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Geological Factors Affecting Well Placement in Deepwater Turbidites, Niger Delta.

Ndokwu, C. N., Okengwu, K. O., Acra, E. J.

Department Geology, University of Port Harcourt
Email: ndokwuchidi@yahoo.co.uk

ABSTRACT

Deep-water oil and gas development in the Niger Delta is complicated by complex slope-basin depositional systems, notably turbidite channels, lobes, sheets, slumps, and slides. These generate heterogeneous interbedded sand–shale sequences that hinder reservoir characterization and well placement. This study synthesizes geosteering results from multiple deep-water wells, integrating seismic interpretation with resistivity data to guide drilling through highly variable depositional architectures. Geological heterogeneities—faults, bed thickness changes, and vertical/lateral facies shifts—were found to significantly disrupt bed continuity. Turbidite reservoirs show pronounced variability from successive sedimentation, erosion, and tectonics, challenging geosteering precision. Integrated datasets improved well trajectory control, reservoir contact, and drilling safety. Results highlight the critical role of depositional morphology in deep-water Niger Delta geosteering and demonstrate that real-time, multi-source interpretation is essential for optimizing well placement and hydrocarbon recovery in structurally and stratigraphically complex turbidite systems.

Introduction

Turbidites, formed by gravity-driven turbidity currents (Fig 1), are among the most prolific hydrocarbon-bearing deposits in deep-marine basins such as the Niger Delta, Gulf of Mexico, and Lower Congo (Spina et al., 2024). These deposits typically comprise a complex arrangement of channel, lobe, and sheet elements, resulting in heterogeneous facies distributions, lateral discontinuities, and variable net-to-gross ratios that complicate reservoir characterization and well placement (Olagundoye et al., 2024). In the deep-water Niger Delta, additional challenges arise from structural segmentation caused by faulting, slumping, and gravitational tectonics, as well as active hydrodynamic regimes that contribute to compartmentalization of stacked turbidite units (Spina et al., 2024). Limited seismic resolution—particularly in deep or low-frequency datasets—further constrains the ability to map fine-scale depositional elements, increasing uncertainty in seismic-to-well ties and NTG predictions unless calibrated with borehole data (Lim & Lee, 2024; Olagundoye et al., 2024). Ndokwu (2020, 2021, 2023) underscores the importance of real-time decision-making and borehole-scale imaging. His case studies demonstrate that successful geosteering in deep-water turbidite settings requires integrated information from image logs, resistivity inversion tools, and structural interpretation to identify sub-seismic faults, conductive boundaries, and heterogeneity during drilling.

Furthermore, anisotropy and lateral heterogeneity reduce the reliability of conventional logging and inversion techniques, necessitating the adoption of integrated geosteering workflows. Recent advances include combining high-resolution resistivity measurements, probabilistic interpretation, and real-time optimization algorithms to adjust well trajectories dynamically while quantifying uncertainty (Pavlov et al., 2024; Rammay et al., 2022).

In light of these practical insights, this study examines critical geological and geophysical considerations for optimizing well placement in structurally and stratigraphically complex deep-water turbidite systems. Emphasizing multi-scale data integration—spanning seismic, petrophysical, and structural domains—we highlight methodological advances that enhance reservoir contact and reduce drilling risk in deep-water contexts.

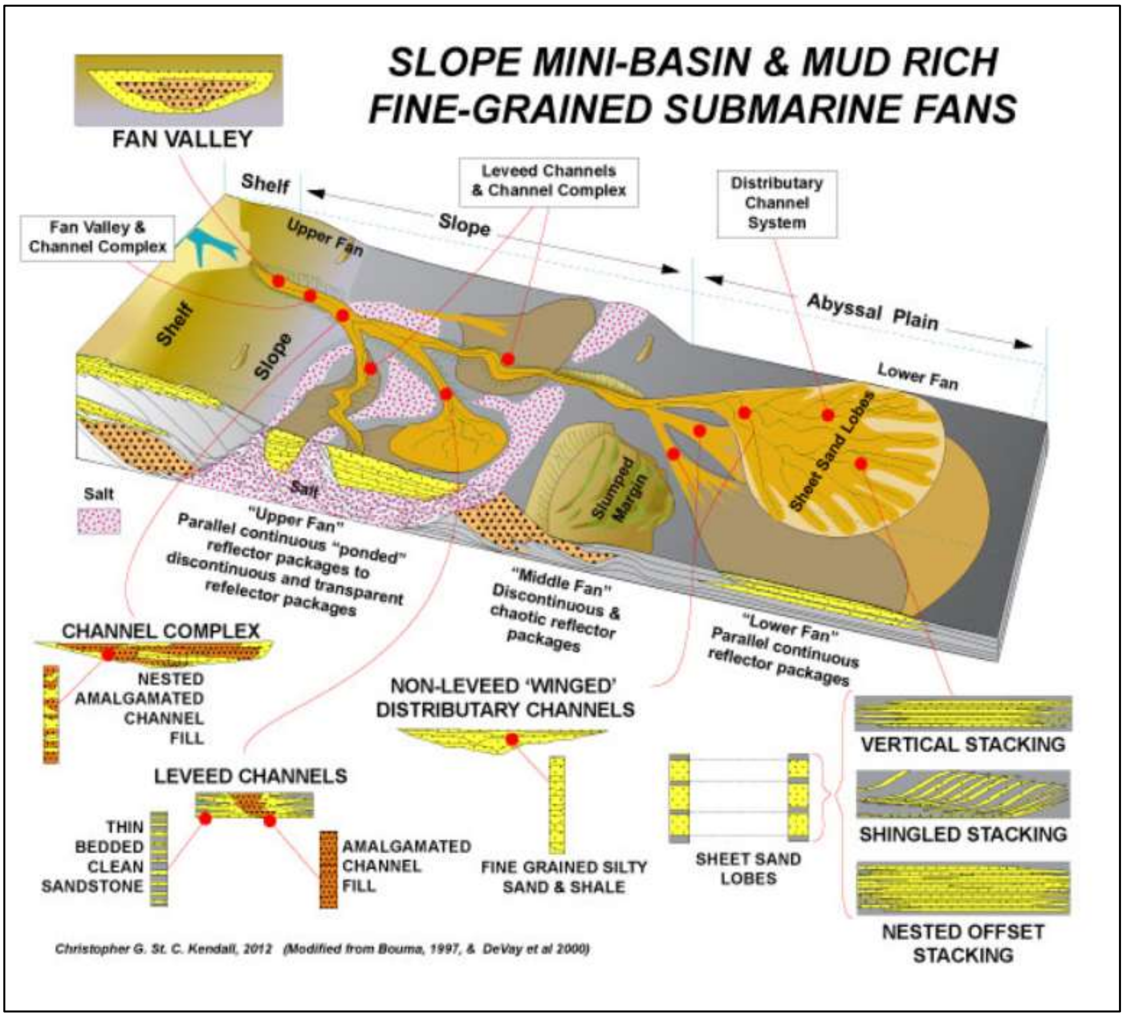

Fig. 1: Turbidite geomorphology, architectural elements, and facies associations (After Kendall, 2012)

Geological Setting of the Study Area

The study area is situated in eastern offshore Niger Delta, in water depths exceeding 1300 metres. The Niger Delta basin is situated at the southern end of Nigeria bordering the Atlantic Ocean and extends from about 4° to 6° N latitude and 3° to 9° E longitude, terminating in the Gulf of Guinea. Structurally, the study area is in the compressional tectonic zone of the delta, specifically within the translational zone. The reservoir comprises Middle to Late Miocene turbidite channels and lobes, often channelized and deposited in a structurally complex setting with dense fault networks. Within this broad framework, the study area (**Fig. 2**) comprises the deeper marine waters – beyond the continental shelf break – where commercial oil and gas production occurs.

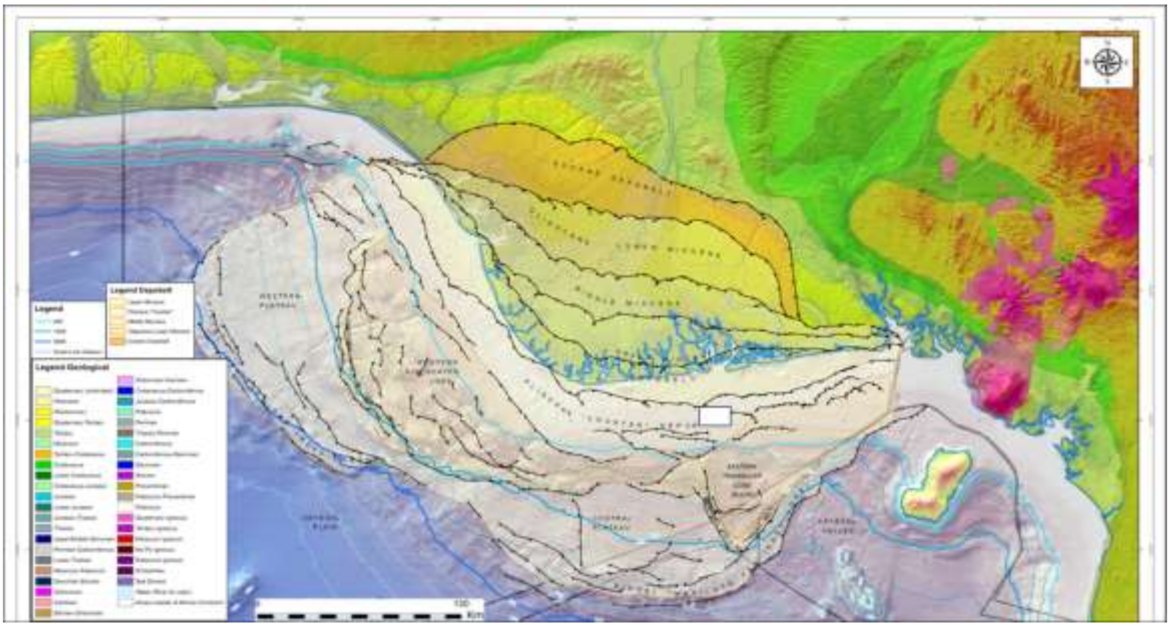

Fig. 2: Location map of the study area

Tools and Techniques for Well Placement

Effective well placement in turbidites requires a combination of:

- **Seismic data and structural maps**
    - This is an integral component needed for pre-drill planning. It involves an integrated approach to seismic reservoir characterization (conventional, lithoseismic, and 4D/time-lapse), dynamic reservoir model simulations, and the incorporation of results from azimuthal resistivity modelling (SPE-211962-MS). Seismic data, although limited in resolution, can be used to map architectural elements such as channels and lobes. Bright seismic events often indicate sand-rich turbidite deposits. Pre-well modeling should incorporate:

        a) Seismic amplitude analysis

        b) Architectural element mapping

        c) Integration of offset well data

        d) Anticipation of structural and stratigraphic traps

- **Logging While Drilling (LWD)**
    - This includes the use of tools that give real-time measurements of natural gamma ray, resistivity, and borehole images. Resistivity tools are particularly sensitive to formation anisotropy, thin beds, and boundary effects, which must be accounted for in interpretation. This integration of borehole imaging data provides more insight into stratigraphic, structural and petrophysical interpretations in different geological scenarios (SPE-207197-MS).

- **Real-time geosteering software**

- o This is needed to both pre-well modelling and real-time handling and interpretation of LWD data, for scenario modelling, for trajectory adjustments and for 3D visualization of results. It also includes the capability to perform inversion on deep-reading azimuthal propagation resistivity data. This real-time inversion of any combination of the deep and extra-deep LWD resistivity measurements, both coaxial and azimuthal, generates a resistivity map (**Fig. 3**) of the well path that respects the depth of detection of the azimuthal propagation technology used and the processing features of the software. Other answers that can be gotten from such processing includes calculated resistivity of the layers detected, distance between the wellbore and the layers, true stratigraphic thickness of each layer, and the relative dip between wellbore trajectory and bed boundaries (IADC/SPE-190993-MS).

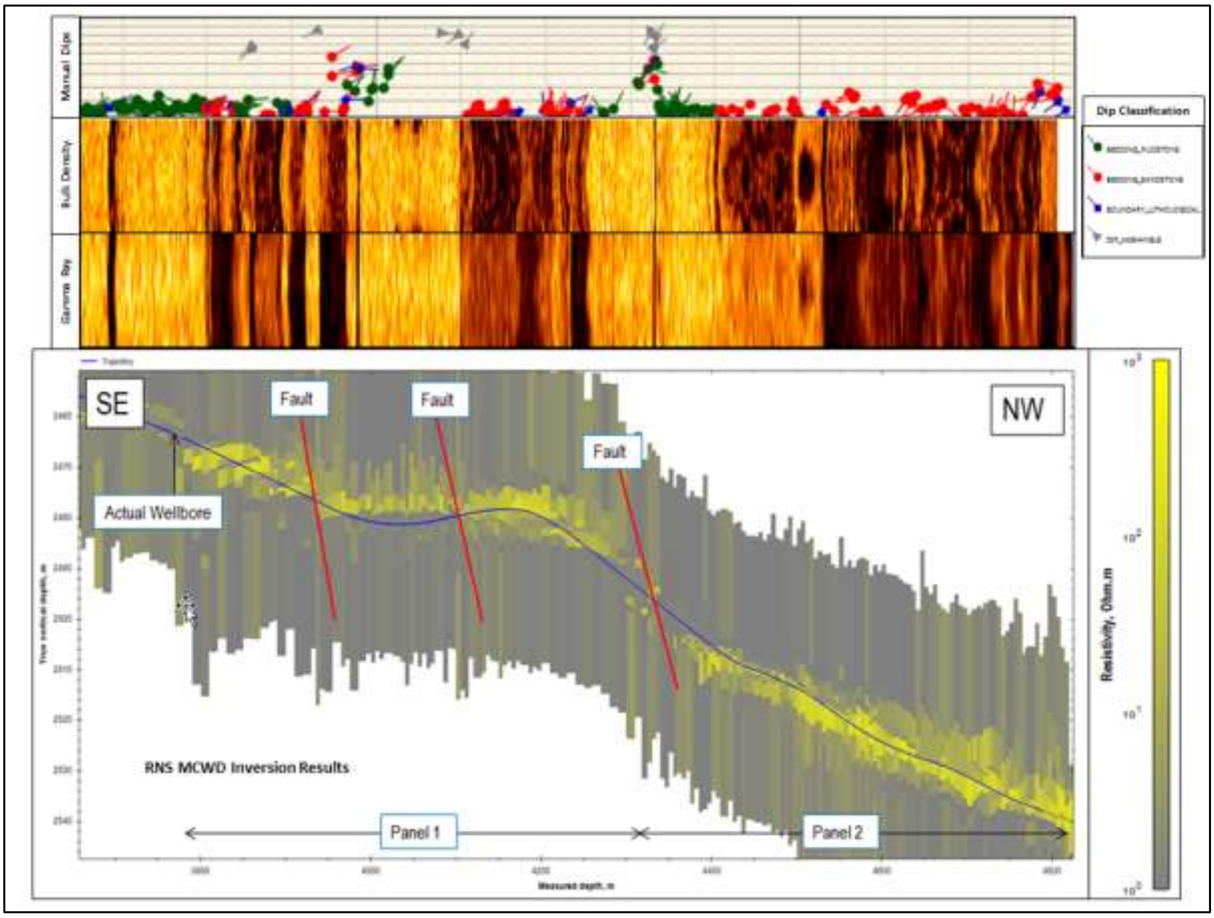

Fig. 3: Resistivity map juxtaposed with borehole image of a reservoir with multiple faults

Geological Factors for Consideration

A lot of authors have written about sedimentary structures and characterisation of turbidites (**Fig.4**). The benefit of turbidite reservoir characterisation is because it helps to elucidate features about heterogeneity, which affects both seismic interpretation and real-time geosteering. Turbidite systems in the Niger Delta exhibit:

- Vertical and lateral discontinuities of sand bodies
- Variations in sand thickness
- Multiple stacked beds and lateral facies variation
- Structural compartmentalization due to faulting

Bedding	Structures	Texture	Grain-size Breaks	Fabric	Composition
Well-defined bedding	Primary sedimentary structures indicative of deposition by unidirectional currents	Grain size ranges from gravel to sand to silt/clay sizes for coarse, medium and fine-grained turbidites, with isolated clasts more than 1m length	Abrupt changes in grain size across an intra-bed surface	Well-developed long-axis grain or clast alignment parallel to the flow direction	Allochthonous elements
Distinct beds with sharp bases and sharp to gradational tops	Parallel and cross-lamination/bedding, lenticular and discontinuous lamination (in thin and very thin beds)	Variable sorting, but better in fine- and medium-grained turbidites (moderate to well-sorted)		Grain and clast imbrication shows up-flow inclination	Siliciclastic, bioclastic, volcaniclastic or a mixed composition
Interbedding of well-defined sandstone and mudstone beds. Beds vary in thickness, from <1cm to >10m	Spaced to indistinct lamination (in thick and very thick beds)	Normal grading (completed ungraded bed may occur). In coarse-grained turbidites, there may be basal zone of reverse-grading overlain by a normally graded or ungraded bed		Presence of strong flow-parallel and bed parallel clay and silt alignment	
	Water-escape structures (pipes, dishes, convolute lamination)				
	Base of beds show loads, flame structures and scours (flutes and grooves)				
	Organized systematically into sequences through normally-graded beds				

Fig. 4: Turbidite Characteristics (Modified from 'Distinguishing between Deep-Water Sediment Facies: Turbidites, Contourites and Hemipelagites', by Dorrik Stow and Zeinab Smillie)

And if those heterogeneities are ignored, it can lead to misinterpretation of formation boundaries and incorrect depth of detection, impacting wellbore trajectory decisions. Since resistivity data is mostly used as the main geosteering data, understanding these effects is critical for accurate formation evaluation and geosteering. The impact on resistivity data includes thin bed effects (where adjacent beds influence the tool response, **Fig. 5**), anisotropic effect (that could lead to over- or underestimation of resistivity), polarization horn effect (artifacts from propagation resistivity tools). Heterogeneities in turbidite systems manifest as:

- Lateral discontinuities and facies changes
- Thin beds that influence resistivity readings
- Anisotropic effects due to bedding dip, multiple beds and tool orientation
- Seismic amplitude variations that may not correlate directly with lithology

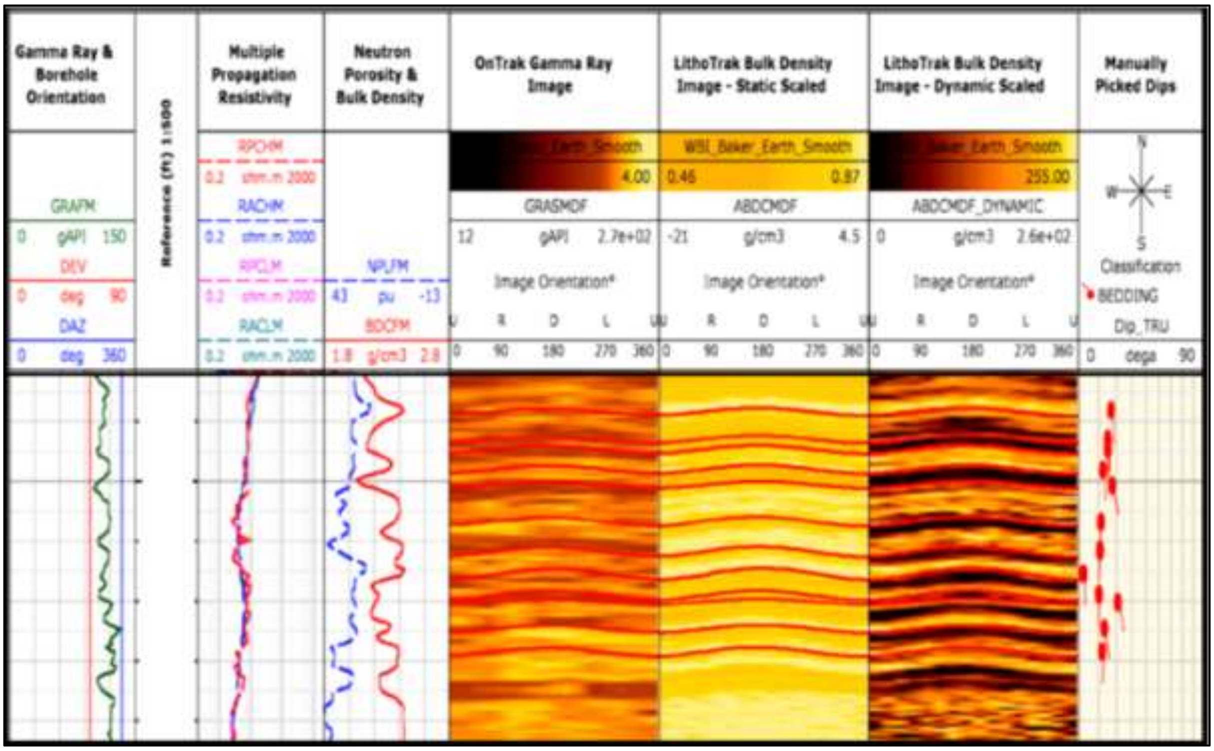

Fig. 5: Thin beds identification using multiple propagation resistivity and borehole images. Oifoghe S., 2014. OTC-24882-MS

Conclusions

Turbidite reservoirs in the deepwater Niger Delta are highly heterogeneous, posing significant challenges for well placement. By addressing geological uncertainties and leveraging real-time data, operators can significantly enhance reservoir contact and production outcomes in complex turbidite systems. Effective geosteering requires:

- Integration of seismic, petrophysical, and real-time data
- Robust pre-well modeling and scenario planning
- Reduce assumptions in modeling (e.g., homogeneity, isotropy) and recognize that sand bodies may not be laterally continuous
- The use of advanced resistivity and imaging tools, multiple resistivity curves and high angle offset data
- Incorporate real-time borehole imaging to assess structural dip
- Continuously update models with real-time data

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