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Research paper

Geological setting and characterization of a methane hydrate reservoir distributed at the first offshore production test site on the Daini-Atsumi Knoll in the eastern Nankai Trough, Japan

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ABSTRACT

To obtain basic information for methane hydrate (MH) reservoir characterization at the first offshore production test site (AT1) located on the northwestern slope of the Daini-Atsumi Knoll in the eastern Nankai Trough, extensive geophysical logging and pressure coring using a hybrid pressure coring system were conducted in 2012 at a monitoring well (AT1-MC) and a coring well (AT1-C). The MH-concentrated zone (MHCZ), which was confirmed by geophysical logging at AT1-MC, has a 60-m-thick turbidite assemblage with sublayers ranging from a few tens to hundreds of centimeters thickness. The turbidite assemblage is composed of lobe/sheet-type sequences in the upper part and relatively thick channel-sand sequences in the lower part. Well-to-well correlations of sandy layers between two monitoring wells within 40 m of one another exhibited fairly good lateral continuity of sand layers in the upper part of the reservoir. This suggests an ideal reservoir for the production test.

The validity of MH pore saturation (S_h) evaluated from geophysical logging data were confirmed by comparing with those evaluated by pressure core analysis. In the upper part of the MHCZ, S_h values estimated from resistivity logs showed distinct differences between the sand and mud layers, compared with S_h values from nuclear magnetic resonance (NMR) logs. Resistivity logs have higher vertical resolution than NMR logs; therefore, they are favorable for these types of thin-bed evaluations. In the upper part, S_h values of 50%–80% were observed in sandy layers, which is in fairly good agreement with core-derived S_h values. In the lower part of the MHCZ, S_h values estimated from both resistivity and NMR logs showed higher background values and relatively smoother curves than those for the upper part. In the lower part, S_h values of 50%–80% were also observed in sandy layers, and they showed good agreement with the core-derived S_h values.

1. Introduction

Since 1996, the Japanese Ministry of Economy, Trade and Industry (METI) has been intensively conducting exploratory surveys of methane hydrates (MHs) in the eastern Nankai Trough; this area has been chosen as a model for MH surveys (Fig. 1). On the basis of the results from the Ministry of International Trade and Industry (MITI) obtained for "Nankai Trough" wells in 1999 (Tsuji et al., 2004) and METI "Tokai-oki to Kumano-nada" exploratory test wells in 2004 (Takahashi and Tsuji, 2005; Tsuji et al., 2009; Fujii et al., 2009), MH-bearing sand-rich intervals (i.e., sand pore-filling-type MHs) have been identified in turbidite fan deposits of the eastern Nankai Trough.

On the basis of the analyses of the aforementioned well data together with 2D/3D seismic survey data acquired in 1996, 2001, and 2002, we identified more than ten prospective MH-concentrated zones (MHCZs) in this area (Saeki et al., 2008). Resource assessments of the methane gas within MHs were performed using a probabilistic approach (Fujii et al., 2008). The total amount of methane gas contained in the MHs within the survey

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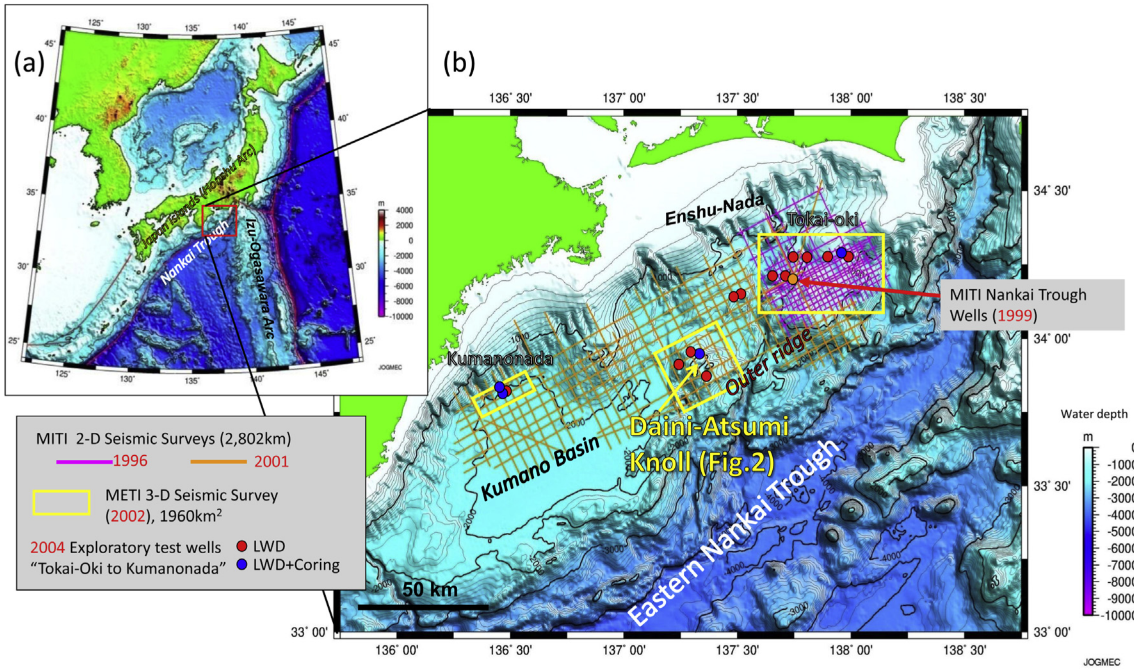

Figure 1. Map showing the history of methane hydrate exploration surveys in the eastern Nankai Trough (1996–2004) and the location of this study area, Daini-Atsumi Knoll (modified from Fujii et al., 2009).

area was estimated at a mean value of 40 trillion cubic feet (Tcf) (equal to 1.1 trillion cubic meter). The total gas in place for the MHCZ was estimated at a mean value of 20 Tcf, which is half the total amount and equal to 0.57 trillion cubic meter. Chemical composition and carbon isotope analyses of methane gas derived from MH-bearing core samples from this area prove that more than 99% is methane, and most of the methane gas is of microbial origin (Uchida et al., 2009; Kida et al., 2015).

Among the interpreted MHCZs mentioned above, the β-MHCZ at the Daini-Astumi Knoll (Fig. 2) was selected to be the test site for the first offshore production, which was performed from 2012 to 2013. This selection was based on water depth, existing well controls, pressure–temperature conditions of reservoir formation (depth from seafloor), the characteristics of MH-bearing layers, and the existence of sealing layers (mud-rich layers with sealing capacity) above them (Fujii et al., 2013).

The main objective of the first production test was to understand the behavior of MH dissociation in an in-situ condition. The final goal was to verify the feasibility of using the "depressurization technique" as a commercial gas-production method from offshore MH-bearing sediments (Yamamoto et al., 2012a). In March 2013, the world's first offshore production test from MH bearing layers was conducted at the site; the cumulative volume of gas produced during the six-day test was approximately 120,000 m^3 (at atmospheric pressure). The rate of gas production was approximately 20,000 m^3/day (Yamamoto et al., 2014).

An integrated reservoir characterization and an analysis of production and monitoring data are required to better understand the formation response and the process of MH dissociation during the flow test. In order to identify dissociation layers and the dissociation front by the test, understanding the initial condition of reservoir properties are very critical. In this study, we first describe the general geology of the study area, then we focus on MH-bearing reservoir characterization based on seismic and geophysical well-logging data. Specifically, we focus on the occurrence and physical properties of MH-bearing layers confirmed from seismic, geophysical logging, and coring data, which will be the basic information for the interpretation of the production/monitoring data.

2. Geologic setting in the β-MH-concentrated zone

Our study area is located in the Tokai–Kumano forearc basins along the eastern Nankai Trough, central Japan (Fig. 1). The tectonic setting of the eastern Nankai Trough is strongly influenced by a collision between the Izu-Ogasawara and Honshu arcs (Fig. 1a). The Daini-Atsumi Knoll, off Enshu-Nada, is part of the ENE–WSW trending outer ridge (Fig. 1b), which corresponds to the boundary between the accretionary prism and the forearc basin (Ashi et al., 2004). In this area, the Plio-Pleistocene Kakegawa and Ogasa Groups have thicknesses of several kilometers (Takano et al., 2009).

The β-MHCZ is located on the northwestern slope of the Daini-Atsumi Knoll (Fig. 2). An outline of the β-MHCZ, as interpreted from 3D seismic data, is shown by the pink line in Figure 2; the area is approximately 12 km^2, and the water depth ranges from 857 to 1405 m. The β-MHCZ was discovered by geophysical logging and coring at the β1 well, which was drilled in 2004 (Fujii et al., 2009). The MHCZ has a thickness of several tens of meters and is confirmed to mainly contain turbidite channel-type sediments within a submarine fan system in the Ogasa Group; its age ranges from middle-to-late Pleistocene (Fujii et al., 2009; Noguchi et al., 2011). On the basis of the evaluations using the oxygen isotope ratios of foraminiferal shells and volcanic ash analysis of core samples, the geological age of the MHCZ at the β1site ranges from 0.7 to 0.25 Ma (Yamasaki et al., 2011, 2012). From coccolith assemblies, the depositional ages of sediment cores range from 0.85 to 0.45 Ma (Egawa et al., 2015), which is in good agreement with that from the oxygen isotope ratio of foraminiferal shells.

Figure 3 shows representative seismic sections from β-MHCZ. Figure 3a is a cross section from NW to SE, which is the direction of the formation dip. On the basis of the interpretations of formation resistivity image logs, the formation dip of the MHCZ is about 20° at the β1 and AT1 sites. Figure 3b shows a cross section from NW to