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Subsurface Mapping And Reservoir Evaluation of Enena Field, Offshore Niger Delta

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Abstract: *An integrated approach using, seismic and geological information was employed for the mapping and evaluation of the S30, T40, U50 and V60 reservoirs of the Enena field for estimation of the reservoir properties, fluid distribution, and 3D modeling. This research focuses on the integration of petrophysical and structural data to develop an algorithm through Guassian random function simulation for static modeling. The resultant static model was then used for volumetric distribution of the field.*

The resultant 3D static model shows that S30, T40 and V60 reservoir have a STOOIP of 51.3, 15.1 and 17.1MBO respectively with recoverable reserves of 18, 5.3 and 6 MBO assuming a primary recovery factor of 0.35 and 33.5, 9.8 and 11.1 MBO using a 2P recoverable reserve of 0.65. The GIIP was estimated to be 28, 8 and 9 BCF of gas and the recoverable reserves shows a P1 of 18.2, 5.2 and 5.85 MBO at a recoverable reserve of 0.65 and a 2P of 22.4, 6.4 and 7.2 MBO at a recoverable reserve of 0.8 was estimated. STOOIP and GIIP was not calculated for the U50 reservoir because despite the thick/ good sand package as seen on the GR log, the reservoir was found to be completely water wet. The S30 reservoir is found to be the most prolific both in the oil and gas case. The individual sands and their sub-units are separated by thick to thin shales.

It was also estimated that the natural drive mechanism of the Enena field is the water drive and recommended for marginal field operators.

Keywords: *Seismic, structural interpretation, 3D static model, prospective zone*

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I. Introduction

The deep-water (offshore) Niger-Delta region has been a beehive of exploration, development and production activities and represents a major oil and gas province. The region holds several giant oil accumulations and large gas fields with a lot of unexplored opportunities trapped in a variety of structural styles. These prospects span through the continental shelf, the continental slope and into the deepwater within the Nigerian offshore depobelt. The diverse and complex structural style entrenched within the region presents challenges to geoscientists and requires the application of specialised interpretation techniques in defining the prevailing structural styles. This can be achieved by the use of a more detailed approach which will help to effectively analyze controlling influences on reservoir geometry, position and hydrocarbon migration pathways by observing the trends of subtle faults and other structural features necessary for hydrocarbon accumulation and migration. One of such methods is through the use of seismic attributes.

Subsurface mapping and reservoir characterization has been a major concern in oil and gas industries to adequately estimate reserve; reason is that better reservoir characterization means higher success rates and fewer wells for reservoir exploitation. Thus there is a need to approach this area of interest with more robust interpretation techniques that helps production geologists and reservoir engineers understand reservoir heterogeneities and reduce uncertainties. This study focuses on subsurface mapping and reservoir evaluation of “Enena” Field, offshore Niger Delta with subsurface interpretation (integration of seismic and geoscience knowledge using the Petrel workstation). The interpretation of this data was used to guide the construction of an environment of deposition for the reservoir.

Several corporate and multinational organizations have carried out geological and geophysical studies in the Niger Delta. The aims of these works were to understand the nature of the subsurface geology with the view to exploring the immense hydrocarbon resource associated with the Tertiary Niger Delta. These works led to the discovery of various giant and minor oil fields notably Bonga, Agbami, Elepa, Emi, Erha, Egbolom etc.

Aizebeokhai and Olayinka, (2010) worked on the structural and stratigraphic mapping of Emi Field, offshore Niger Delta. The research showed that high amplitude reflection events correspond to sand units, whereas, low amplitude reflection events correspond to shale units.

Reyment (1965) and Short and Stauble (1967) published a detailed report on the subsurface lithostratigraphy of the Niger Delta and deduced three diachronous Formations. These are the Akata Formation which is predominantly marine shales, the paralicAgbada Formation which is made up of intercalation of sands and shales and the continental Benin Formation which consists of fresh water sands and gravel.

Olowokere, (2009) presented a study of the amplitude and fluid contact mapping in some part of Niger Delta using seismic attribute analysis and inversion.

Rotimi et al., (2010) carried out a 3D structural interpretation and seismic attribute analysis of X-field, onshore Niger delta to identify its hydrocarbon prospects not considered in previous exploratory work.

Hesthammer, J., 1998 worked on the evaluation of the time dip, correlation and coherence maps for structural interpretation of seismic data. A case history of using spectral decomposition and coherency to interpret incised valleys was shown by (Peyton et al. 1998). Detailed reconstruction of the historical events that lead to the modern seismic attribute analysis may be found in Chopra and Marfurt (2005).

Doust and Omatsola (1990) recognized five depobelts in Niger Delta, which are distinguished primarily by their age. They are: Northern delta (late Eocene-Early Miocene), Greater Ughelli (Oligocene-Early Miocene), Central swamp (Early-Middle Miocene), Coastal swamp I and II (Middle Miocene) and Offshore (Pliocene).

This research therefore seeks to characterize the reservoir in the field and determine key reservoir geometric properties across the field. It is also to delineate the extent and limit of the oil reservoir, to map out the reservoir facies which is integrated with paleobathymetry data in inferring the environment of deposition (EOD), and to provide opportunities to new field development.

The area of study is located in the Enena Field, offshore of western Niger Delta area of Nigeria, The Coordinates of Enena Field lies between Latitude $5^0 42'10.8''$ and $5^0 56'31.2''$ Nand Longitude $4^0 24'57.6''$ and $4^0 47'24''$E in the Offshore depobelt (Fig 1), It covers a total area of approximately 55km² and theacreage is operated by Chevron Nigeria Limited.

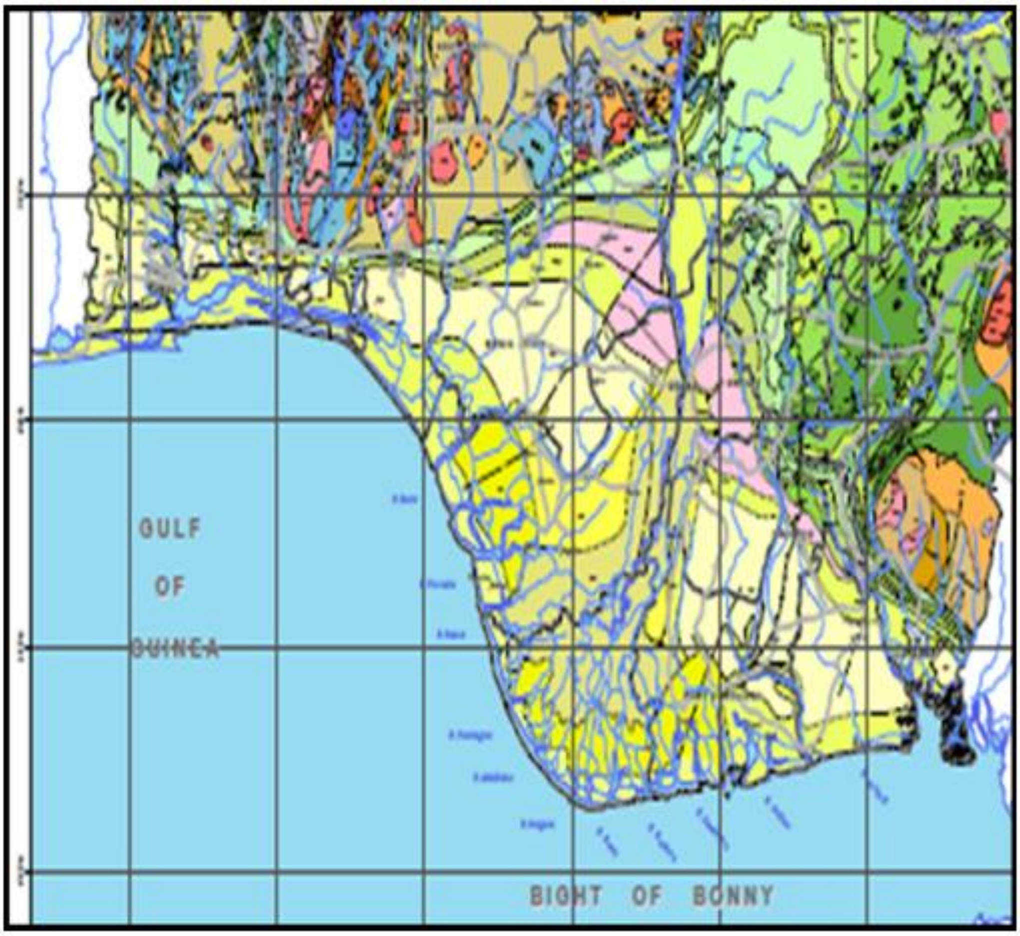


Fig. 1: Study location Offshore Niger Delta

The Geology Of Niger Delta

The Niger Delta is a Paleogene to Recent, wave-dominated delta situated eastward in the Gulf of Guinea and extending into the northern Joint Development Zone of Nigeria and Sao Tome and Principe (JDZ). Following the Mesozoic rifting of the Atlantic, sedimentation began with Albian drift deposits. Sediments filled the Benue Trough and by Late Eocene it began to prograde across the existing continental slope into the deep sea. Continued seaward progradation since the Eocene has extended the continental margin to its present position, forming depobelts that represent the most active portion of the delta at each stage of development (Doust and Omatsola, 1990). The delta is a coarsening upward regressive sequence of Tertiary clastics that prograded over a passive continental margin sequence of mainly Cretaceous sediments. The Niger Delta Province contains only one identified petroleum system (Kulke, 1995, Ekweozor and Daukoru, 1994) and 11 proven plays.

Deposits in Niger Delta have been divided into three large scale lithostratigraphic units: (1) the basal Paleocene to Recent pro- delta facies of the Akata Formation, (2) Eocene to Recent, paralicfacies of the Agbada Formation, and (3) Oligocene – Recent, fluvial facies of the Benin Formation (Evamy et al., 1978; Short and Stauble, 1967; Whiteman, 1982). These formations becomes progressively younger farther into the basin, recording the long-term progradation of depositional environments of the Niger Delta into the Atlantic Ocean passive margin. Stratigraphy of the Niger Delta is complicated by the syndepositional collapse of the clastic wedge as shale of Akata Formation mobilized under the load of prograding deltaic Agbada and fluvial Benin Formation deposits (Evamy et al., 1978).

Deposition of the three formations occurred in each of the five offlappingsiliciclastic sedimentation cycles that comprise the Niger Delta. These cycles (depobelts) are 30-60 kilometers wide, prograde southwestward 250 kilometers over oceanic crust into the Gulf of Guinea (Stacher, 1995), and are defined by synsedimentary faulting that occurred in response to variable rates of subsidence and sediment supply rates resulted in deposition of discrete depobelts when further crustal subsidence of the basin could no longer be accommodated, the focus of sediment deposition shifted seaward, forming a new depobelt (Doust and Omatsola, 1990). Each depobelt is a separate unit that corresponds to a break in regional dip of the delta and is bounded landward by growth faults and seaward by large counter-regional faults or the growth fault of the next seaward belt (Evamy and others, 1978; Doust and Omatsola, 1990). Five major depobelts (Table 1) are generally recognized, each with its own sedimentation, deformation, and petroleum history. Doust and Omatsola (1990) described three depobelt provinces based on structure. The northern delta province, which overlies relatively shallow basement, has the oldest growth faults that are generally rotational, evenly spaced, and increases their steepness seaward. The central delta province has depobelts with well-defined structures such as successively deeper rollover crests that shift seaward for any given growth fault.

Lastly, the distal delta province is the most structurally complex due to internal gravity tectonics on the modern continental slope. These depobelts formed when paths of sediment supply were restricted by patterns of structural deformation, focusing sediment accumulation into restricted areas on the delta. Such depobelts changed position over time as local accommodation was filled and the locus of deposition shifted basinward (Doust and Omatsola, 1990).

Akata Formation is at the base of the Niger Delta basin. It is of marine origin and is composed of under-compacted and over-pressured pro deltaic shale (potential source rock),turbidite sand (potential reservoirs in deep water) and minor amounts of clay and silt (Tuttle et al., 1999).The total thickness of Akata Formation is not known for certain, but Doustand Omatsola (1990) estimated that it may reach 7000 m (22960 ft) in the central part of the Delta. In a more recent work, Bilotti et al., (2005) suggested that in the deep-water fold and thrust belts; Akata Formation is up to 5,000m (16,400ft) thick because of the structural repetitions by thrust ramps and in the core of large detachment anticlines.

The paralicAgbada Formation lies directly on top of the Akata formation. Its deposition started in the Eocene to Recent (Tuttle et al., 1999). It is composed of alternating sequence of sandstone and shale of deltaic front, distributary channel and deltaic plain origin (Nwachukwu and Chukwurah, 1986). The Formation is about 3940m (12923ft) thick in the central part of the Delta and thins out in the northwest and northeast directions. Agbada Formation is absent or poorly developed in the north of Benin city, Onitsha and Calabar axis (Weber, 1971).

Benin Formation is composed mainly of massive and highly porous fresh water bearing sandstones with some thin interbeds of shale. The formation is mineralogically made up of feldspars, and quartz. The Formation has a maximum thickness of 1970m (6465ft) at the Warri area. Its composition, structure and grain size indicate deposition of the Formation in a continental-upper deltaic environment (Short and Stauble, 1967; Avbovbo, 1978). The first marine foraminifera within shale define the base of the Benin Formation, as the formation is non-marine in origin (Short and Stauble, 1967).

Growth faults are the most common subsurface structures in the Niger Delta. A growth fault is a fault that offsets an active plain of deposition. Generally the down thrown blocks have thicker sediments relative to the up thrown blocks. Theoretical calculations and field observations show that growth faults have a dip of 55^{o}or more near the surface (Anderson, 1942). Growth faults are independent of earlier fractures and are not induced by any basement tectonics.

II. Materials And Methodology

The data used for this study for confidentiality was renamed "Enena" and they include; Base Map, 3D Seismic data (SEGY Format). Qualitative study of Enena Field was carried out using Schlumberger's Petrel 2014 suit on a workstation for seismic interpretation, reservoir delineation, volume calculation, 3D static modeling and reserve calculation.

Seismic attribute

In reflection seismology, a seismic attribute is a quantity extracted or derived from seismic data that can be analyzed in order to enhance information that might be more subtle in the traditional (original seismic or before seismic enhancement) seismic image, leading to a better geological or geophysical interpretation of the data. Two attributes (structural smoothening and variance) were extracted and displayed on the inline and crossline sections at different milliseconds. The structural smoothening seismic attribute was first carried out to enhance the seismic reflections for better interpretations of the structure and displayed on the time-slices at different milliseconds (Fig 2a). It was seen that at 2000ms, the amplitude begins to fade out and this was used for better structural interpretation hence, it is important to state that structural smoothening attribute is good for amplitude and reflection interpretation or extraction. Variance attribute of the traditional seismic (Fig. 2b) was extracted and discovered that it is actually the best attribute for fault interpretation which is seen on the time-slices at different milliseconds thus, it helps to understand the fault trend and extent, shows clearly beyond the regions that may ordinarily be subtle in the traditional seismic and it is also useful for edge detection.

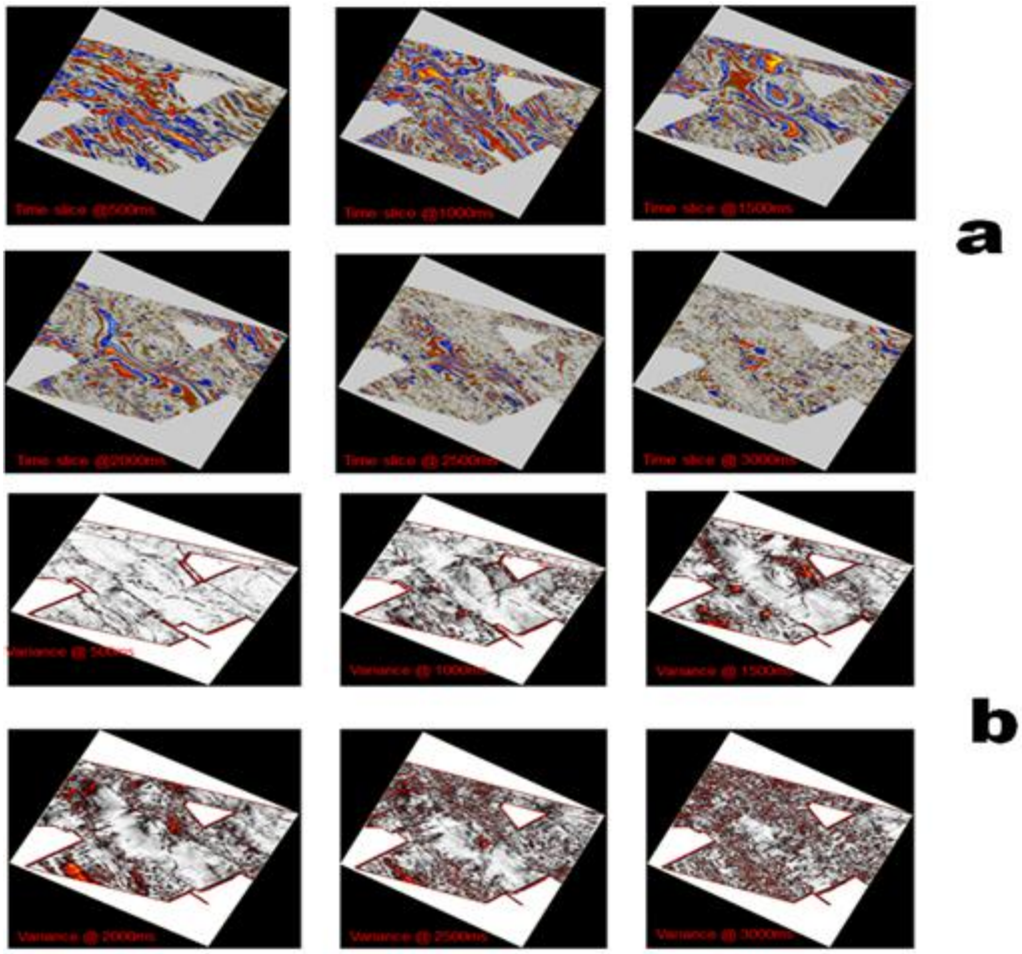


Fig. 2: Seismic attributes of Enena field

III. Results And Discussions

Fault Interpretation

Majorly, the structures identified (Fig. 3) are rollovers and normal faults which are majorly synthetic, listric and downthrowing towards the same direction and also consistent but the few antithetic faults identified were not consistent. Fault interpretation was picked on every 10th inline and crosslines, a total of ten (10) faults were picked and coloured differently but only four (4) were consistent with two (2) major consistent fault (F1 and F3) and two (2) minor consistent faults (F6 and F9).

Structure Maps

Time structure maps

Time structure map and RMS (Root Mean Square) amplitudes (Fig. 4) was generated to show high amplitude zones also, the RMS amplitude map complements the structural map by highlighting prospective zones. After the time structural map was generated, a lookup function (Fig. 5) was generated and used to make the depth structure map.

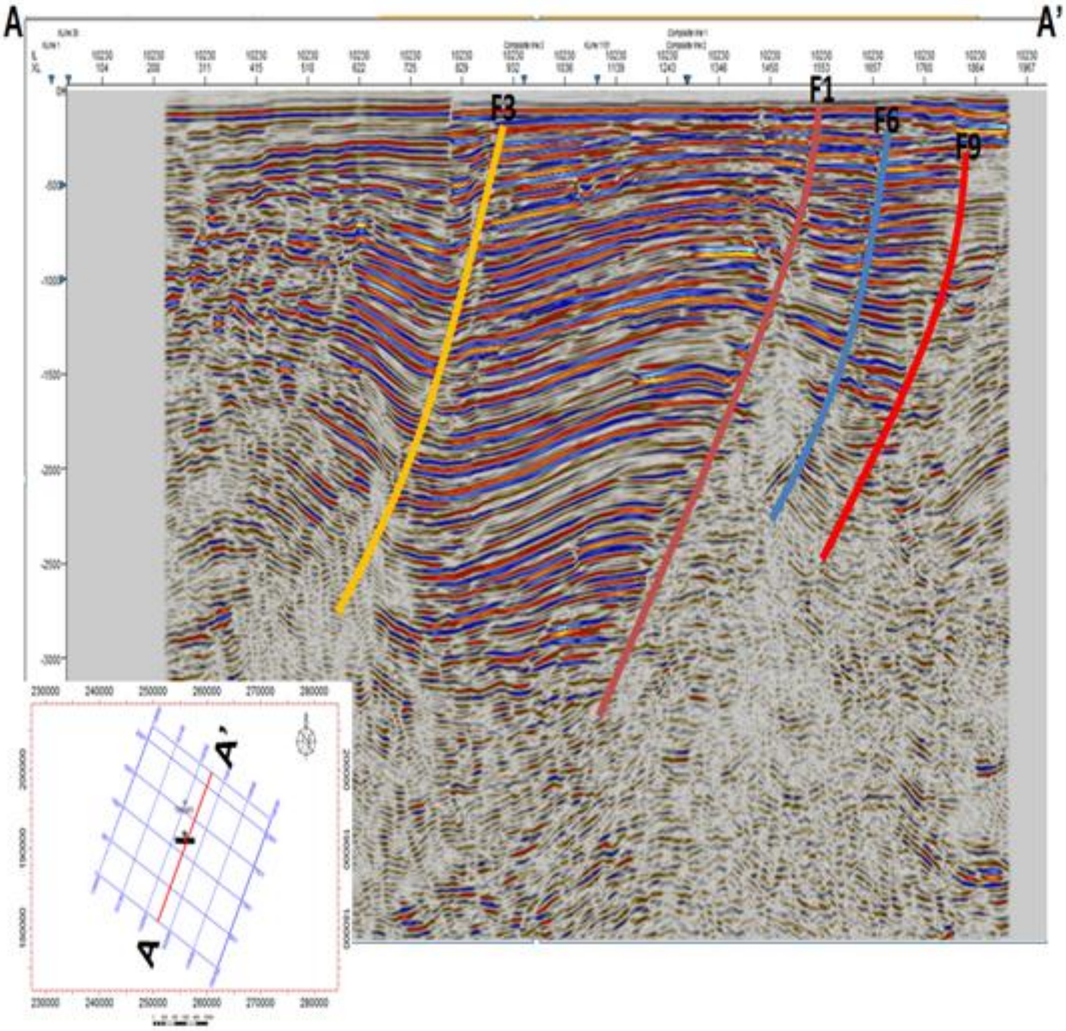


Fig 3: Fault framework of Enena field showing the rollover structures, normal, listric and synthetic faults (structure with multiple growth faults)

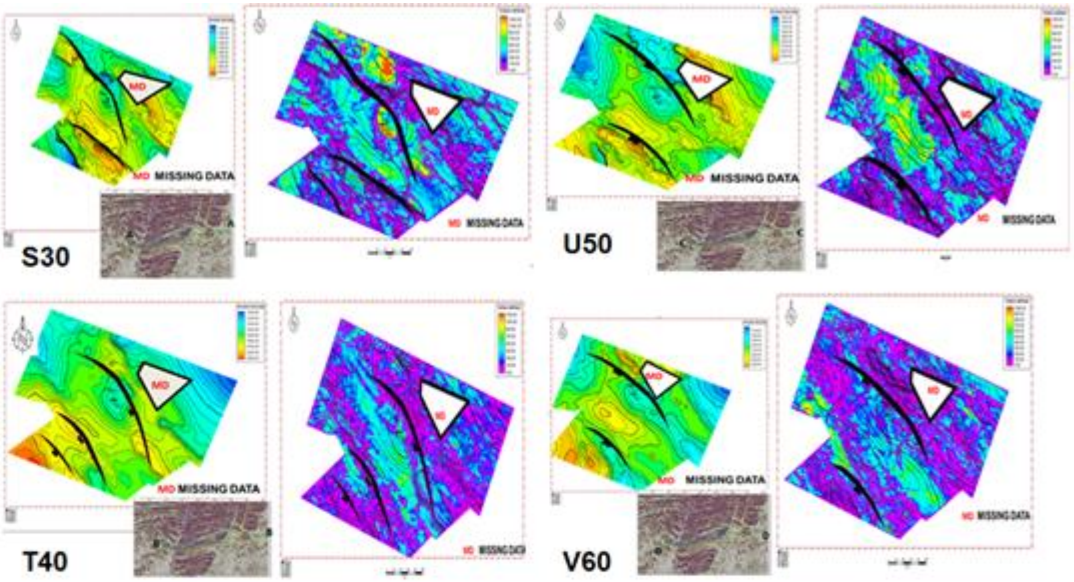
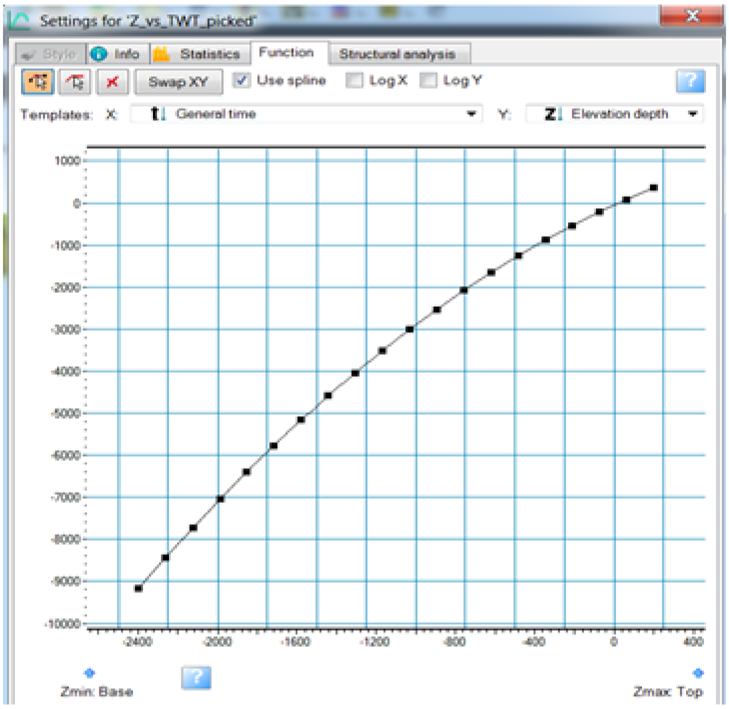


Fig 4: Time and RMS structure maps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Templates: X: General time Y: Elevation depth

Fig. 5: Look up function developed and used for time structural map conversion to depth structural map

Depth structure maps

The depth structural map was derived from the structural framework (fault and Horizon) of Enena field after which the look up function (Fig. 5) was applied to convert the time structure map to depth structure map. The depth structure map (Fig. 6) shows the various highs, lows (structures) and faults. From the map, it shows that the field is a rollover structure with multiple growth faults, fault dependent with no four way dip closure and as such, the growth faults serves a trap that that prevents seepage of hydrocarbon. The structure are proven to contain hydrocarbon. The depth structural map for was used to calculate hydrocarbon by creating a polygon around the prospective zone highlighted by the RMS amplitude attribute, the zone was then divided into discovery, prospects and leads (Fig. 6), the petrel software was then used to calculate the area, the thickness was estimated from the well log, porosity was calculated using equation 4 and the average saturation the Niger Delta which is 25% was used because no core data was given to effectively calculate the capillary and saturation.

Property Modeling

The S30 reservoir is proven to be hydrocarbon bearing with a good sand thickness and a relatively good NTG. Since the effective porosity and water saturation of each well per depth within the reservoir was given, it was interpreted using the property model to determine that the porosity within the reservoir ranges from 0.09 to 0.38 (Fig. 7), water saturation ranges from 0.4 to 1, pore volume ranges from 200 t0 10,000 *10^{6} rm^{3} and STOIIP ranging from 200 to 9200 *10^{6}sm^{3} (Fig. 8).

The T40 reservoir is proven to be hydrocarbon bearing with a good sand thickness and a relatively good NTG. The reservoir was interpreted using the property model to determine that the porosity within the reservoir ranges from 0.5 to 30 (Fig .7), water saturation ranges from 0.4 to 1, pore volume ranges from 0 to 10,000 * 10^{6}rm^{3} and STOIIP ranging from 0 (water wet) to 9200 *10^{6}sm^{3} (Fig. 9).

The V60 reservoir is proven to be hydrocarbon bearing with a good sand thickness and a relatively good NTG. The reservoir was interpreted using the property model to determine that the porosity within the reservoir ranges from 0.05 to 0.29 (Fig. 7), water saturation ranges from 0.45 to 1, pore volume ranges from completely water wet to 10,000 * 10^{6}rm^{3} and STOIIP ranging from 0 (water wet) to 9200 *10^{6}sm^{3} (Fig. 10). Estimation from the model shows that reservoir V60 does not as much hydrocarbon in commercial quantity as reservoir S30 and T40.

IV. Conclusion

Integration of the seismic and geological information was incorporated in developing the static model which was then used to understand the actual behavior and property distribution of the reservoir, In Enena field there are three (3) identified hydrocarbon zones namely Reservoir S30, T40 and V60 with S30 being the most prolific and the field ranges from Discovery to Prospect and Leads.

The horizons mapped are all within the Agbada formation, where most of the hydrocarbon is believed to be trapped in the Niger Delta

Structural framework such as anticlinal closures and fault assisted closures regarded as good hydrocarbon prospect areas have been delineated in the structure contour map, it basically delineates fault assisted rollover structure which also serves as structural traps to prevent seepage of hydrocarbon. The average petrophysical property shows a good reservoir quality. Further interpretation of this field shows that the natural drive energy of Enena field is water drive and this is seen in the water saturation model of all 3 hydrocarbon bearing reservoirs.

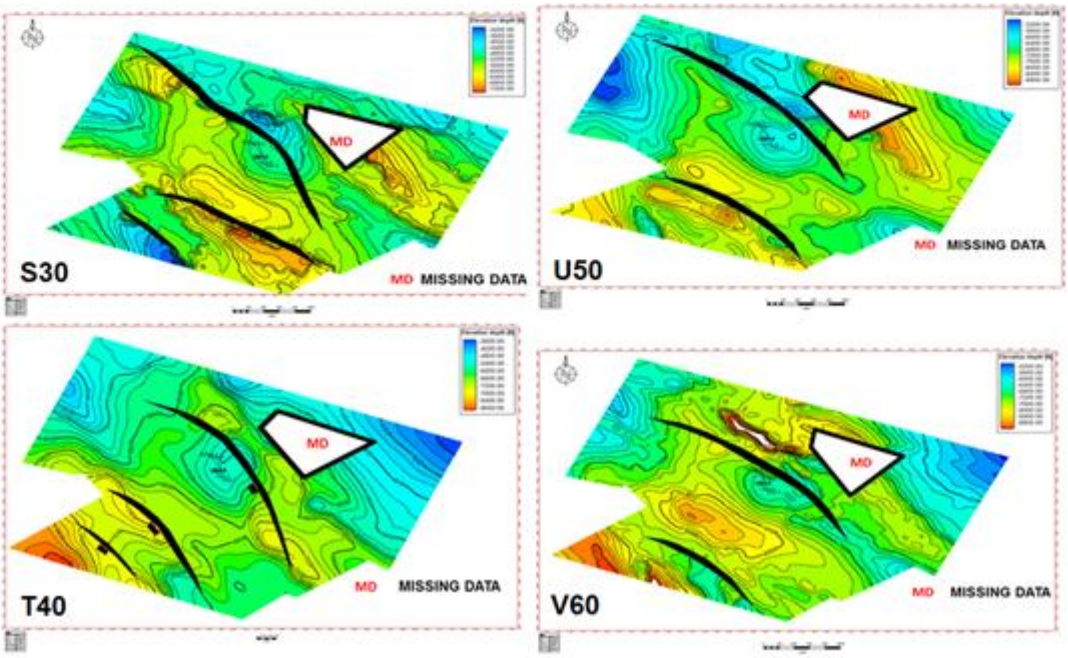

Fig 6: Depth Structure Map

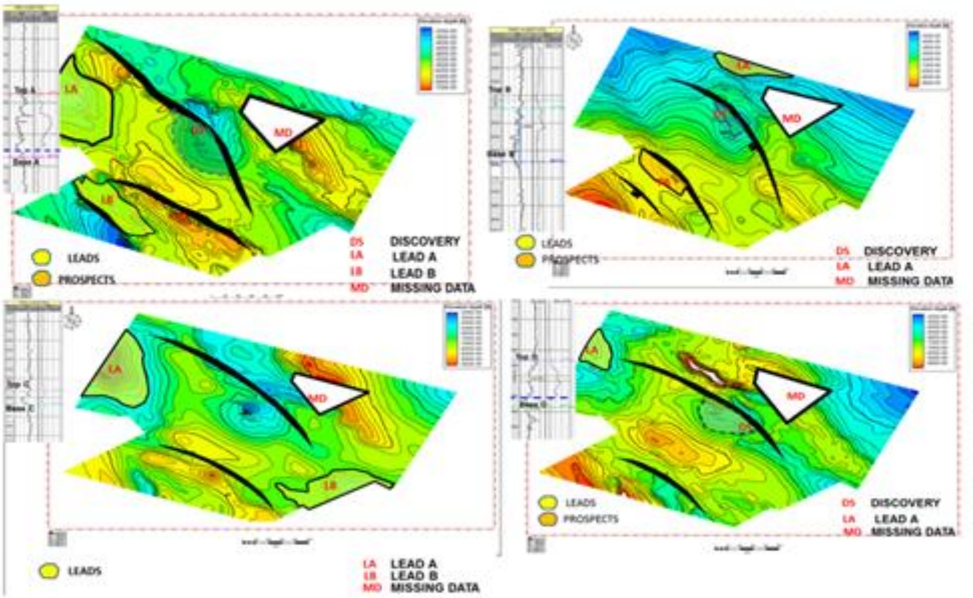

Fig 7: Identified Discovery, Prospects and Leads

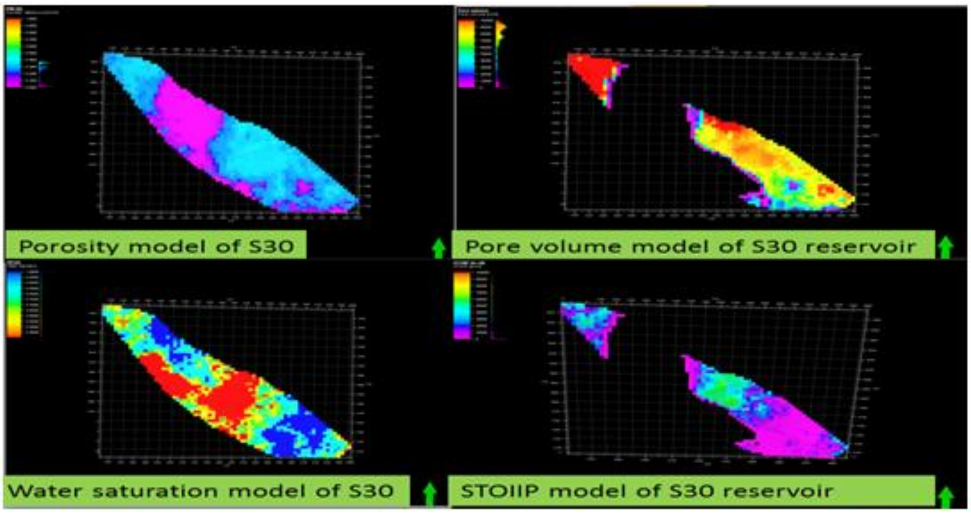

Fig 8: Property distribution of S30 reservoir

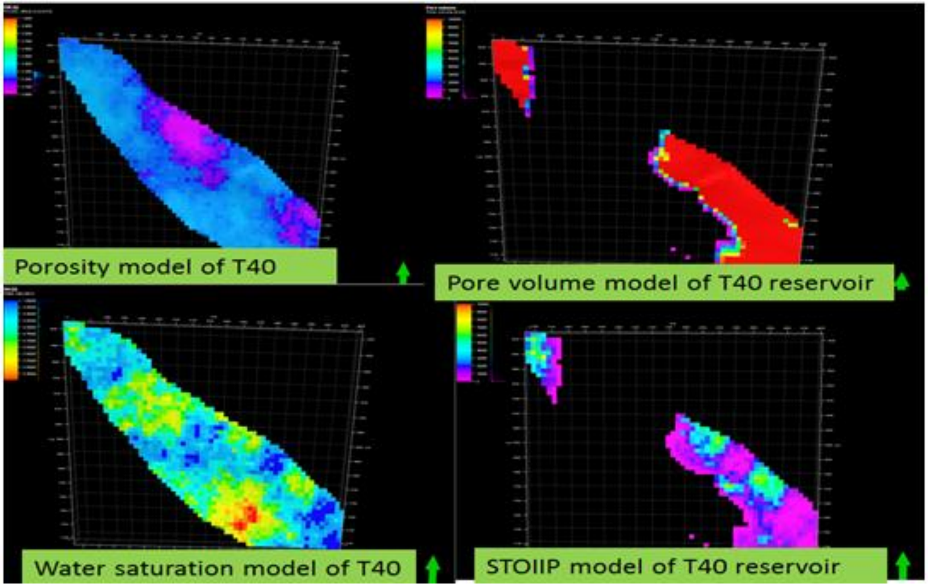

Fig 9: Property distribution of T40 reservoir

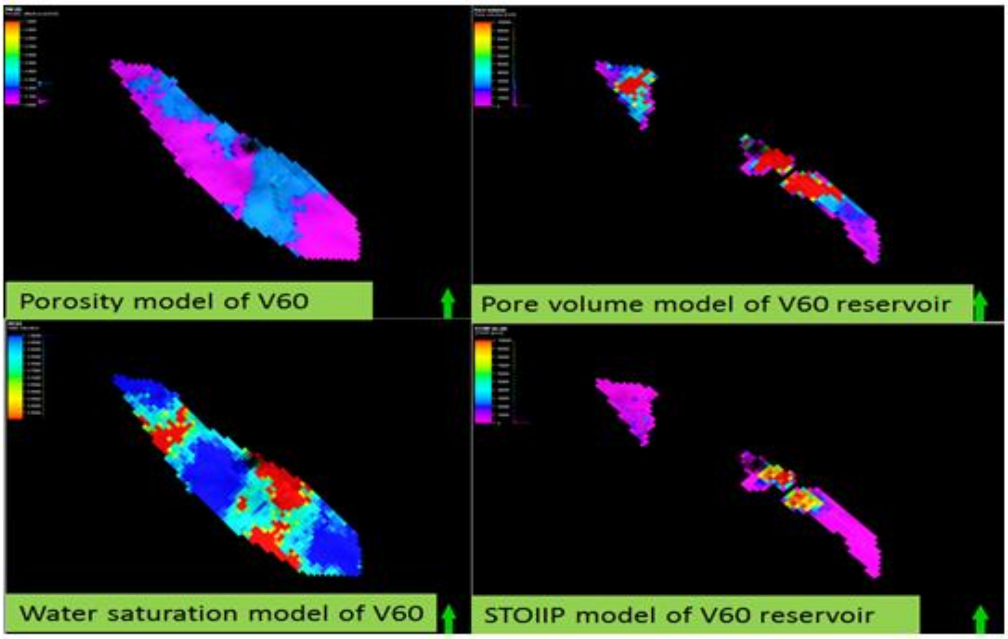

Fig 10: Property distribution of V60 reservoir

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