

Lateral Seal – A Major Exploration Risk in the Faulted Traps of the Cretaceous Petroleum System - Central Muglad Basin, Sudan

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Introduction

Sudan is the largest country in Africa with an area of 2.5 million km² and common borders to eight countries (Figure 1). Oil exploration began in the late fifties but was focused in the offshore areas of the Red Sea. In 1974 Chevron commenced exploration in the interior rift basins, including the Muglad Basin. To date significant hydrocarbon reserves have been discovered, and the country currently produces about 280,000 BOPD.

Muglad Basin (Figure 2) is a northwest-southeast trending rift basin in Sudan. It is more than 100,000 km² in areal extent and probably contains as much as 13,000 m of sediments.

Blocks 1, 2, and 4 lie in the central part of this basin. Greater Nile Petroleum Operating Company operates these blocks for a consortium of China National Petroleum Company (CNPC) (40%), Petronas Carigali Overseas Bhd (PCOSB) (30%), ONGC Videsh Limited (OVL) (25%), and Sudanese Petroleum Corporation (SUDAPET) (5%).

Petroleum Geology

Muglad Basin contains a thick sequence of nonmarine sediments, which range in age from Cretaceous to Tertiary. The basin is A generalized stratigraphic column is shown in Figure 3, illustrating the rift and sag episodes in relation to basin filling and sedimentation.

Exploration results have proved hydrocarbon system in both Tertiary and Cretaceous sections. The main hydrocarbon play is the Cretaceous petroleum system. This petroleum system has a perfect assemblage of source, reservoir, and top seal. The source is the Lower Cretaceous lacustrine shale of “Abu Gabra” Formation.



Figure 1.Sudan in the heart of Africa

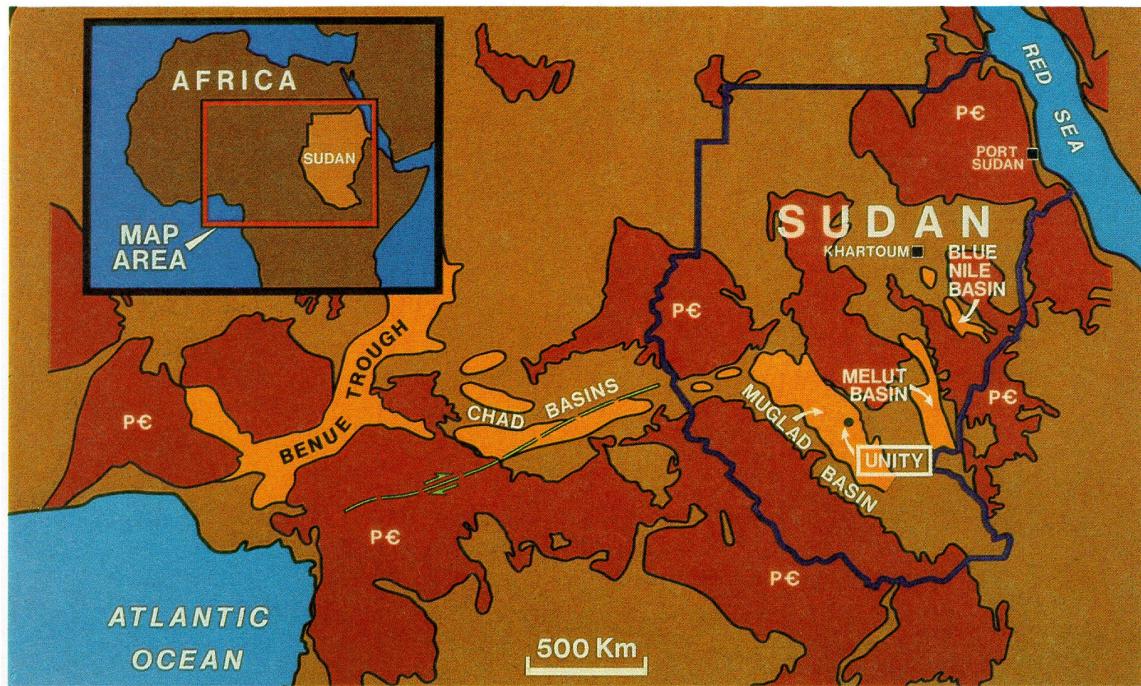


Figure 2. Generalized map of Central Africa showing Central Africa rift system, associated rift basins, Muglad basin, Sudan, with location of Unity field (from Giedt, 1990).

The reservoir is the braided-stream sandstones of “Bentiu” Formation, and the top seal is the fluvial shale of Aradeiba Formation. More than 70% of traps are tilted fault blocks with high dependency on the lateral seal across the bounding fault. Therefore, the above perfect marriage of source, reservoir, and top seal is counter-acted by a higher risk in the lateral seal. Bentiu Formation contains a massive thick sand (over 1500 m in some parts) of good quality reservoir with localized shale interbeds 20-60 m thick.

Lateral Seal

Lateral seal depends on the thickness and the lithology of the Aradeiba shale and the amount of fault throw. Figure 4 is schematic illustration of this relationship. The Aradeiba Formation is highly variable in thickness and in sand/shale ratio. Thickest Aradeiba Formation penetration to date is in excess of 1000 m in the central part of the basin , decreasing to less than 20 m along the basin edges. Most of the perfect lateral seals are due to direct juxtaposition of Bentiu sandstone reservoirs against Aradeiba shale. Examples of this situation are illustrated in Figures. 5, 6, 7 and 8.

In some cases clay smear and shale gouge ratio play an important role in lateral seal integrity. The shale gouge ratio seems to depend on shale thickness and amount of displacement along the fault plane. Shale gouge will, of course, also depend on clay mineralogy, but this aspect has not been fully investigated.

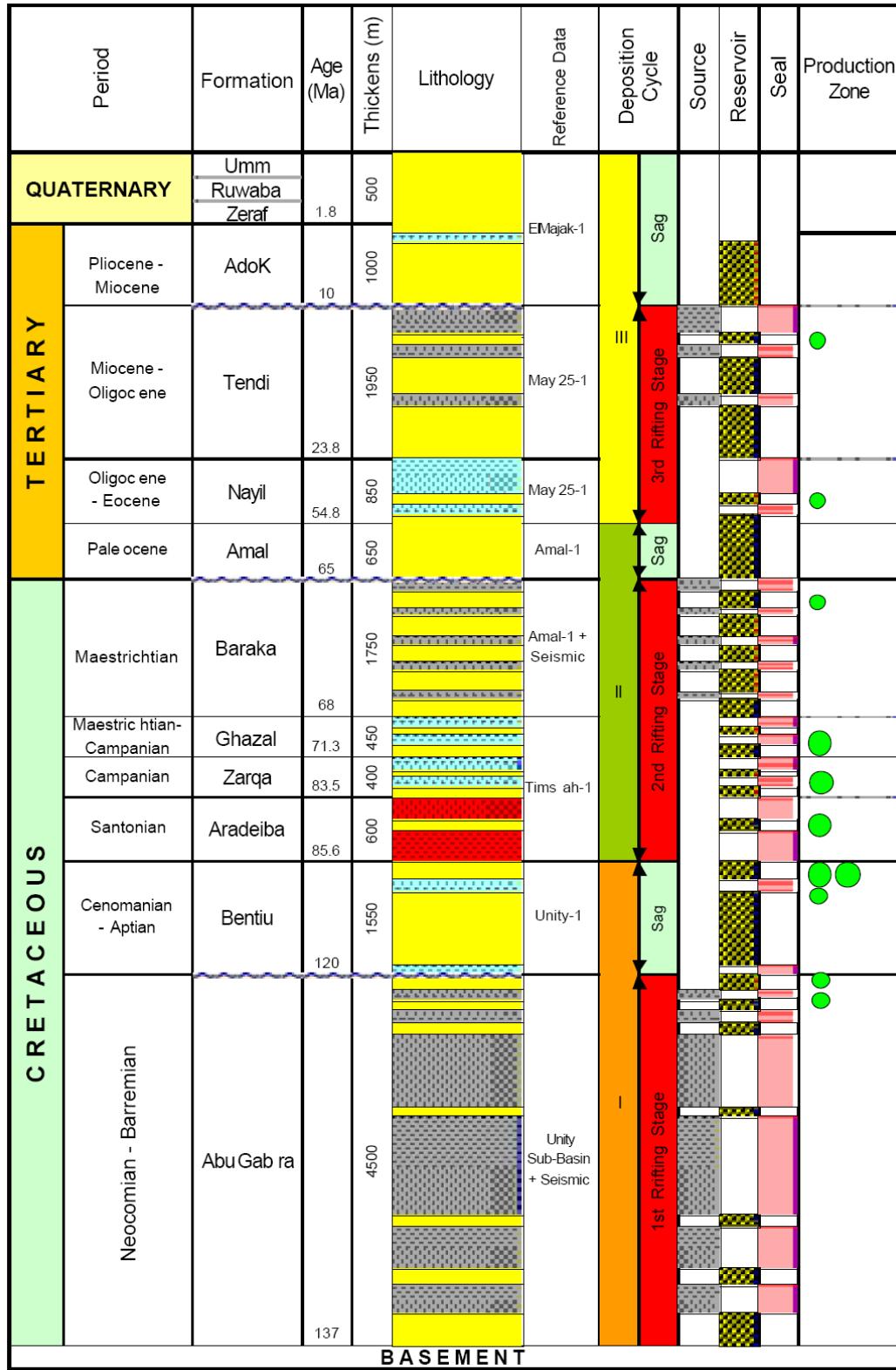


Figure 3. General stratigraphic column - Muglad Basin, Sudan, showing three geological cycles—Neocomian to Barremian, Aptian to Maestrichtian, and Paleocene to Pliocene-Miocene, or Quaternary.

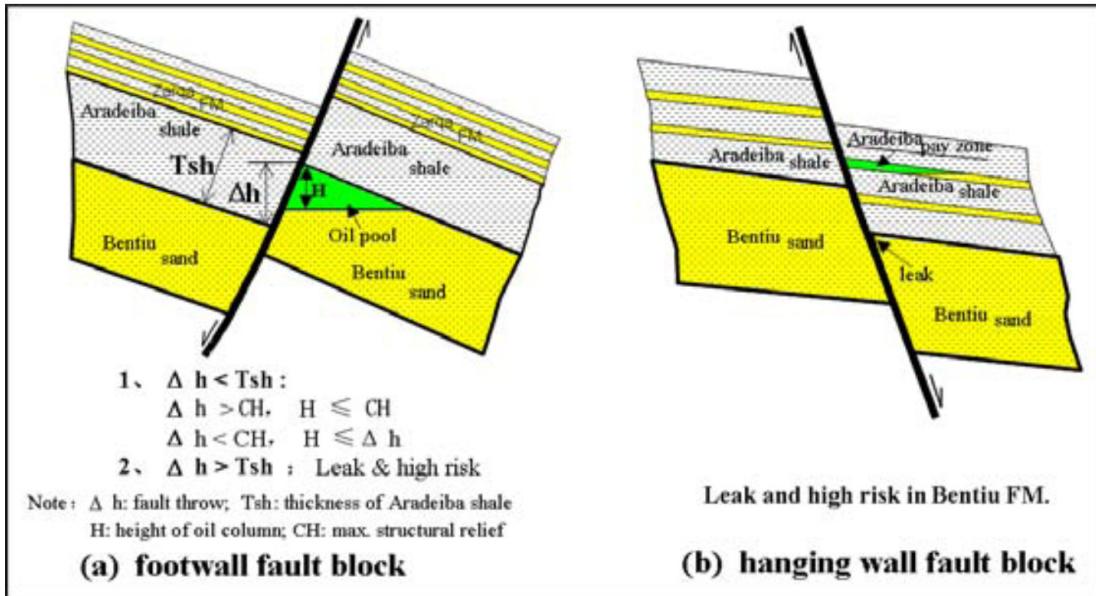


Figure 4. Schematic illustration of lateral seal dependence on the Aradeiba thickness, lithology, and the amount of fault throw. (a) Footwall block; fault throw is less than the thickness of Aradeiba Shale, massive Aradeiba Shale provides the top and lateral seal for Bentiu reservoir. Oil column increases with increasing fault throw. Where fault throw is larger than the thickness of Aradeiba Shale, Bentiu objective is juxtaposed against Zarqa sand, resulting in lateral seal failure. (b) Hanging wall fault block; Aradeiba intraformational shale and fault smear provide the top and lateral seal for Aradeiba reservoirs; for Bentiu Sand, the objective is juxtaposed against the Bentiu massive sand across fault causing lateral seal failure. However, fault smear can provide weak lateral seal to form a limited oil column.

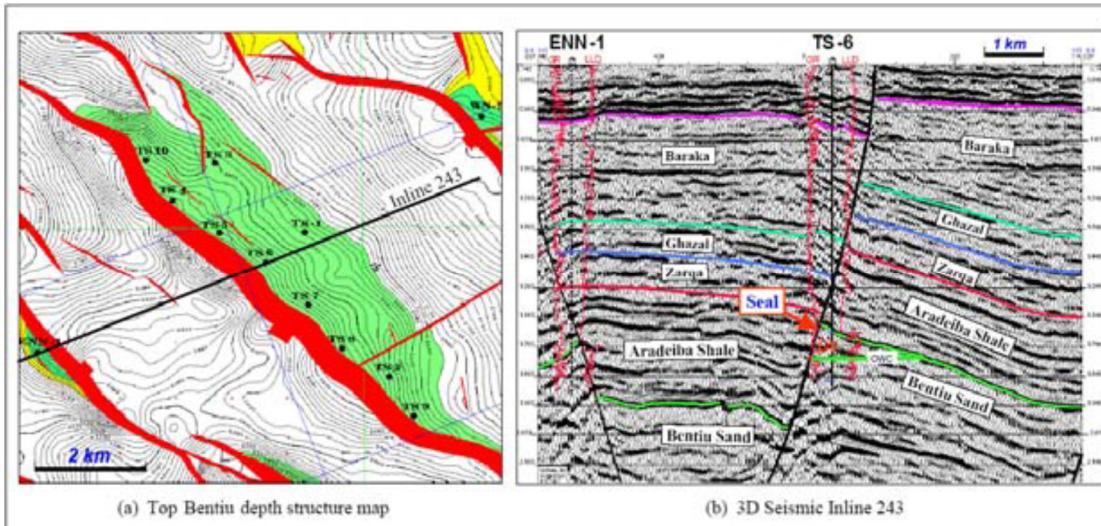


Figure 5. An excellent fault-sealing example. (a) The top Bentiu depth map shows a field charged to structural spill point with 140-m oil column. (b) 3D seismic section illustrates that the thick massive Aradeiba Shale (480 m) provided good top and lateral seal for Bentiu reservoir. The fault throw (430 m) is less than the thickness of Aradeiba Shale.

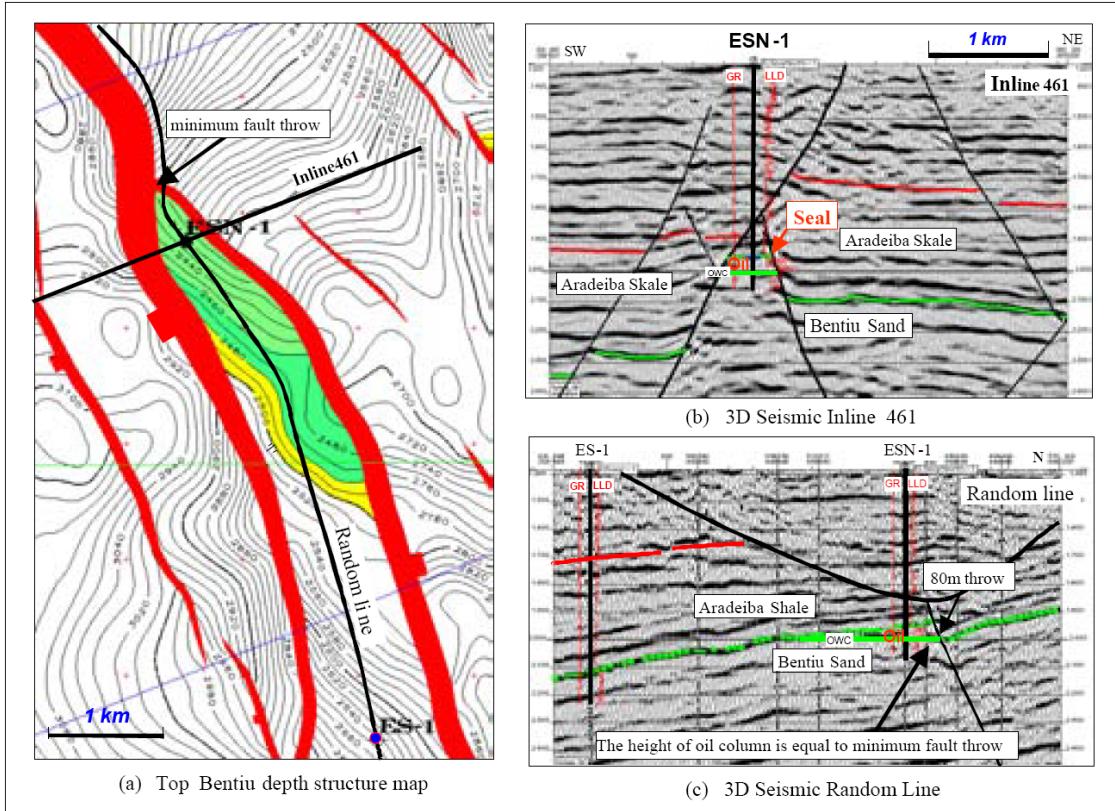


Figure 6. Another excellent fault-seal example. (a) Oil column is controlled by the fault throw in the northern part. (b) The thick (approximately 400 m) massive Aradeiba Shale provided good top and lateral seal for Bentiu reservoir. (c) 3D random section illustrates that the oil column is nearly equal to minimum fault throw (80 m) at which point sand is juxtaposed sand.

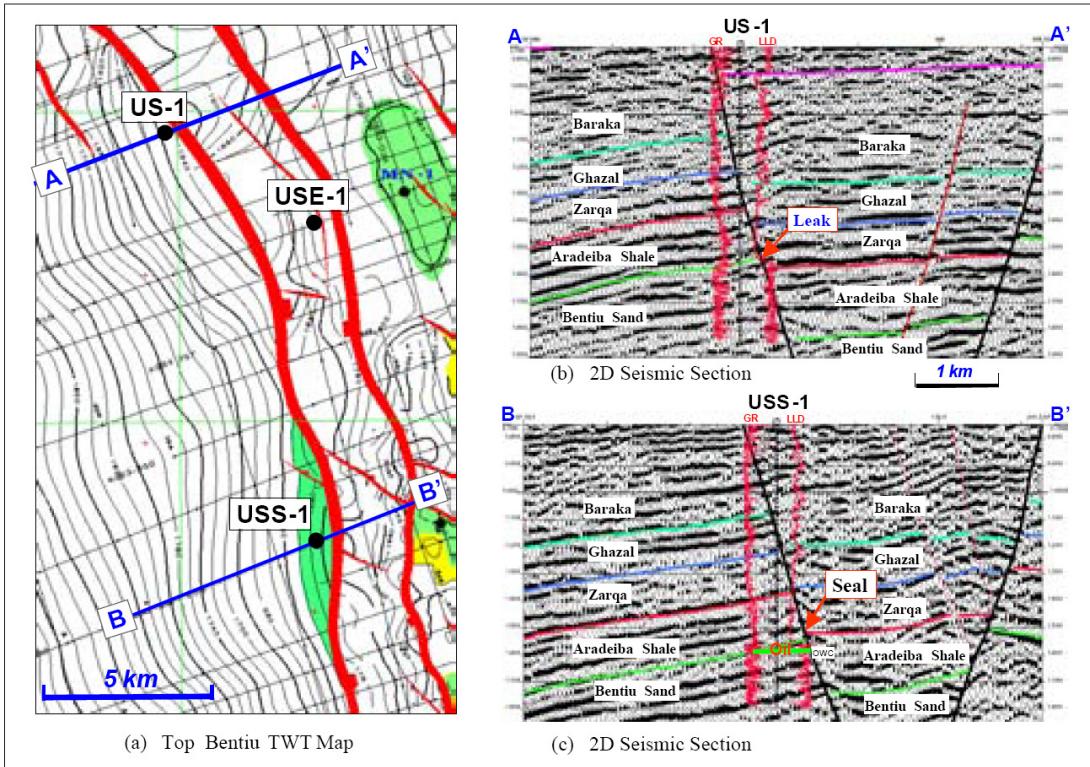


Figure 7. (a) Top Bentiu TWT map shows a tilted footwall fault block with US-1, water-bearing well, in Bentiu, and USS-1 an oil discovery well. The throw of the bounding fault varies from 400 m in the north (across US-1) to 300 m in the south (across USS-1). (b) The section illustrates that the fault throw across US-1 well is larger than the thickness of Aradeiba shale (360m), juxtaposing Bentiu reservoir against Zarqa sands, resulting in lateral leakage; hence, Bentiu sand is water-bearing. (c) The section illustrates that the fault throw is smaller than thickness of Aradeiba shale and thereby provides good lateral seal, resulting in USS-1 discovery (drilled after US-1).

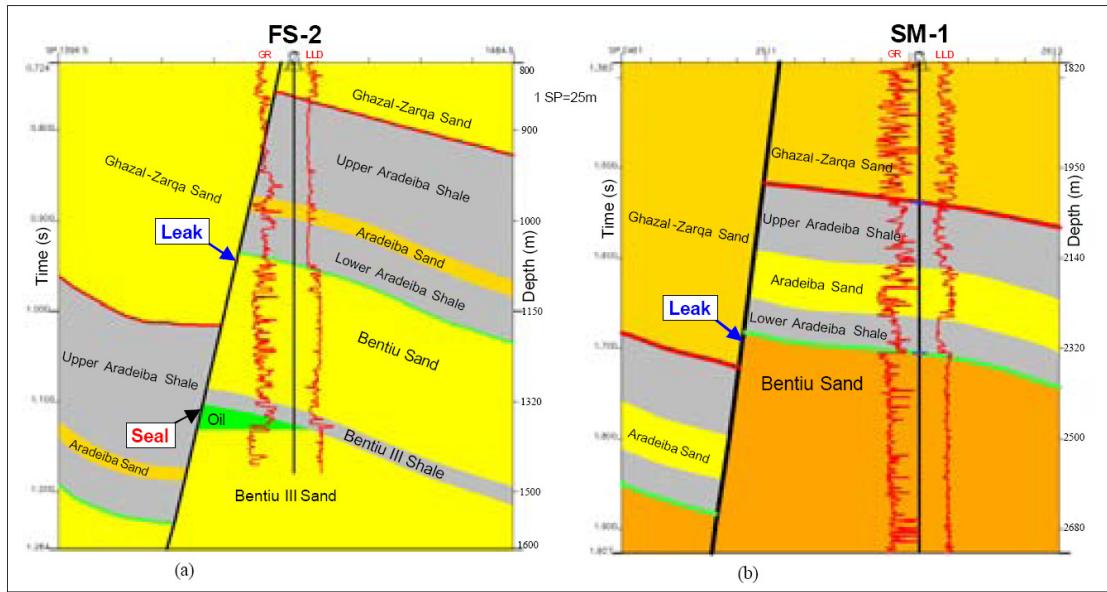


Figure 8. (a) Cross-section showing water-bearing zones in upper part of Bentiu reservoir, due to lateral seal failure, and pay zone in lower part (Bentiu III sand). Bentiu III sand is juxtaposed against Aradeiba Shale resulting in good lateral seal. Top seal is provided by intra-Bentiu shale. (b) Cross-section with dry hole, where there is lack of lateral seal for Bentiu reservoir. These two cross-sections illustrate lateral-seal risk associated with footwall closures. Optimum fault throw in comparison with Aradeiba Shale section is critical for trap integrity.

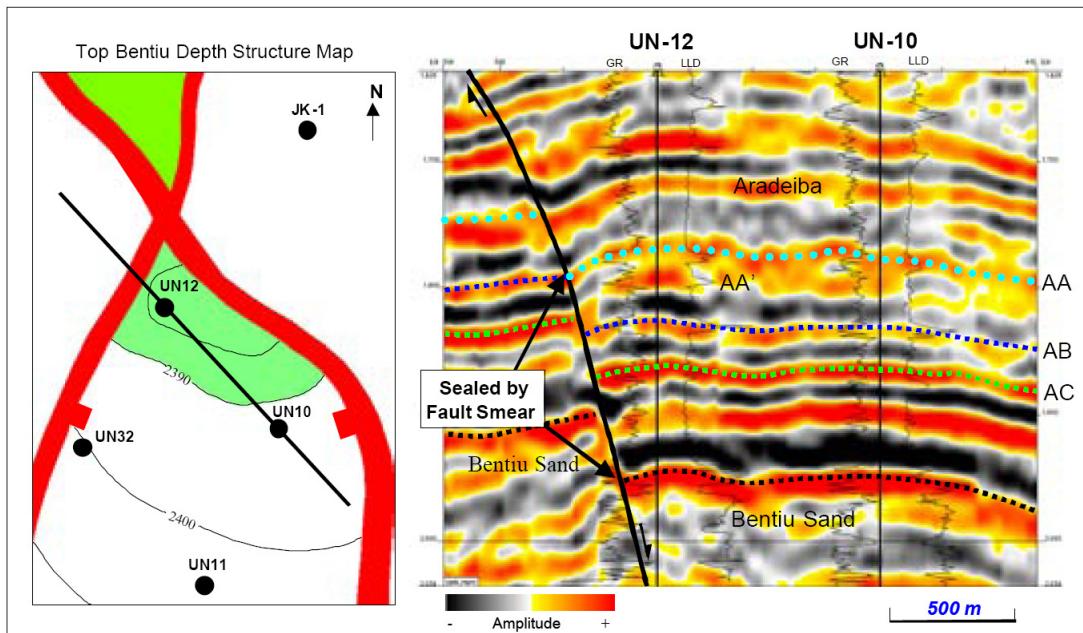


Figure 9. Example of oil discovery in a hanging-wall fault block. AA, AB, and AC sands are production zones with more than 50-m oil columns. AB and AC sands juxtaposed against Aradeiba intraformational shale across the fault to provide good lateral seal; AA and Bentiu sand juxtaposed against AB sand and Bentiu massive sand, respectively, but shale fault smear provided good lateral seal, resulting in a small oil column in Bentiu reservoir.

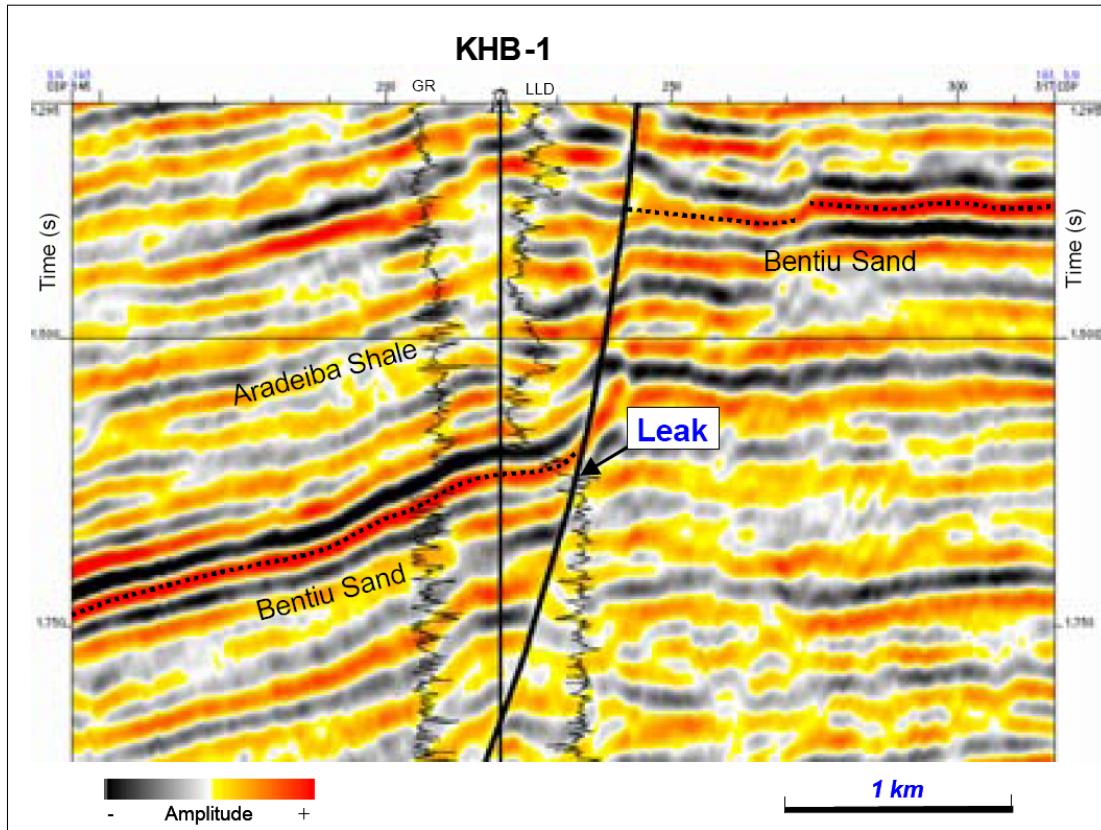


Figure 10. 3D Seismic Section, showing a dry hole in the hanging-wall fault block. This illustrates why the hanging-wall closure bounded by fault has high lateral seal risk. Bentiu reservoir objective is juxtaposed against Bentiu massive sand in the upthrown block across the fault.

Reference

Giedt, Norman R., 1990, Unity field—Sudan Muglad rift basin, Upper Nile province, in AAPG Treatise in Petroleum Geology, Structural traps III: Tectonic fold and fault traps, p. 177-197.