Petroleum and Coal

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Technical Assessment for Carbon Dioxide Storage of a Field in Niger Delta

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Received December 2, 2023; Accepted March 15, 2024

Abstract

Carbon dioxide (CO_2) capture and storage (CCS) is presented as an alternative measure and a promising approach to mitigate the large-scale anthropogenic CO_2 emission into the atmosphere. In this context, CO_2 sequestration into depleted oil and gas reservoirs is a practical approach as it boosts the recovery and facilitates the permanent storing of CO_2 into the candidate sites. However, the estimation of CO_2 storage capacity and properties in subsurface is a challenge to kick-start CCS worldwide. Thus, this paper characterizes the reservoirs of a field to tackle the challenge of CO_2 emission and storage in Niger Delta. To achieve this work's ultimate goal, the Schulmberger Petrel software was used for evaluation of the structural and petrophysical parameters of six well logs, which includes faults for trapping mechanism, porosity and permeability. Eleven reservoir (A-K) storage units were delineated and reservoir A selected for CO_2 storage within sand and shale lithologies. These storage units were furthermore subdivided into three: the shallow, middle and deeper reservoirs. The results demonstrated significant trapping structures, with good closure dependent fault pattern in a major NW-SE trending direction for CO_2 storage without leakage. Also, the reservoir of study indicates 0.01 – 0.35 porosity and 0.5 -350MD permeability ranges respectively, which is a good indication of the ability of the reservoir rocks to retain and allow fluid to flow. Thus, reservoir A was chosen to possess the potential of CO_2 storage and utilization due to well continuous sand geobody across the wells and its structural ability in Onshore Niger Delta.

Keywords: *Reservoir characterization; Carbon dioxide Storage; Porosity; Permeability.*

1. Introduction

The greenhouse gas (GHG) mitigation is becoming a stronger legislative priority in Nigeria as renewable generation technologies (e.g. wind and power) are still unable to provide dispatchable electric power in the country, therefore fossil fuels are likely to remain the principal source of energy. Emissions from oil extraction and energy use will continue to drive atmospheric concentrations of CO2 upwards unless energy conversion systems can be designed to otherwise dispose CO2 generated from combustion and flaring. The Nigeria's Niger Delta ranks the second highest gas-flaring nation behind Russia [1] and efforts to mitigate this effect have brought about one of the United Nations' Sustainable Development Goals (SDGs) of reducing global concentrations of CO_2 in the atmosphere [2]. Studies have shown that Carbon Capture Utilization Sequestration (CCUS) is one of the methods set for greenhouse gas emission reduction before 2030 as demanded by the Kyoto Protocol. This transcends towards cleaner energy which will help to achieve the goal of the United Nations (UN) Framework Convention on Climate Change. Reservoir characterization and accurate mapping of the reservoir's structural and stratigraphic features, along with understanding the rock properties, is crucial for designing optimal injection and storage strategies. However, CCS is yet to be implemented on a local or regional scale in Nigeria. Previous studies on CCS in Nigeria have, so far, mainly focused on the fundamental science of CCS, the present status of global CCS development, terrestrial sequestration and the benefits/potential risks of its future implementation [3-6]. The stratigraphic and structural competence of some reservoir units within the Niger Delta for carbon storage has also been carried out by a few authors [7-8]. The study area in this research is typically characterized by several growth faults associated with rollover anticlinal structures typical of the Niger Delta extensional zone [9]. We also recognize that while some authors have worked on the applications of 3D fault seal attributes to characterize fault planes, hydrocarbon predictions and prospectivity in the Niger Delta basin [10-13], few have commented on the implications of these on CO_2 storage as well as highlighted the importance of seismic data conditioning by applications of structure-orientated filtering seismic attributes which takes account of bed estimated orientations and thereby reduces the noise content without losing information related to edges of geologic units [14-15]before determining the framework of faults within the field. Thus, the aim of this research is to characterize the field and select a prolific reservoir for possible CO_2 storage.

1.1. Geology of the study area

Within the Gulf of Guinea, the Niger Delta Basin covers an area of about 140,000 km2 and is located at the southernmost extremity of the elongated intracontinental Benue Trough [16-17]. To the west, it is separated from the Dahomey (or Benin) Basin by the Okitipupa basement high, and to the east, it is bounded by the Cameroun volcanic line. Its northern margin transects several older (Cretaceous) tectonic elements—the Anambra Basin, Abakaliki Basin, Afikpo Syncline, and the Calabar Flank (Fig. 1).

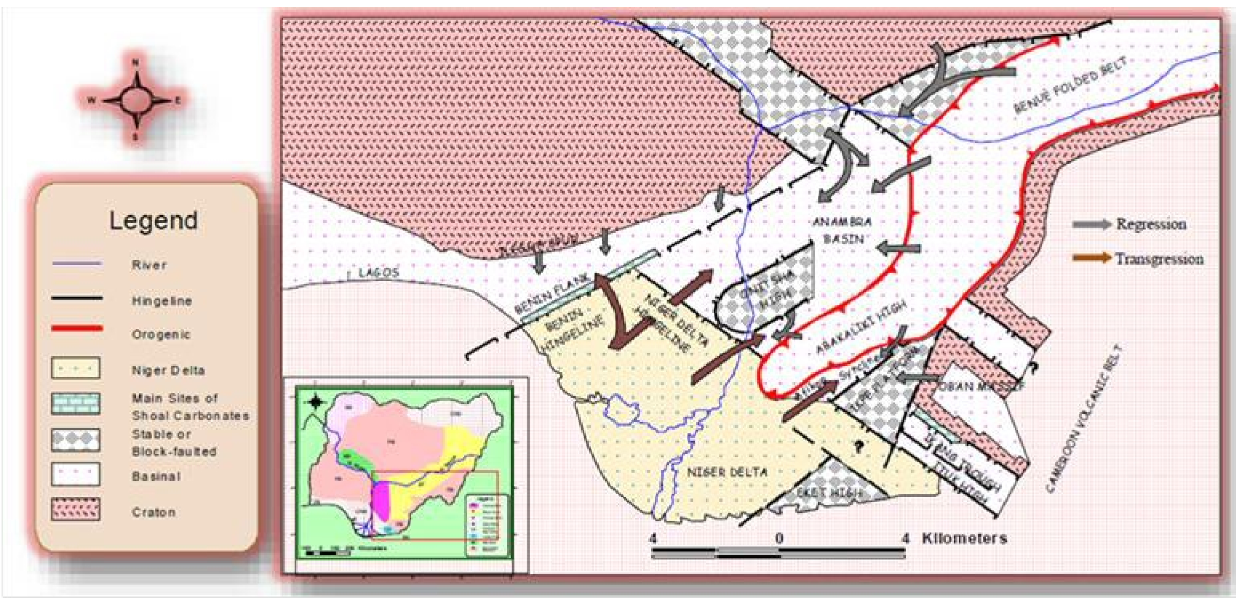

Figure 1. Tectonic map of Niger Delta, (after [22]).

The delta, based on Ekweozor and Daukoru [18] and Tuttle *et al.*, [19] began its development in the Eocene with the accumulation of sediments that are now about 10 kilometers thick. The area is geologically a sedimentary basin, and consists of three basic Formations: Akata, Agbada and the Benin Formations. The Akata is made up of thick shale sequences and it serves as the potential source rock. It is assumed to have been formed as a result of the transportation of terrestrial organic matter and clays to deep waters at the beginning of Paleocene [19] According to Doust and Omatsola [9], the thickness of this formation is estimated to about 7,000 maters thick, and it lies under the entire delta with high overpressure. Agbada Formation is the major oil and gas reservoir of the delta. It is the transition zone and consists of intercalation of sand and shale (paralic siliciclastics) with over 3700 meter thick and represents the deltaic portion of the Niger Delta sequence [9,19]. Agbada Formation is overlain by the top Formation, which is Benin. Benin Formation is made of sands of about 2000m thick [20].

The field under study is a gas condensate field that is situated in the onshore Niger Delta, in the northern depo-belt. The field, which spans approximately 7 kilometers in the strike direction and 3 kilometers in the dip direction, has been explored and developed through the drilling of wells.

In the vicinity of the Field, a three-part stratigraphic sequence can be observed, which is characteristic of the stratigraphy encountered in the Niger Delta region (as illustrated in Figure 2). The oldest sequence identified in the area is the Akata deep marine shales, which exhibit very low sand development. Overlying the Akata sequence is the paralic Agbada sequence, characterized by alternating layers of sand and shale, followed by the massive, sandy, fluvial-dominated Benin Formation.

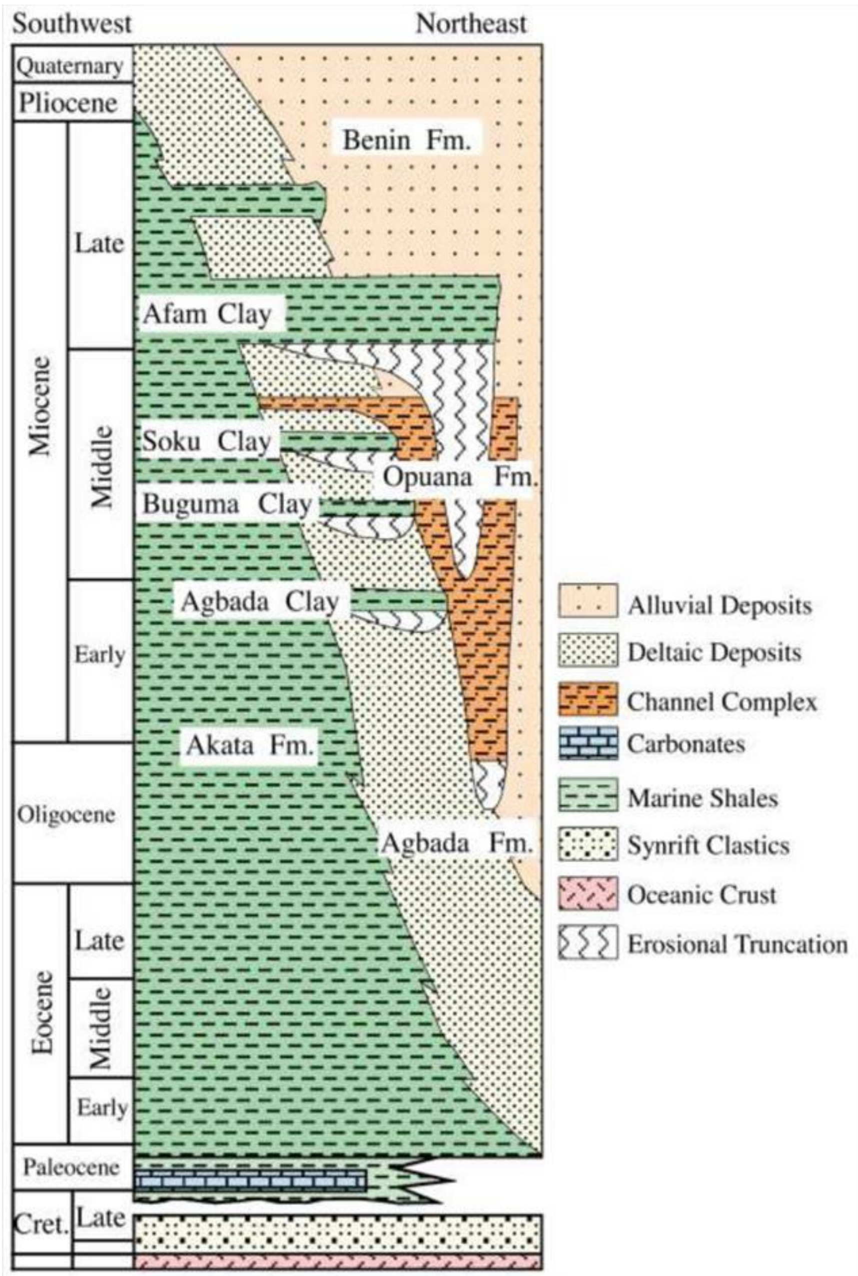

Figure 2. Stratigraphic column showing the three formations of the Niger Delta (modified from [23]).

Interestingly, all of the field's hydrocarbon-bearing reservoirs were found within the Agbada sequence, located in the northern depo-belt of the Niger Delta (as indicated in Figure 3). The reservoirs are typically composed of sand-shale pairs, with the overlying shale acting as a seal to the underlying hydrocarbon-bearing sand reservoir. It is worth noting that the sedimentary environment of the area played a crucial role in the accumulation and preservation of hydrocarbons in the reservoirs in the field.

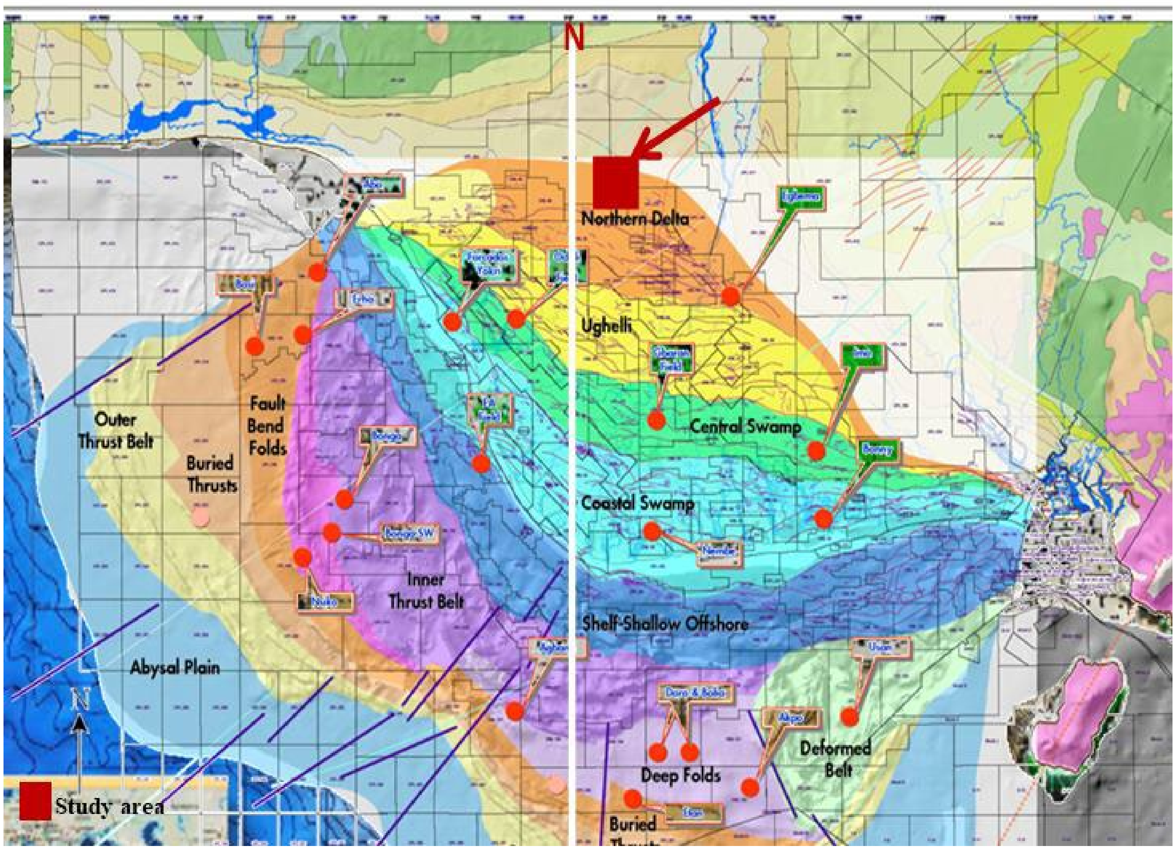

Figure 3. Depobelt map with the structural play segments, onshore and offshore Niger Delta Basin showing the study area in the Northern Depobelt (modified after [21]).

2. Materials and methods

The study integrated the use of available data (not limited to well logs; Gamma Ray GR, Resistivity and Neutron log), 3D seismic section and some software for research analysis. The software that will be used includes: The Schlumberger's "PETREL" and Senergy's "Interactive Petrophysics (IP)" were the software used in the analyses of the data. Petrel was used in mapping horizons and faults on the seismic data, correlating wells across the field, and 3D modeling while IP was used for the petrophysical evaluation.

2.1. Reservoir identification and petrophysical analysis

Reservoirs were identified by using a combination of the log signatures of gamma ray, resistivity and neutron-density logs. Intervals that have high resistivity are considered to be hydrocarbon-bearing while low resistivity zones are water-bearing intervals. A combination of the gamma ray and resistivity logs were used to differentiate between the hydrocarbon and non-hydrocarbon bearing units. The scale increases from left to right, with a range of 0-150 API for the gamma ray log and 0.2-2000 ohm-metre for the resistivity. As the hydrocarbon saturation increases, resistivity also increases; on the other hand as water saturation increases, the resistivity decreases. The gamma-ray logs were then integrated with the resistivity and neutron density logs to identify the distribution of different reservoir fluids (i.e.

water and hydrocarbon) across the wells. Petrophysical properties are very important parameters when evaluating reservoirs for identification and general quality of CO_2 storage units within a field. Petrophysical values derived from the Interactive Petrophysics software (IP 2021) were upscaled and modeled with the aid of the petrophysical modeling procedure in the Schlumberger Petrel software. The sequential Gaussian simulation algorithm was the statistical method employed for the distribution of the petrophysical parameters (effective porosity (ϕ), permeability (mD), and water saturation (Sw)), cross sections in the NW and SE directions were also extracted to recognize both vertical and lateral property distributions in the reservoir.

2.2. Seismic interpretation

The seismic volume is imported into a user defined folder in SEG-Y format and then realized. From the realized volume, Inline and Xline are inserted. A 3-D window and a new interpretation window were used to view and also to carry out fault mapping. The faults were mapped on the Xlines and the continuity viewed on the Inlines.

2.3. Picking of faults

The conditions for fault mapping used were as follows:

(a) Abrupt termination of reflection events

(b) Displacement or distortion of reflection

To generate fault models for faulted levels, the fault centerlines were digitized from provided fault polygons. For the model boundaries, boundary polygons were generated from the depth grids provided and then modeled as pillars. The fault models were then snapped to the bounding depth grids, ensuring that the pillar grid skeletons followed the structural trend of the reservoir.

2.4. Structural analysis

The faults that intercepted the reservoir of interest were modeled and quality-checked using interpreted faults and the respective top structural maps. The fault models constructed were integrated with the top and base depth structural maps of the reservoir to build a 3D structural grid. Facies (sand and shale) identified from gamma-ray logs from wells as well as key rock properties sensitive to fault sealing potential including, porosity and permeability estimated from petrophysical analysis were then upscaled into the mesh-like cellular framework of the three-dimensional structural model. To extrapolate estimates at unknown locations away from well locations, standard geostatistical techniques rely on known data points from multiple locations (e.g. drilled wells) to reduce uncertainties associated with the estimated unknown data values.

3. Results and discussion

3.1. Reservoir identification and petrophysical analysis

Eleven reservoir units were delineated across the wells. The reservoirs comprising shallow reservoir, middle reservoirs and deep/lowermost reservoirs are identified from wireline logs interpretation (Figure 4). Reservoir A was selected as the reservoir of interest because it possesses good sand packages and volume of hydrocarbon across the entire wells The deep resistivity logs indicate all the storage units are gas and water-bearing. Estimated porosities range from 0.01 to 0.35 and permeabilities range from 0.5 to 350 mD (Table 1). However, the estimated water saturation has an average value of 0.4 across the reservoir of interest giving indication of hydrocarbon accumulations. The petrophysical estimates suggest that the reservoirs have varying properties of high to low porosity and varying permeabilities. However, the shallow reservoirs have better reservoir properties than the middle and lowermost reservoir due to good sand packages which is continuous across the wells.

Table 1. Summary of petrophysical analysis of reservoir A.

Wells	Top(ft)	Base(ft)	Thickness(ft)	Porosity	K(md)	Sw (v/v)
01	7840.8	7919.3	78.5	0.15	150	0.02
02	8027.5	8097.3	69.8	0.25	89	0.05
03	7826.0	7891.5	65.5	0.21	125	0.01
04	7679.3	7741.6	62.3	0.22	130	0.03
05	8226.6	8301.2	746	0.25	200	0.04
06	7758.8	7823.8	65.0	0.30	270	0.05

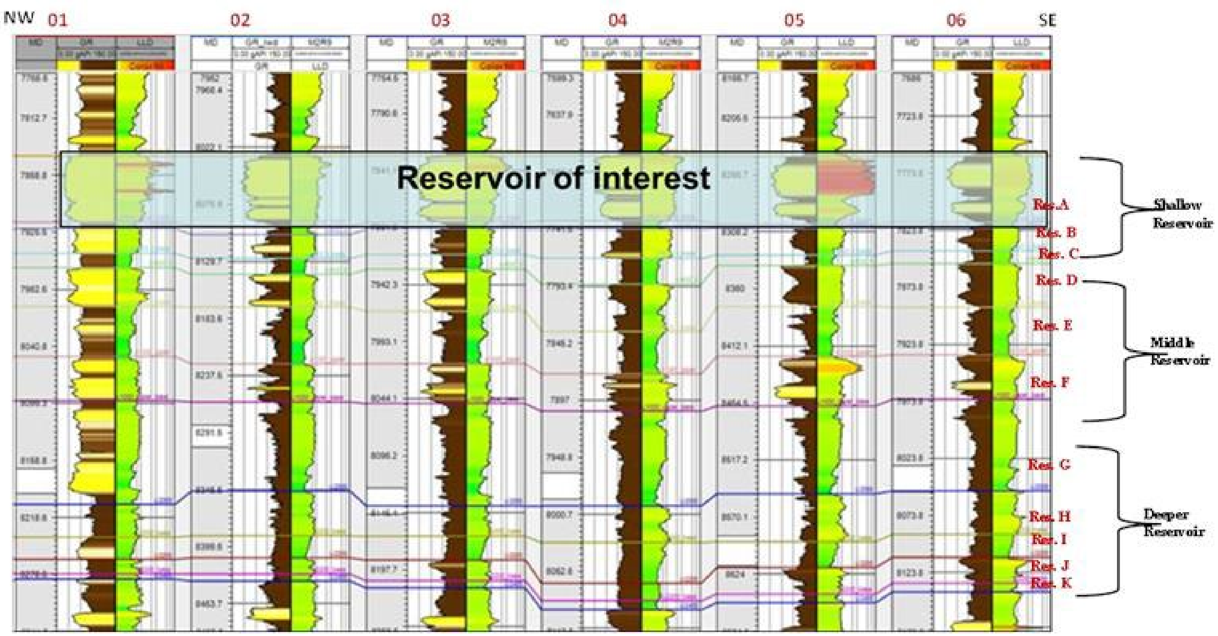

Figure 4. Well correlation panel across the field.

3.2. Seismic interpretation and fault picking

Different faults were identified and mapped across the seismic data. Most of the faults seen on the seismic section (Figure 5) were not continuous across the seismic volume, but major and minor faults that were continuous were mapped. The prominent faulting styles include growth faults with associated rollover anticlinal structures. The faults have a north-west south-east orientation as well as a north-east–south-west direction. Observations from a seismic section indicate that most of the faults have affected all the storage units (Figure 5). The depth structural map of reservoir of interest (shallow reservoir) is shown as a representative depth map (Figure 7).

3.3. Structural interpretation

The field structure is a prime example of a northern depo-belt structure, characterized by the presence of a rollover anticline situated in the hanging wall of a significant listric fault, with a WNW-ESE strike direction. At certain levels, the structure exhibits a 4-way dip closure, while at others, it is dependent on an up-dip fault seal for containment. The reservoir under study is a 4-way closure (as depicted in figure 6). The field is located in an area affected by several synthetic and antithetic faults, some of which may not be detectable by seismic imaging. However, a contemporary 3D seismic dataset of high quality fully encompasses the field, allowing for a relatively confident time interpretation (Figure 5). The 3D fault models of the mapped faults reveal their three-dimensional distribution and orientation across the field (Fig. 6). The faults towards the north central part of the field are four-way dependent closure as revealed by the 3D fault model of the field. The facies from the gamma ray log motifs show the distribution of sands and shale across all the mapped reservoirs. The reservoir showed good quantity of sands across the reservoirs. The permeability values suggest high permeability within sands and low permeability within shales.

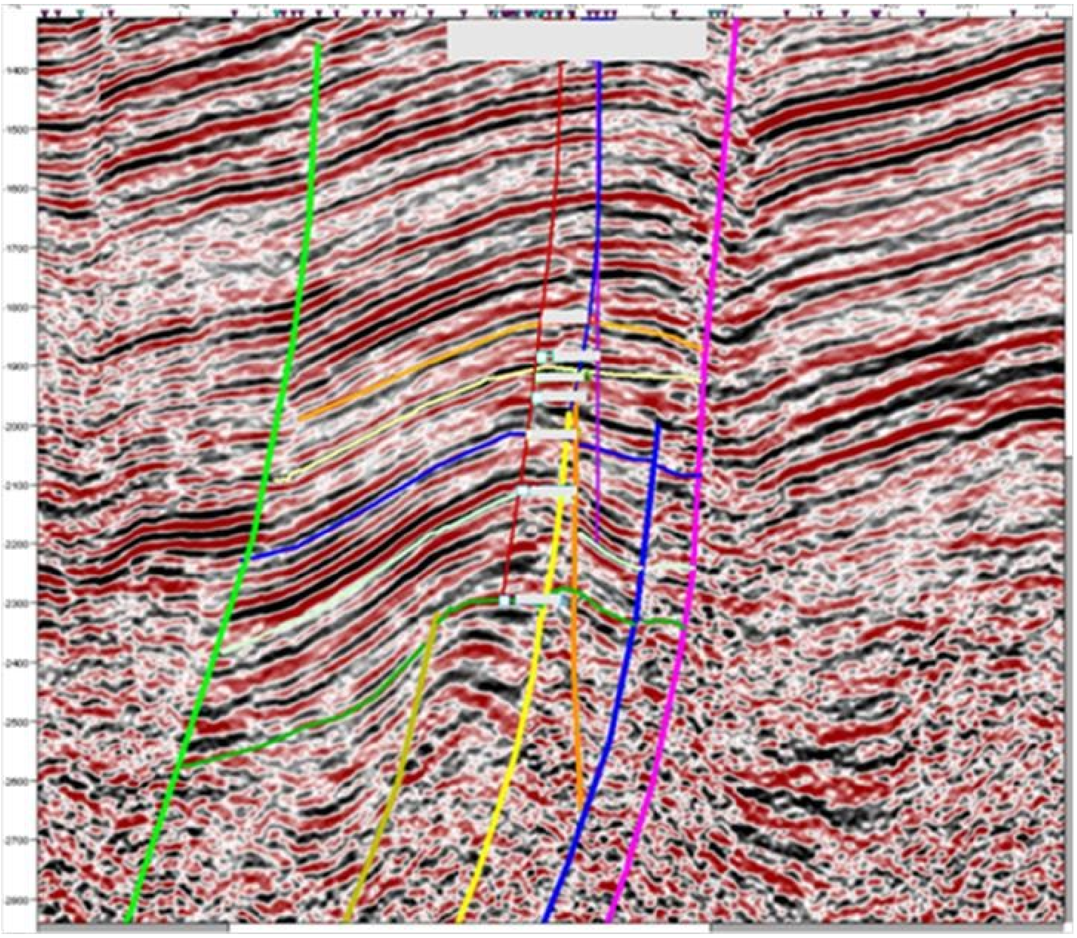

Figure 5. 3D seismic section of the study area.

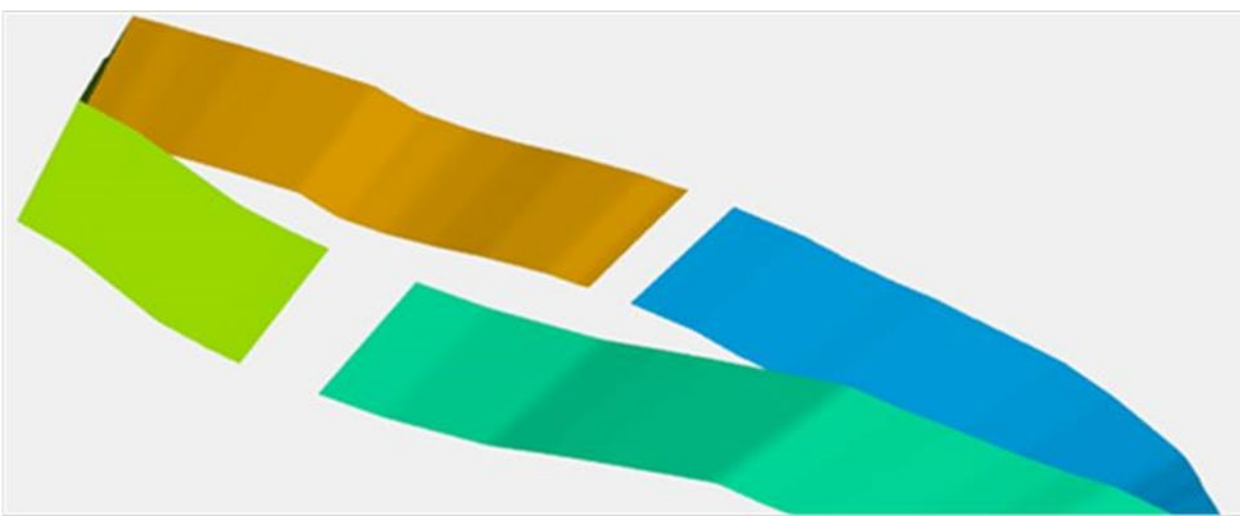

Figure 6. Fault model.

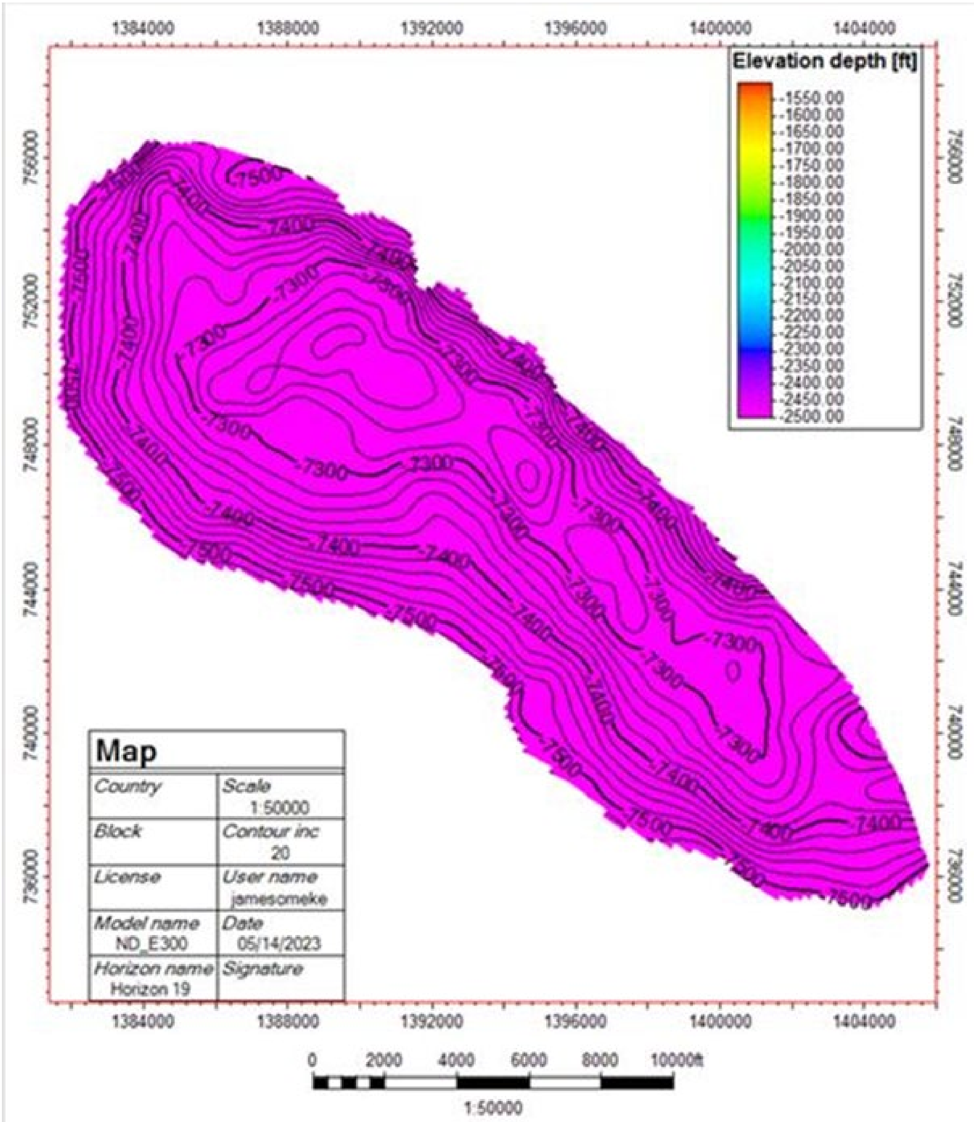

Figure 7. Depth structural map.

4. Conclusion

Carbon capture, utilization and storage remain an important and essential technology for countries and industries to reduce worldwide environmental change, with underground storage of carbon dioxide in geological formations as a core of carbon sequestration, especially in non-renewable energy-centered nations. Reservoir A was selected as the reservoir of interest for CO_2 storage. The reservoir was identified to possess a very good property quality suitable for anthropogenic CO_2 storage, with good sand geobody and average porosity and permeability range of 0.35 and 350mD respectively.

The field of study has demonstrated a fault model which exhibits a four-way dip closure structure in a North-West South East trend, with the ability to retain gas without significant leakage, indicating their potential for containing CO2 as well. The overall understanding of these technical parameters will enable effective storage of CO_2 and reduction of emissions to curb extreme climate effect.

It is recommended that numerical simulation incorporated with the present Petroleum Industry Act (PIA) under the gas fiscal regime be studied to evaluate the potential of gas utilization for revenue while storing anthropogeneic carbon dioxide.

Acknowledgments

The authors are grateful to the oil and gas company in Nigeria for providing the data and well reports for the study. They also thank the Schlumberger Limited for providing access to Interactive Petrophysics (IP 2021 (4.7)) and Petrel software, respectively, used for data analysis.

Funding

The funding provided by the Tertiary Education Trust Fund (TETFund), University of Nigeria toward this research is acknowledged.

Conflict of Interest *The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.*

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