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Review article

Natural gas hydrates occupying fractures: A focus on non-vent sites on the Indian continental margin and the northern Gulf of Mexico

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ABSTRACT

We present a review of the geophysical and petrophysical properties of gas hydrate-filled fracture sites that are not associated with a gas vent or chimney from the Indian National Gas Hydrate Program Expedition 01 and the Gulf of Mexico Gas Hydrate Joint Industry Project Legs I & II. We analyzed logging-while drilling (LWD) resistivity images, well logs and coring information at eight of these sites and found in all cases that the gas hydrate-filled fractures occurred in fine-grained sediments, were near-vertical, and were generally oriented in the same direction at each site. In addition, resistivity was the only physical property always affected by presence of near-vertical gas hydrate-filled fractures, though in one case only the LWD resistivity image detected the presence of gas hydrate. Gas hydrate-filled fractures did not intersect the base of the gas hydrate stability zone at the location of the wellbore at any of the sites. We suggest that at non-vent/non-chimney sites the methane occupying the gas hydrate is likely produced microbially in situ and is not sourced from below.

1. Introduction

Ice-like natural gas hydrates form in shallow sediments in continental margins worldwide (Kvenvolden and Lorenson, 2001); their formation requires high pressure and low temperature conditions as well as a natural gas source. Hydrate morphology in sediment depends on the sediment type and grain size. In coarse-grained sediment, gas hydrate typically forms within the primary pore space (e.g. Clennell et al., 1999; Collett and Dallimore, 2005; Fujii et al., 2009). In fine-grained clay and silt sediment, gas hydrate is commonly found in a grain-displacing mode, clustering in nodules, forming veins and generating fractures (e.g. Clennell et al., 1999; Abegg et al., 2007; Collett et al., 2008; Ruppel et al., 2008), with nodules being the least frequently observed feature. Often gas hydrates in fine-grained sediments fill planar, secondary porosity features, which we refer to as “gas hydrate-filled fractures”. Other studies often refer to similar planar features as veins; here, however, we specifically define veins as elongate tubes similar in shape to a blood vessel.

Gas hydrate-filled fractures associated with seafloor methane vents or chimney structures are frequently discussed in the literature (e.g. Suess et al., 1999; Sassen et al., 2001; Claypool et al., 2006; Liu and Flemings, 2006, 2007; Riedel et al., 2010; Ghosh et al., 2010; Daigle and Dugan, 2011; Daigle et al., 2011). These vents and chimneys likely form by the hydraulic fracturing of marine sediment by overpressured gas. Fractures at vent and chimney sites may fill with hydrate at different rates depending on pore water salinity, water availability and gas supply. Such sites are easy to identify because of their unique signature in reflection seismic profiles, illuminating vertical gas and fluid flux through the sedimentary column (Wood et al., 2002; Shedd et al., 2012). Vent sites, however, may be easily identifiable but may not be the most common marine fractured gas hydrate reservoir.

Fracture formation and gas hydrate accumulation at non-vent sites is much less well understood, and unlike vent sites, these accumulations are not easily identifiable in reflection seismic profiles. Fine-grained gas hydrate reservoirs that are not associated with a seep or vent may be especially important for understanding the magnitude of the global gas hydrate reservoir and its importance in the global carbon cycle, because the majority of global natural gas hydrate most likely occurs within fine-grained marine sediments (Boswell and Collett, 2011). In this paper, we will primarily discuss geophysical and petrophysical characteristics of gas hydrate-filled fractures at non-vent/non-chimney marine sites. We compare results from two drilling expeditions – the Indian National Gas Hydrate Program Expedition 1, NGHP-01, and the Gulf of

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Mexico Gas Hydrate Joint Industry Project Legs I & II, JIP Leg I and JIP Leg II (Fig. 1).

2. Identifying hydrate-bearing intervals

High porosity water saturated fine-grained sediments from the top of the marine sediment column typically have resistivity values of ~1 Ωm, although this value can fluctuate due to variations in porosity, salinity, temperature, and pressure. The addition of gas hydrate to the system increases the measured resistivity. To determine which intervals in a sedimentary section are hydrate bearing, geophysical well log measurements of electrical resistivity and bulk density are acquired and analyzed (e.g. Collett, 2001; Fujii et al., 2009; Goldberg et al., 2010). Using electrical logs and other data from our study sites, we apply Archie's porosity–resistivity relationship (Archie, 1942) to identify which intervals of the log deviate from a predicted background water saturated resistivity, R_o.

$$R_o = \frac{aR_w}{\varphi^m} \quad (1)$$

The resistivity of the pore water, R_w is calculated using a combination of downhole temperature, pressure and salinity (Fofonoff

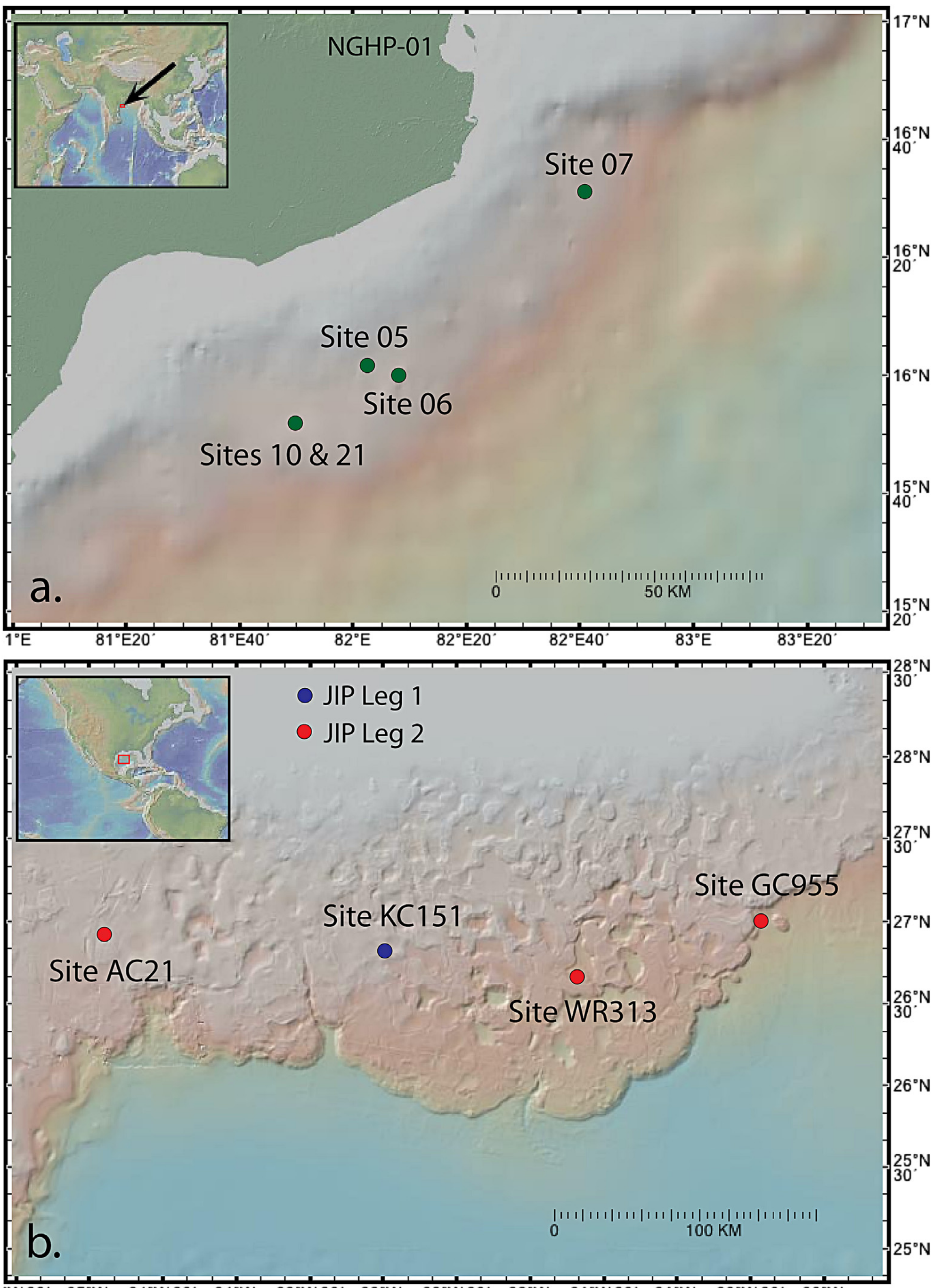

Figure 1. Drill site location map for a.) Indian National Gas Hydrate Program Expedition 01 (NGHP-01) and b.) the Gulf of Mexico Gas Hydrate Joint Industry Project, Leg I (JIP Leg I) and Leg II (JIP Leg II). This figure was generated using GeoMapApp (Ryan et al., 2009).