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Characteristics of bottom-simulating reflectors for Hydrate-filled fractured sediments in Krishna–Godavari basin, eastern Indian margin

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ABSTRACT

The bottom-simulating reflector (BSR) is weak and patchy on the seismic section in the Krishna–Godavari basin, eastern Indian margin, where massive gas-hydrates have been recovered at Site 10 of the Indian National Gas-hydrates Program Expedition 01 (NGHP-01). The depth of the BSR near this site is around 160 m below the sea floor (mbsf). The average reflection coefficient from the BSR is −0.06, significantly smaller than the common global values of −0.1 to −0.2. The BSR shows a strong lateral variation in amplitudes along the seismic line due to the presence of faults. The methane solubility is modeled using a theoretical model of the gas-hydrates system, and methane concentrations from the pressure core show that the distribution of free gas below BSR is not uniform. A combination of synthetic seismogram analysis and rock physics modeling leads to the conclusion that weak and patchy BSRs are primarily caused by lateral discontinuities induced by the gas-filled fractures below BSRs. The free gas zone is thin and it shows segmented characteristics on the seismic section and acoustic impedance profile that we inverted. Fault zones increase the permeability and therefore trap gas in associated fractures that can scatter seismic energy and create low velocity zones.

1. Introduction

Bottom simulating reflectors (BSRs), the main marker for gas-hydrates, have been identified on seismic sections in the Krishna–Godavari (KG), Mahanadi, Andaman, Kerala–Konkan, and Saurashtra regions (Sain and Gupta, 2012). A weak BSR is observed on a seismic section along a line (Fig. 1a) passing very closely through Site 10 of the Indian National Gas Hydrates Program Expedition 01 (NGHP-01), where large quantities of gas-hydrates were recovered through coring (Collett et al., 2008). In contrast, a prominent BSR is observed on a seismic section passing through Site 2 (~2 km from Site 10), where no gas-hydrates were inferred from the logging-while-drilling data (Riedel et al., 2010). X-ray images of pressure core data indicate that gas-hydrates were accumulated as veins or modules in the high angle fractures of fine-grained clay sediments (Collett et al., 2008; Riedel et al., 2010). The BSR is a phase boundary between high impedance gas-hydrate bearing sediments above and low impedance free gas bearing sediments below, and exhibits polarity reversal with respect to the seafloor, velocity reversal, enhanced reflectivity below and amplitude blanking above; cuts across dipping sedimentary strata; mimics the shape of seafloor; and often represents the base of gas-hydrates stability zone (GHSZ).

Numerous authors have reported that BSR is caused not by large concentrations of gas-hydrates above but is due to free gas below (Singh et al., 1993; Bangs and Brown, 1995; Paull et al., 1996; Shedd et al., 2011). This is because even very low concentration of free-gas can reduce the P-wave velocity or impedance significantly (Domenico, 1976).

The continuous BSR is interpreted as associated with a diffusive system controlled by both hydrate recycling and a solubility-curve mechanism, whereas the discontinuous BSR is caused by numerous large and small scale faults (Haacke et al., 2007). The flux of fluids with methane exceeding the solubility will produce a free gas zone, as well as an older episode of either high methane flux or lower temperature that traps the free gas layers. If the methane concentration after dissociation exceeds methane solubility, then a free gas zone could develop even if the methane flux rate is not sufficiently rapid (Xu and Ruppel, 1999). Haacke et al. (2007) analyzed gas-hydrates systems in both the active and passive margins, and summarized different mechanisms for the formation of free-gas. The solubility-curvature mechanism requires downward-decreasing solubility and low rates of upward flow of methane-rich liquid, while hydrate recycling requires the upward shift of the

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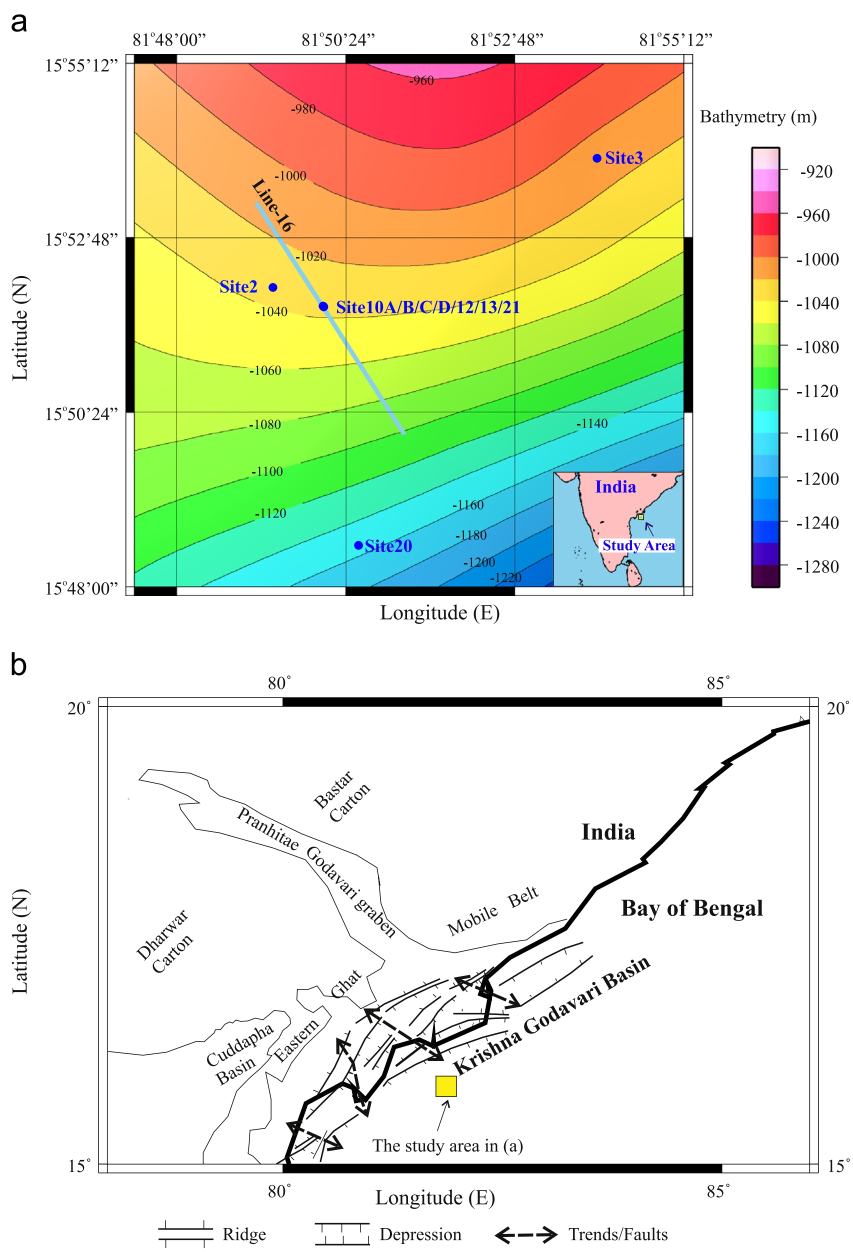

Fig. 1. (a) NW-SE 2-D seismic line-16 with NGHP-01 drilling sites superimposed on the bathymetry in the study area. The yellow rectangle in the inset shows the study area in the KG basin, in the eastern Indian margin. (b) The simplified geologic map of KG basin and its adjacent area (modified after Radhakrishna et al., 2012). The yellow rectangle in the inset shows the study area in (a). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

gas-hydrates stability zone which is caused by sedimentations or tectonic movements. The weak BSRs have also been identified in the South China Sea (Wu et al., 2007) and Hikurangi Margin, New Zealand (Navalpakam et al., 2012). The reflection coefficients of BSR in Hikurangi Margin range from −0.01 to -0.02 (−0.016 average), which is much smaller than those ranging from −0.1 to −0.2 identified globally (Miller et al., 1991, Pecher et al., 1996; Singh et al., 1993). The main objective of this study is to understand the causes of weak BSR in fine grained sediments in KG basin and what controls the variation of BSR strength using acoustic modeling based on rock physics.

2. Geologic setting

The KG basin is located in the central part of the eastern passive continental margin of India (Fig. 1). It is a proven petroliferous basin occupying an area of 28,000 km^2 on land and 145,000 km^2 offshore (Rao, 2001; Bastia, 2006). Tectonically, it is a pericratonic basin with a basement of highly metamorphosed Precambrian rocks. As a consequence of rifting and drifting, the KG basin evolved during the breakup of the Gondwana around 130 Ma when India separated from East Antarctica (Powell et al., 1988). The basin is characterized by en-echelon type horst- and graben-like structures, which is filled with thick sediments of the Permian to Recent age, mainly governed by the Krishna and Godavari river systems (Rao, 2001; Rao and Mani, 1993; Gupta, 2006). The fast rate of deposition on the slope to intraslope basins (numerous isolated and enclosed sea-floor depressions) has led to the development of extensive growth faults (Bastia, 2006; Prather et al., 1998).

The general stratigraphy offshore at the KG basin can be divided into syn-rift (Upper Jurassic to Early Cretaceous) and post-rift (Tertiary) petroleum systems (Fig. 2) (Rao and Mani, 1993). Lagoonal, fluvial, and occasionally brackish water deposits are the main