PSA-088-Offshore Madagascar Part I

Hydrocarbon Potential in Coastal Coral Areas

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Offshore Madagascar Part I: Hydrocarbon Potential

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What is the hydrocarbon potential of the Mozambique Channel, and what has the 'Golden Zone' theory got to do with it?

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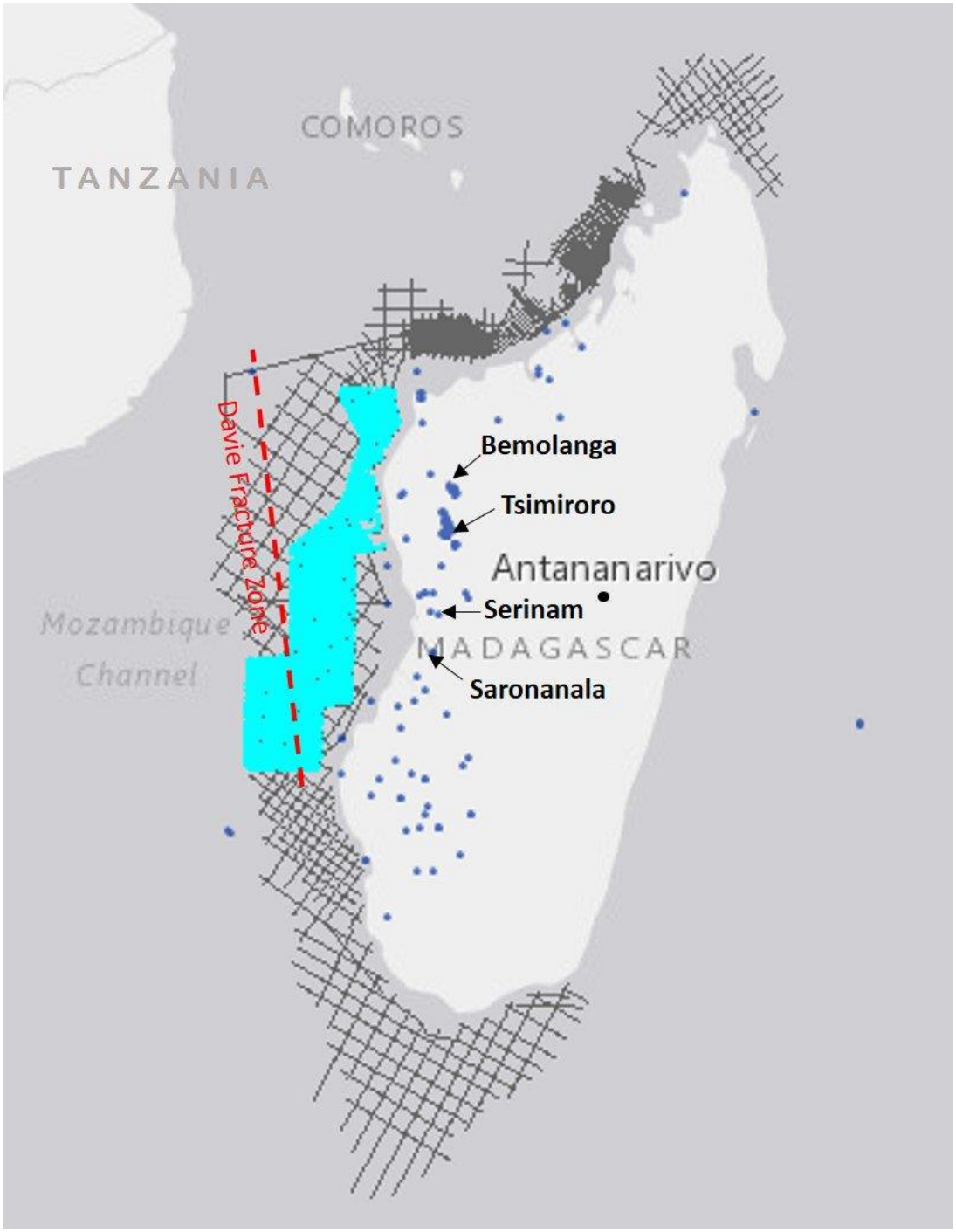
The **Morondava Basin** is located on the west coast of Madagascar, about 400 km from the east coast of the African continent. It covers an area of about **220,000 km2**, extending into deep water, but drilling has been sparse and relatively unsuccessful to date, with the exception of the discoveries in the early 20th century of the large Tsimiroro heavy oil and the giant Bemolanga ultra heavy oil fields onshore. The offshore part of the basin is relatively unexplored, but the presence of an active hydrocarbon system is indicated by gas shows in some of the wells; by gas chimneys and brightening on seismic data, and by geochemical sampling of sea-bottom sediments.

Recent work has shed new light on the tectonic and sedimentary history of **Madagascar** and in particular the **Mozambique Channel**, which has implications on potential of the **offshore Morondava Basin**, as discussed below.

Evidence for Madagascar's Pre-Break-up Position



Map showing the location of the BGP/TGS MAD-13 survey (blue), the basis for the analysis in this article, and wells mentioned in the text.*It is generally agreed that the geological history of Madagascar has been dominated by at least three major tectonic events related to the progressive breakup of Gondwanaland. These were Permo-Triassic rifting; Late Triassic/Early Jurassic rifting and separation from Africa; and Late Cretaceous separation from India. Volcanism was associated with both the Jurassic and Cretaceous rifting episodes, the Cretaceous volcanic episode being particularly recognizable on seismic as high amplitude/low frequency extrusive surfaces (of Turonian age) and as concave upward sills in the earlier sediments.

Until recently the general consensus has been that Madagascar moved to its present location from a pre-breakup

position next to Somalia, along the Davie Fracture Zone (DFZ), starting in the Early Jurassic and ending in the Upper Cretaceous when India separated from Madagascar. This process is represented in the geological record by Early Jurassic syn-rift sedimentation followed by restricted marine sedimentation and then more open marine and passive margin from the Cretaceous onwards.

However recent work (Klimke and Franke, 2016) has shown that there is good evidence from new seismic reflection data that the DFZ does not extend northwards offshore northern Mozambique, Tanzania and Kenya – implying a more southerly pre-breakup position for Madagascar within Gondwanaland and an opening of the West Somalia Basin by oblique rifting.

Read all about the BGP/TGS MAD-13* survey here...

A New Oil Play in East Africa

Newly acquired 2D seismic, which clearly illustrates the tectonic setting and prospectivity of offshore western Madagascar, is set to revive interest in the region.

This fits in with the observations the authors of this article have previously made (2016) regarding the presence of what is believed to be a more extensive offshore Karoo (i.e Late Carboniferous-Late Triassic/Early Jurassic) domain than had been generally assumed, which they termed the proto-West Somali Basin and the proto-Mozambique Channel Basin. Evidence for this comes from the recognition on seismic data of faulted continental crust (i.e a rifted Karoo terrain) in areas previously considered to be made of oceanic crust.

Evidence for this updated position for pre-breakup Madagascar

West Somalia Basin

Third party multi-client seismic data has defined a continental shelf off Somalia reportedly between 100 and 300 km wide (in the south-west and north-east, respectively). Published seismic sections e,g **GEO ExPro Vol. 13, No. 2 foldout 'Offshore Somalia: East Africa's Oil Frontier'** show what the authors of the current article believe to be an approximately 200-km-wide zone of continental crust (rifted Karoo/Upper Jurassic) in the Jubu-Lamu Basin in the south-western part of the Somalia offshore domain. This leads them to conclude that there is more continental crust in the northern margin of the West Somalia Basin than has been generally reported in the past.

Southern Margin of the West Somalia Basin

East of the Davie Ridge and a few 10's of kilometres south of Comoros, there is evidence from work done by the German Research Group BGR of the presence of continental crust in an area previously thought to be made up of oceanic crust.

New Seismic, Gravity & Magnetic Data

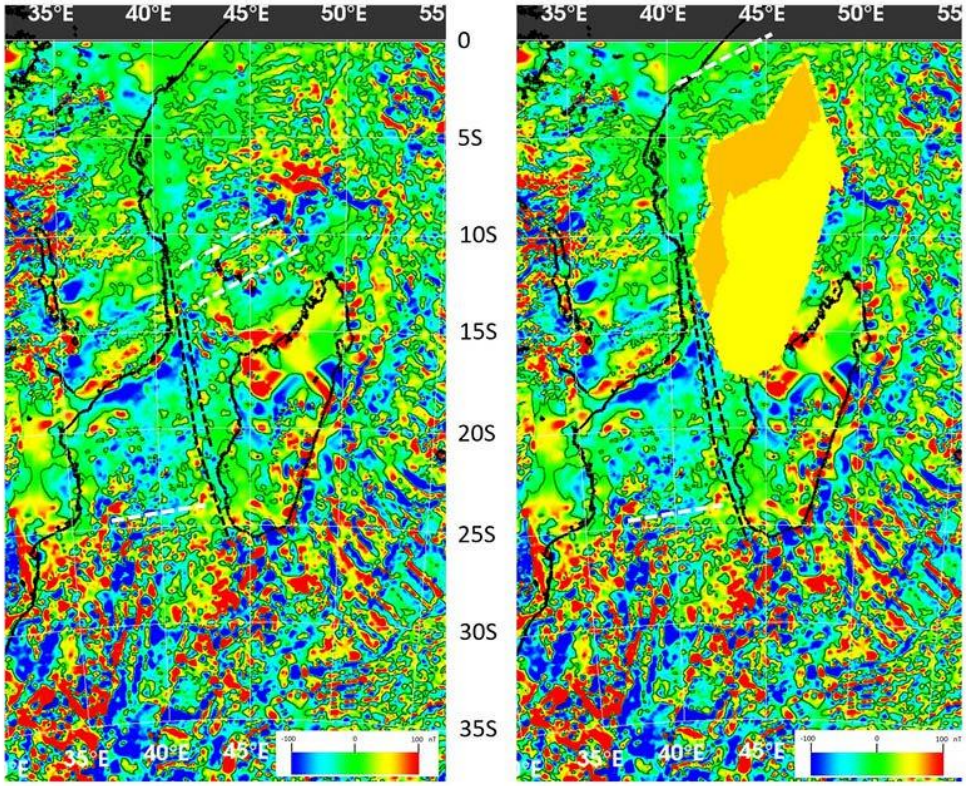
Recent work done by Bahari Resources on new seismic data over Comoros' EEZ combined with a review of regional gravity and magnetic data in the West Somalia Basin has also questioned the presence of oceanic crust in the Comoros offshore. Their evidence showing faulted crust 'considerably thicker than normal oceanic crust' and the absence of linear magnetic anomalies.

Presence of Continental Crust

The argument for the presence of continental crust below the Comoros Islands has been strengthened by the investigation of a large sedimentary xenolith (1.5 x 0.5 km) of Karoo age during field work by Bahari Resources on

the island of Grand Comore. Interestingly, they also found and tested tar balls on a beach in the north of the island, which indicated 'crude oil generated from a restricted marine marl/carbonate algal rich source rock of early to mid-Jurassic age'.

Using Vintage Seismic



Bassias et al. (2015) have shown that the central Mozambique Channel is underlain by an extensive rifted terrain, stretching from a few 10's of kilometres south of the island of Bassas de India northwards, possibly to the southern limit of the West Somalia Basin. Some of this is contrary to the conclusions of many other workers (see references) regarding the presence of oceanic crust in the Mozambique Channel which have been deduced from magnetic striping, which Bassias et al. show is not justified by sufficient convincing data.

You might also like to read...

Was the Mozambique Channel Once Scattered with Islands?

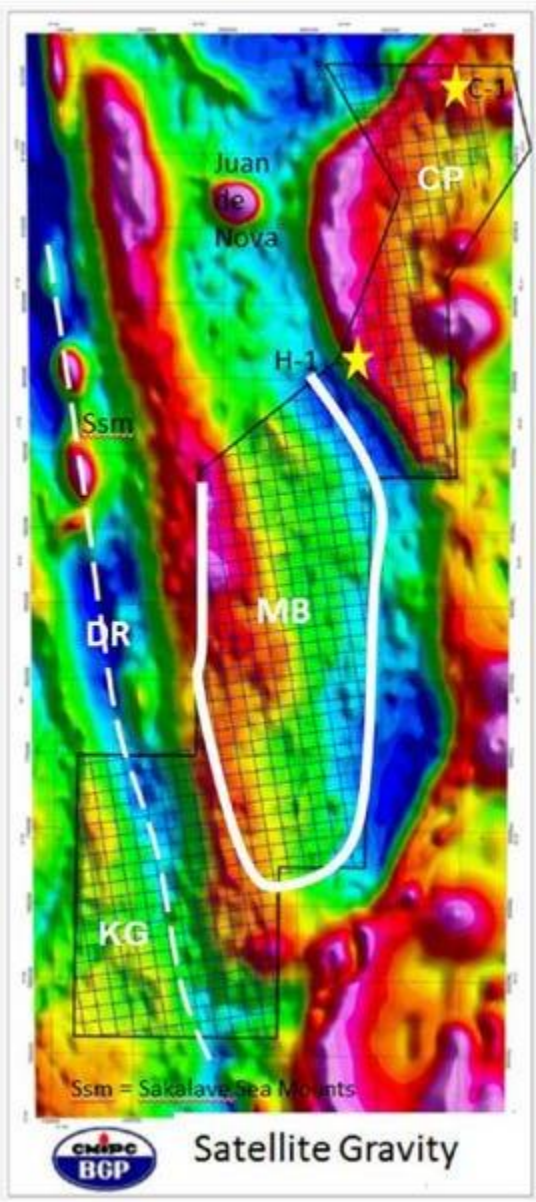
Discover the geological history of the Davie Ridge and how tectonic, erosional and climatic forces shaped this part of the earth.

Regional Influence of the Continental Basement

*Emag 2 non-directionally gridded magnetic anomaly map showing (dashed white lines) the possible northern limit (2 scenarios, based on third party observations) and southern limit (Bassias et al., 2016) of continental crust in the Mozambique Channel. The image shows the Davie Ridge (to 9°S) and the sketched outline of Madagascar indicating pre-drift position and a wider (yellow) and narrower (orange) scenario for the Karoo shelf off the Majunga Basin.*Regionally then, this indicates a much more extensive continental basement than previously assumed, as shown in the magnetic anomaly map. This point is very significant as the Karoo is believed to be an important petroleum system in the region and one of the major sources of the hydrocarbons discovered onshore Madagascar and elsewhere in the region. It is typically a faulted terrain, overlain by syn-rift Jurassic sediments, with later Cretaceous and younger cover and related petroleum systems, as can be seen east of the Davie Ridge in the Morondava Basin below the Turonian volcanics.

From these observations one can consider the influence of the Davie Ridge on the geological story. There is no doubt that the ridge is present in the offshore Morondava Basin and continues up to 9°S. The authors have commented before that they believe the ridge to be a Continent to Continent Transform Fault Zone, which would result in the involvement and erosion of more sand-prone sediment than a continent-to-ocean or ocean-to-ocean transform. The ridge exhibits onlapping late Cretaceous sediments and volcanics and, due to its nature and position, must have had a major influence on sedimentation in the Morondava Basin and Kerimbas Graben.

Geological Domains and Petroleum Systems



*Satellite gravity map showing BGP/TGS MAD-13 survey area (10 km seismic grid) and main geological domains (KG = Kerimbas Graben, DR = Davie Ridge; MB = Morondava Basin; CP = Coastal Platform). The approximate positions of two significant wells are also identified: Chesterfield-1 (C-1) and Heloise-1 (H-1).*Moving from a regional viewpoint, let's now look at the hydrocarbon potential of the Morondava Basin in more detail.

From a seismic sequence stratigraphic point of view, the geology of the Morondava Basin can be split into a number of mega sequences, primarily the Paleogene/Neogene (ie Tertiary) Post Rift; the Upper Cretaceous Post Rift (ie Post Turonian volcanics); the Late Jurassic to Early/Mid Cretaceous Syn Rift; and the Karoo Rifted Terrain (Permian to Lower Jurassic), although further subdivision is possible of course.

Tectonically and geographically the area covered by the BGP/TGS MAD-13 seismic can be split up into four different domains, as shown on the satellite gravity map. These are the Kerimbas Graben, the Davie Ridge, the Morandava Basin and the Coastal Platform.

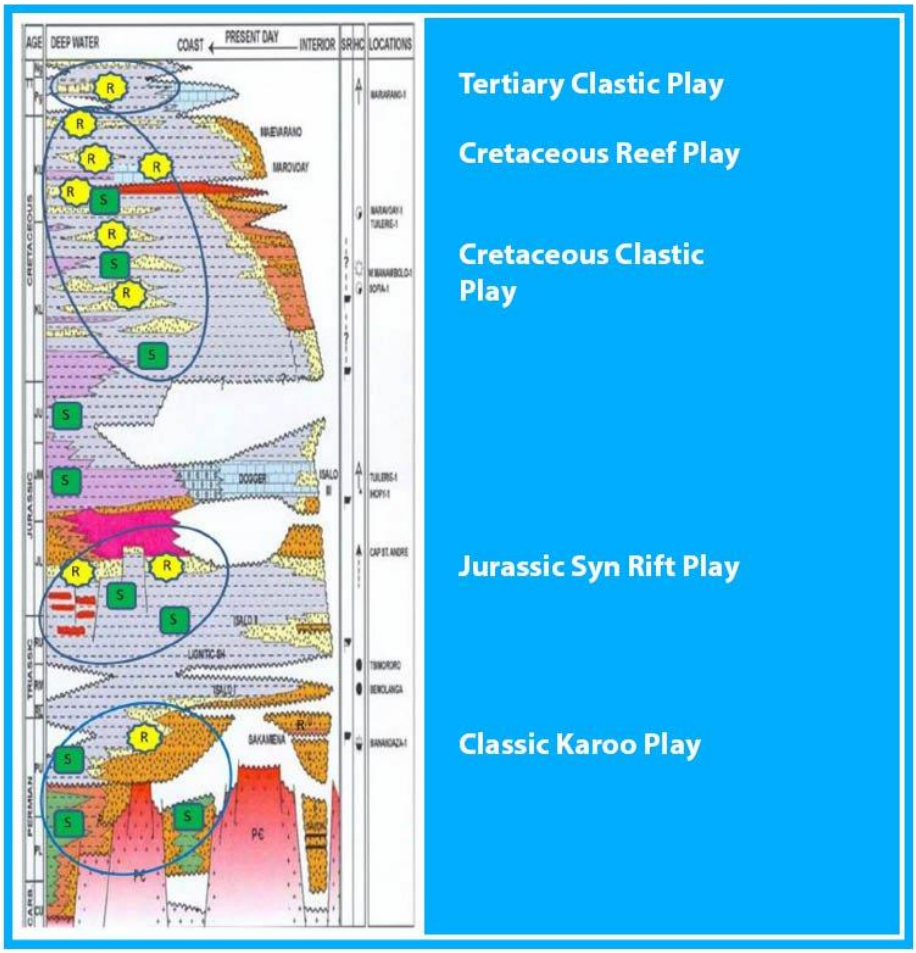
There are thought to be **three major petroleum generating systems** within the Morondava Basin, with **hydrocarbons thought to be sourced** from the following formations:

- **Cretaceous:** multiple source rocks, including Albian-Turonian and/or Maastrichian/Campanian oil prone shales and/or Cenomanian to Valingian, with TOC up to 7%, as reported by OMV and TGS for the onshore Saronanala-1 and Serinam-1 wells;
- **Jurassic:** lacustrine or restricted marine shales of the Beronono and Bemaraha Formations with TOC up to 12 %;

- **Permo-Triassic:** lacustrine shales of the Sakoa and Sakamena Formations (average TOC 5-6%). These are the source rocks for the Tsimirioro and Bemolanga heavy oil fields.

Potential reservoirs are found in the following sediments:

- **Tertiary:** large basin floor fans of Paleocene and Eocene age; possible reef like structures.
- **Cretaceous:** large basin floor fans/turbidite deposits, submarine channels and also reefs.
- **Jurassic:** alluvial and fluvial sandstones.
- **Permo-Triassic:** sandstones of the Sakamena and Isalo Formations.



*Stratigraphic column with elements of the main petroleum systems in the Morondava Basin highlighted. Base source: Omnis.***Seals** are thought to be provided by the **shales, and possibly by volcanics**. Salt has not been recognised in the recent seismic, although it has been interpreted in older seismic images.

There could be an additional possible petroleum system in the Tertiary as evidenced by the gas trapped in what have been previously identified as 'patch reefs'. However, considering their location and the paleogeography at the time, these could alternatively be deepwater cold water coral mounds. The source of the gas could be biogenic or thermogenic, but from deeper in the section as the Tertiary is not buried deeply enough to generate hydrocarbons itself.

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The second part of this article will review the offshore Morondava Basin plays in association with the theory of the 'Golden Zone' of hydrocarbon accumulation.

Learn more about this theory...

[The Golden Zone: It's the Temperature That Counts]

An empirically verified theory provides petroleum geologists with a tool to make it easier to explore oil and gas.

Notes & Acknowledgements

Observations and conclusions made are those of the authors and do not necessarily reflect the views of BGP, TGS or any other party.

*This work is based on an analysis of a ~13,000 line-km long offset 2D Multi-Client seismic survey (BGP/TGS MAD-13 survey) acquired by BGP and TGS in 2013 in the unlicensed offshore part of the Morondava Basin under the jurisdiction of the government authority OMNIS, in preparation for a new International Bid Round.

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