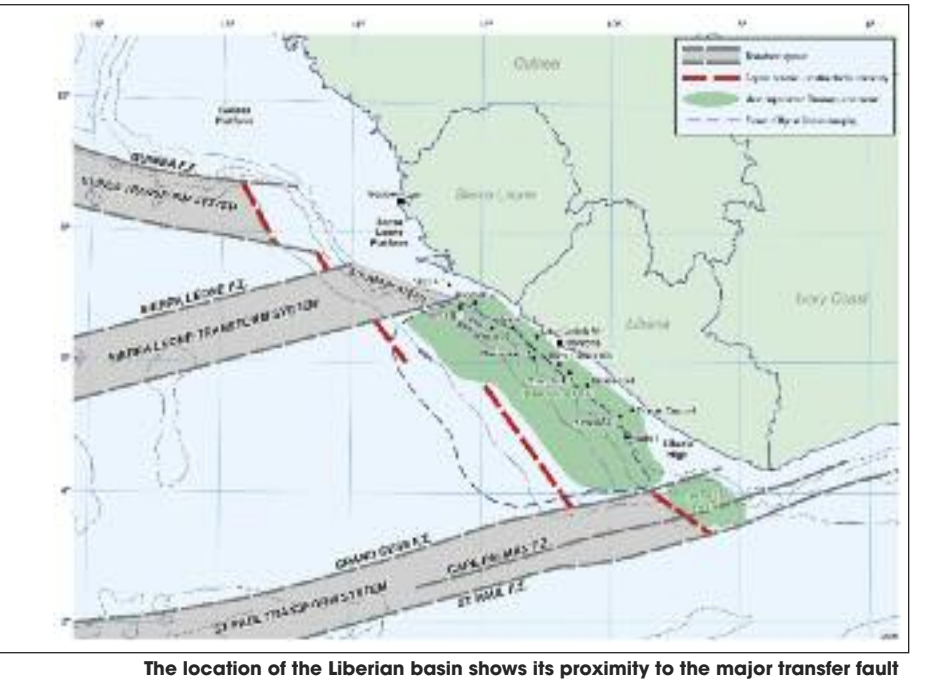
Geological review of deepwater Liberian basin outlines prospectivity

New data and drilling results show great promise offshore Liberia.

Muhammad S. Tamannai, **Ian Deighton**, and **Peter Conn**, TGS

The Liberian basin comprises offshore Liberia and Sierra Leone. Details of the regional structure and petroleum prospectivity of this frontier margin have not been well understood. In 2000-2001, TGS acquired 9,382 line km (5,715 line miles) of regional 2-D seismic data, and an interpretation report was released in 2007 and revised in 2010. Between 2007 and 2011, a series of 3-D seismic surveys was acquired over several blocks in the Liberian basin. All of these datasets have provided better understanding of the regional structure and petroleum prospectivity of this frontier margin.

In 2009-2010, a new long-offset seismic survey was performed in Liberian ultra-deep waters to evaluate its hydrocarbon prospectivity and provide a good-quality extension of existing seismic into ultra-deep waters. Evaluations of all the 2-D and 3-D datasets have provided a good understanding of the structural evolution and hydrocarbon potential of Liberian frontier waters.



The location of the Liberian basin shows its proximity to the major transfer fault zones. (Images courtesy of TGS)

Geological background

The geological evolution of the Liberian basin is related to the opening of the Atlantic Ocean. The offshore Liberia margin is bound by the Sierra Leone transform system to the north and the St. Paul transform system to the south. The area is structurally complex, with transpressional and transtensional systems associated with these major fault zones. Between the major fracture zones, the upper Cretaceous depositional environments were less affected by major faulting, which allowed deposition of thick deepwater shales and turbidite sands.

Exploration in offshore Liberia

On the offshore Liberian continental shelf, two exploratory drilling stages took place (1970-1972 and 1984-1985) with a total of nine wells in 400 m (1,310 ft) maximum water depth. Oil shows were encountered in eight of the wells, but no commercial discovery was made. Deepwater economics and lack of good-quality modern seismic data were among the main reasons for early termination of exploration campaigns.

Recent advances in deepwater technology have opened up the region to a new phase of exploration. In offshore Sierra Leone, the Venus B-1 discovery well (2009), drilled in 1,800 m (5,905 ft) water depth, found 14 m (46 ft) net of hydrocarbon pay in upper Cretaceous deepwater fan sands. This was followed by the Mercury-1 discovery in 2010. Mercury-1 was drilled in 1,600 m (5,245 ft) water depth and encountered 41 m (135 ft) net of oil pay within the same play.

In 2011, two exploration wells were drilled offshore Liberia, Apalis-1 and Montserrado-1. Apalis-1 found upper Cretaceous source and reservoir rock with oil shows. Montserrado-1 was drilled to a depth of 5,400 m (17,720 ft) and made a noncommercial oil discovery in late Cretaceous reservoir sands. The well

encountered good-quality, water-bearing sands in the main objective. In a deeper secondary target, 8 m (26 ft) of hydrocarbon pay was intersected, and a sample of light oil was recovered.

Petroleum systems evaluation

Two petroleum systems exist in the offshore Liberian basin, early Cretaceous and late Cretaceous. Exploration wells drilled on the shelf show that the early Cretaceous contains three or more oil-prone marine and lacustrine (Type II/III) source rock intervals that extend in age from Aptian to Albian.

Abundant structural traps are potential targets within the lower Cretaceous system. They are mainly fault blocks and fault-associated structural closures related to transtensional regimes during the mid-Cretaceous rifting event. Where found as transpressional pop-ups, these structures can be associated with strike-slip motions. Fault blocks were the main exploration targets in wells drilled on the shelf. They also exist in ultra-deep water, where they could be potential exploration targets.

The late Cretaceous system is the most important. Source rocks are formed by late Cenomanian to Turonian organic-rich (Type II) marine shales deposited throughout the central and southern Atlantic during a global anoxic event. Within this system, significant recent discoveries have been made offshore Ghana, Liberia, and Sierra Leone. Multiple sandstone reservoir targets overlie the potential source rock interval.

Following recent discoveries, stratigraphic traps are now seen as the most prospective play type in the offshore Liberian basin (and throughout the West African transform margin). Deepwater fan and lobe structures occur throughout the mid- to upper-Cretaceous sequence, providing potentially attractive reservoirs. A regional channel/fan complex has been identified and mapped across from the slope extending into the deep basinal areas between intra-Campanian and top Cretaceous. Seismic imaging allowed delineation of multiple fans within this thick complex. The presence of sand

bodies is indicated by brighter seismic amplitudes within each fan.

Basin modeling

Shelf wells have been used to constrain a regional crustal model, which was used as the starting point for stretching-based thermo-tectonic geo-history modeling. In addition to the shelf wells, pseudowells have been modeled at various selected deepwater locations to understand sediment paleo-temperatures within the study area.

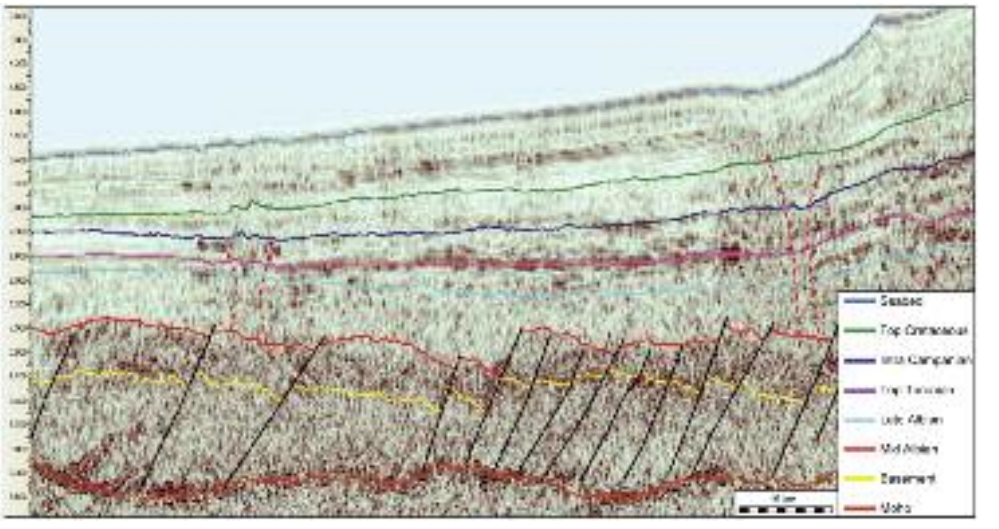
Extreme crustal stretching associated with early Cretaceous Atlantic rifting resulted in rapid subsidence to bathyal conditions in the late Albian.

Two main source rock intervals (Turonian-Cenomanian and late Albian) were modeled for hydrocarbon expulsion. The modeling indicated that:

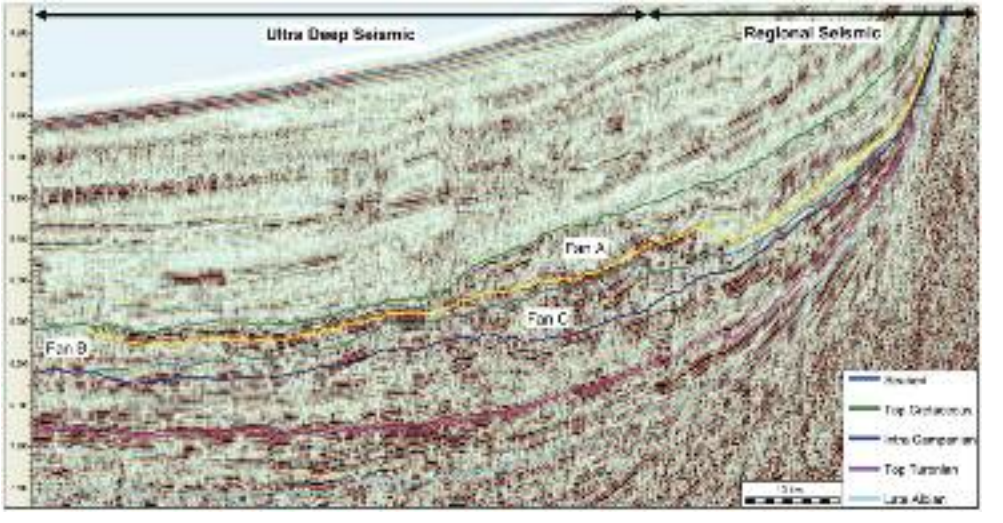
- Burial and temperature conditions in Liberia ultra-deep water are such that the Cretaceous source rocks expelled hydrocarbons during the late Cretaceous to present;
- Early Cretaceous source rocks would have undergone peak expulsion within the late Cretaceous; and
- The major phase of expulsion of Turonian-Cenomanian source rocks occurred throughout the late Cretaceous to early Paleogene.

In summary, the study indicated several aspects of Liberian basin geology:

- The study area is structurally complex in parts. Its evolution and architecture are controlled by ocean spreading and transform movements. It is bounded by the Sierra Leone and the St. Paul transform zones;
- Extensive thick channel/stacked fan complexes (within late Albian-top Cretaceous) have been identified extending from mid-shelf across to the ultra-deep basin;
- Upper Cretaceous stratigraphic and Lower Cretaceous structural play types (tilted fault blocks) have been identified and evaluated;
- An Albian lacustrine shale and a regional Turonian-Cenomanian marine shale are the two main source rocks in the study area. Thermal modeling indicates that these source rocks are mature, with peak expulsion throughout the late Cretaceous to early Paleogene; and
- Numerous potential hydrocarbon indicators (bright/dim amplitudes, gas chimneys) have been identified, suggesting working hydrocarbon systems that have been proven by recent drilling results. E&P



A regional Liberian ultra-deep seismic line shows the complete sedimentary sequence. Structural traps and some potential hydrocarbon indicators (fluid conduits) also are shown.



A composite seismic line extending from Liberian shallow waters to ultra-deep basins (>4,000 m, or 13,525 ft water depth) shows three fans identified between intra-Campanian and top Cretaceous.