Mesozoic Enigma in Kerala-Konkan Basin: An alternate explanation for deep water sub-basalt reflections

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Summary

Kerala-Konkan basin a volcanic passive continental margin has evolved through separation of different continental masses such as Africa, Madagascar, Seychelles from Jurassic onwards indicating possibility of Mesozoic basins. However, after encountering a Late Cretaceous (Santonian to Maestrichtian) sedimentary sequence in one of the well in eighties, till now establishing Mesozoic basin has remained an enigma as subsequent drilling did not encounter the predicted Mesozoic sediments. Latest seismic data particularly the GXT, WC and Long Offset ones have brought out distinct reflection packages below the Paleocene Trap Top reflector in deep water areas and interpreted/believed to be Mesozoic sediments by various authors. But its continuous extensive presence from shelfslope regime up to Laccadive ridge and 3-4km thickness even under Laccadive ridge creates doubt about a huge Mesozoic basin in deep water area. This paper brings out an alternate explanation for these reflection packages by determining the possible crustal type based on analysis of spreading history, age of magnetic lineation in western Indian Ocean and the process of formation of oceanic crust.

Oldest magnetic lineations observed in the south-western part of KK Basin west of Laccadive Ridge is 24n indicating oceanic crust of Late Pleocene-Early Eocene age. Plate tectonic history brings separation of Madagascar around 90 Ma from KK coast which suggests probable existence of oceanic crusts to the east of Laccadive Ridge. Nonrecordance of magnetic lineations is due to subsequent volcanism and intrusive activities due to Re-Union hot spot.

Character of an oceanic crust is dependent on the magmatic activity at Mid Oceanic Ridge. Fast spreading centres will have more volume of magmatic activity and likely to develop thick sequence of layered gabbro and sheet flows of basalt. Fastest (211km/my) spreading rate during Late Cretaceous (73-57Ma) corresponding to Madagascar separation might have triggered large budget of magma with thicker layered gabbro and extensive sheet flows of basalt in an oceanic crustal regime. Polar wander path during 73-57Ma falls within Kerala-Konkan basin and further suggests the possibility of an oceanic crust between Laccadive ridge and KK shelf. The strong parallel seismic reflections observed in deep water area below the Paleocene trap could be from the layered structure within oceanic crust rather than the sediments.

The model of oceanic crust suggested here to the east of Laccadive ridge and record of Santonian-Maestrichtian(8565Ma) sediments in the well in shelfal area gives that Mesozoic basins will be more closer to the continental margin in shelf-slope regime.

Introduction

Inspite of more than three decades of exploration in KeralaKonkan basin (Fig.1) by different companies, it is yet to meet with any hydrocarbon discovery. Over the period several seismic campaigns have been undertaken and seventeen wells have been drilled in the basin. The wells mostly tested the Tertiary prospectivity except one well on Cochin High (Fig.1) in Kerala basin which has penetrated Late Cretaceous sediments enhancing the hope of discovering Mesozoic petroleum system. Subsequently few wells targeted for Mesozoic sediments have turned out to be volcanic raising the doubts on the understanding of Mesozoic sedimentation as well as basin configuration during this period. Last decade the exploratory efforts particularly the seismic acquisition have been focused to improve the sub-basalt imaging. The WC lines by Large (2003), GXT lines(2006-07) and several campaigns of Long offset lines (2008, 2009 and 2012) have brought out distinct reflection packages (Fig. GXT, WC) below the Paleocene Trap particularly in the deep water area. Many blocks have been offered in the NELP rounds in deep water area considering these reflection packages to be of
Mesozoic sediments and of interest. This paper try to analyse these strong reflection packages taking in to account its distribution, westward extent, thickness and bring out an alternate explanation for their origin based on possible crustal type which might have evolved by separation of continents from Kerala-Konkan margin through geological history.

![Location map of Kerala-Konkan Basin showing the seismic lines and well](image)

Determination of type of crust and continent ocean boundary (COB) in a basin particularly passive continental margins gives an idea about the distribution, extent and quality of sediments and ultimately guidance to the exploration strategy. Kerala-Konkan Basin being the eastern most part of western Indian Ocean is linked to the origin of this ocean by separation of several continents from the unified Gondwanaland through different ages and creation of oceanic crust (Fig.2). Two aspects one studying the age of magnetic lineation generated by sea floor spreading in western Indian Ocean and the other by understanding the process of creation of oceanic crust by sea floor spreading have been taken in to account for interpretation. This study will help in locating the possible Mesozoic sediments in the basin and reorient the exploration strategy.

![Western Indian Ocean showing different continental masses, ridges, fractures from freeair satellite](image)

**Analysis of sub-basalt reflections below Paleocene trap in deep water area**

2D seismic lines with better acquisition parameters and with regional coverage have been considered for bringing out a comprehensive understanding and interpretation of reflection packages below the Paleocene Trap top marker. Different lines used are the WC lines having 6km offset, 8 seconds record length; GXT lines having 10km offset, 16 sec record length and representative line close to shelf having 12 seconds record length and 12km offset. The location of the seismic line are shown in fig.1. The WC and GXT lines covers from shelf to abyssal plain covering total deep water area (Laccadive depression) and Laccadive ridge.

![Regional GXT line from shelf to abyssal plain through Laccadive depression & Laccadive Ridge](image)

![Enlarged view showing distinct reflection below Paleocene Trap Top](image)
The WC and GXT lines (Fig.3 & 4) clearly depicts strong parallel continuous reflections from slope area up to Laccadive Ridge with patches of transparent zone with mound shape at Paleocene Trap reflector (Fig.3,4) indicative of volcanic zones. The thickness of the reflection packages gradually increases from the eastern part from almost zero to more than 2 seconds (3-4 km) towards western part in the Laccadive depression and continues up to Laccadive Ridge. Towards eastern part. These reflection packages form a wedge shaped body and terminate on to the Paleocene Trap Top reflector (Fig.5). The termination of reflectors on to Paleocene Trap Top also observed in the central and western part of the line. The other end of the reflectors as discussed goes dipping in to the western side for a long distance before it loses at deeper depth. These packages do show clear cut structurisation with faults and anticlines. But close observation suggests the anticlines and faults are up to Tertiary (Eocene Top Level) strata thereby indicating structurisation process during the Tertiary time rather than Mesozoic time (Fig.3B).

From these observations it is difficult to believe a 3-4 km thick sediments even below the Laccadive ridge far away from the basin margin. The characteristic terminations of reflectors on to the Paleocene Trap top reflector do creates doubt of a sedimentary package. Hence, it was thought to have any other explanation possible to explain these packages taking in to consideration some of the broader aspects of origin of crustal feature vis-à-vis tectonic history of Kerala-Konkan Basin.

**Spreading History of Western Indian ocean, observation on magnetic lineations recorded close to KK Basin**

Observation of a magnetic lineation and its chron in a crust gives certainty of an oceanic crust at that time by sea floor spreading mechanism. The creation of Kerala-Konkan Basin is related to the separation of continental masses from western margin of Indian and creation and modification of ocean floors through geologic time. Kerala-Konkan basin being part of Western Indian Ocean the spreading history along with the published age of the sea floors based on magnetic chron helps to understand the type crust likely to be present in the close vicinity of the Kerala-Konkan margin. Most of the present gravity model suggests an extended/transitional crust for the deep water area up to Laccadive ridge and oceanic crust west of Laccadive ridge. The oldest magnetic chron recorded west of Laccadive ridge is 24N (Early Eocene-Late Paleocene) and confirms a Early Eocene-Paleocene Oceanic crust (Fig.6A).

Looking in to the magnetic chron in Western Indian Ocean(Fig.6A), very close to south-eastern margin of Madagascar 34N chron has been assigned whereas south-western part of Kerala-Konkan basin is devoid of any record except far away from the margin the 24N chron to the west of Laccadive Ridge has been recorded. As popular plate tectonic reconstruction suggests
Madagascar was close to Kerala-Konkan basin (Fig. 6B), the older magnetic lineations similar to Madagascar should have been recorded close to the continental margin.

The non-recordance of lineations are probably due to the subsequent magmatic activities due to Re-Union hotspot activity (Seychelles track) in to an already created oceanic crust by separation of Madagascar. EMAG2 (Earth Magnetic Anomaly Grid 2-arc-min map generated from satellite magnetic data close to Kerala-Konkan basin has indicated north south fractures along with E-W magnetic stripes, ridges going well into the Laccadive depression similar to oceanic crust regime observed west of Laccadive Ridge (Fig. ).

Looking in to south-western part of Indian continent two major fractures and ridges (Laccadive Ridge and Vishnu Fracture) are observed. The Vishnu fracture zone starting from Allepy Platform has an older crustal regime in the eastern part than the western part (Fig. 2). The paleo reconstruction of plates (Fig. 6B) shows southern part of Madagascar jointed with Allepy platform and the Vishnu fracture zone probably represent the track of Madagascar separation from India. The Laccadive Ridge the north south one which starts from south of Mumbai offshore basin represents separation track of southern part of Seychelles-Masacarene continental fragment from India. The area between Laccadive and Vishnu Fracture is the remnant portion left that was created during separation of Madagascar.

Sea floor spreading, process of oceanic crust formation and different layers present within it

Present day Mid Oceanic Ridges helps in understanding the processes involved in formation of Oceanic Crust. In addition, ophiolite suite of rocks exposed at the surface in some part of the world which represents remnant oceanic crust gives idea about the structure & composition of Oceanic crust. As new oceanic crust is formed at Mid Oceanic Ridges, the processes involved such as the magmatic activity and their emplacements will determine the thickness of the total crust and individual layers within the crust.

Formation of oceanic crust is shown in Fig. 8 with four different stages which depicts step-by-step construction and addition of vertical layers. The magma coming from the mantle forms different layers till it reaches the surface which flows as pillow or sheet. The other layers are sheeted dykes, layered gabbro and gabbro. Unlike the sedimentary rocks the horizontal layering of the crust is not the simple superposition but results from spreading due to lateral growth of basalts, sheeted dikes and gabbros.

Different Spreading Ridges have different characters and likely to create different Oceanic Crust and dependent on rate of spreading. Slow spreading centres generally have low magma budget with more structural activity thereby generating wide range of morphologic and geologic features (W. R. Buck et al. 1998). In this case mechanical extensional with development of rift valleys and pillow lavas dominate. In contrast fast spreading centres have high magma budget which leads
to magmatic construction and sheet flows of basalts dominate. The sheet flows of the basalts likely to develop layered structures.

Fig.8: These cross sections show the step-by-step construction of oceanic crust. Horizontal layering of the crust is the results from spreading during lateral growth of pillow basalts, sheeted dikes and gabbro (From Earthdynamic system)

Formation of Kerala-Konkan Basin and the crustal regime in the basin is analysed here based on the rate of movement of Indian plate as shown in Fig.9B. The rate of movement curve shows three distinct regime 1) 120-73Ma with speed of 66km/my, 2) 73-57Ma with speed of 211km/my and 3) 57-20Ma with speed of 95km/my. The highest speed occurring between 73-57 Ma corresponds to the separation of Madagascar from Kerala-Konkan margin which started around 90Ma. Looking in to the polar wander curve the path and area covered during 73-57Ma mostly lies in the Kerala-Konkanbasin(Fig.9A).

Fig.9: A)Motion of Indian Plate with paleomagnetic poles shown at 5Ma intervals. B) Rate of change of Indian Plate with rapid movement from 73 to 57Ma (After Acton G.D., 1999)

From above observation it is clear that the Kerala-Konkan basin particularly the area between Laccadive ridge and shelf represents a crustal regime which is formed by high spreading rate. The high spreading rate between two continental masses here between India and Madagascar probably suggests a quick change over from continent to oceanic crustal regime. The high spreading rate also points to higher magma budgeting and magmatic construction with thicker layers of gabbro and sheeted basaltic flows.

A model prepared by Dick et.al, 2006 shows different crustal accretion for different spreading ridges (Fig.10). Maximum thickness is shown for the layered gabbro in a fast spreading ridge in Cocos-Nazca ridge in East Pacific Rise.

Fig.10: Model for crustal accretion at ocean ridges from Dick et.al. 2006. Model A with thicker layered gabbro occur in fast spreading ridges

In the light of these discussion now the seismic observation as discussed earlier which shows strong parallel reflections from the slope regime to Laccadive ridge can be interpreted to be possibly part of the oceanic crustal regime which has been formed by higher spreading rates with high magma budgeting and magmatic construction. Thick layered gabbro as well as sheet basalt flows which consists this type oceanic crust might have given such reflection characters.

Mesozoics in Kerala-Konkan Basin

After encountering Late Cretaceous sediments in Cochin High well on the shelf(Fig.1), many wells targeted for Mesozoics did not encounter it. Instead all the wells either have penetrated thick sequence of volcanic or intrusive without any hydrocarbon indications. This has created a doubt in understanding the basin configuration and volcanic activity in the basin. The well Cochi High where Late Cretaceous sediments encountered, have only thin Palaeocene trap/trap wash as compared to the other wells where thick trap sequence without any Mesozoics encountered. The Late Cretaceous sediments present mostly shows a
depositional environments of deeper marine (50-200m bathymetry) conditions. This again shows the basin has already in a deeper bathymetry conditions at Location Cochin High which is within shelfal regime. Further west during these periods it is very likely that more deeper bathymetry conditions and an oceanic crustal regime may be imagined.

From this it is likely that the Mesozoic basins can be present more close to the shelf-slope regime rather than deep water area. The volcanics encountered mostly represent the Madagascar separated volcanism (St. Mary, well Cochin High) with additional activities during Re-union hotspot activity which is manifested by intrusives and thin layers over Madagascar related volcanics which are observed in some of the wells.

Summary

- Strong reflection packages below Paleocene trap in the regional seismic lines suggests sub basalt Mesozoic sediments in the deep water area of KK basin. But its continuous extensive presence from shelf-slope regime up to Laccadive ridge and 3-4km thickness even under Laccadive ridge creates doubt about a huge Mesozoic basin in deep water area without any hydrocarbon indications in recently drilled deep water well.

- Different crustal regimes have been identified in KK basin based on magnetic lineations/chrons and spreading history in Western Indian Ocean. This has led to bring out an alternative explanation for these strong reflection packages.

- Oldest magnetic lineation recorded in KK basin is 24n of Early Eocene-Late Paleocene age and an oceanic crust to the west of Laccadive ridge. Plate tectonic history brings separation of Madagascar around 90Ma from KK coast which suggests all probability of existence of oceanic crusts to the east of Laccadive Ridge. Non-recordance of magnetic lineations is due to subsequent volcanism and intrusive activities due to Re-Union hot spot.

- Fastest (211km/my) spreading rate during Late Cretaceous(73-57Ma) corresponding to Madagascar separation might have triggered large budget of magma with thicker layered gabbro and extensive sheet flows of basalt in an oceanic crustal regime. Polar wander path during 73-57Ma falls within Kerala-Konkan basin and further suggests the possibility of a faster spreading oceanic crust between Laccadive ridge and KK shelf.

- The strong seismic reflections observed in deep water area below the Paleocene trap could be from an oceanic crust formed by a faster spreading plates during 73-57Ma.

- The model of oceanic crust suggested here to the east of Laccadive ridge and record of Santonian-Maestrichtian(85-65Ma) sediments in the well in shelfal area gives that Mesozoic basins will be more closer to the continental margin.

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References

Acton G. D., 1999, Apparent polar wander of India since the Cretaceous with implications for regional tectonics and true polar wander In Radhakrishna T and Piper JDA (Eds), The Indian Subcontinent and Gondwana: A Palaeomagnetic and Rock Magnetic Perspective, Memoir Geological Society of India.


Dick, H.J.B.,2006,Past and future impact of deep drilling in the oceanic crust and mantle, Oceanography 19(4), 72-80

Earth's Dynamic Systems, Tenth Edition by Dr. W. Kenneth Hamblin and Dr. Eric H. Christiansen

K K Ajay1, A K Chaubey1,K S Krishna1, D Gopala Rao and D Sar, Seaward dipping reflectors along the SW

Maus et al., 2009, EMAG2: A 2-arc min resolution Earth Magnetic Anomaly Grid compiled from satellite, airborne, and marine magnetic measurements, Geochemistry-Geophysics-Geosystems, Vol.10, No.8

* The views expressed by the author is of his own and not necessarily of the organization, which he represents.