Sierra Leone, the under-explored conjugate

Ben Sayers[1], David Contreras[1] and Ahmed Tejan Bah[2] give an overview on the oil and gas prospectivity of Sierra Leone.

Introduction

Sierra Leone is a West African country situated between the Republic of Guinea and the Republic of Liberia. The country has approximately 8 million people who speak the national language of English, although many local dialects derived from a tribal past are still spoken. The country has a dense tropical rainforest and wetland environment making it a host to a great diversity of flora and fauna, as well as sandy white beaches. The country was originally named Serra Leoa, which is Portuguese for 'Lioness Mountains', referring to the Lion Mountains near the capital of Freetown. Following a study in 2016, about 12% of the population of Sierra Leone had access to electricity, of that 12%, 10% was in the capital Freetown, from the remaining 90% of the country, which equates to 7.2 million people, only 2% have access to grid-fed electricity (Energy Africa Access, 2018). With these low figures Sierra Leone is placed at 183 out of 187 in the development index, creating a real need for resources to be discovered, harnessed and distributed. This article will provide a positive view on the future for Sierra Leone from a hydrocarbon perspective.

An article a decade ago stated: '*Following the recent major discoveries in West Africa, a new focus has been placed on the conjugate margin in northern Brazil, where over the entire 2200 km margin only 20 wells have been drilled in water depths greater than 500 m. Using the analogy from equatorial African discoveries, it appears that the highest potential may be in the deep waters on the slope and continental rise of the Brazilian margin*.' (GeoExpro, 2011)

Fast-forwarding to 2021, we are now looking for the discoveries along the northern South American coastline to see where the highest potential could lie in West Africa. Sierra Leone, which has more than 400 km of Atlantic coastline can be tectonically-reconstructed back to fit with the Guyana Basin. Obviously, the exploration success in that region has led to truly world class oil discoveries (9 Bbbls at the date of publication, but with ever-growing satellite discoveries could be as large as 15 Bbbls), which should be waiting in their eastern twin in Africa. ExxonMobil in Guyana have achieved great success, and Suriname is also surprising the oil industry with four recent similar discoveries by Apache and Petronas. However, French Guiana had the maiden discovery in the Zaedyus well before Guyana and Suriname, with recoverable resources estimated of 250 mmbbls.

The organic-rich source rocks that charge the Liza field complex (producing 120,000 bopd) and the surrounding discoveries from the Canje Formation (Late Cretaceous) were deposited at the

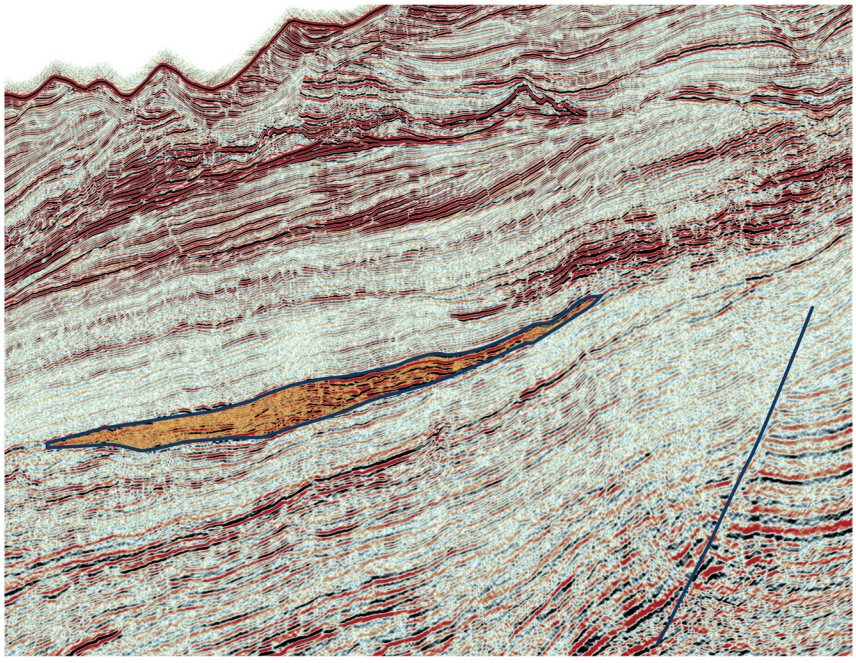

Figure 1 PSTM image showing the Venus non-commercial discovery (2009) drilled in 1800 m of water.

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same time as the similar source rocks that charge the Sierra Leonean discoveries of Venus and Jupiter (drilled by Anadarko in the early part of the last decade). These source rocks were deposited in this unique environment created after the rifting of the two continents. Further to the south in the West African margin, in Republic of Côte d'Ivoire and Ghana, the same age source rocks are deemed responsible for the sourcing of oil in several discoveries, among which Jubilee is the most important (producing 82,000 bopd in 2020).

The same successful petroleum system seems to be present along the entire South American margin of the Equatorial Atlantic Ocean. Interpretation of recently acquired high-resolution seismic data in the Foz do Amazonas and Pará-Maranhão Basins in northern Brazil indicates that the potential for the replication of the success in the neighbouring countries is highly likely. Tens of prospects of stratigraphic traps encompassing slope submarine fans and channels of Late Cretaceous age were mapped and their dimensions are greater than those in Guyana and Suriname.

Previous exploration in Sierra Leone

Sierra Leone has a mature mining industry with extraction in minerals which include diamonds, bauxite, gold, iron ore, platinum, zircon plus other heavy minerals, but the tectonic and thermal regimes that produce these precious mineral resources in the onshore realm also provide the perfect environments for promising petroleum potential.

Offshore exploration started in the 1980s with wells drilled by Amoco and Mobil finding oil shows in the shallow water. The first-deep water wells drilled from 2009 onwards resulted in the discoveries of Venus (Figure 1), Jupiter and Mercury. These wells targeted Late Cretaceous fan systems that had class II/III AVO anomalies and proved that all petroleum system elements were in place and the thermal regime was suited for oil generation at the critical moments. The oils recovered to surface were described as 'light sweet crude oil with a gravity of between 34° and 42° API' (Reuters, 2010) with a secondary target of the Mercury well recovering 24° heavier crude in a shallower reservoir (Tullow Press Release, 2010). Though these recent discoveries were non-commercial the initial early positive confirmation are great indicators of what lies in wait. The first commercial well in the conjugate Guyana Basin was the 23rd well drilled in the basin, so with only eight wells having been drilled offshore Sierra Leone so far, there is already more positivity despite the sparsity of the drilling with only one of the eight previous wells coming up dry.

Geological history

The pre-rift consists of faulting of the Palaeozoic to Jurassic strata with associated volcanics.

From late Jurassic to early Cretaceous period there was active rifting, coincident with tectonic subsidence of the stretched continental crust. This created extensional faulting and continental siliciclastic deposition took place in the resultant grabens. From the Aptian to Turonian, the fluvial and lacustrine environment progressed to a shallow marine environment as the Sierra Leone Basin was finally separated from its conjugate the Guyana Basin; the beginning of the passive margin phase.

Significant amounts of alluvial, fluvial and lacustrine sediments were deposited, and shallow marine incursions flooded the more subsided parts of the rifted terrain in the mid-Albian time. Immediately after the onset of seafloor spreading, the marine realm transgressed and drowned the inner shelf and slope. The continued seafloor expansion developed oceanward, deepening with rotation of the rifted fault blocks and a full deep marine depositional environment established itself on the new crust in the proto-Atlantic basin.

Recent changes

At the end of 2020 TGS entered into a long-term collaboration with the Petroleum Directorate of Sierra Leone (PDSL), which under the new direction of Foday Mansaray has the ambition to bring commercial hydrocarbon industry success to its nation. The new partnership enables TGS to be able to work closely with the in-country experts from the PDSL and review the previous exploration data holistically, while bringing in TGS' additional knowledge from complementary datasets in the neighbouring

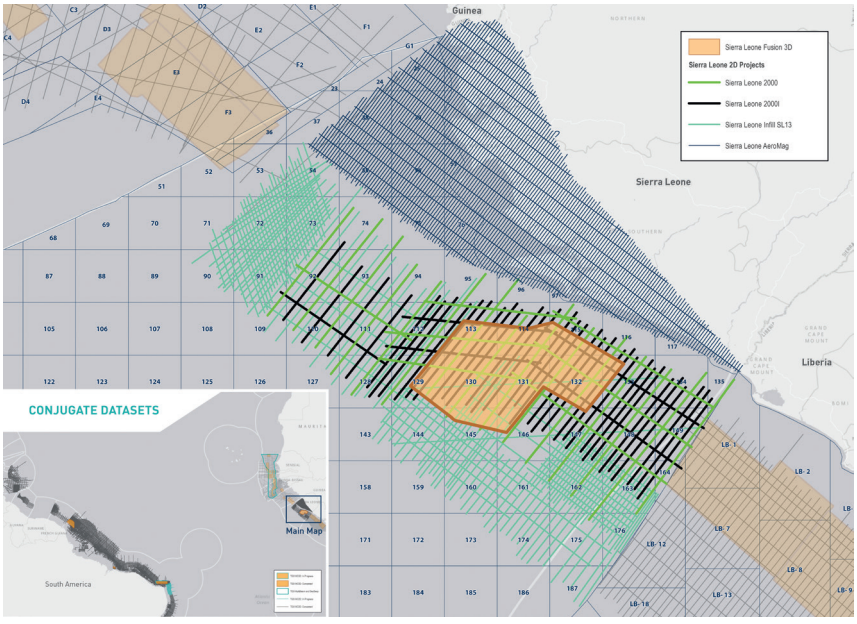

Figure 2 Main map shows the data that TGS is marketing in West Africa, with the inset map showing the conjugate database

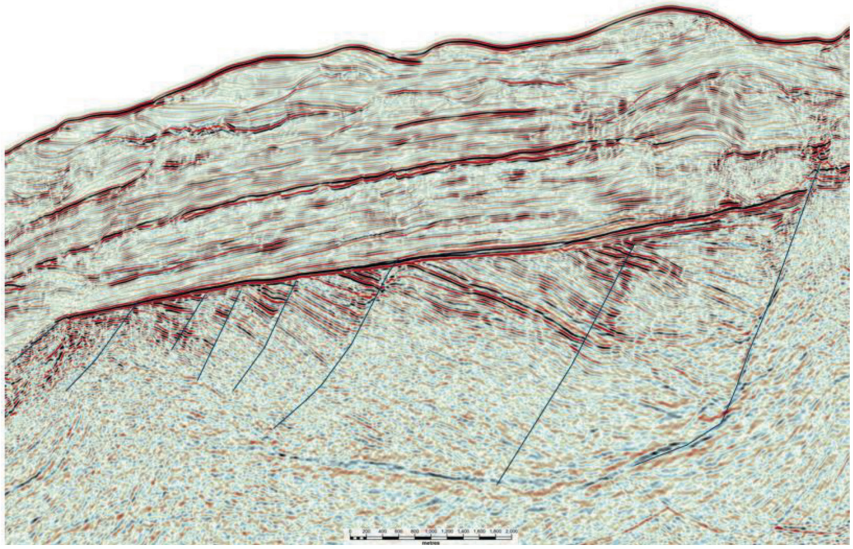

Figure 3 2D PSTM seismic data indicating untested potential in the northern domain of the Sierra Leone basin in particular in the syn-rift section

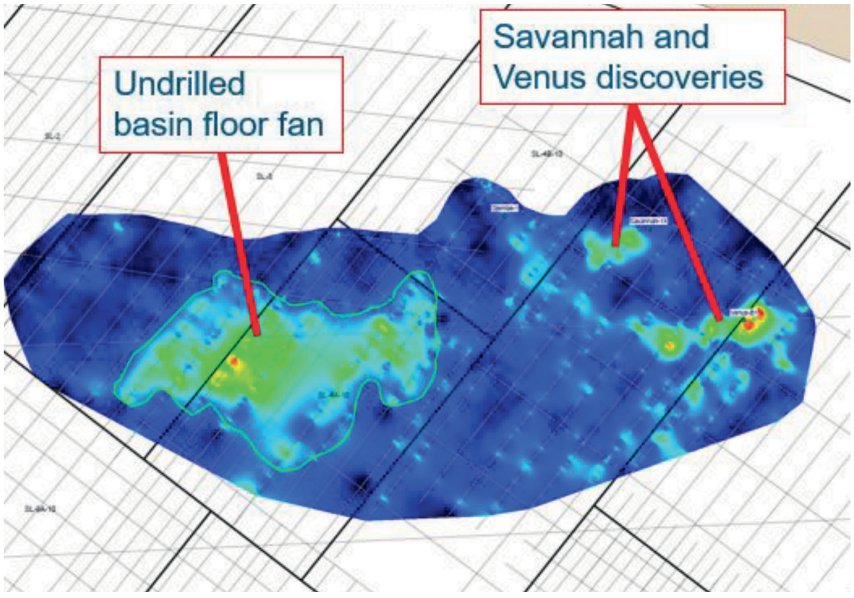

Figure 4 Undrilled basin floor fans many times bigger than the sub-commercial proven up dip siblings. The saddle structure provides the up dip disconnect limiting the up dip migration of hydrocarbons to further charge the Savannah and Venus discoveries and retaining the oil in the deep

basins and on the conjugate margin (as shown in Figure 2). By working both sides of this prolific margin, TGS is well placed to help the PDSL reach its aim of delivering a commercial discovery. The new collaboration is multifaceted and puts in place a long-term strategy for reprocessing and refreshing legacy datasets, alongside acquisition of new data. Interpretation of the legacy datasets in Sierra Leone and coupling with surrounding datasets in appropriate basins highlights that additional information is key to advancing the subsurface understanding. More modern datasets will be able to enhance the imaging around the known plays while illuminating the future untested plays.

The PDSL

Sierra Leone was one of the only countries in 2020 that concluded a licensing round and successfully awarded acreage. The awardees were small players with huge ambition: Cluff Energy and Innoson Oil and Gas. The ability of the PDSL to cope with the disruption of the world economic markets during the global pandemic that halted and delayed many other activities, is a testament to the professionalism and reliable investment climate that the PDSL has created and it is keen to grow with stability. Part of this approach has been through the adoption of the Extractive Industries Transparency Initiative (EITI), which creates a transparent, and fair investment platform that is publicly visible (https://eiti.org/sierra-leone).

After a block re-demarcation in 2018, the PDSL now has a series of smaller blocks that align with the ECOWAS north-south grid system which can be seen in Figure 2. Each block is approximately 1300 km^2 though multiple blocks can be amalgamated to enable larger acreage positions to be taken by the bigger explorers. After the successful conclusion of the last bid round, the country has now moved into a direct tender approach enabling the open access to acreage. By comingling the flexible block system with the direct approach, the PDSL has shown its willingness to adapt to the challenging environments and encourage exploration in the region. The attractive fiscal regime also helps, with independent fiscal economic modelling from Ventura International Energy LLC detailing the break-even price to be approximately $50/bbl for a commercial discovery in the deep-water environment, placing the country firmly in the attractive zone when compared with other African countries. The

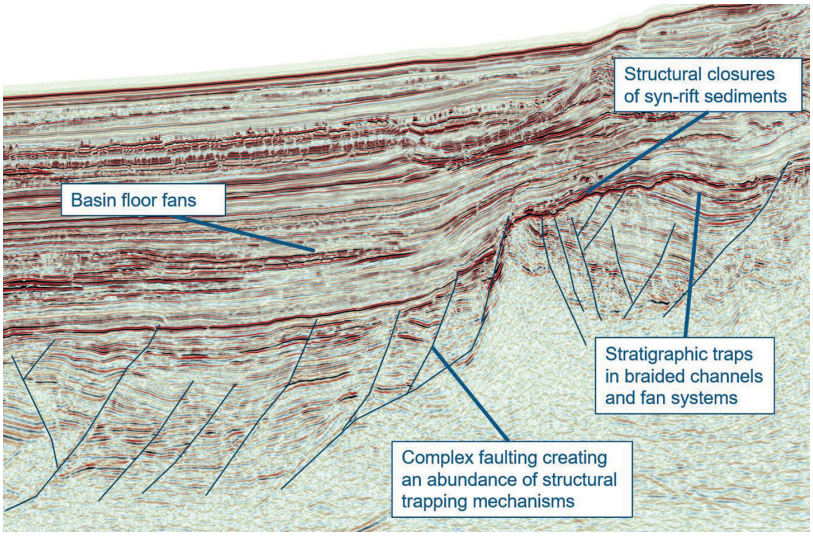

Figure 5 3D PSTM seismic example indicating untested potential of the perched basins in the syn-rift. In the post-rift basin floor fans and deep-water channels are the main reservoir. Numerous paleao-pockmarks are evidenced along with the BSR in the shallower section

latest oil price rally of the last months of 2020 and early days of 2021 bodes well for the attractive opportunity offshore Sierra Leone in the near-term.

The total offshore area of Sierra Leone covers approximately 170,000 km^2, with 140,000 km^2 of offshore open acreage available, creating a lot of potential for future investment in the country.

What we can expect to find going forwards?

So far there have been eight wells to test the deepwater setting in the continental slope. All have been submarine fan systems with prominent AVO anomalies. There is further evidence to suggest that there are also completely untested opportunities for commercial discoveries in the basin floor as well as in the more proximal northern domain of the Sierra Leone basin.

Moving down-dip

"Go deeper" has been the mantra of the industry over the last decade and technical drilling capabilities have progressed so much that water depths of 4000 m are now in sight (Total's Venus and Ondjaba wells in Namibia and Angola are planned and ready for 2021 drilling). This opens up the basin floor domain in the Sierra Leone offshore, where larger lobate sand bodies are more distal, providing better sorted reservoirs, with greater connectivity and ultimately larger spatial areas. They constitute the real prize for chasing the proven plays into deeper water (Figure 4).

New Plays Up-Dip

In Figure 3 we can see a series of tilted fault blocks with high amplitude, high-frequency banding, indicative of clastic sediments that were deposited in the pre-rift environment before they were faulted and rotated during the mid-Albian continental break-up. The stark unconformity eroded the tops of these fault blocks and provided a thick sealing shale layer that forms the perfect top seal for these rotated traps, providing confidence that they were faulted and rotated during the mid-Albian continental break-up. This thick top seal is comprised of the Apto-Albian and Turonian world-class source rocks that have both been tested in the previous exploration campaigns and have been prolific in the nearby production in the Ivorian and Tano basins (i.e. Jubilee field, 82,000 bpd in 2020, proven reserves 3Bbbls, source: Tullow).

Another example of an unexplored play concept can be found in the perched basins, as depicted in Figure 5. These formed during the transpressional events during the rifting and micro plate rotations. The perched basins are bounded by the outer high that in places controls the formation of structural traps. The water depth ranges are favourable for drilling with the deepest perched basins sitting in approximately 2400 m of water with a series of different trap types. The syn-rift contains many structural traps, and the erosion of these sediments indicates sea-level fall, thus allowing for deposition of shallower water sand-prone sediments within the perched rift basin. Examples of these shallower water sediments include braided channels and fan systems within stratigraphic pinch-out traps. The presence of progrades up-dip also implies that sand-prone fan systems are present in this perched rift basin.

The Future is bright

There are many opportunities to develop new and exciting prospects within the northern area of the Sierra Leone basin that differ from the proven system in the south. Considering also the potential waiting down-dip, Sierra Leone has all of the subsurface requirements to be the next big African exploration hotspot - especially when the new stable and transparent above ground investment environment is fully factored in. Access to acreage, good fiscal conditions, transparent and stable government, a positive investment environment, good quality data with reprocessing and new data on the agenda, plus the world-leading conjugate discoveries, all indicate that Sierra Leone should soon join the exclusive club of African oil-producing nations. 'Unity, Freedom and Justice' is emblazoned on the country's coat of arms, but these three words also spell a great investment opportunity to those that look into the subsurface.

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