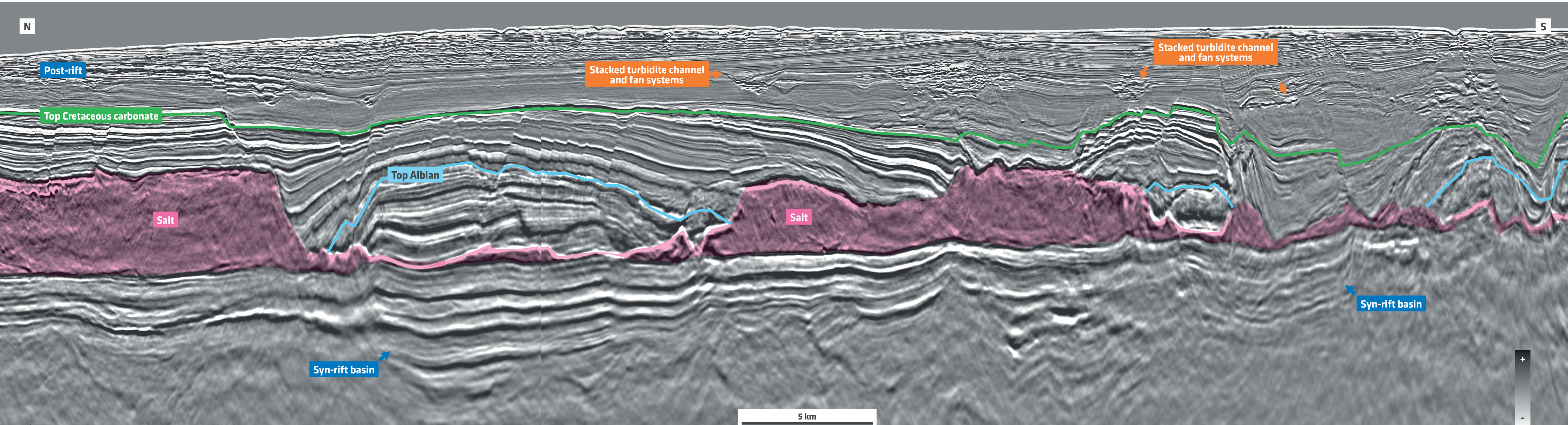
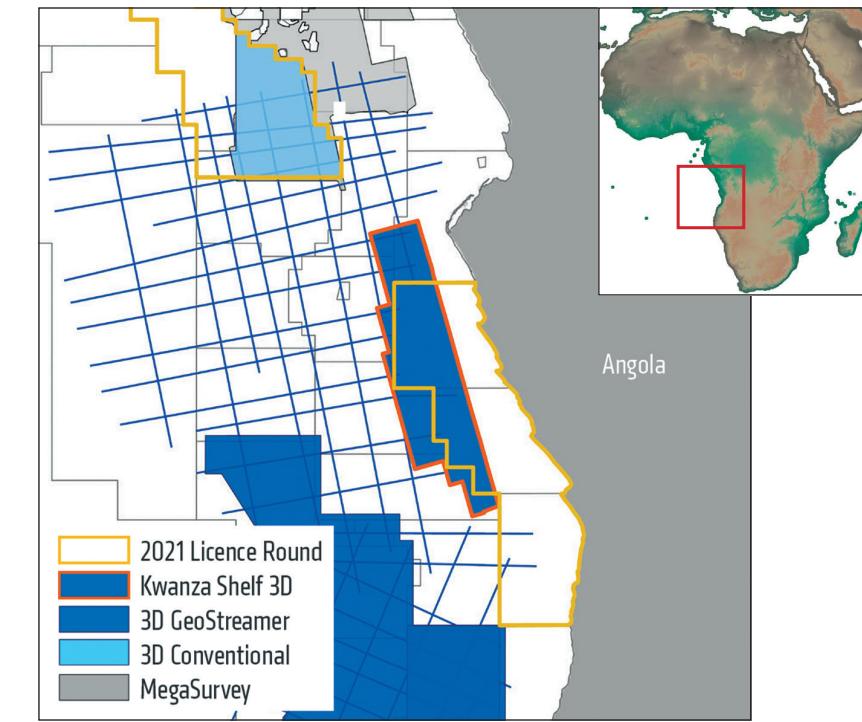


# Kwanza Shelf: New 3D Seismic Imaging Reveals Pre- and Post-Salt Plays

Figure 1: This full-stack PSDM strike line from the Kwanza Shelf survey demonstrates excellent pre- and post-salt resolution. Post-rift stacked turbidite channel and fan systems are well imaged with increased high frequency content revealing detailed depositional features. Complex structures related to halokinesis are unveiled with clear imaging of pre-salt rift basins and basement highs illustrating the prospective potential of the Kwanza Shelf.

The Kwanza Shelf is witnessing a resurgence in exploration interest with new insights indicating that the potential of this misunderstood hydrocarbon system has been previously underestimated. Historic exploration on the Kwanza Shelf has seen 23 exploration wells drilled, 18 of which were spudded prior to 1993. Only two exploration wells were drilled on 3D data, with the remainder based on 2D data of various 1980s vintages. Analyses of well results demonstrate that the key elements of a petroleum system are present, with successful reservoirs in both the pre- and post-salt. However, historical wells were unlikely to be optimally positioned due to a limited understanding of the 3D structure obtained from vintage 2D seismic data.

In partnership with Agência Nacional de Petróleo, Gás e Biocombustíveis (ANPG), PGS has acquired a new multisensor GeoStreamer survey over the Kwanza Shelf. This new data provides enhanced subsurface illumination through broadband acquisition and the use of modern processing workflows tailored to the unique imaging challenges of shallow water and salt presence. This new broadband 3D multiclient dataset will equip explorers with the tools to identify and unlock the pre- and post-salt plays in this underexplored area of the Angolan offshore.





# Unlocking Prospectivity on the Kwanza Shelf

New data shows that the evolution of the Kwanza Shelf demonstrates key elements of a prolific hydrocarbon system, ready for the 2021 licence round.

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The Kwanza Shelf area has been overlooked in recent exploration cycles with the industry focused on the offshore deepwater and ultra-deepwater basin trends. Operators looking to replicate the success of the Brazilian conjugate margin pre-salt play have made a number of successful hydrocarbon discoveries in the equivalent deepwater Kwanza margin. The most notable of these is the Orca field, drilled in 2014, which discovered 75m of net oil pay in sag-phase and syn-rift reservoirs. This field is estimated to be the largest pre-salt discovery made within the Kwanza Basin to date.

With a working petroleum system already proven in the deepwater pre-salt of the Kwanza Basin, and a licence round opening up the underexplored shelf in 2021, a new GeoStreamer 3D survey provides an unparalleled insight into the prospectivity of the basin, with significant untapped potential in the pre- and post-rift plays being unveiled.

## Promising Petroleum Systems

The Kwanza Basin is located offshore Angola and forms part of the larger West African Aptian salt basin. It was initiated during Late Jurassic to Early Cretaceous rifting of the proto-Atlantic and is the conjugate margin to the prolific hydrocarbon-bearing Santos and Campos Basins, offshore Brazil. In broad terms, the petroleum systems of Angola can be split into two main systems: pre- and syn-rift; and post-rift.

### Pre- and Syn-rift: Building a Foundation for Hydrocarbon Potential.

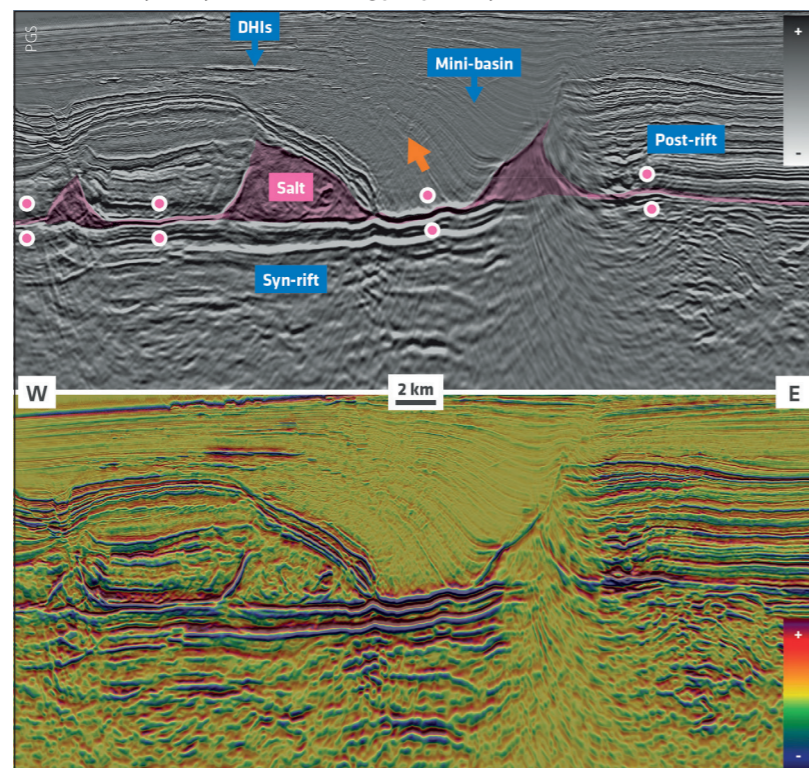
The pre-/syn-rift is characterised by an extensional phase which formed a series of horst and grabens perpendicular to the coastline where mixed fluvial, alluvial and lacustrine facies were deposited. This included deposition of the main syn-rift/pre-salt source rock: the Barremian-aged Bucomazi Formation.

This prolific source rock was deposited in sequences of fluviatile-lacustrine shales in deep lakes with anoxic bottom waters and charges both pre- and post-salt traps. The syn-rift ended with the widespread deposition of carbonates and the Loeme Formation salt, which forms the primary pre-/syn-rift seal (Brownfield and Charpentier, 2006).

Three main syn-rift/pre-salt reservoir rocks have been identified. These are the pre-rift Lucula Formation alluvial sandstones, the syn-rift Red Cuvo Formation alluvial sandstones and the Grey Cuvo Formation (Chela Formation equivalent) fluvial to lacustrine sandstones and limestones.

The Denden-1 well (1983) was one of the earliest wells to make an oil discovery within Grey Cuvo Formation pre-salt carbonates. The well drilled a tilted fault block

**Figure 2: Top: Full-stack KPSDM seismic dip line. Bottom: Full-stack impedance highlighting DHIs. This figure highlights post-rift DHIs sitting above a salt weld, indicated by the pink dots. Mini-basin touchdown has created a possible pathway for hydrocarbons to migrate, indicated by the orange arrow, from a syn-rift source into post-rift reservoirs. This connection may be key for understanding prospectivity across the Kwanza Shelf.**



high where lacustrine carbonates were trapped in a four-way dip-closed structure. Denden-1 found an excellent dolomitised coquina reservoir exhibiting porosities of up to 15%, proving the pre-salt carbonate play on the shelf. Pre-salt sandstone plays have also been targeted across the shelf. The Flamingo-1 well (1982) encountered oil shows in Cuvo Formation sandstones confirming the existence of a good quality pre-salt reservoir sandstone on the shelf.

### Post-rift Transformation Phase: Developing Petroleum System Elements.

The post-rift shifts from restricted evaporitic facies to open marine deposition resulting in four main reservoir units: Albian Pinda Formation shelf carbonates; Late Cretaceous Iabe Formation progradational shallow marine sandstones; Palaeocene/Eocene Landana Formation sandstones; and Oligocene/Miocene Quifangondo Formation sandstones.

In the post-salt Albian section, large carbonate rafts are well imaged and are likely sealed by regional shales. These provide numerous untested leads analogous to the producing fields of the Sendji carbonate play in the Lower Congo Basin.

Tertiary Landana and Quifangondo Formation sandstones provide promising reservoir targets in stacked turbidite and channel sandstones, trapped in structural and stratigraphic traps and sealed by overlying Tertiary shales.

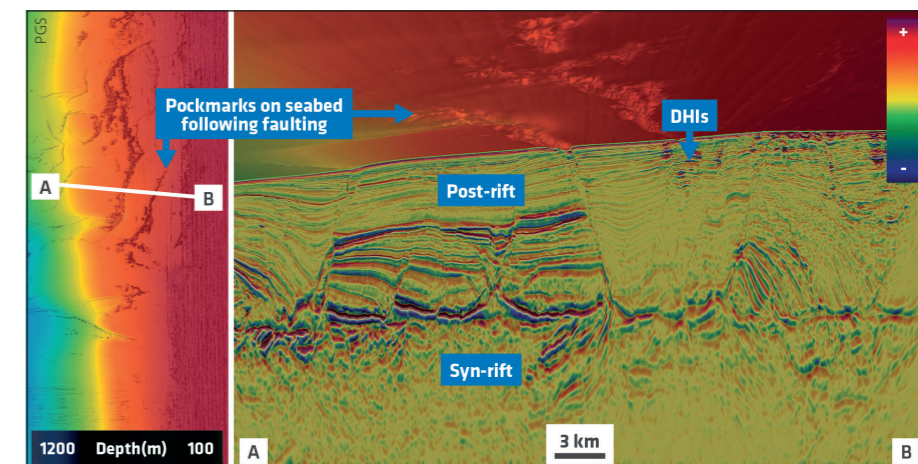
### Overcoming the Challenges of Historical Data

The absence of adequate seismic data on the shelf has posed significant challenges to exploration, with the imaging of complex salt and pre-salt basins being historically poor. Mapping of pre-salt grabens and their associated source and reservoir potential requires high quality 3D seismic data. This is key in understanding the distribution of petroleum systems and is vital for accurate modelling of hydrocarbon migration pathways. The 3D GeoStreamer data acquisition on the shelf reveals considerable uplift from vintage data, greatly improving the understanding of depositional systems and reducing the risks associated with charge, hydrocarbon migration and trap integrity.

Specialist PGS imaging technologies, including Separated Wavefield Imaging (SWIM), Full Wavefield Inversion (FWI) and Q-Velocity Model Building, have been applied to deliver enhanced resolution imaging of the subsurface. These techniques resolve detailed features in shallow water, which is not achievable with traditional reflection seismic imaging.

### Enhanced Imaging Reveals Prospectivity

Figure 1 (foldout on previous page) shows a full-stack seismic section from the Kwanza Shelf survey which highlights previously unseen syn-rift basins where key Bucomazi Formation source rocks are probably deposited and buried



**Figure 3: Right: KPSDM dip line with full-stack impedance shown with a 3D seabed surface drape above. Left: Seabed surface map view. DHIs in the shallow section show a clear correlation to faults which extend down to the salt weld, indicating a possible hydrocarbon migration route from a potential syn-rift source rock to post-rift reservoirs. Where faults extend to seabed, pockmarks are also visible following these fault lines. These features are evidence that a working petroleum system could be active on the Kwanza Shelf.**

to sufficient depths for hydrocarbon maturation. The majority of historical wells drilled on the shelf did not drill the pre-salt and of those which did, almost all encountered basement after targeting poorly imaged pre-salt highs. The new broadband data images the pre-salt sediments and basement structures with improved clarity, de-risking exploration of the pre-salt plays in this area.

The importance of the connection between syn-rift source rocks and post-rift reservoirs is illustrated in Figure 2. This seismic section and trace integration shows a series of post-rift direct hydrocarbon indicators (DHIs) clearly located above a syn-rift graben where the post-rift mini basin has touched down on a salt weld. This suggests a potential pre-salt source could migrate from the syn- to post-rift through the salt weld and reveals the importance of understanding these potential hydrocarbon migration pathways. DHIs seen across the survey can be correlated to the occurrence of faults, and where these reach the seabed pockmarks are also observed (Figure 3). Shallow amplitude anomaly DHIs and numerous pockmarks demonstrate that a working petroleum system is active on the Kwanza Shelf.

### New Data for 2021 Round

The shallow water Kwanza Shelf is an exciting underexplored area that can now be evaluated in detail using new Kwanza survey seismic data. The new data presents multiple undrilled opportunities and enables improved understanding of the geological fundamentals, key to unlocking the prospectivity of the shallow water shelf for the upcoming 2021 licence round.

### References:

Brownfield, M. E. and Charpentier, R. R. (2006). Geology and Total Petroleum Systems of the West-Central Coastal Province (7203), West Africa. *U.S. Geological Survey Bulletin* 2207-B. ■