

Gas hydrate occurrences in the Andaman deep water basin, India

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Keywords

Gas hydrate, Bottom simulating reflector, Hydrate saturation estimation, Resource assessment, Andaman deepwater basin

Summary

Seismic reflection data analysis from Andaman deep water areas shows wide spread high amplitude bottom simulating reflectors (BSR) indicating several gas hydrate accumulations in the area. The BSRs in the area show all the characteristics of a classical BSR associated with gas hydrate accumulation. Double BSRs are also observed on some of the seismic sections in the area suggesting significant changes in pressure-temperature (P-T) regime in the recent past. Mapping of BSRs in the basin depicts varying gas hydrate stability zone thickness (200–650 m) in the basin. The areal extent of the individual accumulations mapped is of the order of 25 km². One of the 3D seismic surveys has been depth migrated and a significant velocity inversion across the BSR (1950 m/s to 1650 m/s) is observed. The high velocity anomalous area above BSR corroborates very well with the areal presence of BSR. The area having low velocity of the order of 1450 m/s below BSR and high amplitudes indicates presence of dissociated or free gas beneath the hydrate layer. Amplitude variation with offset (AVO) analysis of BSRs shows class III AVO anomaly. Two exploratory wells were drilled in the basin for conventional hydrocarbons. Gas hydrates were encountered in both the wells at depths interpreted on the seismic depth sections. The seismic evidence is very well corroborated with the gas hydrates encountered in the well and the base of the hydrate layer derived from the log data are in agreement with the depth of hydrate layer interpreted from the pre-stack depth migrated seismic data. The resistivity and acoustic transit-time logs indicate 30-m-thick hydrate layer at depth interval of 1865 m - 1895 m with 30% hydrate saturation. The total hydrate bound gas in this particular hydrate accumulation is estimated to be $\sim 1.4 \times 10^{10}$ m³, which is comparable (by volume) to the reserves in major conventional gas fields.

Introduction

The energy requirements of the world mainly depend on fossil fuels and the ever increasing demand for sustained industrial growth has forced all of us to look for unconventional/alternate energy resources such as coal bed methane, shale gas, and gas hydrate. Natural gas hydrates have the potential of becoming an alternate energy resource as a result of huge deposits estimated worldwide (Kvenvolden 1993a; Collett 2002; Makogon et al. 2007). The potential reserves of hydrated gas are estimated to be of the order of 1.5×10^{16} m³, and a commercial production of just 15% of this gas reserves could provide the world with energy for over 200 years from now at the current level of energy consumption. At present, many countries have national programs for research & technology development for gas hydrate exploration and as a result of which over 220 gas hydrate deposits have been discovered, more than hundred wells were drilled, and kilometers of hydrated cores have been studied (Makogon et al. 2007). Japan has carried out the first ever offshore gas hydrate production testing at its well known hydrate accumulation site Nankai Trough area in 2013. Canada with its consortium of partners has completed several drilling programs to produce gas from the Mackenzie Delta (Dallimore et al. 1999). Korea (Park et al. 2008), China (Zhang et al. 2007) and Malaysia (Hadley et al. 2008) have also launched major deep-water hydrate drilling expeditions successfully. National Gas Hydrate Programme (NGHP) Expedition-1 of India has confirmed the presence of gas hydrate accumulations in Krishna Godavari (KG), Andaman and Mahanadi basins (Collett et al., 2008).

Seismic surveys (conventional 2D/3D survey, ocean bottom seismic, vertical seismic profiling, and cross-well seismic and multi-component), well logging, and

Gas hydrate occurrences in the Andaman deep water basin, India

controlled source electromagnetic surveys are commonly used geophysical techniques for identification and evaluation of gas hydrate deposits. Most gas hydrates, worldwide have been inferred from the detection of a Bottom Simulating Reflector (BSR) and associated Gas Hydrate Stability Zone (GHSZ) thickness map (Shipley et al. 1979; Hyndman et al, 1992; Yuan et al. 1996; Sain et al. 2000; Dewangan and Ramprasad 2007). The BSR is recognized based on its characteristic features such as; (i) mimicking the shape of sea floor because the 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 (Brooks et al. 1986). The BSR is the interface between gas hydrate-bearing sediments above and free-gas saturated sediments below it and is often associated with the base of the gas hydrate stability field (Kvenvolden, 1993b). The Gulf of Mexico, Blake Ridge, Cascadia Margin, MacKenzie Delta and Nankai Trough are some of the best known examples of gas hydrate deposits (Holbrook et al. 1996; Dallimore et al. 1999; Wood and Ruppel 2000; Hyndman et al. 2001; Ashi et al. 2002; Holbrook et al. 2002; Hornbach et al. 2008). In addition to the BSR, other geophysical anomalies, such as pockmarks, gas up-thrust zone, vents, and blanking zones are also prominent indicators of gas hydrate accumulation. In the present study, 2D and 3D seismic reflection data, as well as bore-hole data from the Andaman deepwater basin (Fig.1) are analyzed to investigate the evidence for gas hydrate accumulations, its saturation and resource estimation. AVO analysis, pre-stack depth migration, and velocity inversion of seismic data have also been carried out. Model-based and grid-based tomography of the seismic data was carried out for detailed velocity information. The logging results from a drilled well in area have been analyzed to identify the hydrate zone, estimation of hydrate saturation and reserve in the hydrate deposits.

Geologic setting

The Andaman Basin is the southeastern part of the Bay of Bengal around the Andaman-Nicobar chain of islands between 6–14° N latitude and 91–94° E longitude and covers an area of more than 47,000 km². The basin has more than 7.5 km thick succession of marine sediments from Cretaceous to recent (Directorate General of Hydrocarbons, India). The basin extends about 1200 km in a north-south direction from Myanmar in the north to Sumatra in the south, and 650 km in the east-west direction from Malay Peninsula in the east and Java trench in the west. The morphology and structure of the Andaman Islands suggest that they are an island arc developed by subduction of Indian plate beneath the Southeast Asian plate since the Late Cretaceous (Curry J.R., 2005). The regional geotectonic units in the basin area from east to

west are back arc basin, volcanic arc, fore-arc, and trench associated with converging plate boundaries. Major tectonic events-subduction/oblique subduction, magmatic intrusion and back-arc spreading led to the development of various sub-basins; fore-deep/trench, fore-arc, ponded fill, inter-arc, and back-arc basins. During the Late Cretaceous under-thrusting of the oceanic plate caused accretion of overlying Bengal Fan turbidites and shallow marine sediments and part of Burmese crust as north south trending prism by the process of reverse faulting, thrusting and folding (Curry J.R., 2005). The study areas correspond to the deepwater part of the fore-arc sub-basin of Andaman basin and are shown in Fig. 1 on the regional tectonic map of Andaman basin.

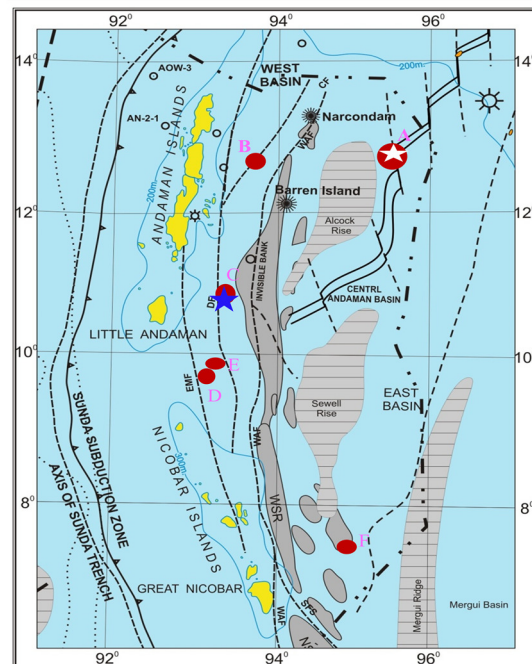


Figure 1: Tectonic map of Andaman Basin. Red dots show the areas of seismic surveys whose datasets are analyzed in the present study and gas hydrate accumulations are interpreted. The stars indicate drilled well locations (source: ONGC).

Data and methods

Andaman deepwater basin is covered by several 2D and 3D seismic surveys. 2D seismic surveys are generally 162-fold with Common Depth Point (CDP) interval 12.5 m and 3D seismic surveys are 62-fold with a bin size of 12.5 m x 25 m. These data are analyzed to look for possible gas hydrate accumulations in the basin. Standard as well as special 3D seismic data processing scheme, such as pre-stack time and

Gas hydrate occurrences in the Andaman deep water basin, India

depth migration, very close grid migration velocity analysis, amplitude, phase and frequency attributes were performed. Coherency inversion of seismic data was used to derive interval velocity model for the 3D data and thereafter model-based tomography is used to update the velocity field. However, some of reflection events between the mapped horizons are not flat. As a result, residual depth move-out analysis in vertical mode in a grid of 250 x 250 m followed by grid-based tomography techniques was implemented to obtain the final interval velocity model in the depth domain. The amplitude versus offset (AVO) analysis of pre-stack time and pre-stack depth migration gathers at representative locations was carried out to investigate the nature of the BSR. Well log data was analyzed and correlated with the seismic data. The gas reserve estimation is carried out using resistivity log in one of the gas hydrate accumulations in Andaman basin.

Seismic data analysis, result and discussion

Seismic sections from the Andaman area show BSRs at 200–800 ms below the sea bottom. These events are distinct and have characteristic features of a classical BSR, such as mimicking the sea floor, polarity reversal, cross-cutting the lithological boundaries, and blanking above and below the BSR. There is an abundance of BSRs seen in the seismic sections within the deep water of Andaman basin (Fig. 1). The non-systematic distribution of BSRs at different depths reflect varying pressure-temperature (P-T) regime at different locations in the area. The variation in BSR depths is significant and it may be attributed to high sedimentation rate, ongoing erosion of ridges, and variation in geothermal gradient. The seismic sections show very clearly that erosion is still continuing which suggest a dynamic hydrate system in Andaman deep water areas. Gas hydrate stability zone thickness in the basin has been calculated as 200 m – 650 m. Very shallow BSR ~200 mbsf is interpreted due to very high thermal gradient in the area around Sea-floor spreading centre. The thermal gradient derived from the well data is of the order of 52°C/Km in the area closer (less than 100km) to the seafloor spreading center. This has pushed the gas hydrate stability zone to very shallow depths (~ 200 m) in this part of the basin (the well location is marked by a red star in Fig. 1). However, the thermal gradient estimated from the well (shown in Fig. -1 by blue star) data in Area C which is more than 300 km away from the ocean floor spreading center is ~25° C/km.

In this part of the basin, gas hydrate stability zone is estimated ~460 mbsf. Some of the seismic sections in Area B reveal two distinct BSRs. The upper BSR is traced as a continuous reflector stretching over 3 km of length, while the lower BSR is traced at approximately 50 m below the upper one having limited areal extent. The upper BSR is interpreted an active methane hydrate BSR and the lower BSR is a residual or relict one. The double BSR may be due to changes in the P-T regime in the recent past caused by low order tectonic activities in the area.

The AVO analysis of BSR shows class III AVO anomaly of varying degrees. Strong AVO anomaly is observed where there is seismic evidence of free or dissociated gas (significant low interval velocity below BSR). A very weak AVO anomaly is observed at locations where there is no evidence of free gas below the hydrate layer. Conditioned pre-stack time migration gathers are used for generation of AVO curves in our study by careful parameterization for geometrical spreading correction, amplitude equalization for each offset, Q-correction, residual move-out correction, and band pass filter. The study of AVO responses of the BSR at various locations reveals that the AVO anomaly is mainly due to underlying free gas rather than due to hydrate layer above the BSR. An example of the change in amplitude and waveform of the BSR as a function of offset is shown in Figure 2a. At far offsets in the PSDM gather, the amplitude increases rapidly and there is a phase change at higher offsets (> 3622m). Figure 2b shows another seismic section from the area depicting very prominent BSR between 2.15 sec and 2.25 sec and PSTM gathers are revealing significant increase of amplitude with offset. Figure 2c depicts AVO response curves indicating low impedance class –III type sand. The gradient of the AVO response curves indicate positive correlation with BSR amplitude, thereby indicates qualitatively hydrate concentration above BSR or free gas concentration below BSR.

Gas escape root in the seismic section is a spectacular feature, where even water bottom reflection gets affected and is not imaged properly due to absorption and scattering of seismic energy by the gas mixed with unconsolidated sediments. A continuous dissociation of hydrate and gas escape through water bottom is interpreted in the area. Reduction in relative amplitude of BSR at this location is another indication of continuous dissociation of hydrate.

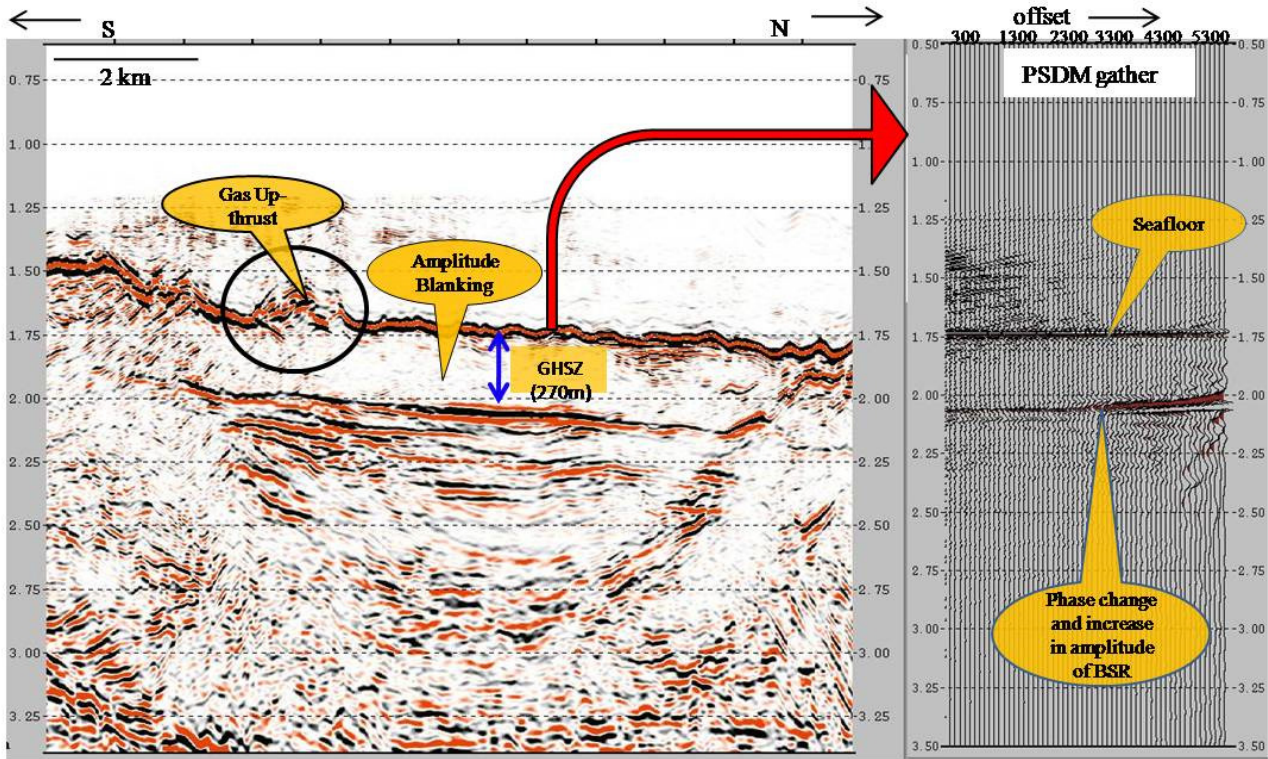


Figure 2a: PSDM stack section from area B showing BSR and gas escape features. PSDM gather depicts significant increase in amplitude as well as phase change of BSR at higher offset.

Pre-stack depth migration of a 3D seismic survey in the area depicts BSR and anomalous velocity areas quite prominently. Figure-3 shows a representative seismic depth section depicting base of the hydrate layer at about 1900 m, with a high interval velocity of 1950 m/s. The very low interval velocity ~1450 m/s and high amplitude reflection events beneath the BSR suggest free gas accumulation below the hydrate layer. Reflection events on the anticline below the BSR are seen truncating against the BSR, which shows that the hydrate layer functions as a seal preventing the upward movement of gas.

Seismic sections in the area shows high amplitude and low frequency events below the BSR suggesting that gas might have been generated at deeper depths and it might have been migrated to a structurally higher location. The gas has been trapped around the area and might not have been converted into hydrate due to higher temperature gradient. The overall seismic signatures derived from the analysis of seismic datasets from Andaman deepwater basin reveal wide spread presence of gas hydrate deposits. Mapping of BSR on seismic data have been carried out and prospective areas are identified. Figure-1 shows the locations of gas hydrate accumulations in the basin. Gas hydrate stability zone thickness (GHSZ) map for the basin is also prepared.

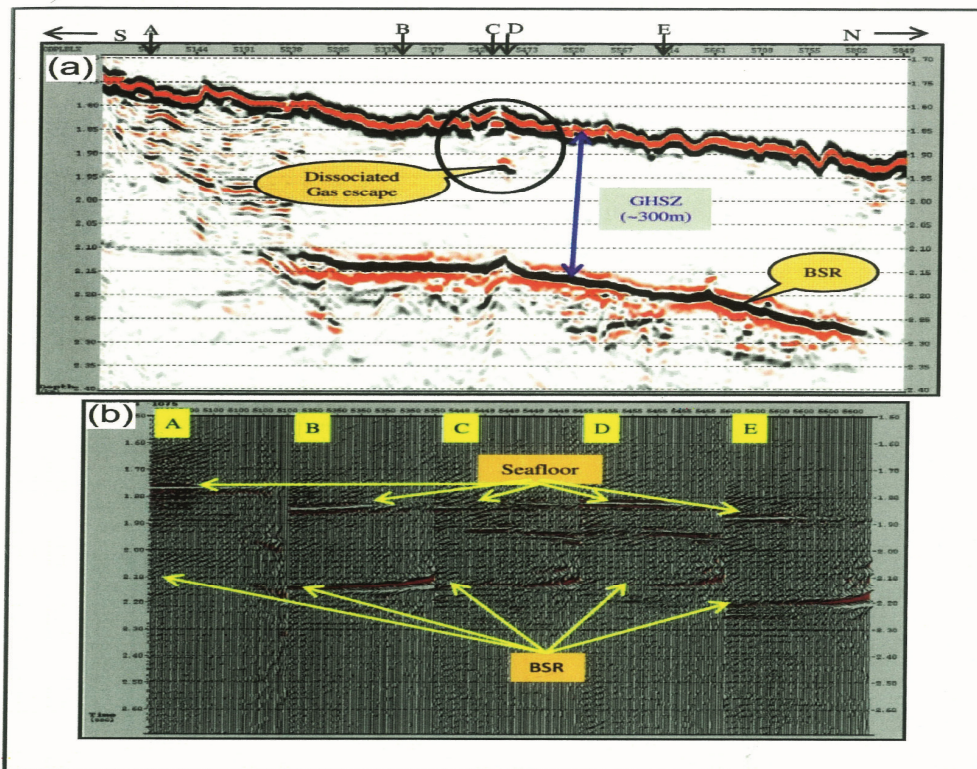


Figure2b: (a) seismic section showing gas hydrate accumulation and associated features (b) PSTM gathers depicting AVO effects on BSR at the locations shown in figure (a)

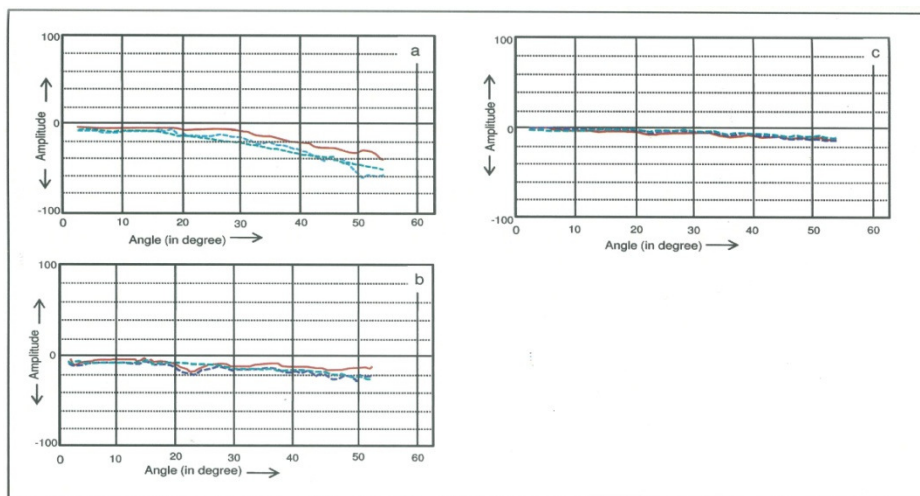


Figure2c: AVO curves generated from analysis of PSTM gathers. (a) Strong AVO anomaly where free gas below BSR is indicated by velocity and amplitude anomalies. (b) Moderate AVO anomaly where some indication of gas & moderate amplitude of BSR (c) Weak or no AVO anomaly where no gas indication & weak amplitude of BSR.

Gas hydrate occurrences in the Andaman deep water basin, India

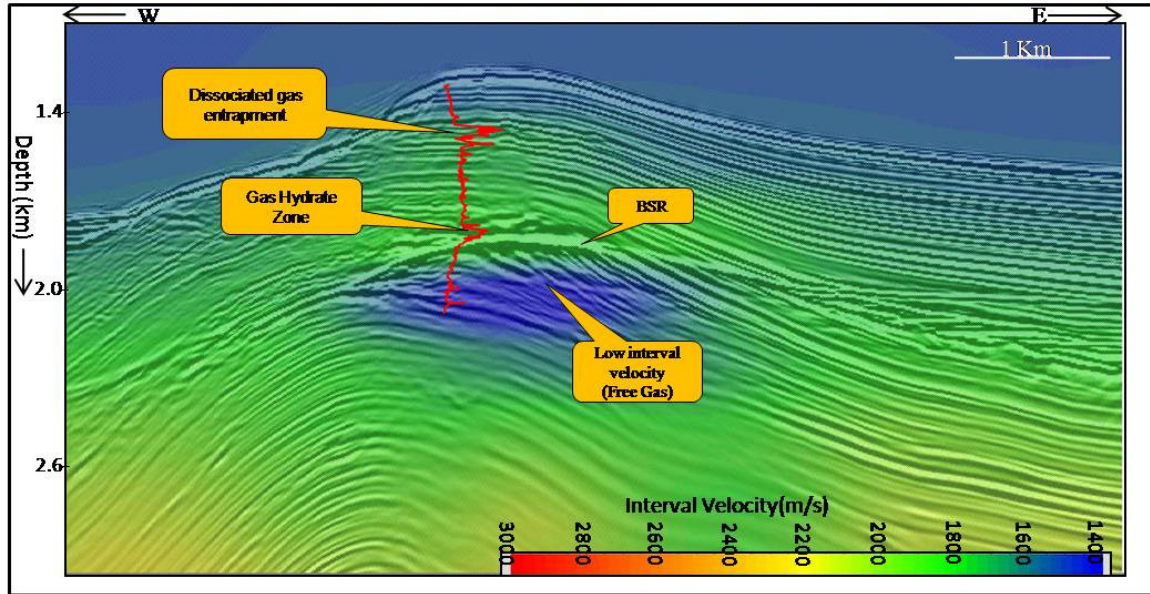


Figure 3: PSDM section from area C overlain by interval velocity section. High velocity (~1900 m/s) above BSR depicts gas hydrate accumulation and very low velocity (< 1500 m/s) below BSR indicates free gas below the Gas hydrate layer which is working as barrier for further upward migration of the gas. Resistivity Log superimposed on the seismic section shows gas hydrate zone above BSR where an increase in resistivity from the background value of 1.1 Ωm to 2.2 Ωm is observed. The high resistivity in the shallow zone at ~1600 m indicates dissociated gas accumulation.

Down-hole log data analysis and reserve estimation

A well was drilled in the study Area C with logging measurements obtained while drilling (LWD). The resistivity log superimposed on the seismic section is shown in figure-3 which clearly indicates a hydrate layer above the BSR. High seismic amplitude events on the seismic section at shallow levels (~1600 m) in the section coincide with high resistivity log responses indicates secondary hydrate accumulation or free gas accumulation. However, seismic attributes indicate dissociated gas accumulation. Flat spot is a prominent feature in the seismic section confirming dissociated gas pool at shallow depth levels. Minor faults seen on the seismic sections might have worked as conduits for the dissociated gas. Seismic attribute sections generated also helped in characterizing hydrate layer as well as shallow gas accumulations in the basin. The responses of the gamma ray (γ), P-wave-velocity, resistivity and bulk density logs are analyzed to identify the hydrate layer.

The resistivity and velocity logs indicate the presence of gas hydrate at depth interval 1865 to 1895 m. The hydrate layer is characterized by increased velocity from 1650 m/s to 1950 m/s, and increased resistivity from 1.1 Ωm to 2.2 Ωm . The well log data largely validates the velocity profile obtained by pre-stack depth migration across the hydrate zone. To estimate the volume of hydrate-bound gas at specific site, the areal extent of hydrate occurrence, thickness of gas hydrate layer, the hydrate concentration and the yield are the required parameters. Figure 4 shows the areal extent of BSR mapped in one site in the fore-arc basin which is about 25 Km². The average thickness of the gas hydrate layer, as per the log data is 30 m. Since, gas hydrate, like ice, acts as an electrical insulator; therefore gas hydrate saturation can be estimated by using Archie's equation (Archie, 1942). Resistivity log provides estimate of hydrate saturation as 30%. The well encountered mainly claystone and siltstone, so average porosity of hydrated

Gas hydrate occurrences in the Andaman deep water basin, India

sediments is assumed 40% without any loss of generality. For the purpose of this study, the gas hydrate yield is taken 150 m³ of hydrocarbon gases. The total volume of hydrate-bound gas (V) is estimated of the order of 1.4 x 10¹⁰ m³ at standard temperature and pressure. This gas hydrate

resource is comparable (by volume) with the reserves within large or major conventional gas fields.

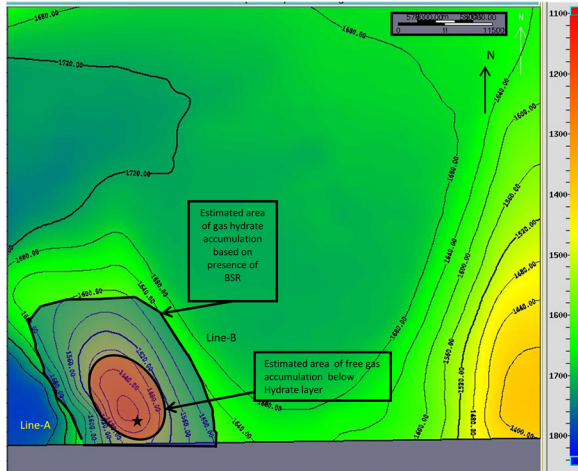


Fig.4 Bathymetric map shows the estimated area of hydrate accumulation in the area based on the presence of BSR. The location of well is indicated by star

Conclusion

Analysis of seismic data from Andaman deep water areas indicated wide spread occurrence of gas hydrate accumulations. The drilled data also confirmed the seismic studies carried out to identify and delineate hydrate deposits. The log data confirms a 30 m thick hydrate layer at depth of 1895 m in one of the hydrate accumulations. The resistivity and acoustic transit-time log data provides an estimate of hydrate saturation ~ 30%. The total hydrate bound gas in one of the hydrate deposits of the basin is estimated to be 1.4 x 10¹⁰ m³, a volume comparable to the reserves in major conventional gas fields.

Acknowledgements

The authors are grateful to ONGC for permission to use the data for this study. The authors express their sincere thanks to Sh. A.K.Dwivedi, Director (E), Sh. C.M.Jain, GGM-HGS, Sh. K.V.Krishanan, GGM-Head SPIC, ONGC and for their kind support and encouragement.

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Gas hydrate occurrences in the Andaman deep water basin, India

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