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Gas hydrate saturation from acoustic impedance and resistivity logs in the Shenhu area, South China Sea

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ABSTRACT

During the China's first gas hydrate drilling expedition -1 (GMGS-1), gas hydrate was discovered in layers ranging from 10 to 25 m above the base of gas hydrate stability zone in the Shenhu area, South China Sea. Water chemistry, electrical resistivity logs, and acoustic impedance were used to estimate gas hydrate saturations. Gas hydrate saturations estimated from the chloride concentrations range from 0 to 43% of the pore space. The higher gas hydrate saturations were present in the depth from 152 to 177 m at site SH7 and from 190 to 225 m at site SH2, respectively. Gas hydrate saturations estimated from the resistivity using Archie equation have similar trends to those from chloride concentrations. To examine the variability of gas hydrate saturations away from the wells, acoustic impedances calculated from the 3 D seismic data using constrained sparse inversion method were used. Well logs acquired at site SH7 were incorporated into the inversion by establishing a relation between the water-filled porosity, calculated using gas hydrate saturations estimated from the resistivity logs, and the acoustic impedance, calculated from density and velocity logs. Gas hydrate saturations estimated from acoustic impedance of seismic data are ∼10–23% of the pore space and are comparable to those estimated from the well logs. The uncertainties in estimated gas hydrate saturations from seismic acoustic impedances were mainly from uncertainties associated with inverted acoustic impedance, the empirical relation between the water-filled porosities and acoustic impedances, and assumed background resistivity.

1. Introduction

Gas hydrates are solid, ice-like substances and composed of water and natural gas (mainly methane), which form under conditions of low temperature, high pressure and proper gas concentration (Kvenvolden, 1993). Since 1999, high-resolution multichannel seismic surveys and three-dimensional seismic survey have been carried out for gas hydrate resource studies in the northern South China Sea. BSRs have been identified in the Xisha Trough (Wu et al., 2005), Qiongdongnan Basin (Wang et al., 2010), in Pearl River Mouth basin (Guo et al., 2004) and in the Taixinan Basin of the northern South China Sea (Wu et al., 2007; Zhang et al., 2002; Wang et al., 2006). In April–June of 2007, eight sites were drilled by the Guangzhou Marine Geological Survey (GMGS), China Geological Survey (CGS), and the Ministry of Land and Resources of China by using M/V Bavenit along with Fugro and Geotek equipments in Shenhu area, Pearl River Mouth basin, the northern of SCS (Zhang et al., 2007; See Fig. 1). Downhole wireline logs were acquired at each site. Conventional wireline piston cores and pressure cores were used to recover samples at five borehole sites as SH3, SH1, SH2, SH7, and SH5. The sites, SH6, SH9, and SH4, were not sampled because they were considered to contain little or no gas hydrate after the analysis of wireline log data (Yang et al., 2008; See Fig. 1). The sediments were inferred to be gas hydrate-bearing from pore water freshening and pressure core degassing at sites SH2, SH3 and SH7 in silt and silty-clay sediments. The distribution of gas hydrate within the sediment column and at the grain scale is in a relatively homogenous layer, directly above the base of gas hydrate stability.

Gas hydrate saturations were calculated using downhole log measurements of electrical resistivity and compressional velocity. Gas hydrate was found in depths from 196 to 206 m below seafloor (mbsf), with a maximum gas hydrate saturation of 25% of pore space estimated from pore water freshening at Site SH3. A 25-m-thick

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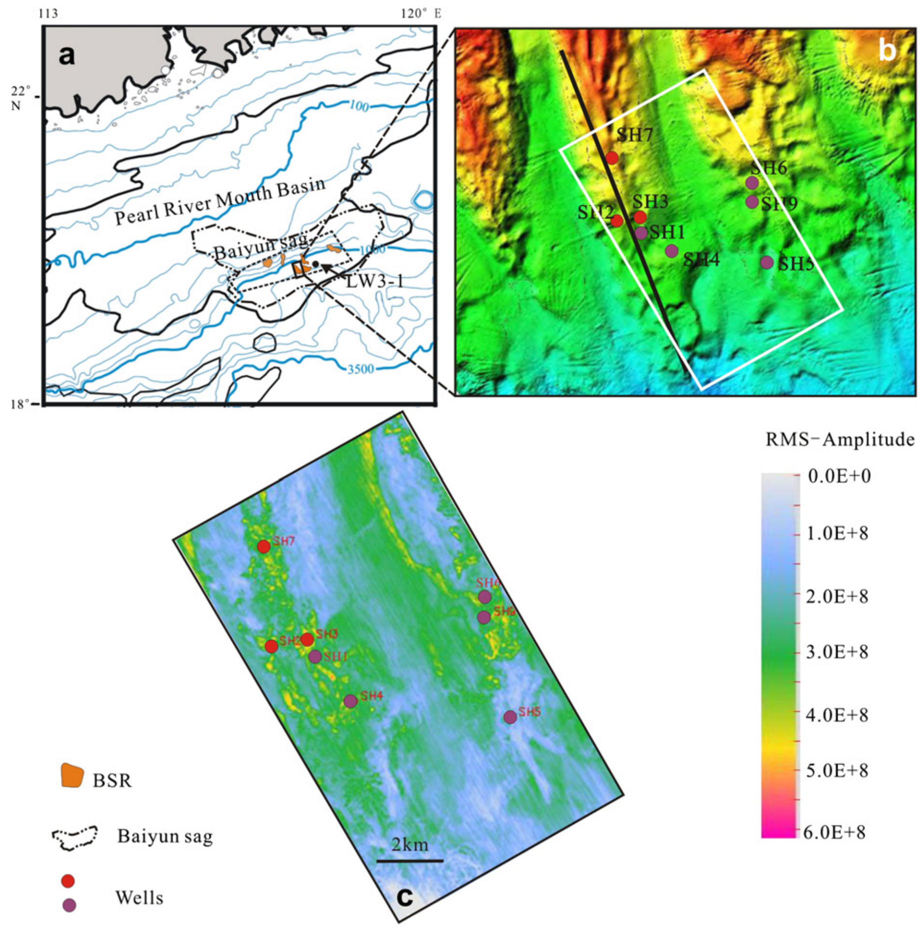

Figure 1. (a) Areas of gas hydrate exploration in the Baiyun sag, the Pearl River Mouth Basin, northern part of the South China Sea and BSR identified from 2D and 3D seismic data; (b) Bathymetric map of drilling area with sites drilled during GMGS-1, red dots show cored samples with gas hydrate and dark purple dots show cored samples with no gas hydrate; Black line shows seismic line across sites SH2 and SH7; (c) Root-mean-square (RMS) amplitude map calculated for the shaded zone of Figure 8a and the white rectangle zone in Figure 1b. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

layer of gas-hydrate-bearing sediment was identified at the depth of 195–220 mbsf at Site SH2. The average gas hydrate saturation is about 25% of pore space in this interval and with a maximum value of 47% of pore space. At Site SH7, gas-hydrate-bearing sediment was found at the depth of 152–177 mbsf and had a maximum saturation of 43% of the pore space (Yang et al., 2008). Gas hydrate saturation at site SH2 was calculated using resistivity based on Archie equation (1942) and low gas hydrate saturation was identified in the depth above 195 mbsf (Wang et al., 2011). Gas hydrate saturations estimated from borehole logging data indicate the heterogeneous distribution of gas hydrate vertically and laterally.

In addition to gas hydrate saturations estimated from downhole logs, various theoretical and semiempirical models were proposed to estimate gas hydrate saturation from the acoustic velocity such as those of Wood et al. (1994), Wyllie et al.'s time average equation (1958), effective medium theory (Helgerud et al., 1999). Full waveform pre-stack inversion was applied to calculate P-velocity, S-velocity and density in the Gulf of Mexico and gas hydrate saturation was estimated from P-impedance (product of velocity and bulk density) using rock physics model (Dai et al., 2004, 2008). Seismic P-wave and S-wave velocities of high-resolution seismic data were used to estimate gas hydrate saturations from ray tracing inversion and 1D waveform inversion (Westbrook et al., 2008). P-wave velocities computed by reflection tomography applied to multi-component ocean-bottom seismometer data were used to estimate gas hydrate and free gas saturation based on a Biot-type approach (Carcione et al., 2005). The acoustic impedance of seismic data is inverted using constrained sparse spike inversion in Blake Ridge (Lu and McMechan, 2002) and South China Sea (Wang et al., 2006). Gas hydrate saturation from seismic profile was calculated from water-filled porosity using Archie's parameters, the resistivity of the fully water-saturated formation and the pore water resistivity. Elastic impedance inversion of multichannel seismic data were used to estimate the elastic properties of sediments containing gas hydrate from angle dependent P-wave reflections (Lu and McMechan, 2004) and pre-stack seismic data (Shelander et al., 2010). The acoustic impedance inversion of 3D seismic data, log to seismic correction and seismic attribute analyses were combined to delineate gas hydrate zone in the Mallik site, Mackenzie Delta, Northwest Territories, Canada (Riedel et al., 2009).

In our case study, our main objective is to use borehole data from GMGS-1 to estimate gas hydrate saturation and to use acoustic impedance inverted from seismic data to investigate the lateral distribution of gas hydrate away from the wells. We developed empirical relations between acoustic impedance and water-filled porosity from well logs to relate acoustic impedances to the gas hydrate saturation.

2. Geologic setting

The seismic survey and drilling expedition of gas hydrate located in the Baiyun sag, PRM basin of the northern slope of South