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PROSPECT EVALUATION OF 'NSID' FIELD, NIGER DELTA PROVINCE, NIGERIA

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Abstract - Hydrocarbon reservoir beds have been delineated using direct hydrocarbon indicator on seismic sections as well as well logs data to evaluate the prospects in Nsid Field, Onshore Niger Delta, Nigeria. Well log suites from five wells and 3D seismic volume across the study area, were used for this study. The study involved well log correlation of the reservoir units, seismic interpretation of key horizons, evaluation of reservoir thickness, porosity, net-to-gross sand thickness, hydrocarbon saturation and, determination of fluid contents. Three reservoir units (R1, R2 and R3) were delineated and interpreted in all the wells across the study area. The top of the each of the three reservoir sands (HA, HB and HC) were identified and interpreted on the seismic volumes and sub-surface structure maps produced. Geophysical well log motifs were used in identifying hydrocarbon bearing sands. Two major lithologies (sand and shale) were delineated from the well logs. Three major faults (mainly synthetic and antithetic growth faults), were delineated and mapped from the seismic volume. The seismic-to-well tie was good and the reservoir sands from the wells, tied perfectly with hydrocarbon indicators on seismic. Average gross thickness of the three reservoirs R1, R2 and R3 was 93ft, 208ft and 172ft respectively. Average porosity for the three reservoirs was 0.22 (R1), 0.25 (R2) and 0.23 (R3). Average net-to-gross sand thickness was 0.74 (R1), 0.82 (R2) and 0.76 (R3) while average hydrocarbon saturation for the reservoirs was 0.81 (R1), 0.84 (R2) and 0.83 (R3). Stock-Tank-Oil-Initially-In-Place (STOIIP) for each of the three reservoirs was calculated using petrophysical data obtained from well logs and, seismic data, using empirical relationship. The results of the research show that Nsid Field has very good hydrocarbon potentials.

Keywords: *Well logs, reservoirs, seismic sections, petrophysics and hydrocarbon-in-place.*

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1.0 INTRODUCTION

The aim of this study is to assess the quality of the reservoirs in the study area based on the evaluation of the reservoir parameters of the sands in the area. The study also looks at the hydrocarbon accumulation potentials of the area based on the structural styles of the sands in the area.

1.1 Regional Geology of the Study Area

The study area is located within the Niger Delta, Nigeria. The Niger Delta sedimentary basin is a product of triple junction phenomenon comprising the Gulf of Guinea, South Atlantic Ocean and Benue Depression. It is a prolific field [13] that is situated in the Gulf of Guinea on the West Coast of Southern Nigeria between latitude 3˚ and 6ºN and Longitude 5˚ and 8˚E [2]. The Niger Delta is bounded on the Northwest by a subsurface continuation of the West African shield, the Benin Flank. The Eastern edge of the basin coincides with the Calabar Flank to the south of the Oban Masif [5]. The Niger Delta developed in Late Jurassic along the failed arm during the separation process between South American and African plate [14,15,16] . The two rift arms that followed the South-Western and South-Eastern coasts of Nigeria and Cameron developed into passive continental margin of West Africa while the third arm formed the Benue Trough in the Gulf of Guinea. During the rifting process in the Late Mesozoic, the elastic wedge gradually prograded into the Gulf of Guinea and advanced over 200 km southwards and broadened from less than 300 km.

Well sections through the Niger Delta generally display three vertical lithostratigraphic sub-divisions. These lithostratigraphic units are the Benin Formation (Oligocene-Recent), Agbada Formation (Eocene-Recent) and Akata Formation (Paleocene-Recent) as shown in Figure 1 [1]. The Benin Formation is a continental deposit of alluvial and upper coastal plain sands. It is mainly made up of non-marine fine to coarse grained sands with a few shale intercalations. It consists predominantly of freshwater bearing massive continental sands and gravels deposits in an upper deltaic plain environment. The Agbada Formation underlies the Benin Formation. The Agbada Formation consists of fluvial-marine sands, siltstones and shale. The sandy parts constitute the main hydrocarbon reservoirs. The grain sizes of these reservoirs range from very coarse to fine. The formation is of marine origin and is composed of thick shale sequences (potential source rock), turbid sand (potential reservoirs) in deep water and minor amount of clay and silt. The thickness of the formation is over 3,700 meters. The Agbada Formation is the major petroleum bearing units in the Niger Delta. The Akata Formation forms the base of the Niger Delta lithostratigraphy. It is composed mainly of marine shale, with sandy and silky beds which are thought to have been laid down as turbidities and continental slope channel fills. It is estimated that the formation is up to 7000 m thick. The formation is a continuous shale unit consisting of massive dark grey uniform shale especially in the upper part. The Akata Formation is the hydrocarbon source rock in Niger Delta [20]. Since its formation, the delta has prograded south-westwards forming depobelts which are the active portion of the Niger Delta. These depobelts are regarded as one of the largest regressive deltas in the world [3,5,6] with an area of 300,000 km^2.

2.0 Materials and Methods

The data used for this work are composite geophysical well logs of all the five wells in the study area, base map of the area, 3-D seismic volume covering the entire study area, check shot data from three of the five wells, deviation data from all the five wells, well header, formation pressure data. The suite of geophysical logs comprised of gamma ray, resistivity, neutron and density logs. The data were obtained from an offshore field in the Niger Delta. The well logs were obtained from five wells, Nsid 1, Nsid 2, Nsid 3, Nsid 4 and Nsid X01. The wells used for this study were plotted as they appear on the base map (Figure 1). The reservoirs (R1, R2 and R3) were identified using gamma ray and resistivity logs and, correlated across the wells to give an idea of the continuity of the reservoirs at different depths across the study area. The three horizons (HA, HB and HC) corresponding to top of the three reservoirs R1, R2 and R3 respectively, were identified on the seismic volume using check shot data, and mapped across the field. Faults were identified on the seismic section based on reflection discontinuity at fault planes [7,8,9]. Time and depth structure maps of the three horizons were produced from the seismic mapping to show the structural dispositioning of the wells in the study area. Porosity determination was done using the porosity logs available for the study. Net-to-gross sand thickness was determined from gamma ray log using 75 gamma ray API cut-off while fluid type was determined using resistivity and porosity logs [11,12,13,18,19]. Water saturation hence, hydrocarbon saturation and hydrocarbon-in-place were calculated using empirical relationship.

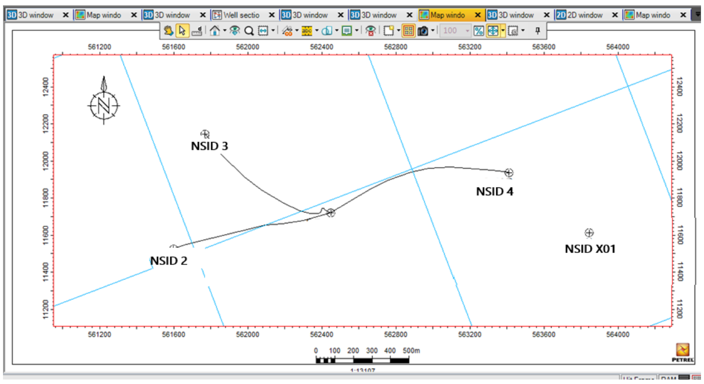

Figure 1: Nsid Field Base Map

3.0 RESULTS AND DISCUSSION

Two lithologies (sand and shale) were delineated from the gamma ray as shown in figure 3. The shale (dark colour) is associated with maximum deflection of the logs while the sand (yellow) is obtained from the minimum deflection of the logs. Three reservoirs R1, R2 and R3 were delineated and interpreted from the lithology and resistivity logs across the five wells (Figure 2).

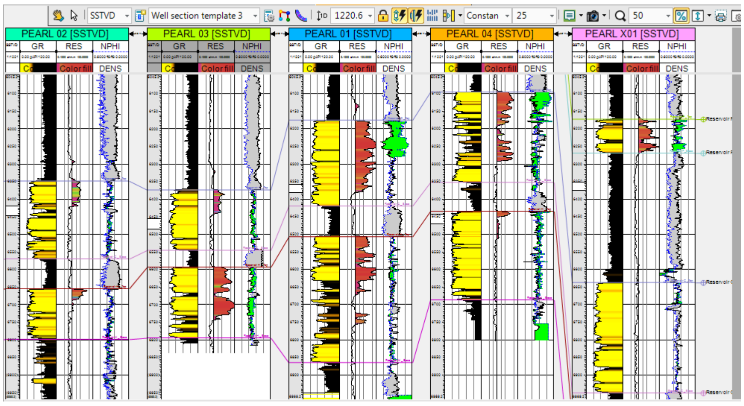

Figure 2: Geophysical composite logs and well correlation across the five wells

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R1 in the study area occurs at subsea depth of 6172 feet and (well X01), (table 1). R2 occurs between subsea depths of 6098 feet (well 01) and 6635 feet (well X01) while R3 occurs between subsea depths of 6442 feet (well 04) and 6650 feet (well 02) (table 1).

The gross sand thickness of R1 is 93 feet, net sand thickness is 71 feet while net-to-gross thickness is 0.76 (table 2). The gross sand thickness of R2 varies from 172 feet (well 03) to 313 feet (well X01), net sand thickness varies from 161 feet (well 03) to 280 feet (well X01) while net-to-gross thickness varies from 0.68 (well 04) to 0.96 (well 01) (table 2). The gross sand thickness of R3 varies from 150 feet (well 02) to 360 feet (well 01); net sand thickness varies from 138 feet (well 02) to 223 feet (well 04) while net-to-gross thickness varies from 0.57 (well 01) to 0.90 (well04) (table 2). Porosity and hydrocarbon saturation in R1 are 0.22 and 0.81 respectively (tables 3 and 4). In R2, porosity and hydrocarbon saturation range from 0.22 to 0.28 and 0.79 to 0.88 respectively while in R3, porosity and hydrocarbon saturation range from 0.21 to 0.27 and 0.78 to 0.88 in that order (tables 3 and 4). The top of the reservoirs in the wells corresponds to the delineated horizons.

Several major and minor faults (mainly synthetic and antithetic growth faults), were delineated and mapped from the seismic volume (Figure 3). The seismic-to-well tie was good and the reservoir sands from the wells, tied perfectly with hydrocarbon indicators on seismic.

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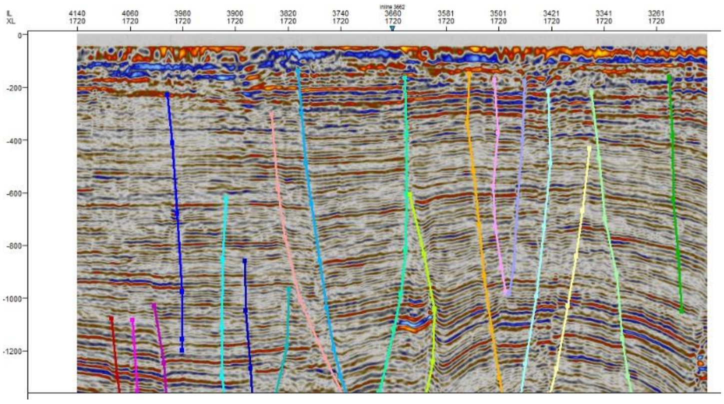

Fig. 3: Delineated faults on Seismic in Nsid Field

Table 1: Top and base of reservoirs in Nsid Field

Sand Units		Wells				
		01	02	03	04	X01
R1	Top (ft-ss)	NA	NA	NA	NA	6172
	Base (ft-ss)	NA	NA	NA	NA	6265
R2	Top (ft-ss)	6175	6350	6375	6098	6635
	Base (ft-ss)	6420	6570	6547	6350	6948
R3	Top (ft-ss)	6507	6650	6592	6442	NA
	Base (ft-ss)	6867	6800	6788	6688	NA

Average gross thickness of the three reservoirs R1, R2 and R3 was 93 feet, 208 feet and 172 feet respectively. Average porosity for the three reservoirs was 0.22 (R1), 0.25 (R2) and 0.23 (R3) (table 3). Average net-to-gross sand thickness was 0.74 (R1), 0.82 (R2) and 0.76 (R3) while average hydrocarbon saturation (S_{hc}) for the reservoirs was 0.81 (R1), 0.84 (R2) and 0.83 (R3) (table 4).

These reservoir parameters values compare positively with published values of good quality reservoir. Stock-Tank-Oil-Initially-In-Place for each of the three reservoirs is 15.41 MMSTB (R1), 62.52 MMSTB (R2) and 39.48 MMSTB (R3) (table 5). R2 is assessed to be more prolific than the other reservoirs.

Table 2: Gross sand thickness, net sand thickness and net-to-gross sand thickness ratio in Nsid Field

Sand Units		Wells				
		01	02	03	04	X01
R1	Net	NA	NA	NA	NA	71
	Gross	NA	NA	NA	NA	93
	Net/ Gross	NA	NA	NA	NA	0.76
R2	Net	235	192	161	172	280
	Gross	245	220	172	252	313
	Net/ Gross	0.96	0.87	0.93	0.68	0.89
R3	Net	208	138	158	223	NA
	Gross	360	150	196	246	NA
	Net/ Gross	0.57	0.87	0.81	0.90	NA

Table 3: Porosity and average porosity within the reservoirs in Nsid Field

Sand Units	Wells					
	01	02	03	04	X01	Sand Averagef
R1	NA	NA	NA	NA	0.22	0.22
R2	0.27	0.23	0.22	0.24	0.28	0.25
R3	0.21	0.24	0.22	0.27	NA	0.23

Table 4: Water and hydrocarbon saturations within the reservoirs in Nsid Field

Sand Units		Wells					Average saturation
		1	2	3	4	X01	
R1	S_w	NA	NA	NA	NA	0.19	0.19
	S_{hc}	NA	NA	NA	NA	0.81	0.81
R2	S_w	0.13	0.20	0.21	0.15	0.12	0.16
	S_{hc}	0.87	0.80	0.79	0.85	0.88	0.84
R3	S_w	0.22	0.16	0.19	0.12	NA	0.17
	S_{hc}	0.78	0.84	0.81	0.88	NA	0.83

Table 5: Volumetric Analysis of the reservoirs in Nsid Field

Reservoirs	Volumetric Analysis							
	Area (acre)	Av. Thickness (ft)	GRV (ac-ft)	Av. NTG	NRV (ac-ft)	Por.	S_{hc}	STOIIP MMSTB
R1	174	93	16182	0.74	11974	0.22	0.81	15.41
R2	225	208	46800	0.82	38376	0.25	0.84	62.52
R3	206	172	25432	0.76	26928	0.23	0.83	39.88

Time structure maps of the three horizons were made from the seismic interpretation. Time-depth function using the check shot data was used to convert the time structure maps to depth structure maps (Fig. 7,8,9). Structure maps highlight the geometry of the reflectors (Kearey and Brooks, 1984) and in the study area, they show the presence of structures (growth faults and anticlines) that facilitate hydrocarbon accumulation in the study area.

The integration of the well logs and seismic data provides insight to reservoir hydrocarbon volume which may be utilized in prospect evaluation and, in well bore planning. Interpretation of well logs from the study area identified two lithologies (sand and shale). These lithologies are intercalated and, is typical of Agbada Formation in the Niger Delta. The values of the reservoir and petrophysical parameters show that the reservoirs in the study area are good. Three horizons (*HA, HB and HC*) were identified in the seismic sections (Fig. 4).

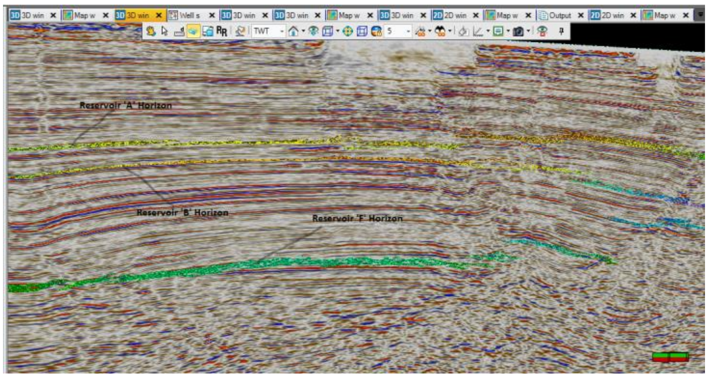

Figure 4: Horizons on seismic

Seismic reflections discontinuities were identified and interpreted as faults on the seismic sections. These faults act as hydrocarbon traps. Growth faults and anticlines are apparent in this field and, serve as the dominant trap styles [9], in the study area. The anticlines and fault-assisted closures are good hydrocarbon prospects in the Niger Delta [10].
The wells in this field are located on the downthrown block of the major fault M2 (Fig. 5), in the rollover anticlines formed against the fault. The capability of the faults to act as seals depends on the amount of throw and the volume of shale smear along the fault planes. Faults were identified on the seismic section based on reflection discontinuity at fault plane. Three growth faults were identified on the seismic sections. The faults observed in the seismic sections are acting as seals to the hydrocarbon migration from the reservoirs. This type of structure is usually associated with growth faults in the Niger Delta.

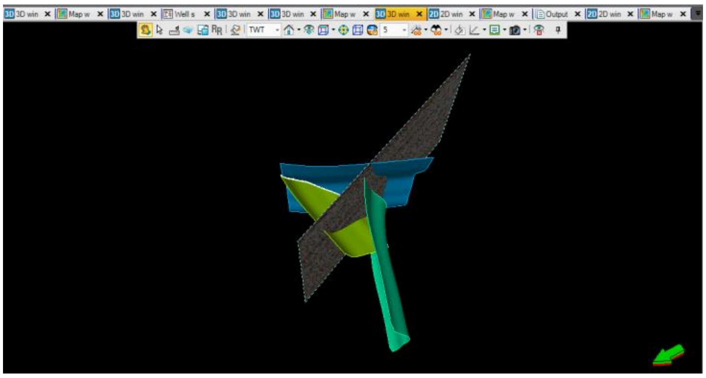

Figure 5: Fault model on inline

Hydrocarbon potentials of the sands in the study area were evaluated based on their petrophysical and reservoir properties. The evaluation method used for this study is volumetric estimation of the reserves which involves integration of various geological parameters obtained from both surface (seismic) and subsurface (well log) geophysical data. The average values of the petrophysical and reservoir parameters obtained from well logs and geophysical data for the mapped reservoirs, were computed and used in calculating the volume of hydrocarbon-in-place for the reservoirs.
Stock Tank Oil Initially In Place (STOIIP) was computed using the standard volumetric estimation equation:

$$STOIIP = 7758 * A * h * n/g * \phi * (1 - Sw).$$

Where:
STOIIP = Hydrocarbon (Gas/oil) initially in Place acre-feet
A = Areal extent of the accumulation acre
H = Average Net Pay for the reservoir zone (feet)
Φ = Average Effective Porosity (fraction)
n/g = Average net-to-gross (fraction)
Sw = Average Water Saturation (fraction)
7758 The constant that converts the volume from acre-feet to stock tank barrels

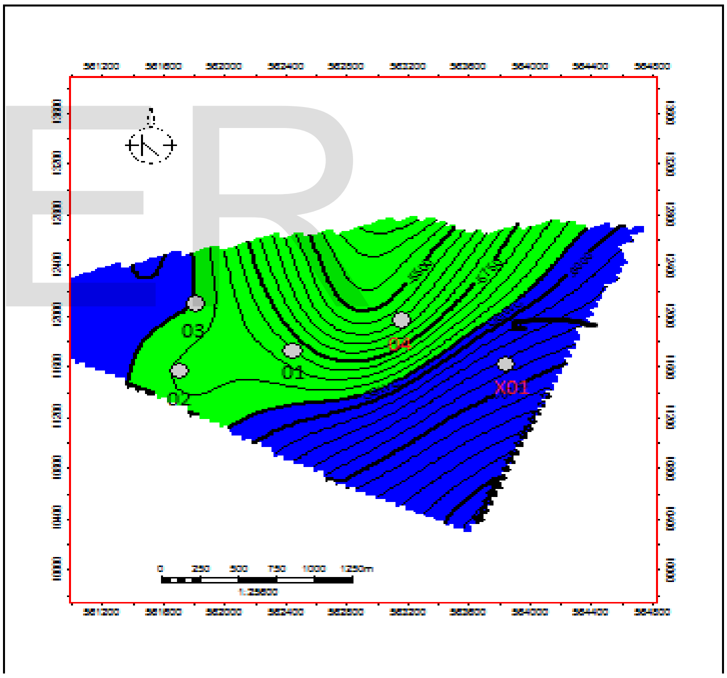

Fig. 6: Reservoir A fluid contact map indicating the GWC.

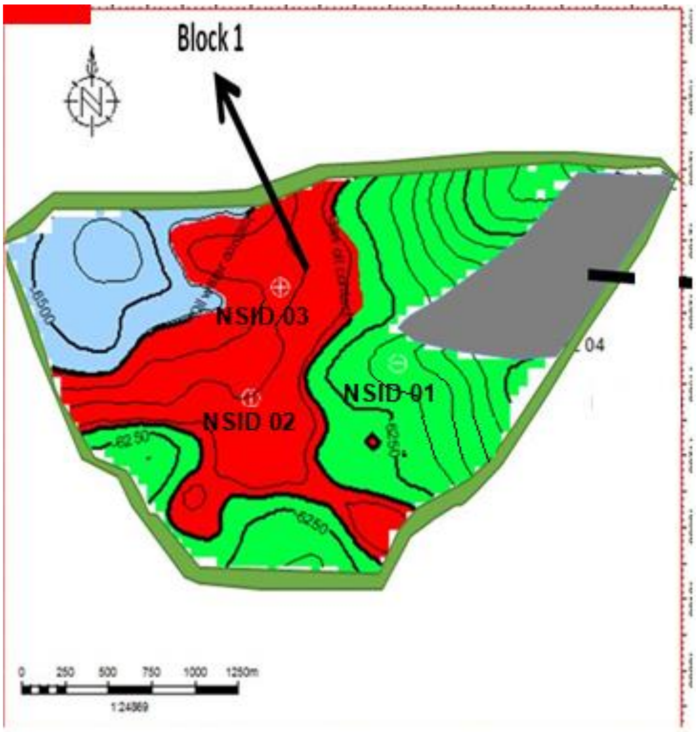

Fig. 7: Reservoir B fluid contact indicating both the OWC and the GWC

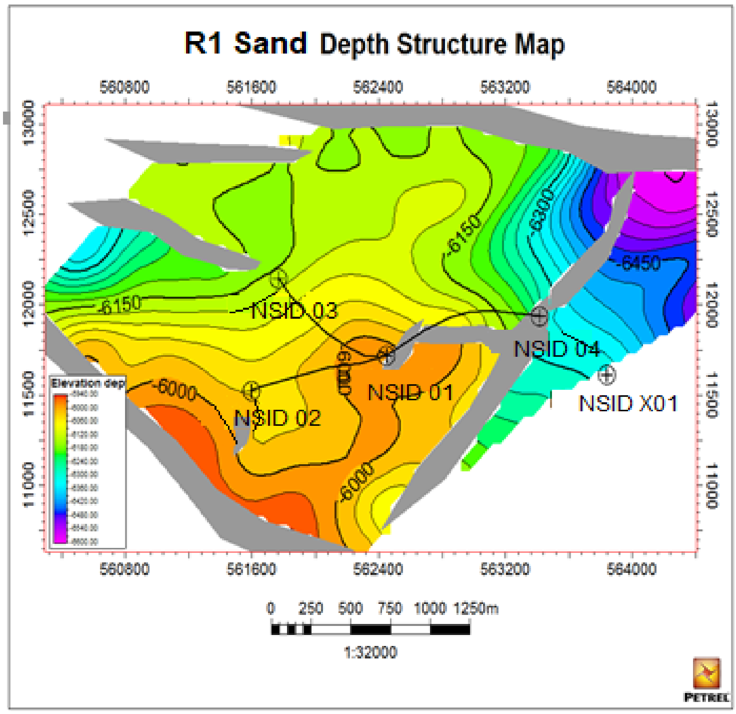

Fig. 9: Depth structure map for R1

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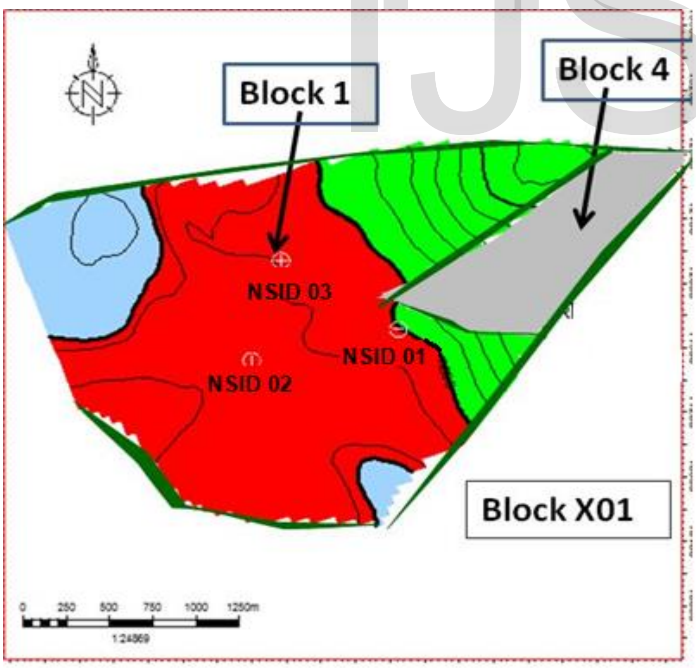

Fig. 8: Fluid contact map for reservoir C showing the OWC and the GOC respectively.

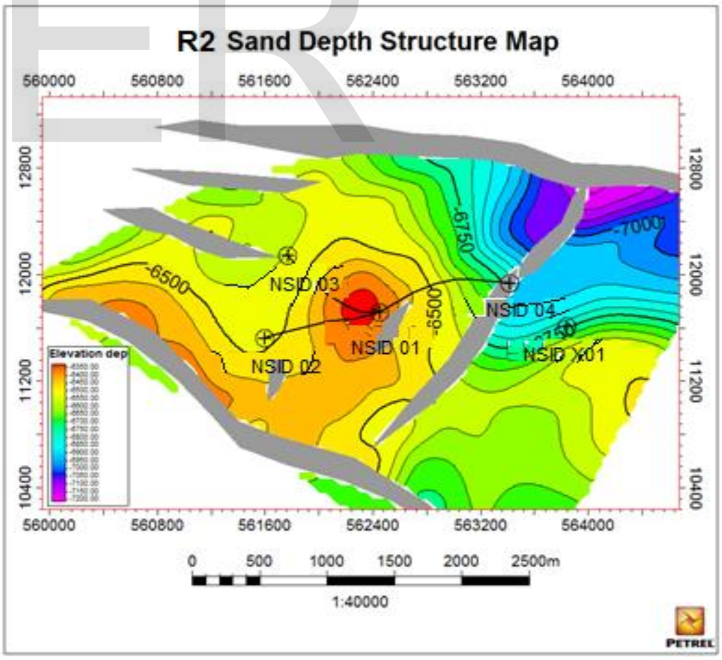

Fig. 10: Depth structure map for R2

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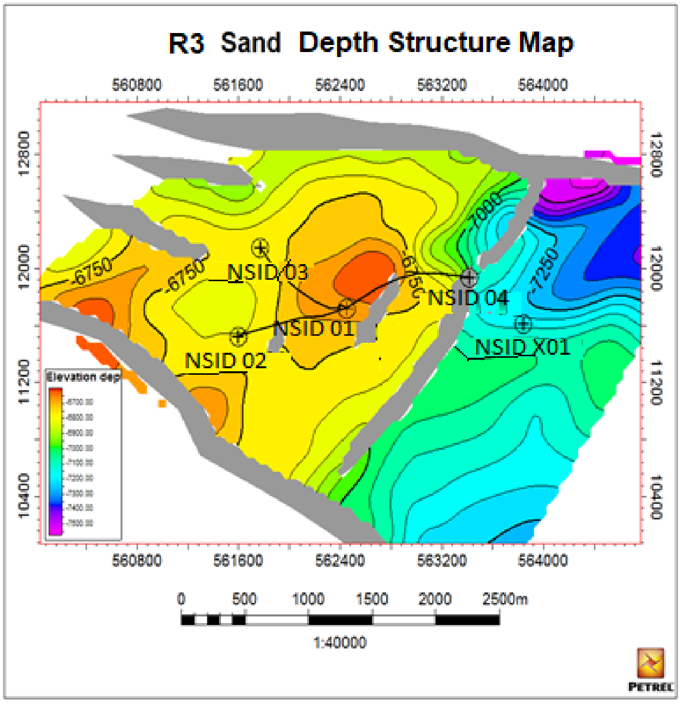

Fig. 11: Depth Structure Map for R3

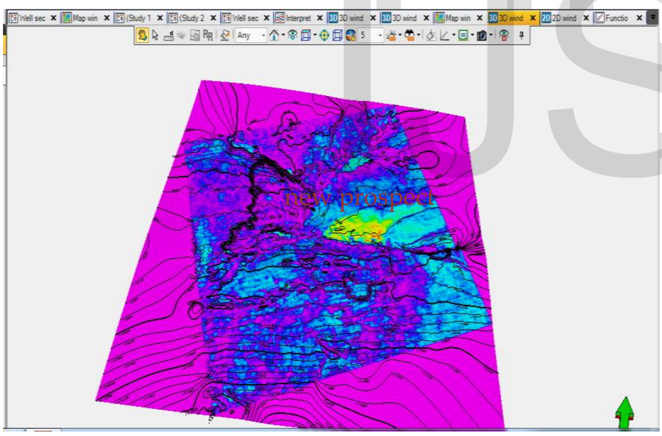

Figure 12: Surface map showing new prospect

CONCLUSION

Well logs and other well data from five wells as well as 3D seismic volume across the entire field were used to evaluate the hydrocarbon potentials of Nsid Field. Interpretation of the 3D seismic data volumes provided the framework to understand the structural styles and architecture, and delineate the reservoir blocks, in the study area. Within the scope of this work, the trapping mechanisms in the study area are faults and rollover anticlines. Faulting and folding play a prominent role in the definition of the structural setting in a field. These structural features constitute the main structural traps in the study area. The major anticlinal ridge in the mapped horizon is favorable to the accumulation of hydrocarbon. The study revealed that the central fault blocks in the field where the five wells are located, have structural highs (anticlines) that are sandwiched between the growth faults.

From the well log correlation across the entire wells in the field, the reservoirs are well developed. The values of the petrophysical and reservoir properties in the study area compare favorably with published values for excellent reservoirs. The three reservoirs in the study area have good hydrocarbon potentials that make them economically viable. These are responsible for possible hydrocarbon accumulation in the study area. The reservoir thickness in the five wells in the study area, are very thick and have great potentials for hydrocarbon accumulation. The estimated hydrocarbon-in-place in the reservoirs is high.

Since all the available wells were located based on 3D seismic survey, high resolution 4D seismic survey should be carried out within the field in order to better define the structural framework and capture any possible by-passed hydrocarbon in the area. More well data should be obtained and integrated with seismic data to build a robust stratigraphic framework and better develop the prospects. There should be a development plan that covers the surrounding fields since the reservoirs in this study extend beyond the study area.

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