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Seismic derived chimney cube in hydrocarbon detection via artificial neural network analysis in "kaiama" field, niger delta, nigeria.

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ABSTRACT

Seismic chimney cube technique was applied on seismic data from "kaiama" field of the niger delta via the artificial neural networks (ann) with the aim of using the technique in the identification of direct hydrocarbon indicators (dhis) and gas detection. Several inlines, cross-lines and z-slice were selected for use in this work and few ones that gave high reflectivity were selected for use. Artificial neural networks template within the opendtect environment was employed to generate the algorithm used during the application of chimney yes and chimney no. The result showed that the density of chimney were more concentrated in the vicinity of bright spot at time 3000 msec on inline 5800 and dim spot at time 1600 on inline 6000. Prominent faults were detected at time 2000 to 3800 msec on inline 5800 and at time 1800 to 4400 msec on inline 6000. The concentration of chimney cube density around the bright spot shows that the zone is gas rich while concentration around the dim spots shows a region that is oil rich. Those around the flat spot show evidence of fluid contact. However, the density of the chimney on the bright spot diminishes upwards until it fizzles out. The fade in density indicates that other zones with different direct hydrocarbon indicator such as dim spot are present. It is concluded that the artificially generated chimney cube when applied on seismic data gives a clearer result than when viewed under traditional seismic interpretation section without an applied chimney.

KEYWORDS: Chimney cube, kaiama, neural networks, niger, delta, artificial

INTRODUCTION

The seismic chimney technique in geophysical exploration and interpretation (popularly called the chimney cube) is a relatively new seismic interpretation method using neural networks and direct attributes to detect and display fluid indicators in seismic cubes. It has received worldwide acceptance as an alternative more competent seismic attribute analysis and interpretation tool especially in the midst of experts in seismic interpretation. The method employs a 3 dimensional volume of stacked seismic data with pre-defined set of information to describe the vertical chaotic behavior found associated with gas chimney [1]. This method of seismic interpretation is based on the principle of fluid migration. For instance, when fluids (oil, gas, brine) move up through sedimentary rock strata, as the rocks undergoes disintegration, they also undergo chemical compositional changes, and as a result, gas within the rock remains behind to bring about changes in the acoustic properties of the rock. The actual pathway of migration is usually seen on post-stacked seismic data as subtle vertical noise trails[2]. The chimney therefore highlights these vertical seismic disturbances so that they can be interpreted as fluid migration path. Seismic derived gas chimneys have a number of applications in oil and gas exploration. It can be used to determine migration path and relate them to surface seeps and mud volcanoes [1]. Chimney cubes reveal vertical hydrocarbon migration paths that can be interpreted from their source into reservoir traps all the way to near surface (shallow gas) and the surface (seeps)[3]. Not that alone, chimneys frequently tie in with faults especially associated with shallow hydrocarbon migration[3]. Since the introduction of the chimney analysis techniques, a number of authors have been able to apply the tool successfully in the interpretation of seismic data. For instance, [4] was able to employ the artificial neural network technique in the prediction of reservoir gas content and secondary migration routes in south africa's ibhubesi field in orange basin. [5] was also able to detect gas clouds by employing the phased velocity modelling method. [6] also employed four component seismic data obtained from offshore gulf of mexico for the interpretation of gas clouds while seismic effect of gas chimney of the valhall field has been successfully simulated by [7] using a detailed velocity model. The works of [3], [8], [9] revealed that this technology has also been successfully used to delineate subtle hydrocarbon migration pathways much better than employing the traditional seismic processing. It is also proven that a gas chimney is able to display different morphologies, which can be useful for prospect identification [10] and also to lower the risk of seal and charge via detection of fluid migration pathway on seismic data [10]. Fault related chimneys over a prospect do indicate vertical leakage from the prospective formation, and thus higher seal risk. The presence or absence of chimneys, their shape and their origination point and their extent can sometimes be correlated with the integrity of the trap [9] and so it has been used in fault seal analysis and detection. Although due to their diffuse appearance, seismic chimneys are very difficult to map on conventional seismic images, one major advantage of seismic detection of gas via artificial neural network seismic derived chimney cube over the convectional seismic method is that the chimney cube is able to reveal the presence of gas especially clearly where low amplitude reflections exist in the vicinity of gas. [11] observed that seismic attributes employed by neural networks to delineate the gas chimneys include the verticality, coherency, local average frequency, windowed root mean square amplitude as well as a "chaos" attribute. [1] observed that chimney cubes are able to reveal the source of hydrocarbon within the subsurface, how they migrated into a prospect, and how they are expelled or leaked forming shallow gases, mud volcanoes, or pockmarks at the sea bottom. In recent times, it has been used in geoharzards study[1] and also in differentiating between charged and non-charged prospects, and also in the study of history of basin migration. [12] while working in the norwegian sea realized that at times, realize that gas chimneys occurrence may be attributed to gas released from water within the subsurface moving forward upward-moving as a result of pressure release, as well as gas released from upward migrating oil or free gas. Trials are been carried out in recent times to employ the same technique in the delineation of potential geopressure zones, predicting hydrocarbon phase as well as the efficiency of a charge when dealing with especially in multiphase petroleum systems. In this project, artificial neural network (ann) seismic derived chimney cube is applied to seismic data obtained from a gas field from the niger delta nigeria with a view to among other things delineate direct hydrocarbon indicators (dhis) especially distinguish areas that are gas prone to areas that are not. This we intend to do by selecting choice inlines on seismic and mapping structural features possible for hydrocarbon migration pathway e.G. Faults, and fractures, identify possible direct hydrocarbon indicators (dhi), and applying chimney yes to possible direct hydrogen indicator area and chimney no to non-hydrocarbon zones.

LOCATION OF THE STUDY AREA

The area of study is located in the "kaiama" field of the onshore eastern niger delta area of nigeria which is situated in the gulf of guinea on the west coast of central africa. Niger delta lies between latitude 4on and 60n and longitude of 30e and 90e in the south - south geo-political region of nigeria [13]. See figure 1.0. The study area is situated within the oil mining lease (oml) 53 belonging to chevron texaco oil company. It is bordered by jisike field, ossu field, oguta field to the north, egbema and egbeme west field to the west, opl 227 to the south and opl 208 and kwale nlg plant to the east. An outline of the different geomorphology of the niger delta of nigeria is as shown in figure 1.0. The niger delta is bounded to the northwest and west by the western african shield, which ends at the benin hinge line and to the east, by the calabar hinge line. To the northern part of the basin is the anambra basin and abakaliki anticlinorium. To the immediate south of the area is the gulf of guinea which extends into the atlantic ocean. Geologically, it is situated at the intersection of the benue trough and

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the south atlantic ocean where a triple junction developed during the separation of the continents of south america and africa in the late jurassic [14]. The total area of niger delta land mass covers about 75,000 km2. From the eocene to the present, the delta is believed to have prograded southwestward, forming depobelts that constitute the most active part of the delta at each stage of its development [15]. These depobelts form one of the largest regressive deltas in the world with an area of some 300,000 km2 [16], [17], a sediment volume of 500,000 km, and a sediment thickness of about 12 km in the basin depocenter. Lithostratigraphically, the delta is basically made up of the benin formation which is the youngest and is a loose fresh water bearing sand with occasional ignite and clay and going up to 7500 ft (2286 m) deep with no overpressure [18]; the agbada formations, made up of alternations of sand and shales with the sand mostly encounter at the upper parts while shales are found mostly at the lower parts and finally the agbada formation is the oldest and the thickest. It is thickest at the center of the delta and goes up to 1500 ft (457 m) [19],[20]. The climate of the niger delta region varies from the hot equatorial forest type in the southern lowlands to the humid tropical in the northern highlands and the cool montane type in the obudu plateau area. Temperatures are generally high in the region and fairly constant throughout the year. Average monthly maximum and minimum temperatures vary from 280c to 330c and 210c to 230c, respectively, increasing northward and westward. The warmest months are february, march and early april in most parts of the niger delta region. The coolest months are june through to september during the peak of the wet season. The vegetation of niger delta is composed of four ecological logical zones. These include mangrove forest and coastal vegetation, fresh water swamp forest zone, lowland rain forest zone and the montane zone.

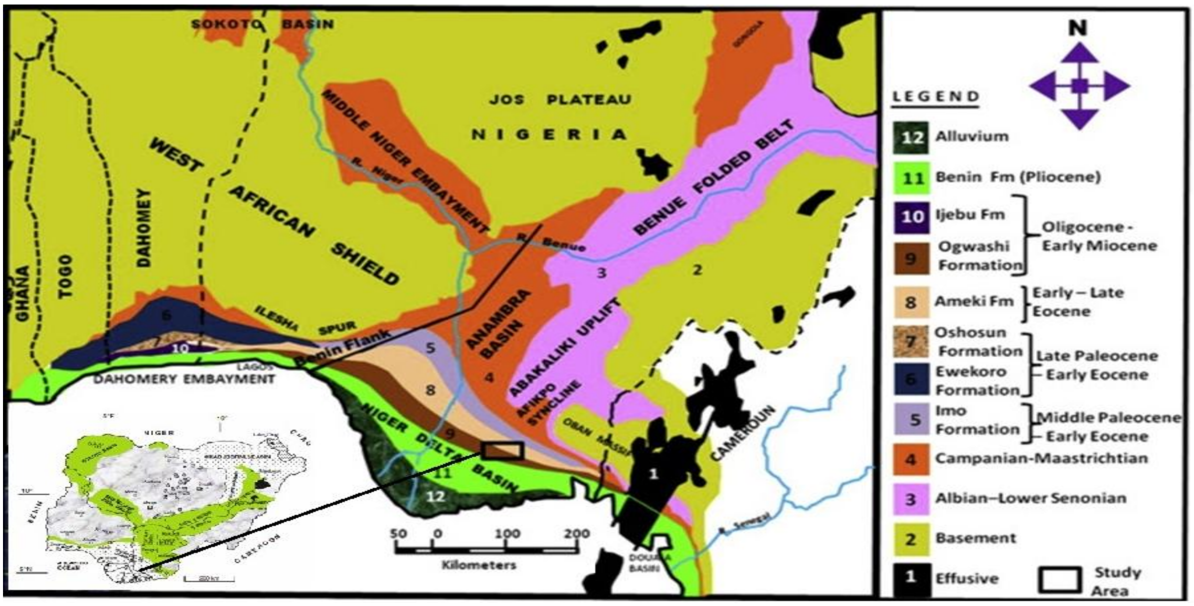

Figure 1: Map Showing the Different Lithostratigraphic Units along the Nigerian Coastand the Location of the Study Area (modified after Awosika et. al., 2000)

RESEARCH METHODOLOGY

The data used for this project include 3D seismic data procured from Chevron Oil Company showing the inlines, crosslines and z-slice in SEGY format Preliminary work on the data involved interacting with the data to ensure quality control. The project was carried out in stages. The first stage involved the uploading of the seismic data in Segy format into the Opendtect work area. This is followed by selection of choice inlines that indicates possible location of prominent direct hydrocarbon indicators (DHIs) such as bright spots, dim spots and flat spots. The DHIs areas were later deselected while the artificially generated neural network chimney YES and chimney NO algorithm is applied on the entire seismic section in order to identify areas where gas would accumulates. It is expected that locations where gas accumulates would show evidence of high amplitude chimney YES reflection while zones without gas would show no chimney evidence.

COMPUTATIONAL WORKFLOW

Objects on a typical seismic section are usually recognized as seismic anomaly that differs from the background response. These sharp departures from background have been captured by a number of seismic attributes which possess information of the object to be detected [12]. Hence an understanding of the shape and orientation of objects sum up to the process for enhancing the detection strength of the geologic objects. The step by step computational workflow that show the procedure adopted is involved (i) targeting a specific geologic object, (ii) adopting a number of potential seismic attributes that could assist in enhancing the targeted geologic object, (iii) selecting locations on the seismic volume that depicts the presence or absence of the object, (iv) applying a supervised neural network to train

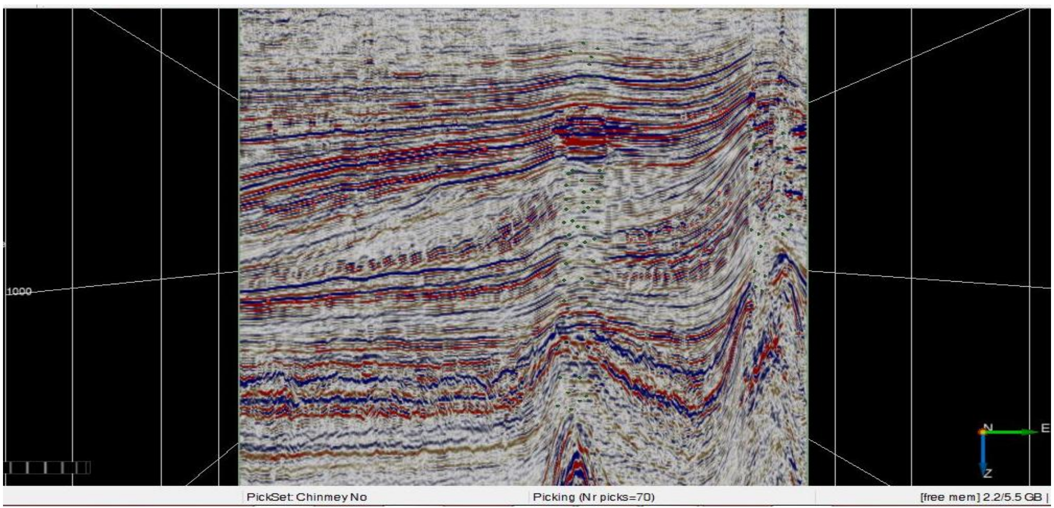

Figure 2: Seismic Section of Kaiama Field

over the entire seismic cube to generate a new cube with high values at positions that defines the high probability of the presence of the object. This we described as Chimney Yes zones and Chimney No zones respectively and finally (v) improving the output by iterating steps 1- 4. The end result of this workflow is a seismic cube in which the chimneys are observed by high density (high probability) and the surrounding volume by low density (low probability). Thus, the network assist helps in enhancing the presence of vertical disturbances in the seismic data. Before carrying out the workflow, a dip-azimuth volume is generated from the existing seismic data which contains the information regarding the local dips of the seismic reflectors and associated discontinuities. This steering cube is then taken as an input for the computation of several dip steered attributes that are used as an input for chimney computation. Then a supervised artificial neural network (Figure 2) is used to train these multi trace attributes for distinguishing the chimney and non-chimney zones in the seismic data. The use of a pre-computed steering cube produced a successful progress of the workflow. Apart from the chimney processing workflow, other workflows like geologic formation picking is performed. Other attributes analysis performed include the energy, instantaneous and frequency attributes. With the help of available geological markers, bright spots were picked at inline 5800 while dim spots were picked on inline 6000. Faults were also picked same inlines. All these processes made us to move further for analyzing and interpreting chimneys from the 3D seismic volume of the Kaiama field.

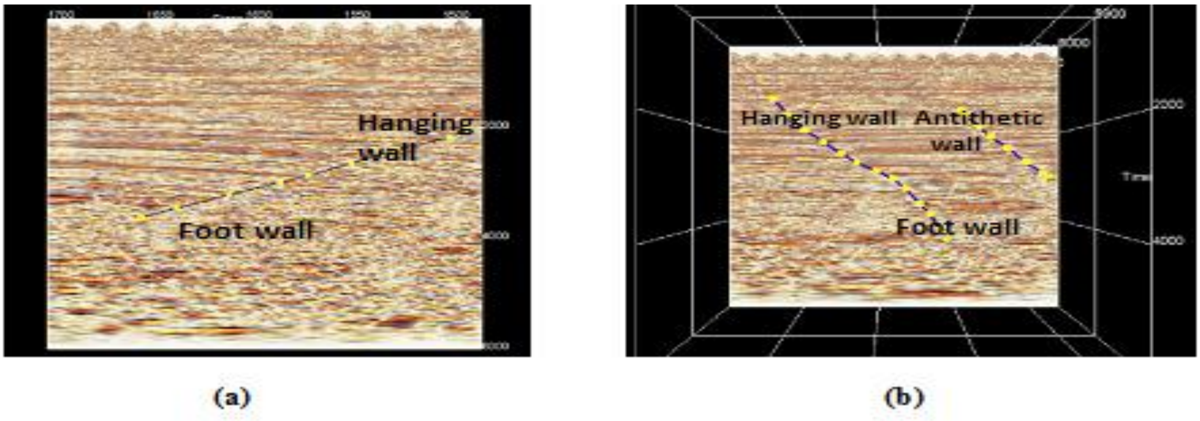

Figure 3: Fault pattern on Inline (a) 5800 msec and (b) 6000 msec

PRESENTATION OF RESULTS

The Figure 2 shows the original seismic data obtained from "Kaiama" Field of the Niger Delta while Figure 3 shows the faults interpretation from the seismic section. Figure 4 shows the interpretation of the direct hydrocarbon indicators from the selected inline of the seismic data. Figure 5 and 6 represents the chimney cube attributes set and seismic data for neural network training. Figure 7 is the result obtained from the application of the seismic derived neural networks algorithm based chimney YES and chimney NO on the seismic section. Faults from prominent inlines were selected for mapping. For instance, on inline 5800, prominent faults occur between time 2000-3800 msec. The fault seen on inline 5800 is a reverse fault with the footwall moving downthrown and the hanging wall upthrown (Figure 5a). However, this fault may act as trap, seal or migration pathway for hydrocarbon. Normal fault seen on a seismic section is an indication of displacement on the sub surface rocks and may trap hydrocarbon. Inline 6000 shows two different fault types which are reverse fault and an antithetic fault. These occur between time 1800 and 4400 msec below the subsurface. The reverse fault here has a displacement of hanging wall moving upward relative to the foot wall. The hanging wall here is upthrown while the footwall is down thrown (see the Figure 3b). The faults here may act as migration pathway, trap or seal for hydrocarbon. Two prominent seismic inlines were selected for the identification of bright spot. These are inlines 5800 and inline 6000. They were observed at time 3000 - 3500 msec and 2100 - 4000 msec respectively. The bright spot show high amplitude which increases with depth. Inline 5800 and inline 6000 reveal that there is increase in the amplitude of bright spot on the seismic section downward and decrease in amplitude of the bright spot upward. This increase in amplitude shown on these inline may be due to the displacement of the hydrocarbon phase. The fault observed on the seismic section may be responsible for the trapping of the hydrocarbon in place, such that gas, oil and water do not settle under gravity. The fault may also be responsible for holding the hydrocarbon rich in gas from migrating. Reservoir fluids under normal condition settles down such that water which is denser settles below and gas which is least dense floats on top due to buoyancy effect. The presence of gas which is

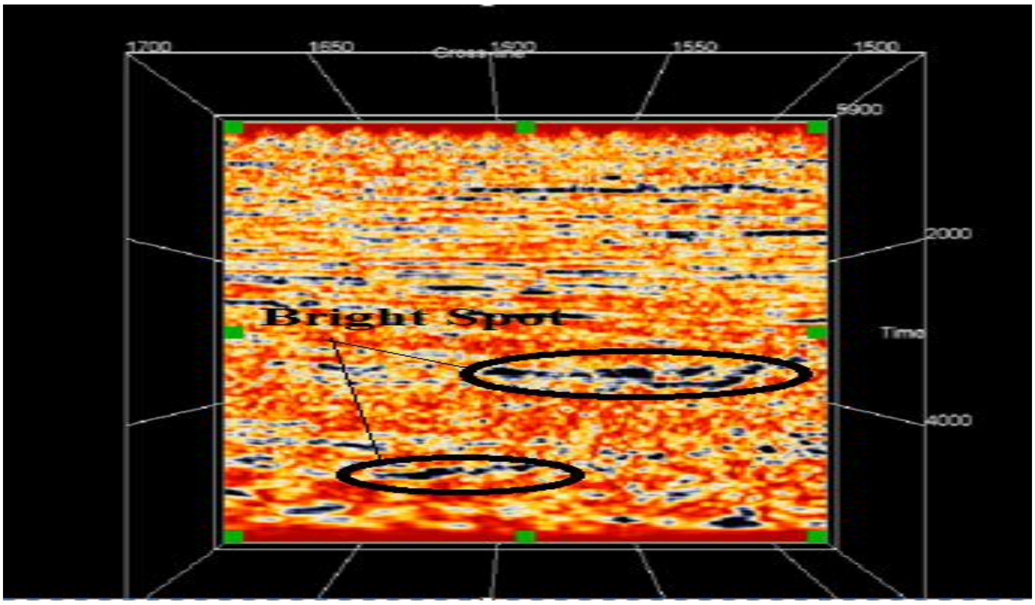

Figure 4: Direct Hydrocarbon Indicator on inline 6000

known to be of high amplitude and oil which is known to be of low amplitude is observed in inline 5800 below and above the reservoir. [21] observed that bright spots primarily results from the increase in acoustic impedance contrast when a hydrocarbon (with a lower acoustic impedance) replaces the brine-saturated zone (with a higher acoustic impedance) that underlies a shale (with a higher acoustic impedance still), increasing the reflective coefficient and that the effect decreases with depth because compaction for sands and shales occurs at different rates and the acoustic impedance relationship stated above will not hold after a certain depth/age. This shows that hydrocarbon rich in gas can be found towards the deeper part of the section; a situation that contradicts the differential density between oil and gas and also the phenomenon that explain how bright spots are formed naturally . It therefore suggests that the gas might have been displaced and trapped at that time (t) by a structural feature such as fault.

CHIMNEY INTERPRETATION

The neural network is trained on attributes extracted at chimney and non- chimney example locations identified by the interpreter. After training, the network is applied to the entire dataset. In the chimney detection process, multiple vertical attribute extraction windows are used. This enables the network to distinguish between objects with a certain vertical extent and objects with similar attribute characteristics but 'without' a vertical dimension. The neural network finally makes a classification of the seismic data into chimneys and non-chimneys. The output samples are given high values for chimneys (high probability) and low values for non-chimneys (low probability). Figure 7 shows chimney cube superimposed on seismic section displaying energy attributes. This chimney cube enhances the visibility of the energy attributes. However, these increase in the amplitude downward and decrease upward may be an indication of gas rich zone on the seismic section occurring at time 1200 to 1400 msec. Figure 8 shows chimney cube that has been superimposed on a seismic data section. The chimney processing and analysis clearly indicate the origin of chimney from deeper depth and exhibiting an upward migration towards the top of the section.

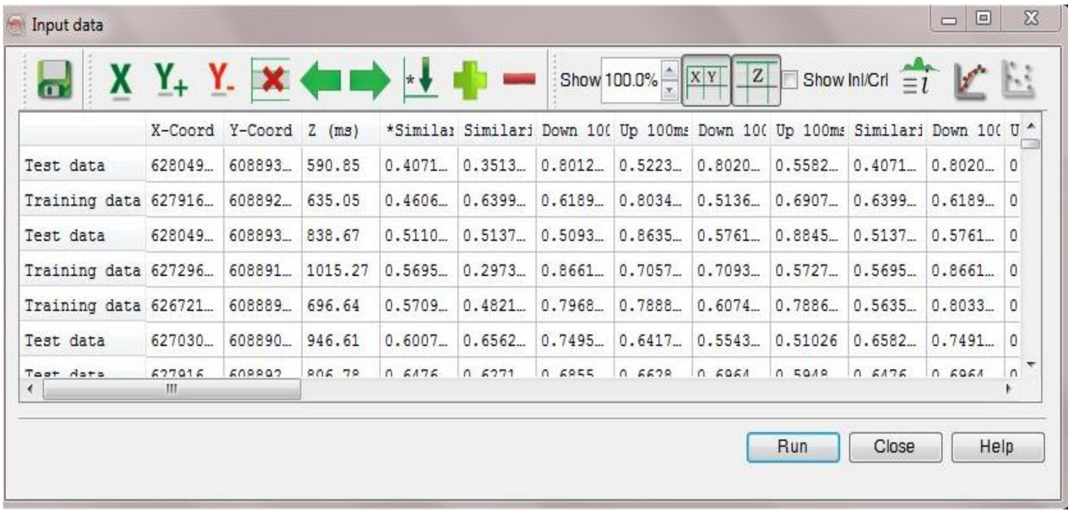

Figure 5: Seismic Data Set for Neural network Training

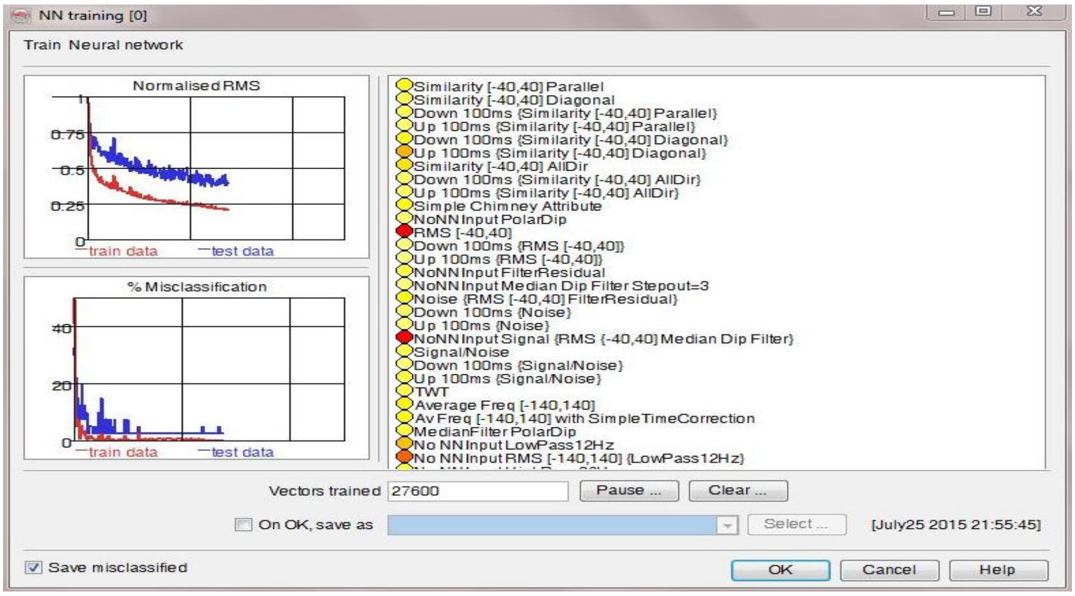

Figure 6: Neural Network Algorithm for all Seismic Attributes

This is evident in the observed Figure 7 and 8 where there is increase in density of chimney at time 1200 to 1400 msec and decrease in density at time 450 to 600 msec due to the presence of gas, hydrocarbon rich in gas has higher density of chimney compared to hydrocarbon rich in oil. Between time 800 to 1100 msec, there are faults on this seismic section which may serve as migration pathway for the chimney, due to this migration, the chimney is observed at the top of the seismic section where dim spot is observed on raw seismic section. It is observed that most of the chimneys tend to have a deeper origin, thereby indicating higher probability of their origin from the base of the Agbada Formation. This fact is better confirmed from Figure 10 and 11 where the seismic data have been removed. These observations were confirmed with few key criteria as suggested by Connolly and Garcia,[22]. The gas chimney is observed to propagate through the faults (indicated by red arrows in Figure 7 and 8 from the reservoir traps all the way to the surface. Pockmark morphology (circular appearance) sometimes when observed over a time slice are usually features that indicate the presence of gas leakage and may represent shallow gas reservoirs[23]. It is also observed that between times 650 to 900 msec, there is an increase in density of the chimney cube, between time 1050 to1150 msec, there is decrease in density, and at time 1300 msec, there is a drastic decrease in density. This increase in chimney density may be due to the fault which tends to trap the hydrocarbon oil rich zones which is mapped as the area where there are occurrences of dim spot. It is noted that the chimney has high density in the area mapped with dim spot. This is correlated with the seismic section so as to take note of the features on the seismic section and their time of occurrence. Figure 9 and Figure 10 represents the seismic section removed after superimposing chimney on it. The result here shows that there is an increase in the amplitude downward and decrease upward may be an indication of gas rich zone on the seismic section occurring at time 1200 to 1400 msec. There is increase in density of chimney at time 1200 to 1400 msec and decrease in density at time 450 to 600 msec This increase is due to the presence of gas, hydrocarbon rich in gas has higher density of chimney compared to hydrocarbon rich in oil. Between time 650 to 900 msec there is an increase in density of the chimney cube, between time 1050 to1150 msec there is decrease in density, at time 1300 msec, there is a drastic decrease in density.

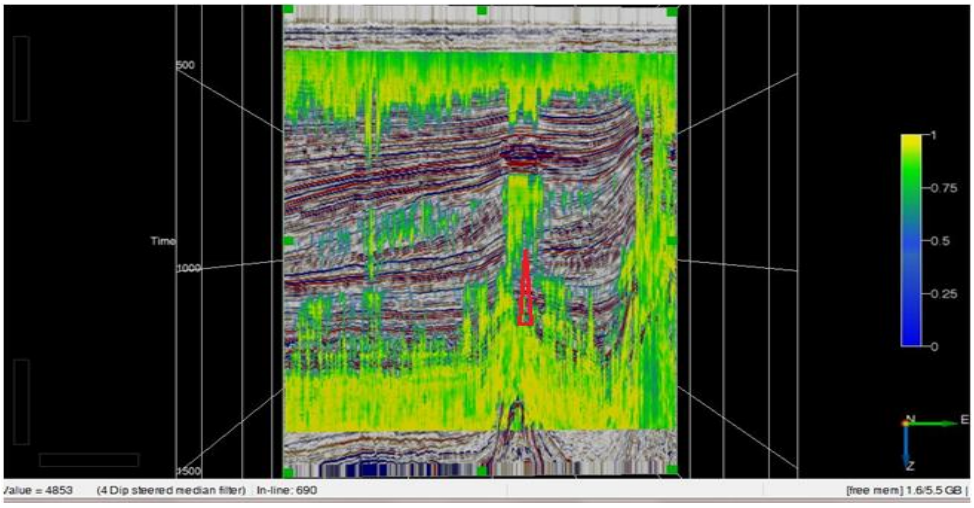

Figure 7: Chimney Cube Superimposed on Seismic section showing Energy Attributes with high chimney density at deeper depth

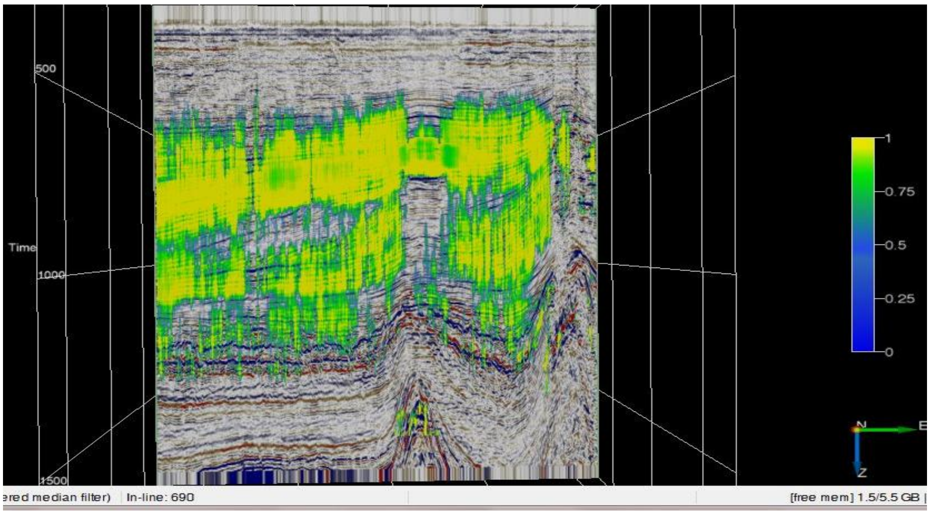

Figure 8: Chimney Cube Superimposed on Seismic section showing Frequency and Instantaneous attribute

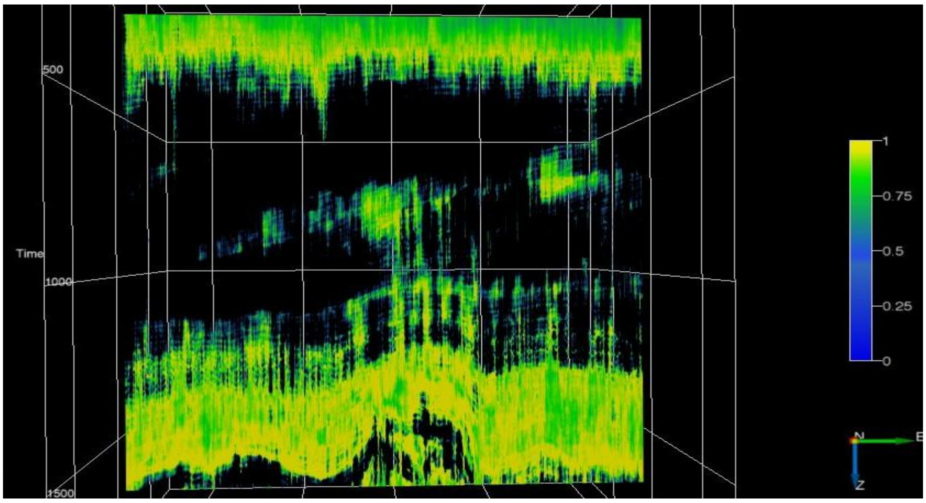

Figure 9: Chimney with Seismic section removed showing energy attribute

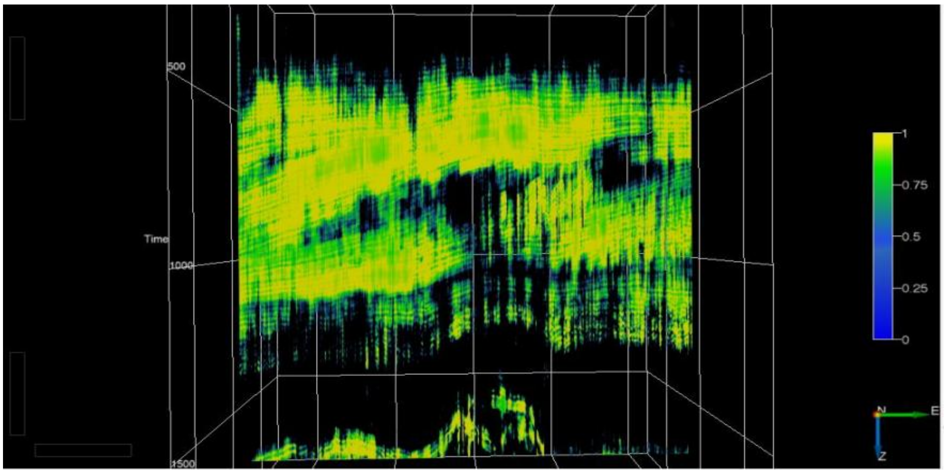

Figure 10: Chimney with Seismic section removed showing Dim Spot and Flat Spot

CONCLUSIONS AND RECOMMENDATION

The detection of chimneys by the use of neural networks has improved the identification of chimneys and made the mapping easier, more consistent, and clearer as compared to manual mapping of geological features and attributes. The method has been used to determine hydrocarbon migration path way, geologic features such as fault and hydrocarbon indicators. It has led to new insights in hydrocarbon migration research, such as revealing factors that can change the consistency of the reservoir fluids. Seismic attributes and a supervised neural network can help transform seismic input data into a new 3-D data output which cube in which one type of object is highlighted. This approach has been successful in detecting chimneys and faults, but the method has general application by different geological subfield related to petrophysics for detecting different types of hidden features on the seismic section which cannot be seen clearer during manual mapping. Chimney helps in the identification of faults that serves as trap or seal or those that leak hydrocarbon.

CONTRIBUTION OF AUTHORS

Olabanji Ojo and Oyewo Itunu designed the research and carried it out. Anusiobi developed the model code and performed the simulations while Olabanji Ojo prepared the manuscript with contributions from all co-authors."

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest whatsoever as regards the manuscript submitted for publication.

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