9th Biennial International Conference
& Exposition on Petroleum Geophysics

"HYDERABAD 2012"

P-072

A Seismic Study to Investigate the Prospect of Gas Hydrate in Andman Deep Water Basin, India

Anand Prakash*, B. G. Samanta, *ONGC*

Summary

The presence of gas hydrates along the Indian continental margins has been inferred mainly from bottom simulating reflector (BSR) and the gas hydrate stability zone thickness map. Multidisciplinary investigations have confirmed gas hydrate deposits in KG basin after drilling. In the present study, BSR like features are observed during the analysis of 2D and 3D seismic data of Andman deep water basin. It shows all the characteristics of classical BSR such as mimicking the seafloor, cutting across the underlying and overlying dipping strata and exhibiting strong amplitude. The polarity of the event is opposite to that of the sea floor reflection. Seismic sections from 2D and 3D surveys in the study area show that amplitude of BSRs at several places is large coupled with high interval velocity (1950m/s) just above the BSR whereas at some places amplitude of BSR is small along with the interval velocity of the order of 1750m/s. Base of the Gas hydrate stability zone in Andman area varies between 200-650ms indicating different Temperature-Pressure conditions. Double BSRs are also seen on seismic sections pertaining to the study area-B indicating changes in P-T conditions during past 10-20K years.

3D seismic data of area-B has been Pre-stack depth migrated. Coherency inversion, model based and grid based tomography of seismic data shows interval velocity inversion of across BSR. Large velocity inversion across BSR (1950 m/s to 1650m/s) is observed in the area-B. At places, Very low velocity of the order of 1450m/s below the BSR and high amplitude indicate free gas deposit beneath the gas hydrate layer.

AVO analysis of the BSR data shows an increase in amplitude with offset. The AVO anomaly is more pronounced and conspicuous at places where very low velocity is observed on interval velocity section obtained by Pre-stack depth migration processing of 3D Seismic data. This could be an indication of a possible free gas deposit beneath the hydrate layer.

A well has been drilled in the area-B for hydrocarbon exploration on the anomaly where gas hydrate deposit is predicted by our study. The base of the hydrate layer in resistivity log is matching with the depth migrated seismic section. The resistivity log indicates about 25m thick hydrate layer with 35% hydrate saturation.

Introduction

India's energy requirements mainly depend on fossil fuels, although it has significant coal and hydro resources. Ever increasing demand for sustained industrial growth has forced all of us to look for renewable and alternate energy resources such as coal bed methane in coal seams, shale gas found in shale, and the gas hydrate found below ocean floor. Hydrocarbon Vision 2025 of India also stressed the need to explore gas hydrate in the east and west coast of India to ensure the energy security. Natural gas hydrates do have the potential of becoming an alternate energy resource due to its huge deposits envisaged worldwide (Collette 2002, Kvenvolden 1993a; Makogon Y F ,2007). Potential reserves of hydrated gas are more than 1.5X1016 m3. Commercial production of just 15% of this gas would provide the world with energy for 200 years at the current level of energy consumption. The production of natural gas from gas hydrate could be used to contribute not only to the sustained economic growth of individual countries, but also to the political stability of the world.

RCC, ONGC, Kolkata
anandprakash999@gmail.com

Presently, in many countries national programs exist for the research and production of natural gas from gas hydrate deposits. As a result, over 220 gas hydrate deposits have been discovered, more than hundred wells drilled, and kilometers of hydrated cores studied. The commercial production of natural gas from gas–hydrates exists for many years now with good results (Messoyakha Gas-Hydrate Field, East Siberia).Still many complex problems have to be resolved. India has also began active research since 1996 with its first National Gas Hydrate Programme (NGHP) initiated and funded by Ministry of Petroleum and Natural Gas, Government of India for establishing gas hydrate reserves in east and west coast by collecting geophysical, geological, geochemical and microbiological data. The drilling by JOIDES Resolution drill ship under NGHP Expedition-1 in KG basin has confirmed the presence of massive gas hydrate accumulation (>80 m thick) in KG basin.

Gas hydrates are white, crystalline, ice-like materials comprised of a methane molecule surrounded by a cage of water molecules. The hydrates are mostly methane rich, but are sometimes associated with ethane, propane, butane, carbon dioxide and hydrogen sulfide. The gas hydrates are generally found in the permafrost and outer continental margins of the world where the methane concentration exceeds their solubility limit (Sloan 1998; Kvenvolden 1993). These are formed at high pressure (8-30 MPa) and low temperature (100–200 C) in shallow sediments, and are stable up to a few hundred meters below the sea floor. Methane trapped in hydrates and free gas below the hydrate bearing sediments is found in huge amount.

Gas hydrates are mostly identified by mapping a Bottom Simulating Reflector (BSR) on seismic section (Shipley et al. 1979, Hyndman et al, 1992). The BSR is recognized based on its characteristic features such as; (i) mimicking the shape of sea floor as BSR follows isotherms which are nearly parallel to the morphology of sea floor, (ii) cutting across the underlying/overlying dipping strata and (iii) exhibiting large amplitude but opposite polarity to that of the seafloor reflections. Presence of gas hydrates reduces the permeability of the sediments and hence traps free gas underneath. The bottom simulating reflector (BSR) is an interface between gas hydrate-bearing sediments above and free-gas saturated sediments below the interface and is often associated with the base of the gas hydrate stability field. The BSR may not be continuous but patchy events indicating the upward gradational hydrate layer above and downward gradational free gas layer below the BSR. Most of the gas hydrates, worldwide have been inferred from the BSR and Gas Hydrate Stability Zone (GHSZ) thickness map. The Gulf of Mexico, Blake Ridge, Cascadian Margin, McKenzie Delta and Nankai trough are some of the excellent examples (Holbrook et al., 1996). However, in addition to geophysical anomalies, such as BSR, pockmarks, gas up-thrust zone, vents, blanking zones, etc., other geochemical and microbial proxies are required to be studied in order to reduce the exploration risk. Gas hydrate stability zones thickness map have also been prepared on the basis of available data for bathymetry, heat flow, seabed temperature and geothermal gradient etc., within the EEZ of India (Kuldeep Chandra et al,1998, Rastogi et al. 1999; Sethi et al. 2004; Ramana et al. 2007, Vayavur Rajesh et. al. 2010). Geophysical, Geochemical and Microbiological proxies observed in east coast of India have suggested a strong indication for gas hydrate deposits in KG, Cauvery, Mahanadi and Andman basins (Ramana 2006; Satyavani et al. 2008, Nandi, A.K. et al, 2010 and Anand Prakash, et. al, 2010).

In the present study, 2D and 3D seismic data analysis from Andman deep water have been carried out to establish gas hydrate deposits in the area. AVO analysis, pre-stack depth migration, and velocity inversion lead to positive indication for the gas hydrate deposits in the area. Some of the seismic sections show double BSRs indicating change in the Pressure-Temperature Conditions of the area in the past 10-20K years. The double BSRs phenomenon have also been reported in Nankai Trough(Golmshtok A Ya, et al 2006, Foucher Jean-Paul, et al, 2002), and West Norway(Posewang J,et al,1996). Model based and Grid-based tomography of the seismic data provides detailed Velocity profile which indicates free gas below the hydrate layer. One well drilled for hydrocarbon exploration recently in the study area-B has indicated presence of gas hydrate accumulations in the area.

Geologic set up

The Andaman Basin situated between 6° and 14° N latitude and 91° and 94° E longitude holds a thick succession of marine sediments (6000m+) from Cretaceous to Recent. It extends 1200 km. from Myanmar in the north to Sumatra in the south. It is 650 kms wide with Malay Peninsula in the east and Andaman-Nicobar Island to the west. The morphology and structure of the Andaman Islands suggest that they are an Island Arc Orogen developed due to subduction of the Indian Plate beneath the Southeast Asian Plate, since Late Cretaceous.

Major geotectonic units from east to west are back arc, volcanic arc, fore arc, island arc and fore deep; which are related to the subduction tectonics. During Paleocene – Eocene time, subduction of Indian plate beneath Burmese plate caused the rise of accretionary zone and formation of Fore-arc sub-basin. The present study deals with various seismic features identified in the deep water of Andman basin to the east and south-east of Andman islands. Figure-1 shows the study areas on the regional tectonic map of Andman Basin.

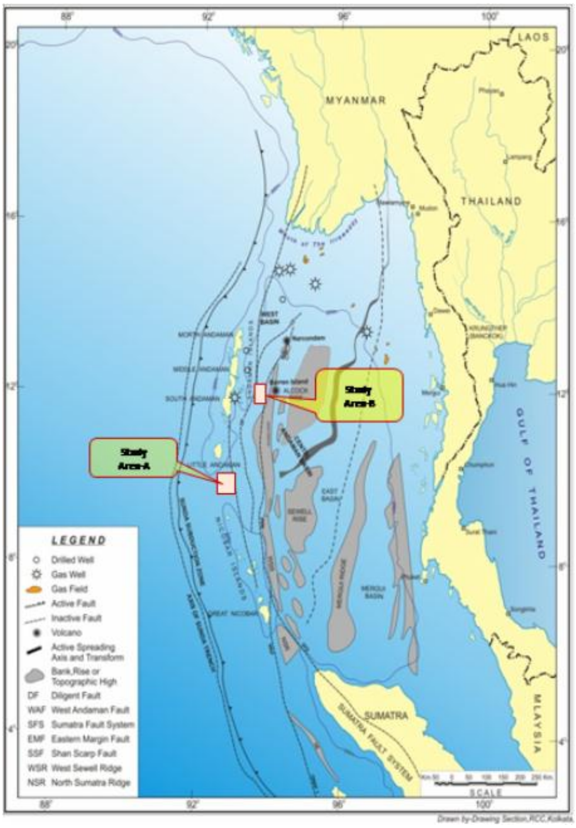

Figure-1 Tectonic map Andman Basin showing study areas.

Data and Methodology

The area of study in Andman deep water basin is covered by 2D as well as 3D seismic surveys. Area-A is covered by 162 fold 2D seismic survey with CDP interval 12.5m while area-B is covered by 62 fold 3D seismic survey with a grid of 12.5X25m. Analysis of seismic data shows BSR like features on the seismic sections. Special processing efforts are made to analyze the BSR. Detailed velocity analysis on Pre-stack Time and Pre-stack Depth Migration (PSTM and PSDM) gathers have been done to obtain the best estimate of RMS and interval velocity fields. Coherency inversion of seismic data is used to derive interval velocity model for the 3D data and afterwards Grid Tomography technique is adopted to update the interval velocity model in depth domain.AVO analysis of PSTM/PSDM gathers at certain important locations is carried out. Table-1 shows the processing scheme and parameters for 2D/3D data processing and PSDM processing.

Table-1 Seismic Data Processing scheme and Parameters

1. Re-formatting to Processing Format
2. Bad Shot & Trace Editing
3. Recording Delay Correction : 100ms
4. Band Pass Filter : 3Hz,18dB/oct-125 Hz 72dB/oct,
5. Swell Noise Attenuation
6. Automatic De-spiking
7. Navigation and Seismic data Merging
8. Spherical Divergence Correction
9. Radon Linear Noise attenuation
10. De-signature to minimum phase and Reverse Polarity
11. Tidal Correction
12. Gun & Cable Static Correction
13. Deconvolution PD: 24 OL: 240ms, White Noise: 0.1%
14. RADON De-multiple
15. Spherical Divergence Correction Removal
16. Offset Regularization
17. Stacking Velocity Analysis in a grid of 2X2 Km
18. Target Line Pre-stack Time Migration
19. RMS Velocity Analysis in 1X1 Km
20. RMS velocity Volume Creation
21. Kirchoff Pre-stack Time Migration
22. Residual move-out analysis in 250mX250m grid
23. Residual move out Volume Creation
24. Flattening of PSTM Gather
25. Front-end and Inner mute Design and Stacking
26. Random Noise attenuation
27. Band Pass Filter : 8Hz,18dB/oct-80Hz, 72dB/oct,

PSDM Processing Scheme

1. Horizon interpretation
2. Coherency Inversion along the horizons
3. Initial interval velocity model
4. Model based Tomography to update velocity model
5. Grid tomography to arrive final interval velocity model
6. Pre-stack depth Migration
7. Mute and stack, Band pass filter

Result and Discussion

Seismic sections from Andman area (Figure-2a and 2b) show BSRs at 200-800 ms below the sea bottom. These BSR events are distinct and having characteristic features (i) mimicking the sea floor ,(ii) polarity reversal,(iii) cross-cutting the lithological boundaries, and (iv) blanking above and below it. There is abundance of BSRs seen in the seismic sections in the deep water of Andman Basin. Some where it is as shallow as 400ms while at places it is quite deep about 800ms below the sea bottom. The reason could be the varying Pressure-Temperature regime at different locations in the area. The BSR events are very strong at some locations and weak at other places, the reflection strengths may be attributed to the saturation of gas hydrate.

Gas Hydrate stability zone thickness in the area has been calculated and found of the order of 300-650m which confirms to the findings of Rastogi et al, 1999 computed on the basis of geothermal gradient, seabed temperature and bathymetry data using GIS based approach. BSR is discontinuous with varying amplitudes, at places where very high amplitude is observed (Figure-2a). BSR is observed as shallow as 200ms below the sea bottom at some places; this might be possible due to high heat flow in the area.

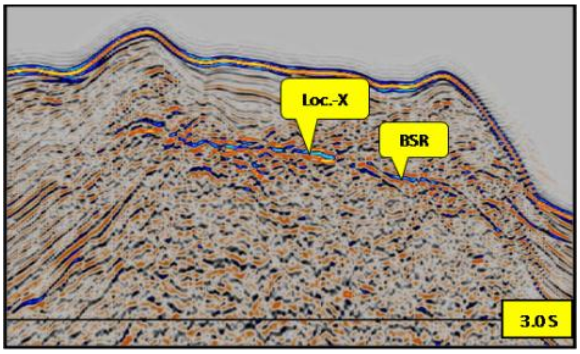

Fig.2a PSTM Stack section shows BSR indicating gas hydrate accumulation. Gas hydrate stability zone thickness is of the order of 400m

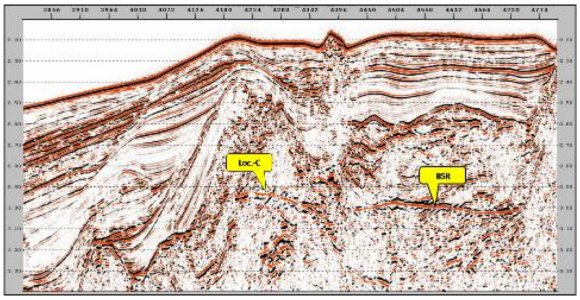

Fig.2b PSTM Stack section shows BSR indicating gas hydrate accumulation. Gas hydrate stability zone thickness is of the order of 650m

Some of the seismic sections in area-B reveal two distinct BSRs (Fig. 3a&b), The upper BSR is traced as a continuous reflector over about 3km. The lower BSR is traced at 50-350m below the upper one at various locations and is localized. It is interpreted that upper BSR is an active methane hydrate BSR and the lower BSR is a residual hydrate-related BSR. Migration of methane hydrate stability zone from lower BSR to upper BSR might have happened due to sea bottom warming, tectonic uplift and changes in the hydrate stability fields during past 10-20K years. Two or more thick hydrate layers separated by water bearing sediments might be the other possibility which may give rise to Double BSR (DBSR) in the area.

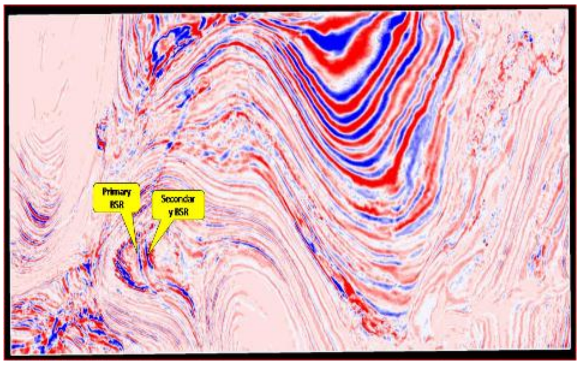

Fig.3a Depth slice from PSDM data volume indicates Double BSR. The primary BSR is far more regional while secondary BSR is localized and seems to be relict indicating low order change in Pressure-Temperature conditions during past 10-20K years.

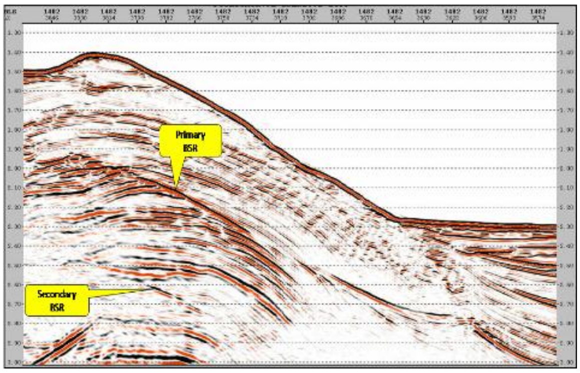

Fig.3b PSTM section showing Double BSR indicating high order change in Pressure-Temperature conditions during past 10-20K years

Amplitude-versus-offset/angle (AVO/AVA) analysis that determines the change in reflection amplitude as a function of receiver offset or reflection angle is an important method used by the petroleum industry for gas detection beneath an interface (Shuey, 1985). The AVO analyses of PSTM gathers at various locations in the area are carried out. An example of the change in amplitude and waveform for the hydrate BSR as a function of offset is shown in figure-4 at a location-X in the figure-2a. At far offsets the amplitude increases rapidly and there a phase shift at higher offset. Figure-4 shows the AVO anomaly obtained at three

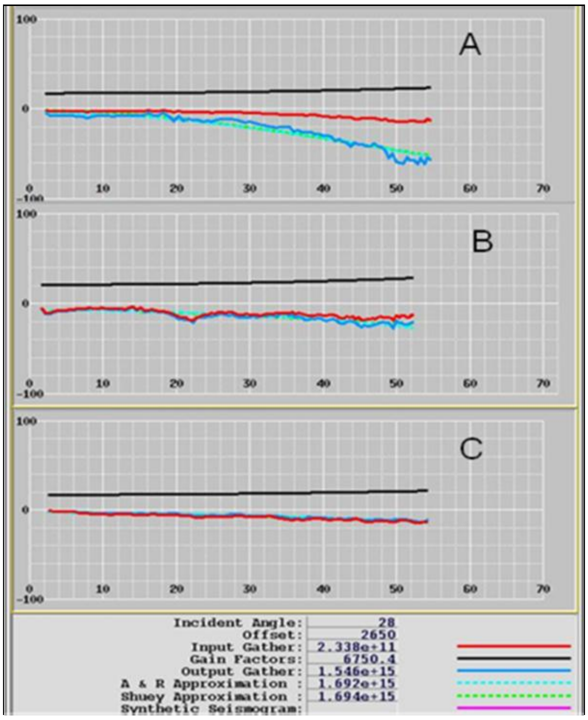

Fig.4 AVO analysis of PSTM data.(A) Strong AVO anomaly where free gas below the BSR is indicated by velocity and amplitude anomalies ,location for the analysis shown in figure-6 (B) Moderate AVO anomaly where some seismic indication for free gas below BSR, location for analysis is shown in figure-7 (C) Low or no AVO anomaly where no free gas indication below BSR , location for analysis is shown in figure-7

Representative locations. Figure-4A represent AVO response at locations where there is significant evidence of free gas below the hydrate layer such as very low interval velocity and high amplitude(Figure-6). The AVO anomaly is very strong at such locations. But very weak AVO anomaly is observed (Figure-4C) at locations where there is no evidence of free gas below the hydrate layer (figure-2b). Moderate AVO anomaly (Figure-4B) is observed at locations where some indication for free gas beneath BSR is observed such as lowering of interval velocity as compared to the background velocity (Figure-7). The study of AVO responses of BSR at various locations in the area reveal that AVO anomaly is mainly due to underlying free gas rather than due to the hydrate layer above the BSR. Ecker and Lumley, 2001, reported the similar AVO results in Blake Outer Ridge through modeling methane hydrate in sediment overlying a layer of free methane gas-saturated sediment.

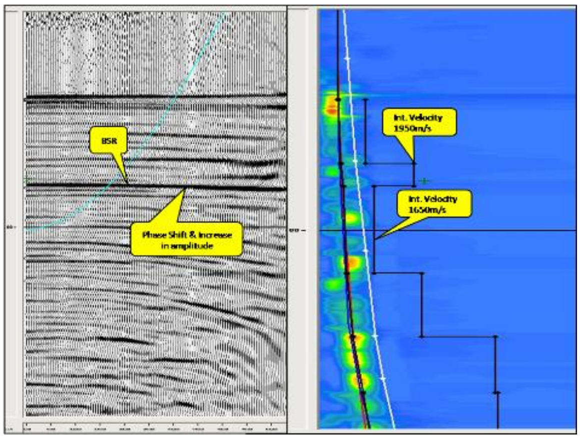

Fig.5 PSTM gather shows BSR and phase change at higher offset at a location –X in figure-2a. Migration Velocity analysis shows higher interval velocity(1950m/s) than the background velocity for the gas hydrate layer.

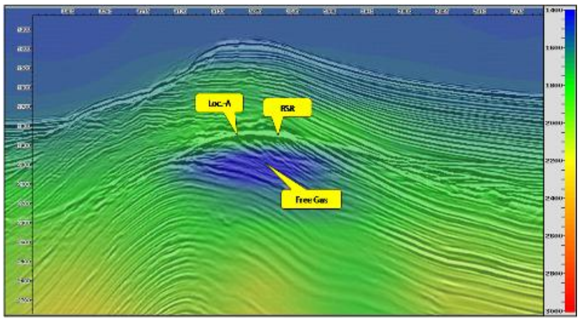

Fig.6 Pre-stack Depth Migrated section overlain by Interval Velocity section shows BSR. Very low Interval velocity below BSR indicates free gas below the Gas hydrate layer which is working as barrier for further upward migration of the gas.

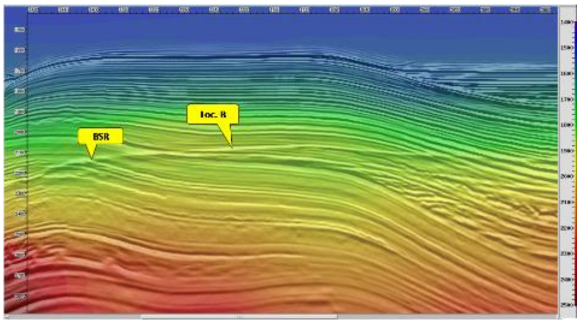

Fig.7 Pre-stack Depth Migrated section overlain by Interval Velocity section shows BSR. Locations for AVO analysis in figure-4 are shown

Pre-stack time migration(PSTM) velocity analysis of 2D and 3D seismic data reveal the variation in hydrate layer velocity between 2000m/s to 1750m/s. Figure -5 shows one such a panel indicating hydrate layer velocity of 1950m/s. The hydrate layer velocity reduces to 1750m/s at places where BSR amplitude is weak. There must be a relationship between saturation of hydrate and interval velocity & reflection strength of BSR.

To obtain the best possible estimate of depth and interval velocity, 3D seismic data of area-B has been depth migrated. Coherency inversion followed by model based and grid based tomography have been carried out to get the best estimates of depth model and interval velocity model of 3D data. Figure-6 shows a representative seismic depth section (Line-A figure-8) showing base of hydrate layer at about 1900 m having high interval velocity of the order of 1950m/s. Free gas below the hydrate layer is expected since very low interval velocity; of the order of 1450m/s and high amplitude of the reflection events beneath BSR are observed. The hydrate layer seems to be working as perfect seal disallowing the upward movement of gas. Figure-7 shows a seismic section (Line-B figure-8) without any indication of free gas beneath the hydrate layer since there is no significant lowering of interval velocity observed. Here the hydrate layer is deeper and is at about 2100m. The gas might have been migrated to structurally higher location and trapped around the area towards south of line –B in figure-8. The area of possible free gas is mapped and is shown in figure-8. The area of BSR without indication of free gas is also mapped and is shown in figure.8 which is structurally lower than the area where there is an indication of free gas. Therefore, seismic signatures derived from our study of the seismic data in area-B of Andman Deep water basin reveal the presence of free gas below the hydrate layer.

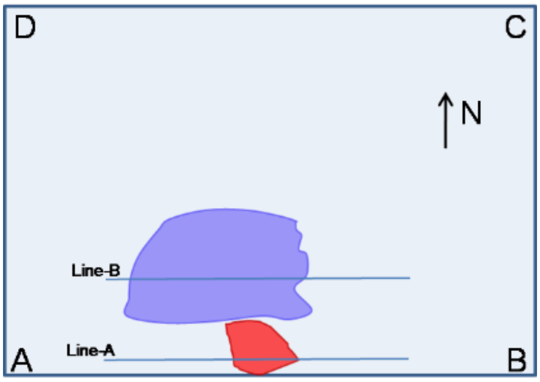

Fig.8 Base-map of Area-B shows the area of free gas beneath hydrate layer inferred from low velocity layer below BSR(in red colour). Line-A indicates the location of seismic section shown in figure-6. Line-B indicates the location of seismic section shown in figure-7.The blue colour indicates an areal distribution of BSR without any significant lowering of velocity below BSR.

Thus our study supports the model for gas hydrate formation and the development of BSRs proposed by Claypool and Kaplan, 1974 wherein it is envisaged that methane is generated microbially from organic matter within the zone of gas hydrate stability and hydrate formation takes place concurrent with sedimentation.

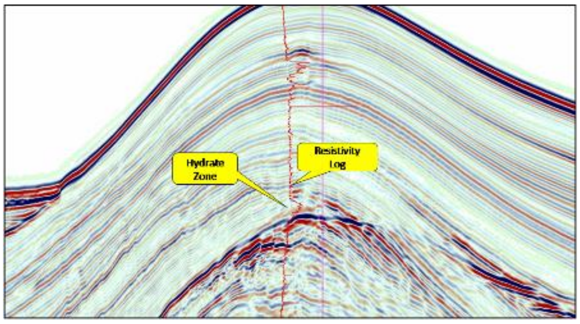

Fig.9 Resistivity Log superimposed on Seismic section shows an increase in resistivity from 1.1 ohm meter to 2.5 ohm meters in the hydrate zone.

A well has been drilled in the study area-B. The resistivity log is superimposed on the seismic section as shown in the figure-9. The base of hydrate layer is matching with the depth migrated seismic section. The resistivity log shows an increase in the resistivity from 1.1 to 2.5 ohm meter in the hydrate layer which is estimated more than 25m thick. Gas hydrate saturation is estimated by using Archie's(1942) equation,

$S=1-(Ro/Rt)^{1/n}$ ----------------(1)

Where Ro is resistivity of the formation fully saturated with water which can be estimated as the background resistivity which is in our case taken as 1.1 ohm meter. Rt is the measured resistivity in the hydrate zone which is 2.5 ohm. For hydrate clastic sediments, n=1.9386 (Pearson et al., 1983).

The hydrate saturation is estimated about 35% using the above parameters. The exponent "n" in the above equation (1) is empirical and can introduce error in hydrate concentration estimates. The critical factor for the estimation using resistivity log is choosing baseline indicating hydrate free sediments, which is dependent on the pore water salinity.

Conclusions

Pre-stack Depth migration of 3D Seismic survey in area-B of Andman Deep water basin reveal a possible pool of free gas beneath the hydrate layer. Strong AVO anomalies of the BSR at the locations of strong velocity inversion further substantiate the presence of gas hydrate layer and a possible free gas pool beneath hydrate layer in area-B. The drilled well in the study area-B also confirms the hydrate deposit as predicted by the seismic data. The resistivity log data provides an estimate of hydrate concentration of about 35% in 25m thick hydrate layer.

Note: This paper represents views of the authors. Organizations to which authors belong to may have different opinion.

References

Anand Prakash, B.G. Samanta, and N.P. Singh, Gas Hydrate : Prospect and Potential of Mahanadi Deep Water Basin, 8th Biennial International Conference & Exposition on Petroleum Geophysics, 2010

Anand Prakash, B.G. Samanta, and N.P. Singh, Gas Hydrate: Prospect and Potential of Mahanadi Deep Water and Andman Basins - A Comparative Study; Proceedings 9th International Oil & Gas Conference and Exhibition, PETROTECH-2010

Archie, G.E., The electrical resistivity log as an aid in determining some reservoir characteristics: J.Petr. Tech., 1942, Vol-5,PP 1-8.

Colltee T.S. Energy resource potential of natural gas hydrates, AAPG Bull. 86, 1971-1992, 2002

Claypool W.G, and Kaplan I.R.; The origin and distribution of methane in marine sediments, in natural gases in marine sediments, edited by I.R.Kaplan, pp.99-139 Plenum,Newyark,1974

Ecker Christine and Lumley David,E; Seismic AVO analysis of methane hydrate structures; Stanford Exploration Report 80, 2001,pp 1-288

Foucher Jean-Paul, Nouze Herve and Henrry Pierre; Observation and tentative interpretation of a double BSR on Nanaki slope; Marine Geology,Vol.187,2002,161-175

Golmshtok A Ya, and Soloviev Valery A; Some remarks on the thermal nature of the double BSR;Marine Geology Vol.229,2006, pp 187-198

Holbrook W.S. , Hoskins H., Wood W.T., Stephen R.A. and Lizarralde; Methane hydrate and free gas on the Blake Ridge from vertical seismic profiling, Science, 1996, 273, 1840-1843

Hyndman R and Spence G; A seismic study of methane hydrate marine bottom simulating reflectors; J. Geophys. Res.,1992, 97 ,pp 6683-6698

Kuldeep Chandra, Singh R.P. and Julka A.C. ; Gas Hydrate potential of Indian Offshore area, 2nd Biennial International Conference & Exposition on Petroleum Geophysics, 1998

Kvenvolden K. A; Gas Hydrate- Geological perspective and global change, Review of Geophysics, 1993 , 31, pp 173-187

Makogon Y.F., Holditch S.A. and Makogon T.Y.; Natural Gas Hydrates-A potential energy source for 21st Century; Journal of Petroleum Science and Engineering , 2007,56, pp. 14-31

Nandi A.K., and Chaudhury C.; Gas Hydrates in relation to Seismic Geomorphic features and its Impact on the Hydrocarbon Prospectivity of Deep Water Andman Basin, India, 8th Biennial International Conference & Exposition on Petroleum Geophysics, 2010

Pearson, C.F., Halleck, P.M., McGuire, P.L., Hermes,R., and Mathew, M.: Natural Gas Hydrate: A review of insitu properties: J.Phys.Chem.,Vol.87,1983,pp 4180-4185.

Posewang J, and Mienert J; The enigma of double BSR: indicators for change in the hydrate stability field Geo-marine Letters,Vol.19,1996,pp 157-163

Ramana M.V. , Ramprasad T., Desa M., Sathe M.V. and Sethi A.K.; Gas hydrate-related proxies inferred from multidisciplinary investigations in the Indian offshore area; Current Science 2006,Vol.91, No.2

Ramana M.V., Ramprasad T., Raju K.A.K. and Desa M. ; Occurrence of gas hydrates along the continental margins of India, particularly the Krishna-Godavari offshore basin; International Journal of Environmental Studies, 2007 , Vol. 64, No.6, pp 675-693

Rastogi A., Deka B., Bhattacharya G. C., Ramprasad T. et al.; Gas hydrate stability zone thickness map of Indian deep offshore areas- A GIS based approach; Proceedings Third International Conference and Exhibition, PETROTECH-99, 1999, pp 489-494

Sloan Jr E.D., Gas hydrate: Reviews of physical/chemical properties, Energy and Fuels, 1998, 12, pp 191-196

Shipley T.H., M. H. Houston, T.T. Buffer, et al.; Seismic reflection evidence for widespread occurrence of possible gas-hydrate horizons on continental slopes and rises; AAPG Bulletin, 1979, 63, pp 2204-2213

Sethi, A.K.,Sathe,A.V. and Ramana M.V.; Potential natural gas hydrates in Indian offshore areas; Am. Assoc. Pet. Geol. Hedberg Conference" Gas Hydrate Energy Resource Potential and Associated Geologic Hazards' Vancouver,BC, Canada, Proc. AAPG, 12-16 Sept. 2004, pp 1-6

Shuey R.T. ; A simplification of Zoepritz equation : Geophysics,1985, 50, pp 609-614

Vayavur Rajesh, Sain Kalachand,and Satyavani N. Gas Hydrate Stability Thickness along Indian continental margins, 8th Biennial International Conference & Exposition on Petroleum Geophysics, 2010

Acknowledgements

Authors are grateful to ONGC for giving permission to use the data. Authors express their sincere thanks to Shri S. V. Rao, Director (E) and Sri D. P. Sahasrabudhe, ED- Basin Manager for his kind support and encouragement. We acknowledge the guidance, suggestion and continuous encouragement by Sh. B.K. Das, GGM –HGS and Sh. S. Panigrahi, GM(GP) to carry out the study. We sincerely thank Dr. A. K. Nandi, CG for his technical support.