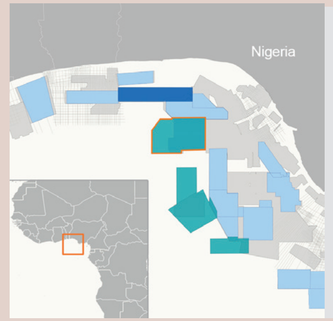
Deepwater Niger Delta:

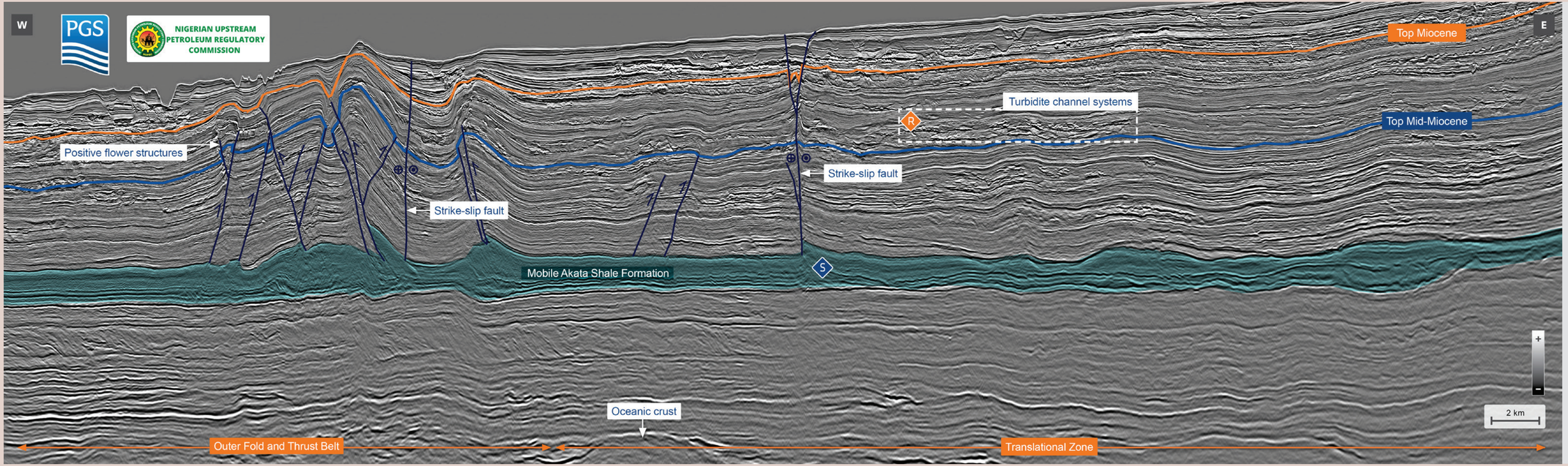
Revealing the structural influence on reservoir channel deposition to highlight remaining prospectivity

The Niger Delta Basin is a classic example of a passive margin delta that has experienced extensive gravity-driven deformation facilitated by detachment on an under-compacted, over-pressured shale sequence. The offshore area can be divided into the Western and Eastern Deltaic Lobes which are separated by a remnant basement high related to the underlying Cretaceous-aged Charcot Fracture Zone. The Western Lobe has produced significant volumes of hydrocarbons throughout its prolific exploration history with large discoveries found in the offshore Bosi-1 Field and larger Bonga cluster.

Exploration in the basin has historically focused on the inboard, shallow water extensional province where hydrocarbons are found trapped against major growth faults and in associated rollovers. This leaves the deeper water area comprising the Outer Fold and Thrust Belt relatively untested. Understanding the complex interplay between the occurrence of fold-thrusts derived from the detachment of the Akata Shale Formation and turbidite channel deposition is key to unlocking prospectivity in this area. Using newly reprocessed PGS MegaSurveyPlus 3D seismic data, this closely interlinked relationship between structural development and reservoir distribution can be uncovered, highlighting the significant remaining potential in the area.



PGS MultiClient data library, offshore Nigeria. Location of the MegaSurveyPlus 3D data is shown in teal, with the area of interest highlighted in orange.



This West-East full-stack PSTM (prestack time migrated) seismic line is taken from the northern area of the Nigeria MegaSurveyPlus and shows the transition from the proximal Translational Zone in the east to the distal Outer Fold and Thrust Belt in the west. Post-Akata Miocene aged turbidite channel systems provide the main reservoir in the Akata-Agbada petroleum system, and these are visible as high amplitude chaotic seismic facies. A variety of structural and combination structural/stratigraphic trapping configurations are illustrated.

Nigeria MegaSurveyPlus:
Reprocessing delivers excellent resolution of complex structure, de-risking prospectivity in underexplored areas

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THE NIGER Delta Basin contains up to 12 km of Upper Cretaceous to Quaternary clastics deposited in an overall upward-coarsening regressive deltaic sequence. The Tertiary section is composed of three main diachronous units. At the base is the Akata Formation, comprising pro-delta shales deposited in a deep marine, anoxic environment. As the Niger Delta is one of the largest deltas in the world, extensive progradation has resulted in Akata Formation deposition directly over oceanic crust in distal areas. Overlying this are the paralic siliciclastics of the Agbada Formation, representing the main deltaic sequence. Finally, the Benin Formation completes the section and is dominated by continentally sourced sands.

The Niger Delta Basin is renowned for the highly prospective Akata-Agbada Petroleum system. The main source rocks are thought to be the Akata Formation marine shales and the Lower Agbada Formation paralic shales. Proven reservoirs in the basin are found in sandstones of the Agbada Formation deposited as stacked turbidite channel and fan complexes. Interbedded transgressional marine shales provide excellent seals. The largest hydrocarbon accumulations are trapped in roll-over anticlines in the hanging-walls of growth faults, but hydrocarbons may also be found in fault closures and subtle stratigraphic traps.

The area of focus for this article is a 4700 sq. km area in the northwestern Nigerian offshore. The area of interest (AOI) is located across two main structural provinces directly linked to the gravity-driven detachment of the Akata Shale Formation. The eastern part is in the Transitional Zone and contains subtle faulting along with long wavelength detachment folds of Eocene to Quaternary stratigraphy. The west of the area, situated in the Outer Fold and Thrust Belt, is structurally controlled by closely spaced fold-thrusts and oblique transpressional strike-slip faults.

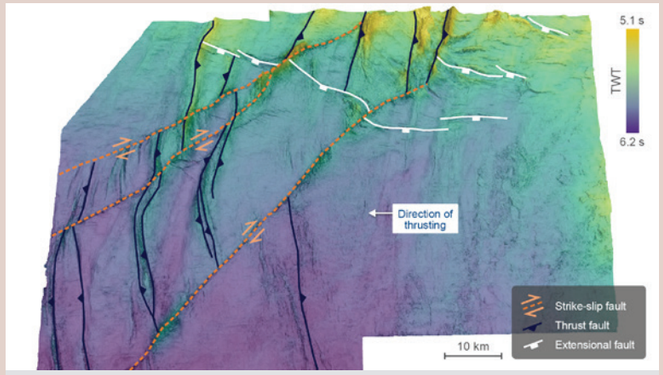

Figure 1: Top Akata TWT surface with a minimum similarity attribute overlain highlighting the main structures within the AOI. Reprocessing results in a better image of the structural complexity in the Outer Fold and Thrust Belt, uncovering the three main structural trends in this area of the deepwater Niger Delta.

MEGASURVEYPLUS: DATA LIBRARY REJUVENATION

MegaSurveyPlus 3D seismic data is used here to show unparalleled imaging of the complex interplay between shale tectonics and the deposition of turbidite channel systems. The MegaSurveyPlus concept aims to revitalize the PGS MultiClient data library in Nigeria by applying a modern broadband reprocessing sequence to vintage 3D data. Contemporary techniques including optimized denoising algorithms and a full deghosting sequence have improved data bandwidth and signal-to-noise ratio. Application of a multiple attenuation process also leads to enhanced image integrity by eliminating complex multiples.

The extensive MegaSurveyPlus 3D data delivers an expanded and consistent regional geological perspective. The resulting full-stack PSTM data can be used for regional interpretation, providing a greater understanding of plays and migration pathways across open acreage. Improved imaging of the reflectivity within and around the Akata Shale Formation gives a clearer image of the deformation of surrounding stratigraphy. Pre-stack PSTM products also allow for AVO analysis to be undertaken, helping to derisk exploration.

COMPLEX STRUCTURE UNVEILED BY REPROCESSING

The AOI is dominated by three main structural trends which are most easily observed by overlaying a minimum similarity attribute on the top Akata Shale TWT surface (Figure 1). The Akata Shale imbricate toe-thrusts and anticlinal folds are trending in a north-south direction, correlating with thrusting propagating from the east, towards the west. This compression is created by the progradational sediment loading of the Niger Delta and the detachment-driven, down-slope gravitational movement of the shale.

Cross-cutting this, in a northeast to southwest orientation, are a series of dextral strike-slip faults which transect the northwestern deepwater area of the dataset. These faults could be linked to underlying crustal fracture zones and occur at an oblique angle to the dip of slope and as shown in the seismic foldout line. The faults are observed to be long-lived, propagating from the top of the Akata Shale through to the present-day seabed. The strike-slip faults appear to accommodate and compartmentalize the compressional strain of the Akata Shale thrusting, demonstrated by the occasional termination of shale thrusts at these lineaments. The lateral movement on the faults is however relatively minor, indicated by the minimal offset of the Akata Shale thrusts. Unsurprisingly in an area undergoing transpression, positive flower structures are observed to occur in between the strike-slip faults.

Finally, a series of en-echelon extensional faults can be observed in the northern portion of the AOI, which form small pull-apart basins off-stepping in an east-west direction. These tear faults occur at the northeastern termination of the strike-slip lineaments and are interpreted to accommodate extensional stress.

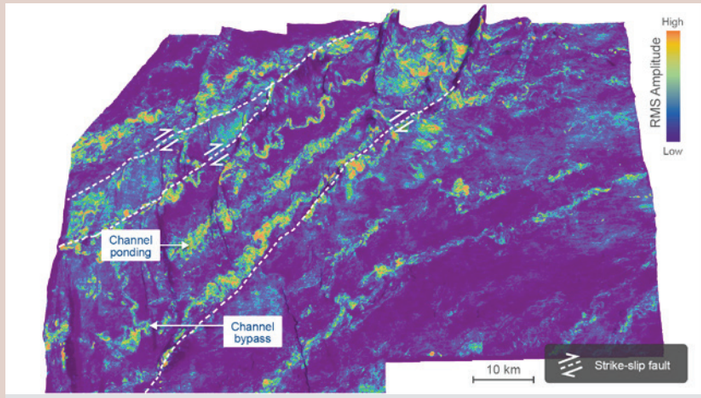

Figure 2: RMS amplitude extraction generated 100 ms above and below the Top Mid-Miocene TWT surface. This indicates the main reservoir sands were deposited as turbidite channel systems and highlights their interaction with strike-slip faults and Akata Shale thrusts.

STRUCTURAL CONTROLS ON CHANNEL DEPOSITION

From around the Mid-Miocene, we can observe thickening of stratigraphy between the shale thrusts, indicating the syn-kinematic deposition of sediments at this level. Turbidite channel complexes progress downslope in a northeast to southwest orientation, transferring sediment to the base of slope beyond the Outer Fold and Thrust Belt. These channels flow into topographic lows, following the path of least resistance.

In Figure 2, an RMS Amplitude extraction at a 100 ms window around the Top Mid-Miocene horizon demonstrates how the channels have interacted with the complex structure in the Outer Fold and Thrust Belt. Where active Akata Shale thrusting and folding has created significant topography during Agbada Formation deposition, the channels are seen to pond behind the thrusts, unable to overcome the topographic highs as thrusting out-paced the rate of channel sedimentation. In some locations where the rate of structural deformation is slower, channels are observed to incise the hanging wall anticlines and continue downslope without having to re-route.

In the areas adjacent to the strike-slip faulting, channels are seen to have bypassed the thrusts and folds by exploiting these zones. In these cases, we observe the continued vertical stacking of channel complexes through the section indicating these areas were key incision points for turbidites.

DERISKING THE UNDEREXPLORED DEEPWATER

Miocene aged Agbada Formation channel systems are demonstrated to have been consistently deposited along or adjacent to strike-slip faults in the AOI. These prolonged corridors of channel deposition could result in favorable sand body connectivity within key reservoir facies. Potential reservoirs may also benefit from being advantageously located near hydrocarbon migration pathways, with strike-slip faults providing routes for fluids to charge from deeper Akata-Agbada Formation source kitchens into shallower sands. The Nigeria MegaSurveyPlus reprocessing has provided better images to enable explorers to derisk the complex interplay between channel deposition and structure in the underexplored deepwater Niger Delta Basin.