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Characteristics and interpretation of fracture-filled gas hydrate – An example from the Ulleung Basin, East Sea of Korea

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ABSTRACT

Through the use of 2-D and 3-D seismic data, a total of thirteen sites were selected and drilled in the East Sea of Korea in 2010. A suite of logging-while-drilling (LWD) logs was acquired at each site. LWD logs from the UBGH2-3A well indicate significant gas hydrate in clay-bearing sediments including several zones with massive gas hydrate with a bulk density less than 1.0 g/m^3 for depths between 5 and 103 m below the sea floor. The UBGH2-3A well was drilled on a seismically identified chimney structure with a mound feature at the sea floor. Average gas hydrate saturations estimated from the isotropic analysis of ring resistivity and P-wave velocity logs are 80 ± 13% and 47 ± 16%, respectively, whereas they are 46 ± 17% and 45 ± 16%, respectively from the anisotropic analysis. Modeling indicates that the upper part of chimney (between 5 and 45 m below sea floor [mbsf]) is characterized by gas hydrate filling near horizontal fractures (7° dip) and the lower part of chimney (between 45 and 103 mbsf) is characterized by gas hydrate filling high angle fractures on the basis of ring resistivity and P-wave velocity. The anisotropic analysis using P40H resistivity (phase shift resistivity at 32 mHz with 40 inch spacing) and the P-wave velocity yields a gas hydrate saturation of 46 ± 15% and 46 ± 15% respectively, similar to those estimated using ring resistivity and P-wave velocity, but with quite different fracture dip angles. Differences in vertical resolution, depth of investigation, and a finite fracture dimension relative to the tool separation appear to contribute to this discrepancy. Forward modeling of anisotropic resistivity and velocity are essential to identify gas hydrate in fractures and to estimate accurate gas hydrate amounts.

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1. Introdtion

In 2010, the Second Ulleung Basin Gas Hydrate Drilling Expedition (UBGH2), Korea, conducted logging-while-drilling (LWD) operations at 13 sites in the East Sea of Korea (Fig. 1A). These locations were selected primarily from the 2-D and 3-D seismic data. Primary scientific objectives of the drilling program were to collect information on the distribution and types of gas hydrate occurrences and to identify sites suitable for the initial production test (Ryu et al., 2013).

Resistivity and velocity well logs are often used to estimate gas hydrate saturations in sediments because of their elevated resistivity and velocities compared to those of water-wet sediments using appropriate rock physics models. For isotropic gas hydrate-bearing sediments (GHBS), currently available rock physics models such as the Archie equation (Archie, 1942) or connectivity equation (Montaron, 2009) for the resistivity and effective medium and Biot–Gassmann theories for the velocity (e.g., Ecker et al., 1998; Helgerud et al., 1999; Jakobsen et al., 2000; Lee, 2008; Lee and Waite, 2008) can be used to estimate gas hydrate saturation. However, for anisotropic gas hydrate occurrences, models based on the anisotropic resistivity and velocity should be used to accurately estimate gas hydrate saturation (Lee and Collett, 2009).

This paper presents a detailed analysis of gas hydrate saturations in fractured reservoirs in clay-bearing sediments at the UBGH2-3A well using anisotropic rock physics models. Site UBGH2-3A was selected to test a relatively large chimney feature and possible sea floor vent with a mound feature at the sea floor (Fig. 1B). To conduct appropriate anisotropic resistivity analysis, theories developed by Kennedy et al. (2001) and Kennedy and Herrick (2004) were used. For anisotropic velocity, a transverse isotropic theory for laminated media for gas hydrate (Lee, 2009; Lee and Collett, 2009) was used.

2. Well logs

The UBGH2-3A well is located at water depth of ∼898 m and a suite of good quality LWD logs was acquired. In this analysis, the

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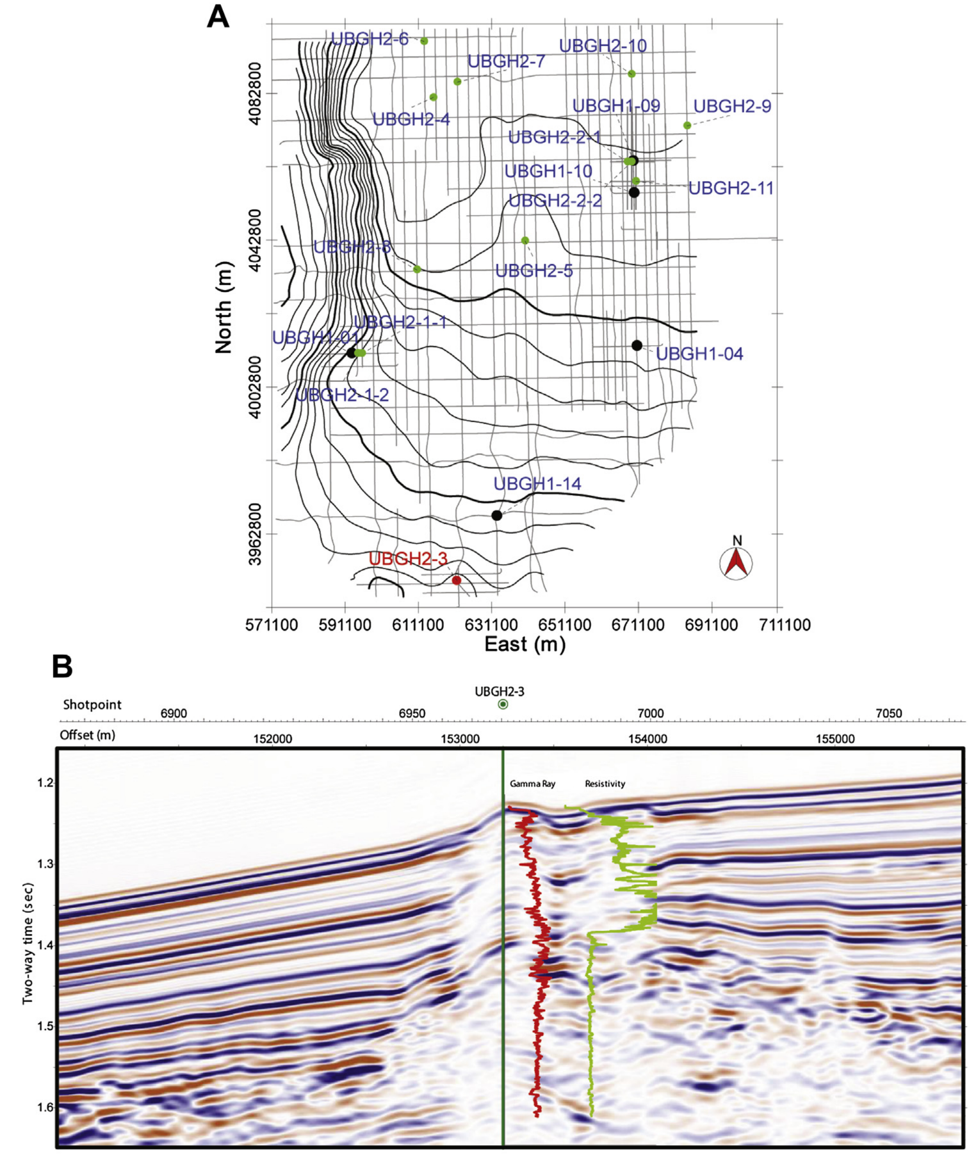

Figure 1. Location map of 13 drill sites (A) and a seismic profile intersecting the UBGH2-3A well (B).

caliper, gamma-ray, bulk density, resistivity, and compressional-wave (P-wave) velocity log data are used to assess the gas hydrate occurrence and saturations in the fractured reservoirs. Detailed LWD operations and bottom hole assembly were discussed in Ryu et al. (2013).

Resistivities were measured with different source-receiver configurations. In this analysis, ring resistivity, which measures resistivity along a horizontal plane, and P40H, which is the phase shift resistivity measured at 2 mHz with 40 inch spacing, were used to assess the effect of scale of measurement on the log analysis. The vertical resolution of ring resistivity and P40H measurements are 5–8 and about 30 cm, respectively and the depth of investigations are 18 and about 79 cm, respectively. On the other hand, the vertical resolution and depth of investigations for the P-wave velocity measured by the SonicVision tool are 61 and 10 cm, respectively (Mrozewski et al., 2009).

The caliper log was in-gauge for most of the hole with only significant washouts in the interval from the sea floor to 15 m below sea floor (mbsf). Because of the good borehole condition, good quality log data were acquired in this well. Clay volumes were calculated by a standard approach used for Tertiary clastics (Western Atlas International Inc, 1995).

The sediment porosities were derived using a grain density of 2.62 g/cm^3 and water density of 1.03 g/cm$^{3.}$ The grain density of 2.62 g/cm^3 is derived from the grain densities measured from the recovered core samples. The bulk densities range from less than 1.0 g/cm^3 in some places to the maximum is 1.87 g/cm^3. Low density less than 1.0 g/cm^3 indicates that the hole likely penetrated massive gas hydrate.

Because the bulk density is less than the density of water, porosity derived from the two-component system (water and grain) would be greater than 1.0. Therefore, the porosity should be corrected by accounting for the presence of gas hydrate as shown in Lee and Collett (2009).

The resistivity of the pore water was calculated using the Arp's formula (Arp, 1953) with the temperature given by $T = 0.68 + 0.11d$, where T is temperature in °C, d is mbsf, and a salinity of 35 ppt.

Logs used in this numerical analyses, namely gamma-ray, density porosity, ring resistivity, P40H resistivity, P-wave velocity, and the RAB (Resistivity-at-the-bit) image logs, are shown in Figure 2.