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PETROPHYSICAL PROPERTY EVALUATION AND RESERVOIR CHARACTERIZATION IN THE B-FIELD, NIGER DELTA

Orji O., Egwuonwu, G. Ndubuisi and Okpara, A. Obiora[2]
Department of Physics and Industrial Physics, Nnamdi Azikiwe University, Awka, Nigeria
Department of Geological Science, Nnamdi Azikiwe University, Awka, Nigeria
Correspondence: Orji, Obinwa, Department of Pure and Industrial Physics, Nnamdi Azikiwe University Awka, Nigeria.
E-mail: orjiyo@yahoo.co.uk

Abstract
The Niger Delta Basin in southern Nigeria is a prolific hydrocarbon province characterized by complex structural and stratigraphic settings. This study aimed to characterize and evaluate reservoir intervals within the basin using an integrated approach combining well log analysis, seismic interpretation, and petrophysical assessments. Four reservoir intervals, labeled A-D, were identified through detailed well log analysis of gamma ray, resistivity, neutron, and density logs in four wells (B3 ST1, B10, B2, and B4) aligned in a southwest-northeast direction. Well log signature evaluation revealed a decrease in reservoir quality from the southwest (B10) towards the northeast (B3 ST1 and B4), as evidenced by diminishing electrical resistivity responses. This observation was corroborated by seismic mapping, which indicated a southward dip in the structural elevation of the reservoir beds. The updip/structurally higher positions were represented by B10 and B2, while B3 ST1 penetrated the downdip/structurally lower portion of the reservoirs. Seismic-to-well ties enabled the generation of structure maps for each reservoir top, facilitating the characterization of reservoir distribution and structural styles. Petrophysical assessments provided insights into key reservoir properties, including gross pay, net pay, porosity, and water saturation. The results suggest that the reservoirs have not reached their maximum potential and may involve both structural and stratigraphic trapping mechanisms due to lithological changes. This integrated approach has provided valuable insights into the reservoir characteristics and distribution within the Niger Delta Basin, which can inform future exploration and development strategies in the region.
Keywords: *Niger Delta Basin, Reservoir Characterization, Petrophysical Analysis, Reservoir Quality Assessment*

Introduction

The Niger Delta has been a prolific hydrocarbon province, contributing significantly to Nigeria's oil and gas production (Doust & Omatsola, 1990). However, as the basin matures, the exploration focus is shifting from conventional structural traps to more subtle stratigraphic and combination traps (Reijers, 2011). This transition necessitates a more comprehensive understanding of reservoir characteristics, particularly in complex deltaic settings where reservoir quality can vary dramatically over short distances (Ainsworth *et al.*, 2011).

The B-field in the Niger Delta presents an excellent case study for this evolving exploration paradigm. The Agbada Formation is a regional reservoir stratigraphic interval within the Niger Delta. A paralic sequence characterized by alternating sand and shale units, the field's reservoirs exhibit intricate stratigraphic and structural relationships (Short & Stäuble, 1967). The interplay between depositional environments, from continental to marine settings, coupled with post-depositional modifications, has resulted in a highly heterogeneous reservoir system (Weber, 1971).

This paper focuses on the petrophysical property evaluation and reservoir characterization of the B field. Using well log analysis, we aim to delineate and highlight the factors controlling reservoir quality. Our study examines four key reservoir intervals, assessing their gross pay, net pay, porosity, and water saturation.

Understanding these petrophysical variations is critical for several reasons. For example, it is an essential input in refining reservoir models, leading to more accurate volumetric calculations and production forecasts (Esan, 2002). Also, it can guide well placement, by ensuring that only high-quality zones are targeted (Ainsworth *et al.*, 2011).

Geology of Study Area

Nigeria's Niger Delta Basin is a tectonically complex region shaped by a prolonged history of geological processes (Lehner, 1977; Okpara *et al.*, 2021). The basin comprises six principal structural provinces: the Delta Edge, Central Swamp, Coastal Swamp, Northern Delta, Greater Ugheli, and Offshore Depobelts (Okpara *et al.*, 2021). The formation of these depositional belts was governed by Cretaceous fault belts or zones that progressively evolved into a network of trenches and ridges in the depths of the Atlantic Ocean (Okpara *et al.*, 2021).

The Niger Delta's formation commenced in the late Jurassic and continued into the middle Cretaceous (Lehner, 1977). As a component of a larger rift system, the basin's current structural style is primarily shaped by gravity-induced shale tectonism (Okpara *et al.*, 2021). The delta's Tertiary sequence is stratigraphically divided into three formations: Benin, Agbada, and Akata (Lehner, 1977; Okpara *et al.*, 2021). The Benin Formation, the youngest of the three, predominantly consists of continental sandy facies with occasional interspersed with shale deposits (Okpara *et al.*, 2021). Vertically and laterally, this formation grades into the paralic deposits of the Agbada Formation (Lehner, 1977; Okpara *et al.*, 2021). Offshore, the Agbada Formation transitions into the marine shales of the Akata Formation, which are thick and massive, with occasional sand deposits likely representing turbidites (Lehner, 1977; Okpara *et al.*, 2021).

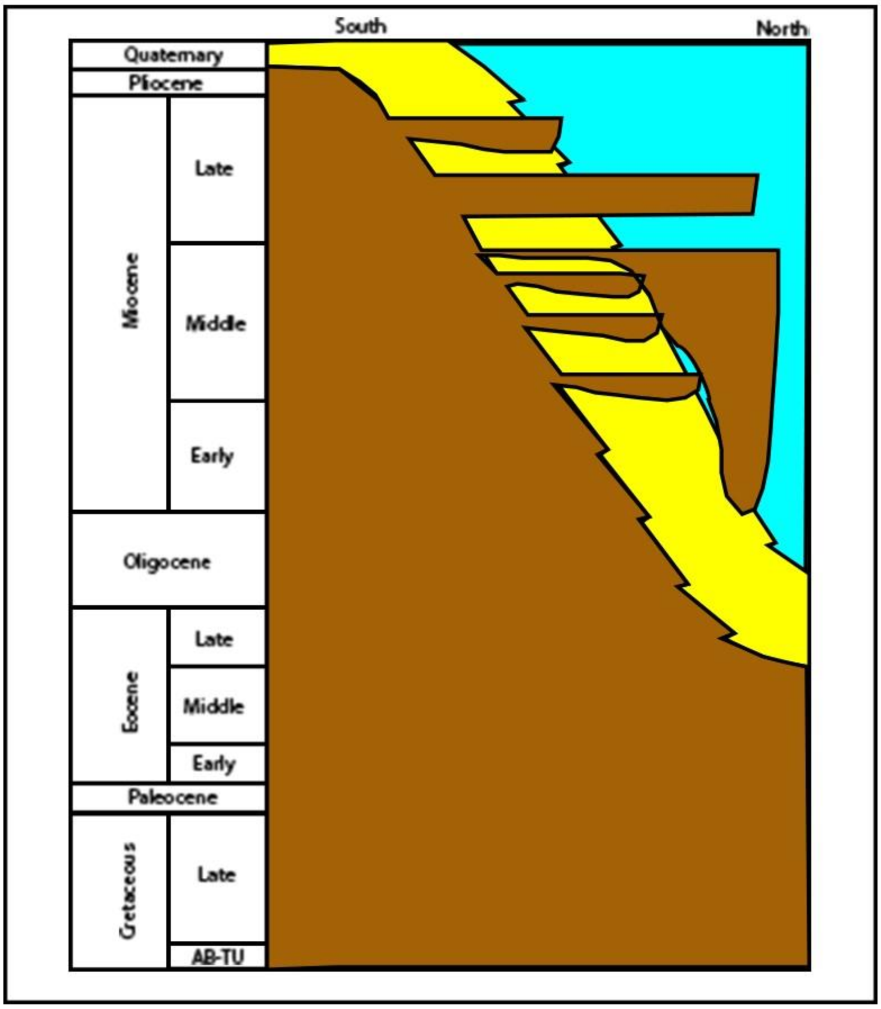

Figure 1.0: Schematic representation of Stratigraphic column of the Niger Delta and relationship of clay filled channels on the delta flanks (Doust and Omatsola, 1990).

The study area is in southern Nigeria, within the Niger Delta (figure 1.2), one of the world's largest delta systems (Lehner, 1977; Okpara *et al.*, 2021). The structural and stratigraphic evolution of the delta played a significant role in shaping hydrocarbon trap and seal formation (Okpara *et al.*, 2021). Various plays within the basin, such as shallow or deep simple/failed rollover, K-type structures, reverse footwall termination, back-to-back structures, and inversion structures, have proven to be viable exploration targets (Okpara *et al.*, 2021). Additionally, structural traps have demonstrated greater potential as exploration targets compared to stratigraphic traps (Okpara *et al.*, 2021).

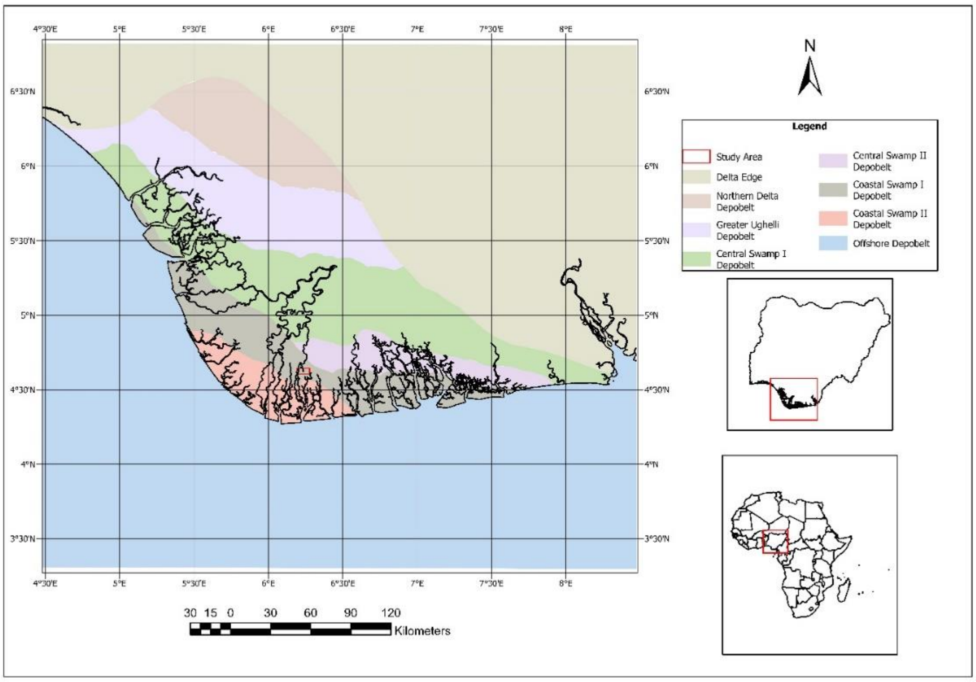

Figure 1.2: Various maps revealing the location of study (a) location of Nigeria in Africa (b) Niger Delta provinces in Nigeria (drawn after Jayeola and Adiela 2018), (c) the depobelts of Niger Delta (drawn after Nwozor et al. 2013 and Ebong et al., 2020)

Materials and Methods

For this study, the dataset used included a 3D seismic volume and a set of well logs for four wells: B3 ST1, B10, B2 and B4. Analysis and correlation of the reservoir well logs was carried out using these four wells in a southwest-northeast direction. Four reservoir intervals were identified. Using key well logs (neutron, density, acoustic, gamma ray and resistivity), a petrophysical assessment of the identified reservoir intervals was performed to determine key reservoir properties: porosity, water saturation, gross thickness and net thickness. This was done using key equations described in detail by Onyebum *et al.*, 2021. A well-to-well seismic connection was carried out to connect the reservoir tops to the B 10 and B 2 wells. This step enabled the creation of structural maps for each well reservoir top by linking them to key horizons in the seismic volume. These structural maps facilitated the structural characterization of the reservoirs.

Results and Discussion

Reservoir Correlation

Four reservoir intervals, labeled A-D, were identified through detailed well log analysis utilizing gamma ray, resistivity, neutron, and density logs in wells B 3 ST1, B 10, B 2, and B 4. These reservoir units were subsequently correlated through the wells in a southwest-northeast direction (Figure 4.4). The evaluation of electrical resistivity and gamma ray log signatures revealed a noticeable decrease in reservoir quality from well B 10 towards well B 3 ST1 and B 2 towards B 4 in the southwest and northeast directions, respectively. Correspondingly, the strength of the electrical resistivity response also diminished along this same trend, as both B 3 ST1 and B 4 wells are located on the flanks of the dominant structural style in the field.

This observation aligns with seismic mapping of the reservoir unit across the field, indicating a southward dip in the structural elevation of the reservoir beds. Wells B10 and B2 represent the updip/structurally higher position, while B3 ST1 penetrates the downdip/structurally lower portion of the reservoirs (figure 4.4a). Furthermore, the reservoirs do not appear to be filled to the structural spill point, which represents the lowest elevation along the plunging roll-over anticline towards the south (figure 4.4b).

Additionally, log signatures in well B3 ST1 suggest the presence of a gas-water contact near the base of the reservoir interval. Similar trends of reservoir deterioration were observed in the other identified intervals. Finally, seismic signatures and well log analysis indicate that the trapping may involve some stratigraphic component due to lithological changes and may not be entirely structural.

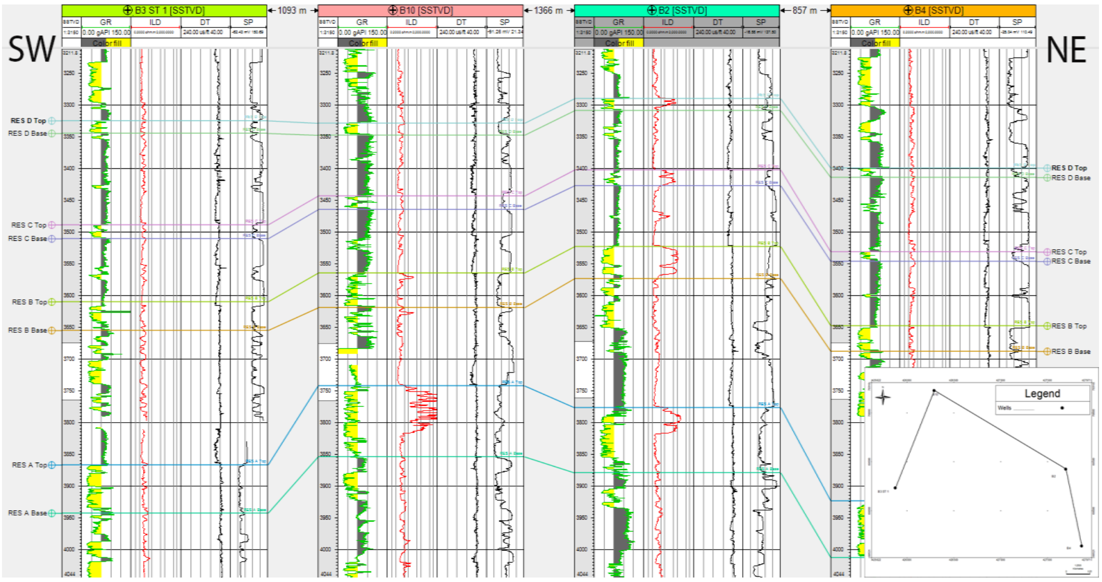

Figure 4.4a: Well section through B3 ST1 to B4 displaying the reservoirs A to D intervals zones.

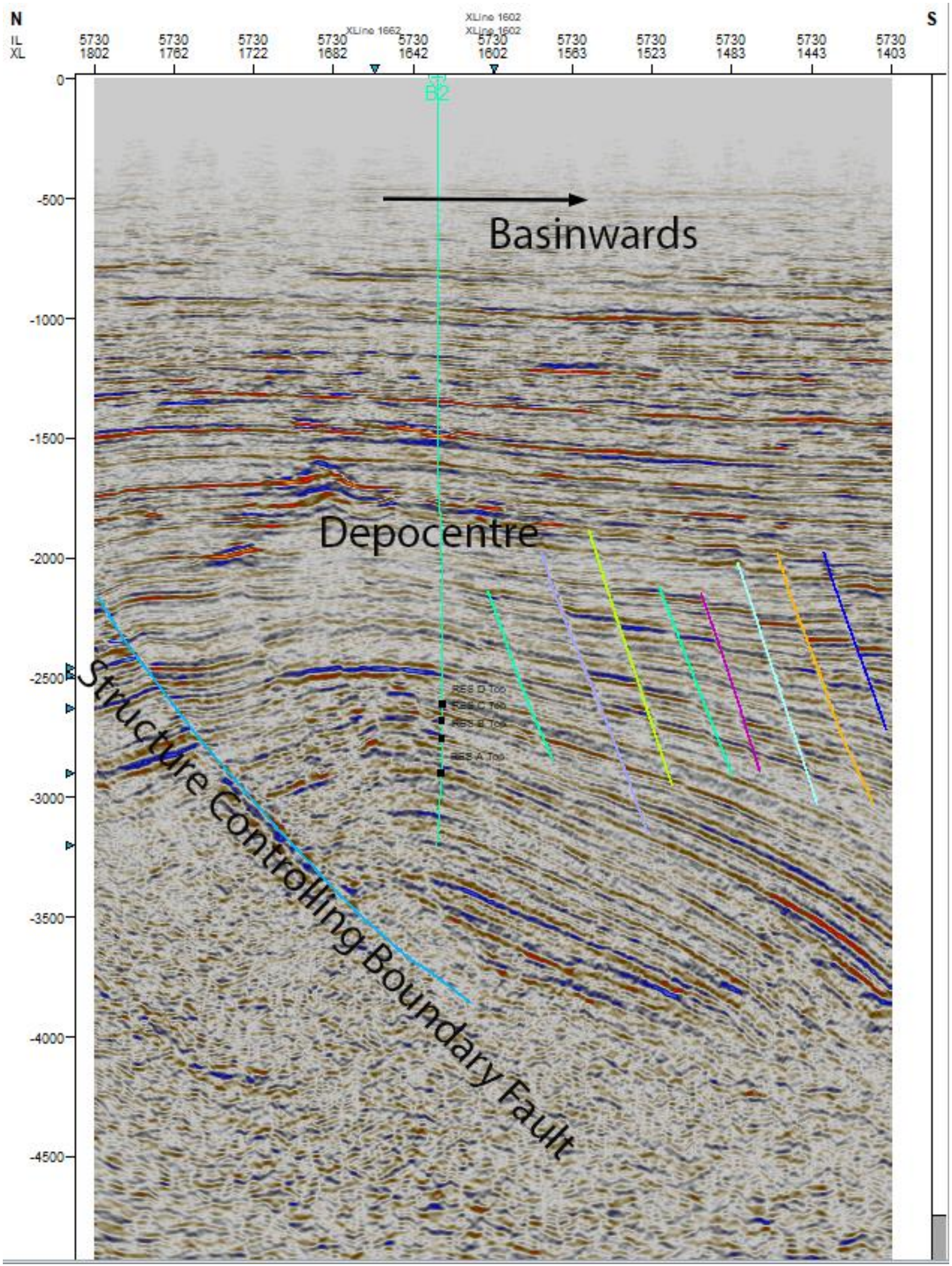

Figure 4.4b: Seismic section through well B2 showing reservoir B top. The top can be seen to dip southwards.

Reservoir Petrophysics

The petrophysical assessment was conducted using four wells: B10, B2, B3 ST1, and B4, lying on a roughly southwest-northeast line. During the assessment, four key or main reservoir intervals were identified and designated as RES: A, B, C, and D (figures 4.5a to 4.5d). These reservoir intervals are extensive over the well section, and their tops were tied to key seismic reflections and mapped over the entire field.

Top structure maps were generated from the interpreted seismic horizons, initially in time (figures 4.6a to 4.6d). Subsequently, a time-depth function (figure 4.6e) was used to convert the time structure maps into depth structure maps (figures 4.6f to 4.6i). The petrophysical assessment yielded results for four main properties: gross pay, net pay, porosity, and water saturation, as shown in Table 4.1. Averages for each reservoir interval were then calculated based on the results along the wells (Table 4.1).

Table 4.1: The petrophysical properties of the reservoir intervals.

Well	Reservoir ID	Gross (m)	Net (m)	Porosity	Water Saturation	Av. Gross (m)	Av. Net (m)	Av. Porosity	Av. Water Saturation
B10	A	119.3	95.2	0.16	0.23	90.6	69.8	0.17	0.52
B2	A	90.5	64.9	0.17	0.47				
B3 ST1	A	81.9	62.8	0.17	0.70				
B4	A	70.7	56.4	0.18	0.68				
B10	B	56.2	40.5	0.29	0.20	49.4	35.1	0.21	0.44
B2	B	56.2	40.5	0.16	0.13				
B3 ST1	B	30.5	20.9	0.20	0.70				
B4	B	54.6	38.4	0.21	0.71				
B10	C	20.8	10.8	0.20	0.52	26.5	11.0	0.20	0.46
B2	C	30.5	9.3	0.19	0.12				
B3 ST1	C	27.3	14.5	0.21	0.60				
B4	C	27.3	9.5	0.22	0.60				
B10	D	20.8	16.6	0.21	0.55	24.1	14.4	0.22	0.50
B2	D	22.5	14.6	0.22	0.23				
B3 ST1	D	30.5	19.2	0.22	0.62				
B4	D	22.5	7.3	0.22	0.60				

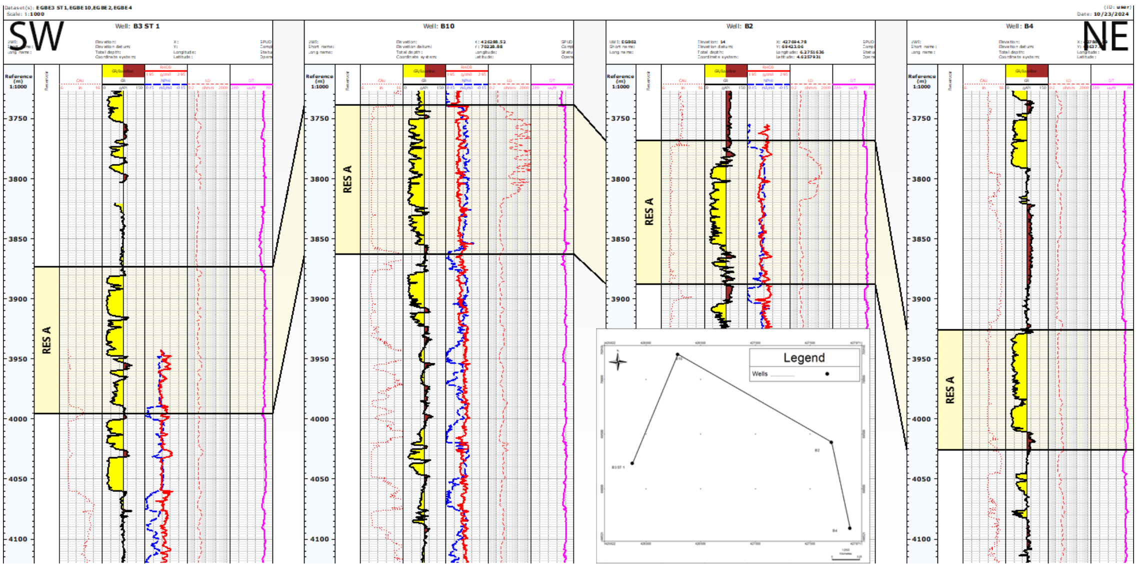

Figure 4.5a: Well section showing the gamma ray log, porosity logs and resistivity log and a reservoir interval A through wells B3 ST1, B10, B2 and B4.

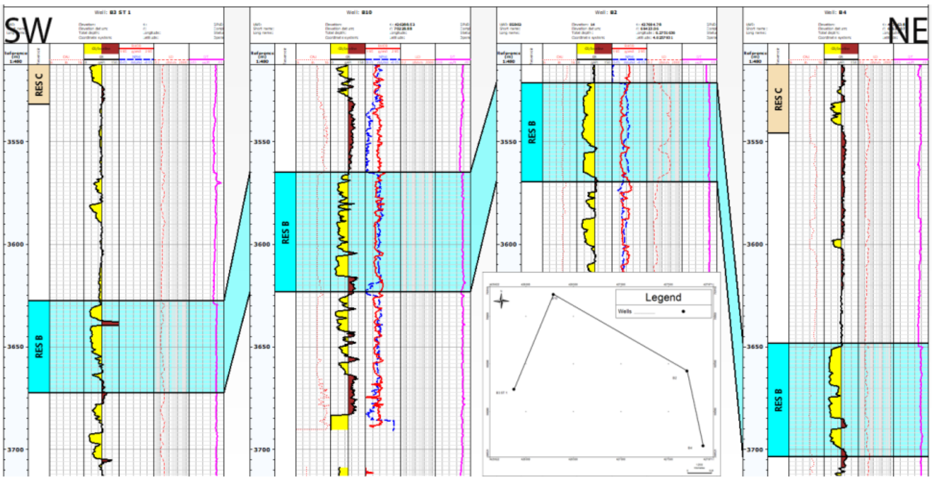

Figure 4.5b: Well section showing the gamma ray log, porosity logs and resistivity log and a reservoir interval B through wells B3 ST1, B10, B2 and B4.

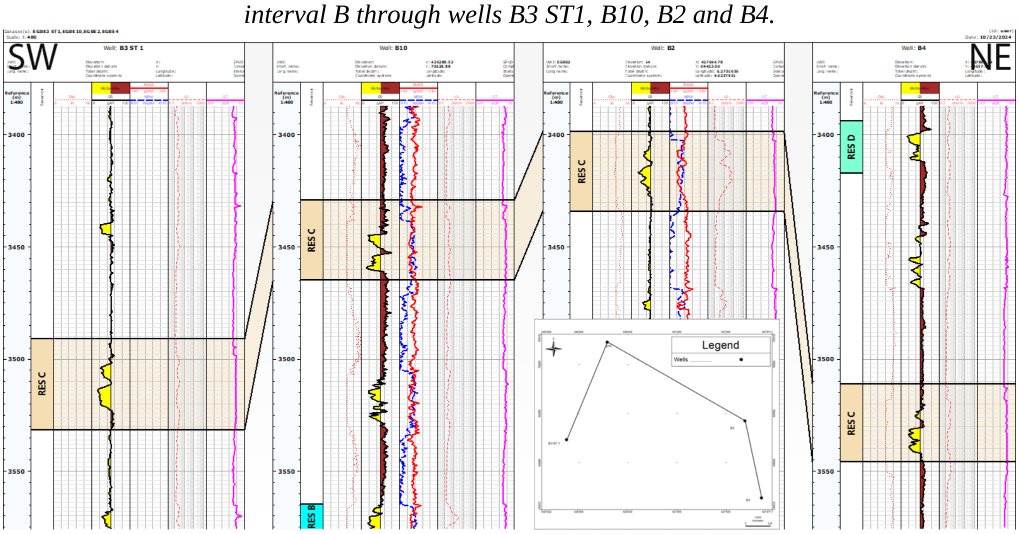

Figure 4.5c: Well section showing the gamma ray log, porosity logs and resistivity log and a reservoir interval C through wells B3 ST1, B10, B2 and B4.

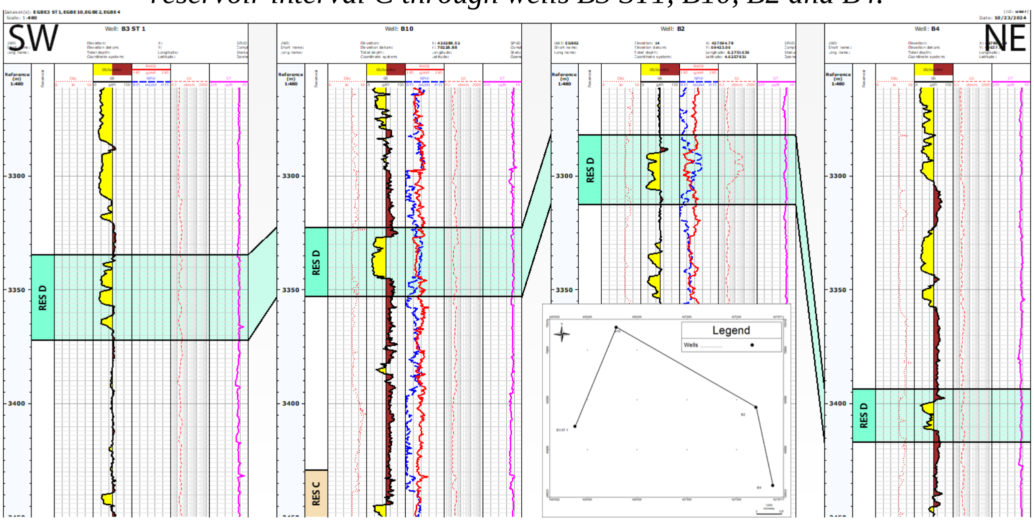

Figure 4.5d: Well section showing the gamma ray log, porosity logs and resistivity log and a reservoir interval D through wells B3 ST1, B10, B2 and B4.

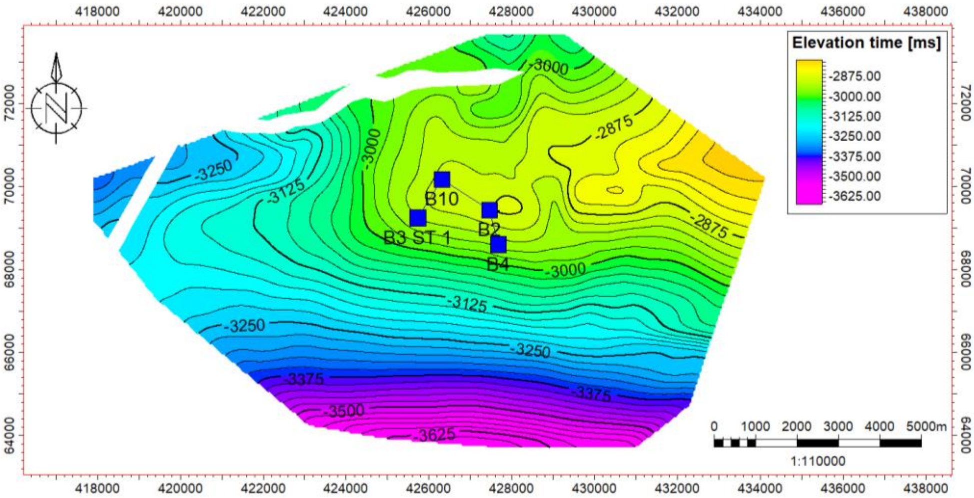

Figure 4.6a: Time structure map for reservoir A

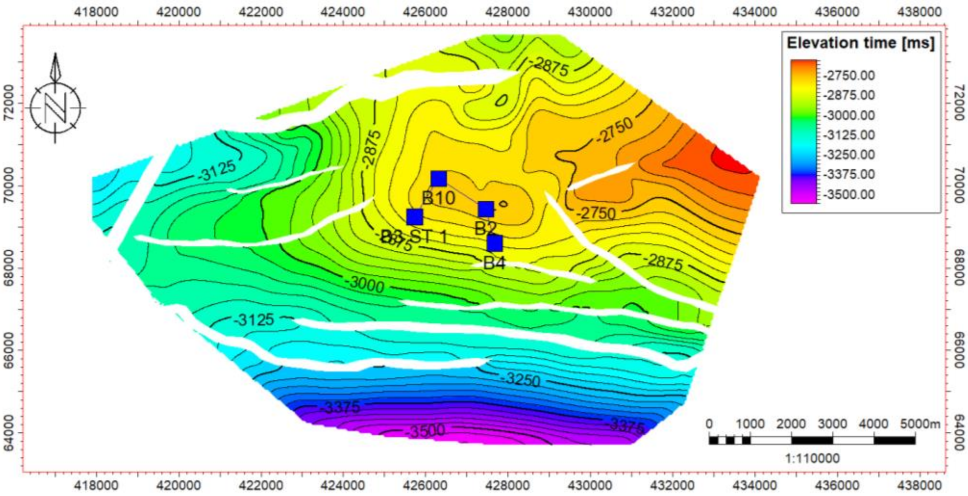

Figure 4.6b: Time structure map for reservoir B

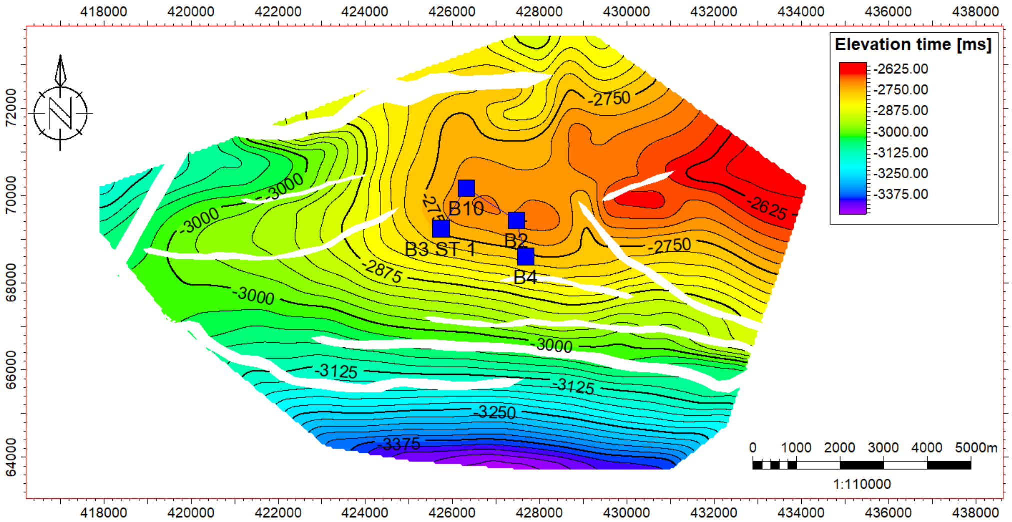

Figure 4.6c: Time structure map for reservoir C

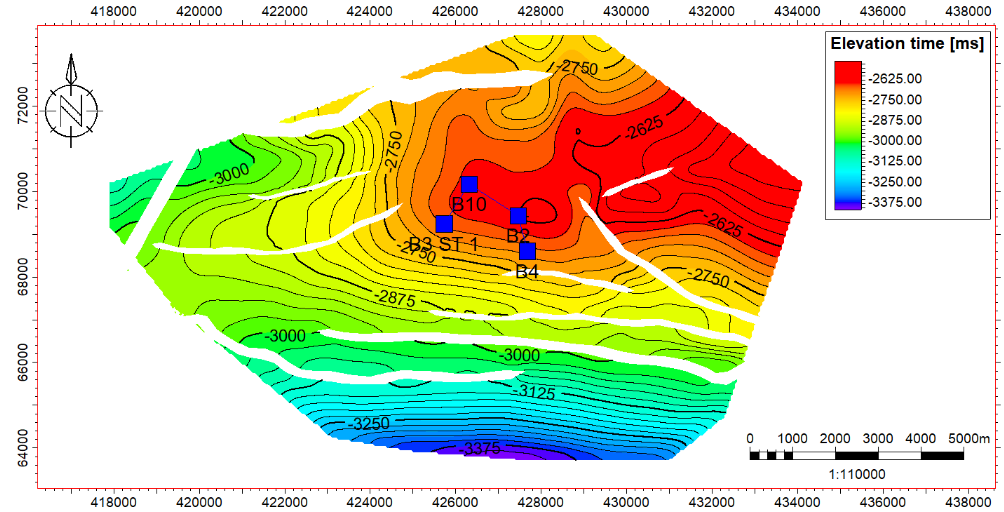

Figure 4.6d: Time structure map for reservoir D

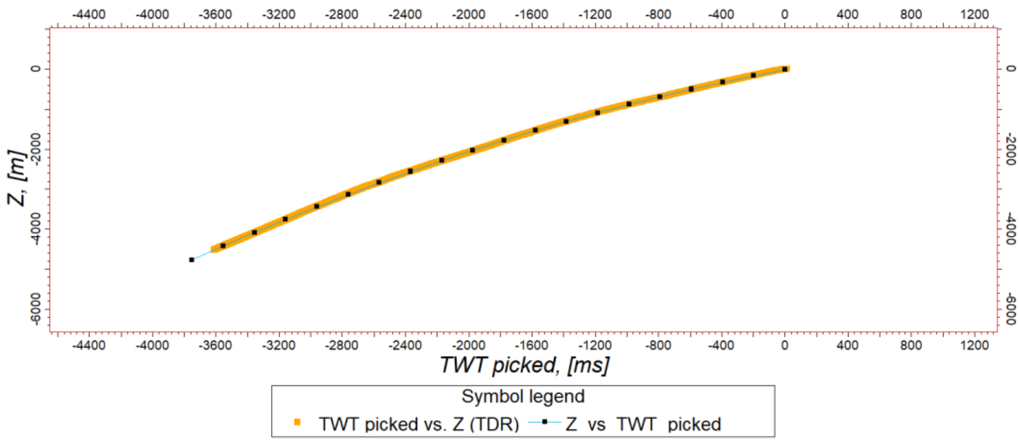

Figure 4.6e: Time-Depth function for well B2

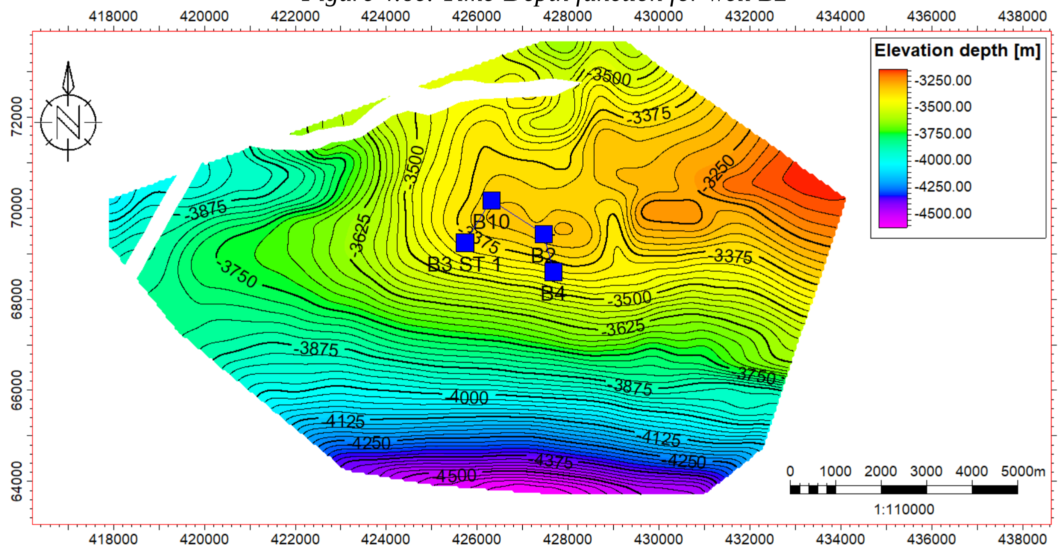

Figure 4.6f: Depth structure map for reservoir A

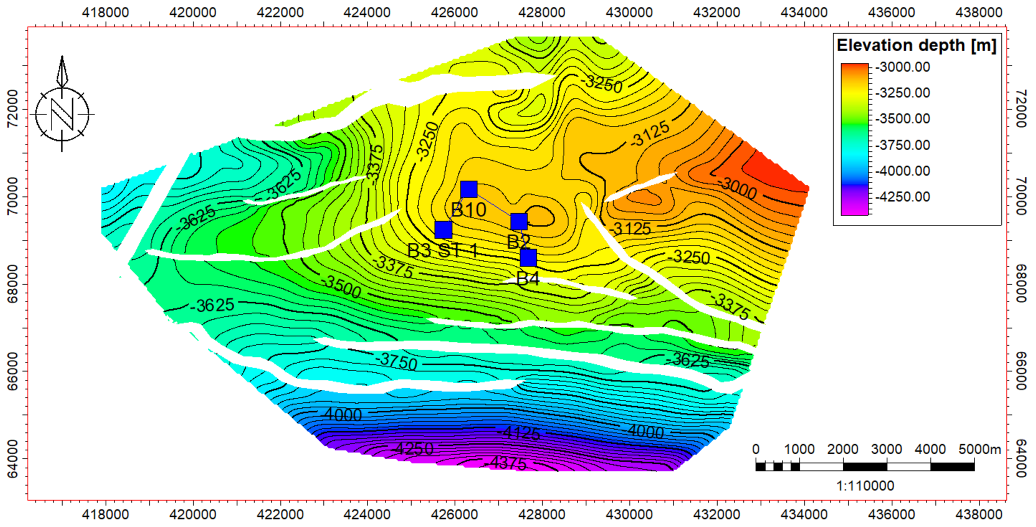

Figure 4.6g: Depth structure map for reservoir B

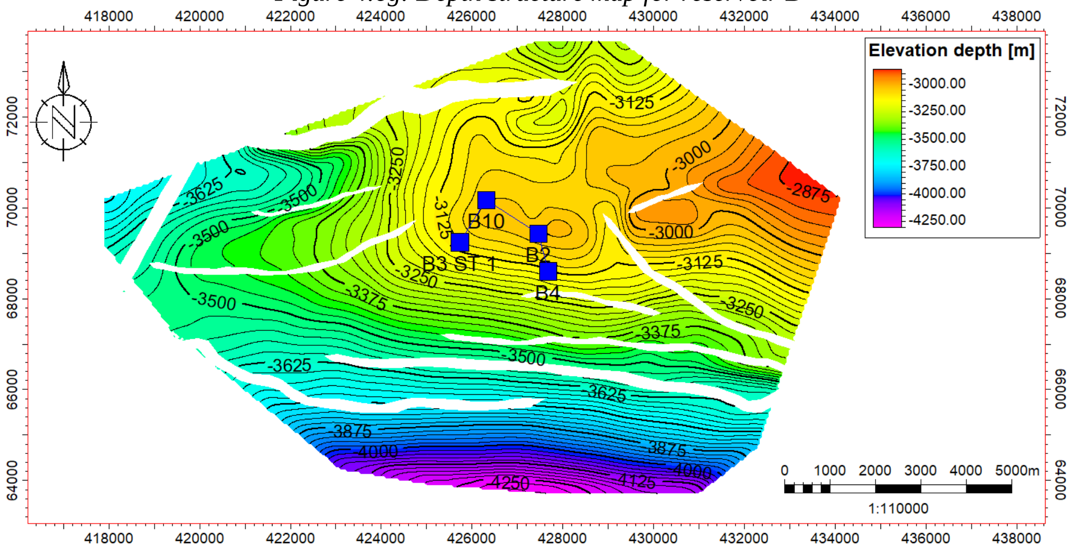

Figure 4.6h: Depth structure map for reservoir C

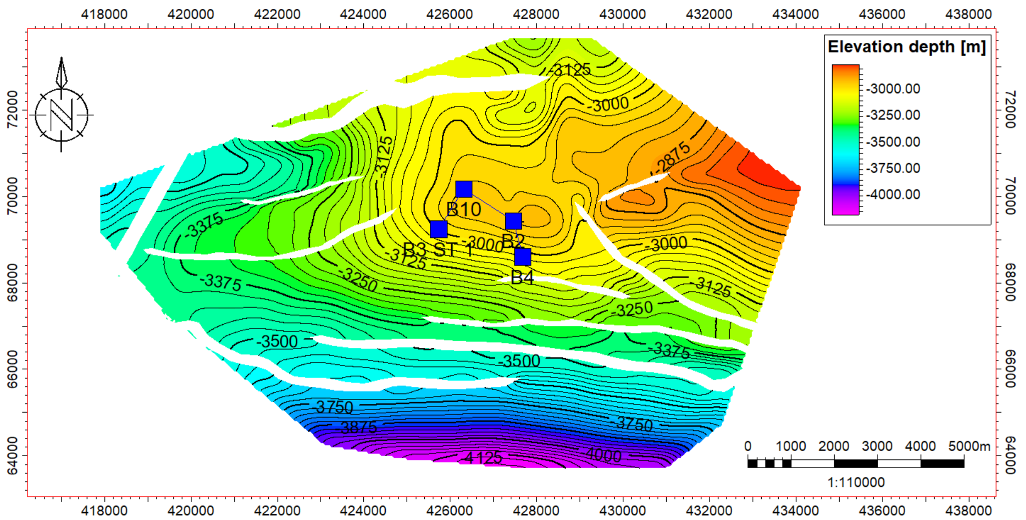

Figure 4.6i: Depth structure map for reservoir D

Conclusion

This study integrated well log analysis, seismic interpretation, and petrophysical assessments to characterize four reservoir intervals (A-D) in the study area. The reservoir units were correlated across four wells (B3 ST1, B10, B2, and B4) aligned in a southwest-northeast direction. Evaluation of well log signatures revealed a decrease in reservoir quality from the southwest (B10) towards the northeast (B3 ST1 and B4), as evident from the diminishing strength of electrical resistivity responses. This observation was supported by seismic mapping, which indicated a southward dip in the structural elevation of the reservoir beds. The wells B10 and B2 represented the updip/structurally higher position, while B3 ST1 penetrated the downdip/structurally lower portion of the reservoirs. Notably, the reservoirs do not appear to be filled to the structural spill point, suggesting that they have not reached their maximum potential. Additionally, log signatures in well B3 ST1 indicated the presence of a gas-water contact near the base of the reservoir interval, further highlighting the complex nature of these reservoirs. The study's findings suggest that the trapping mechanism may involve both structural and stratigraphic components due to lithological changes, rather than being purely structural. This integrated approach has provided valuable insights into the reservoir characteristics and distribution, which can inform future exploration and development strategies in the study area.

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