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Scale-dependent gas hydrate saturation estimates in sand reservoirs in the Ulleung Basin, East Sea of Korea

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ABSTRACT

Through the use of 2-D and 3-D seismic data, several gas hydrate prospects were identified in the Ulleung Basin, East Sea of Korea and thirteen drill sites were established and logging-while-drilling (LWD) data were acquired from each site in 2010. Sites UBGH2–6 and UBGH2–10 were selected to test a series of high amplitude seismic reflections, possibly from sand reservoirs. LWD logs from the UBGH2–6 well indicate that there are three significant sand reservoirs with varying thickness. Two upper sand reservoirs are water saturated and the lower thinly bedded sand reservoir contains gas hydrate with an average saturation of 13%, as estimated from the P-wave velocity. The well logs at the UBGH2–6 well clearly demonstrated the effect of scale-dependency on gas hydrate saturation estimates. Gas hydrate saturations estimated from the high resolution LWD acquired ring resistivity (vertical resolution of about 5–8 cm) reaches about 90% with an average saturation of 28%, whereas gas hydrate saturations estimated from the low resolution A40L resistivity (vertical resolution of about 120 cm) reaches about 25% with an average saturation of 11%. However, in the UBGH2–10 well, gas hydrate occupies a 5-m thick sand reservoir near 135 mbsf with a maximum saturation of about 60%. In the UBGH2–10 well, the average and a maximum saturation estimated from various well logging tools are comparable, because the bed thickness is larger than the vertical resolution of the various logging tools. High resolution wireline log data further document the role of scale-dependency on gas hydrate calculations.

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1. Introduction

In July 2010, the Second Ulleung Basin Gas Hydrate Drilling Expedition (UBGH2), conducted logging-while-drilling (LWD) operations at 13 sites in the East Sea of Korea. These locations were selected primarily from the 2-D and 3-D seismic data to test geological and geophysical interpretation methods of prospecting for gas hydrate-bearing sand reservoirs. 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 often are used to estimate gas hydrate saturations in sediments because of their elevated resistivity and velocities compared to those of water-saturated sediments using appropriate rock physics models (e.g., Guerin et al., 1999; Collett and Ladd, 2000). Gas hydrate in sand reservoirs generally exhibits isotropic physical properties (Lee and Collett, 2011). Therefore, for the analysis of isotropic gas hydrate-bearing sediments (GHBS), the 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 saturations.

This paper presents a detailed analysis of gas hydrate saturations in sand reservoirs at the UBGH2–6 and UBGH2–10 wells (Fig. 1A). Site UBGH2–6 well was selected to test a series of high amplitude seismic reflectors terminated against a normal fault just above the bottom simulating reflectors (BSR) (Fig. 1A). Site UBGH2–10 site was selected to test a seismic amplitude blanking zone within 20–40 m below seafloor (mbsf) and seismically imaged amplitude package at about 100 mbsf that possibly represent gas hydrate in a localized fan or channelized facies (Fig. 1B).

Many wells drilled during UBGH2 expedition targeted chimney structures, but the UBGH2–6 and UBGH2–10 wells are two of the four wells drilled into volcanoclastic and siliciclastic sand reservoirs (turbidite sand unit), which probably hold the greatest promise for the substantial gas hydrate occurrence and production in the Ulleung Basin. The purpose of this investigation is to accurately estimate gas hydrate saturations from various well logs and investigate the effect of the vertical resolution of the logging tool on

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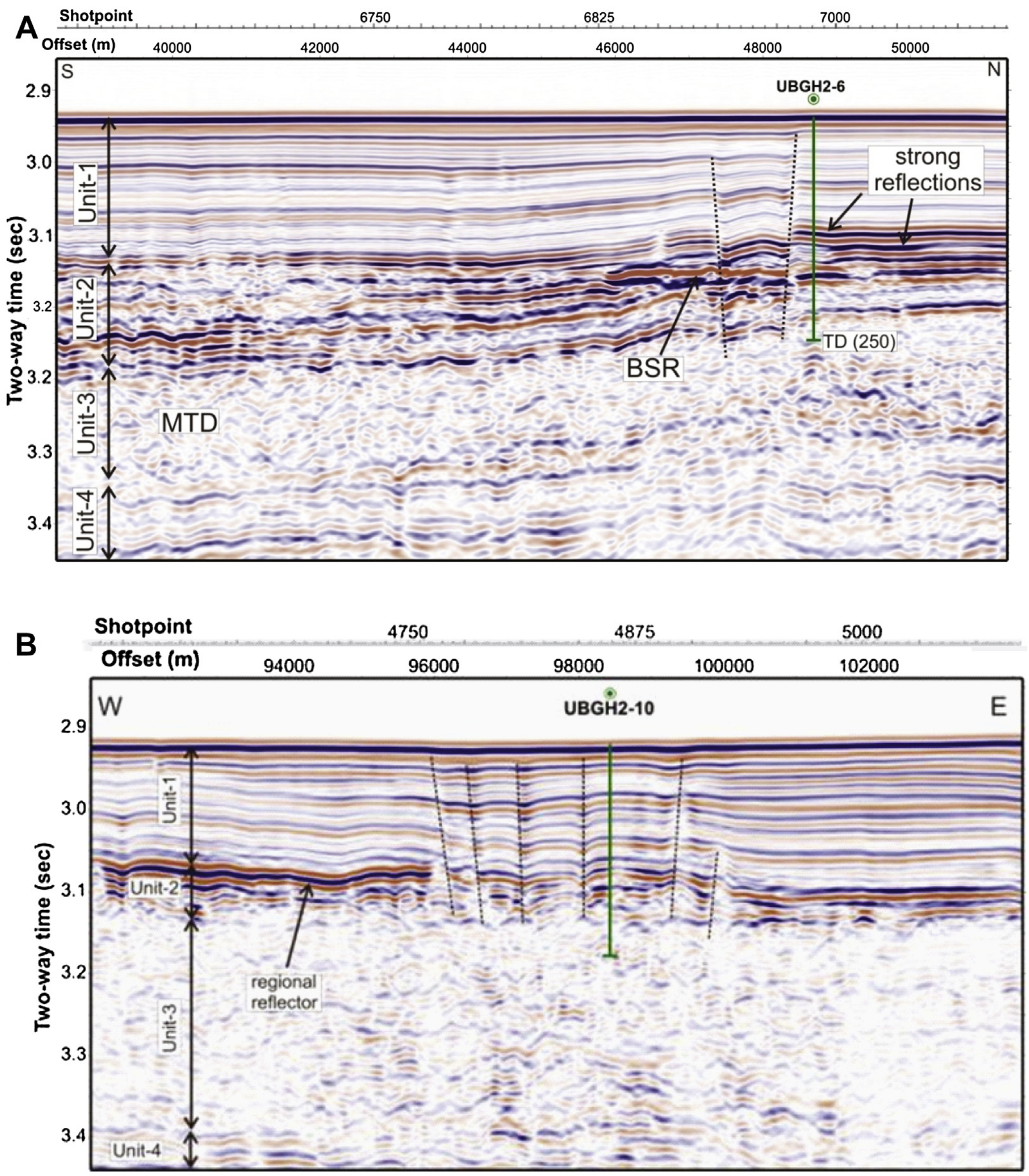

Figure 1. (A), section of N–S seismic profile intersecting the drill site UBGH2–6, East Sea, Korea. (B) Section of N–S seismic profile intersecting drill site UBGH2–10, East Sea, Korea. Four main seismo-stratigraphic units are identified and strong reflections that were the target of the drilling are shown. BSR; bottom simulating reflector. MTD; mass transport deposit.

the estimated gas hydrate saturations. For the resistivity analysis, a connectivity equation (Montaron, 2009; Lee, 2011) is used and for the P-wave velocity analysis, three-phase Biot-type equation (Lee, 2008; Lee and Waite, 2008) is used.

2. Well logs

The UBGH2–6 well (Fig. 1A) is located at water depth of ~2150 m and a suite of LWD logs was acquired using the Schlumberger tools at the UBGH2–6A well. In this analysis, the caliper, gamma-ray, bulk density, ring resistivity, P40L resistivity, A40L resistivity, and compressional-wave (P-wave) velocity log data are used to assess the gas hydrate occurrence and saturations in sand reservoirs at the UBGH2–6 site. The UBGH2–10 well (Fig. 1B) is located at water depth of ~2152 m and an identical suite of LWD logs was acquired and analyzed at the UBGH2–10A well. Detailed LWD operations and bottom hole assembly are discussed in Ryu et al. (2013).

At these two sites, wireline logs were also acquired in second wells about 10 m from each of the LWD wells (UBGH2–6B, and UBGH2–10D). Deep resistivity and P-wave velocities were acquired using Fugro logging tools and were used to compare the gas hydrate saturations estimated from the LWD logs.

LWD resistivities were measured with different source-receiver configurations. In this analysis, ring resistivity, which measures resistivity along a horizontal plane; P40L, which is the phase shift resistivity measured at 0.4 MHz with 40 inch spacing; and A40L, which is the attenuation resistivity measured at 0.4 MHz with 40 inch spacing, were used to investigate the scale-dependent gas hydrate saturations. The vertical resolutions of ring resistivity, phase shift, and attenuation resistivity are 5–8, 21–30, and 55–122 cm, respectively (Mrozewski et al., 2009) and the depth of investigations are 18, 33–79, and 48–102 cm, respectively. Because the vertical resolution of the resistivity tool depends on the measurement type (phase shift or attenuation) as well as source–receiver spacing, the vertical resolution for P40L and A40L are