APPLICATION OF GEOLOGICAL AND GEOPHYSICAL DATA TO CHARACTERISE E8000 RESERVOIR IN AFENMAI FIELD OF NIGER DELTA BASIN, NIGERIA

[1] Unuevho, C.I., [2]Onuoha, K.M., [1]Amadi, A.N., [1]Ejepu, J.S and [3]Udensi, E.E
[1] Department of Geology, Federal University of Technology, Minna, Nigeria
[2]Department of Geology, University of Nigeria, Nsukka, Nigeria
[3]Department of Geophysics, Federal University of Technology, Minna, Nigeria
***Correspondence E-mail*:** c.unuevho@futminna.edu.ng

Abstract
Afenmai Field is a partially assessed discovery within the Central Depobelt of eastern Niger Delta Basin in Nigeria. It occupies 242 km^2 surface area and presently has eight wells, giving it an average well density of one well per 31 km^2. Improved assessment of the discovery is required to upgrade the field to development drilling status. As a contribution to improving the assessment, this study characterised the E8000 sand, which bears hydrocarbon in Well 007. The data utilised comprised information on subsea vertical depth to top and base of sand and shale units, foraminifera content, geophysical logs, checkshot data, fluid contact depths, and 3D seismic volume. Sequence stratigraphic concept was employed to anlayse the sand and shale units, foraminifera content, and geophysical logs. The E8000 sand was mapped through the 3D seismic volume, and a depth- structure map was produced. The map reveals a major structure building synthetic fault in the middle of the field. The fault runs approximately east –west in the eastern part of the field and northwest- southeast in the western part. The sand is a lowstand systems tract with a roll-over anticlinal structure that forms a three-way closure with a crestal synthetic fault. The reservoir pay occupies about 4.5 km^2 areal extent, with opportunities for drilling four development wells along the east-west axis of the closure. Opportunities exist for drilling a minimum of three development wells southwards of Well 007. Approximately 4000 – 5000 root mean square amplitude value characterise hydrocarbon in the reservoir. A prospect is generated within the eastern part of the of the major structure building fault's upthrown block.

Keywords: Partially assessed discovery, roll-over anticlinal structure, development wells

INTRODUCTION

The Niger Delta Basin in Nigeria contains many unassessed discoveries (UAD) and partially assessed discoveries (PAD). Among these are Oguali Field in its Northern Depobelt (Edeki 1991), Elepo Field in Central Swamp Depobelt (Overell and Nwachukwu, 1995), and Forcardos Yokri Field in shallow offshore (Wood *et al.,* 1991). Afenmai Field is a pseudo-name adopted to preserve data confidentiality and protect economic interests of the asset operators. The field is located within the Central Swamp Depobelt in eastern Niger Delta Basin (Figure 1). It covers approximately 93.44 square miles (242 km^2). Eight wells have presently been drilled within it, and this gives it an average well density of 1 well per 11.68 square miles (1 well per 31 km^2). The field is one of the PAD in the Niger Delta Basin (Unuevho and Onuoha, 2020), with possibility of opportunities for development drilling.

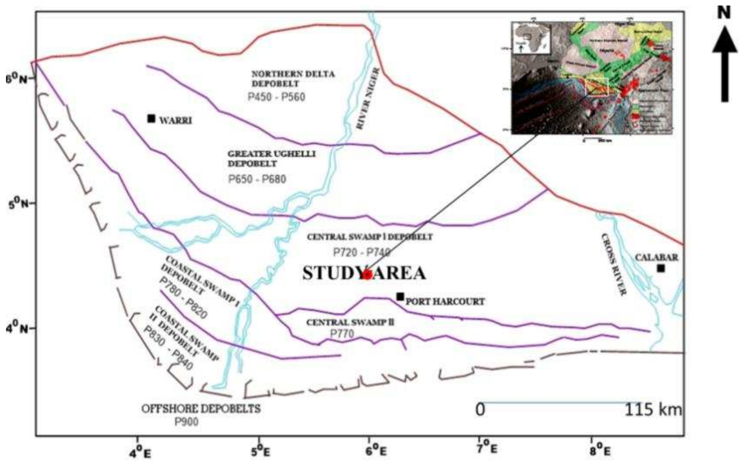


Fig.1. Study area (Unuevho and Onuoha, 2020)

Reservoir characterisation is an aspect of field appraisal upon which optimal hydrocarbon recovery hinges. Like all the UAD and PAD in the Niger Delta Basin, the Afenmai Field begs for characterisation of its reservoirs for development drilling to commence in the field. E8000 sand is among the reservoirs the asset operator found to be hydrocarbon bearing. The sand body was selected for characterization because it was penetrated by seven out of the existing eight wells in the field. The objective for characterizing this reservoir is to ascertain its spatial extent and the spatial distribution of its hydrocarbon fluids.

REGIONAL GEOLOGICAL SYNOPSIS

The origin and evolution of the Niger Delta Basin hinged on intra continental Cretaceous extensional processes. The sedimentary rock succession in the basin is Akata Formation, Agbada Formation and Benin Formation (Unuevho and Onuoha, 2021). Akata Formation is the basin's basal lithostratigraphic unit. It is dominantly a shale unit punctuated with occasional siltstones and sandstones. The formation is deposited in shelf to bathyal environments. It is overlain by the Agbada Formation comprising alternating sandstones, siltstones, mudstones and shales deposited in littoral, inner neritic, middle neritic, outer neritic and bathyal environments. It is the Agbada Formation that contains the hydrocarbon reservoirs. Hydrocarbon entrapment in the formation is structural, stratigraphic, and combined structuro-stratigraphic. The hydrocarbon source rocks are shales in the upper part of the Akata Formation, as well as shale and mudstone interbeds within the lower part of the Agbada Formation. The Benin Formation is the uppermost lithostratigraphic unit. It consists of fresh water bearing massive continental sands and gravels deposited in upper deltaic plain environment.

STUDY DATA AND METHODS

The data used in this study comprised information on subsea vertical depth to top and base of sand and shale units, foraminifera information, open-hole geophysical logs, checkshot data, and 3D seismic volume. The geophysical logs comprised gamma ray, resistivity, sonic, neutron and density log data. The foraminifera information comprise *Nonion, Cassigerinella, chiloguembelina, Uvigerina,* and *Bolivina* generic occurrence.

The project was created as Afenmai Field in a workstation with *Petrel* 2008.1.1 Geology and Geophysics interpretation software. The Imperial (British) unit system was chosen for storing depth values, while spatial extent values were stored in metres. Minna in Nigeria Mid Belt was chosen as the Co-ordinate Reference System for the data base. The well base information, geophysical logs and 3D seismic volume were imported into the project. The lithologic data were plotted on the geophysical logs. The top and base of the lithologic units were appropriately adjusted in consonance the with respective gamma ray response. Depositional environments were reconstructed using a hybrid of the following criteria:

i. Continuity of lithologic units following Allen and Roberts (1982), Serra (1989), and Boggs (2006).
ii. Gamma ray motif following Weber (1971), Selley (1978), Larue and Lagarre (2004).
iii Foraminifera content following Okosun and Liebau (1999) on association of *Cassigerinella Chipolensis* with *Uvigerina* and *Bolivina,* Boersma (1980) on association of foraminifera genera with depositional environments (Figure 2), Ozumba (1995) on association of benthic foraminifera with depositional environments (Table 1), and Peters (1980) on paleo bathymetric interpretation of benthic foraminifera.

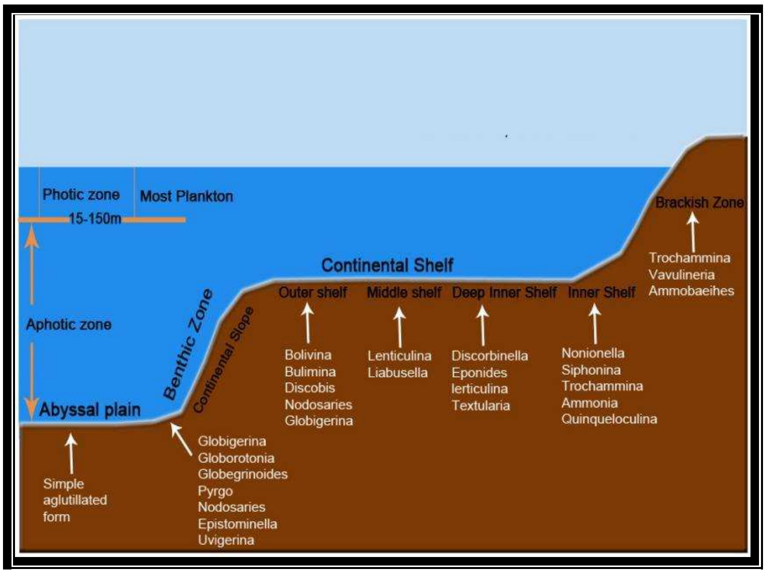
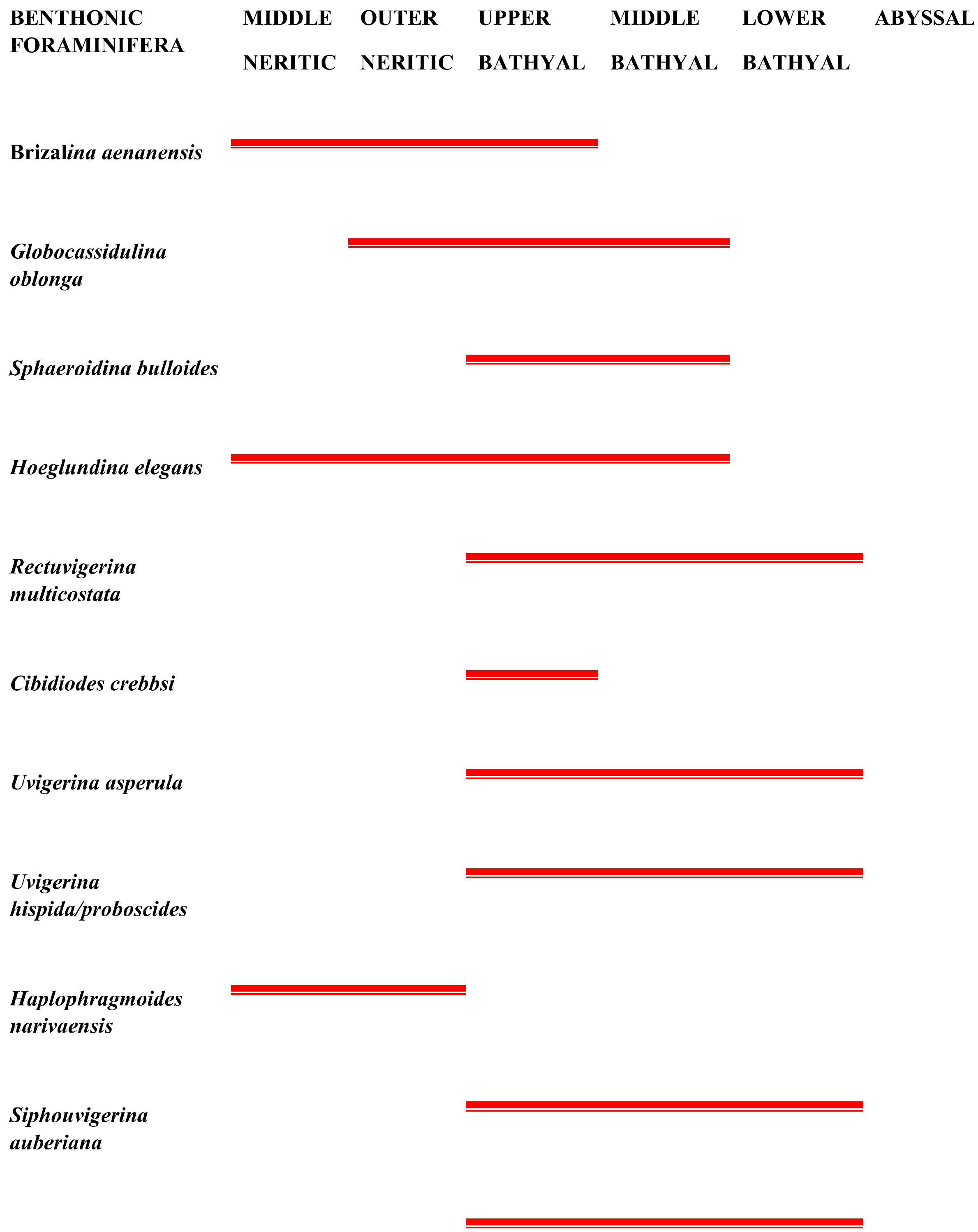


Fig. 2. Benthic foram genera association with bathymetric trend (Boersma, 1980)

Vertical juxtaposition of depositional environments was interpreted using sequence stratigraphic concepts, following Van Wagoner *et al* (1990) and Shell GLP (2011). E8000 sand was then associated with a systems tract and correlated throughout the wells.

The sonic log data was calibrated with the checkshot data in well W1000. Acoustic impedance and reflection coefficient logs were generated as products of density data and calibrated sonic log data. Synthetic seismograms were created by convolving a zero-phase synthetic wavelet with reflection coefficient log. The reservoir tops were posted to the 3D seismic volume via a well-to-seismic tie exercise. This transfers reservoirs vertical position from depth domain to time domain. A good tie was obtained with a bulk shift of 2 ms. A time depth (TDR) curve was generated from the checkshot data for well W001, which was then shared to other wells. A velocity function that describes the variation of velocity with depth was obtained from the TDR. Faults and the seismic horizon that tied with top of E8000 Sand were mapped on every tenth inline and on every tenth crossline section. The entire inlines and crosslines were gridded, and time structure map was created. Depth structure map was created from the time structure map using the velocity function. Root mean square amplitude was extracted along the mapped surface and values that characterise the pay identified. Fluid contact information was posted onto the depth structure map to ascertain reservoir areal extent. New prospect was identified using combined analogous reservoir closure and pay characteristic RMS amplitude values.

Table 1:Benhic foraminifera association with specific depositional environment in Niger Delta (Ozumba, 1995)



RESULTS AND DISCUSSION

Table 2 presents subsea vertical depth (SSVD) to top and base of E8000 Sand in the wells, foraminifera content in lithologic units vertically juxtaposed above and below the sand. The E8000 Sand is barren in foraminifera, indicating a high energy environment. Marine fossil in the shale directly above the E8000 Sand indicates marine transgression from top of the sand. This shows that the top of the E8000 Sand is a transgressive surface. Marine fossils in the shale directly below E8000 Sand base indicate the E8000 Sand is a regressive sand body. This makes the E8000 Sand base a regressive surface. Thus the E8000 Sand is juxtaposed between an older regression phase and a younger transgressive episode.

Table 2: Subsea vertical depth (SSVD) to top and base of E8000 Sand, foraminifera content in vertically adjacent shale units

WELL	SSVD E8000 SAND TOP (FEET)	SSVD E8000 SAND BASE (FEET)	FORAMS WITHIN E8000 SAND	FORAMS IN SHALE ABOVE E8000 SAND	FORAMS IN SHALE BELOW E8000 SAND
W001	8400	8500	BARREN	*NONION*	*BOLIVINA*
W002	9000	9200	BARREN	*UVIGEINA*	*NOT GIVEN*
W003	8700	8790	BARREN	*UVIGERINA*	*BOLIVINA*
W006	8410	8530	BARREN	*CHILOGUEMBELINA/ CASSIGERINELLA*	NOT GIVEN

W007	8300	8400	BARREN	*CHILOGUEMBELINA/ CASSIGERINELLA*	NOT GIVEN
W008	7134	7308	BARREN	NOT GIVEN	NOT GIVEN

Figure 3 shows some lithologic units vertically associated with the E8000 Sand, and the correlation of the E8000 Sand in wells W001, W002 and W003. The correlation of the sand and associated lithologic units in W006, W007 and W008 is given in Figure 4. The base of the E8000 Sand (E8000B) is sharp, showing a sharp lithofacies change from blocky (cylindrical) motif above to shale motif below. Such a sharp base represents a chronostratigraphic surface. The *uvigerina* as well as *cassigerinella* and *chiloguembelina* reflect outer shelf to upper bathyal depositional facies. The presence of *bolivina* reflect outer shelf to middle bathyal facies. The fossil barren E8000 Sand represents a marginal marine facies. The juxtaposition of marginal marine facies above outer shelf to bathyal facies indicates an unconformity. Since this unconformity is field-wide, it constitutes a sequence boundary. The juxtaposition of inner shelf facies above marginal facies indicates a transgressive surface. Thus the E8000 Sand is a lowstand systems tract.

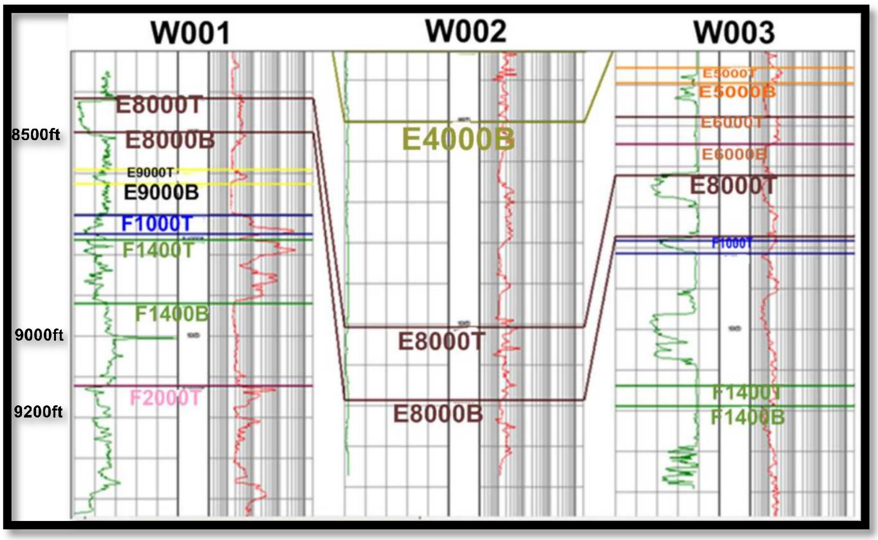


Fig. 3. Lithologic units associated with E8000 Sand, and correlation of the E8000 Sand in W001, W002, W003

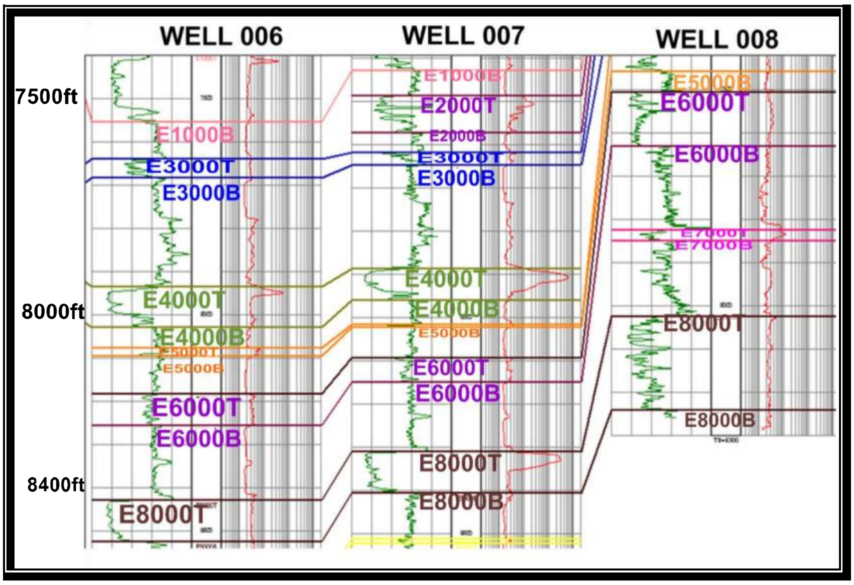


Fig. 4: lithologic units associated with E8000 Sand, and correlation of the E8000 Sand in W006, W007, W008

Figure 5 is seismic inline 11033 section. Posted on this inline section are wells 006 and 007, as well as the top of Agbada Formation, E8000 reservoirs and some other reservoirs penetrated by the wells.

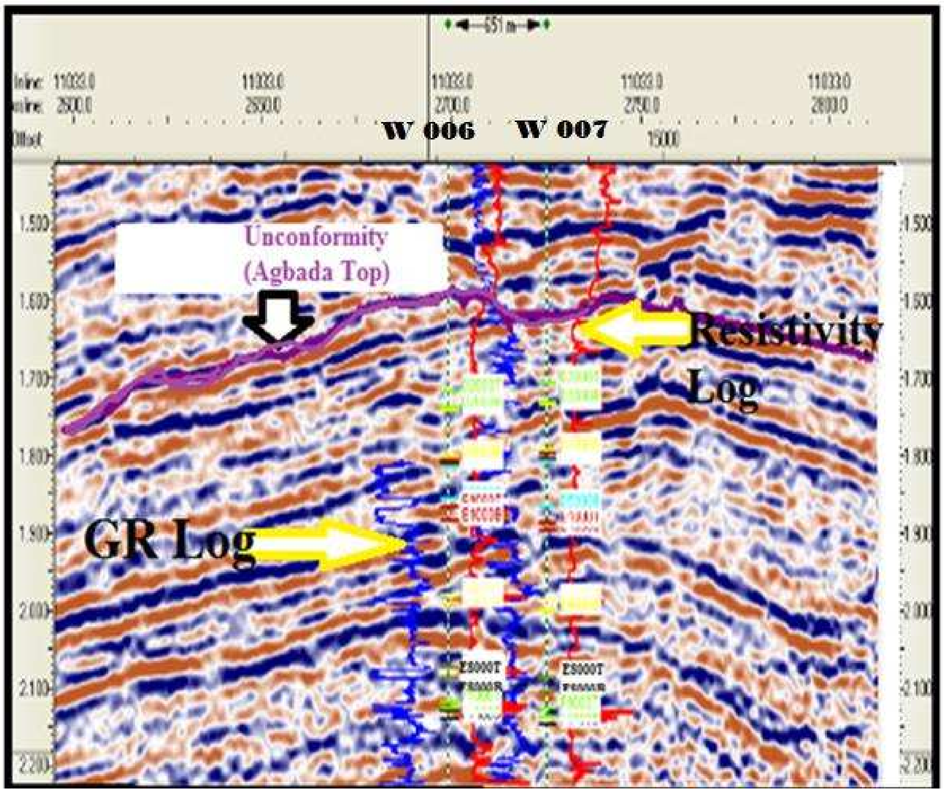


Fig. 5. Wells w006 and w007, logs and Sand tops on inline seismic section 11033

Figures 6 is a depth-structure map for the E8000 Sand. The map presents a major structure building synthetic fault that runs approximately east –westward in the eastern part of the field and northwestsoutheast in the western part. Such a major structure building synthetic fault was reported in Otigwe Field in Niger Delta Basin's Coastal Swamp Depobelt by Kurah *et al* .(2021)

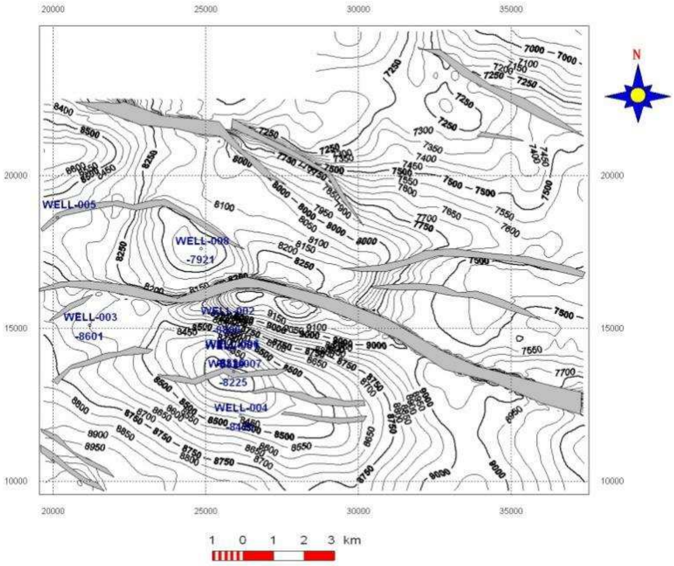


Fig.6. Depth- structure map for top of E8000 sand

Figure 7 presents spatial variation of RMS amplitude extracted along the top of the E8000 Sand. The E8000 Sand is hydrocarbon bearing only at W007. The RMS amplitude value of E8000 that characterise hydrocarbon in this well is 4000 – 5000. These are mediun RMS amplitude values. Ebere (2016) reported an association of medium – high RMS amplitude values with hydrocarbon bearing sands in deep offshore Niger Delta Basin. Onoja and Obiekezie (2019) found that similar RMS amplitude values characterise hydrocarbon reservoirs in Uzot – Field in onshore Niger Delta Basin.

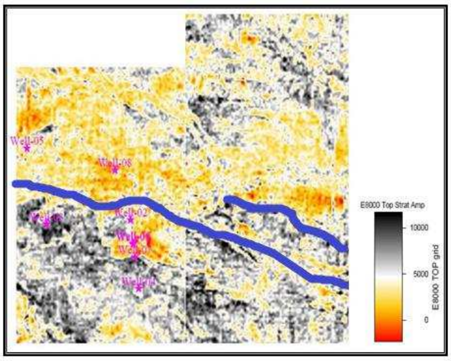


Fig. 7. RMS amplitude extracted along the top of the E8000 Sand

Figure 8 presents the the spatial extent of the reservoir pay, as well as the areal distribution of its oil and gas content. The W007 well is located on the downthrown block of the structure building synthetic fault, where it penetrated a roll-over anticline that forms a three-way closure with a crestal fault. The areal extent of this hydrocarbon filled closure is 4.5 km^2. A three – way closure is associated with a flank fault located on the eastern part of upthrown block of the structure building synthetic fault. The medium – high RMS amplitude that characterise this closure make it a hydrocarbon prospect. Hydrocarbon bearing roll-over anticlines in the form of three-way closure, as well as three-way closure prospect have been delineated in the Niger Delta Basin by Tijani *et al.* (2020) and Oloye and Olorunfemi (2021).

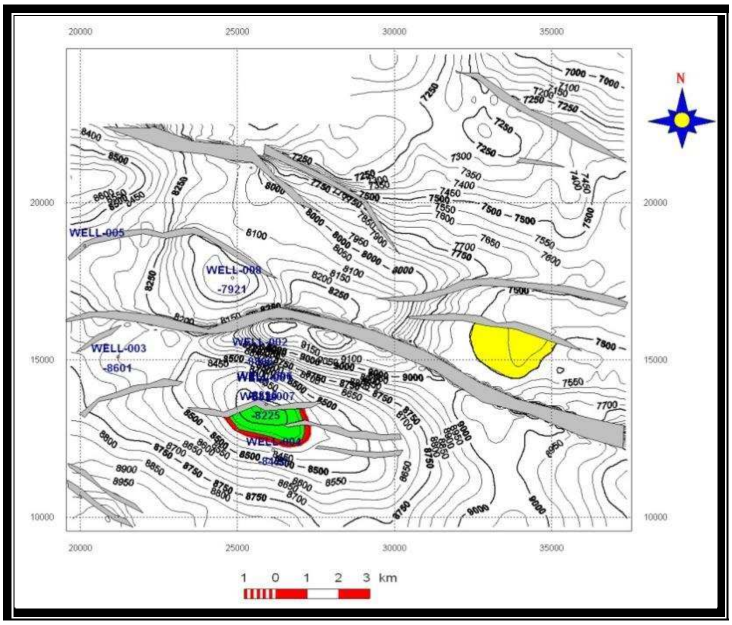


Fig.8. Areal extent of hydrocarbon accumulation and new prospect (shown in yellow) in E8000 sand

CONCLUSION AND RECOMMENDATION

Seismic structural mapping of the E8000 Sand was achieved using 3D seismic volume. The sand was delineated as a lowstand systems tract from sequence stratigraphic interpretation of combined lithologic, foraminifera and geophysical log data. The reservoir was found to be a roll-over anticline that constitutes a three-way closure with a crestal fault. Its hydrocarbon content occupies a surface area of 4.5 km^2. Only well W007 has been drilled in this closure, and opportunities for development drilling were identified southwards, eastwards and westwards of the well. RMS amplitude values of 4000 – 5000 (medium amplitude values) characterise hydrocarbon in the reservoir. A prospect was delineated on the eastern part of the upthrown block as a three-way closure with medium RMS amplitude values.

RECOMMENDATIONS

The well W007 should be re-entered and deviated southwards, eastwards and westwards in a three-phase directional drilling programme to produce E8000 optimally. The delineated prospect on the upthrown block of the structure building fault should be drilled to ascertain whether it is hydrocarbon bearing.

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