

Integrated 3D seismic interpretation techniques enable definition and assessment of prospects and risk in the Harper Basin Cretaceous fan reservoir play

Felicia Winter¹ and Richard Hedley¹ present their interpretation of several attractive Late Cretaceous deep-water play types in the Harper Basin.

Introduction

During the Late Cretaceous, global sea level was at an all-time high and thick organic-rich shale accumulated in the newly formed Atlantic Ocean. The equatorial Atlantic was a mere 700 to 1000 km wide, separating West Africa and South America (Figure 1). Multiple mid-ocean spreading centers formed and differential spreading was accommodated by offset on east-west trending ocean transforms. Late Cretaceous movement along these transforms created fracture zones resulting in transpression in some adjacent basins.

The Harper Basin is a relatively narrow basin that formed between two major transform fracture zones. The transforms play an important role in focusing sediment in the basin. They may also play an important role in maturing source rocks – especially if they offset spreading ridges on one side of the transform against source rock depocenters on the other side.

There are several attractive play-types in the Harper basin including:

- Late Cretaceous reservoirs sourced from Cenomanian-Turonian source rocks
- Late Albian shallow marine sandstones sourced from underlying syn-rift lacustrine source rocks

- Syn-rift continental sandstones sourced from syn-rift source rocks

This article will focus on the Late Cretaceous deep-water sandstone play.

In the Middle Albian, regional uplift of West Africa occurred as a result of thermal bulging of the crust. This was followed by the onset of Atlantic seafloor spreading. The uplifted Precambrian hinterlands onshore West Africa were eroded, and quartz-rich sand were carried down-stream to the adjacent continental shelves.

Throughout the Late Cretaceous, global sea level periodically fell and rose by about 70 to 100 m. During periods of low-stand, sands on the shelf were ripped up and transported through canyons over the shelf edge and re-deposited on the continental slopes and far out onto the abyssal plain (Figure 2).

The resulting sand bodies have a distinctive high amplitude response on seismic and exhibit characteristic channel and fan morphologies. These are easily identified on horizon-consistent amplitude extraction (RMS) maps. In the RMS example in Figure 3, the sands are identified by red coloration compared to the background mudstones in blue. This example in the Harper Basin

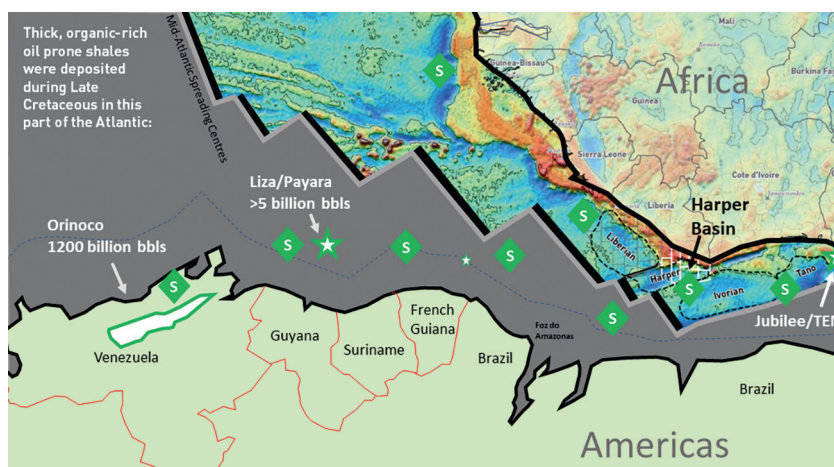


Figure 1 Turonian plate reconstruction showing source rock deposition in proto-Atlantic Ocean.

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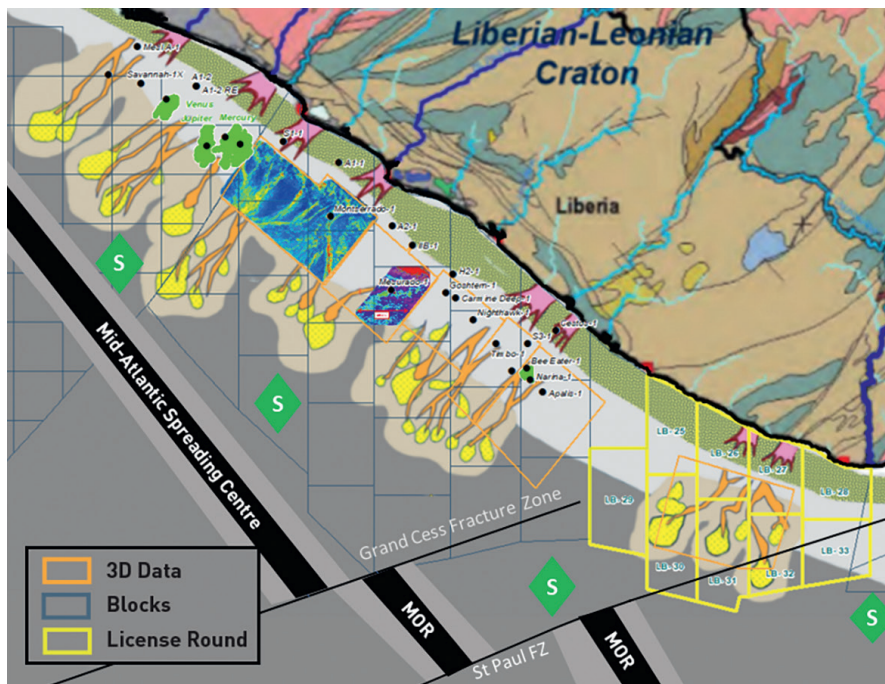


Figure 2 Schematic diagram showing Late Cretaceous channel and turbidite fan systems offshore Liberia.

shows fairways with high amplitude signature of a comparable size to the Jubilee field in Ghana (Sills et al, 2012), for example. The adjacent shale facies have generally lower seismic amplitude on the stack volumes and are often described as being more transparent in character.

An example of a Turonian low-stand fan system is shown in Figure 4. Note the high amplitude character of the fan, highlighted in yellow, and the lower amplitude character of the overlying mudstones that form the down-lapping low stand wedge, highlighted in blue. Mature Cenomanian source rock in the basin may have charged these Turonian low-stand fans, whereas the down-lapping mudstone wedges could provide a top seal to the underlying sandstones.

The feeder channels that link to this fan system are shown in Figure 5. This is a strike line across the channel thalweg which is about 7 km wide. It is interesting that successive lowstands often use the same feeder canyons and therefore channels cut down and incise the previously filled valleys. Overall, the channel sands within any one thalweg are a vertical stack of sands from several 3rd order low-stand episodes. When interpreting time equivalent seismic horizons through the channel thalweg, it is evident that a whole stacked reservoir system of interconnected channel sand-bodies is created by stacked sands of different ages as successive channel systems cut-down and erode into their predecessors. A generalized model of stacking channel and associated levee systems is shown for comparison (Cronin, 2019).

Keys to Exploration Success

Mapping the extent and interconnectivity of the sand bodies is key to defining prospects and leads and identify sealing surfaces. This task can only be effectively and feasibly done on high quality 3D seismic, preferably using a combination of full stack depth data, offset angle stacks and attribute volumes.

Knowing the extent of interconnected sand bodies is essential for defining hydrocarbon stratigraphic traps. The key

to successful exploration is finding sand bodies that are cut-off and isolated from those sand bodies that communicate back up onto the continental shelf.

The Jubilee Field in Ghana (> 600 mmstb reserves) is a good example of a turbidite channel sand system being disconnected from the shelf sands by a series of small shelf edge faults. The combination of lateral pinch out of the sands in the channel plus the up-dip bounding faults provides an effective trapping mechanism (Figure 3).

On the conjugate margin offshore Guyana, Exxon have had significant success in finding >6 billion barrels reserves in Late Cretaceous slope fan systems. Without having access to the data we can only speculate as to the reason these sands no longer communicate with up-dip feeder channels. One reason could be that the channels are offset by faults. Alternatively, the channel systems could be backfilled with pelagic muds during periods of highstand.

Harper Basin Traps & Workflow

In the Harper Basin of Liberia, a large (6172 km²) 3D seismic survey exhibits well developed stacked Late Cretaceous turbidite systems with feeder canyons, slope channels, overbank splays and low-stand basin floor fans.

In order to identify hydrocarbon leads, a workflow was used involving four steps:

- generate attribute volumes (near, mid and far stacks, (Far-Near)*Far, Coherency and Extended Elastic Impedance)
- define parameters to distinguish low impedance sands that have increase in amplitude with offset
- identify geobodies (i.e. contiguous regions of the seismic attribute volumes that match the expected hydrocarbon sand attribute parameters).
- identify and interpret facies boundaries to delimit the boundaries of the fan and its up-dip feeder channel/thalweg and map seismic events that encompass the geobodies

The resulting integrated interpretation maps show fairway systems divided by bodies of interest with the desired attributes and help identify the charge and seal story of these leads.

Using this technique, we can identify attractive sand body trapping geometries in the Harper Basin and show linkage to underlying potential Cenomanian source rocks.

De-risking mapped exploration leads

As mentioned previously, the channel systems in the thalweg are diachronous and therefore it is not always possible to adequately show an interconnected sand body on a single time horizon consistent amplitude map. Take note all you Senior VP Exploration who are approving drilling well locations. Far better to ask to see a rendered 3D seismic volume and working with opacity to

make it partially opaque and partially transparent. That way the true three-dimensional nature of the geobodies can be appreciated.

Seismic Evidence for Source Rocks

There is evidence for source rocks being present in the Liberia and Harper Basins by examining the seismic data. There are a number of direct hydrocarbon indicators (DHIs), including; bottom simulating reflectors at the base of a gas hydrate zone, as well as abundant chimneys of high energy seismic bursts within the Late Cretaceous intervals.

In places, the basal Turonian lowstand fan systems seem to sit directly on a high amplitude, low impedance, seismic event that appears to have a class IV amplitude versus angle (AVA) response, dimming with offset.

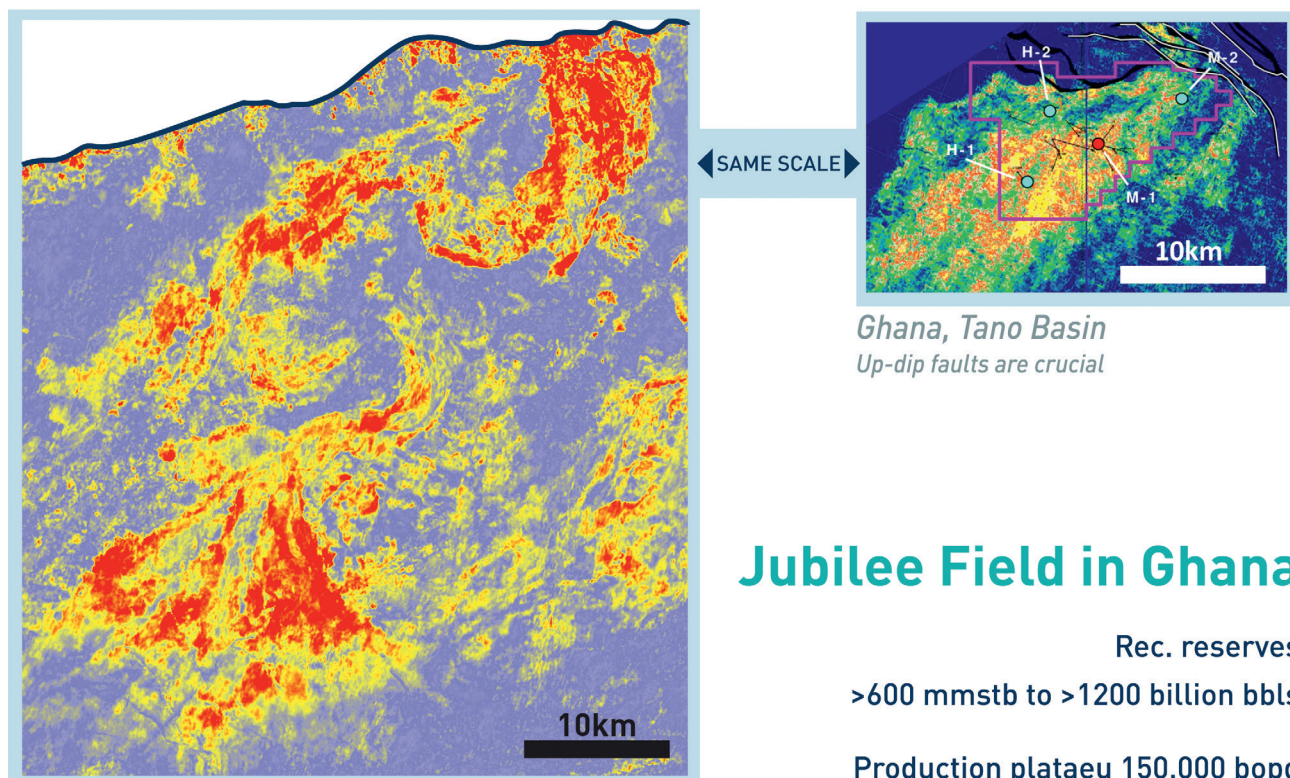


Figure 3 Late Cretaceous amplitude extraction from Harper Basin on left, compared to amplitude extraction from Jubilee Field on right (Sills et al., 2012).

Harper Basin 3D Late Cretaceous Play

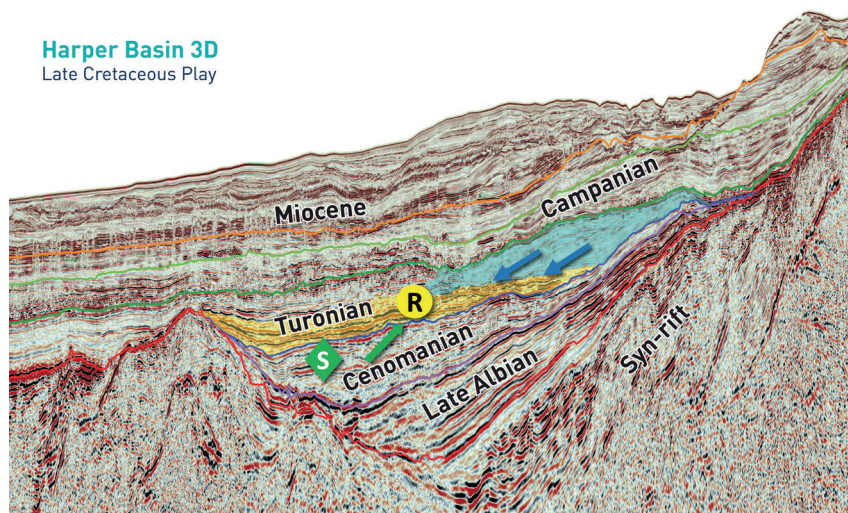


Figure 4 Dip line through Harper basin showing Turonian low stand fans (shaded yellow) overlain by more transparent low stand wedge (shaded blue).

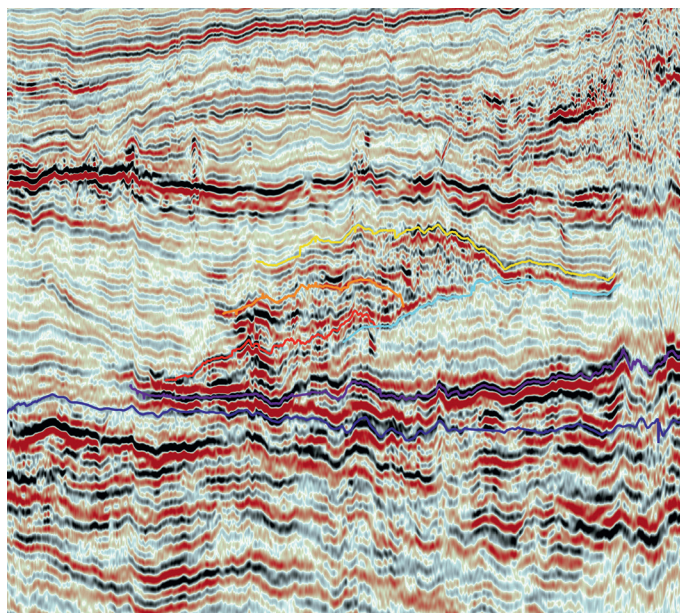


Figure 5 Comparison of Strike line through Harper basin showing stacked Turonian channel/levees migrating eastwards through time with slope channel complex model (Cronin, 2019).

It is well known that oil generation significantly increases kerogen porosity and overall shale porosity – which causes a reduction in seismic impedance (Vernik and Landis, 1996; Sondergeld et al, 2011).

Kerogen-rich shales consist of fine laminations on a millimetre to metre scale, composed of alternating ‘squishy’ kerogen rich and harder detrital and clay mineral interbeds. This hard-soft layering results in a strong intrinsic anisotropy in the source intervals.

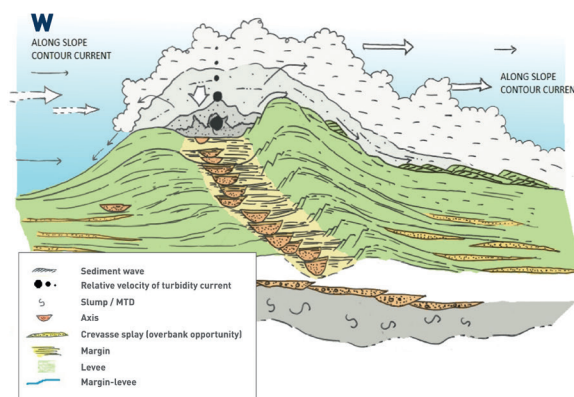
The anisotropy means the source rocks have a higher compressional wave velocity parallel to the bedding, compared with a lower velocity orthogonal to bedding. Strong anisotropy is responsible for more pronounced mode conversion of P to S waves on the downgoing and upgoing paths through the source interval, and also at the top and base source rock interfaces, resulting from increased refractive ray-bending - primarily due to the increased incident angles at the interfaces. The seismic velocity anisotropy and wave mode conversion create a large reflection amplitude dimming effect with increased source to receiver offset (Class IV AVO), which has been shown to increase with TOC content (Løseth et al. 2011).

Conclusions

Although no wells are present in the Harper Basin, we are encouraged that the 2D & 3D seismic data shows good evidence of abundant, stacked turbidite fan system reservoirs and the pos-

Down Slope Turbidity Current

Asymmetric levees, more sand-prone crevasse splays at base.



sibility of immediately down-dip Albian-Cenomanian-Turonian source intervals showing Class IV AVO response in places.

Mapping interconnected sand bodies using multi-attribute visualisation based on high quality, semi-opaque rendered 3D seismic volumes is a critical exploration step towards addressing the technical risks and understanding the reservoir sands trapping potential.

References

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