10th Biennial International Conference & Exposition

P 186

Ninety Degree East Ridge & hydrocarbon prospectivity of West Andaman area

*Chandan Samajdar, Amitabha Sengupta, Rahul Kumar**

Summary

The present study throws light on the hydrocarbon prospectivity of the rank exploratory area in WestAndaman basin lying to the west of Andaman Islands, in the trend of Ninety Degree East Ridge (NER)

Keywords*: Ninety East Ridge, WestAndaman,*

Introduction

Two major aseismic ridges in Bay of Bengal are 85^0 East Ridge and 90^0 East Ridge (NER), out of which the morphology, tectonic framework and evolution of NER influenced the geology of the study area. The 85^0 East Ridge is characterized by a negative free air anomaly whereas NER is characterized by positive free air gravity anomaly (**Fig.1**). The study area lies at the northern extremity of Ninety East Ridge and western flank of the Trench.

The NER is a linear, aseismic, seamount chain in the Indian Ocean and is a prominent tectonic feature in the area under discussion. It is approximately 5,000 km (3,100 miles) in length. It extends from about 34^0S to about 10^0N Latitude, where it is buried under the sediments of the Bengal Fan. The relief of the Ninety East Ridge varies from 15003000m and some peaks on the southern end to 700m. North of Latitude 8^0 N the morphology of the ridge is a series of en echelon blocks.

The origin and emplacement of NER[1] is believed to be related to the northward movement of Indian plate over the Kerguelen hot spot. Oldest trace of the hotspot is dated approximately 80 Ma in the north as the NER emerges from underneath the sediments of the Bengal Fan. Youngest trace of the hotspot is dated 43 Ma in the south when major spreading center reorganization left subsequent products of the hotspot exclusively on the Antarctic plate. In the northern most part, in the study area, the NER is covered by the younger sediments of Bengal Fan, also known as the Ganges Fan, which is the largest submarine fan on Earth. The fan is about 3000 km long, 1000 km wide with a maximum thickness of 16.5 km near the apex. The fan resulted from the uplift and erosion of the Himalayas and the Tibetan Plateau produced by the collision between the Indian Plate and the Eurasian Plate. Most of the sediment is supplied by the confluent Ganges and Brahmaputra Rivers through the Ganges Delta in Bangladesh and West Bengal, with several other large rivers in Bangladesh and India providing smaller contributions. Turbidity currents have transported the sediment through a series of submarine canyons and channels, to be deposited in the Bay of Bengal up to 30^0 S Latitude. In the eastern part the fan continues along the west side of the NER. The Nicobar Fan, another lobe of the fan, lies east of the Ninety East Ridge.

A schematic east-west profile shows the tectonic position of the study area, west of accretionary prism that forms the Andaman archipelago (**Fig.2**). It lies in between 90^0 E to 92^0 E Longitude and 13^0 N to 15^0 N Latitude. The rifting and subsequent drifting of Indian plate over the Kerguelen hot spot and subduction below the Asian plate gives rise to very complex geology along with volcanism in the area which poses a major interpretation challenge in terms of lithology identification, geological age estimation and sediment-basement interface identification.

MBA Basin ONGC Ltd., Kolkata, India
KUMAR2_RAHUL@ongc.co.in

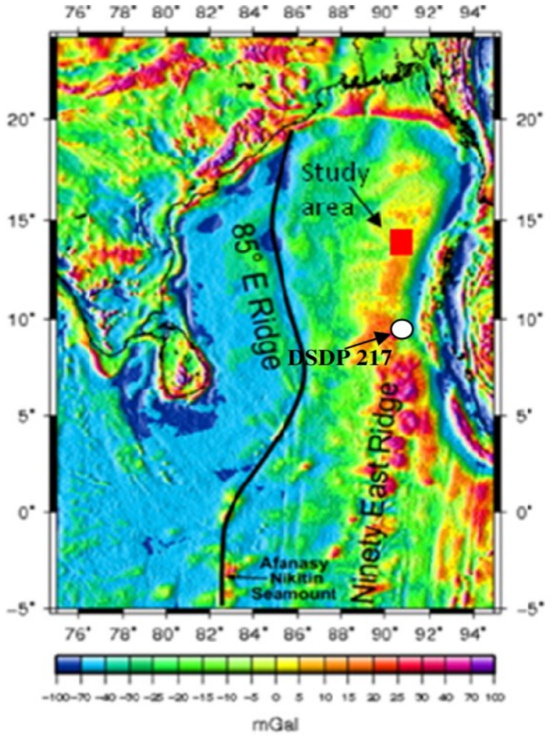

Fig.1 Free Air Gravity Anomaly in Bay of Bengal/Indian Ocean Basin showing the study area and DSDP site 217

The present study includes the interpretation of acquired 2D seismic data and *free air* Gravity data from ‘Public Domain’.

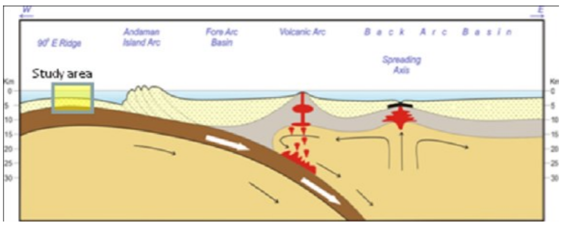

Fig.2 Schematic Diagram from West to East showing the tectonic elements of Andaman Basin along with the study area

Ninety East Ridge and Beyond

The free air gravity data[1] shows the major tectonic elements as well as the major depocenters of the total Andaman Basin. It shows a major N-S trending curvilinear low in the ‘*fore arc*’ as well as in the ‘Martaban Basin’ towards further east. The southern part of NER is represented by positive gravity anomaly which also follows the curvilinear trend (parallel to ‘*Sunda subduction zone*’) with decreasing gravity values towards north. Based on gravity modeling (**Fig. 3**)in the study area, the total sedimentary pack in the axial trend of Ninety East Ridge is around 4-5Km which increases to approximately 5-7Km, both in the eastern and western flank of the central ridge. The observed gravity values matches with the calculated gravity value based on the sediment model shown in the bottom part of the Figure. If we replace the lowest sedimentary layer with basalt then a variation of ~90mgal is observed between the calculated and observed gravity values.

In order to realize the geological relationship between the NER from south to the study area in North, public domain free air gravity values have been extracted along different constant longitudes with 20’ interval viz. along $90^{0}20$’, $90^{0}40$’, $91^{0}00$’ and $91^{0}20$’E longitudes (**Fig.4).** The longitudes are so chosen that it covers the study area from west to east.

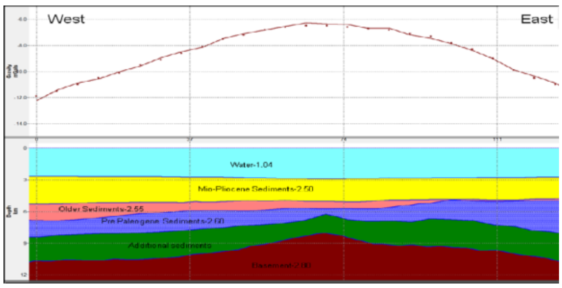

Fig.3 Gravity values modelled along E-W line showing the match between the calculated and observed anomaly and possible sedimentary thickness in the study area

The free air gravity along $90^{0}20$’E longitude (***red curve***) shows that the positive gravity highs in the NER continues from South to ~ $9^{0}30$’N latitude (**B in Fig.4**), then the gravity values reduces from +25mgal to around +5mgal near ~ 10^{0} N latitude. Near 12^{0} N latitude the gravity value rises again to +20mgal. North of ~$12^{0}40$’ N latitude (at the southern margin of study area) the gravity value starts decreasing and tends to zero further north. It indicates the continuation of NER towards North, with reduced gravity values remains speculative probably due to sediment cover over the ridge.

The free air gravity along $90^{0}40$’E longitude (***green curve***) shows positive gravity highs upto $8^{0}15$’N latitude and after that it reduces to ~ 0 mgal at $10^{0}30$’N and continues upto latitude $11^{0}30$’N. The change in gravity slope coincides with NER boundary. The upward trend continues from $11^{0}30$’ to $13^{0}30$’N latitude which represent the positive gravity signature seen in central part of study area.

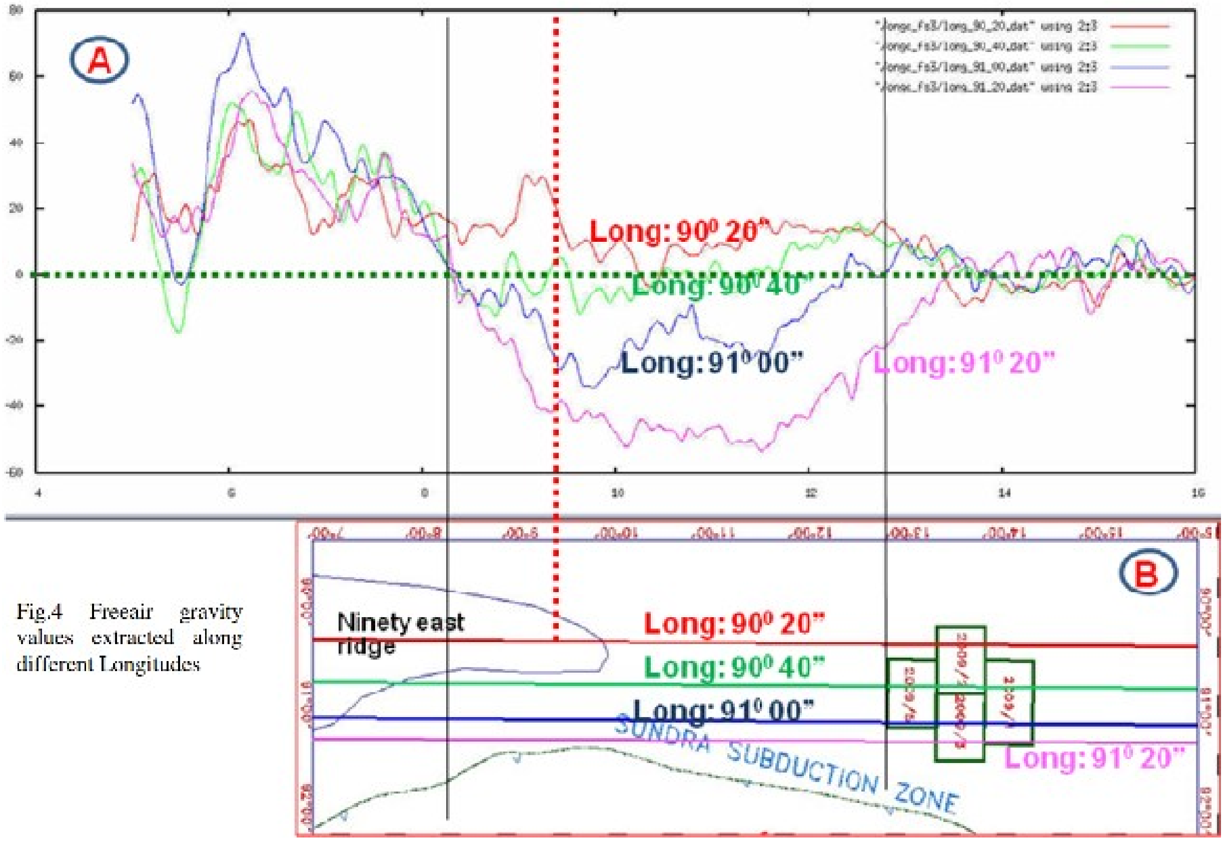

Fig.4 Freeair gravity values extracted along different Longitudes

The freeair gravity along 91^{0}00’ E longitude (***Blue curve***) shows positive gravity highs upto 7^{0}15’N latitude and after that it starts receding and reaches ~ 0 mgal at latitude 08^{0}15’N, then the gravity shows high negative trend ~ (-) 20mgal at 11^{0}30’N latitude. It takes an upward trend at ~12^{0}45’N latitude and become flat ~0mgal beyond 13^{0}45’N latitude. This curve indicates absence of NER between latitude 8^{0}15’ to 12^{0}N in the longitudinal zone 91^{0}00’ to 91^{0}20’E which is represented by a major gravity low and lithospheric slope towards the trench. The ‘*highs*’ seen in seismic data in eastern part of study area (**Fig.5A**) seems to coincide with this upward trend of gravity value beyond 13^{0}30’N latitude.

The freeair gravity along 91^{0}20’ E longitude (***Pink curve***) shows positive gravity highs beyond 7^{0}00’ N latitude with an intermittent high between 7^{0}15’and 7^{0}45’ N latitude and after that it starts receding and reaches ~ 0 mgal at latitude 8^{0}15’N, then it becomes negative ~(-)40mgal and continues upto 13^{0}15’N latitude. The major high in eastern part of study area as seen in the seismic, is represented by the near zero gravity anomaly beyond 13^{0}15’N latitude. It signifies that the NER and the high in eastern part of study area are separated by a major low due to strong ENE-WSW strike slip movement.

The following *conclusions* have been drawn from the above study.

- The NER is represented by high positive gravity value with a maximum of around +80mgal
- Towards north, the major gravity low indicates the separation of two culminations in enechelon pattern i.e. NER and the highs in the eastern part of study area
- The gravity low between 9^{0}00’and 12^{0}30’N latitude may also be affected by the presence of ‘*Sunda subduction zone*’ (longitude 91^{0}00’ and 91^{0}20’E profile). This also depicts the differential tilting of individual block through strong ENEWSW strike slip fault.

Seismic Interpretation

On the basis of seismic characteristics, reflectors have been correlated throughout the area from bottom to top. Two major unconformities have been identified. One prominent unconformity is represented by a high amplitude event and the other lies below it. Several structural closures have been observed at different levels. Few Wedges and Pinch outs have also been mapped giving some stratigraphic closures (**Fig.5**).

At Deepest Mappable Reflector Level, ENE-WSW trending fault system with formation of a low in the Southern part of study area is visible. Presence of a central basement high with a major ENE-WSW axial trend is visible. A persistent low is also observed in the Southern part of study area in all the lower horizons**.**

The structural alignment in the central part of the blocks is having both N-S and E-W trending components which indicates superposition of two structural trends. A Western high trend (bounded by faults) is distinguished which may be a part/ continuation of NER as observed from longitudinal *free air* gravity data. The maximum depth/sediment thickness comes out to be around ~6.5 KM from seabed in the southern low.

But gravity modeling studies indicates maximum sediment thickness ~5-6 Km. Minimum thickness of sediment is around ~ 2100m from sea bed over the central high.

A major unconformity (**Fig.5**) which may be equivalent to Cretaceous/Tertiary boundary is visible throughout the study area. Huge anticlinal closure could be seen at this level, covering almost the entire area. Intermediate Closures are also seen in the eastern part of the study area. It is also visible in the lower levels as well. Late Maastrichtian-Paleocene is assumed to be the period of soft collision of Indian-Asian Plate. The tectonic fore-bulge during this period in a NS axis is reflected in the structural pattern of *high–amplitude* reflector (probable K/T boundary), which masks the earlier tectonic grain in the area.

Reflectors truncating over the main high amplitude event is also observed (**Fig.5**). Truncation is observed from both northern and southern side of the central high which indicates sub aerial exposure of the main high at the central part at this level. Anticlinal Structural closures are seen in NE-SW axial trend covering northern and western part of study area with number of culminations within main closure, separated by a gentle low.

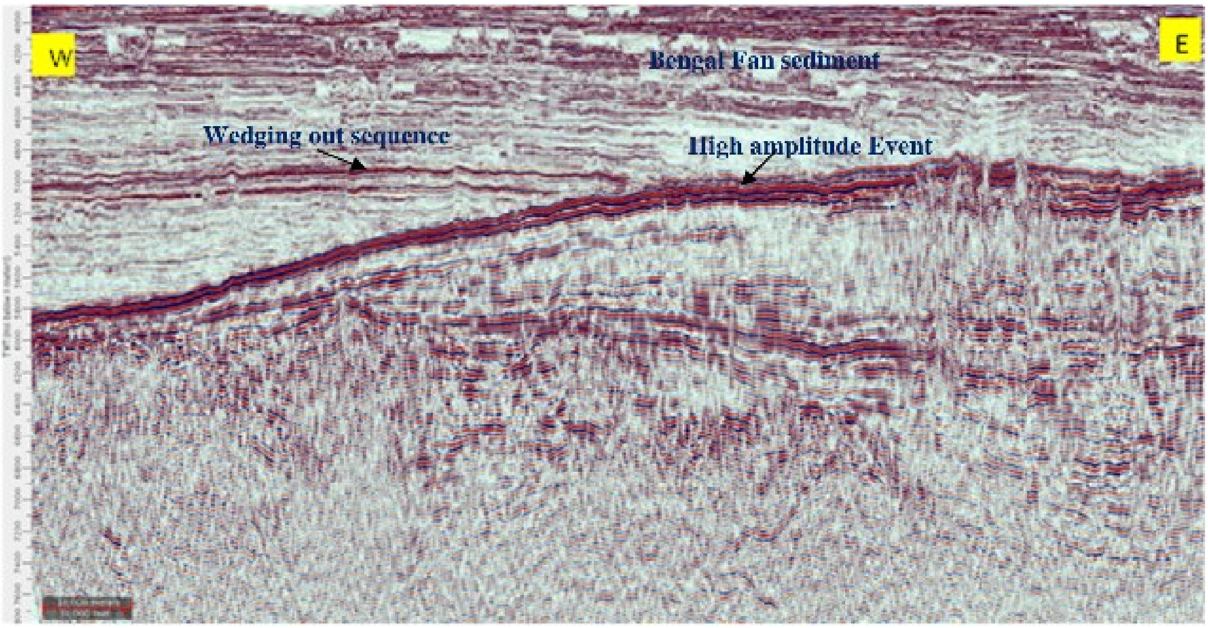

Fig.5A E-W seismic section across the study area showing the High Amplitude Event, Wedge Out sequence forming closure and unconformity below the high amplitude Event.

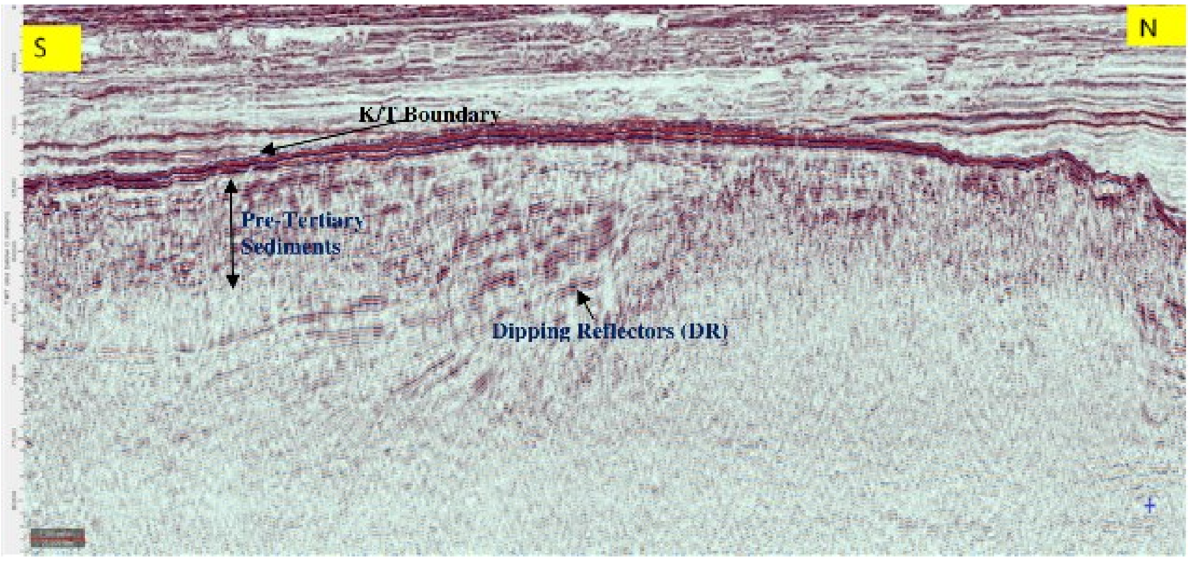

Fig.5B N-S seismic section across the study area showing the Dipping Reflectors in the deeper section

The recent deposition is affected by number of channels and canyon cuts with huge incision at places. The sequence is represented by high amplitude parallel reflections. Basin dip continues to be in South-East direction which still persists.

Lithology Envisaged

The velocity range and the high amplitude nature of the probable Cretaceous/Tertiary (K/T) boundary and the sequence just below it indicate probable carbonate deposition within this zone. The reflectors truncating against this high amplitude event show a velocity range of ~2500m/s indicative of clastic domain. The high amplitude reflectors above the truncating reflectors are showing low velocity as well which in turn indicates clastic deposition. Some steeply dipping reflectors (DR) are observed in the seismic lines and which may be the signature of 'D*ipping Reflectors (DR)*' in the deeper section associated with volcanic episode in the initial phase.

Geological Model

The present area is unique in its geological setting and evolutionary history. A geological model (**Fig.6**) has been conceived based on the regional available data.

The emplacement of NER is a post rift phenomenon of the Gondwanaland and is perceived to be related to the movement of Indian plate over the Karguelen hotspot. It shows a progressive ageing from south to north. The oldest dated sediments on the NER (*Refer DSDP site 217*)[4] is *Campanian* (~83.5 MY), which is incidentally the northern most age data available for NER. On the basis of available age data of basalt over the NER and oldest dated sediments at DSDP sites located about 450 Km south of the study area, Older Cretaceous sediments are expected to be present in the study area according to the model as we move 450 km north of the DSDP site. Also further north, the NER is expected to be buried under thick pile of Bengal fan sediments in the study area and can be assigned a further older age.

Some intricate seismic features are observed at places which may also be interpreted as manifestation of intermittent igneous activity /volcanism in the area. However this is also to be noted that such features are generally present in back arc basins of the overriding plate as seen in world geological examples. But the present study area is situated on the subducting plate where subduction related igneous activity is not expected. This needs to be confirmed with subsequent input of data.

Petroleum System Elements

Source rock

Regional **OAE** (Oceanic anaerobic events)[5] during Cretaceous have been reported globally. Concentration of high TOC black beds have been reported to occur in the

Cretaceous section of the ocean basins, which charged some of the global giants. A regional map showing the global occurrences of Cretaceous black beds have been published**.** The stratigraphic positions of the occurrences of black bed during OAE2 is shown as **Fig.7.** Occurrence of CTBE black shale (Coniacian-Turonian boundary Event) in the Indian Ocean are reported from DSDP site 1138 in Karguelen Plateau[6].

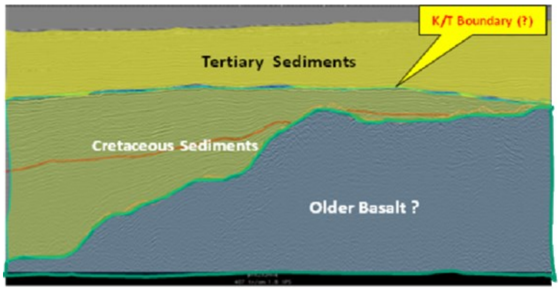

Fig.6 Envisaged Geological Model showing sedimentation pattern in the study area.

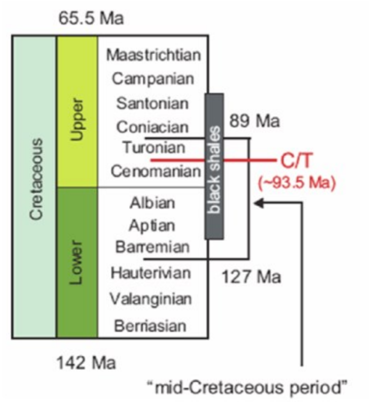

Fig.7 Stratigraphic setting of the cenomanian/Turonian Oceanic Anoxic Event (OAE2)

Reservoir

Clastic, unconventional as well as non-clastic reservoir facies is envisaged at different Levels. Deep water pelagic carbonates/Chalk/dolomites followed by shallow water carbonates due to local oscillation/shoaling caused by tectonic fore-bulge is anticipated upto K/T boundary. Paleogene/Neogene Clastics may act as possible reservoir for the stratigraphic pinch out closures. Non conventional reservoirs (volcaniclastics) may also be present at few limited zones.

Maturity

As of now, availability of regional source **(OAE II),** quite deep burial of source facies in the grabenal part may be assumed to provide proper maturity of the source rocks. In addition the Cretaceous deposition in a comparatively warm condition.

Conclusions

On the basis of regional tectonic setting, and interpretation of newly acquired 2D seismic data and gravity data available in public domain a geological model have been perceived for the present area. Older Cretaceous sequences as old as >90Ma are assumed to be present in the area, in the flank of the central basement high. The study brings out the existence of huge structural closure at the basement level (central basement high), as well as at probable Cretaceous top (high-amplitude continuous event). The structure is flanked by a prominent graben to the south. Considerable thickness of pre-Tertiary sequences are expected to be developed in this graben with appreciable source rock facies (OAE II).The nearby structures and wedge features are expected to be adequately charged. Both clastic and non-clastic reservoirs are expected in the study area. Some seismic signatures may also be interpreted as indication of presence of extrusive and intrusive igneous rocks in the study area. The structural closures at the target levels show good entrapment situation. Presence of nonclastic and unconventional reservoirs are expected more than conventional clastic reservoir in the pre-Tertiary section. Clastics of Bengal fan and Paleogene turbidites which wedges out against *high-amplitude event* and forms broad flexure will also be the targets for hydrocarbon exploration.

The areal extent of existing closures is so high that any of them being charged with hydrocarbon may lead to a giant discovery, which encourages our exploration efforts in this area.

Acknowledgement

The authors express their gratitude to ONGC for permission to publish this paper. The authors are grateful to Shri A. K. Dwivedi, GGM, Basin Manager, MBA Basin for giving an opportunity to work in this area.. We are thankful to Shri B. G. Samanta, GM (G), Block Manager, Andaman, for constant encouragement, interest and cooperation. Shri A. Pal, DGM (GP) (Retd.), RCC kolkata is sincerely acknowledged for his technical help.

References

Subrahmanyam. C et al, 2008; Geophysical characteristics of the ninety east ridge – Andaman island arc/trench convergent zone, Earth and Planetary Science Letters: 266(1-2); pp 29-45

G.M. Stampfli, G.D. Borel, A plate tectonic model for the Paleozoic and Mesozoic constrained by dynamic plate boundaries and restored synthetic oceanic isochrones Earth and Planetary Science Letters 196 (2002) 17^33

Joseph R. Curray,(2003), Frans J. Emmel, David G. Moore, The Bengal Fan: Morphology, geometry, stratigraphy, history and processes, Marine and Petroleum Geology 19 (2003) 1191–1223

Sclater et al. Regional synthesis of the deep sea drilling results from leg 22 in the eastern Indian Ocean (Chapter 41, DSDP Vol.XXII; www.deepseadrilling.org;2007)

Arthurs, Michael A. et al (1979) Cretaceous "Oceanic Anoxic Events" as Causal Factors in Development of ReefReservoired Giant Oil Fields' ;American Association of Petroleum Geologists Bulletin ;V 63, No. 6 P. 870-885

Meyers Philip A. et al (2009) Origins and maturity of organic matter in mid-Cretaceous black shales from ODP Site 1138 on the Kerguelen Plateau Marine and Petroleum Geology 26 ;pp 909–915

The Views expressed in the paper are of the authors and not necessarily of the organization they belong to.