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Research paper

Physical properties and sedimentological features of hydrate-bearing samples recovered from the first gas hydrate production test site on Daini-Atsumi Knoll around eastern Nankai Trough

Kiyofumi Suzuki [a,*], Peter Schultheiss [b], Yoshihiro Nakatsuka [a], Takuma Ito [c,1], Kosuke Egawa [c,2], Melanie Holland [b], Koji Yamamoto [a]

[a] Methane Hydrate Research & Development Group, Japan Oil, Gas and Metals National Corporation (JOGMEC), 1-2-2, Hamada, Mihama-Ku, Chiba-City, Chiba 261-0025, Japan
[b] Geotek Ltd., 4 Sopwith Way, Daventry NN11 8PB, UK
[c] Methane Hydrate Research Center, National Institute of Advanced Industrial Science and Technology (AIST), Sapporo 062-8517, Japan

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ABSTRACT

Before producing gas from gas hydrate, it is important to clarify the physical properties of the methane hydrate reservoir and its sediments. During the 2012 pressure coring campaign, pressure core samples were retrieved from the northwest slope of Daini-Atsumi Knoll, one of the outer ridges of fore-arc basins along the northeast the Nankai-Trough. The pressure cores were sampled continuously throughout the turbidite sequences in the Methane Hydrate Concentrated Zone (MHCZ); the cores were subjected to onboard nondestructive property analyses, and X-ray Computed Tomography (X-ray CT) images of the cores were collected. Internal structures of the cores were observed in the X-ray images, which were used to judge core quality. Results for P-wave velocities and bulk densities, which were also measured on the pressure cores aboard the ship were compared with data from logging-while-drilling (LWD).

P-wave velocities of cores that were retrieved by pressure corer were compared with methane-hydrate saturations calculated from several methods. In general, P-wave velocities from logging while drilling (LWD) measurements corresponded to gas hydrate saturation calculated from LWD. After compensating for the different vertical resolutions of LWD tools and pressure core analysis, P-wave velocities from the pressure cores corresponded well to methane hydrate saturation calculated from logging. A unique interval at 290–300 m below seafloor was identified where methane hydrate saturations computed from LWD data did not correspond to P-wave anomalies measured in cores from the same interval. This difference could be due to lateral inhomogeneity in lithology between the logging and coring wells, with distinct local hydrate crystallization/precipitation environments.

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1. Introduction

Gas hydrates consist of guest gas molecules trapped in cages of water molecules, and such hydrates form in unconsolidated sediments at high pressures and low temperatures. Development of gas-hydrate resources has been difficult because of the lack of information about the complex properties of gas-hydrate-bearing unconsolidated sediments. Without pressure-coring tools, it is difficult to sample hydrate-bearing sediments without changing their properties.

Many attempts have been made to retrieve cores without causing dissociation of the gas-hydrate. During the 2004 drilling campaign at Nankai Trough, JOGMEC used a pressure-coring tool, called the Pressure Temperature Core Sampler (PTCS) for analyses (Fujii et al., 2010). Core recovery greater than 70% was achieved by the PTCS, but because it was a stand-alone pressure-coring device, every gas-hydrate core sample was depressurized on the drilling vessel and stored in a liquid nitrogen Dewar for onshore analysis.

Over the last decade, several kinds of pressure-coring tools have been developed, including a system for performing analyses under

* Corresponding author.
E-mail address: suzuki-kiyofumi@jogmec.go.jp (K. Suzuki).
[1] Present address: CO_2 Storage Research Group, Research Institute of Innovative Technology for the Earth (RITE), Kyoto 619-0292, Japan.
[2] Present address: Subsurface Evaluation Unit, Technical Division, INPEX Corporation, Tokyo 107-6332, Japan.

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pressure. Those tools have been tested on sediments containing gas-hydrates (e.g. Schultheiss et al., 2006, 2008; Abegg et al., 2008). We sampled gas hydrate using pressure-coring tools during the 2012 Nankai Trough campaign prior to the 2013 Nankai Trough gas-hydrate reservoir gas production test. The tool we used is the Hybrid-PCS (Pressure Coring System), which was developed by JAMSTEC and JOGMEC in collaboration with Aumann and Associates (Kubo et al., 2014). This tool worked successfully, and many samples were recovered from the test site (Yamamoto, 2015).

In this study, we describe the properties of gas-hydrate-bearing sediments obtained by pressure coring analyses. To characterize the gas-hydrate reservoir at the eastern Nankai Trough forearc sedimentary basin, we compared P-wave velocity and methane-hydrate saturation obtained from logging data and pressure cores.

2. Geological setting

The Daini-Atsumi Knoll is an outer ridge of the fore-arc basin along the northeast Nankai Trough (Fig. 1). The landward slope of the Daini-Atsumi knoll is covered with turbidite sediments. On the basis of seismic data, turbidite sediments at the Daini-Atsumi Knoll were interpreted as channel and lobe environments of a submarine fan by seismic data (Takano et al., 2009, 2013; Noguchi et al., 2011). Strong seismic anomalies obtained at ~300 m below seafloor (mbsf) have been identified as a gas-hydrate reservoir (Fujii et al., 2015). The age of the slope sediments is not certain, but the age of the gas hydrate-reservoir is probably between 0.45 and 0.85 Ma (Egawa et al., 2015). The gas hydrates in this area are described as the pore-filling type (e.g. Matsumoto et al., 2004; Tsuji et al., 2004; Uchida et al., 2004), in which the pore spaces in sandy sediments are occupied by gas hydrate-crystals. Gas hydrate veins and layers in mud sediments have not been confirmed around the Daini-Atsumi Knoll. Studies of this area show that the guest gas in the gas hydrates is mainly biogenic methane (Kida et al., 2009). Hereafter in this study, we use the term methane hydrate rather than gas hydrate, because phase equilibrium conditions differ for different guest gases in hydrates. Temperatures around the reservoir depth (275–337 mbsf) were 13–14 °C (Kanno et al., 2014).

3. Pressure core operations

3.1. Coring well setting

A coring well, AT1-C, was drilled 40 m northeast of the LWD well (AT1-MC); however, at the reservoir depth, the distance between two wells was 20 m because AT1-MC was inclined toward AT1-C. The orientation of the two wells was determined on the based of the direction of an estimated feeder channel of reservoir sediments (Tamaki et al., 2015).

On the basis of data obtained from the LWD analysis in borehole AT1-MC (water depth 997.7 m), where the MHCZ lies between 275 and 337 mbsf, it was decided to core the interval 260–320 mbsf at the nearby AT1-C borehole (water depth: 998.7 m). AT1-C penetrated 60 m into the methane-hydrate reservoir, and ~37 m of reservoir sediments were sampled. We performed 18 runs using the Hybrid-PCS and three runs using unpressurized coring tools. The coring interval at AT1-C consisted of a silt-dominated zone, followed by alternations of thin sands and muds, with increasing thicknesses of sand layers towards the bottom of the section. Methane-hydrate bearing cores were sampled from sandy layers of these alternating units.

Our drilling campaign was conducted during June–July 2012, and temperatures on the drill floor were high enough to dissociate methane hydrate within the pressure cores even though they were maintained at the in-situ pressure. To prevent dissociation, each retrieved corer was immediately placed in a vertical ice bath using a mouse hole near the rig floor, and into a horizontal ice bath as necessary during removal of the Hybrid PCS autoclave (the portion of the corer containing the core under pressure). The autoclaves were maintained at controlled temperatures in ice baths prior to transfer to the pressure core analysis and transfer system (PCATS; Schultheiss et al., 2006, 2008, 2011). To preserve the methane-hydrate-bearing reservoir sediments, we controlled the temperature between 0 and 10 °C. The controlled temperature was below the reservoir temperatures (14 °C) but not so low that water in the samples would freeze.

3.2. Results of pressure coring

During the drilling campaign, 21 successful pressure coring deployments were completed (Yamamoto, 2015). The table in Figure 2 lists all cores retrieved during the 2012 drilling campaign at Nankai Trough. We chose eight pressure core samples and stored them for further analyses onshore. After initial X-ray observations and nondestructive tests were conducted under pressure, the other cores collected with the Hybrid PCS were treated as unpressurized cores. These cores, which are labeled as "C-cores" in Figure 2 (Workflow column), were depressurized and analyzed on the drilling vessel (Komatsu et al., 2015).

The "P-core" cores to be kept under pressure were chosen to represent the sediments throughout the MHCZ. Cores AT1-C-8P,

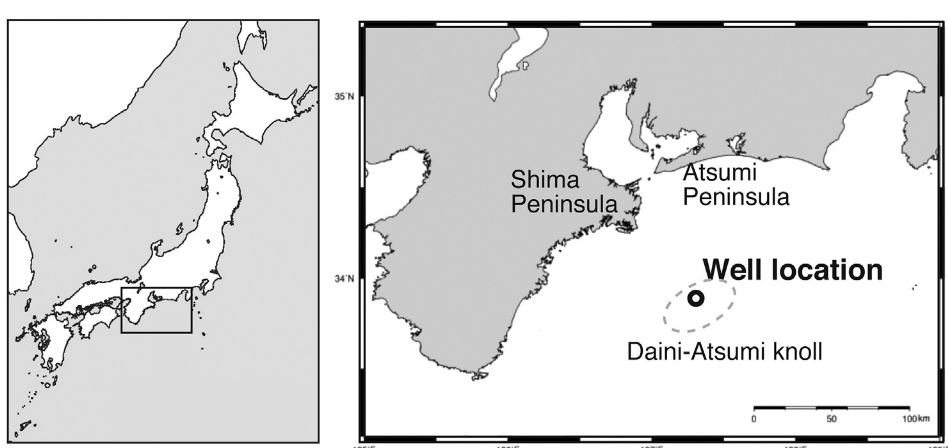

Figure 1. Well location of this study.

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