Crustal architecture, Magmatism and Sedimentation in Kerala Basin- southern part of Western Continental Margin of India

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Abstract

Kerala basin, part of western continental margin of India has evolved through separation of continental masses like Africa, Madagascar, Seychelles and creation of Arabian Sea. Exploration activitiesbegan in 1976;however, hydrocarbon discoveryis yet to be made. Unexpected occurrence of volcanics in many wells has puzzled and thrown further challenges in the basin in terms of geometry, geodynamic processes, magmatism and sedimentation.The present study aims to bring out the crustal architecture, magmatic activities during and after break up phases and sedimentation style in Kerala Basin.

Recently acquired SBN velocity data and seismic reflection pattern brings out the structure of Moho, Conrad, Top Basement and defines the depth of Mantle and thickness variation of Lower and Upper Crust across and along the basin. Shallowing up of Moho from 28-30km from the shelf to 16-18km in deep water area with the inflection point around present day slope regime (1000-2000m bathymetry)is seen. Presence of half grabenslike features of extensional regime evident and are characterised by wedge shaped seismic facies with continent ward dipping faults. From well data these seismic facies have been proved to be dominantly volcanics with intermittent volcaniclastics.

Analysis of seismic facies, velocity profiles, electro-facies andlitho-facies suggest presence of multiple set of Sea Ward Dipping Reflectors(SDR) overlying the extensional/transitional crust. The SDR sets become younger towards southwest and go in to proto-oceanic/oceanic crustal regime.

The wells have proved the sedimentation from Santonian onwards with volcanism at Late Cretaceous (90Ma) and Paleocenetime. Overlying the Paleocene trap the basin received clastic sedimentation in thermal subsidence regime with major depocentres adjoining to the present day shelf. Comparatively,shelfal area experienced thicker (at places >2200m) carbonates (Eocene to Miocene) along with subsidiary amount of clastics during Paleocene-Early Eocene and Late Miocene-Recent periods.

Absence of hydrocarbons particularly in deep water regime is due to presence of thick volcanics in form of SDRs and lack of thick sediment deposition during the extension cycle. The continental stretching and breakup over a hotter mantle (Marion Hot Spot)andhigh rate of extension of the lithosphere during Late Cretaceous to Paleocenecausing catastrophic mantle melting arepossible reasons for the accretion of thick volcanic rocks in the basin.

Introduction

Kerala-Konkan basin (Fig.1) part of the western continental margin has been in exploration for nearly four decades. The prolific producing Mumbai offshorebasin to the north has always encouraged several E&P companies for exploration activities.Evolutionary history of western continental margin of India and well data in Kerala basin suggest existence of Mesozoic basin and possible petroleum system like in other parts of world. Drilling of identified prospects have not yielded desired results, instead thick sequences of volcanics have been encountered in place of predicted sediments ofMesozoics. This has raised question to the interpretation and model conceived so far for the basin in terms of its architecture, sedimentation and petroleum system. This paper is an attempt to bring out the crustal picture, basin evolution and sedimentation history through geologic time based on interpretation of newly acquired geological and geophysical data.

Data

Several seismic campaigne, particularly over last decade have been focussing the sub-basalt imaging in the basin. The WC lines by Large(2003), GXT lines(2006-07) and several campaignes of Long offset lines (2008, 2009 and 2012) have been utilised for this study. Recently acquired reflection-refraction (SBN) data having 40km offset and 36 seconds record length were used for deeper crustal level understanding. Out of total 18 wells drilled in the basin 8 wells located in Kerala Basin including recent wells representing from shallow shelf to deep water of >2000m are considered(Fig.2).

SW7000 line spreading from shelf through Laccadive depression and Laccadive ridge to Arabian abyssal plane was used along with the long offset line close to shelfslope and covering partly deep water area (Fig.2). Seismic horizons close to Paleocene trap top, Eocene top and below the trap the Mesozoic and crustal levels have been mapped considering the well data, seismic facies and velocity profiles derived from refraction data. The presence of unexpected thick basalt in some of the wells have been critically analysed through lithology-petrography and selected available radiometric age and their occurrences vis-a-vistectonic evolution.

Interpretation & Analysis

The regional SW7000 and WC seismic lines have been interpreted considering the various stratigraphic levels from wells. The Paleocene Trap top is consistently correlated from shelf to the deep water on SW7000 and WC linesseparating the Tertiary from the Mesozoic and older sequences(Fig.3 & 4). However, the horizons below the Paleocene trap has been difficult to map due to non-availability of well control as most of the wells penetrated the Tertiary sequence and ended in thick section of volcanics. The well A drilled in the shelf has proved the presence of about 700m of Late Cretaceous(Santonian-Maestrichtian) sediments with thin(about 20m) Paleocene trap and terminated in thick section(600m+) of older traps (90Ma). Correlation of the pre-Paleocene Trap sequences encountered in this well towards the basinal side on regional lines has been difficult due to poor continuity of reflections and imaging below the trap. The improved quality of latest longoffsetMCS and velocity information from the SBN refraction data has helped in understanding the sub-trappean geology in the basin. In addition to this wells B & C in deep water has also helped in givinglitho-bio-stratigraphic information.

The long offset dip line (Fig.5) has shown two strong reflectors towards lower part with velocity contrast; the bottom one represents mantle-crust boundary (Moho) and above it is the boundary between Lower and upper crust(Conrad). Shallowing up of Moho from 28-30km in the shelfal regime to 16-18 km in the western part in slope and deep water area has been observed along with the Conrad deepening and converging towards Moho and remain parallel thereafter. Unlike Moho the Conrad loses its signature against a thick wedge of seismic reflection packages which sharply thins and vanishes to the east. Below this wedge and above the upper crust distinct half grabenal architecture with east ward dipping faults have been observed. These half grabens are just above the shallowest portion of Moho and indicate extension and rifting.The long offset strike line(fig.6)passing through two wells in deep water areas of Kerala Basin show the Mohoshallowing up from north to south and loses its character with different seismic reflection configuration. Similarly the Conrad also does not have a distinct reflectors and more of a discontinuous nature in deep water regime and towards southern part it vanishes probably indicating only existence of lower crust or proto oceanic crust. The strong continuous seismic reflection packages of lower crust, characteristic of ductile basic rock composition is distinguished from the upper crust having discontinuous, chaotic reflection, characteristic of a brittle acidic rock composition. Similar half graben architectures are also observed with wedge shaped filling corresponding to the point of shallowingup of Moho where possible rifting,extension and creation of spaceis expected. The half grabens and wedge shaped fillings described are observed to have been controlled by continent ward dipping faults, and the growth of the fault has accommodated thicker sequences close to it.

The well-C penetratedupper wedge consisting of volcanic (basalts) and intermittent thin volcaniclastics with minor sediments in the lower part. However, therock types in the half grabensbelow the upper wedge has been conjectural with indirect evidences of look ahead VSP and non-occurence of hydrocarbon in the well. The compositions of the fill in half grabens are probably more of volcanics similar to the upper wedge rather than the expected lacustrine good quality source rocks. The well-B further south is located in a different setup has penetrated thickest (about 4000m) Tertiary sediments in the basin with dolerite/gabbroic intrusive in the lower part. These crystalline basic rocks further suggests the intrusive activity due to thining of crust and closeness to mantle and magma generation centre.

Crustal Architecture, Basin Evolution& Magmatism

Continental Crust of Kerala-Konkan basin is the extension of onshore Dharwar and Southern Granulite Terrain into the offshore area. In the process of separation of Africa, Madagascar and Syechelles from western continental margin of India the continental crusts have been extended modified, and finally given rise to oceanic crust in the Arabian abyssal plain. In case of Kerala-Konkan basin west of Laccadive ridge has been clearly identified as the oceanic crustal regime. However, the area between Laccadive ridge and shelfal area is although mostly believed as a stretched continental crust, the identification of volcanic wedges and there identification as SDRs close to shelf-slope regime brings a new analysis on the type of crustal regime in the Kerala basin. Two mantle plume activities one the Marion hotspot during Madagascar separation and the other Re-union hotspot during Syechelles separation from India are well known in the western Indian margin. The presence of thick volcanics in the shelfal regime and the present identification of number of volcanic wedges as SDRs in deep water areas, classify the basin as a volcanic passive margin having active mode of rifting where lot of traps/volcanics are accumulated similar to the observations madeby Laurent Geoffroy, 2005.

As per the model by Laurent Geoffroy,2005 the Crustal extensions at volcanic passive marginscreates number of SDR wedges, the inner one being on continental crust and the other sets generated in transitional to oceanic crustal regime. The origin of SDRs aresyn-magmatic roll over tectonic flexures whose development is controlled by major continent ward dipping normal faults. The geological section prepared along the dip line(Fig.7) has shown wedge shaped bodies right above the shallowest point of Moho indicating thining, stretching andthe filling of volcanics as SDR due to its closeness toa hotter buoyant mantle. Further oceanic side thicker wedge shaped packages are seen in long offset as well as SW7000 lines. The continent ward dipping faults progressively inactivatedas the SDR wedges develop ocean ward with rifting and creation of oceanic crust.

SDRs in general represents the boundary between continental and oceanic crust. In this case an extensive zone (>100km) are represented by number of SDRs from the slope area to the deep water areas which probably indicate a wider transitional crust with signatures of proto oceanic crust in deep water areas as evidenced from gabbroic intrusive in the well-B.

Sedimentation Style & Hydrocarbon Potential

Based on the evolutionary history, it is believed that the basin should have sedimentation commenced from Mesozoic (Jurassic) onwards. The drilling activity has proved so far the sedimentation from Santonian onwards. The older sequences to Santonian and even the Santonian-

Maestrichtianpackageencounterd in only well A have not been proved in nearby areas inspite of deliberate efforts in recent years. The targeted Mesozoic wells have encountered thick sequence of traps compounding the interpretation problems in the basin. Now with the reflection packages below Paleocene Trap in deep water area turning to be dominantly of volcanics and represent a SDRs in a transitional to proto oceanic crust, the area within shelf-slope remains to be analysed for Mesozoic prospectivity. But again the volcanic areas to be separated from the sediment prone area with better seismic API control.

Regarding the Tertiary, the basin has received clastics during Paleocene to Early Eocene period (Kasargod Formation) within shelf and adjoining lows in slope and deep water area close to the present day shelf. Few wells including well-Bhave encountered thick sequence of clastics having adequate entrapment conditions with reservoir facies and seals without any hydrocarbons. Source rock parameters of these sequences suggests poor hydrocarbon generation potential. Overlying Kasargod Formation the shelfal area continuously received carbonate sediments (at places >2200m) from Eocene to Miocene with minor clastics. Middle Eocene to recent the deep water areas received deep water finer clastics in the basin. Eventhough, the Tertiary carbonates possess good porosity and entrap conditions, no hydrocarbons were found.Absence of Tertiary petroleum system could be mainly attributed to absence of potential source rocks.

In spite of long years of exploration, it remains to be understood in terms of generation, migration and entrapment cycle particularly for thel Mesozoic sequence which are yet to be proved. The present study with identification of crustal boundaries and number of SDR packages consisting of volcanic suggests dimprospectivity in deep water areas and involves huge risk for future exploration. However, the areas in shelf-slope regime, specifically south of Allepy platform still warrants focus exploration for establishing hydrocarbons in Kerala basin.

Summary & Conclusions

The evidences and structural architecture suggests a volcanic passive margin with strong magmatic activity and fillings of mostly volcanic materials during the synrift stage due to hotter mantle plume activity.

The strong reflection characters having wedge shaped bodies with continent ward dipping faults are identified as SDRs and generated during shallowing up of Moho and extension giving rise to a transitional crust and proto-oceanic crust.

Search for Mesozoic petroleum system should be focussed to shelf-slope areas particularly south of Allepy Platform.

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References

1. Geoffroy, Laurent, Volcanic Passive Margins, C.R.Geoscience 337(1395-1408) 2005, published by Elsevier SAS.
2. Unpublished report by ONGC on well A, B & C ; 2010, 2014
3. Unpublished report by M/s MGS on Long offset data, 2013

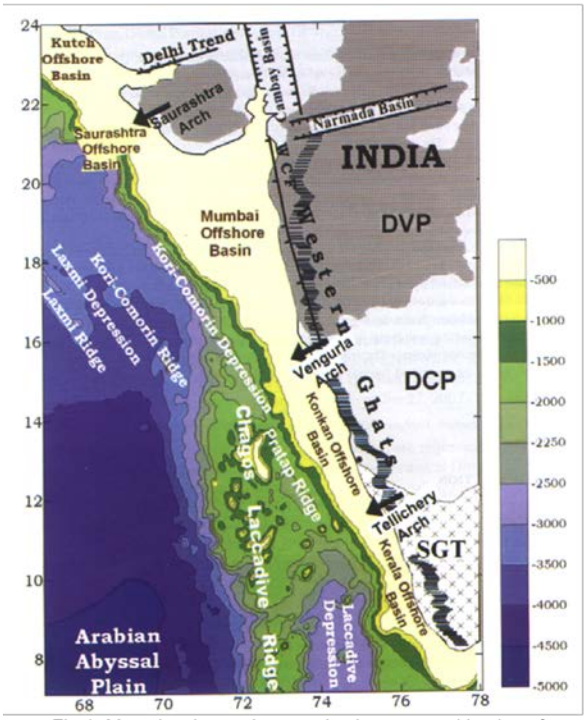

Fig.1: Map showing major teconic elements and basins of western continental margin of India (Kerala-KonkanBasin to the south of Mumbai Offshore).

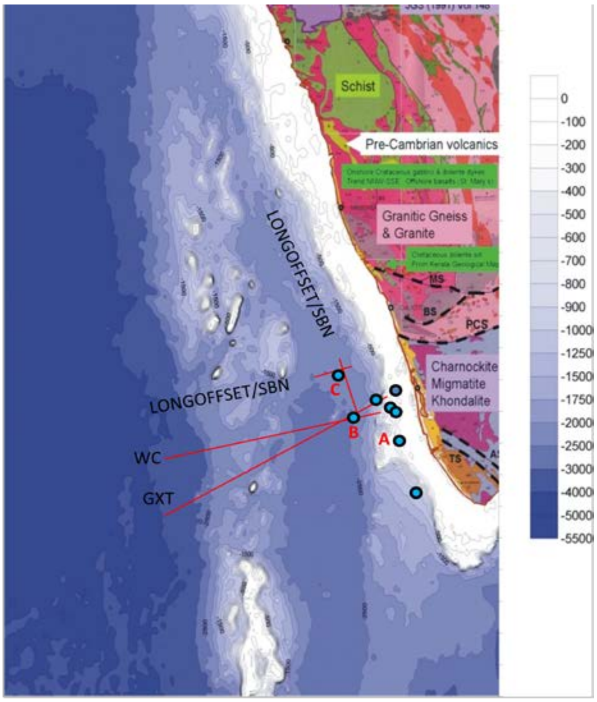

Fig.2: Location map of Kerala-KonkanBasin showing the seismic lines and well (Bathymetry & onshore geology in the background

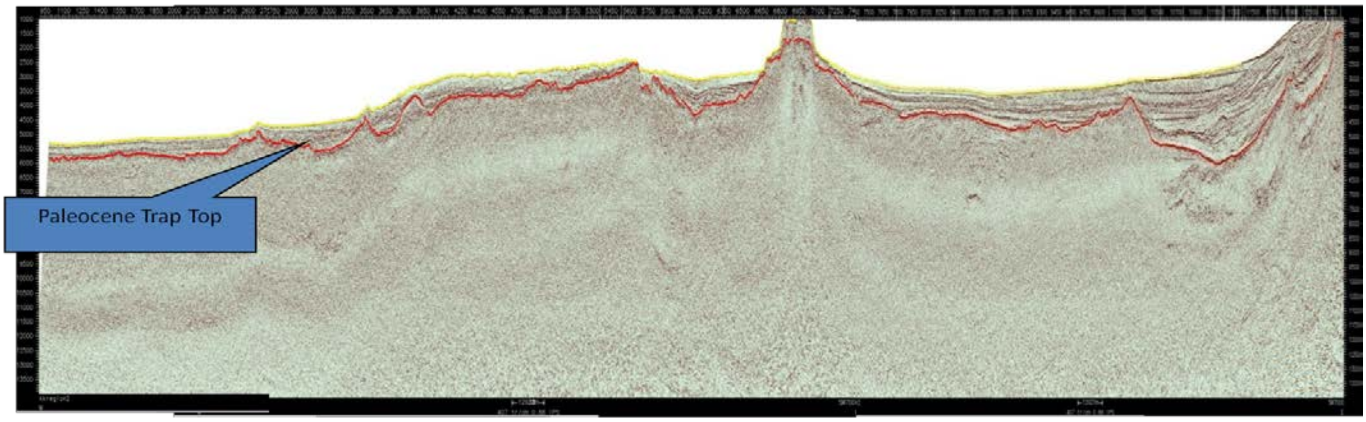

Fig.3: GXT-7000 line(time) across the basin from shelf to Arabian abyssal plane with Paleocene trap top (red) separating Tertiary sediments from older volcanic & crustal reflections.

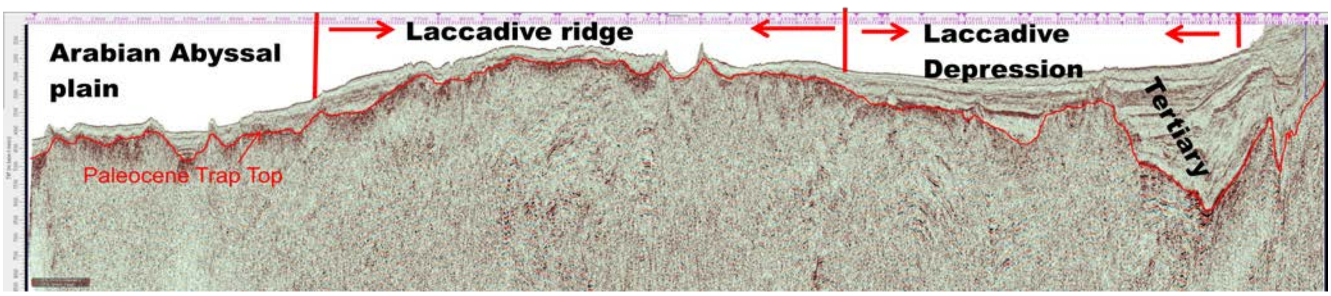

Fig.4: WC line (psdm) across the basin from shelf to Arabian abyssal plane with Paleocene trap top (red) separating Tertiary sediments from older volcanic & crustal reflections.

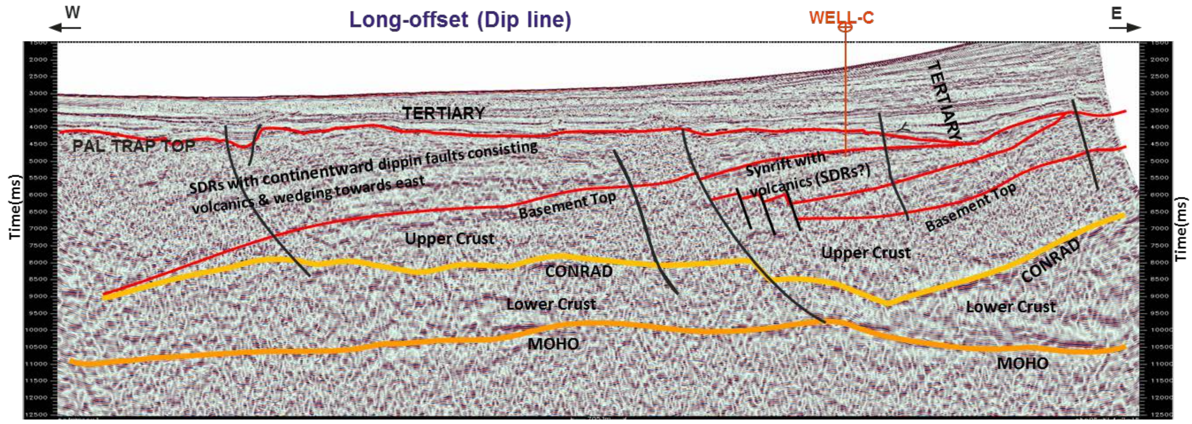

Fig.5: Long-offset(Dip Line) showing crustal features, basin architecture and sedimentation close to shelf in Kerala-Konkan Basin.

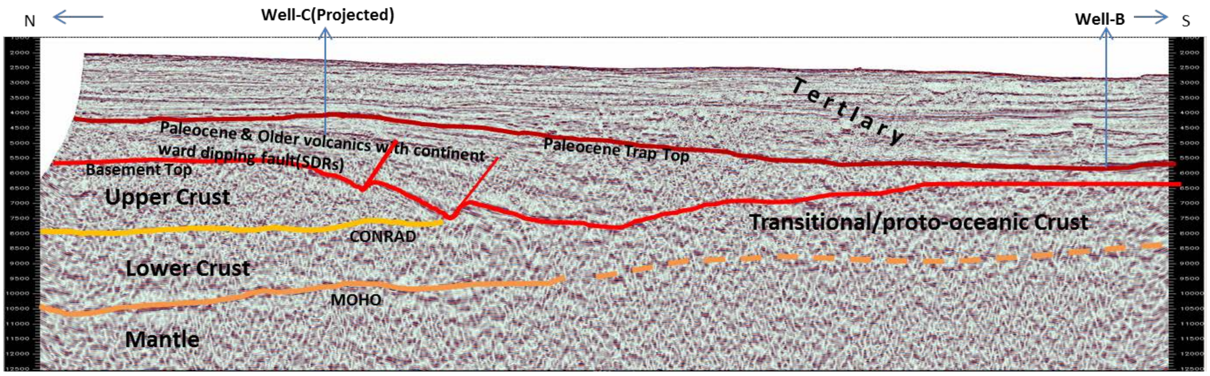

Fig.6: Long-offset(strike line)(time) showing crustal features, basin architecture and volcanic facies from shelf to Laccadive depression towards south west in Kerala-Konkan Basin.

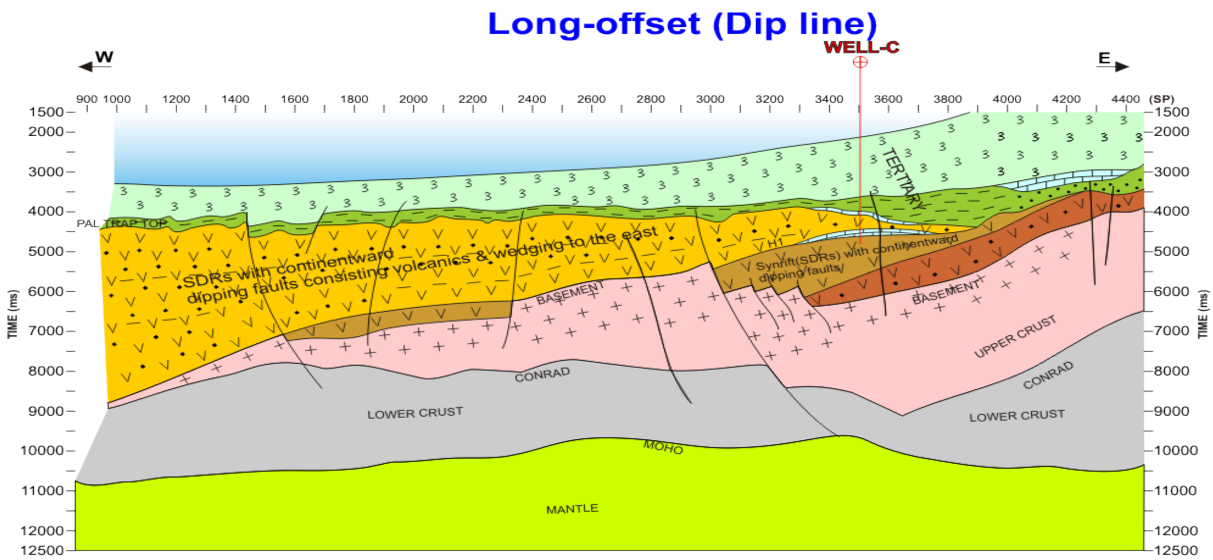

Fig.7: Seismogeological section along long-offset(dip line) showing crustal features, basin architecture and sedimentation along with pre-Tertiary volcanic faciesin the shelf,slope and deep water area of Kerala-Konkan Basin.