Petroleum System Related to 85° E Ridge: A Conceptual Study*

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Abstract

85° E Ridge, one of the important N-S trending aseismic ridges, lies in the Eastern offshore of India. The ridge has been interpreted to be formed during passage of Indian plate over stationary hot spot known as "Kerguelen". Although several studies have been carried out to understand the evolution and genesis of the ridge, its importance in hydrocarbon exploration is yet to be probed. In the present work the importance of 85° East Ridge in hydrocarbon potential has been discussed with the help of available seismic data as well as conceptual model in the deep Mahanadi Offshore Basin. Emplacement of ridge in the deeper oceanic crust has significant influence on sediment dispersal pattern from the early part of Late Cretaceous times until the end of Oligocene. The ridge acts as a barrier for sediment transport at least till Oligocene time. The well developed lows between isolated highs related to the ridge are favorable for source rock generation and maturation. Well developed channel feature and the depositional fairway evident from seismic data and isopach maps point toward the reservoir potential in the area. On the other hand the isolated closure at the top of the ridge, as well as onlap of Paleogene sediments is quite important for the entrapment condition. Published data from similar aseismic ridge elsewhere shows the possible exposure of ridge in shallow water / sub aerial condition hence chances of carbonate build up on the top of ridge is very much feasible. With systemic and careful approach the area can provide good locale for hydrocarbon potential for the country in future.

Introduction

Eastern offshore of India is characterized by presence of two aseismic ridge systems namely 85° East and 90° East Ridge. While the 90° East Ridge is having expression on present day sea bottom the 85° is buried under huge thickness of Bengal sediments, expect in the southern part (near afanasy nikitin sea mount). For the last two decades there has been ongoing debate on the evolution and nature of the 85° East Ridge. Negative gravity anomaly over the ridge led to a number of different models/hypothesis to explain the genesis of the ridge system. The most commonly invoked models to explain the evolution of the ridge is related to plume origin, (Curray and Munasinghe, 1991), whereas the alternate models include continental origin of the ridge (Sar et al., 2009). Detail descriptions of the different models of ridge evolution are beyond the scope of this paper. The main focus of this contribution is to evaluate implication of 85° E Ridge over hydrocarbon exploration. The present study area (Figure 1) is located at deep water regime off eastern offshore of India with the water depth varying from

2000 m to 3000 m. The entire region of the present study area is located in the oceanic crust.

The objective of the present work is to discuss existence of active petroleum system in the area and its relation to ridge evolution. A number of seismic profiles have been used to discuss presence of source, reservoir, and entrapment condition related to 85° East Ridge.

Ridge Morphology

A time structure map on Basement showing 85° East Ridge is presented in Figure 2. From the above figure it is evident that the ridge complex is characterized by presence of several N-S trending linear highs of which two are more prominent. The western high with greater elevation has been considered as the main whereas the one towards east with more continuity is termed as offshoot.

However such division is subjective and for present purpose all linear ridge like features in the area are considered as part of 85°E Ridge complex. Seismic sections depicting the morphology of the ridge in the area are shown in Figure 3. The ridges height varies from 200 m to 2500 m.

The ridges are flanked by well developed confined lows with a sediment thickness of 4 to 6 km

Age of Ridge

In absence of any drilled well data the chronology used in this paper is subjective and is purely based on data from published literature and paleo-reconstruction models. According to Curray and Munasinghe, 1991 age of the ridge in the east coast of India lies within 117 to 84 Ma. All these models are based on the plume related origin of the ridge and its correlation to Rajmahal trap (~117 Ma) to the north and afanasy nikitin seamount towards the south. The accurate age determination of the ridge is of utmost important as this can provide insight on the oldest sediments present around the ridge which in turn will decide the source rock potential of the basin. The approximate age of the ridge emplacement has been assigned on the basis of relation between the ridge and the oceanic crust and relationship of the overlying sediments with the ridge. It is important to understand 1) what is the comparative age of the ridge and the oceanic crust in this area? and 2) the relationship of the sequences that onlap against the ridge on either side.

Age of Ridge vis-à-vis Oceanic Crust

With basic assumption that the oldest plume activity related to the same hot spot that formed 85°E Ridge is Rajmahal trap (~117 Ma) and youngest in afanasy nikitin sea mount (~). From all published material and structural modeling, the age to the ridge can be assigned to 102 - 110 Ma in the study area. The oldest oceanic crust in the eastern offshore India is dated as 119 Ma. Hence it can be argued that the 85° E ridge in the study area was emplaced into the pre-existing oceanic crust. Additionally the seismic reflection pattern showing no preservation of oceanic MOHO below ridge further confirms the younger emplacement of the ridge.

Age of Ridge vis-à-vis Sediments

A conceptualized model showing relation between the pre-ridge, post-ridge sediments and the ridge is presented in Figure 4. The figure suggests that the pre-ridge sediments deposited on the oceanic crust will be buried under the volcanic basement generated by the plume activity. Figure 3 shows a seismic section demonstrating probable pre-ridge sediments below the ridge. In the section, the red color horizon is interpreted to be top of Volcanic top, which is generated due to plume activity. Below this reflector another conspicuous marker can be interpreted as the original oceanic crust. If this is the case then in between these two reflectors, pre-ridge sediments are expected. Seismic signatures of sediments could not be clearly interpreted below the ridge. But presence of pre-ridge sediments below the ridge could not also be denied. The huge thickness of the sediments filling the flanks of the ridge is thought to be younger to the ridge and hence is termed as post-ridge sediment. This age assignment is based on the stratal relationship between the ridge and the seismic reflectors. Based on the age assumption these sediments are of Albian and younger age.

As discussed earlier the main focus of this paper is to discuss on the presence of probable hydrocarbon system related to the 85° E Ridge. In recent time the 85°E ridge has become one of the focuses of E&P companies in hydrocarbon point of view. The positive structure associated with the ridge as well as onlap of sediments on either side are important aspect in reservoir point of view. However it is important to understand the complete petroleum system in this area which if proved would open huge area in the east coast deep to ultra deep water regime for further exploration.

Petroleum System

In this section we will be discussing few conceptual models describing possibility of source, reservoir rock, and entrapment condition.

Source Rock Potential

85° East Ridge in the study area lies on the oceanic crust. The area in close proximity to the ridge is devoid of any other tectonic elements. Hence presence of any structural low in the region is least possible. However emplacement of the ridge has generated few structural highs and low features in the area. From the basement time structure map (Figure 2) it is evident that the ridge is flanked by well developed lows. A close investigation reveals presence of well developed and restricted lows between the western and eastern mound of the ridge. These confined lows are believed to act as a good source kitchen area for generation of hydrocarbon.

The depression is filled with thicker Cretaceous sediment sequences. An isopach map of the total Cretaceous sediment thickness shows presence of more than 1.5 km of sediments within the lows.

Parallel seismic reflectors within this sequence indicate presence of low energy sediments which can be good source rock. In essence it can be summarized that the lows flanking the ridge can be considered as having good source rock potential in the study area.

Reservoir Dispersal

Another concern, which needs to be addressed, is the presence of reservoir facies in the region As already stated the ridge stands in the distal part of the basin, hence delineating a sediment dispersal pattern is required .The reservoir dispersal systems in the study area can be studied under two headings : 1) Cretaceous-Paleocene-Eocene and 2) Oligocene and younger. This division is based on the control of the Ridge over sediment fairways. In the older section the isopach (Figure 5a) shows sediment dispersal from NW direction while for the Younger Tertiary (Figure 6) the fairway is from north. So based on the direction of sedimentation it can be stated that the provenance for sediments of the above section were different. For the Cretaceous and Older Tertiary (Paleocene and Eocene) the major sediment dispersal is probably from Godavari region while in Tertiary the same are from Mahanadi-Ganges system. A seismic section showing well developed channel features in the Late Cretaceous-Early Paleocene section is presented in Figure 7. The trend of the above channels can be related to the sediment fairway from NW direction (Figure 7). The Late Cretaceous – Early Paleocene channels abuts against the ridge and forms splay which provide better reservoir facies in the study area.

Sediments on top of the ridge

One of the interesting facts to be understood is the paleobathymetry when the ridge was evolved. The present day water column over the ridge is ~ 2000 m. However it is important to study whether in some point of time the bathymetry was much less or the ridge was subaerially exposed. This is significant to understand the nature of the sediments on the top of the ridge, which could be good reservoir. Importantly, prominent canyon cuts which may have originated due to emergence of the ridge could be seen in seismic sections (Figure 8a).

Another important feature which could be very well observed in various seismic sections is a low amplitude seismically blank zone (Figure 8b). This zone is seen to cap the ridge top over an extensive area. The geometry of the transparent pack is similar to that of a carbonate buildup. To explain the carbonate buildup, it is important to understand the paleobathymetry during the time of the development of the transparent facies on top of the ridge. To discuss the probable paleobathymetry of the region during evolution a few analogues of similar aseismic ridge from various part of the world are presented in Table 1, compiled from published DSDP and ODP reports (Detrick et al 1977). The relevant ridges taken for discussion are Ninety degree East Ridge (Indian Ocean), Rio Grande Ridge (Atlantic Ocean), Walvis Ridge (Atlantic Ocean), and Iceland Faore Ridge.

Ages of the various ridges are based on the drilled well results and age of the surrounding oceanic crust (where there is no age data for basement). Similar to 85° E Ridge, present day bathymetry over the ridge of all the above mentioned ridges are more that 1000 m. However, interesting to note, all the wells drilled on these important ridges encounter shallow water sediments in paleo time. This clearly indicates even the ridges are located in deeper water during its evolution all of them were subaerially exposed or reach shallow water condition. If we extend this observation to 85°E Ridge it may be logical to assume that the evolution of the ridge must be in a shallow water condition or it might have been subaerially exposed for certain point of time. Well developed channel feature as well as carbonate mound like feature on the top of ridge are additional proof to the concept. However, only drilled well data can provide conclusive answer to this question.

Entrapment style

The entrapment conditions in the area can be divided into two categories namely structural closure and wedgeouts (Figure 7). There are well developed sedimentary wedgeouts against the ridge which could act as a good trap. Again structural closures on the top of the ridge can also be prospective trap condition.

Conclusion

85° East Ridge has a unique position in the eastern offshore of India. Well developed source kitchen area in the lows flanking the ridge, clearly defined reservoir dispersal pattern and presence of various trap styles related to the ridge indicates presence of a prospective petroleum system in the region. Proper understanding of the above system will help to extend exploration campaign to ultra deep water region in the eastern offshore, India, which till now is underexplored.

Acknowledgement

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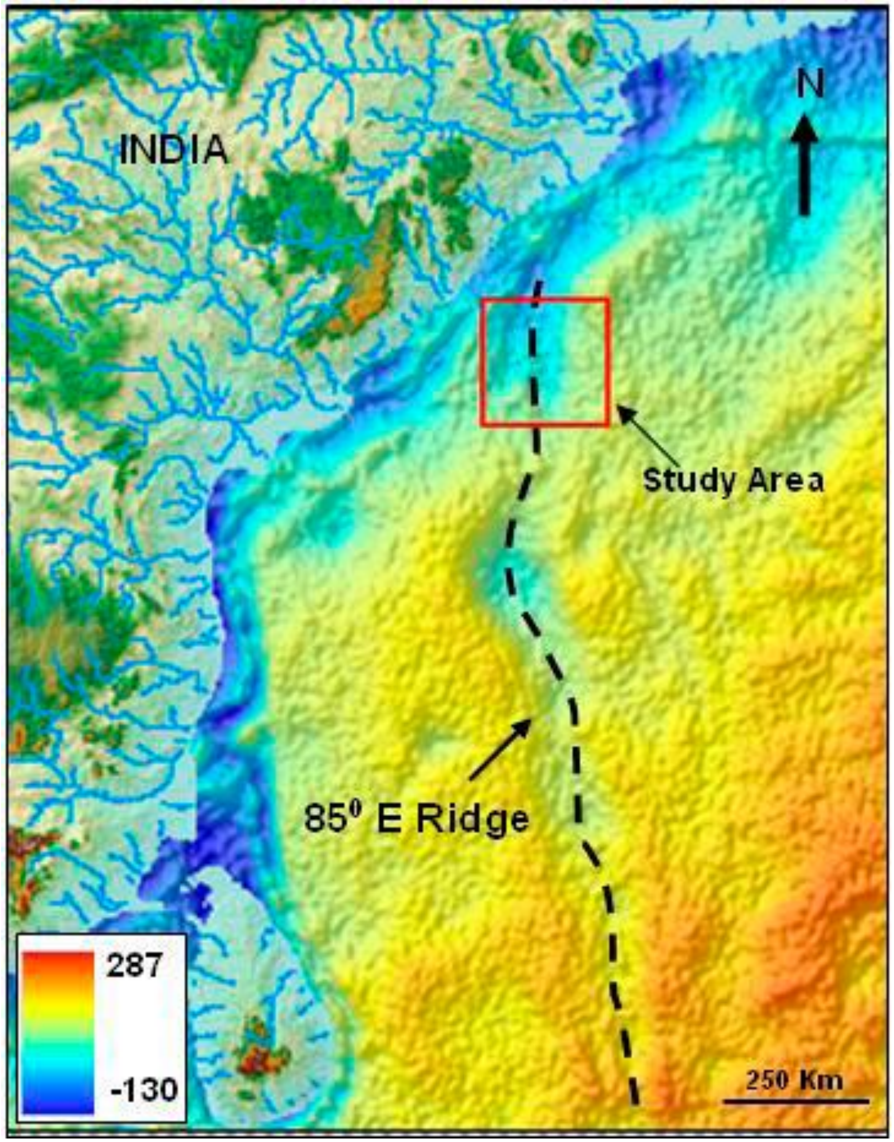

Figure 1: Bouguer gravity map showing gravity low along 85 East Ridge. The study area is shown in the box.

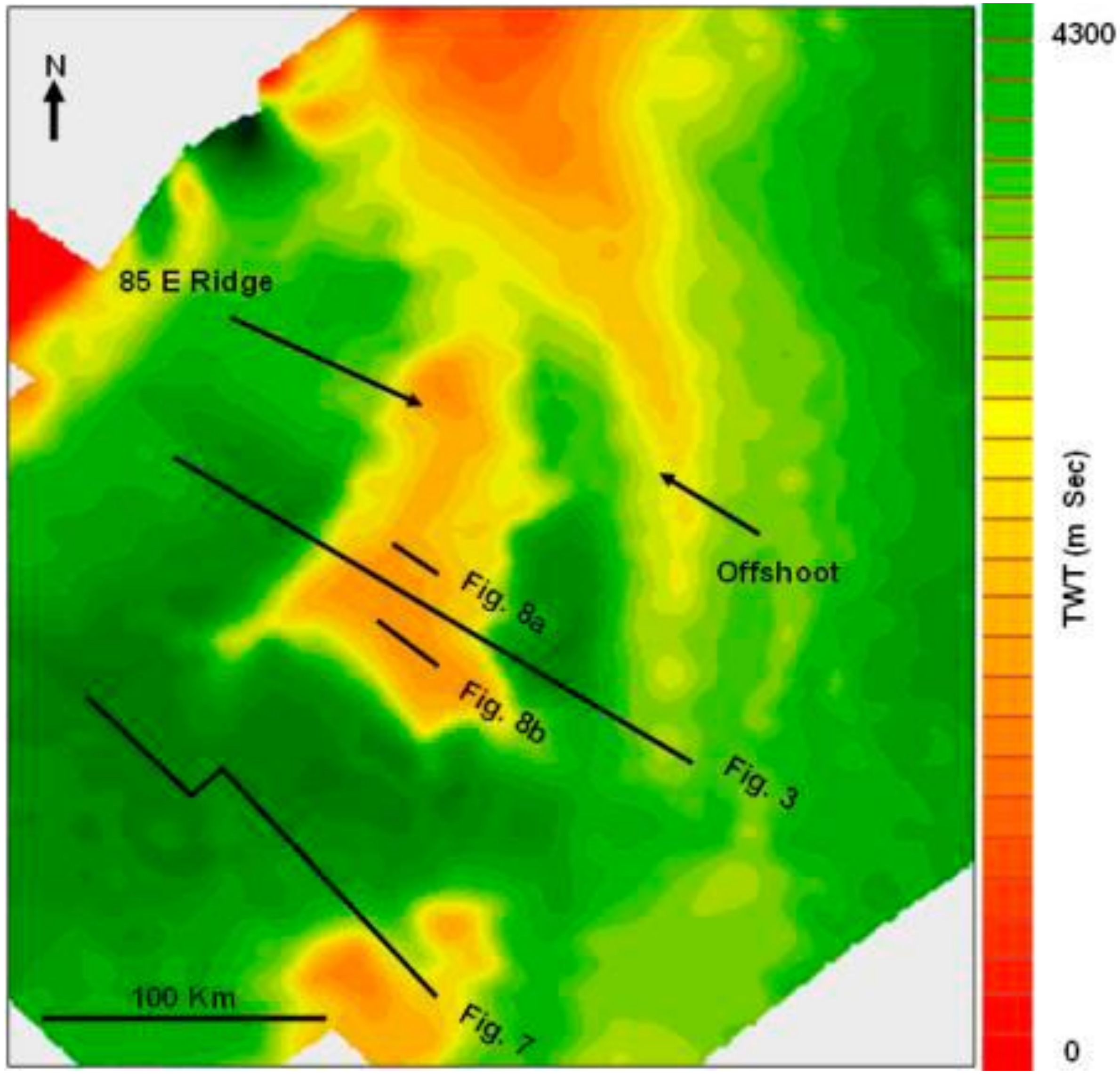

Figure 2: Basement Structure map showing Ridge trend in the area. Locations of various seismic profiles area marked on the map

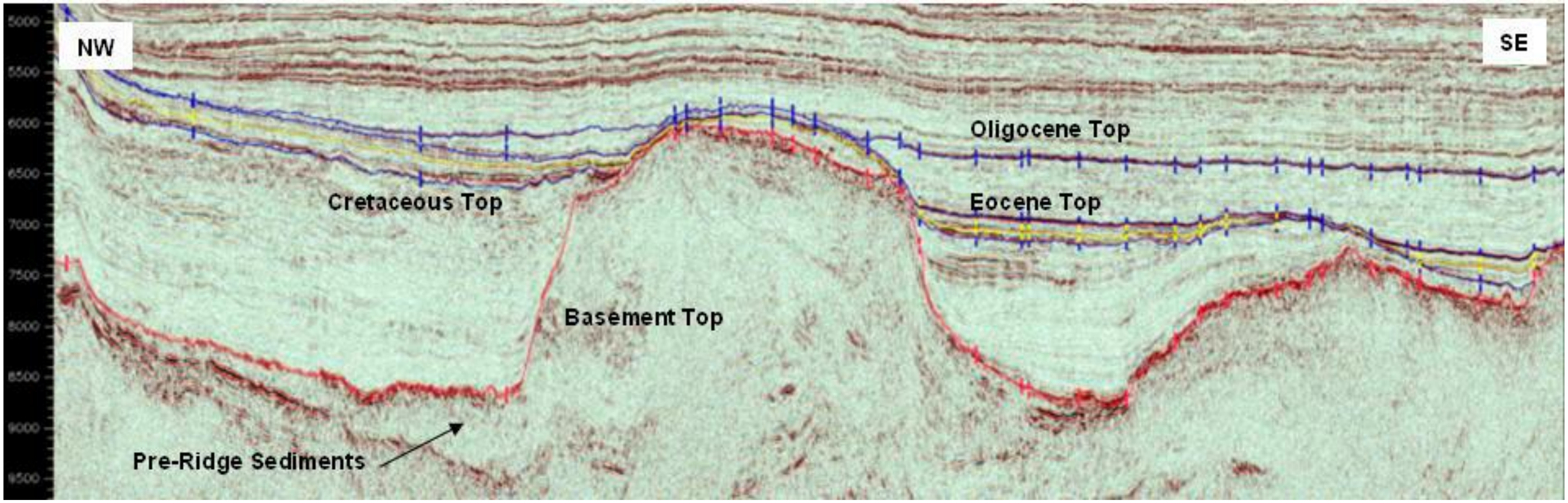

Figure 3: Regional seismic section showing ridge geometry and various age boundaries

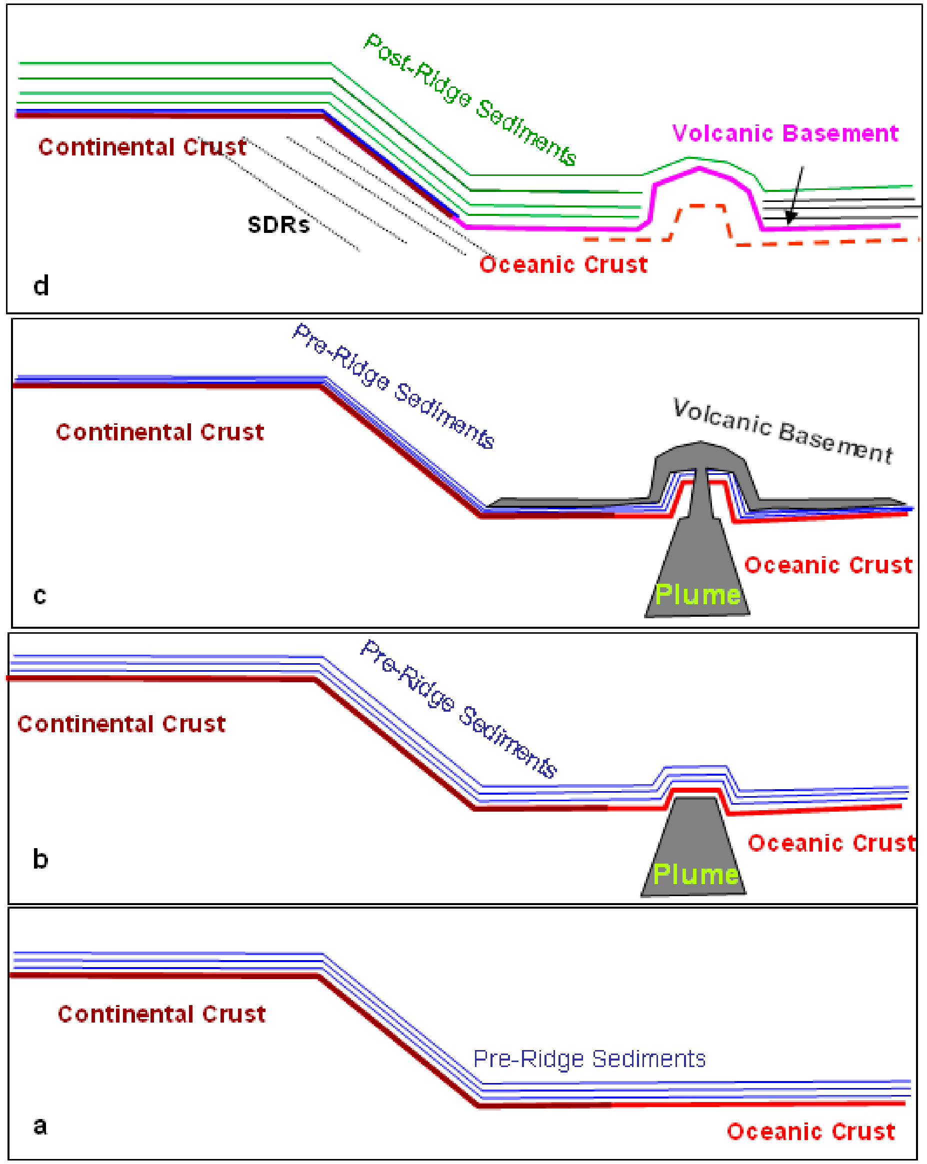

Figure 4: Schematic diagram showing conceptualized model for ridge evolution, and its relation to pre and post ridge sedimentation

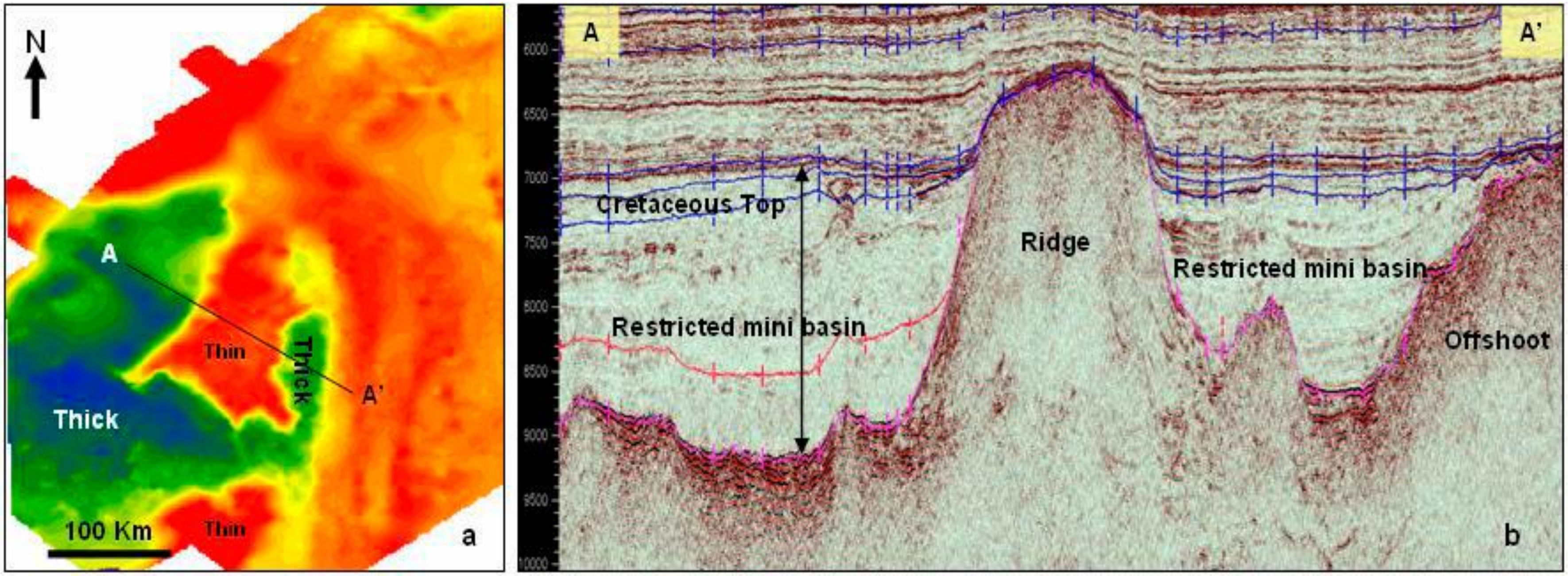

Figure 5: a) Isopach map between Basement and Cretaceous Top showing varying thickness in the area (Red – less thick, blue/green - Higher thickness). b) A seismic profile along AA' (marked in figure a) depicting seismic character of the sediments filling the lows.

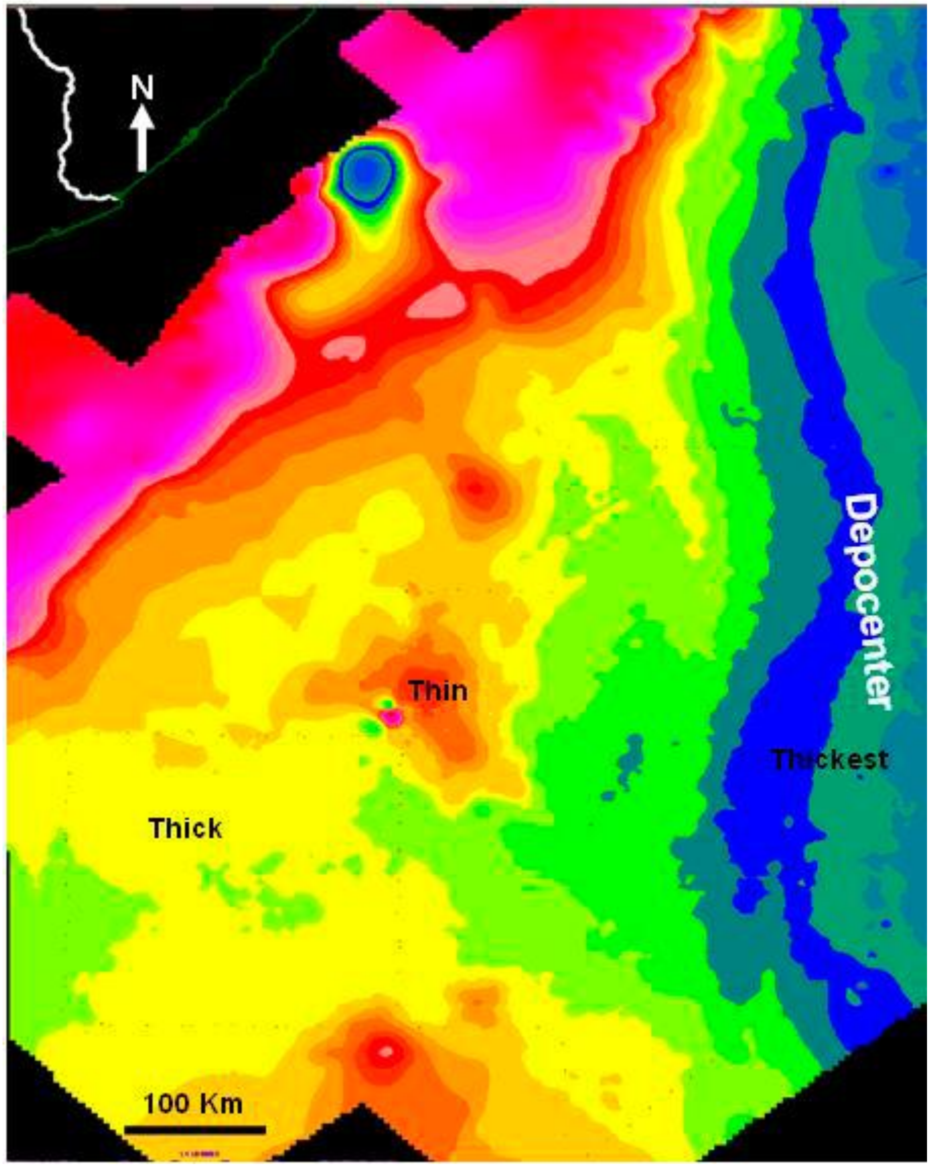

Figure 6: Isopach for Tertiary sediments showing sediment fairway from north. Higher thicker sediments are present towards deeper basinal part in the eastern part of the area. (Red – less thick, blue/green - Higher thickness)

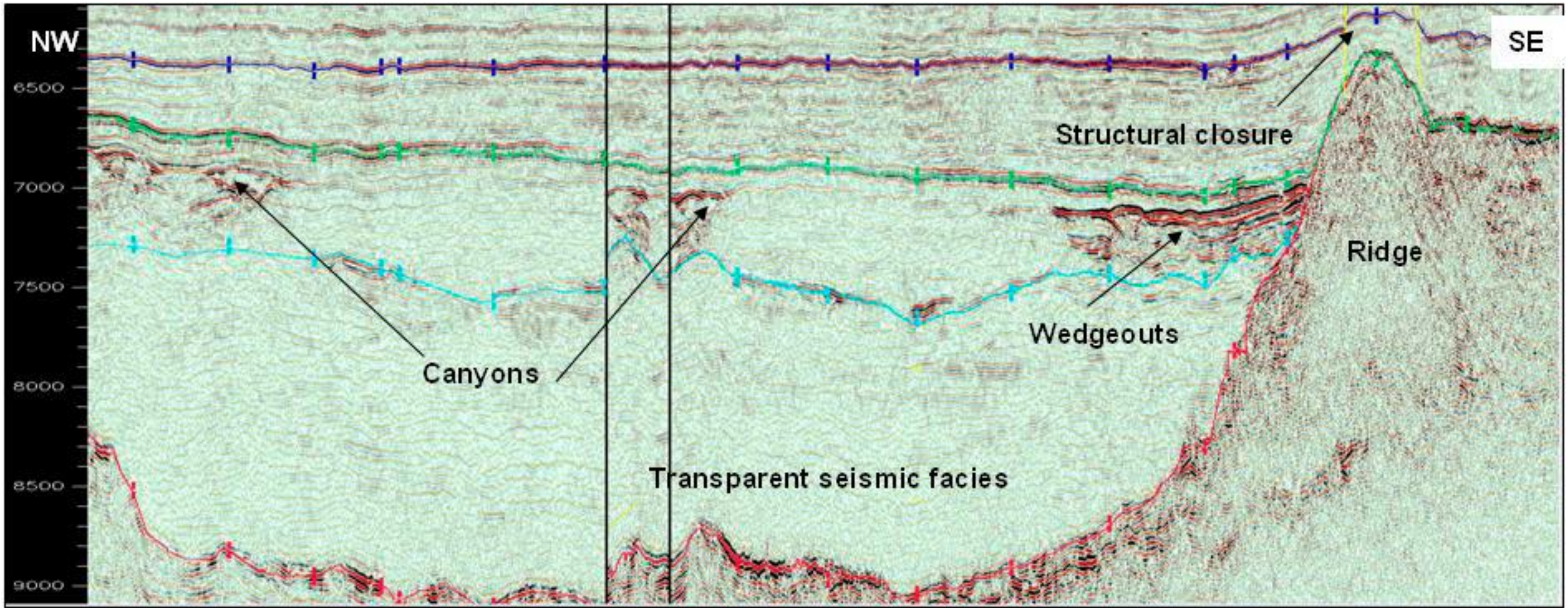

Figure 7: A representative seismic section showing interpreted channelized features in Cretaceous sediments. These are characterized by chaotic seismic reflectors and are seen to be wedging out against basement

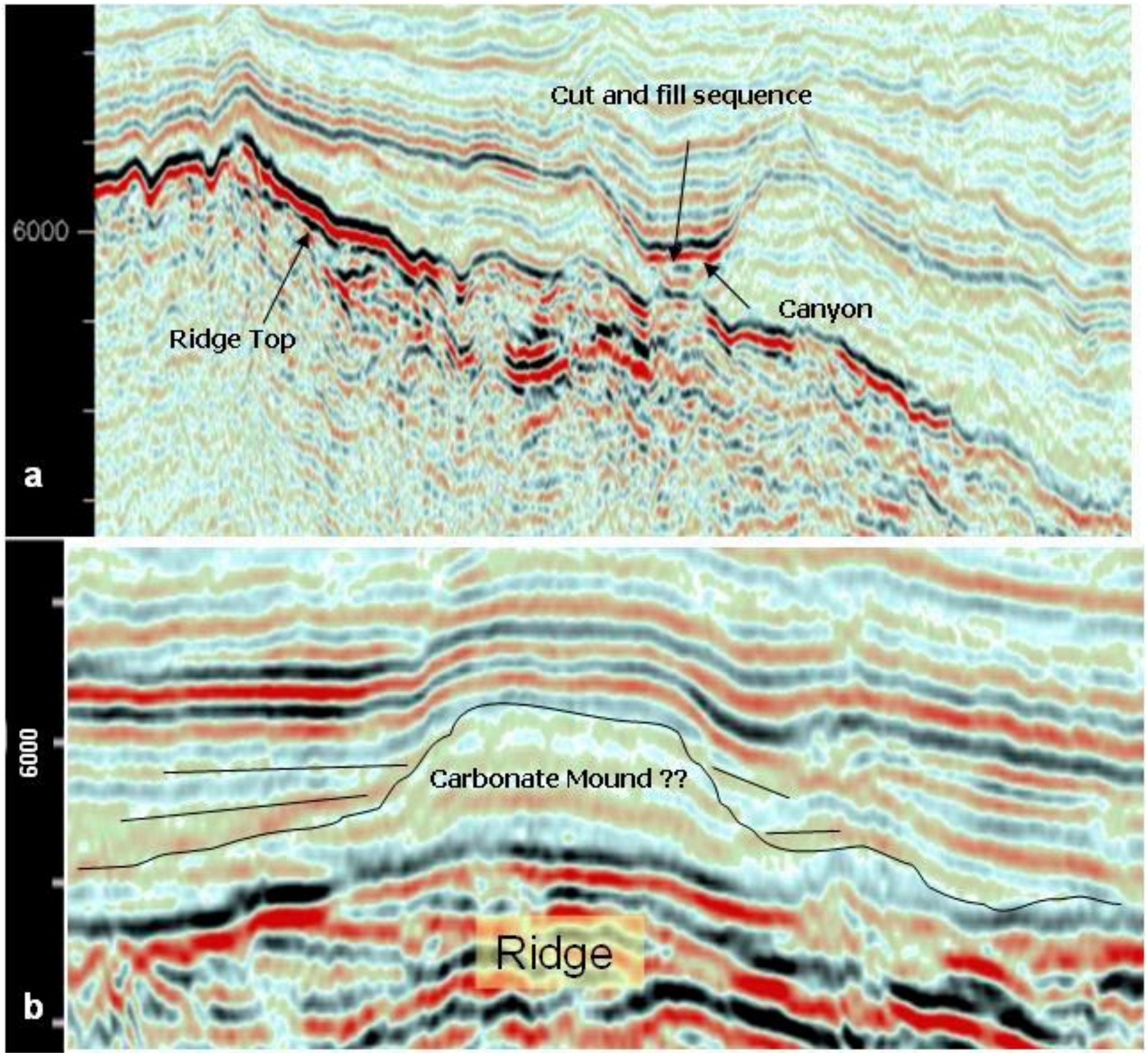

Figure 8: a) well developed canyon cut seen in seismic section. b) Carbonate build up like feature identified on top of ridge

Site (Ridge)	Age of Ridge/ Oceanic crust	Depth Water/ Basement	Sediment Thickness (m)	Sediment Encountered on Top of Ridge
214 (Ninety East Ridge)	53-60	1665 2155	490	Encounterred coal sample on basement top
253 (Ninety East Ridge)	43-49	1962 2521	559	Shallow water condition in the middle Eocene
21 (Rio Grande Ridge)	>71	2102	>130	Very Shallow depths in Campanican
359 (Walvis Ridge)	38-43	1658 1765	107	Emergent in Late Eocene
336 (Iceland Faeroe Ridge)	43-49	811 1311	500	Shallow water middle Eocene Sediments

Table 1: Drilled well results from various Aseismic ridges showing nature of sediments encountered above basement highs. (compiled from Detrick et al., 1977)