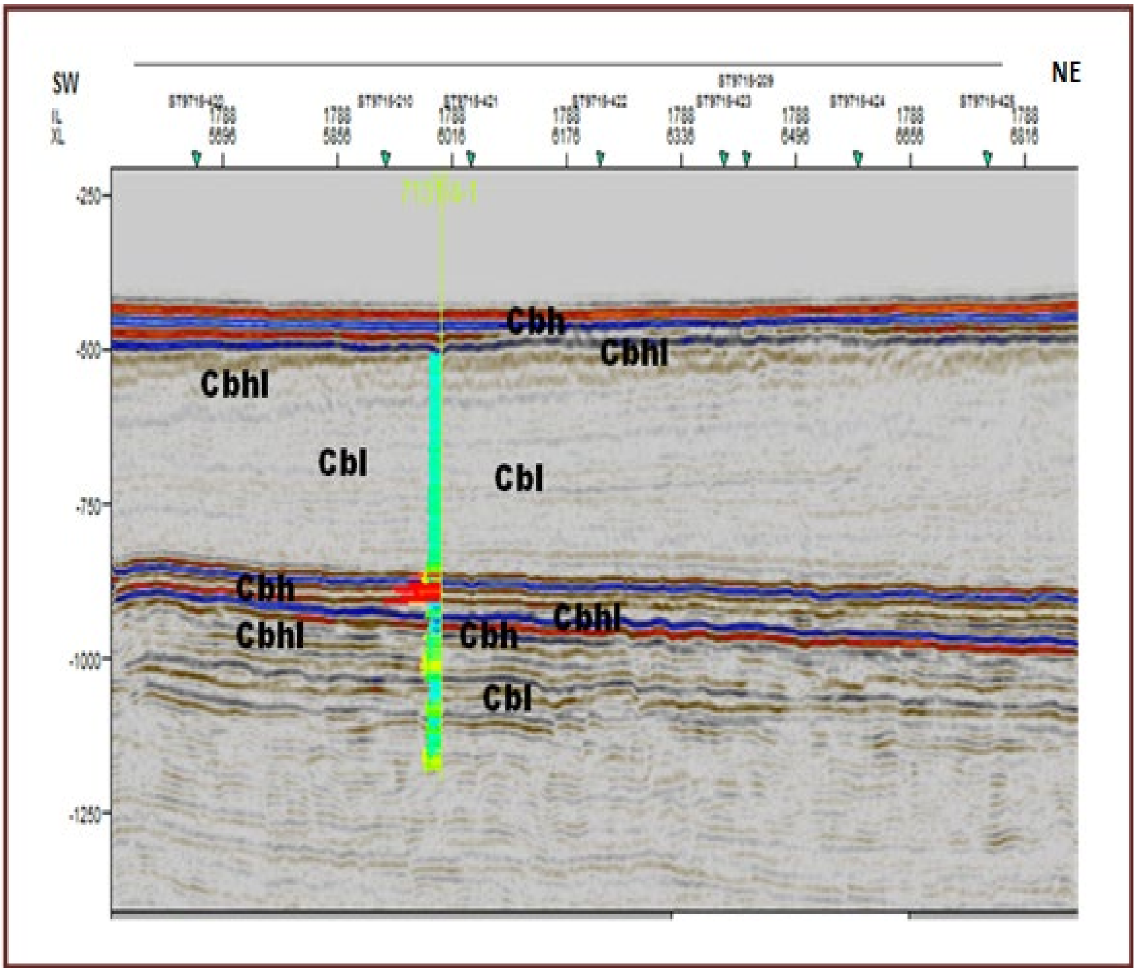

Figure 4. Seismic facies identified on seismic dip line 1788

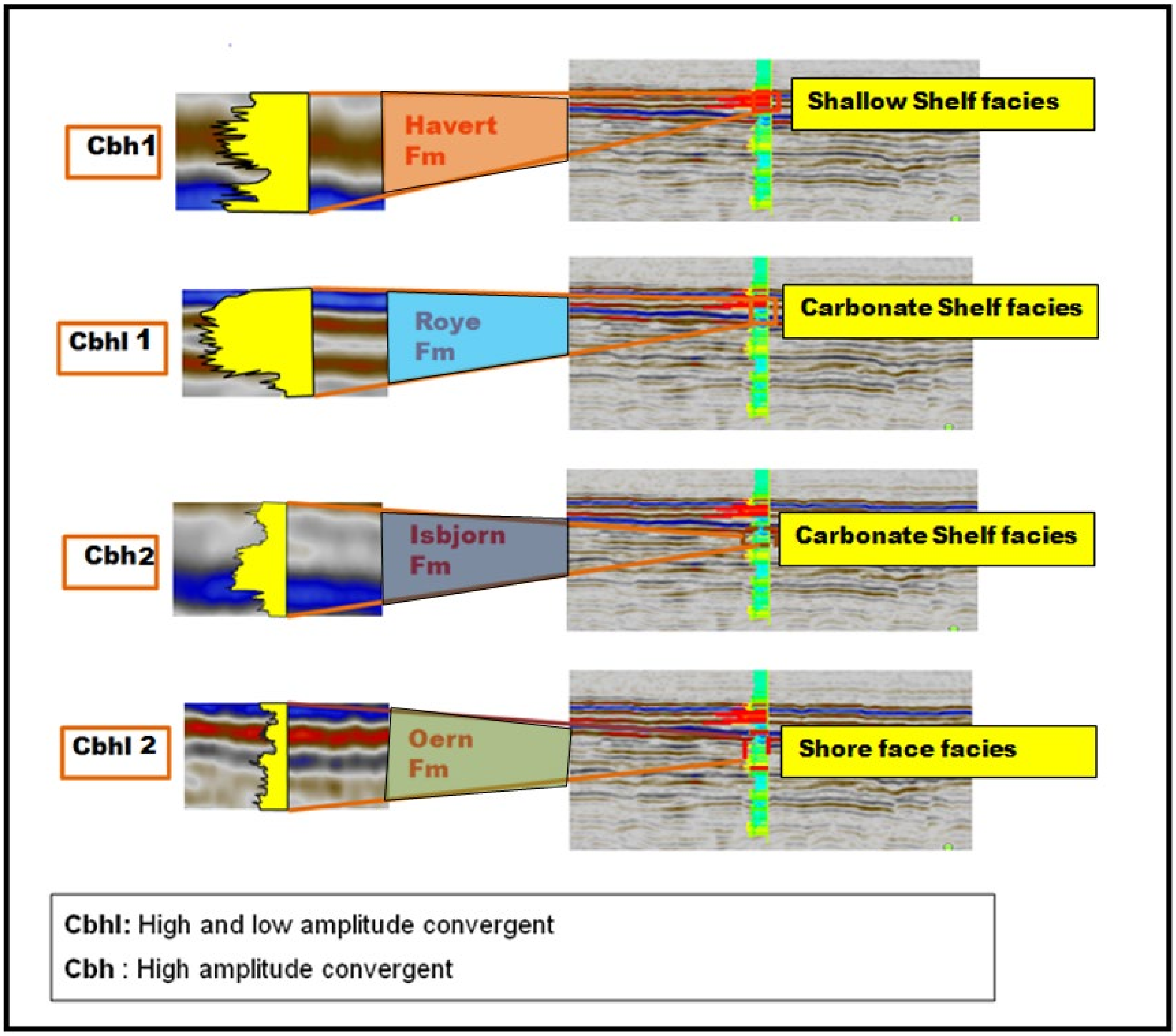

Figure 5. Seismic facies interpretation projected together with Gamma Ray log

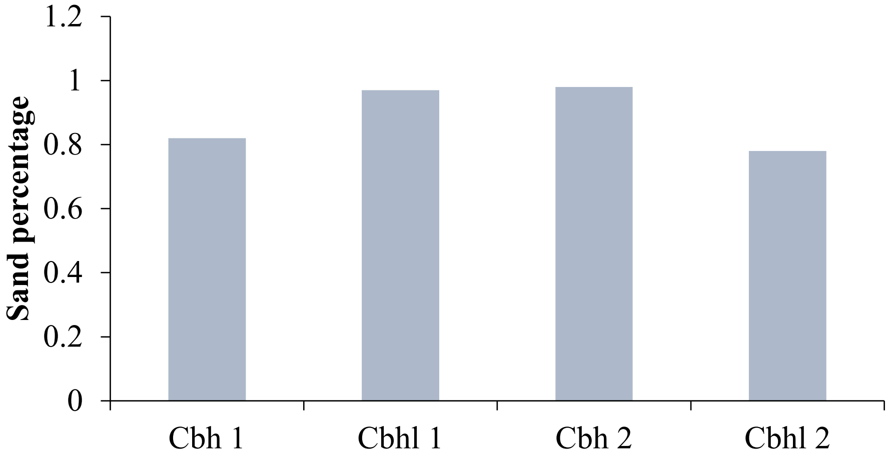

Figure 6. Reservoir percentage / ranking of seismic facies

The Calculations of percentage and net-to-gross ratio of sand gives room to foresee and better understand reservoir rock potentials and a better ranking of these reservoirs (figure 6). This invariably shows that seismic facies with higher sand percentages should be where our interests should lie and be targeted during exploitation. From our research, two major exploration play facies were identified. This includes the Cbh (high amplitude convergent) and Cbhl (high and low amplitude convergent as seen in figures 4 and 5). The Havert Formation was deposited on a shallow marine shelf; its seismic facies corresponded to the Cbh facies which is the high amplitude convergent facies. The Roye Formation was deposited on the carbonate shelf and its facies corresponds to the Cbhl facies which is high and low amplitude convergent. The Isbjorn Formation was also deposited on the carbonate shelf; its seismic facies correspond to the Cbh facies which is high amplitude convergent. The Havert Formation was deposited in a shallow marine shelf and its seismic facies corresponds to the Cbh facies which indicates a high amplitude convergent facies. Lastly, the Oern Formation was deposited on the shoreface environment; its seismic facies correspond to the cbhl which indicates a high and low amplitude convergent facies. From the seismic facies' analysis above, the best exploration play facies identified in the Finnmark Platform is the Cbh 2 and the cbhl 1 which invariably corresponds to the Isbjorn and Roye Formation respectively.

3.1. Seismic attribute analysis

Attribute maps are used to determine the properties of the reservoir such as porosity and permeability. The higher the amplitude, the higher the porosity and the permeability of the reservoir. However, porosity and permeability as petrophysical properties has a direct relationship with the amplitude of rock, hence, porosity and permeability are directly proportional to the amplitude of the rock and its fluid content such as water and hydrocarbon. This analysis was carried out in other to understand better the significant petrophysical properties of the mapped reservoir surfaces and also to identify zones of higher porosity and permeability.

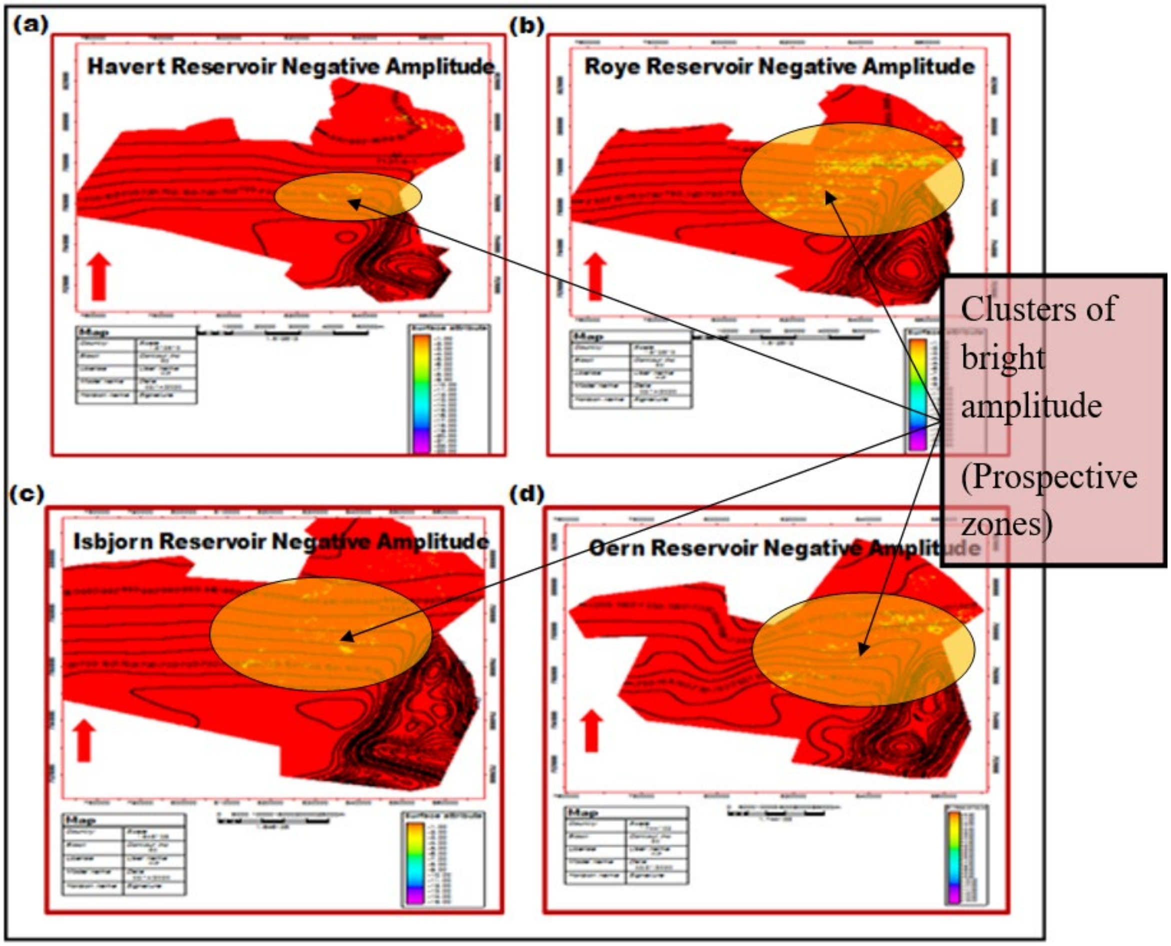

Figure 7. Sum of Negative Amplitude Maps a-d for the four reservoirs

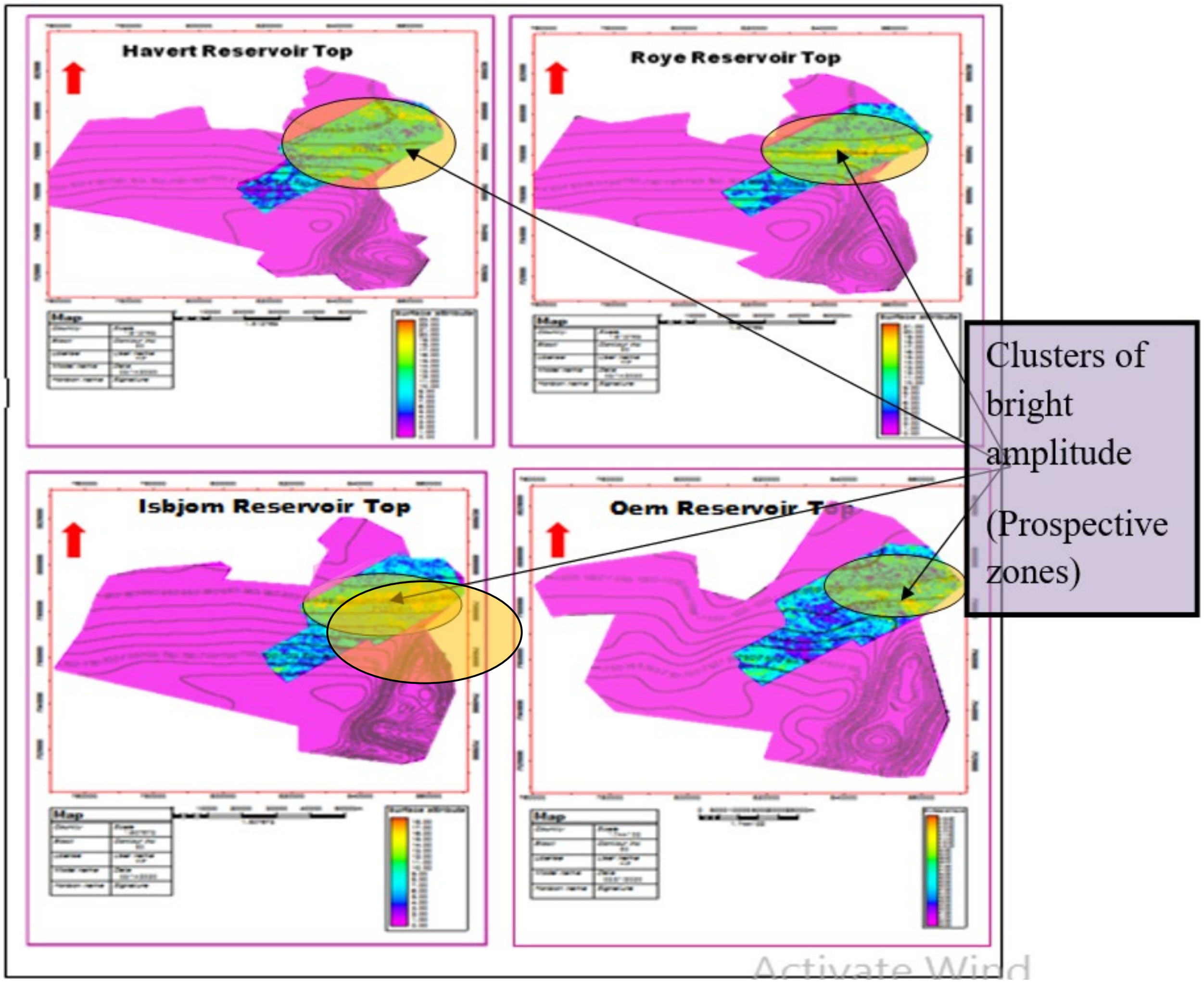

Figure 8. Root Mean Square (RMS) Amplitude Maps a-d for the four reservoirs

From the Sum of negative attribute maps generated in figure 7 above, the Roye Formation reservoir ranked the highest on application of the sum of negative amplitude attribute with more yellow coloration clusters. The Isbjorn Formation reservoir ranks second, the Oern Formation reservoir ranks third while the Havert Formation reservoir ranks the least. Sequel to that, the RMS (root mean square) amplitude attribute maps were also generated for the four reservoirs. From figure 8 above, the Roye Formation reservoir depicts the highest clusters of bright amplitude coloration and ranks the highest. This is followed by the Isbjorn Formation reservoir, the Oern Formation reservoir and then the Havert Formation reservoir ranks the least of all the reservoirs. The result of the RMS amplitude confirmed that of the sum of negative amplitude attribute ran across the reservoirs. However, it is worthy to note that the reservoir with the best porosity and permeability is the Roye Formation reservoir and as such, has the highest fluid contents compared to other reservoirs. This is also the reservoir we strongly recommend for further drilling activities.

4. Conclusion

Having integrated the multiple datasets provided for this study, two depositional sequences were identified with their associated systems tracts, nine bounding surfaces and parasequence such as (aggradation, retrogradation and progradation) were also identified. The seismic facies analsysis indicates that the Roye Formation was deposited on the carbonate shelf and corresponds to the Cbhl facies; the Isbjorn Formation was also deposited on the carbonate shelf and corresponds to the Cbh facies, the Havert Formation. was deposited in a shallow marine shelf and corresponds to the Cbh facies while the Oern Formation was deposited on the shoreface environment corresponds to the cbhl facies. The best exploration plays facies identified in the Finnmark Platform is the Cbh 2 and the cbhl 1 which invariably corresponds to the Isbjorn and Roye Formation respectively. The attributes extraction also showed that the reservoir with the best porosity and permeability is the Roye and Isbjorn reservoirs respectively. We also recommend that the Roye and Isbjorn Formation reservoirs be targeted during hydrocarbon exploitation activities.

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Biographies

Okeke Solomon is a Geologist and currently pursuing his Master of Science in Petroleum Geosciences in Department of Geological Sciences, at the Nnamdi Azikiwe University, Awka, Anambra State, Nigeria. He earned B.S. in Geology from Nnamdi Azikiwe University, Awka, Anambra State, Nigeria. He has published journal and conference papers. He has completed projects with Garnet Ventures (NIG.) Limited, Zenith Global Construction Co. Limited. His research interests include Petroleum Geochemistry, Petrophysics, Stratigraphy, Rock Physics, Basin Analysis, Sedimentology, and Seismology. He is member of Nigerian Mining and Geosciences Society (NMGS), Nigerian Association of Petroleum Explorationists (NAPE), Society of Petroleum Engineers (SPE), American Association of Petroleum Geologists (AAPG), Society of Exploration Geophysicists (SEG).

Didi Chekwube is a graduate student at Nnamdi Azikiwe University Awka, Anambra State, Nigeria in the Department of Applied Geophysics. He completed his Bachalor's degree in Applied Geophysics Department, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria. His research interest is on the integrated lithostratigraphy, structural, and depositional environment studies of Chad (Borno) Basin using 3D seismic data and well log suits.

Ngene Tochukwu is a graduate of Physics (Geophysics) at the Niger Delta University, currently studying a Master's of Technology in exploration geophysics at the Papua New Guinea University of Technology, Papua New Guinea as under the Queen Elizabeth Commonwealth Scholarship (QECS) Program. His research interest is geophysical methods in geothermal exploration and any other science-related areas that support the UN sustainable development goals.

Peter O. Oyekola is a graduate student at the Papua New Guinea University of Technology, Lae Morobe in the department of Mechanical Engineering. He completed his Bachelor's Degree in Mechanical Engineering from Bells University if Technology Nigeria where he was a recipient of the Chevron undergraduate scholarship for the entire duration of his study. Similarly, he is currently sponsored by the Queen Elizabeth Commonwealth Scholarship for his Master's degree program where he focuses on research areas such as automation, Structural Health Monitoring, Robotic, and design for manufacture.