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Fracture orientation and induced anisotropy of gas hydrate-bearing sediments in seismic chimney-like-structures of the Ulleung Basin, East Sea

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ABSTRACT

During drilling in 2010 in the Ulleung Basin, East Sea, Logging-While-Drilling (LWD) was conducted for thirteen sites. LWD data shows various characteristics indicating presence of gas hydrate-bearing sediments. In particular, a series seismic chimney sites are characterized by anomalous log data (i.e. high resistivity and velocity values), compared to surrounding marine sediments. At chimney sites, the resistivity and velocity log values are over 200 Ω-m and 3000 m/s, respectively. Moreover, log values of low density (less than 1.1 g/cm^3) indicating the presence of massive hydrates also correlate with intervals with the highest resistivity and velocity. Gas hydrates at the seismic inferred chimney sites occurred within inclined fractures in the mud dominated sediments. These gas hydrate-filled fractures were identified on LWD resistivity images and X-ray images of pressure cores. The gas hydrate-filled fracture intervals coincide with high measured resistivity intervals at three sites (Sites UBGH2-3, UBGH2-7, UBGH2-11). In most cases, high measured resistivity translated into high hydrate saturations via Archie's relationship; but the high saturations derived from the Archie's relationship appear to overestimate gas hydrate saturations when compared to pressure core samples and acoustic log measurements. Also, in intervals with inclined gas hydrate-filled fractures (e.g., UBGH2-3), there is notable separation between phase-shift and attenuation resistivity logs, with 2 MHz resistivity measurements being significantly higher than 400 kHz resistivity measurements. In this study, the analysis of fractures with dip angles greater than 30° on the resistivity log-images show dip angles between 43 and 63° in average for the three sites examined. The dip azimuth of the fractures at Sites UBGH2-3 and UBGH2-7 dominate westerly to southwestern direction, while the fractures at Site UBGH2-11 are characterized by no preferred orientation. This fracture pattern indicates that maximum horizontal stress direction at the time of fracture formation was not constant. In addition, the differential compaction of the sediments after deposited may be contributed to the development of fracture.

1. Introduction

In 2010, the Gas Hydrate Research and Development Organization (GHDO) of Korea acquired Logging-While-Drilling (LWD) data for thirteen sites in the Ulleung Basin, East Sea. Subsequently the core samples for ten sites were also obtained. The program was named the Ulleung Basin Gas Hydrate Expedition 2, UBGH2. Gas hydrates were identified at most of the sites based on log data and core sample data. The goal of UBGH2 was to investigate the presence of gas hydrate as a potential energy resource in the Ulleung Basin.

Natural gas hydrates are a solid, ice-like materials composed of water molecules surrounding gas molecules. In recent years, gas hydrates have received attention because of their widespread occurrence in permafrost regions and oceanic margins and associated potential importance as an energy resources, seafloor stability related geohazard, and possible impact on global climate (Kvenvolden, 1993; Paul et al., 1991).

Downhole logs provide effective information for quantitative estimates and occurrence of gas hydrate (Collett and Ladd, 2000; Lee and Collett, 2012; Cook et al., 2008). Gas hydrates show relatively high acoustic velocity and resistivity values compared to

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water-saturated sediments (Tucholke et al., 1977). In the case of marine sediments, electrical resistivity changes reflect changes in porosity and fabric because the conduction of the electrical current passing through sediments depends on the porosity of the sediments. Thus electrical resistivity may be considered as an indicator for the presence of gas hydrates.

The presence of gas hydrate in the Ulleung Basin has been suggested based on the recognition of the bottom simulating reflector (BSR) on seismic profiles (Lee et al., 2005; Horozal et al., 2009; Ryu et al., 2009). The previous drilling during the Ulleung Basin Gas Hydrate Expedition1 (UBGH1) had confirmed the presence of abundant gas hydrate in the central part of the Ulleung Basin (Bahk et al., 2011; Chun et al., 2011; Kim et al., 2011).

During UBGH2, gas hydrate was discovered in high concentration in sandy sediments and as fracture-filling in fine-grained sediments. Fracture-filling gas hydrates mostly occurred into seismic chimney structures dominated by faults, fractures, and other high permeability conduits (Hornbach et al., 2004; Nimblett and Ruppel, 2003; Cook et al., 2008). Generally, the gas hydrate saturations of the fracture-filling gas hydrate using Archie (1942)'s relationship have been reported to be significantly overestimated (Cook and Goldberg, 2008; Cook et al., 2008; Kim et al., 2011; Lee and Collett, 2009; Collett et al., 2012).

In this paper, we examine log data from three chimney sites (UBGH2-3, UBGH2-7, UBGH2-11) in the Ulleung Basin, East Sea. We also estimate gas hydrate saturations within these chimney features from electrical resistivity and acoustic velocity. In addition, we investigate the dip and azimuth direction of fractures through fracture analysis from LWD resistivity (deep, medium, and shallow buttons) images and infer the distribution of fracture filling hydrates.

2. Geologic setting

The Ulleung Basin is characterized by a bowl-shaped back-arc basin (Fig. 1). The basin is bounded by the continental slope of the Korean Peninsula, the Korea Plateau, the Oki Bank, and the Japanese Arc. The relatively thick section of Neogene strata, uplifted and faulted by the back-arc closure, exists in the southern margin area. The central part of the basin has a fairly smooth seafloor and is underlain by an undeformed sedimentary section up to 5 km thick, while the acoustic basement in the southern part of the basin lies below ~10 km of sediments (Lee et al., 1999). The acoustic basement consists largely of volcanic materials and is covered by thick layers of volcanic sill/flow sediment complexes in the northern part of the basin (Lee and Suk, 1998).

Based on the previous studies (Tamaki et al., 1992; Chough et al., 2000), the opening of the East Sea was initiated by crustal thinning and rifting in the Early Oligocene, followed by seafloor spreading in the Late Oligocene. Thus, the Ulleung Basin was likely formed during Late Oligocene to Early Miocene by crustal extension associated with southward drift of the Japan Arc. At the end of the Middle Miocene, the tectonic regime changed from tensional to compressional. This process led to thrust faulting and folding in the southern and western margin of the basin and to the sediment compression and consolidation that probably has been responsible for the upward migration of gas-rich fluids and gas hydrate formation (Ryu et al., 2009).

The sedimentary processes in the Ulleung Basin are mainly characterized by mass flows or debris flows (Lee and Suk, 1998). During the latest Neogene, slope failures caused by the regional deformation due to the back-arc closure, resulted in widespread deposition of mass-transport deposits (MTDs). During the Pleistocene through Holocene, mass flow processes retreated rapidly

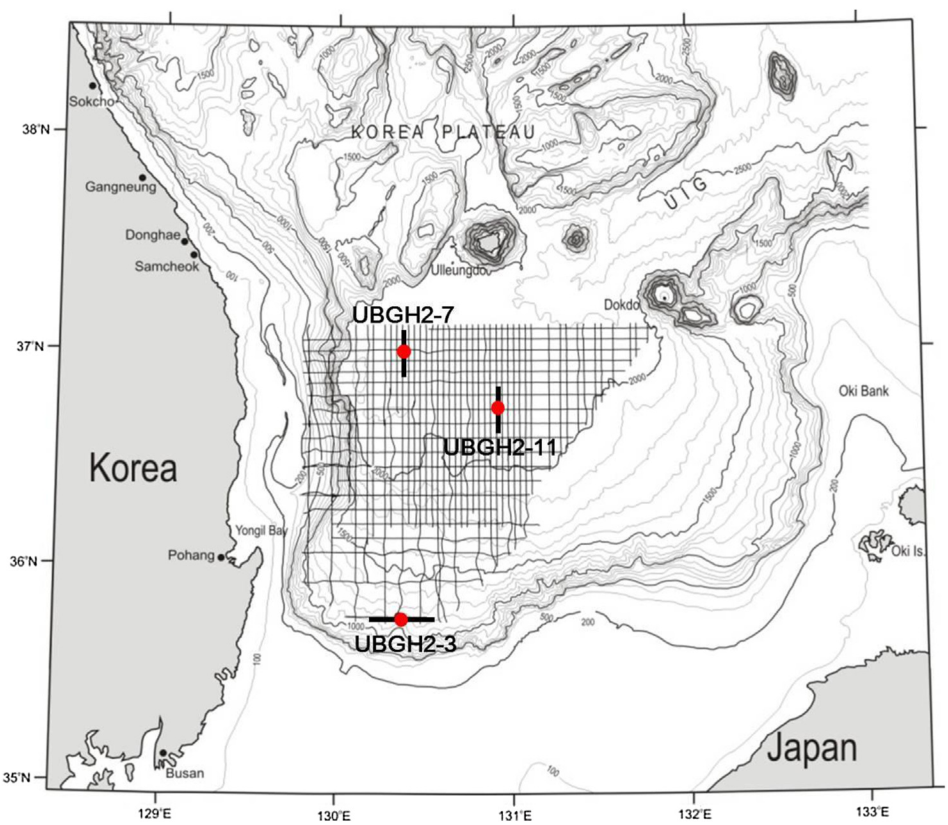

Figure 1. Location of the Ulleung Basin in the East Sea. Three sites drilled during UBGH2 are marked. The bars (not to scale) represent seismic track lines on the drill sites.