ISSN 2229-5518

Shallow Geohazard Prediction and Assessment in Niger Delta, Nigeria

N. B. Osuamkpe, O. I. Horsfall, I. Tamunobereton-ari

Abstract— The application of a conventional 3D seismic data to detect shallow geohazards has been conducted successfully. For any hydrocarbon development, understanding the integrity of the surface and near-surface is important in the decision process of well pad placement and pipeline routing. The project area lies in the Cawthorne Channel oil field, an onshore field in the Coastal Swamp Depositional Belt of the Niger Delta, Nigeria. The methodology is based on the integration of seismic interpretation techniques and seismic attribute analysis. By detailed interpretation and analysis of the 3D seismic, the study provided an insight into the structural architecture of the field through horizon and fault interpretation. Two major horizons were mapped based on the clarity and uniqueness of their features characterized by low to high or variable amplitude reflections with moderate to good continuity namely; Horizons 1 and 2 respectively. Seismic volume reveals the presence faults marked as fault 1-17. Apart from the major faults (faults 1, 4, 7, 8 etc.) seen on the section, there are other minor faults (faults 15, 16, 14, 13, 12, 11, 5, 6 etc.), formed by post depositional process. The presence of these faults in the study area is an indication that there is a possibility of hydrocarbon accumulation which is definitely a lead to shallow geohazards. The principal geohazards identified using seismic amplitude anomalies includes bright spot, enhanced reflection, acoustic masking, shallow fault and gas chimneys at shallow depths. Use of the 3D seismic has demonstrated to be effective in the detection of high-risk areas due to shallow geohazards.

Index Terms— Geohazard, gas chimneys, bright spot, enhanced reflection and Seismic Attribute.

1 Introduction

Hydrocarbon resource potential and a growing population have increased the need for new oil and gas infrastructure in the Niger Delta region. Exploration and production come along with various geohazards, both at the shallow and greater depths. Prior to selection of well and drilling path, it is imperative to assess and understand the geology of the subsurface of the region using geological and geophysical data. Geohazards assessment is done to avoid problems, such as gas blowout or subsidence of sediments in the well, causing loss of equipment and, in the worst-case loss of the drilling rig and human lives.

Geohazards prediction and assessment involves acquisition, processing, and interpretation of geophysical data specifically designed to characterize the shallow sub-surface in fine detail in order to identify drilling hazards. In simplest terms, geohazards assessment points the way to the safest location to drill. Drilling activities have revealed numerous geohazards including fault scarps, gas vents, unstable slopes, reefs, faults, gas-charged sediments, buried channels, abnormally pressured sands, and gas hydrates. Drilling hazards increase the awareness and need for adherence to health, safety, and the environment guidelines. 3D seismic data are usually acquired to explore for oil and gas by the petroleum companies. But for most 3D seismic datasets, interpretations are focused mainly on the deep exploration targets of the petroleum companies. Less attention is given to shallow (younger) sediments. But these shallow (younger) sediments often contain channels that could serve as potential reservoir units. The mapping and identification of these shallow channels and defining their infill lithology in a fluvial-deltaic system is thus important in exploration and production. This is because these channels could serve as tools for shallow geohazards analysis [1, 14].

A seismic attribute is any measure of seismic data that helps us better visualize or quantify features of interpretation interest. It could be described as powerful aid to improve accuracy of interpretations and predictions in hydrocarbon exploration and development. Seismic attributes allow the geoscientists to interpret faults and channels, recognized depositional environments, and unravel structural deformation history more rapidly. They are also useful in checking the quality of seismic data for artifacts delineation, seismic facies mapping, prospects identification, risks analyses and reservoir characterization. Combining information from adjacent seismic samples and traces using a physical model (such as dip and azimuth, waveform similarity, or frequency content), seismic attributes often organize features into displays that provide enhanced images for either a human interpreter or for modern geo-statistical or neural-network computer analysis. While seismic attributes are sensitive to lateral changes in geology, they are however also quite sensitive to lateral changes in noise. 3D seismic attributes could be used to delineate shallow geohazards.

In this study, seismic interpretation and seismic amplitudes analysis shall be used to investigate a high-resolution 3D seismic data for evidence of shallow geohazards and geologic constraints to onshore exploratory drilling and potential hydrocarbon development.

2 Location and Geology of the Study Area

The Cawthorne Channel oil field is an onshore field in the coastal swamp depositional belt of the Niger Delta. Figure 1 shows the Cawthorne Channel oil field. The field is located in Oil Mining Lease (OML) 18. Its coordinates are Latitude: 4° 26' 56.5" (4.449°) north and Longitude: 7° 5' 1.8" (7.0838°) east. OML 18 covers an area of 1,035 square kilometres and includes the Alakiri, Cawthorne Channel, Krakama, and Buguma Creek fields and related facilities. OML 18 is located in Rivers State in the Southern Niger Delta. Geologically, OML 18 lies in the eastern part of the Cenozoic Niger Delta (a typical wave and tidally dominated delta) where the main reservoirs are the sandstones of the heterolithic Agbada Formation (Eocene to Recent) deposited within delta-front, delta-topset, and fluvial-deltaic environments.

The tectonic setting and geological evolution of the Niger Delta basin goes beyond the post-Eocene regressive clastic wedge that is conventionally ascribed to the modern delta, and the sedimentary entity within which the modern Niger Delta lies [13]. The development of the proto-Niger delta began with the formation of the Benue-Abakaliki trough in the early Cretaceous as a failed arm of a rift triple junction with the opening of the south Atlantic [3,17]. Progradation of the delta has been accompanied and helped by growth faults, associated rollover anticlines, and mud diapirism. Rapid sedimentation load and the gravitational instability of the Agbada sediment pile accumulating on the mobile, under-compacted Akata shales generate the growth faults. Toe thrusting at the deltaic front, lateral growth faulting and related extension also account for the diapiric structures of the continental slope of the Niger Delta, in front of the prograding depocenter with paralic sediments. Other structures include antithetic and synthetic faults and crestal faults.

The Tertiary stratigraphy of the Niger Delta has been described and defined by the [15], who recognized three distinct facies belts (formation). In ascending order, they are the prodelta facies (Akata); the paralic delta (Agbada) front facies; and the continental delta top facies (Benin formation). Petroleum occurs throughout the Agbada Formation of the Niger Delta. However, a southeast-northwest trending belt that cut across the depositional and structural trends of the delta form an "oil-rich belt" having the largest field and lowest gas-oil ratio [6,7,8]. The belt comprises the central, easternmost, and northernmost parts of the delta. Hydrocarbon distribution is attributed to timing of trap formation relative to petroleum migration (earlier landward structures trapped earlier migrating oil)

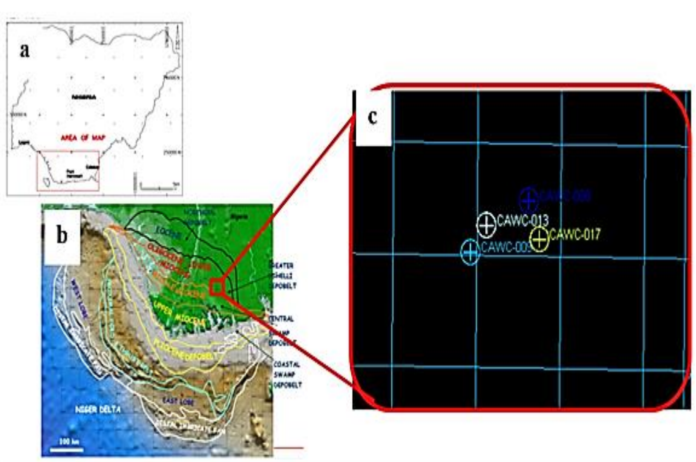

Fig. 1: Schematic map of (a) Nigeria showing, the location of Niger Delta (b) inMap of the Niger Delta Showing Study Area in the OML 18 block highlighting the Cawthorne Channel oil field in red Box (c) Cawthorne Channel oil field show well locations [12]

3 Materials and Methods

3.1 Dataset

The data used in this work are well log data and 3D post-stack seismic data from an Onshore Niger Delta oil field. The data consist of suites of well logs from four wells (CAWC-009, CAWC-017, CAWC-013, and CAWC-008) and a 3D seismic data. Conventional suites of well log data available for the study includes Gamma Ray (GR) Logs, Spontaneous Potential (SP) Logs, Porosity Logs and Resistivity Logs. Seismic data has a dominant frequency of 60 Hz and extends to 3000 milliseconds two-way travel time (TWT), below which reflection continuity is generally poor.

3.2 Fault and Horizon Interpretation

Interpretation of the 3D volume was performed on a workstation using a seismic interpretation software, Petrel 2018 version. After carrying out a good correlation between seismic and well data which help identify the geologic horizons of interest, the next stage is seismic interpretation. Although the aim of this work is about shallow geohazards, the deeper parts of the field shall be interpreted which could give a lead on shallow geohazards.

Seismic interpretations of the subsurface structure were based on picking horizons along coherent reflections of the same phase. This usually translates to picks on a peak or trough in seismic surveys with zero phase correlation type. These seismic responses (e.g. peak and troughs) resemble differences in acoustic impedance between different earth materials. The continuous same-phase reflections are interpreted as horizons representing stratal surfaces, whereas discontinuities are interpreted to represent fault displacements or unconformities. Horizon interpretations of the 3D seismic volume began on vertical sections at the well-tie location and extended outward. Observations of the seismic images were made on different display orientations, including horizontal slices, vertical sections of in lines, cross lines and arbitrary lines.

Faults are generally indicated by observations of discontinuities or breaks in reflections (i.e. hanging-wall and footwall cutoffs). Fault picks are then extended upwards and downward until the fault trace is near flexure or invisible. Manual picking was also the basis for horizon picking near faults' intersections and in complex areas such as narrow fault blocks. Picking closer line spacing was performed for higher level of details in more complex area.

3.3 Identification of Shallow Geohazards

Shallow gas (geohazards) is a subgroup of hydrocarbon indications seen at shallow depths on seismic data. The process of identifying shallow gas is the same as the process of identifying hydrocarbons in a seismic section. There are several well-known seismic indications of hydrocarbons, some of them are known as direct hydrocarbon indicators (DHI). The most common seismic amplitude anomalies identified and associated with hydrocarbons are; bright spot, dim spot, flat spot, acoustic masking, pull-down, phase-reversal, and chimneys/pipes. These are well-known features that are also defined as seismic evidence of shallow gas by [10].

ISSN 2229-5518

3.4 Seimic Interpretation

Seismic attributes describe the features and characteristics of seismic data. A seismic attribute is defined as the rate of change in quantity with respect to time or space or both. They assist in qualitative interpretation and can describe the geometry related to structure and stratigraphy [9]. Basic seismic properties are used to derive seismic attributes such as frequency, amplitude etc. Seismic amplitudes are sometimes, unable to display minor features like small faults or thin lithological units.

Attributes can be directly measured or can be derived from a seismic volume and can serve as an interpretational tool for subsurface structure, stratigraphy, and reservoir properties. [2] classifies seismic attributes based on time, amplitude, frequency and attenuation. Here seismic attributes can be used to observe the desired features [4]. Seismic attributes are classified as surface and volume attributes. Volume attributes are more useful for this project as these attributes define the major faults in 3D. Often, many attributes are combined to work together and produce desired results for enhancement of subsurface physical and geometric features [4].

Analyses of seismic attributes in the studied 3D volume were helpful for delineating some faults and detecting possible geohazards and gas presence. The most effective attributes are the ones that amplify the contrast between seismic responses caused by gas reflections and other non-gas related reflections. Several useful attributes applied in this study were categorized by [16] as geometrical attributes. These attributes scan adjacent traces for each computed trace and describe the spatial and temporal relationships based on character such as phase, frequency, amplitude, etc. [16]. By understanding the characteristic response of acoustic waves passing through gas zones, leaky faults could be predicted by the output of seismic attributes. Variance Attribute, minimum amplitude Attribute, Reflection Intensity Attribute, Root Mean Square (RMS) Amplitude and Amplitude Contrast Attribute were applied in this work to delineate shallow geohazards in the CACW field

4 Results and Discussions

4.1 Lithostratigraphic Correlation

Figure 2 shows the litho-stratigraphic correlation which provides information on the general stratigraphy of the study field. This is also a proof that the wells in the field contains reservoirs and have similar corresponding lithology. A litho-stratigraphic correlation (also known as well-to-well tie) involves matching geologic phenomena based purely on rock type. Five sand bodies marked reservoirs G200, G300, G400, G600 and G700 were correlated across the four wells, which are CACW 009, 017, 013 and 008 in the field. This analysis shows that each of the sand units extends through the field, varies in thickness and some units occurring at greater depth than their adjacent unit which is possibly an evidence of faulting. The shale layers were observed to increase with depth along with a corresponding decrease in sand layers. The subsurface geology is that of alternating sand and shale layers with shale layers increasing in thickness with depth. This pattern in the Niger delta indicates a transition from Benin to Agbada Formation.

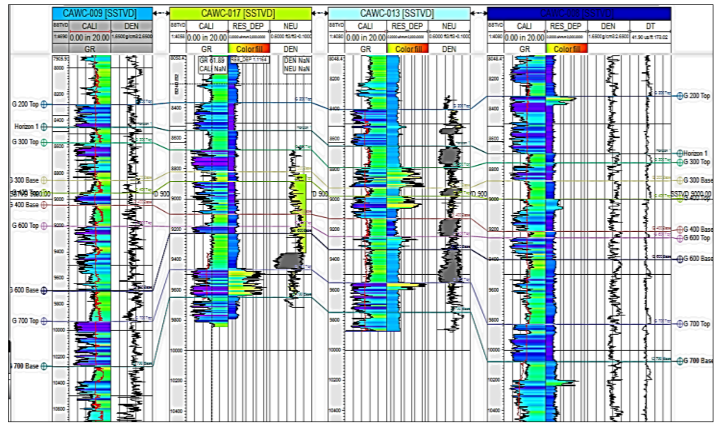

Fig. 2: Litho-stratigraphic correlation of five sand bodies (G200, G300, G400, G600 and G700) correlated across four wells (CACW 009, 017, 013 and 008) giving a brief overview of the stratigraphy in the area.

4.2 Structural Interpretation

The seismic section was mainly used for structural interpretation and the following the interpretations are deduced. The time window is between 1050 ms and 2250 ms. Horizon/events were mapped, interpreted and correlated all through the study area. Horizon picks were done iteratively in in-line and crossline directions, and corrected for mis-ties. In areas where reflection quality and characteristics are of good quality, lines are picked at larger intervals while at areas where reflection quality is relatively poor and characterized by discontinuities and chaotic, lines were picked at closer intervals in order to reduce misties to acceptable minimum. Figure 3 shows the inline 5347 with a cross-section of both fault and horizon interpretation. The Crosslines display the horizons and top of shale diapir delineated. The crossline displays less structure inferring strike lines. Two major horizons were mapped based on the clarity and uniqueness of their features characterized by low to high or variable amplitude reflections with moderate to good continuity namely; Horizons 1 and 2 respectively. Seismic volume reveals the presence of patterned reflection discontinuities which are identified and interpreted as faults. The faults were marked as fault 1-17. Apart from the major faults (faults 1, 4, 7, 8 etc.) seen on the section, there are other minor faults (faults 15, 16, 14, 13, 12, 11, 5, 6 etc.), formed by post depositional process. In most cases, they are often referred to as synthetic secondary faults as some are formed on the foot wall and upthrow axis of the major faults.

The seismic horizons have fault assisted hanging wall/footwall closures with distinctive high amplitude reflection events, which are indicative of probable hydrocarbon accumulation. The horizons are characterized by moderate to strong reflection strength, medium to high amplitudes and good reflection continuity. These suggests wide spread and uniform deposition of clastic sediments with thick sand facies and inter-bedding shales, which is characteristic of hydrocarbon reservoirs in the Niger Delta basin. The prospect for hydrocarbon in the field is high and this is an indication of the possibility of leakage to the shallow subsurface.

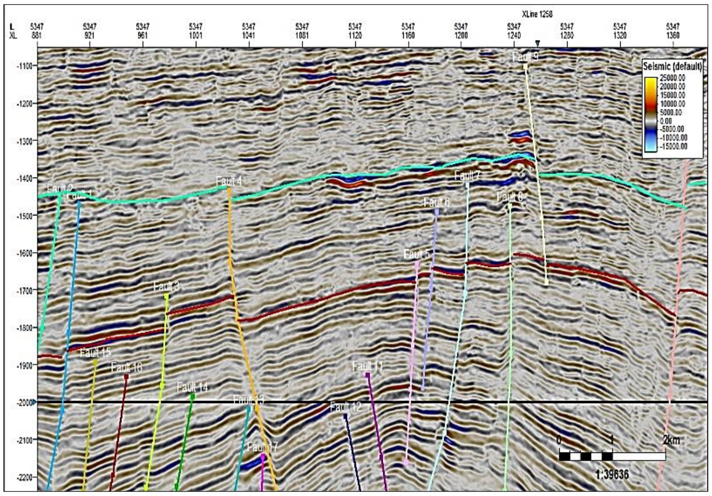

Fig. 3: Seismic interpretation showing faults and seismic horizons at shallow depth in inline 5347

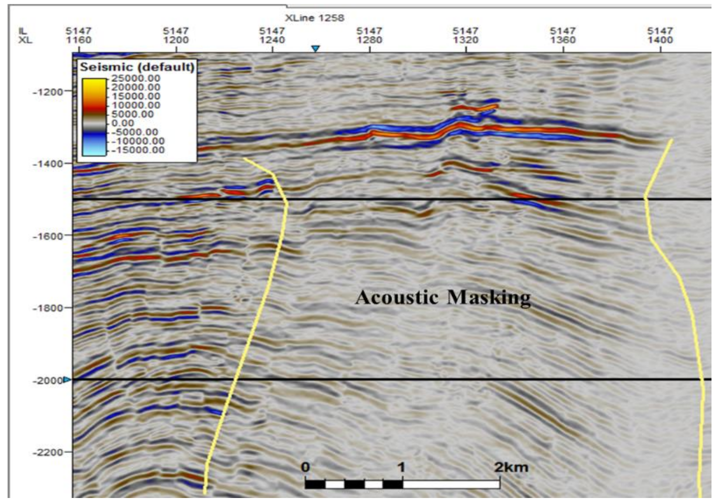

Fig. 3: Seismic section with an area of acoustic masking.

4.3 Identification of Shallow Geohazards

Indications of shallow geohazards accumulations are found throughout the majority of the study area. The following type of geohazards were identified.

4.3.1 Acoustic Masking

Acoustic blanking/masking is the faint or absence of reflections due to absorption of acoustic energy in the overlaying gas-charged sediments. Acoustic masking are seismic anomalies found in association with the mapped fluid-flow systems. Acoustic masking is a common seismic amplitude anomaly identified an as seismic evidence of shallow gas [10]. Figure 4 illustrates a Seismic section with an area of acoustic masking. Figure 5 shows an area of acoustic masking or wipe-out zone located in a fluid-flow system, beneath a large bright spot. This specific bright spot is a large potential shallow gas accumulation. The base of this feature also shows a reversed-phase reflection, most likely related to the base of the gas accumulation. here are no indications of seepage to the seafloor or other areas located above these features, being evidence of this to be fluids or gas still trapped in the subsurface. Its origin is difficult to identify as the seismic signal loses its strength further down. Figure 5 shows an illustration of a Seismic section with an area of acoustic masking.

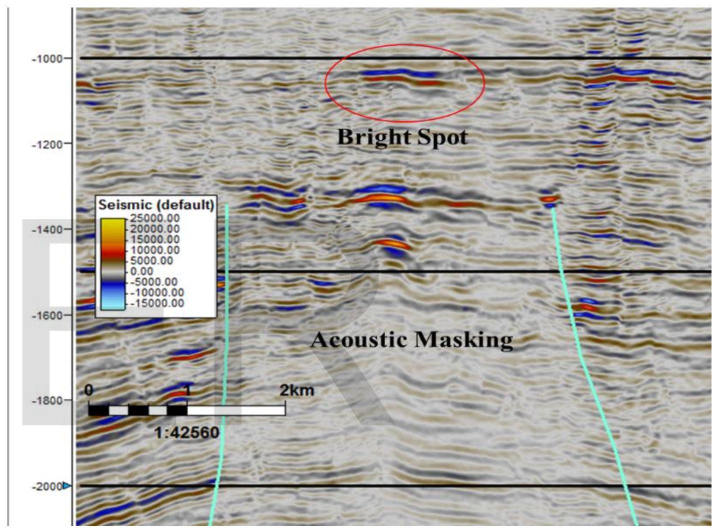

Fig. 5: Seismic section with a bright spot being a potential shallow gas accumulation, located above an area of acoustic masking.

4.3.2 Gas Chimney

Gas chimneys were observed at shallow depth. Figure 6 and 7 show part of the 3-D seismic section with detected gas chimneys displayed. Gas chimneys generally appear as diffuse columnar features in seismic data, taking various shapes. Figure 6 indicate a gas chimney and the red arrows show the direction of fluid-migration pathways. Gas chimney is a subsurface leakage of gas from a poorly sealed hydrocarbon accumulation. The gas can cause overlying rocks to have a low velocity. Gas chimneys are visible in seismic data as areas of poor data quality or push-downs. The benefits of mapping gas chimneys are as follows: they can indicate fluid-migration pathways and show where gas accumulations are likely to be present, as they can indicate charging of reservoirs from a deeper level. Gas chimneys lining up with faults above a possible reservoir indicated leakage and a probable pressure release. Absence of chimneys along faults across possible gas-charged channel sand may indicate risk of overpressure.

ISSN 2229-5518

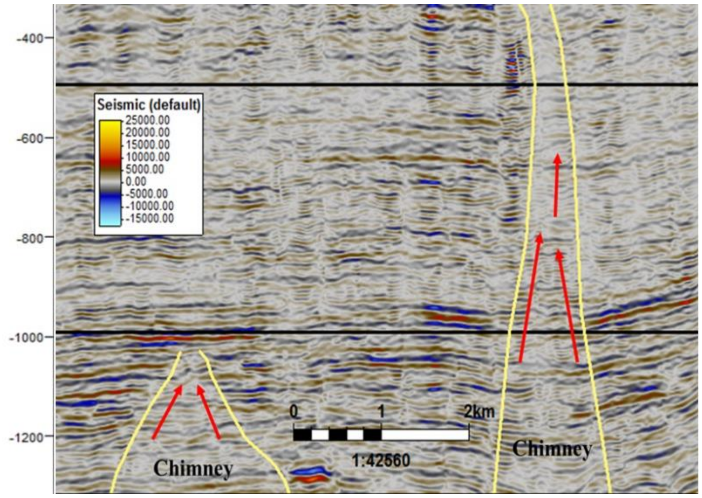

Fig. 6: Part of the 3-D seismic section with detected gas chimneys displayed and zones of fluid flow

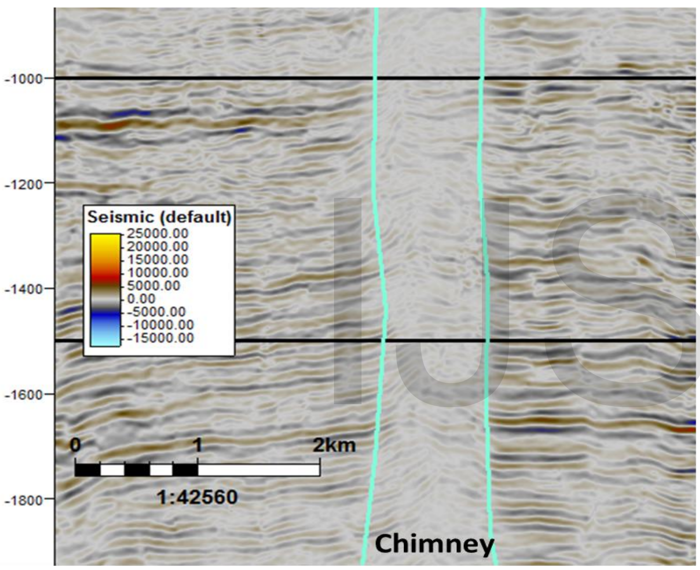

Fig. 7: Part of the 3-D seismic section with detected gas chimneys displayed

4.3.3 Bright Spots

Bright spots are local increase in reflection amplitude, related to high-amplitude anomalies with a phase-reversed signal compared to the seafloor reflection. These anomalies possibly represent shallow gas or sand bodies (channels). They may be indicative of shallow overpressure, which in turn may pre-condition the sediments to mass failure. Negative-polarity or phase-reversed reflections can represent top of low density or low velocity events in seismic data, often a sign of hydrocarbons or gas-charged sediments. Bright spots are seen in figures 8 to 10, showing the wiggle trace of both the seafloor reflection and different bright spots being potential shallow gas accumulations.

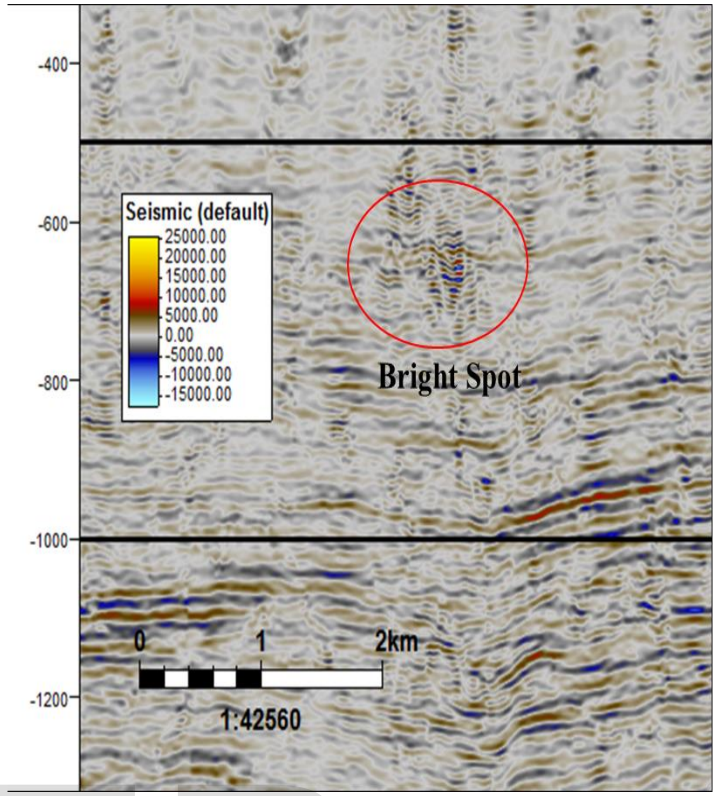

Fig. 8: Mapped bright spots at about 600 ms.

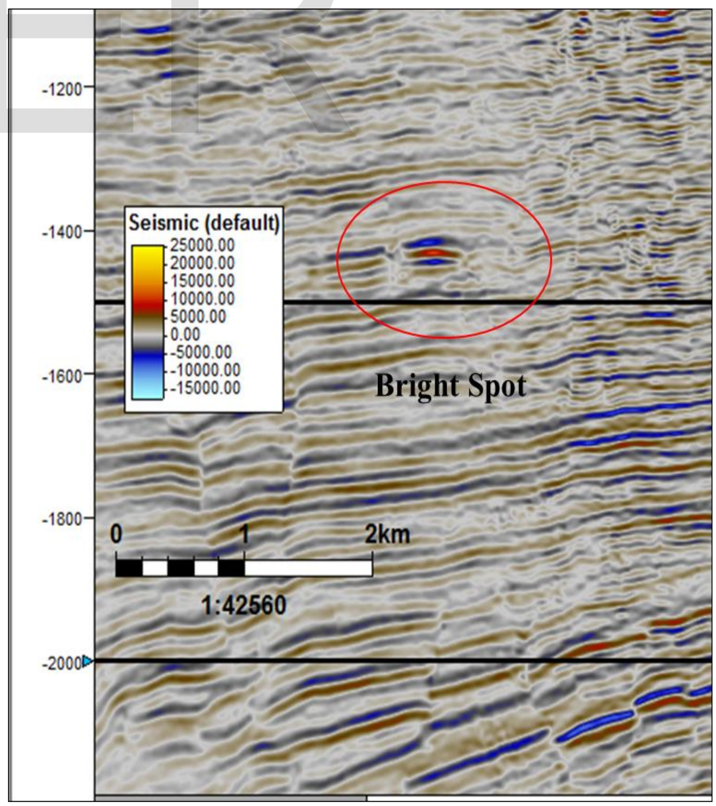

Fig. 9: Mapped bright spots at about 1450 ms

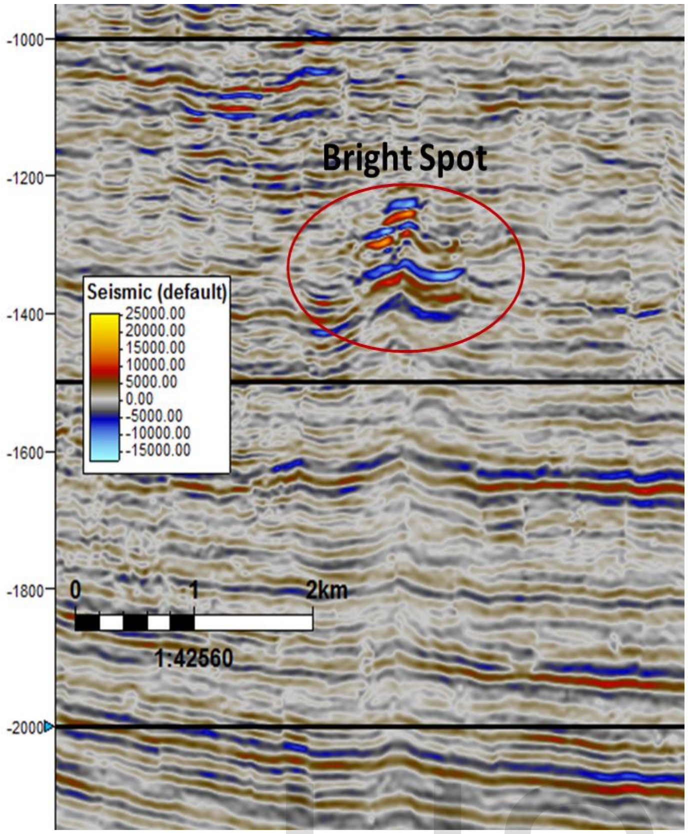

Fig. 10: Mapped bright spots at about 1300 ms.

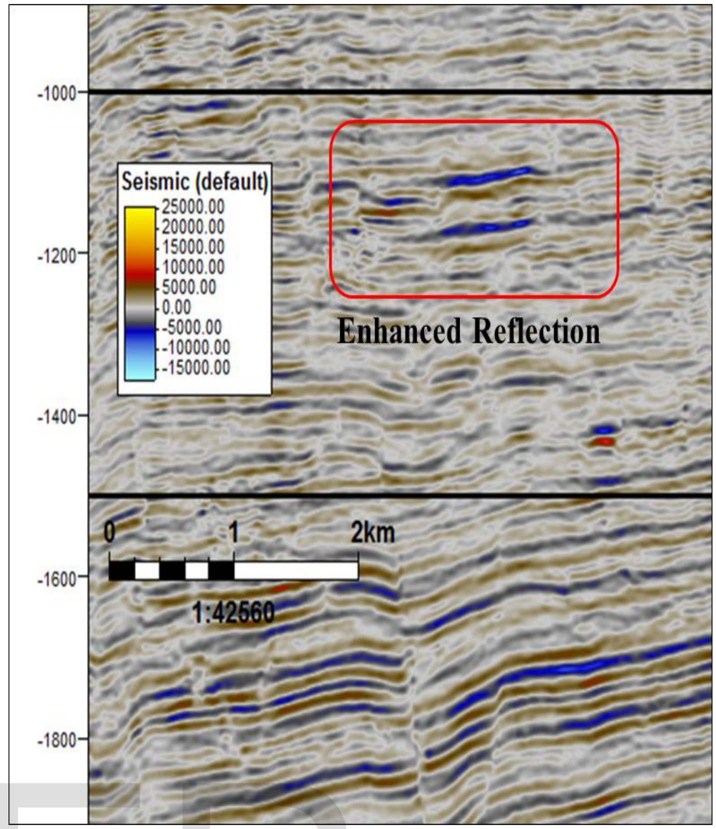

Fig. 11: Mapped Enhanced reflection at about 1100 ms.

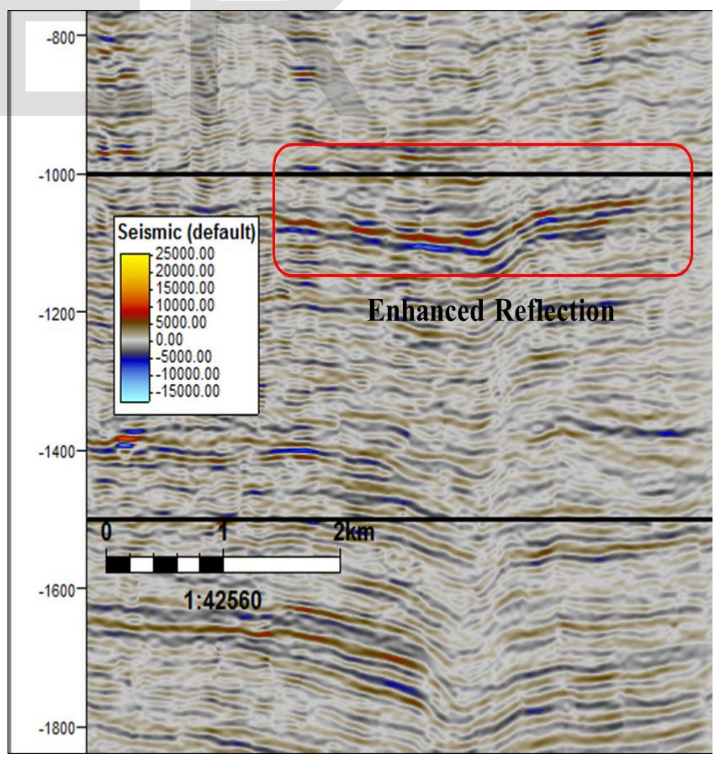

Fig. 12: Mapped Enhanced reflection at about 1050 ms

4.3.4 Enhanced Reflections (ER)

Enhanced reflections (ER) are related to the increase in reflection amplitude, normally in a lateral extent close to gas chimney and fluid-flow systems. ERs are accumulations associated with trapping by either impermeable layers or very porous sediments. Mapping amplitude anomalies associated with shallow gas accumulations in areas without fluid-flow systems and leakage along faults are often associated with enhanced reflections. The enhanced reflections are generally located along sealing structures or stratigraphy. Figure 11 to 13 show a reflection being a flat enhanced reflection located just between 1000 ms and 1200 ms.

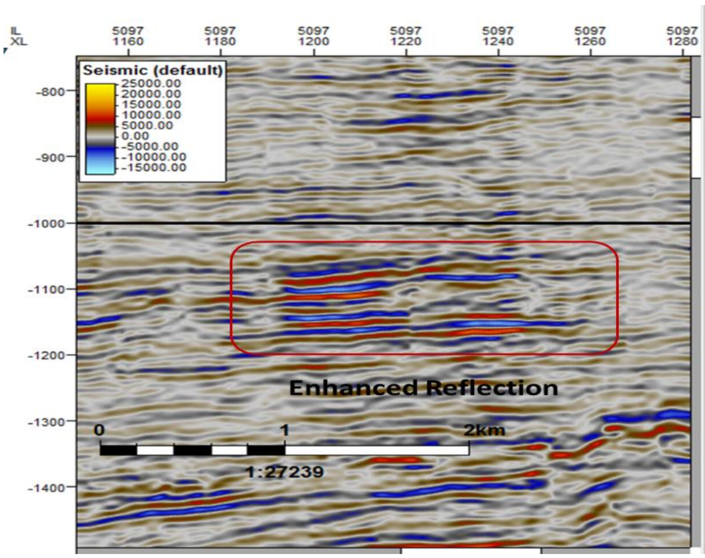

Fig. 13: Mapped Enhanced reflection between 1000 and 1200 ms

4.3.5 Shallow Fault

Shallow fault was seen in some parts of the seismic volume (figure 14). The time interval is between 800 and 1300 ms. The figure below shows one type of mapped fluid flow associated with faulting and is indicated by a light green horizontal line. The line is interpreted to be leaking fault. Faults such as this represent hazards in several senses: 1) they may act as conduits for overpressure fluids or gas from depth, and 2) they form a plane of weakness, which in this particular case is adjacent to a free slope and subsequently there is a risk of detachment and mass failure. Faults provide conduits for overpressured gas and fluids and provide planes of weakness for initiation of mass failures.

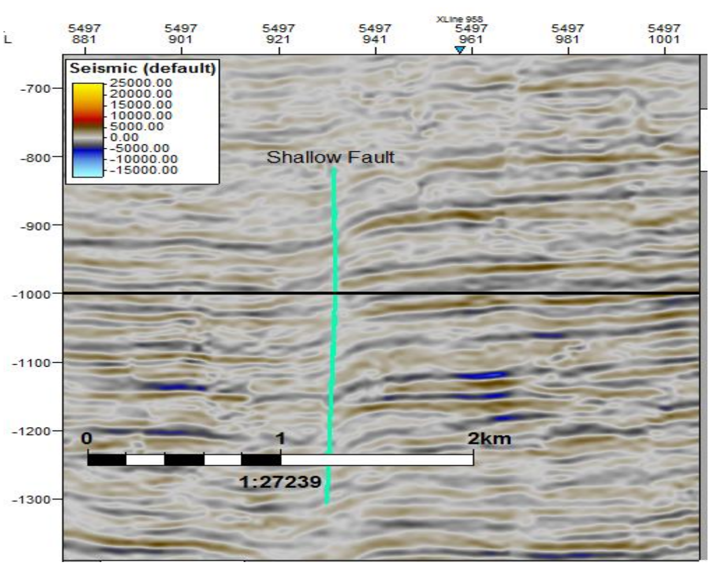

Fig. 14: Shallow faults as a potential geohazard

4.4 Seismic Attribute Analysis

Seismic attributes typically provide information relating to the amplitude, shape, and position of seismic waveform. Variance Attribute, minimum amplitude Attribute, Reflection Intensity Attribute, Root Mean Square (RMS) Amplitude and Amplitude Contrast Attribute were applied in this work to delineate shallow geohazards in the CACW field.

Figure 15 shows chimney distribution and acoustic masking on minimum amplitude attribute respectively. In both cases, the areas of anomalously high amplitude correspond to the geohazard interpreted on the seismic section beside it. Figure 17, 18 and 19 show enhanced reflection distribution and bright spot distribution on reflection intensity attribute. The orange coloured amplitude represents high amplitudes. The high amplitudes are indications of likely geohazards at those depths. Low amplitudes are probably areas that are safe from hazards to drill wells. Variance attribute can be effective for improved shallow facies and fault delineation as seen in figure 20. Variance edge seismic attribute correlate well with faults and fractures within the study area. Faults signatures were enhanced through calculating the variance within the seismic data volume with an edge enhancement option, thereby enabling the mapping across discontinuities within the data. A number of faults reaching up to the shallow subsurface have been seen. Amplitude map also shows high amplitude associated with these fault systems. An example of such faults with gas escape is shown in Figure 20 and 21 which is the variance attribute for improved shallow facies and fault delineation. These "leaky" faults may act as conduits for that transport deep geopressured fluids into the shallow section where they would be drilling hazards.

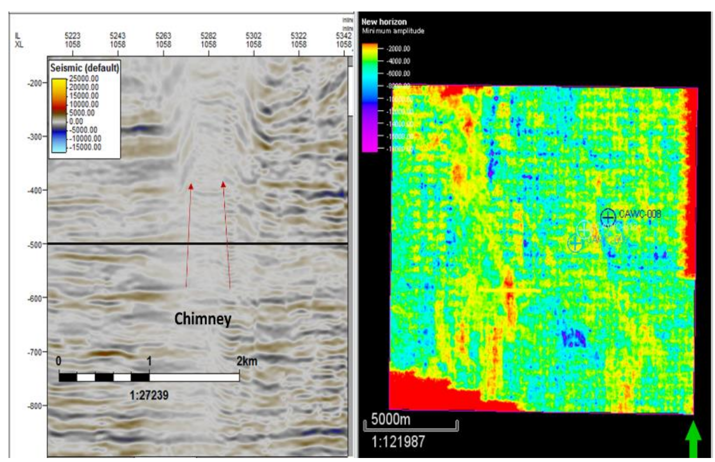

Fig. 15: Chimney distribution on minimum amplitude Attribute

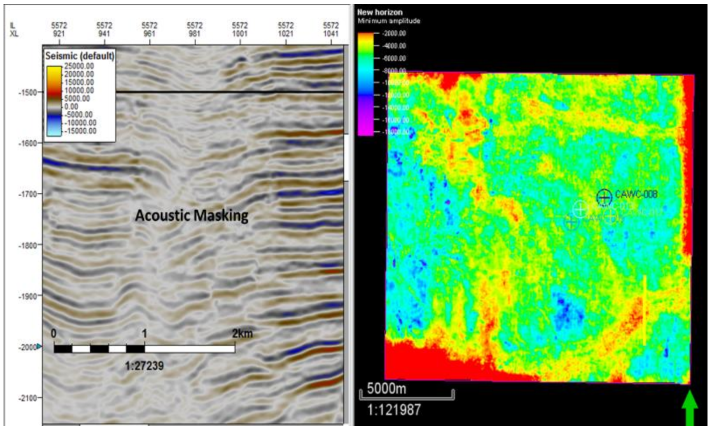

Fig. 16: Acoustic Masking distribution on minimum amplitude Attribute.

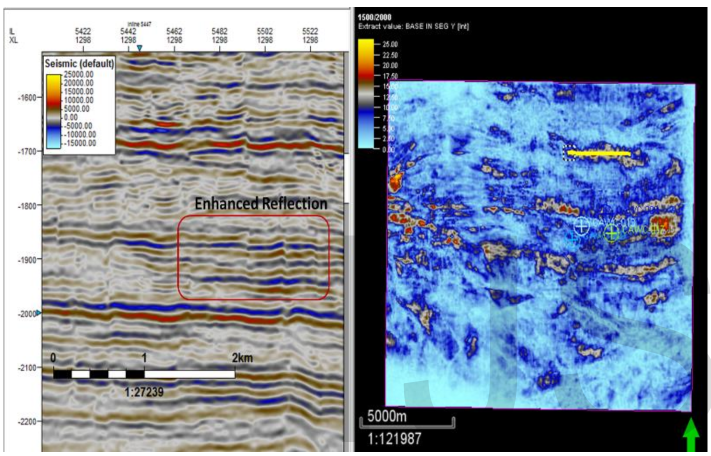

Fig. 17: Enhanced Reflection distribution on Reflection Intensity Attribute at about 1700ms.

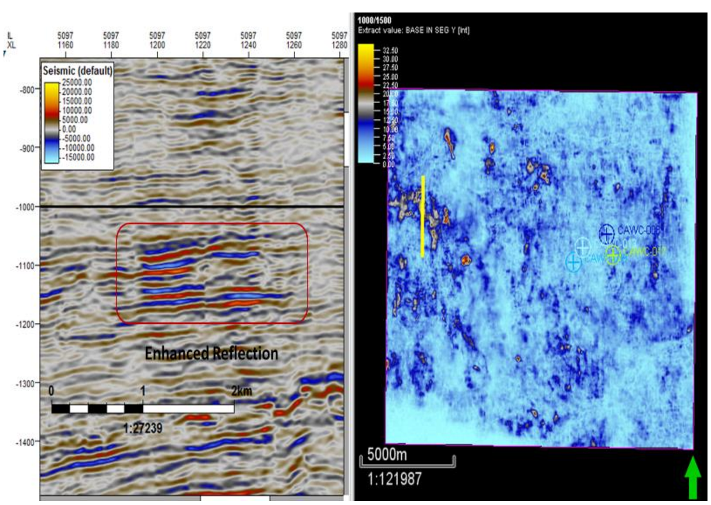

Fig. 18: Enhanced Reflection distribution on Reflection Intensity Attribute at about 1100 ms.

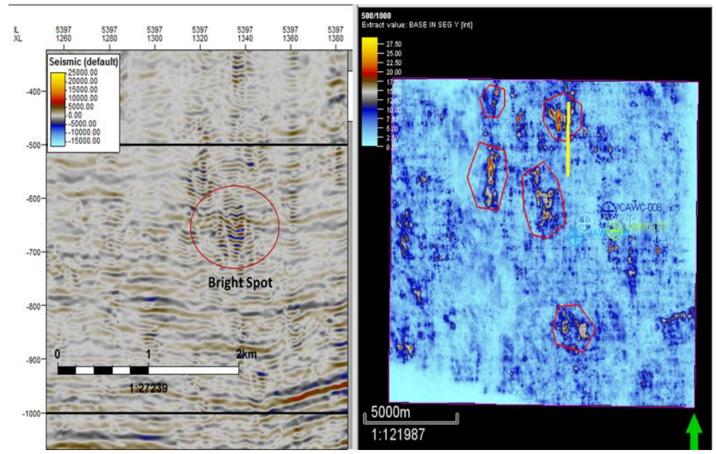

Fig. 19: Bright spot distribution on Reflection Intensity Attribute.

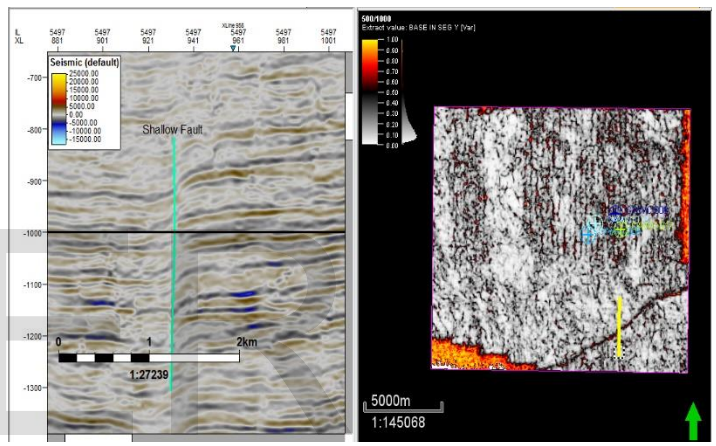

Fig. 20: Shallow fault trend on Variance Attribute for improved shallow facies and fault delineation.

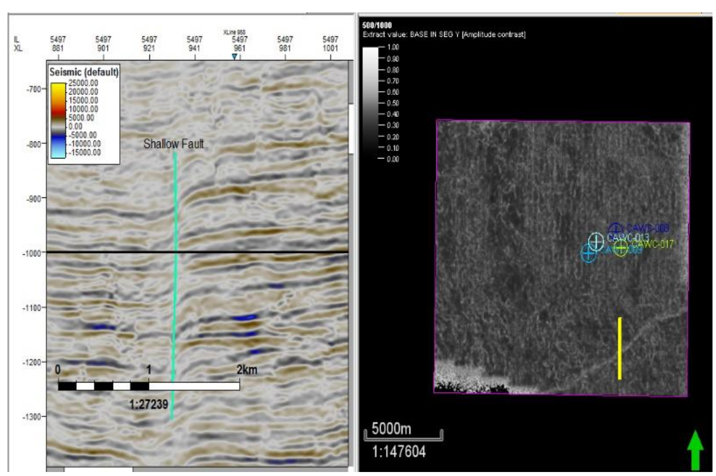

Fig. 21: Shallow fault trend on Amplitude Contrast Attribute.

ISSN 2229-5518

4.5 Root Mean Square (RMS) Amplitude

Root mean square (RMS) amplitude is a post-stack attribute that computes the square root of the sum of squared amplitudes divided by the number of samples within the specified window used. With this, one can measure reflectivity in order to map direct hydrocarbon indicators in a zone of interest. However, RMS is sensitive to noise as it squares every value within the window. RMS amplitude attribute correlate strongly with formation porosity and/or liquid saturation (oil/water vs. gas). RMS amplitude provides a scaled estimate of the trace envelope.

Figure 22, 23 and 24 shows RMS Extraction between 500 – 1000ms, 1000 – 1500ms and 1500 – 2000 ms. The amplitude map is noticeably the distribution of high and low amplitude across each horizon and delineates any special features in the study area, such as lithology and fluid content at greater depth. At shallow depth, which is the interest of this study, areas that have high amplitude (red, yellow and green colour) at the black circles are areas of possible geohazards. The black circled areas are likely shallow faults, gas chimneys, shallow gas accumulations and could deter drilling operations. Extraction of seismic attributes from seismic data can bring to fore new information and insights into stratigraphic and structural interpretations, which has been also said to be a pointer to the presence of geohazards

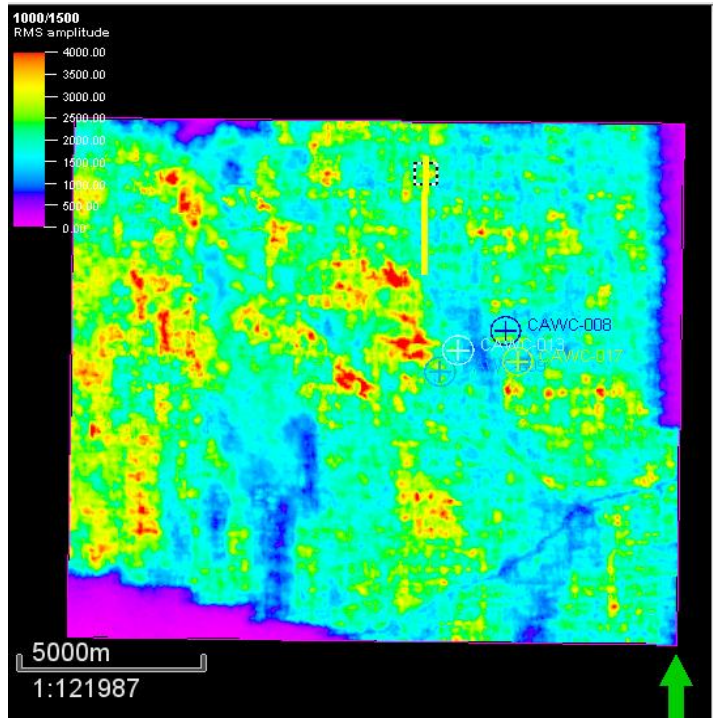

Fig. 23: RMS Extraction between 1000 - 1500.

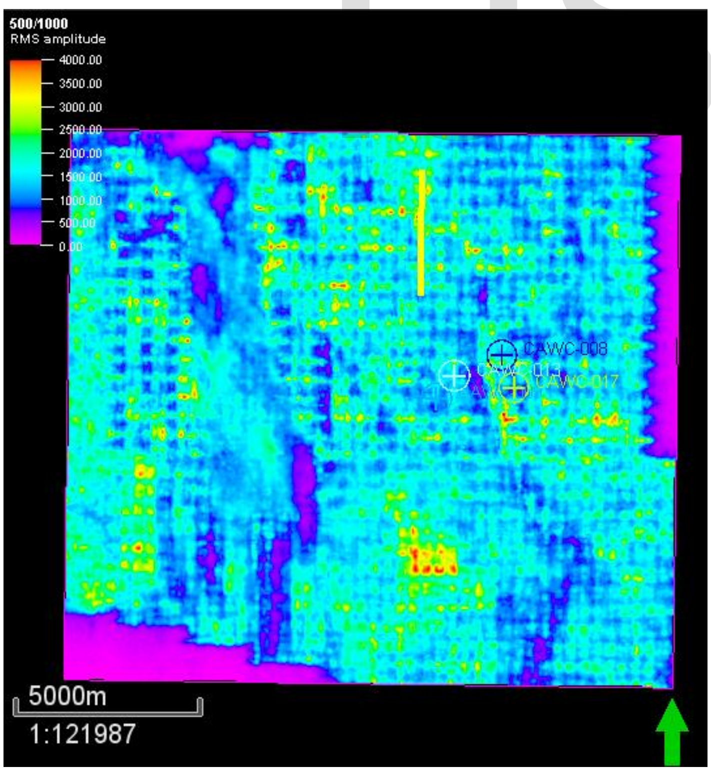

Fig. 22: RMS Extraction between 500 - 1000.

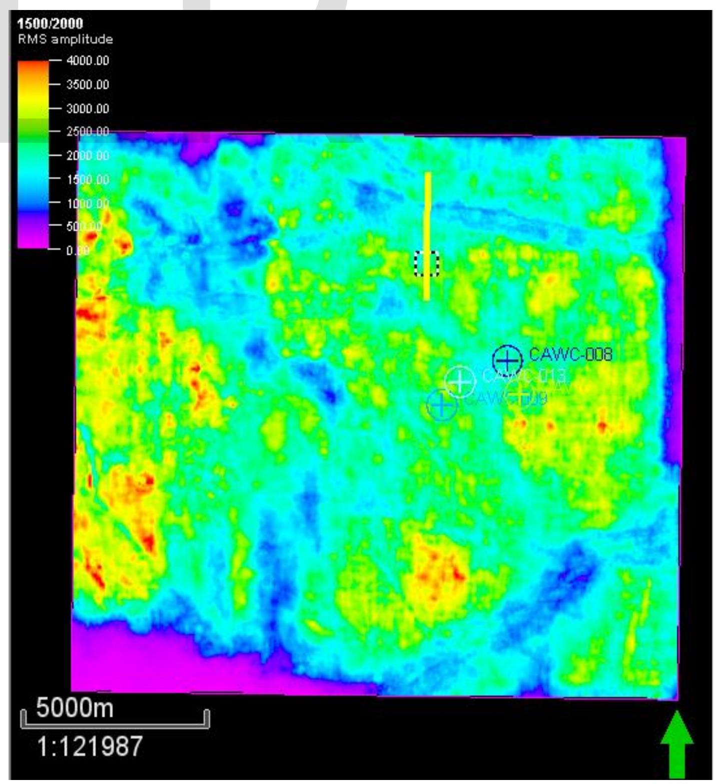

Fig. 24: RMS Extraction between 1500 - 200.

5 Conclusion

The understanding and management of geohazards play a prominent role in a successful Exploration and Production venture in the coastal swamp environment. Inadequate containment of these hazards could result in significant loss or damage to personnel and equipment. A shallow geohazard assessment and prediction study was carried out in Cawthorne Channel oil field, coastal swamp of the Niger delta using well logs and post stack seismic 3D data instead of carrying out high resolution seismic acquisition so as to reduce cost. The absolute deliverables of this work were to investigate these data for evidence of shallow geohazards and geologic constraints to onshore exploratory drilling and potential hydrocarbon development. A suite of four well logs and a post stack 3 D seismic data were used in this work. Shallow geohazards assessment is a very important part of any hydrocarbon development project. The project area lies in the Cawthorne Channel oil field, an onshore field in the coastal swamp depositional belt of the Niger Delta, Nigeria. The methodology is based on the integration of 3D seismic interpretation techniques and seismic attribute analysis. 3D seismic interpretation involved fault and horizon picking and delineation of all possible geo-hazards in the field. Also, attribute assisted seismic interpretation is a robust interpretational tool for subsurface structure, stratigraphy, and reservoir properties. The principal geohazards identified at the near surface using seismic amplitude anomalies includes shallow gas, bright spot, enhanced reflection, acoustic masking, shallow fault, and chimneys/pipes at shallow depths.

Use of the 3D seismic has demonstrated to be effective in the detection of high-risk areas due to near surface faults, shallow gas and gas chimneys. This geohazard study resulted in a significant reduction of the scope of additional surveys and therefore a significant reduction in the cost of pre-development of the Exploration and Production business. The study has also proved that Seismic attribute can help the interpreter to extract more information from conventional seismic data, which can support the geomorphology and also shallow geohazards interpretation.

References

[1]. Bouanga, E., Selvage, J., Qayyum, Q., Jones, C., Brazier, S., and Edgar, J., (2014). Implications of Horizon Cubes in Shallow Hazards Interpretation, First Break, 32: 67-73.

[2]. Brown, A., (1999). Interpretation of Three-Dimensional Seismic Data, Fifth Edition. AAPG Memoir 42 SEG Investigations in Geophysics, No. 9, pp. 355.

[3]. Burke, K.C.B., Dessauvagie, T.F.J., and Whiteman, A.J., (1971). The Opening of The Gulf of Guinea and The Geological History of The Benue Depression and Niger-Delta: Nature phys. Sci., 233(38), p.51-555.

[4]. Chopra, S. and Marfurt, K. J. (2006) Seismic Attribute Mapping of Structure and Stratigraphy: CSEG Recorder. Special Edition, 110-121.

[5]. Donald A. H. and Colin M. S. (2006). Introduction to this special section: Geohazards and pore-pressure prediction. The Leading Edge, 25(12), 1477-1477. https://doi.org/10.1190/1.2405332.

[6]. Doust, H. & Omatsola M. (1990). Divergent and Passive Margin Basins. American Association of Petroleum Geologist Bulletin, 48(1), 201-238.

[7]. Ejedawe, J. E., Coker, S. H. L., Lambert-Aikhionbare, D. O., Alofe, K. M., & Adoh, F. O. (1984). Evolution of Oil Generative Window and Oil and Gas Occurrence in Tertiary Niger Delta Basin. American Association of Petroleum Geologists, 60(1), 599 – 614.

[8]. Evamy, B. O., Herembourne, J., Kameline, P., Knap, W. A., Molloy, F. A. & Rowlands, P. H. (1978). Hydrocarbon Habitat of Tertiary Niger Delta. American Association of Petroleum Geologists Bulletin, 62, 1-39.

[9]. Hart, B.S. (2008). Channel detection in 3-D seismic data using sweetness. AAPG Bulletin. 92:733–742. doi: 10.1306/02050807127

[10]. Judd, A. G., & Hovland, M. (1992). The evidence of shallow gas in marine sediments. Continental shelf research, 12(10), 1081-1095. http://dx.doi.org/10.1016/0278-4343(92)90070-Z

[11]. Kulke, H. (1995). Nigeria. In (Ed.), Kulke, H., Regional Petroleum Geology of the World. Part 2, Africa, America, Australia and Antarctica (pp.143-172). Berlin: Gebrüder Borntraeger

[12]. Nton, M. E. & Esan, T. B. (2010). Sequence Stratigraphy of EMI Fields, Offshore Eastern Niger Delta, Nigeria. European Journal of Scientific Research, 44(1), 115 – 132.

[13]. Reijers T. J. A., Petter, S. W. & Nwajide C. S. (1996). The Niger Delta Basin. In T.J.A. Reijers (Eds.), Selected Chapters on Geology: Sedimentary Geology and Sequence Stratigraphy of Anambra basin (pp. 103-117). Warri, Nigeria: SPDC Corporate Reprographic Services.

[14]. Selvage, J., Jones, C., and Edgar, J. (2012). Maximizing the value of 3D seismic data for shallow geohazard identification, First break, 30, 73-83.

[15]. Short, K. C. & Stauble, A. J. (1967). Outline of the Geology of Niger Delta. Bulletin of America Association of Petroleum Geologists, 51, 761-779.

[16]. Taner, M. T., 2001, Seismic Attributes: Canadian Society of Exploration Geophysicists Recorder, 26 September, 48 - 56.

[17]. Weber, K. J., & Daukoru, E. M. (1975). Petroleum Geological Aspects of the Niger Delta. Tokyo, 9th world Petroleum Congress Proceedings, (pp.209-221).