9th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2012"

P-212

"Lava delta" below 85º ridge, Mahanadi offshore basin; identification, characterisation and implication on hydrocarbon prospectivity

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Summary

85° East Ridge is a prominent structural feature in the deep to ultra deep water regime of East coast of India. In the recent times a lot of scientific study has been done to understand the genesis and importance of this ridge system for hydrocarbon exploration. Many operators have acquired 2D and 3D seismic data set to understand the ridge geometry. The present paper focuses on the internal architecture of the ridge which could be helpful in characterizing the ridge genesis. Well developed prograding seismic reflectors have been found below the acoustic basement. These interesting features give an insight to the process which accompanied ridge formations. Prograding events identified in the seismic data can be due to delta formation in a clastic depositional regime or it can also form due to lava flow. The Present study supports the formation of lava delta in the region during the formation of the ridge. Characterizing these lava deltas has been helpful in predicting a hydrocarbon system in the region.

Introduction

Two prominent aseismic ridges characterize the east coast of India, 85°East Ridge and 90° East Ridge. Out of these two ridges the 90 East Ridge is thoroughly worked and genesis for the ridge is understood to a larger extent, thanks to the DSDP wells drilled on the ridge. But in case of the 85° East Ridge, no drilled well data is available for characterization. Many authors have tried to understand the genesis of the ridge using available gravity and magnetic data and models derived from them. Recently seismic data, acquired by various operators for their respective blocks, have put forward chances to unravel the truth. But still with no drilled well information, there lies two schools of thoughts on the ridge formation. Some authors feel the ridge is formed by plume activity related to hot spot, few others think it is a part of the continental sliver which got detached from the Indian subcontinent .Till now origin and nature of 85° E ridge is debated to be evolved as a result of hotspot trace, lithospheric flexure, sagging of the crust or a micro continent. Curray and Munasinghe (1991) put forward the hotspot origin for the ridge which is related to the trace of Crozet hotspot (which also formed Rajmahal trap) with avg. age of 117 Ma. Murthy et al., (1993) and Gopala Rao et al., (1997) supported the concept of hotspot model of Curray & Munasinghe, (1991).Sar et al (2009) thought of a continental origin of the ridge. With so many postulations on the ridge origin it is really difficult to reach a final statement. In the present paper the authors focus on some interesting observations made below the basement. In the study area seismic sections show interpretable seismic reflectors within the basement. By basement the authors mean "acoustic basement" or the shallowest reflector defining ridge feature. Interpretation of these features have resulted in refining our understanding of the ridge formation and the hydrocarbon system related to the ridge.

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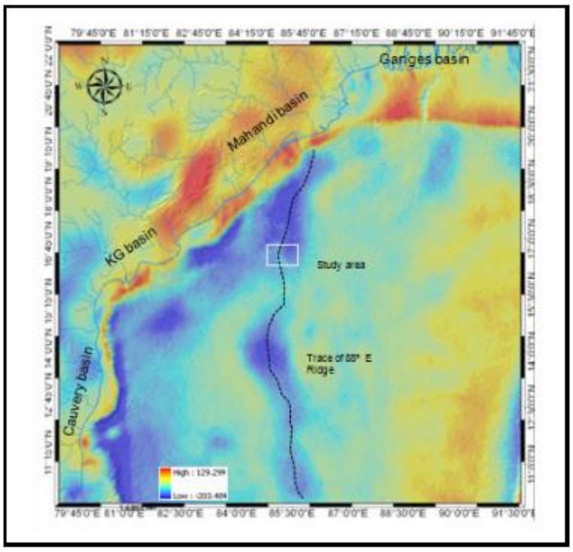

Figure 1: Bouguer Gravity map showing trace of 85º East Ridge, and the study area. The study area forms a part of deep water basins of Mahanadi.

Study area and Objective

The study area for the present work is part of Mahanadi deep water basin (Figure 1). Present day water depth in the region varies from 2000 to 3200 m. Gravity & magnetic modeling shows the area sits over the oceanic crust. Using gravity data the regional trend of the 85 East Ridge is marked .Seismic data in the study area helped more accurate mapping of ridge. Few basement highs related to the ridge activity could be mapped (figure 2). Objective of this work is to identify and characterize the prograding seismic reflectors (events) within the basement, correlate these to the ridge formation and understanding its implication to the hydrocarbon potential of the region

Data Used and Methodology

Long offset 2D reflection seismic data set have been used for the study. While the regional trend of the ridge is interpreted from the available bouguer gravity data, the actual ridge geometry and extent have been mapped using seismic data set. Pre-stack time migrated (PSTM) data are used for the interpretation process. Few seismic attributes are also being used for detail analysis.

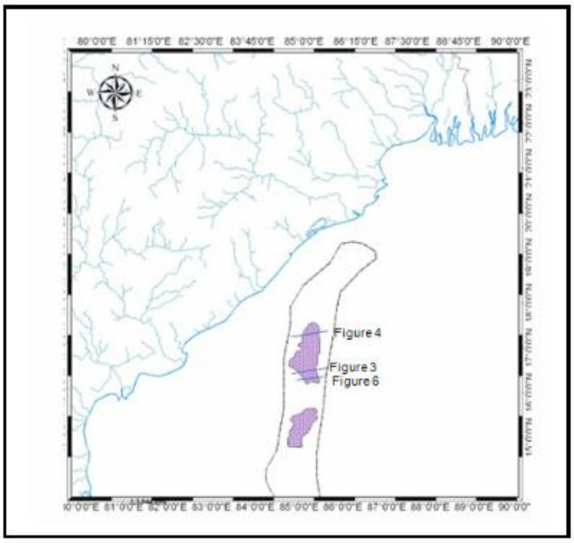

Figure 2: Trend of 85° East Ridge interpreted from Gravity and seismic data set. Location of the seismic profiles used are also shown in the map.

Observations and Interpretation

Seismic reflectors below basement shows some interesting features. One representative seismic section across the ridge trending in SW-NE direction is shown in figure 3. In the above section only the portion below the basement is shown so that the internal reflections could be seen better. From the section it could be seen that a bunch of reflectors dipping towards SW. The inclined reflector bunch is overlain by a pack of parallel high amplitude reflectors. The reflections are found to be onlaping on the underlying bounding reflection. The base of these inclined reflectors are not very clear but can be interpreted to be downlaping to the deeper reflectors. Height of these inclined reflectors are of the order of 400 to 500 ms (TWT), and length more than 5 km. This reflection pattern is similar to prograding reflection pattern identified by Vail et al (1977) in siliciclastic environment. The stratal terminations observed in the section are similar to those identified in world wide clastic environment. But at the same time these types of prograding reflections with steeper inclinations have been interpreted to be subaerially erupted lava flows moving into the sea, forming steep delta like formations (Smythe et al., 1983, Kiorboe, 1999, Spitzer et al, 2008). So this reflection pattern could be corresponding to delta / low stand delta in clastic depositional set up or may be lava delta.

Delta Prograding seismic reflection pattern are clearly seen while the sedimentation continue from shelf to slope settings. These are caused due to interaction of sedimentation rate and relative sea level change. The reflection pattern are characterized by presence of topset, foreset and bottom set (Catuneanu, 2005).

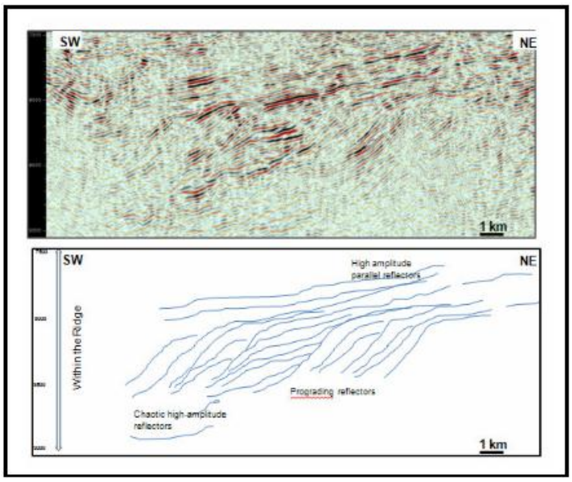

Figure 3: Seismic section showing the below basement events related to 85° East Ridge. The basement reflector is not shown in the figure. The inclined reflection pack representing prograding event are clearly seen.

Lava Delta: These unique features form when lava enters into water. When the lava hits the water it cools off and creates fragments due to sudden cooling. These fragment material accumulate on the slope and forms a base for further coming lava flows. The younger, overlying lava-flows, starts building up on the already formed platform. With more and more volcanic input the lava moves seaward, forming those prograding deposits. These lava deltas do preserve the transition from subaerial to submarine strata and can be used for identifying paleo-shore line (Wright et al 2011).

The above discussion points out the challenges associated with interpretation of the prograding reflection pack below basement. To address this problem many seismic sections in the area were interpreted and the prograding events were marked. A representative seismic section showing the basement and the features below basement is shown in figure 4.

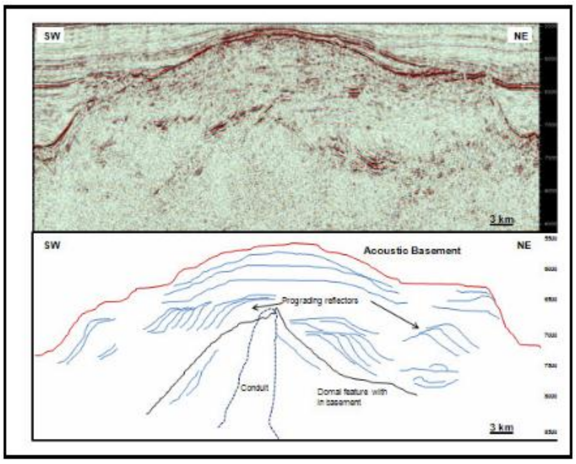

Figure 4: Seismic section and seismogeological section showing prograding seismic reflector packs dipping in different directions

The seismic section (figure 4) shows two sets of prograding reflector packs. The two set of reflectors are seen to be dipping into different (opposite) direction. From the seismic data set various set of prograding reflection packs could be identified and the gross dip directions are marked (figure 5a).It is found that reflectors of the same set are dipping in almost in all directions. This observation is significant in defining the origin of the reflectors, whether by sediment progradation or by lava flow.

In case of deposition in clastic environment the progradation is along the direction of sedimentation or perpendicular/oblique to the coast (the provenance).The progradation pack shows the movement of sediment from shelf to slope to abyssal plain. So in this setting the prograding pack should dip only in one direction. If we consider sedimentation in the area was from NW direction (during rifting) then we should expect events prograding towards SE direction. But in case of these reflectors (below basement) the reflectors dip in various directions showing almost no specific trends. To discuss the various options two speculative models are also represented in the figure 5. The continental rift model is also discussed here as Sar et al (2009) put forward the continental origin of the ridge. In case of the continental rift model (figure 5b), the area consisting of horsts and grabens should show sedimentation from NW to SE direction. Nayak et al (2011) have discussed the Mesozoic sedimentation was mostly from the NW direction resulting in a thick Mesozoic sediment sequence along the ridge. But as already stated the various dip directions of the prograding sequence does not fit into the model. Another speculative model showing lava flow from a plume is shown in figure 5c. In case of a volcanic activity the lava can flow in various directions from the conduit. So in this situation, getting prograding events dipping in different direction is very much possible. In the figure4 the prograding reflector pack is associated with a vertical conical feature which may be representing a conduit in a volcano. Hence the dip direction of the prograding reflection packs corresponds to volcanic activities in the area or more specifically formation of lava deltas. Apart from these qualitative observations, velocity interpretation has also been done in the area. PSTM interval velocity value for the prograding sequence varies from 4100 m/sec to 4800 m/sec. This high velocity is very much similar to the basement velocity and hence could indicate association of volcanic material with the prograding events.

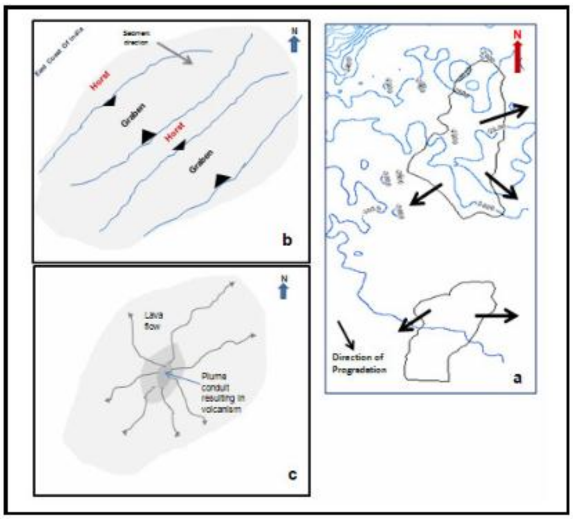

Figure 5: (a) map showing dip direction of the prograding reflection pack for one set. The reflectors are seen to be dipping in various direction without any biasness to a particular direction. (b) speculative model showing direction of sedimentation in a continental rift model .(c) Schematic diagram showing lava flow in all direction from the conduit .

Another interesting observation was different set of prograding reflection packs below basement. Scanning of various data sets has confirmed presence of more than one set of prograding reflector pack or lava deltas below basement. These are separated from each other based on dip direction, height and length. Parallel to chaotic seismic reflections between different set do confirm separate age for the packs. Figure 6 clearly shows presence of at least three set of lava deltas.

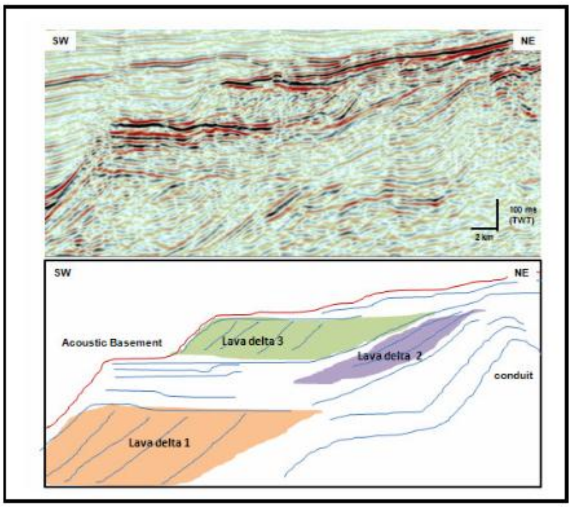

Figure 6: Seismic section and a seimogeological section showing presence of three set of lava deltas. All of the above three can be characterized by presence of different nature of reflectors based on height, length and inclination.

The different size and shape of the lava deltas could be correlated to the variation in volcanism with time. The geometry of the lava delta is controlled by relative sea level change, lava supply and available accommodation space (Wright et al., 2011).This multiple lava deltas could suggest multiple phases of volcanism as well as variation of sea level changes.

Lava delta, ridge genesis and implication on hydrocarbon prospectivity

From the above discussions it can be stated that the available data and analysis do suggest presence of well developed lava delta system below the basement in 85° East Ridge in the study area. Another facet of this discussion is how this interpretation affects hydrocarbon prospectivity of the region. Various Authors have discussed the speculative petroleum system for the region associated with 85° east ridge (Sar eta al, 2009, Nayak et al 2011, Jena., 2011).Few of them envisaged petroleum system associated with Mesozoic and Tertiary sediments flanking the ridge, while others gave an idea regarding presence of a petroleum system below basement (acoustic basement).This study focuses on the implication of presence of lava delta over petroleum prospectivity of the region .Few of the understandings are discussed below :

Presence of lava delta suggests that there was sub aerial volcanism after which the volcanic material moved into the sea. This points to the fact that the ridge was exposed (not under submarine condition) during formation. This fact is coherent with other drilled well data derived from aseismic ridges worldwide (Detrick et al, 1977).Drilled well data from various DSDP and ODP sites over various aseismic ridges have confirmed that the ridges which are at present under deep to ultra deep condition were exposed during the time of formation. So from the presence of lava delta and with these analogues it is clear that the ridge which is presently is in deep water condition could have been exposed during the initial time of ridge formation.

Presence of lava delta implies that the lava moves from sub aerial to submarine condition. Hence it could be envisaged that some part of the delta (prograding reflectors) could be in shallow water condition. These shallow water conditions are suitable for carbonate buildups. Various seismic attributes have been used to identify the probable Carbonate buildups. In the Instantaneous Phase section the carbonate buildups could be interpreted clearly (Figure 7). From various attribute sections if we could identify the shore line, shallow water area we could probably identify probable locale for carbonate buildups.

Different sets of lava deltas refer to various stages of volcanism and changes in sea level. If there is considerable amount of sea level change which in turn could have exposed the carbonate buildups. This exposure of carbonate can create secondary porosity favorable for hydrocarbon accumulation.

Lava delta interpretation fits more into the volcanic origin of the ridge related to plume activity rather than the continental theory. In this case (volcanic origin), there is a little chance that any older sediments of considerable thickness could be found below basement (thinking that the less thickness of sediment deposited on the oceanic crust could easily be destroyed due to volcanic activities). Hence there is a little chance of getting a source kitchen below basement.

Even if carbonate buildups could be envisaged on the top of lava deltas, connecting these to the source area is a task.

If we consider the youngest volcanic activities which form the present acoustic basement top, then there is a possibility that at the outer flanks there could be some carbonate build ups. Thick Mesozoic sediments in the lows flanking the ridge are thought to be locale for good source tock (Dangwal et al. 2008, Nayak et al. 2011). The carbonate reservoirs could be charged from the kitchen area in the lows flanking the ridge. (Figure 7).

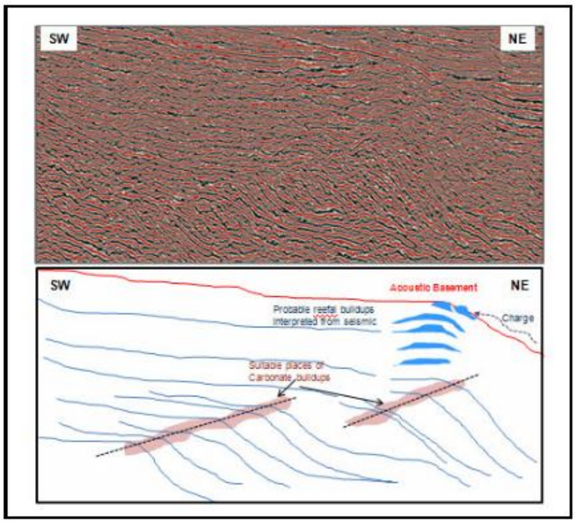

Figure 7: Instantaneous Phase section showing lava deltas and probable location for carbonate buildups.

Conclusion

Interesting prograding seismic reflection packs are found below basement in the 85º East Ridge. These can be generated both by clastic sediment deposit or volcanic activities. Detailed observation and analysis have shown that these are lava deltas formed due to lava movement from sub aerial to sub marine condition. Presence of lava delta suggest the 85º east ridge which is in a deep to ultra deep setting now must have been exposed during formation. Carbonate buildups are possible on the top of lava delta. These carbonate could be treated as potential source rock in the region. Various stages of lava buildups imply changes in sea level which could generate porosity in the carbonates. Any drilled well data for these sequences could help in firming a model for ridge evolution.

Acknowledgement

Authors are thankful to Reliance Industries Ltd for allowing use of data for the study

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