Geological and Geophysical Evaluation of Offshore Morondava Frontier Basin Based on Satellite Gravity, Well and Regional 2D Seismic Data Interpretation*

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Abstract

Madagascar is situated in the South West of the Indian Ocean at a distance of about 400 km off the East coast of Africa. It is the third largest island in the world and covers an area of about 592,000 km^2. The study area (offshore Morondava Basin) is located on the west coast of Madagascar and extends up to 300 km into the deep water. (Figure 1)

In 2003, TGS acquired, processed and interpreted 2158 line Km of good quality seismic data across the offshore regions of Western Madagascar to explore the offshore Morondava basin. Once the presence of deep water basin had been confirmed, 10300 line Km of new regional seismic data was acquired in 2005-2006 to further investigate the geology, structure and hydrocarbon potential of the basin.

This study addresses the regional interpretation of TGS Nopec 2D seismic surveys available satellite gravity and limited well data. It describes the geology and structure of the offshore area of Morondava basin between west coast of Madagascar to the Davie Ridge.

Interest in hydrocarbon exploration in Madagascar started in the early 1900s, with the discovery of two large accumulations of tar and heavy oil at Bemolanga and Tsimiroro, respectively, in the onshore part of Morondava Basin. These two fields are reported to contain up to $6x10^9$ barrels of oil.

Modern exploration began in the early 1950s and since then 72 exploration and appraisal wells have been drilled. Despite this effort, the results have been disappointing and only three small hydrocarbon discoveries have been made. Most of the unsuccessful wells appear to have tested features that are either lacking in closure, or were based on questionable geological concepts. This lack of success, in turn, can be attributed partly to poor quality seismic and well data, and partly to inaccuracies in the geological maps of Madagascar. Offshore Morondava basin is regarded as under-explored basin because only six wells have been drilled in it in 1970's and 1980's. These wells were drilled near the shelf in a maximum water depth of 40m.

Sedimentation and Megasequences

Several sub-basins have been identified on the seismic data during the regional structural interpretation. The whole sediment package within these sub-basins has been divided into four Megasequences (Figure 2). The sediments below Permo-Triassic and Jurassic age form Pre-Rift sequence. They include sediments of Carboniferous age. Immediately overlying sediments of Permian, Triassic and Jurassic age constitute Syn-Rift Megasequence as this was the time when the first phase of rifting occurred in the area. The second rifting stage occurred in the Cretaceous time and sediments from this age form another Syn-Rift sequence. The sequence above them consists of Tertiary Post-Rift sediments.

Satellite Gravity and Well Data Interpretation

The satellite gravity data was mainly used to delineate regional structural elements of the Morondava basin and the adjacent areas. A composite interpretation of Bouguer Gravity, Bouguer Horizontal Gradient and Residual Gravity has been made and on the basis of this interpretation, Madagascar can be divided into two tectonic provinces; a passive margin and a failed rift. The passive margin extends along the entire length of western Madagascar while the failed rift passes down the eastern side of coastal basin and extends between passive margin and central highlands

Only six wells have been drilled in the offshore part of Morondava basin. These wells were drilled near to the coast and are just confined to the shelf. Gas shows have been found from four of these wells from Tertiary, Jurassic and Cretaceous age sandstone reservoirs. The uneven presence of volcanic rocks in these wells suggest that they are limited in distribution and do not uniformly blanket the whole area.

Regional 2D Seismic Data Interpretation

A regional 2D seismic survey composed of 18 strike and 22 dip lines, covering 12458 line km of entire offshore Morondava Basin, parts of Mujanga basin and Davie Fracture Zone, acquired in 2003 and 2005-2006 by TGS Nopec (Figure 1) was utilized for this study. The seismic line length varies from 35 km to 350 km. Strike lines are generally longer than the dip lines in the survey.

The subsurface geology can be analyzed up to 10 seconds quite clearly. Many obvious features like structures, traps etc can easily be understood by looking on to these seismic lines. Time thickness maps display the changes in thickness and distribution of various sediment packages and were interpreted to understand the processes responsible for these changes.

It was found that the highs and lows follow a similar pattern below the Base Tertiary showing a similar depositional geometry and follow deeper horizons or pre-existing basin physiography. But the depositional trend is opposite from Tertiary onward (Figure 3). Such sediment trends had been generated because the basin was in the post rift stage from Tertiary time. No tectonic activity occurred and

sedimentation took place in a relatively calm environment. Erosion took place from the nearby highs and in-filled the pre-existing lows created by the previous rifting events.

Petroleum Prospectivity

Two source rocks: Mid Jurassic and Permo-Triassic, have been modelled and found mature with respect to hydrocarbon generation within the study area. Mid Jurassic source rocks (Berono Shales) expel oil and gas from early Tertiary. Permo-Triassic source rocks (middle Sakamena Shales) expelled oil and gas from early to mid Cretaceous when they stopped expelling.

The study area contains numerous examples of structures that form potential hydrocarbon reservoirs. They include anticlinal features, sand pinch-outs, large-scale channel features and stratigraphic trapping mechanisms etc (Figure 4). Anticlinal features range in size from a couple of kilometres to 10-15 kilometres. They also show the presence of high seismic amplitudes within their closures. These structures are mostly distributed within the Cretaceous strata and some may possibly be covered by Cretaceous mudstones. Many wide spread channel features sand pinch-outs and fan deposits have also been identified (Figure 4). Channels and fans are generally composed of sand bodies and considered to be prospective. Stratigraphic trapping mechanisms are more abundantly distributed within the study area. Such structures can be considered as primary targets for drilling.

Conclusions

- The Seismic data interpretation suggests that offshore Morondava is a Mesozoic to Recent basin, in places over 10 kilometres thick, extends from the shelf to the west of the Davie Fracture Zone.
- The offshore sector of the Morondava Basin extends over 160,000 sq. km. with a maximum water depth of 2500 metres.
- Potential reservoir sands and limestones are interbedded with the source shales, thus providing effective migration route from source to the reservoir. These reservoirs are also covered by thick mudstone units acting as effective seals.
- Source rock modelling indicates that multiple petroleum systems are likely to be present in the basin.
- Madagascar consists of two exploration provinces. A partially explored "Onshore" area with a proven hydrocarbon system but many "breached/shallow" features drilled by old wells with little or no seismic control. This contrasts sharply with the under-explored offshore area covered by the new good quality seismic data, which has same hydrocarbon system but without the uplift/breaching.

Figure 1. Location of the study area and the seismic surveys.

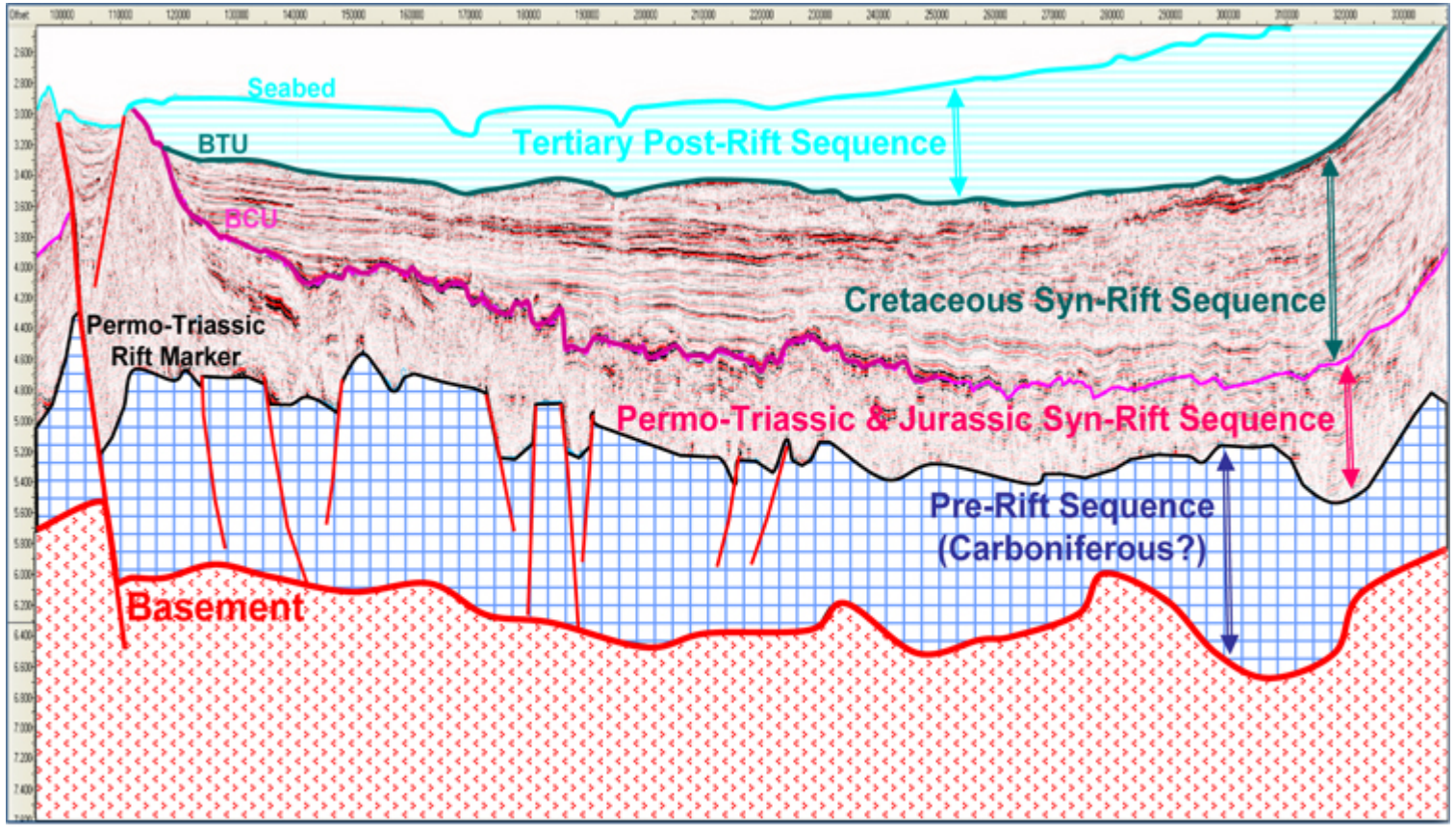

Figure 2. Interpreted seismic megasequences.

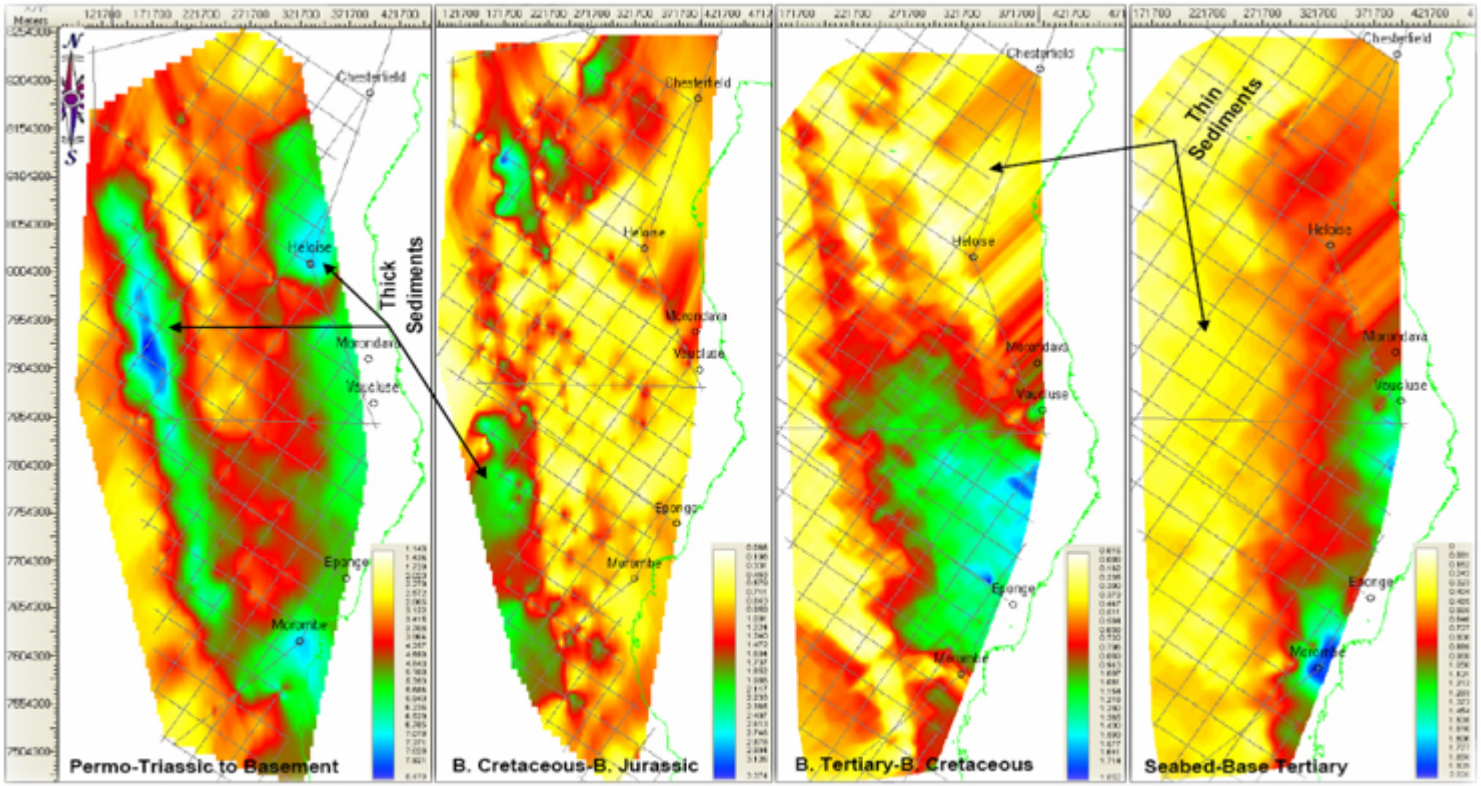

Figure 3. Comparison of vertical time thickness maps for various intervals.

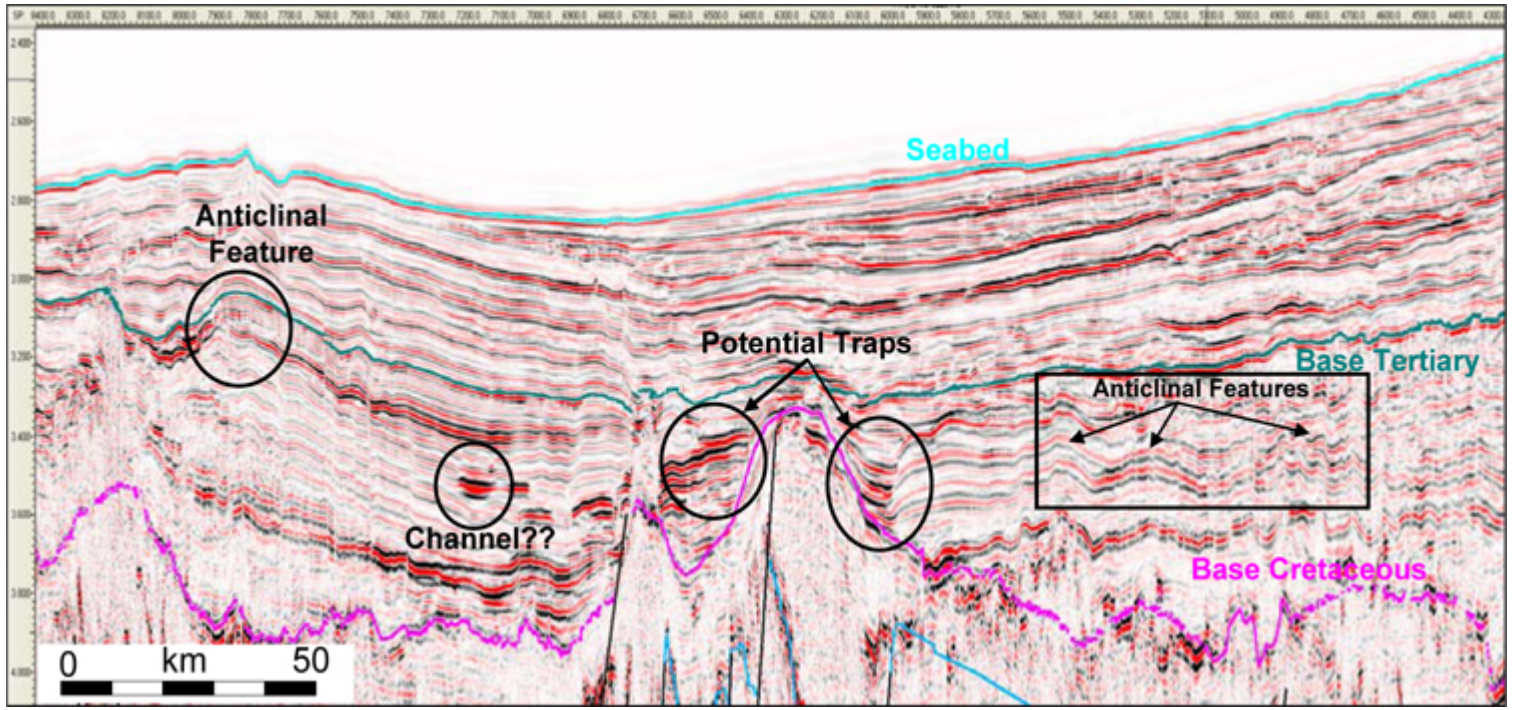

Figure 4. Potential play types in offshore Morondava Basin identified on seismic.