

An Evaluation of the Petroleum System Offshore Morondava Basin, Madagascar

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Summary

This study addresses the regional interpretation of 2D seismic surveys across the offshore regions of Western Madagascar (Morondava Basin). It describes the geology, structure and hydrocarbon potential of the offshore area of Morondava basin between west coast of Madagascar to the Davie Ridge.

In 2003, TGS acquired, processed and interpreted 2158 line Km of good quality seismic data from offshore Morondava Basin. Once the presence of deep water basin had been confirmed, 10300 line Km of new regional 2D seismic data was acquired in 2005-2006 to further define basin detail.

Satellite gravity data interpretation suggests that western coastal basins of Madagascar can be split into two tectonic provinces i.e a western passive margin and an eastern failed rift. The structural, depositional environments and burial histories of these two provinces are quite distinct. Hence, the potential petroleum systems that occur in each province are also different. Morondava Basin is filled with 10 km thick sediments from Mesozoic to recent age with minor volcanics and no evidence of salt.

The offshore part of the basin is under-explored but found to be highly prospective. Direct hydrocarbon indicators have also been identified. The burial and hydrocarbon expulsion histories for source rocks of Permo-Triassic and Mid-Jurassic ages were modelled and encouraging results have been seen. The structuration happened before the oil expulsion from these potential source rocks which maximize the chances of finding hydrocarbons in place. Potential good quality reservoirs including predominantly sandstones and limestones have been found present covered by interbedded seals. Hence, all elements of an effective petroleum system were identified during this study.

Introduction

Madagascar is situated in the South West of the Indian Ocean at a distance of about 400 km off the East coast of Africa (figure 1). It is the third largest island in the world and covers an area of about 592,000 km².

The area studied is called the Morondava Basin which is located on the west coast of Madagascar and extends up to 300 km into the deep water (figure 1). It covers an area of about 400,000 km².

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 northern Morondava Basin. These two fields are reported to contain up to 6×10^9 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. The overall drilled well density in Madagascar is only 1 in 8500 km².

Methods and Key Results

Satellite Gravity and Well Data

The satellite gravity data was mainly used to evaluate 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.

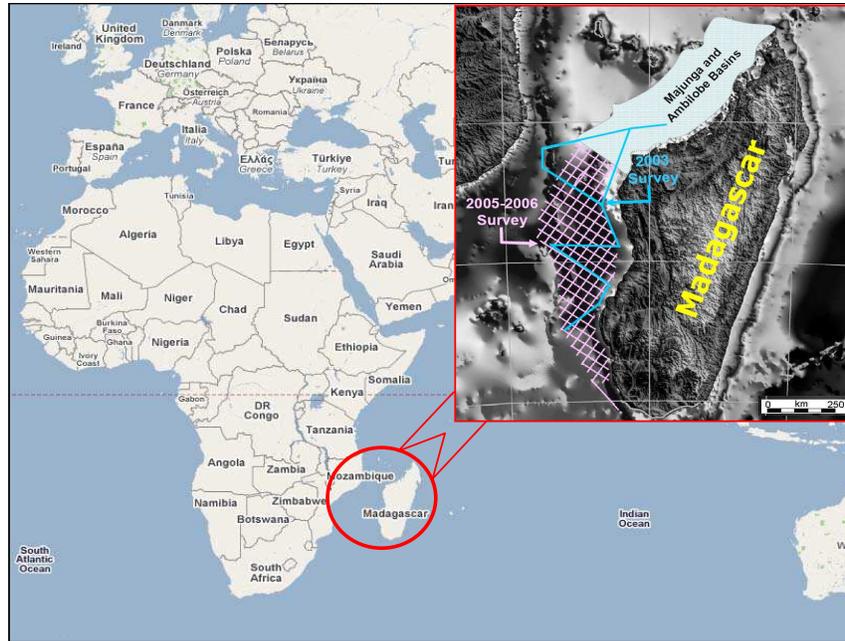


Figure 1:- Location of the study area and the Seismic Surveys

Only six wells have been drilled in the offshore part of Morondava basin. These wells were drilled near the coast into 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 aerial extent and do not uniformly blanket the whole area.

Regional 2D Seismic Data

TGS acquired 2D seismic data from offshore Madagascar in 2003 and 2005-2006 to evaluate the hydrocarbon potential of offshore Morondava basin. The two surveys (Figure 1) consist of 12458 line km of 2D seismic (2158km old and 10300km new) and cover whole offshore Morondava basin and parts of Mujanga basin and Davie Fracture Zone.

The subsurface geology can be analyzed down to 10 seconds TWT quite clearly. Many obvious features like structures, traps etc can easily be identified by looking on to these seismic lines.

Time thickness maps were also generated for the sediment packages to analyze the changes in thickness and to understand the processes responsible for these variations.

Vertical Time Thickness Mapping

Vertical time thickness maps of various intervals have been generated and displayed together (figure 2) to understand the relationship of various sediment packages. It was found that the highs and lows follow a similar pattern below the Base Tertiary which revealed that the sediments below the Tertiary show a similar depositional geometry to the deeper horizons and pre-existing basin physiography.

Such sediment trends had been generated because the basin was in the post rift stage from Tertiary onwards. No tectonic activity was occurring and sedimentation took place in a

relatively calm environment. Erosion took place from the nearby highs and infilled the pre-existing depressions and lows created by the previous rifting events.

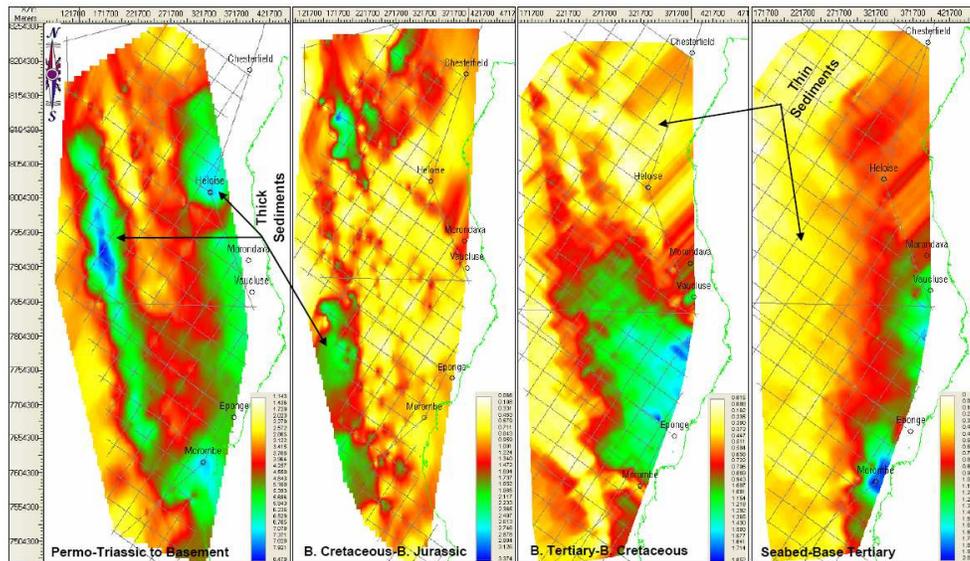


Figure 2:- Comparison of Vertical Time Thickness maps for various intervals

Seismic Megasequences and Sub-basins

Several sub-basins have been identified on the seismic data during the regional interpretation. The whole sediment package within these sub-basins has been divided into three Megasequences. The sediments of Carboniferous age form the Pre-Rift Sequence. Immediately overlying, sediments of Permian, Triassic and Jurassic age constitute Syn-Rift megasequence deposited during the first phase of rifting in the area. The second rifting stage occurred in the Cretaceous time and sediments from this age form an overlying Syn-Rift sequence. The sequence above them consists of Tertiary Post-Rift sediments.

Petroleum Play types

Many types of structures which may have hydrocarbon potential have been identified in the study area. They include anticlinal features, sand pinch-outs, large scale channel features and stratigraphic trapping mechanisms (figure 3). Anticlinal features range in size from few kilometres to 10-15 kilometres. High seismic amplitudes exist within many of the identified closures. Such structures mostly occur within the Cretaceous strata and some may be covered by Cretaceous mudstones. Such structures can be regarded as suitable targets for drilling. Many wide spread channel features have been identified on the seismic data during the interpretation (figure 3). The presence of good quality porous and clean sands can be expected within these channels. Some of them are more than five kilometres wide and infilled material show high seismic amplitudes which may be an indication of good quality sands or possibly hydrocarbons.

Stratigraphic trapping mechanisms are more abundantly distributed within the study area. Sand pinch-outs and fan deposits have been identified on the seismic data. Fans are generally composed of sand bodies and considered to be prospective.

Direct Hydrocarbon Indicators

On the basis of seismic character, several Gas Chimneys have been identified during data interpretation. Some of them are of quite large scale. It seems that the gas is being emitted from a deeper source (may be Triassic or Jurassic) and migrating vertically into the possible reservoirs of late Cretaceous and early Tertiary ages as evidenced by the presence of relatively higher amplitudes immediately above the gas chimneys (figure 4).

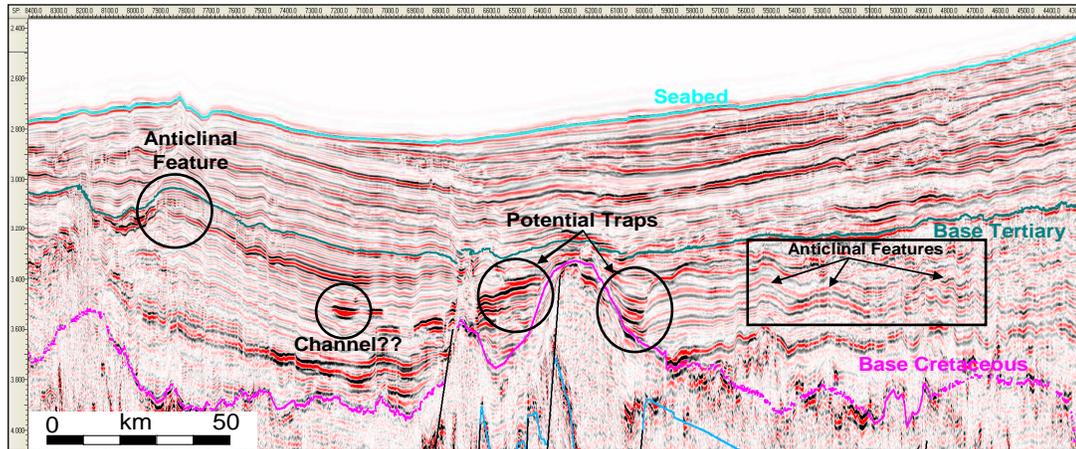


Figure 3: Regional Seismic Line showing Potential Play Types in Offshore Morondava Basin

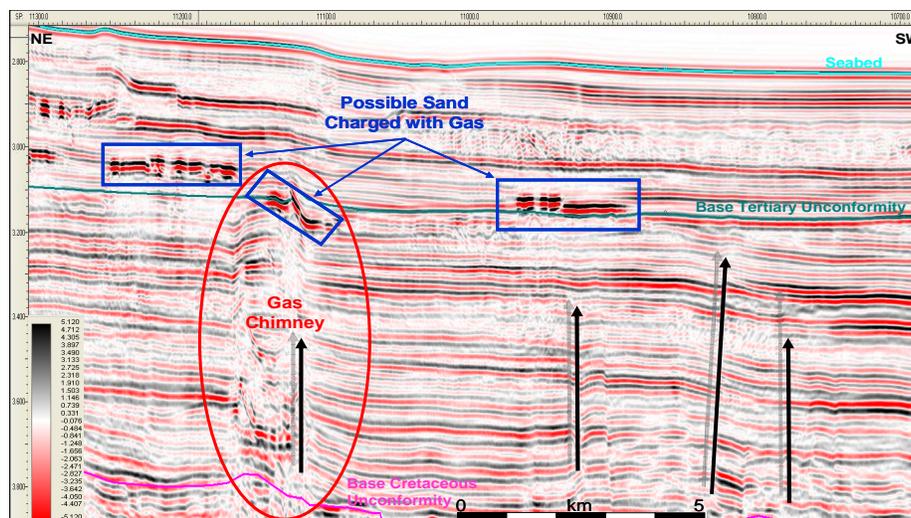


Figure 4:- Direct Hydrocarbon Indicators on the Seismic Data

Source Rocks Expulsion Modelling

Two potential source rocks: Mid Jurassic and Permo-Triassic, have been modelled and found to be mature within the study area. This modelling indicates that Mid Jurassic source rocks (Berono Shales) should have expelled oil and gas from early Tertiary. Modelling also suggests that Permo-Triassic source rocks (middle Sakamena Shales) expelled oil and gas from early to mid Cretaceous.

Conclusions

The seismic data interpretation indicates that the Morondava Basin, offshore Madagascar is of Mesozoic to Recent age and in places is over 10 kilometres thick. This sedimentary sequence contains large volumes of shales to act as both source and seal with interbedded reservoir sandstones and limestones providing an easy migration route.

The under-explored offshore area of the Morondava Basin is covered by a good quality grid of regional seismic data which appears to demonstrate a working hydrocarbon system that has not been affected by the uplift and breaching which characterises the adjacent onshore area.

Acknowledgement

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