[PS]Passive Continental Margin Basin Evolution and Giant Gas Discoveries in Offshore East Africa*

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Abstract

Passive continental margin basins in offshore east Africa (PCMBOEA) include Somali, Lamu, Tanzania, Ruvuma, Mozambique, and Zambezi Delta basins totaling over 2,000,000 km^2 in area. Gas discoveries date back to the 1970s; however, since 2010, about 141 Tcf gas discoveries make it an area of extreme interest. The basin evolution mainly involves three stages. First stage was the NE-SW trending intracontinental Karoo system developed in the Permo-Triassic with facies ranging from fluvial to lacustrine to deltaic. The second stage was the initiation of the Gondwana break-up, occurring in the Middle Jurassic, resulting in the southward drift of Madagascar away from east Africa. A passive continental margin developed along the western coast of Madagascar and eastern coast of Africa from the Middle Jurassic to the Early Cretaceous represented almost by continental- transitional to shallow marine deposits, followed by development of widespread marine transgression. The third state is seen after the end of the sea-floor spreading between Madagascar and Africa and the initiation of India's separation from Madagascar in late Cretaceous as a passive margin developed along the eastern coast of Africa. Several potential lacustrine and marine organic-rich source rocks are present in the PCMBOEA, ranging in age from Triassic to Middle Jurassic to Tertiary, respectively. Cretaceous sandstones represent a regional proven reservoir, while Tertiary deltaic sandstones or limestones are a local proven reservoir. The Permo-Triassic Karoo Group sandstones and Jurassic sandstones or limestones are considered potential reservoirs. Cretaceous siltstones and shale are regional seals and Jurassic evaporates, if present, may provide local effective seals whose quality deteriorates towards the eastern Africa coast. Three distinct structural phases corresponding to basin evolution are recognized: E-W Karoo rifting, S-N extension during the early stages of Gondwana break-up, followed by Tertiary extension and listric fault growth. Hydrocarbon generation from different levels of source rocks probably occurred at various times throughout late Cretaceous and Tertiary times, followed by vertical and lateral migration with a relatively short and long distance, respectively, lead to the hydrocarbon accumulation within the drift sequence such as delta sand bodies and deep-sea turbidite deposits. Area 4, whose main reservoir is Paleocene-Oligocene sand, is operated by EniEAfrica and is the largest gas discovery with total recoverable reserves over 10,000 mmboe, and occurs in such a setting.

Passive Continental Margin Basin Evolution and Giant Gas Discoveries in Offshore East Africa

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1. BASIN LOCATION AND THE GIANT FIELDS

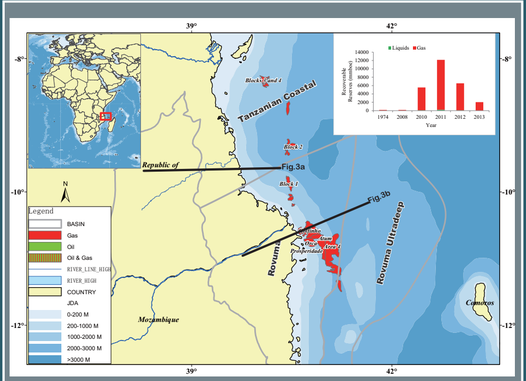

Figure .1 Location map including basin boundary, giant fields and cross sections of eastern offshore Africa.

Basin Name	Field Number	Field Name	Country	Discovery Date	Field Type	Water Depth (m)	Operator	Total Recoverable Reserves (mmboe)
Rovuma	1	Area 4	Mozambique	2011/10/20	Gas	1,707	EniEAfrica	10,382.74
	2	Prosperidade	Mozambique	2010/2/18	Gas	1,500	Anadarko	4,577.69
	3	Golfinho	Mozambique	2012/5/15	Gas	1,027	Anadarko	3,316.00
	4	Block 1	Tanzania	2011/4/4	Gas	1,295	BG	1,599.65
	5	Espadarte	Mozambique	2013/7/5	Gas	468	Anadarko	1,232.00
	6	Atum	Mozambique	2012/6/11	Gas	1,000	Anadarko	1,165.00
	7	Orca	Mozambique	2013/4/18	Gas	1,061	Anadarko	717
Tanzanian Coastal	8	Block 2	Tanzania	2012/2/24	Gas	2,490	Statoil	2,023.99
	9	Blocks 3 and 4	Tanzania	2010/10/16	Gas	1,750	BG	968

Table1. Giant gas fields of the eastern Africa, for locations see Figure.1.

(1) Basins and location

Passive continental margin basins in offshore east Africa (P-CMBOEA) include Somali, Lamu, Tanzanian Coastal, Rovuma, Mozambique, and Zambezi Delta Basin.

(2) Gas discoveries

Gas discoveries dates back to 1970s, but the giant gas discoveries start from 2010, which make the offshore Africa be a hot exploration area.

(3) Giant gas fields

The giant gas discoveries mainly locate in Tanzanian Coastal and Rovuma Basins within the (ultra-)deepwater environment, with the water depth from 450 m to 2450 m. The Rovuma basin has a total recoverable reserves of 23 bboe, while the Tanzanian Coastal basin has 3bboe.

2. GEOLOGICAL SETTINGS, PALEOPLATE RECONSTRUCTIONS AND REGIONAL CROSS SECTION

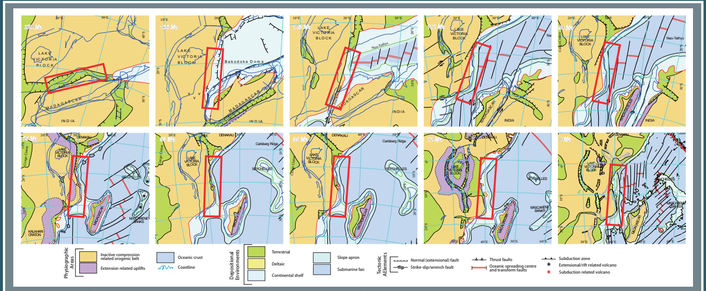

Figure 2. Paleocontinental-paleographic map of east Africa, the red rectangular represents the approximate location of the Ranzanian coastal and Rovuma basins (Modified from Tellus and scotese et al. (1994))

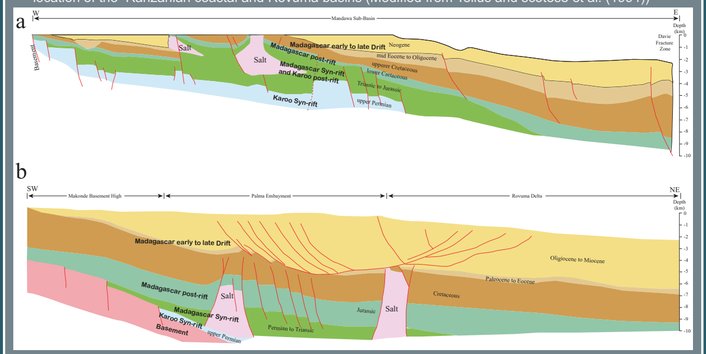

Figure 3. Simplified regional cross sections of Tanzanian coastal and Rovuma basins(Fig. 3a and 3b respectively, for locations see Figure 1). modified from kajato (1994) and Tanzanian Petroleum Development Corporation(1999)

(1) Basin evolution

mainly involves three stages: 1) The NE-SW trending intracontinental Karoo system was developed in Permo-Triassic with a range of facies from fluvial to lacustrine to deltaic; 2) The initiation of Gondwana break-up occurred in Middle Jurassic, resulting in the southward drift of Madagascar away from east Africa and a passive continental margin development along the western coast of Madagascar and eastern coast of Africa from Middle Jurassic to Early Cretaceous represented almost by continental- transitional to shallow marine deposits, followed by development of widespread marine transgression; 3) After the end of the sea-floor spreading between Madagascar and Africa and the initiation of India's separation from Madagascar in late Cretaceous, a passive margin developed along the eastern coast of Africa.

(2) Cross sctions

Three distinct structural phases corresponding to the basin evolution are recognized: E-W Karoo rifting, S-N extension during the early stages of Gondwana break-up, followed by Tertiary extension and listric fault growth.

3. PLAYS, BURY HISTORY AND MAIN STRUCTURES

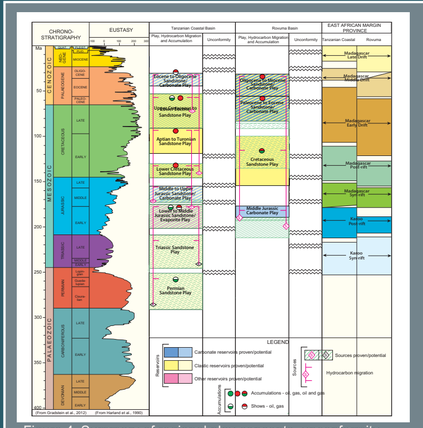

Figure 4. Summary of regional play concepts, unconformity, and rift events of Tanzanian Coastal and Rovuma basins (Modified from Tellus, Gradstein et al., 2012)

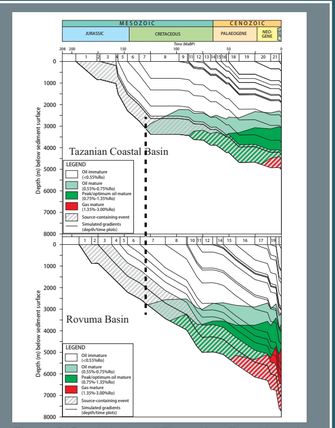

Figure 5. Bury history of Tanzanian Coastal and Rovuma basins (Modified from Tellus)

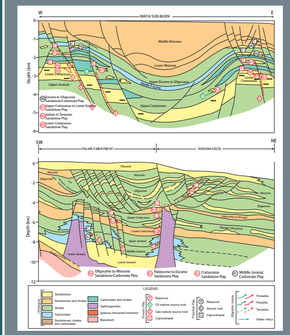

Figure 6. Play cartons of Tanzanian Coastal and Rovuma basins (Modified from Tellus)

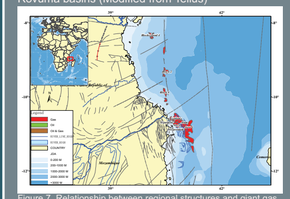

Figure 7. Relationship between regional structures and giant gas fields(Modified from Tellus and Mahanjane et al., 2014)

(1) Plays

Cretaceous sandstone can represent a regional proven reservoir, while Tertiary deltaic sandstones or limestone is a local proven reservoir. Permo-Triassic Karoo Group sandstone and Jurassic sandstone or limestone is considered as the potential reservoirs. Cretaceous siltstone and shale is a regional seal and Jurassic evaporates if present may locally provide effective seals.

(2) Bury history

The two basins come to the oil windows at the early Cretaceous time following the peak oil mature period at the mid-Cretaceous, while the gas windows start between Eocene and Miocene. Affected by the salt diapir the strata within mid-Cretaceous undergo the obveous uplift and the upper stratum have a thrust structure.

(3) Structures affecting the hydrocarbon migration

From the cross sections and planar distribution between the structures and giant gas fields, fields within the Tanzanian coastal basin distribute within the sandbody between the normal faults affected by the basement uplift, mainly the vertical migration. Fields within the Rovuma basin distribute within the sandbody between the updip and downdip faults above the salt diapir structures.

4. SUMMARY AND CONCLUTIONS

(1) Paleoplate reconstructions and cross sections indicate three stages, including E-W Karoo rifting, S-N extension during the early stages of Gondwana break-up, followed by Tertiary extension and listric fault growth.

(2) Giant gas discoveries located within the Tanzanian Coastal and Rovuma basins with Cretaceous sandstone as regional proven reservoir and Tertiary deltaic sandstones or limestone as local proven reservoir.

(3) Giant gasfields within the Tanzanian coastal basin distribute within the sandbody between the normal faults affected by the basement uplift, mainly the vertical migration. While Fields within the Rovuma basin distribute within the sandbody between the updip and downdip faults above the salt diapir structures.

(4) Unconformities make the long-distance lateral migration to be possible.

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