Introduction

To date, the main deep (>400m water depth) offshore exploration efforts offshore India have concentrated on the East Coast where a number of large discoveries have recently been made in the Krishna Godvari and other basins.

Now attention is turning to the deep offshore area of the West Coast of India where outside the petroliferous (shallow water) province of the Mumbai High, exploration to date has been frontier in nature with very little wells drilled to date.

Using recently re-processed seismic data (from a 12,000 km regional 2D seismic survey collected for the DGH in 2002) we show how the application of modern seismic techniques (Radon Demultiple, PSTM and PSDM) has upgraded the petroleum potential of the area – showing plays both in the Tertiary and in the deeper Mesozoic section where a potential petroleum province can now be recognised below the Deccan basalts. Our interpretation of this dataset shows that this Mesozoic province extends over 200km offshore and into water-depths of up to 3500m – covering a large number of open blocks in Indian territorial waters.

Geological History

It is generally accepted that India was formed initially by the progressive breakup of the Gondwana supercontinent, variously reported as starting about 150-180 my ago (i.e in Middle to Upper Jurassic time). This resulted in the creation of West Gondwana (Africa) and East Gondwana (Madagascar, Seychelles, India, Antarctica and Australia) which itself started to break up about 128-130 my ago (Bastia 2006, and others). This lead to the rifting of West India from Madagascar about 90 my ago (Mid Cretaceous) and the beginning of a number of stages of volcanism and rifting which shaped the present day structure of the West India offshore area.

Tectonic Structure

The Western Margin of India is regarded as a rifted volcanic continental margin as opposed to a simple passive margin and extends northwest to southeast from Kutch in the north to Cape Comorin in the south. It is tectonically differentiated into shelfal horst-graben complex of ridges and depressions.

The principal features observed by the seismic data include the Shelfal Horst and Graben Province, Lakshadweep Basin, Laxmi Basin, Laccadive Ridge and Arabian Cenozoic Spreading Basin (Figure 1). The Laxmi and Laccadive ridges are believed to be continental remnants which rifted away from the western continental margin and subsequently affected by volcanism, in the latter case by the Reunion hotspot which forms part of the Chagos-Laccadive-Maldive hotspot trail (Naqvi, 2005).
Stratigraphy

The stratigraphy of the offshore western margin of India can be postulated from pre-drift paleogeographic reconstructions evidenced by well and outcrop data from India, Madagascar and the Seychelles.

**Triassic – Early Jurassic:** Karoo type sediments consisting of sands and silts from alluvial fans and meander belts and supplied by Precambrian uplands on Madagascar, Seychelles and India.

**Middle Jurassic:** Marine conditions developed between Madagascar, Seychelles and India with deposition of shales and silts, oolites around the Seychelles, and beach sands and shallow marine sediments in the recently formed Kutch graben.
**Early Cretaceous:** Rifting along the Narmada and Cambay fault trends created grabens with alluvial systems culminating in delta complexes and fans in the vicinity of the Surat Depression and, more distally, prodelta-shales between the Seychelles and India.

**Late Cretaceous:** Restricted marine conditions prevailed in the zone between the Seychelles and India with deltas and fans providing sediments from both landmasses. Rifting on the NE side of the Seychelles commenced at this time. Shelf carbonates and open marine conditions developed to the south of the Seychelles and may have also characterised deposition in the Konkan Kerala region.

**Late Cretaceous/Early Tertiary:** Significant volcanic activity developed in association with rifting and ocean spreading. Deccan Trap flood basalts covered much of western India and extended offshore to the Seychelles and beyond.

From the above, a prognosed stratigraphic section for the western offshore continental shelf of India has been developed (Figure 2). The reprocessing of the 2002 seismic survey has revealed significant sedimentary section preserved below the Base Tertiary – Deccan Trap event. This older section may range from Triassic Karoo fluvial sandstones and shales, through Jurassic marine shales and sands, to Early Cretaceous restricted marine shales and paralic sands which persisted into the Late Cretaceous between India and the Seychelles. Elsewhere shallow marine limestones and basinal shales may have developed prior to major outpourings of Deccan lavas.

![Postulated stratigraphy: offshore west coast India (modified from Jenkins 1992)](image)
Hydrocarbon Potential of the Mesozoic

The basal Tertiary is a proven source horizon for the Bombay High Hydrocarbon Province and may prove a suitable source where sufficiently buried in the offshore western Indian continental shelf. Aspects of the post-basalt deep water plays have been covered in a previous paper (The Petroleum potential of Deep Offshore West Coast India from newly reprocessed 2D seismic data by Roberts, Rutherford and O’Brien and presented at GeoIndia 2008). This paper concentrates on the Mesozoic potential seen underneath the basalts on reprocessed data.

Figure 2 illustrates the potential source and reservoir rocks for the western offshore area of India. Jurassic aged section has been encountered offshore Kutch graben and onshore Saurashtra basin. For example, the onshore Lodhika well penetrated gas-prone, organic rich sediments of the Upper Jurassic Dhrangadra Formation (Singh, 1997). However, most evidence for Mesozoic source rock potential is derived from the Seychelles, so this consequently reflects on the potential in the offshore of India.

The oil explorer, East African Exploration Ltd, has revealed that migrated black oil was found in side-wall cores from the Karoo succession in wells drilled by Amoco during the early 1980s (Machette Downes, 2007). Apparently the same oil characteristics are also found in numerous tar balls stranded around the many islands of the Seychelles archipelago.

The postulated source is of early maturity (Rc 0.8%). Basin and thermal modelling confirms the timing of generation for these Type II kerogens as late Tertiary to present-day in extensive depocentres located along the shelf edges and under the plateau. The Karoo-sourced oil shares many similarities with oil shows found both in East Africa and in Madagascar, but the tar balls also share affinities with the hydrocarbon provinces of the Bombay High, Cambay and Indus basins.

Figure 3 shows the structural-stratigraphic correlation of three Seychelles wells; Owen Bank-1, Seagull Shoals-1 and Reith Bank-1 and demonstrates the occurrence of Jurassic and Cretaceous shallow marine sediments in grabenal troughs.

A thick Mesozoic succession, including Jurassic and Triassic sediments, thus underlies the Seychelles Platform and is believed to contain thick source sequences that have charged the exhumed super-giant oil fields onshore Madagascar. It is considered that a similar Mesozoic sequence may exist offshore the west coast of India both in the deepest grabens observed on several of the reprocessed seismic lines, particularly in the Konkan-Kerala basin (Figure 4) where hydrocarbon indications (such as gas chimneys are observed); as well as below the basalts in the northern part of the survey area (Figure 5).

Additional evidence of a working petroleum system comes from satellite slick observations – these can be correlated to some of the major faults in the area and also point to possible hydrocarbon generation in the Mesozoic.

Conclusion

The deep offshore West Coast of India has undoubted hydrocarbon potential, with new evidence pointing to a deeper Mesozoic province. In addition to extending the area of
interest to hydrocarbon explorers in depth, this extends it geographically into the deeper offshore.

Fig 3: Structural-stratigraphic correlation of the three Seychelles wells (from Walton & Khanna 1992)

Fig 4: Gas chimney on a W-E line from the Kerala-Konkan area (Data is PSDM and displayed in depth with timing lines every 1000m. Section width 38km. Vertical exaggeration approx 3.5:1; Main Horizons: Pink & Yellow: Intra Tertiary events; Turquoise: Base Tertiary; Light Green: Top syn-rift)
Fig 5: PSDM section from the northern part of the survey area showing Mesozoic section under the Deccan basalts (Top basalt is yellow, Base basalt is blue. Mesozoic section in Green. Timing lines every 1000m. Section width:140 km.

Further work needs to be done to understand fully the petroleum systems (e.g hydrocarbon charge, timing, preservation etc) and in gathering new seismic data (with long offsets) which can be integrated with potential field (gravity/magnetic) and geochemical data to give a fuller picture of the potential of this huge offshore area.

A considerable percentage of the area is unlicensed and expected to be offered in future petroleum license rounds.
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