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Assessment of gas hydrate stability zone and geothermal modeling of BSR in the Andaman Sea

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ABSTRACT

Wide-spread bottom simulating reflectors (BSRs) are observed along available multichannel seismic profiles covering an area of about 290 km^2 in the Andaman Sea. The seismic data shows that the BSR occurs at places where water depth exceeds 1000 m, and is identified by cross-cutting relationships with the dipping reflectors. The BSR that represents the base of gas hydrate stability field can be used to infer the gas hydrate stability thickness, which ranges between ~518 m to ~861 m depending on water depths. *In situ* measurement at site 17 during the Indian National Gas Hydrate Program (NGHP) Expedition-01 shows very low geothermal gradient 19 ± 2 °C/km. A conductive model was used to determine geothermal gradients from BSRs, which is calculated and varying between 10 °C/km to 40 °C/km. The low geothermal gradient is responsible for the deepest BSR or gas hydrate stability zone (GHSZ) in the Andaman region and in the world. The geothermal modeling shows a close match of the predicted base of the gas hydrate stability zone with the observed BSR depths.

1. Introduction

Gas hydrate is an ice-like crystalline naturally occurring substance that is formed by water and gas molecules (mainly methane) at low temperature and high pressure (Milkov and Sassen, 2001). Gas hydrate is identified almost along all the continental margins and permafrost region worldwide and gradually considered as a potential source of energy in coming decades. The thickness of gas hydrate stability zone (GHSZ) is mainly governed by seafloor temperature, geothermal gradient, water depth, gas composition and pore water salinity. In this paper we attempted to delineate a potential gas hydrate reservoir off the little Andaman and to estimate saturation of gas hydrates from well data using different approaches with a view to understand the deepest hydrate deposit in the world.

In 2006, the coring and drilling of Indian National Gas Hydrate Program (NGHP) Expedition-01 were carried out after analyzing available multichannel seismic data from Krishna–Godavari (KG) basin, Mahanadi (MN) basin and Andaman region. The Wire-line logging was performed at one site (NGHP-01-17) in the Andaman Sea. The drilling site was selected primarily from the 2D seismic data to test geological and geophysical interpretation of prospective gas hydrates reservoirs. Primary scientific objectives of the drilling program were to collect information on the distribution and types of gas hydrate occurrences and to identify suitable site for the initial production test (Collett et al., 2008). Recently detail comprehensive study on detection and assessment of gas hydrates in the continental margins of India using geophysical, geological and geochemical data presented by Sain and Gupta (2012). The new data analysis delineates the prospective zone of gas hydrates in the KG, MN basins and Andaman region, where the ground truth has been validated by the drilling and coring of Indian NGHP Expedition-01.

Presence of gas hydrate in marine sediments usually elevates the resistivity and velocity compared to water saturated sediments. Therefore, the resistivity and velocity measured at wells are frequently used to estimate gas hydrate saturations using Archie's equations and rock physics models respectively (e.g., Guerin et al., 1999; Helgerud et al., 1999; Collett and Ladd, 2000; Wang et al., 2011; Shankar and Riedel, 2011, 2013). Gas hydrate saturations are also estimated from the pore water chemistry data (e.g., Chlorinity) (Trehu et al., 2004; Torres et al., 2008; Malinverno et al., 2008; Wang et al., 2011; Yuan et al., 1996). The pore water chlorinity method is based on the process that chlorinity decreases due to fresh water generated by gas hydrate dissociation upon core recovery (Ussler and Paull, 2001). This reduction in chlorinity anomalies in the pore water within GHSZ is used to calculate gas hydrate saturation.

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The Andaman Sea (Fig. 1) is a region of interaction among three major tectonic plates: the Myanmar, Thailand and Malaysia. Gas hydrate investigation in the Andaman Sea has been carried out by number of research using geophysical data (Chopra, 1985; Sethi and Ahmad, 2006; Collett et al., 2008; Shankar and Riedel, 2013). NGHP-Expedition-01 first recovered gas hydrate samples from shallow sediments lying below ~1344 m water depth in the east of little Andaman Island (Collett et al., 2008). Most gas hydrate samples collected in this area were biogenic methane gas.

The main objectives of this study are to prepare GHSZ thickness map and to model the thickness of the GHSZ using linear geothermal gradient function from *in situ* measurement during NGHP Expedition-01 and bathymetry derived from multi-channel seismic (MCS) data. The estimated values are compared to available drilling data and BSR along drilling transect. This paper also presents a detailed analysis of gas hydrate saturations in Andaman Sea at drill site NGHP-01-17 using different methods.

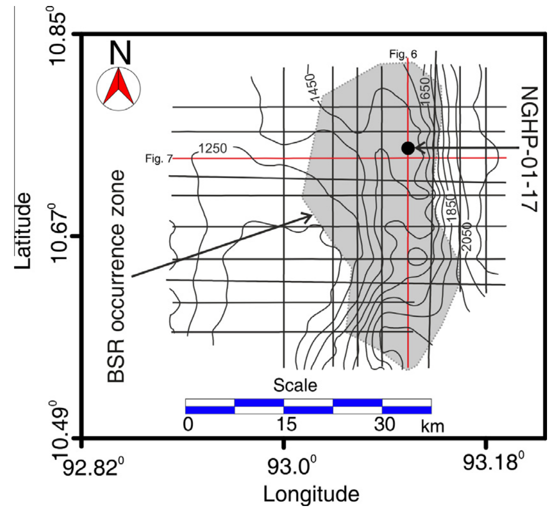

Fig. 2. Detail map of 2D multi-channel seismic data coverage, water depth and observed BSR occurrence zone (gray shaded zone). Red seismic lines in vicinity of drill site location are used in this study. Drill site location is shown with black circle. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2. Data and method

The seismic data used for this study are explained by Shankar and Riedel (2013) and Collett et al. (2008) in great details. The seismic data to investigate the area in the vicinity of drill site NGHP-01-17 consists of 2D multichannel seismic lines with detail map and BSR occurring zone (Fig. 2). Here we used 2D seismic line crossing to the drill site NGHP-01-17. The wireline log-data (P-wave velocity, electrical resistivity, bulk-density, porosity) from site NGHP-01-17 is shown in Fig. 3. The core data (salinity, *in situ* temperature and conductivity) are shown in Fig. 4. Seismically derived BSR depth position is marked on the wireline and core data with dotted line matching with the log trend, which shows distinct properties above and below the BSR. The interpretation was supported by resistivity, P-wave and S-wave velocity at drill site NGHP-01-17.

Geothermal gradient was derived from the temperatures and depths at the seafloor and BSR. The seafloor temperature was obtained by using the available Conductivity Temperatures Depth (CTD) profiles and constrained from *in situ* measurements from study area. The temperature at the BSR depth was estimated using the experimental stability condition for the methane–seawater system (Bouriak et al., 2000), which is based on pure methane and standard seawater (35 ppt). Standard geothermal gradient equation was used to calculate geothermal gradient (Shankar and Riedel, 2010; Shankar et al., 2010; Shankar and Sain, 2009) from the *in situ* temperature measurements. The heat flow is simply product of geothermal gradient and thermal conductivity of the sediment. The thermal conductivity of the sediment cores was measured during the drilling (Collett et al., 2008).

The GHSZ thickness map is estimated from assuming uniform interval velocity of 1.6 km/s for the entire sediment column from seafloor to the BSR. The uniform velocity was decided after detail analysis of the MCS staking velocity and acoustic log and VSP data (Collett et al., 2008; Shankar and Riedel, 2013). We further assumed water velocity 1.48 km/s and a hydrostatic pressure regime and calculated the pressure using a constant water density 1.03 g/cc. The GHSZ is known for a specific range of temperature and

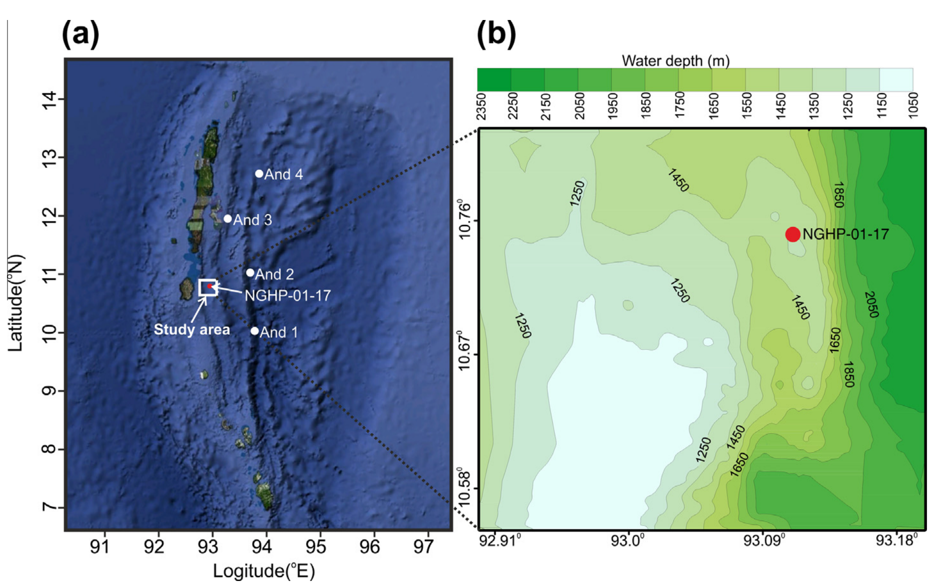

Fig. 1. Andaman Sea/Andaman Basin of India; (a) Location of the study area in the East of little Andaman with four heat flow measurements site by Burn (1965); (b) Detail bathymetry of the study area derived from the 2D multichannel seismic lines and the location of the drill site (red circle) from NGHP Expedition-01 of 2006. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)