Benin Ultradeep seismic study reveals transform margin and potential hydrocarbon prospectivity

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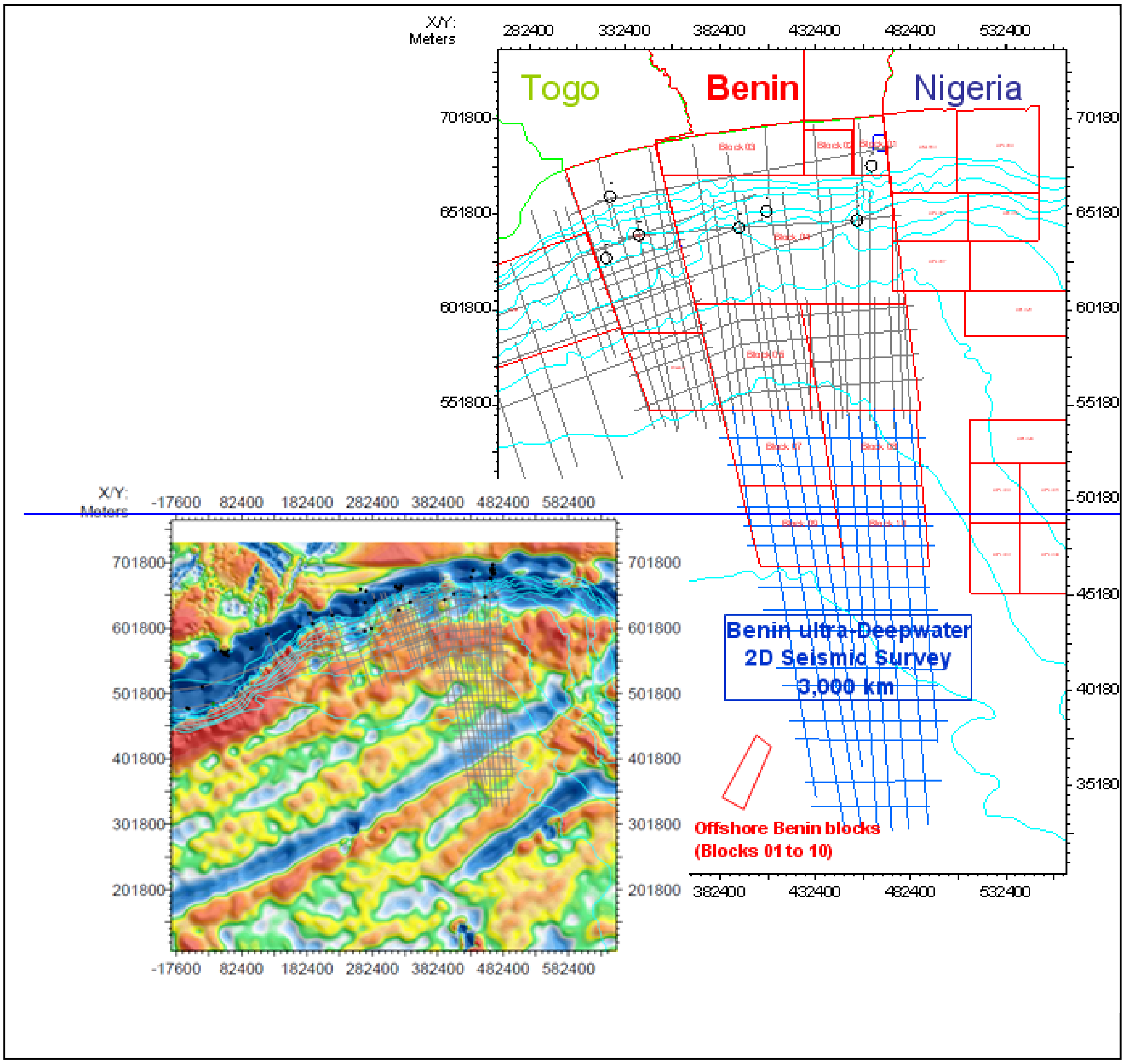
Introduction

The Benin Ultradeep seismic survey was acquired by TGS in 2009. 2D migrated seismic data shows the boundary between oceanic and stretched continental crust occurs at a transform fault zone. Up to 4 seconds two-way time of sediment cover exists above stretched continental crust. The data quality is very good and allows for the interpretation of sequences from Recent to Early Albian above the stretched continental crust. The ages of the sequences interpreted are considered to be reasonably well constrained and a good correlation can be made from ultra deep updip to the wells on the shelf.

Thermal modelling indicates that Albian-Turonian sediments in this area are likely to have been in the oil expulsion window during Paleocene and from Miocene to present due to increased burial depth. Stratigraphic plays and structural traps with four way dip closure have been identified from the new ultra deep data within the Upper Cretaceous interval and offer the promise of a new play in this region.

Regional Setting and Structural Evolution

Offshore Benin is on the West Africa Transform Margin and borders the oil rich Nigerian Delta region to the east and Togo to the West. The Ultradeep seismic survey was shot in water depths from 3000-4500m (Figure 1).


X/Y: Meters
Togo
Benin
Nigeria
Block 03
Block 04
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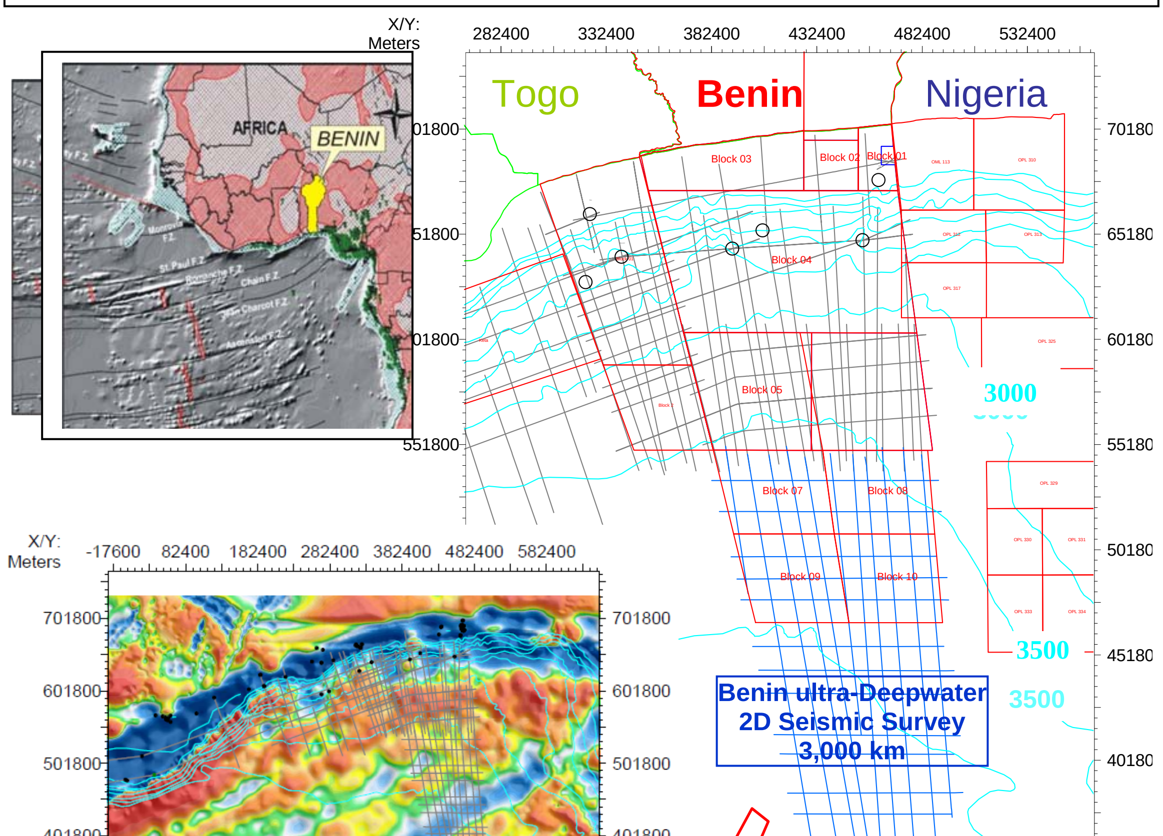
Block 10
Benin ultra-Deepwater
2D Seismic Survey
3,000 km
Offshore Benin blocks
(Blocks 01 to 10)


AFRICA
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X/Y: Meters
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Block 07
Block 08
Block 09
Block 10
3000
3500
3500
Benin ultra-Deepwater
2D Seismic Survey
3,000 km

Figure 1 Basemap of seismic coverage and satellite gravity image

The structural evolution of this area can be divided into three main phases:

1. Pre-Rift/Early Rift
   Fluvial-lacustrine throughout the Early Cretaceous becoming more fluvial-deltaic by Aptian-Albian.

2. Syn-Transform; Albian-Santonian
   Deltaic-deep marine with episodes of uplift and shelfal erosion followed by rapid subsidence of the margin with anoxic periods in the Turonian.

3. Post-Transform/Passive Margin
   Mostly deep water marine with anoxic periods in Maastrichtian-Campanian. The ultra deep area became part of the Niger Prodelta near the end of the Mesozoic.

An example seismic section (Figure 2) shows a transitional continental - oceanic crust boundary occurs at the Chain Transform Fault. This may be interpreted as where highly stretched continental (or transitional) crust meets true oceanic crust. The three major divisions of the sedimentary system are identified and it is noted that syn-rift faulting is largely extensional whilst post-rift faulting shows possible evidence of transform movements through to Turonian-Santonian.

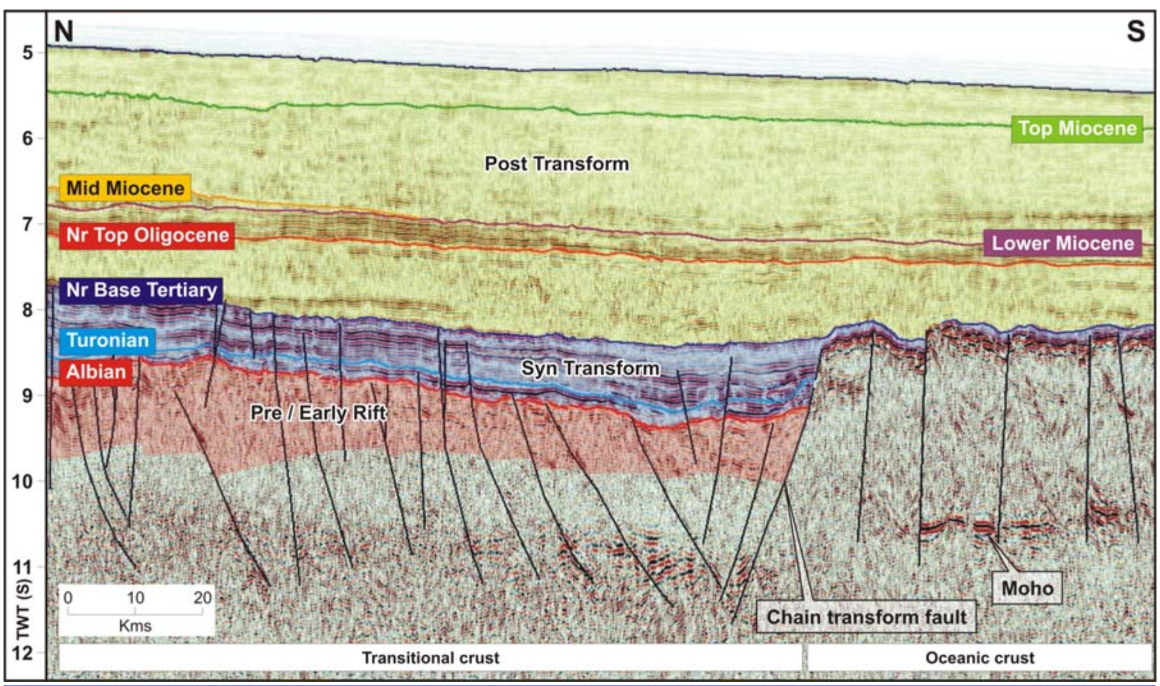

Figure 2 Example ultradeep dip line with main depositional episodes colour shading

Stratigraphy

The current understanding of the stratigraphy is largely based on lithostratigraphy from wells on the continental shelf and by analogy with data from Nigeria. Deeper offshore (on the continental slope) there is evidence for expansion of the Upper Cretaceous sequences with a significant thickness of deepwater clastics thought to be present. In the ultra deep area increased thickness of Tertiary sediments form part of the Niger Prodelta. A simplified stratigraphic chart was created from existing knowledge and from nearby analogue areas to illustrate the major elements of the system, their relationship to the structural evolution of the area, the intervals where source and reservoir are expected and the picked seismic horizons (Figure 3).

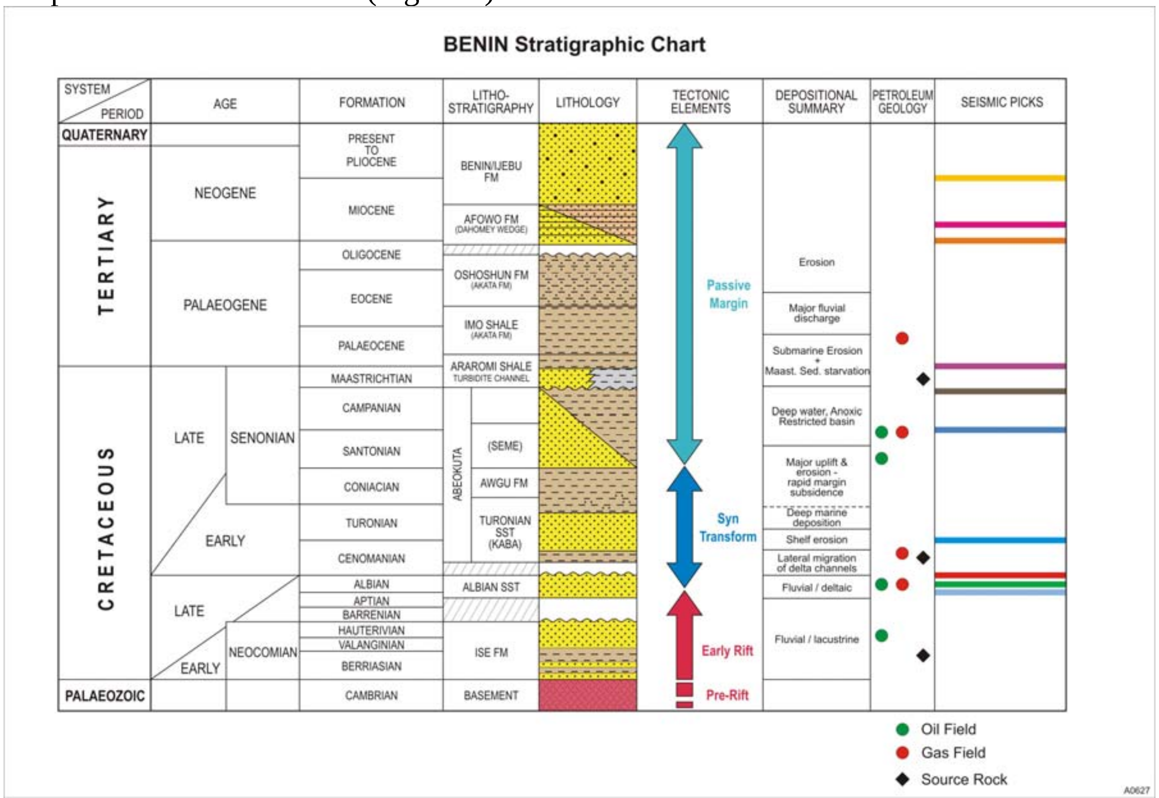

Figure 3 Stratigraphy

Seismic Interpretation

The major sequence boundaries interpreted were:

- Top Miocene
- Mid Miocene
- Lower Miocene
- Near Top Oligocene
- Near Base Tertiary (Maastrichtian)
- Top Turonian
- Top Albian
- Near Base Albian / Top Aptian

The interpretation can be tied from the wells on the shelf via the 2004 West African Seismic Well Tie Survey and through the Ultradeep survey data, (Figure 4). Structural maps and thickness maps in two-way time and depth were created.

The Tertiary section in the ultra deep is part of the Niger Prodelta and comprise the Akata (Oligocene) and Agbada (Miocene) Formation equivalents and the Dahomey wedge just above the base Agbada near base Miocene.

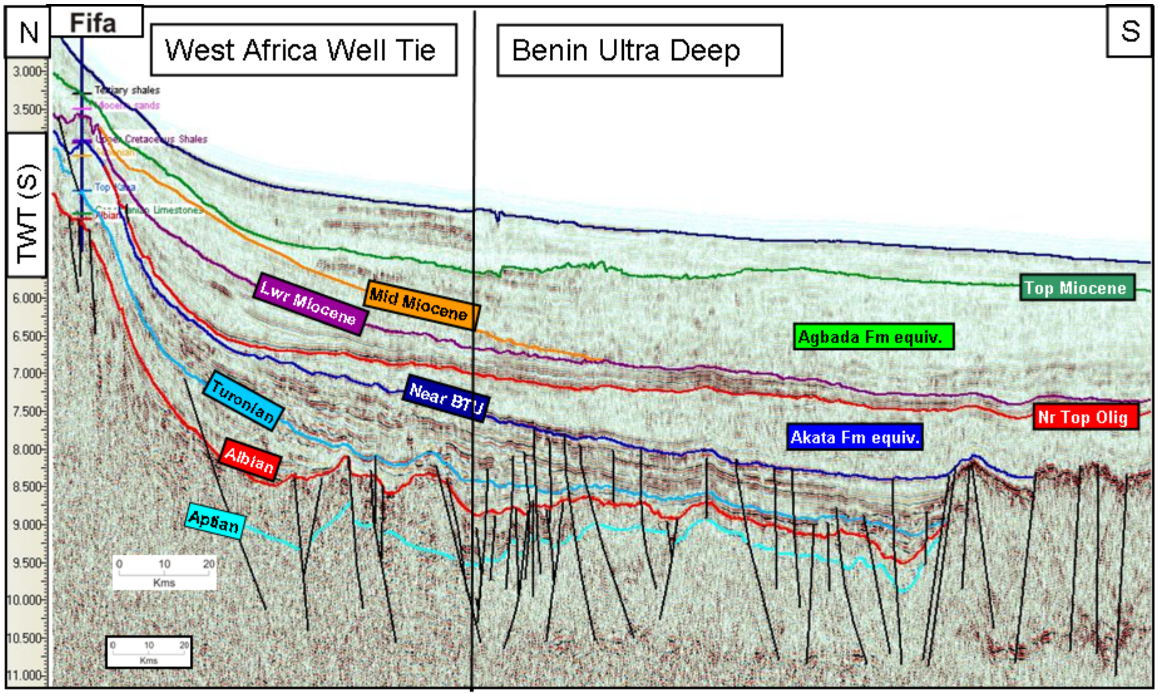

Figure 4 Interpretation from well tie to ultradeep

Petroleum Systems

Current understanding indicates that source rocks occur in four main intervals:

1. Early Cretaceous fluvial-lacustrine Ise Formation.
2. Turonian anoxic shales (that occur widely across offshore West Africa).
3. Maastrichtian Araromi shales.
4. Paleocene-Oligocene Akata shales in ultra deep.

Basin modelling, using interpreted seismic, crustal heat generation, basin stretching history and thermal simulation, appropriate for highly stretched marginal basins, has been conducted to determine the timing of oil expulsion and reservoir temperatures. Source rocks probably include terrestrial to shallow marine Type II/III in the early Cretaceous and richer deep marine Turonian and Maastrichtian Type II anoxic shales.

Expulsion peaks are seen in the Palaeocene and again in the Miocene during increased burial, (Figure 5).

Study of the Ultra Deep data reveals the following:

- Potential reservoirs from Turonian to Early Miocene should have received a late charge which will not have undergone biodegradation.
- Shallower reservoirs, which were cooler during the early phase charging, may have experienced biodegradation, resulting in heavy oil and mixed phases of oil.
- Hydrocarbons expelled from Albian-Turonian source rocks in the ultra deep area are anticipated to have good vertical migration paths along faults to top Santonian and also updip via Turonian sand channels.

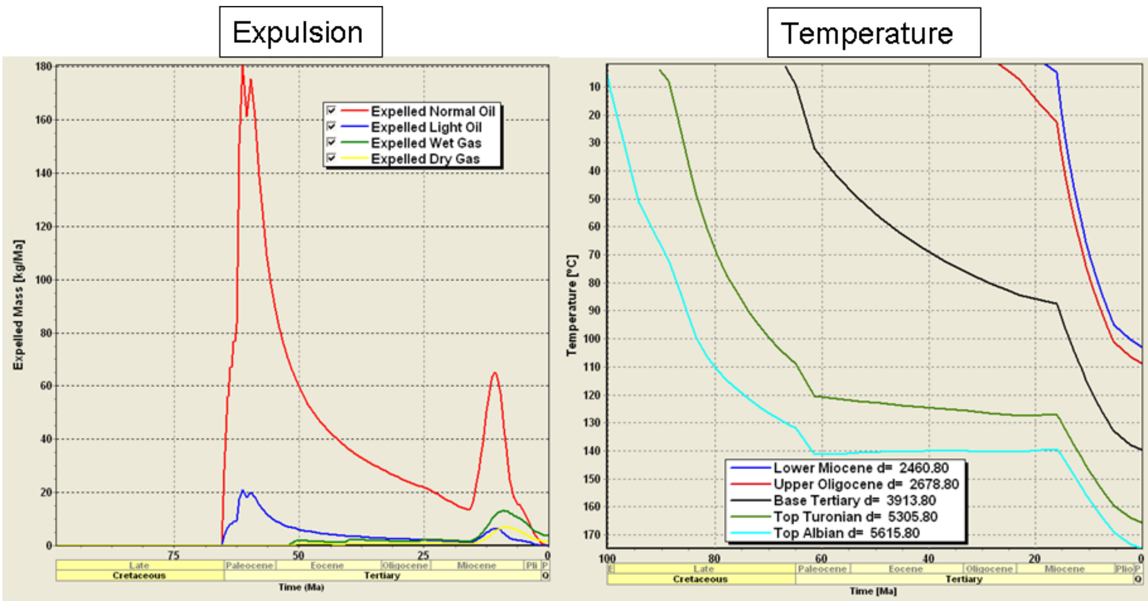

Figure 5: Shows peak expulsion from Turonian source rock in Paleocene and Miocene

Traps

Channel systems that feed turbidites and basin floor fans have been interpreted in the Paleocene-Lower Miocene section seismic interpretation indicates thick widespread muds and shales above and below these channels forming stratigraphic traps.

Large channel systems are present in the Upper Cretaceous and form stratigraphic traps with some fault control. It is also noted that some four-way structural closures have been identified at this level.

Fault-bounded and associated structural traps have been created in the rift sediments (Aptian-Albian) but are considered to be too deeply buried to be prime targets.

Channel Systems and Leads

Extensive channel systems have been identified in the Upper Cretaceous section (Turonian-Maastrichtian) and the Oligocene-Miocene interval. The sediment source direction is from the Northeast. The channels trend Northeast-Southwest and appear to be controlled by Cenomanian-Santonian faulting.

Examples of potential reservoirs in Upper Cretaceous and Oligocene-Miocene are shown on Figures 6-8.

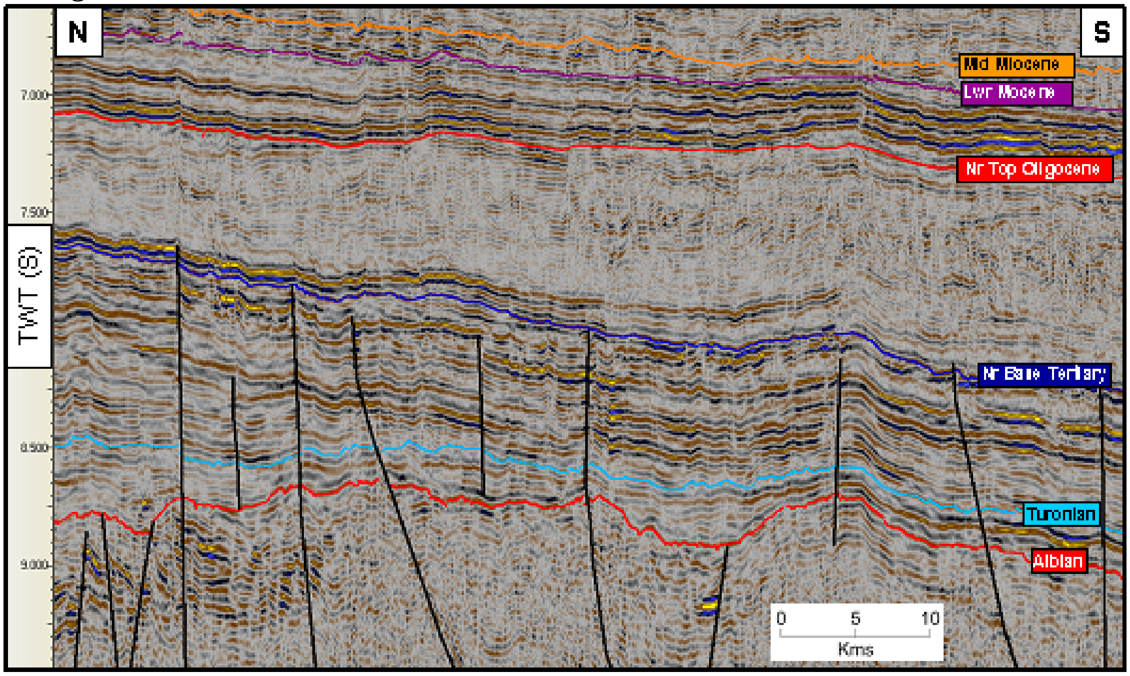

Figure 6 Basin floor fan of Lower Miocene-Oligocene age and deeper Upper Cretaceous channel systems

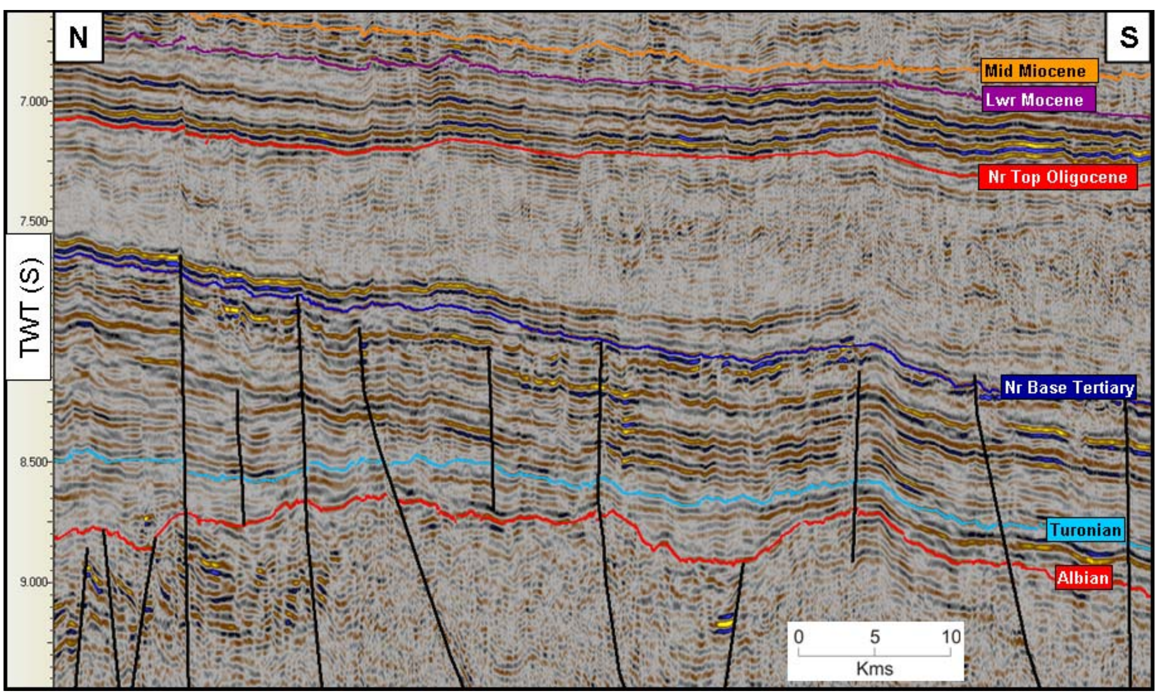

Figure 7 Upper Cretaceous sand channels have fault control and both stratigraphic trapping and some four-way structural closures

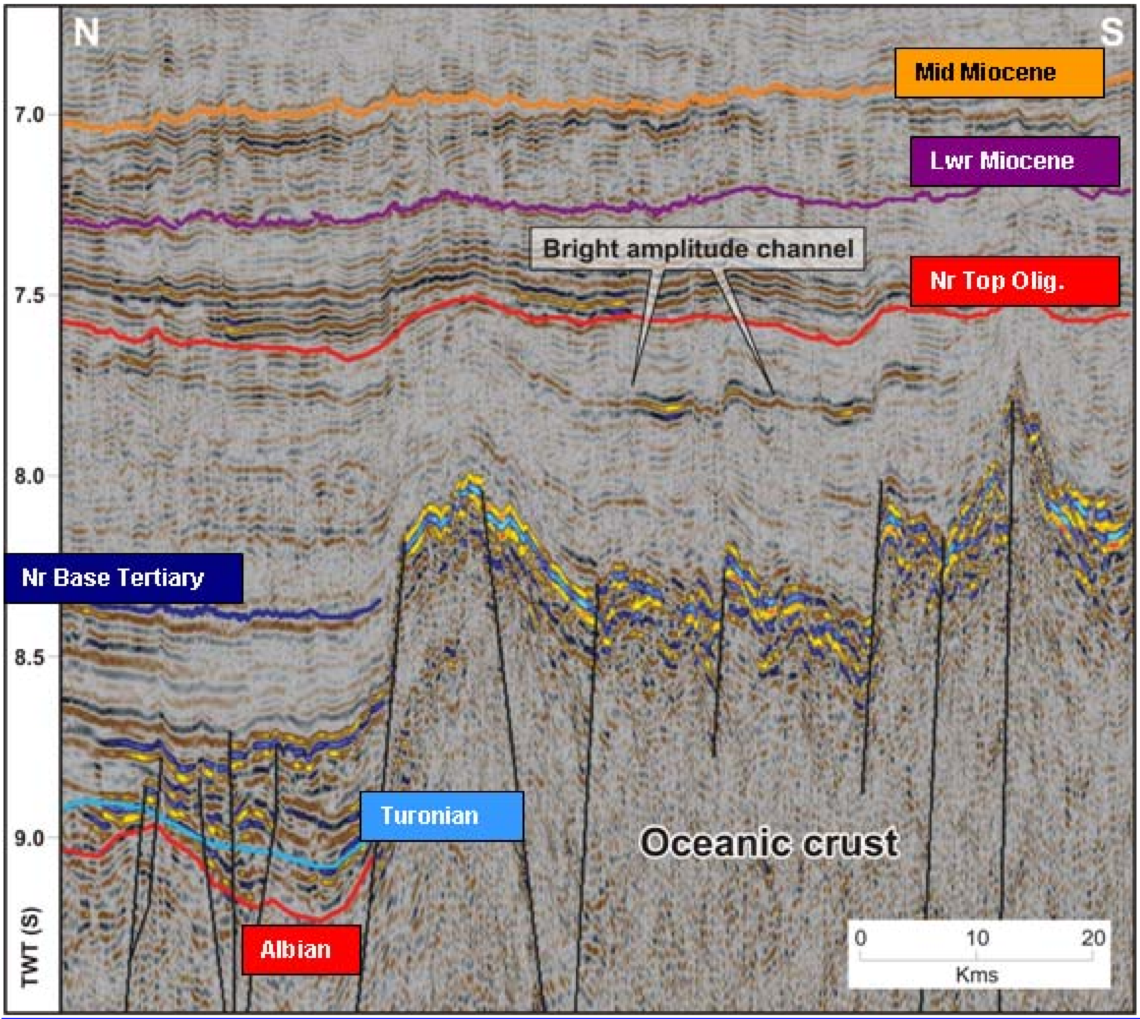

Figure 8 Oligocene channels overlying oceanic crust on strike line

Conclusions

The Benin Ultradeep 2D seismic survey has imaged the continental-transitional-oceanic crust boundaries. The Moho is seen below the oceanic crust and a high amplitude near horizontal reflection below the transitional continental crust indicates a possible stretching factor of approximately eight that is consistent with tectonic (stretching) modelling results and present day depth to seabed.

Thermal modelling has suggested that Albian-Turonian source rock over much of the area is likely to have had peak oil expulsion in Palaeocene followed by a secondary peak in the Miocene.

Migration pathways both vertically and updip are likely to be present.

Channel systems in Miocene-Oligocene and Upper Cretaceous have good reservoir potential and some four-way dip closures have been identified.

This study shows that the ultra deep area has significant hydrocarbon prospectivity within the Upper Cretaceous and Tertiary and that stratigraphic traps, by analogy with offshore Ghana, are regarded as highly prospective.