8th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2010"

P-334

Hunting Sub-Basalt opportunities in Kerala Konkan Deepwater Frontier: An Enticing ride through Geophysical Challenges.

Chandan Kumar Mishra, D.M.Nathaniel, Rabi Bastia, Muralikrishna Akella, Ravi Verma, Shashirekha Mahapatra, Megha Saxena*
Reliance Industries Ltd (Petroleum Business, E&P)

Summary

Skepticism is an essential part of hydrocarbon exploration as it is not possible to proclaim a law of nature until the idea has survived the exploration drill test. In the recent decades, worldwide hydrocarbon discoveries below basalt have brought considerable attention to exploration in the areas of volcanic margins. So far along the Southwestern continental margin of India, Kerala Kankan offshore exploration efforts were confined to the shelfal shallow Tertiary petroleum system only in view of its complex geologic setup, extensive episodic volcanism and poor sub basalt imaging. Beyond that, a synergic approach with in the frame-work of modern geophysical technologies, regional geologic studies & global analogies has geared up the optimism regarding the existence of sub basalt Mesozoic opportunities in the Kerala Konkan deepwater avenues. In this paper, some of the challenging issues like the sub-basalt imaging, Mesozoic sediment thickness, uncertainties in velocity estimations have been vividly discussed in the light of modern seismic acquisition & processing techniques blended with regional gravity studies & global analogies. An optimistic perspective for the sub basalt Mesozoic opportunities have logically re-enforced over the pessimism regarding the hydrocarbon prospectivity in Kerala Konkan deepwater Frontier.

Introduction

In the recent decades, sub basalt hydrocarbon discoveries have accelerated the exploration interests beyond the conventional areas to the volcanic provinces world wide. So far, along the south western continental margin of India, Kerala Kankan offshore exploration efforts were confined to the post trap shallow shelfal Tertiary petroleum systems due to its various geological & geophysical complexities. Although plate tectonic reconstruction studies in light of multi episodic rifting in the Kerala Kankan Basin have indicated the existence of pre trap thick Mesozoic sediments, sub basalt seismic imaging has been a major constraint in delineating and effective mapping of these prospects. Deccan basalts of Paleocene age which overlay the Late Cretaceous sections play a detrimental role in seismic imaging of underlying Mesozoic sediments. A definitive approach integrating seismic, gravity-magnetics, available well data & regional geologic studies with global analogies have triggered a paradigm shift in prospect hunting from post trap Tertiary to sub-basalt Mesozoic sediments as potential exploration targets.

Sub basalt imaging is critical, since the hydrocarbon targets are obscured by the distinct elastic behavior of the basalts. Dependent on the nature of basalts, incident seismic energy tends to get absorbed & scattered which result very poor quality data in sub basalt sections infested with multiples, high velocity diffractions and other noises. Hence, state of the art techniques in seismic data acquisition and processing are warranted to improve the sub-basalt imaging.Integartion of different geoscientific studies along with seismic in the concerned area have indicated the presence of structural and strati-Structural prospects in the sub-basalt Mesozoic levels.

Regional Geological Setting and Mesozoic Prospectivity of KK Basin

The South Western Continental Margin of India is characterized as complex volcanic passive margin bounded by NNE-SSW trending Vengurla arch separating from Bombay offshore basin in the north, NNW-SSE trending coast line to the east and dispersed continental fragments, volcanic mounds and open abyssal planes to the west. In

Reliance Corporate Park, Building No: 11, 1st Floor, "B" Wing, Thane-Belapur Road, Ghansoli, Navi Mumbai, India-400701
chandan.mishra@ril.com

the area under consideration, six contiguous, NW-SE trending major tectonic elements identified are shown below (Figure-1),

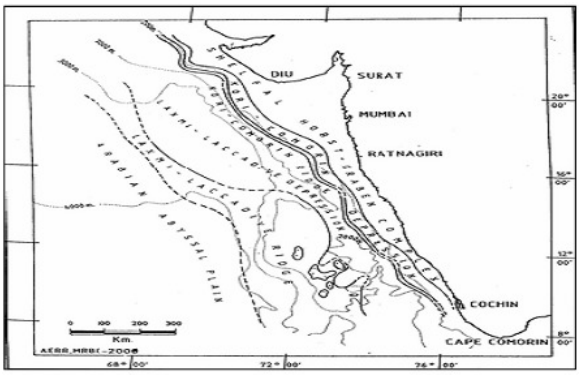

Figure-1: Map showing major tectonic elements identified in Western Offshore, India (N.K. Singh & S.K. Biswas, 1988)

They are namely, the Shelfal horst graben complex, KoriComorin Depression, Kori-Comorin Ridge, LaxmiLaccadive Depression, Laxmi-Laccadive Ridge and Arabian abyssal plain(Figure-1).

Hydrocarbon exploration in KK offshore has only been confined to the Tertiary stratigraphy for obvious reason being in structural contiguity with the prospective Bombay offshore basin. Further more, problems in seismic imaging beneath basalts is an added factor for not concentrating in the Mesozoic exploration in this area. Regional geoscientific studies considering the benefit of the episodic rift systems, catastrophic igneous flows and subsequent tectonic readjustments, Mesozoic sediments overlain by basalt layers have been inferred as potential hydrocarbon prospects in KK basin. Regional plate reconstruction studies have boosted the high possibility of thick pre trap Cretaceous & Jurassic sedimentation in deepwater along the south western continental margin of India from Antarctica as well as Africa may be acting as major sediment dispersal provinces. Moreover, before the east wardly shift of the river drainage pattern in India around the late part of the late Cretaceous, their contribution for the deep water sediment depositions could be a reasonable perception adding Mesozoic prospectivity in KK basin. Uniting the role of fracture zones & transform margins drawn from the analogies of world wide proven petroliferous basins like Ivory-Ghana(non-volcanic margin),Exmouth Platue, Voring Basin, Angola(all these are volcanic margins) vis-à-vis to the geological setting of KK basin has provoked fare optimism regarding the Mesozoic prospectivity in this deep water frontier area. A symbiotic convolution of the bold geological concepts & modern "fit for purpose" geophysical technologies have emerged as an effective tool to circumvent various criticalities for establishing hydrocarbon prospectivity in this challenging exploration paradigm

.

Geophysical Challenges & Circumventing Approach

In the concerned Kerala Konkan deep water regime, sub basalt imaging & vagaries of seismic velocities are the major concern for the effective mapping & prospect delineation. However, Seismic imaging problems are associated with the physical properties of basalts lying above the reservoir. The physical properties of basalt section are directly related to the lava emplacement process causing heterogeneous bodies characterized by vertically and laterally varying velocities with irregular interfaces. The basalts encountered in KK basin have multiple flows and the thickness of the basalt varies considerably in this area. Low velocity sediment layers overlain by high velocity basalt layers lead to major imaging intricacies like multiple reflections, attenuation and mode conversion of seismic waves at the basalt/sediment interface and with in the basalt layers. The seismic data acquired in eighties and nineties with 2.4 km offset could not image the sediment sequences below basalts. Seismic imaging in KK basin faces some common reflectivity issues related to reflection ray bending in comparatively hard rock sequences. Strong density and velocity contrast between lithological boundaries cause the incident seismic wave to move away from the normal incidence. As a result, with in shallow depths, the critical angle is achieved constraining the deeper penetration of the seismic waves. So the initial challenge has been identified as imaging of deeper targets with increased signal penetration and recovery. Accordingly, the 2D/3D data were acquired in 2005/2007 using comparatively long offset with optimized acquisition parameters. The broad acquisition parameters of different Surveys are mentioned below (Table-1):

Parametres	Set A	Set B
Type of Survey	2D	3D
Streamer Length(m)	7950	6000
No of Groups	636	480
Group Interval/Shot Interval(m)	12.5/50	12.5/25
Sample Interval(ms)	2	2
Record Length(sec)	10	9
Gun Depth/Streamer Depth(Varies 1m up/down)	5/6	5/6
Nominal Source Volume(cu inch)	4460	4300*2
Filter LC/HC (Hz)	3-206	3-200

The area covering these 2D/3D deepwater acquisition campaigns are situated way beyond the shelf at the southern part of KK basin. The present day bathymetry in the concerned area ranges from 1.5-2.5 km (Figure-2).

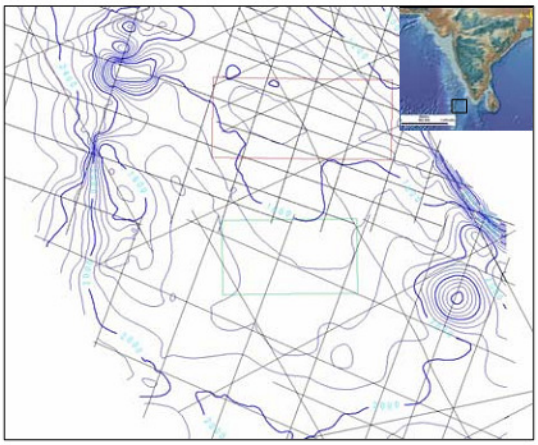

Figure-2: Map showing the concerned 2D profiles in Black, two 3D areas outlined in Red & Green as well as present day bathymetry contours in Blue

The reflected part of energy from the sea floor and the hard sediments close to sea beds along with the shallow basalt generates strong short and long period multiples, which interfere with primaries from deeper depths and mask the primary weak signals. The basalt has the strongest reflectivity and hence energy penetration is very less with reduced frequency content. Strongly reflected energy from the top of the basalt undergoes multiple reflections at interfaces between the sea floor and the basalt. The multiples generated at the base of the basalt are stronger than the reflection response from the sub basalt reflectors. The heterogeneous basalts of KK basin generate multiples with severe deteriotion of signal to noise ratio in the recorded reflection events from the deeper targets.

Some of the aforementioned imaging issues have been mitigated especially surface multiples related to sea bottom and interbeded multiples with in and below the basalt layers by applying the processing techniques like SRME, Radon demultiple techniques & multipass velocity analysis enhancing the signal to noise ratio. A broad reprocessing sequence adopted for long offset 2D data is outlined below.

- Reformatting
- LC filter.denoising & spiking
- Resampling
- 2D SRME
- First pass velocity analysis
- High resolution radon demultiple
- Diffracted multiple attenuation
- Inner trace muting
- Initial PreSTM
- Second pass migration velocity analysis
- Final PreSTM
- Final inner trace muting
- Post migration high resolution radon demultiple
- Residual velocity analysis
- Outer trace muting
- Bands pass filtering
- Equalization
- Stack Random noise attenuation
- Equalization

The following figures show the improvement in the pretrap-seismic signatures through the above reprocessing in comparison to the vintage processed data. The continuity in the reflection patterns has increased with better S/N ratio in the seismic section leading to mappable structural features. In the 3D data, the reflection configurations have come up more clearly in comparison to the 2D reprocessed data enhancing the low frequency stuffs(<20 Hz) below basalt. Some of the geologically reasonable but feeble reflection patterns present in the vintage data have emerged as more apparent, conducive & genuine in 2D reprocessed data & in 3D data for mapping interests. Furthermore, the various post stack attribute analysis run on these sections

have complimented in reducing the ambiguities in extending the structural interpretation spatially & temporally.

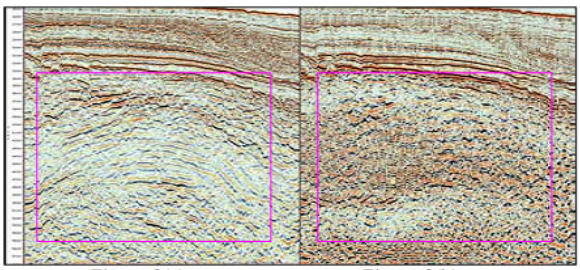

Figure-3(a) Figure-3(b)

Figure-3(a) & Figure-3(b) are the final PreSTM stack Sections after reprocessing & with vintage processing of a 2D part profile

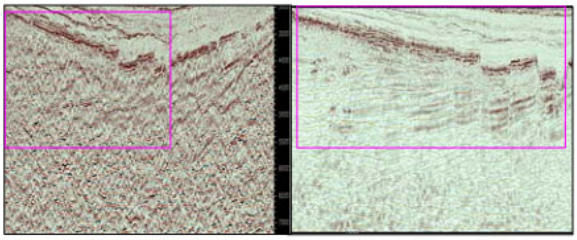

Figure-4(a) Figure-4(b)

Figure-4(a) & Figure-4(b) are the final PreSTM stack Sections of 2D reprocessed data & a 3D line overlying the same 2D part profile.

The interval velocities calculated from the final stacking velocities for the basalt layer & the sub basalt layers has shown lateral as well as vertical variations leading to the strong perception that the thickness of the flood basalt may be gradually thinning towards southern part of the basin as well as rapid facies variations in the aforementioned area. Though predicting basalt thickness only from the seismic velocity information still poses a formidable challenge, it can be assumed to be thinner than the nearest well i.e.: CH1-1.Moreover, the shifting of Reunion Hot spot trails leading to increase of effective elastic thickness of the crust towards southern part of the basin consolidate the perception that the volcanic impact & lava emplacement would much lesser in the aforementioned acreage area. The wells drilled in the northern part of KK basin, adjoint Gulf of Mannar, Conjugate basins like west Madagascar & Mozambique have encountered thick Mesozoic sediment piles with velocity 3000-4000m/s at a comparable depth of 2.5-4 km from the sea bottom. Although in the concerned area, the seismic velocities are 10-15% higher, it could be an over prediction as well velocities are generally less than seismic velocities in the available data. The experimental results using Beam migration technique in 3D data has shown drastic improvement in sub basalt section with high S/N ratio and relatively less interval velocities compared to PreSTM Velocities.

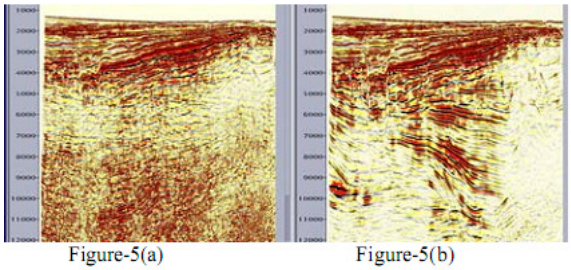

Figure-5(a) Figure-5(b)

Figure-5(a) & Figure-5(b) are the Final PreSTM & PreSDM (Beam Migration) sections of a 3D line flipped.

Combining the available velocity information from 2D/3D PreSTM data, Mesozoic sediment thickness have calculated conservatively as 2500 m to 7500m

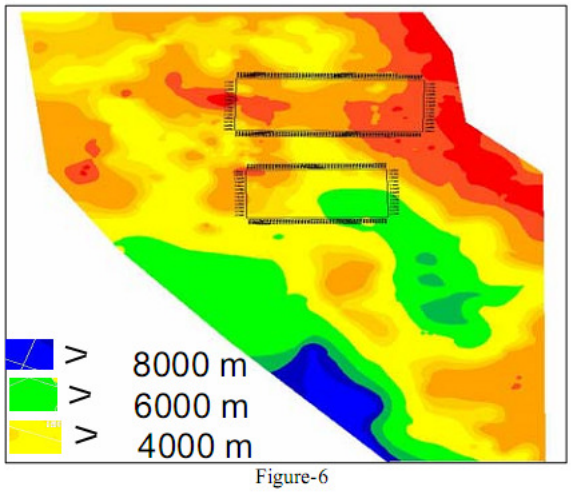

Figure-6

Figur-6: A tentative sub-basalt Mesozoic thickness map of the concerned area

The regional gravity modeling studies also have predicted the basement depth at 7 to 8 km inferring presence of low density litho-pach of 4-6.5 km between basalt & the modeled basement.

Discussions

The above illustrations regarding the seismic imaging below basalt in KK basin reveal that long offset seismic data after an optimized processing using better demultiple techniques has enhanced the signal to noise ratio as well as structural imaging in the interested zone. However, the intricacies related to attenuation, mode conversion of seismic waves as well as anisotropic behavior of the propagating medium has to be dealt with the innovative acquisition and processing trends for better imaging. The following acquisition and processing techniques may bring out improved sub basalt imaging. & will make the lithology prediction more sensible.

- Recording of long offset data (>10km) using low frequency source (<30Hz) to avoid scattering problem.
- Recording of over/under towed streamer data
- Recording of multi component OBC data to use both converted P and S wave information.
- Model based inverse Q-filtering to suppress attenuation effects.
- Multi pass SRME and Radon filtering for multiple removal
- Super offset refraction data for delineating base of the basalt
- Prestack depth migration (with anisotropic correction, if possible) blended with good interpretative knowledge into velocity model for correct imaging.
- Regional ship borne Gravity-Magnetic data as well as Marine Magnetotelluric data for predicting Basement Depth & precise Lithology contrasts.

Conclusions

Strong Optimism for Sub Basalt Mesozoic opportunities is high in the deepwater sectors of South western continental margins of India as demonstrated by a synergic approach of state of the art geophysical technology in conjunction with bold geological concepts. Exploration of this enticing sub – basalt exploration targets is expected to contribute substantial additional reserves in tune with Hydrocarbon Vision-2025 of the country.

Acknowledgement

We sincerely thank Reliance Industries Ltd, Mumbai for allowing us to publish this paper. We are highly acknowledged to M/s CGG Veritas, M/s PGS and RIL processing group for their help and constructive suggestions.

References

Al Danforth, Steve Henry, 2007, Plate-Tectonics and Hydrocarbon Potential along Indian Continental Margins: Interpretation from regional GXT Profiles, Project Report, GX Technologies.

David, H., Leendert, C., and John B.,[May 2006] Imaging beneath basalt using an over/ under towed-streamer configuration, World Oil, **227**, No. 5.

Dhananjay, K., Bastia, R., and Guha, D., [July 2004] Prospect hunting below Deccan basalt: imaging challenges and solutions, *first break*, **22**, 35-39.

Nathaniel, D. M., Jain, M., Verma, R., Tenepalli, S., and D'Silva, K., Optimism versus Pessimism: The future of hydrocarbon exploration in offshore KK basin, India, [2006] *APG, India.*

Maresh, J., White, R.S., Hoobs, R.W., and Smallwood, J.R.,[2006] Case History: Seismic attenuation of Atlantic margin Basalt: Observations and modeling .*Geophysics,* **71**, No 6, B211-B221.

Reeves, Colin [September 2009], Re-examining the evidences from plate-tectonics for the initiation of Africa's passive Margins, Geological Society of Houston/Petroleum Society of Great Britain, London

Sheena V, Dev, Radhakrishna, M, and Subrahmanyam,C, [September 2007]Estimates of effective elastic thickness along the Southwest Continental Margin of India using coherence analysis of Gravity & Bathymetry DataGeodynamic Implications, *Journal of Geological Society of India,* **70**, 475-487.

Wang, Y., and Satish, S. C. [2003] Separation of P- and Swavefields from wide- angle multi component OBC data for a basalt model. *Geophysical Prospecting*, **52**, 233-245.
Yilmaz, O.Z. [2001] *Seismic data analysis: processing, inversion and interpretation of seismic data*, SEG publication.

Ziolkowski, A., Hanssen, P., Gattilf, R., Jakubowicz, H., Dobson, A., Hampson, G., Li, X., and Liu, E. [2003] Use of low frequencies for sub-basalt imaging. *Geophysical Prospecting* **51**,169-182.

RIL-Fugro Robertson Interpretation report for for offshore sedimentary basins of India (Internal),2008