Unravelling Salt Structural Evolution: Case Study from West Africa

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The offshore area of Guinea Bissau is part of the Mauritania-Senegal Basin that forms a part of Mesozoic-Cenozoic basin in the Central Atlantic passive margin of West Africa (Figure 1). Its geological history reflects the evolution of the Atlantic Ocean. The area is also located in one of the salt basins in West Africa, with a syn-rift salt sequence of Triassic–Early Jurassic age. The sequence formed various salt structures, which provide potential hydrocarbon trapping mechanisms. To reveal the distribution and evolution of the salt structures in the Offshore Guinea Bissau will lead to the better understanding of interaction between the sediments and the structures. The study will also give explanation for reservoir distribution, the timing of trap formation and the shape of the salt structures, hence helping to better locate the prospects in hydrocarbon exploration activity.

A schematic east-west cross-section across the area from onshore to the continental slope shows the pre-rift, syn-rift and post-rift sequences of the area (Figure 2). The pre-rift section is represented by sediments of the Paleozoic basin below the Mesozoic-Cenozoic section that formed the basement for the Mauritania-Senegal Basin. The Mesozoic and Cenozoic successions in the basin are as follows: (1). Permo-Triassic syn-rift sequence; (2). Jurassic thick carbonate post-rift sequence; (3). Cretaceous sequence, which records regression in the Aptian and the Albian with the deposition of thick fluvio-deltaic sands, transgression during the Cenomanian and Turonian resulting in the deposition of the most potential source rock section in the area, regression during the Senonian, and major sandstone deposition during the Maastrichtian; (4). Tertiary sequence, which only consists of thin continental sediments deposited in the eastern part of the coastal basins (Dillon & Sougy, 1974; Seibold, 1982; Jones & Mgbatogu, 1982; Dumestre & Carvalho, 1985). The sandstones of the Albian and the Maastrichtian are the two major exploration targets in the area.

Optimizing Problematic Data Availability

The data available for the study consists of a selection of lines from two large 2D datasets, one was shot in 1981-1982 and the other in 1988. The selected data consist of 66 lines, covering an area of 18,400 km², with the longest line reaching approximately 90 km in length. The 3D seismic data set covers an area of 16,800 m x 19,800 m in the northern part of the study area, encompassing an area around one of the larger diapirs. Although the 2D seismic data appears to be of better quality than the 3D seismic data and shows reflectors with better continuity especially in the deeper horizons, neither the 2D nor the 3D seismic data gives optimum resolution of the salt shape; especially at depth where the base of the salt are.

Because of the great thickness of the post-rift sediments, the seismic data does not image well the syn-rift section or the basement. To obtain some information regarding the overall structure of the basement, an additional data set of a regional marine gravity anomaly from Geosat and ERS-1 satellite altimetry was used in the project.

Data from 11 wells were also available. The oldest wells were drilled in late 1960s to early 1970s, and the newest was drilled in 2002. Many of the older wells do not have time-depth data. However, five of the six wells with check-shot surveys lie within the seismic dataset and these have been used to tie the seismic data. Dummy check-shots have to be created for the other wells for the well-seismic tie, mainly using analogues from adjacent wells.

Most of the wells were drilled at salt diapir edges where exact horizon ties are problematic because the steep primary dips are not always well imaged, especially on 2D migrated lines. This therefore, gave the low confidence in some of the well-seismic ties and horizons were often identified on character away from the wells. Problems were also encountered with age determination of deep horizons, since none of the wells reached sections older than Cretaceous, except where they penetrated the top of a salt structure. As a consequence, the identification of pre-Aptian horizons is speculative.

Horizon and Salt Structure Determination

The determination of salt structure was started by interpreting several main horizons as shown in the north-south seismic line in Figure 3. The youngest horizon interpreted is the seabed, followed progressively by older horizons as follows: Near Top Lower-Middle Eocene, Top Upper Maastrichtian, Top Lower Maastrichtian, Near Top Lower Senonian, Top Cenomanian, Top Albian, Top Aptian, Top Neocomian, Top Jurassic and Intra Jurassic event. All the sediments imaged in the seismic section belong to

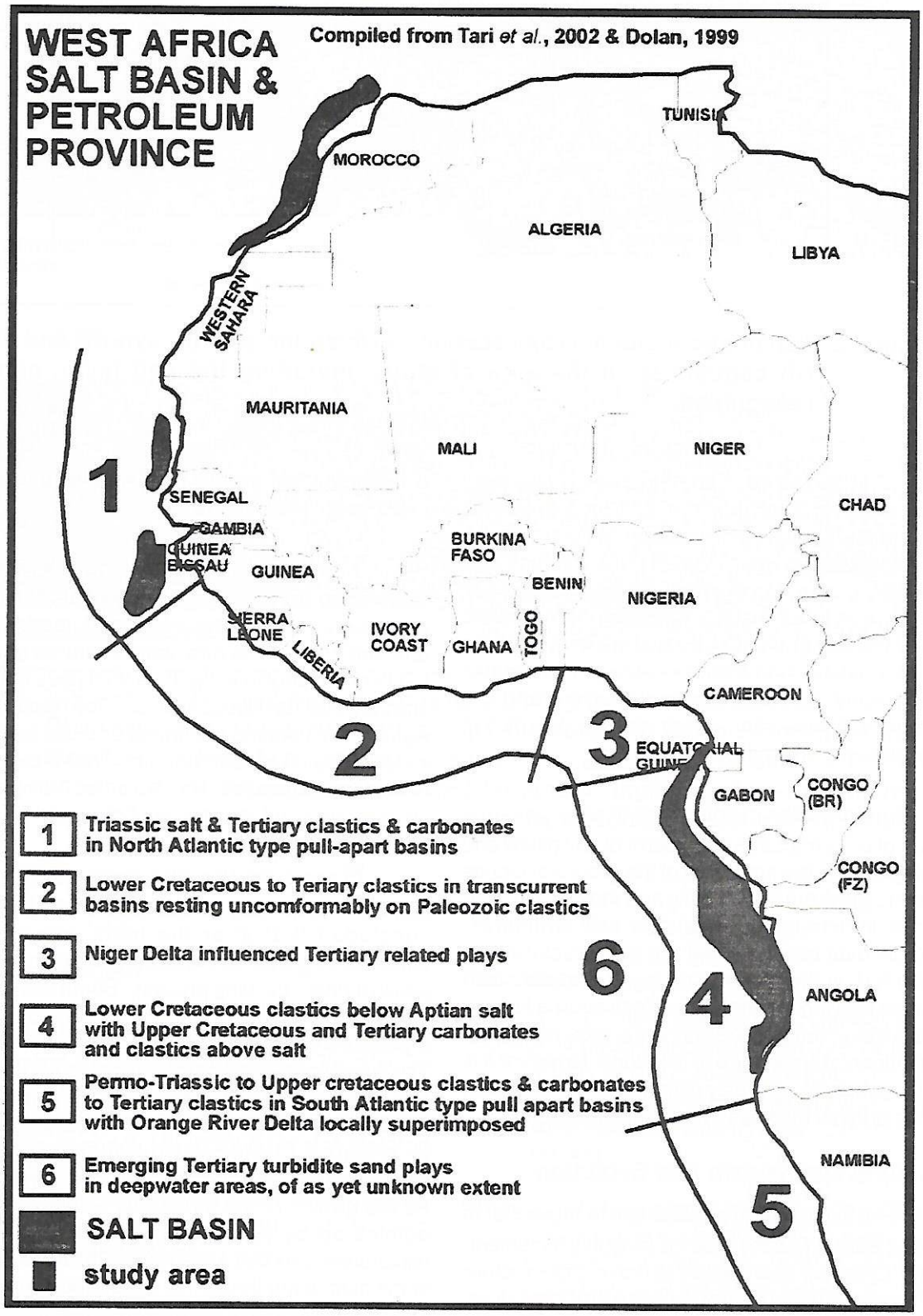


Figure. 1 Location map. The study area is located in the Central Atlantic passive margin of West Africa. It is also located in one of the salt basins in West Africa.

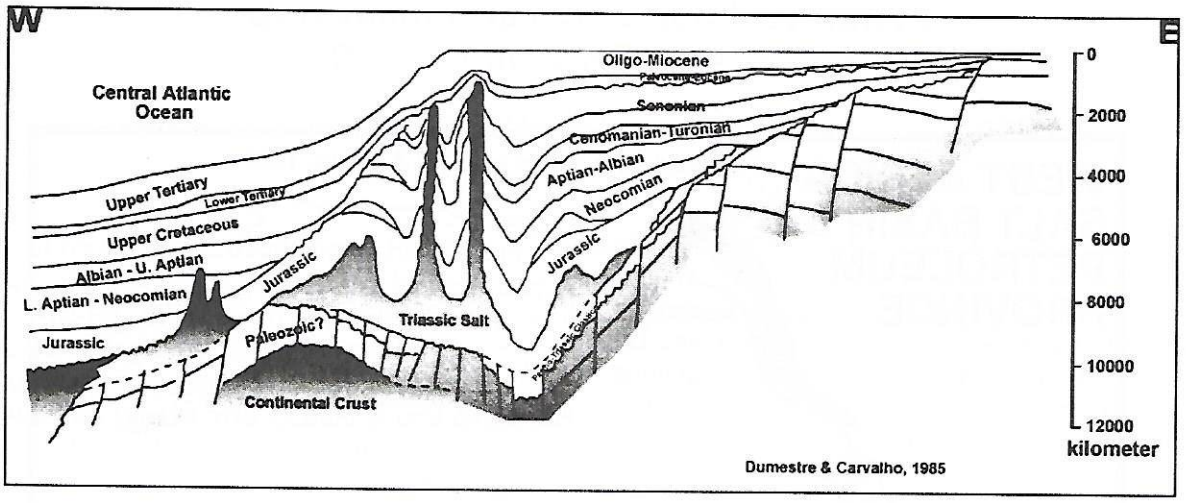


Figure. 2 Schematic regional cross section in which the pre-rift, syn-rift and post-rift sequences in the area of study, including the salt layer, can be recognised.

the post-rift sequence. Time structure maps were constructed for each horizon and time thickness maps created for adjacent horizons. The process was then continued by analysing: (1). the thinning and thickening patterns of the time thickness maps (2). the nature of relationships between the reflectors around the salt structure and (3). the fault patterns around the diapirs, to determine the pre-kinematic, syn-kinematic and post-kinematic layers and the sediment-salt interaction, which will provide a clue to the evolution of the salt structure.

Interpretation of seismic data shows several groups of salt structures in the form of salt pillow and salt diapirs over the area. Two of the groups of diapirs appear to grow out of salt walls and the rests appear to grow individually as isolated salt structures. Available data indicates that the salt structures are directly fed by the mother salt layer. The data also indicates that the original syn-rift salt source layer is available over the whole study area, extending from the continental shelf edge to the slope. However it is also thought to be unevenly distributed over the basin and the original thickness was not uniform.

Structural Mechanism and Evolution

The initial trigger mechanism to move salt to form salt walls is faulting, and it is probably basement-related. Once the fault ceased to move, the structure grew passively through down-building process to form point diapirs. The salt structures situated along the present-day shelf edge are considered to have always been located along the shelf edge throughout their evolution. It is not clear what trigger the mechanism that initiated the movement of the salt to form these structures. However, it is possible that the mechanism was associated with the shelf-edge location, such as sedimentary differential loading or faults bounding a prominent feature which determined the location of subsequent shelf edges.

The initial movement of the salt is thought to have occurred very early in the post-rift stage. The evidence is shown by the onlapping Jurassic sediments onto the flanks of several salt structures and also by the thinning shown in the time thickness maps of the Top Jurassic-Top Neocomian and Top Neocomian-Top Aptian. The thinning continued and can be observed in Top Albian-Top Cenomanian time thickness map before it disappeared. This indicates movement from Jurassic time to Cenomanian time.

Based on the characteristics of active diapirism according to Jackson et al. (1994), it is concluded that after the initial movement the subsequent growth of the structures is mainly through passive down-building process. Some active piercing events may have happened episodically, but the indications of the timing of these events are not clear. The growth continued over the Cretaceous and Eocene and ended sometime between Eocene and Recent, due to either source depletion or lack of sedimentation to promote further down-building, so that no expressions of the structures are found on the seabed. As the growth of the structures is interpreted to be dominated by passive down-building, the main exploration objective Albian sands located in the flanks of the diapirs are thought to experience considerable thinning, more than if the growth of the structure were through active piercing.

The characteristics and evolution of the salt structures in the area of study clearly indicates that the salt tectonic style in the Triassic syn-rift salt of the Central Atlantic is very different than that found in the Aptian post-rift salt of the South Atlantic.

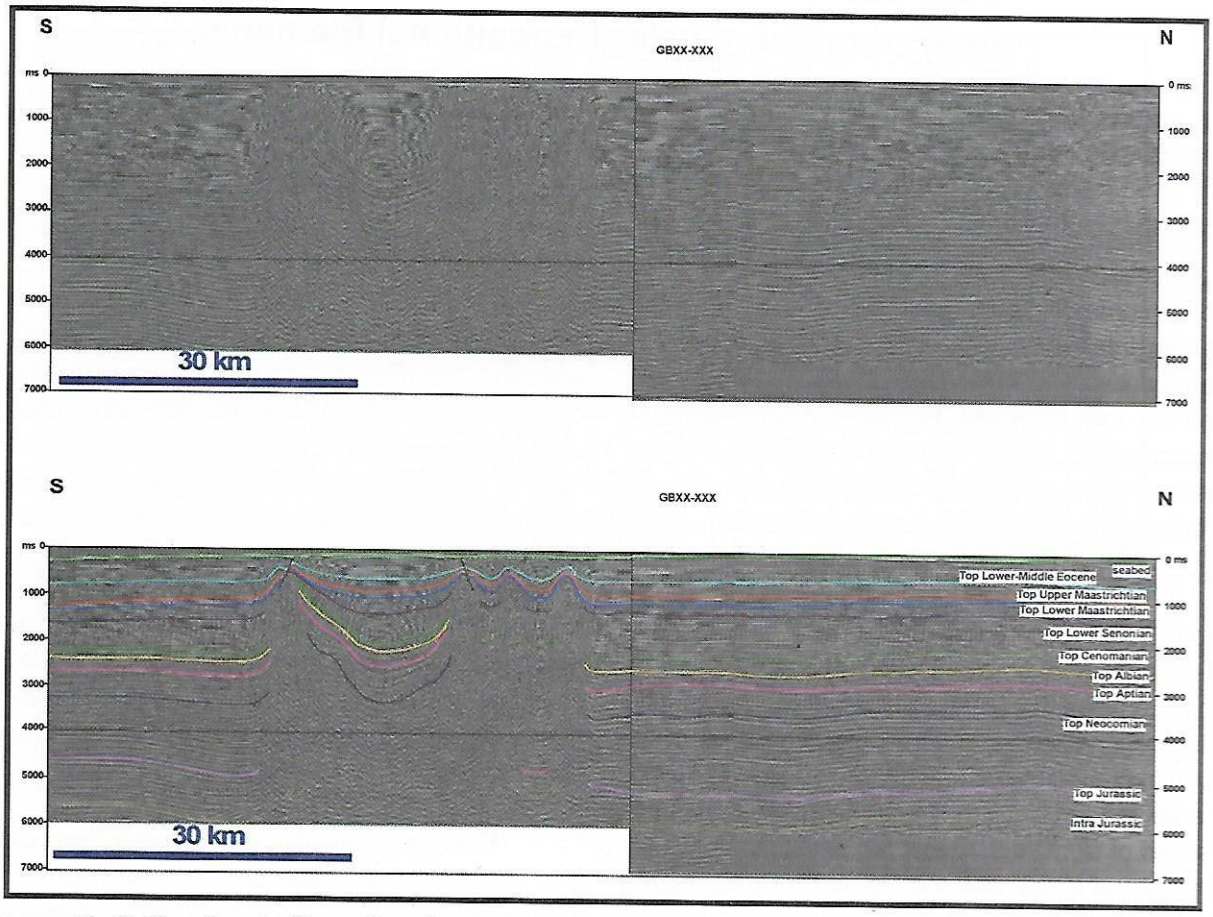


Figure. 3 N-S seismic line showing a salt wall, which grows out into several salt diapirs. Observing the nature of relationships between the reflectors around the salt structure and the fault patterns around them enables us to determine the pre-kinematic, syn-kinematic and post-kinematic layers and the sediment-salt interaction, which will provide a clue to the evolution of the salt structure.

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detail flow on the implementation on a particular area, however, must be determined through a feasibility study, observing the rocks behavior on that field based on the wireline logs.

Conclusions

Interpreters need to consider seismic inversion whenever interpretation is complicated by interference from nearby reflectors or the end result is to be a quantitative reservoir property such as porosity. Output in the format of geologic cross-sections of rock properties (as opposed to seismic reflection amplitudes) is endlessly useful as a means to put geologists, geophysicists, petrophysicists and engineers "on the same page". It is almost always useful to do sparse spike inversion first so that we may be crystal clear about what the seismic is telling us, free from bias from logs.

The days of viewing seismic inversion as an extra processing step or subject of an isolated special study are long gone. Modern inversions are intimately connected to detailed and quantitative reservoir characterization and enhanced interpretation productivity. The process requires and integrates input from all members of the asset team. Horizons should be re-assessed, models re-built, log processing reviewed and inversion steps iterated toward the best result. After drilling, new information should be used to create a "living cube", always up-to-date with all available information. It is this partnership directed to the solution of real reservoir characterization problems

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