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Research paper

Sedimentary facies and paleoenvironments of a gas-hydrate-bearing sediment core in the eastern Nankai Trough, Japan

Yuhei Komatsu*, Kiyofumi Suzuki, Tetsuya Fujii

Japan Oil, Gas and Metals National Corporation, Technology Research Center 1-2-2, Hamada, Mihama-ku, Chiba 261-0025, Japan

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ABSTRACT

From June to July 2012, the Ministry of Economy, Trade and Industry completed a pressure core-sampling well (AT1-C) for determining reservoir properties at the first offshore methane hydrate production test site on the north slope of the Daini–Atsumi Knoll off the Atsumi and Shima peninsulas. Coring through the targeted gas-hydrate-bearing reservoir was completed using the hybrid pressure coring system and the extended shoe coring system. The coring program achieved 61% recovery through 60 m of the hole. The recovered core consists of alternating clayey to sandy siltstones and very fine to fine sandstones. The stratigraphic pattern indicates upward thinning of the sand layer. Grain-size distributions indicate that the transition to mud facies is marked by an increase in fine particles and more poorly sorted sediments. Sedimentary structures and bioturbation characteristic of conventional cores are absent in the pressure cores due to the effects of fluidization attributed to the release of water from dissociation of gas hydrates. The core sediments were subdivided into four facies: Facies 1 (hemipelagic setting or slope) structureless silt; Facies 2 (abandonment surface mud drape) silt-dominated alternating beds of sand and silt; Facies 3 (non-amalgamated channel deposit) proportionally interbedded sand and silt; and Facies 4 (semi-amalgamated channel deposit) sand-dominated, with alternating beds of sand and silt. The results aid the interpretation of subsurface data and to quantitatively constrain geological models, thereby reducing uncertainties in the development of reservoirs.

1. Introduction

Gas hydrate is a naturally occurring, ice-like, crystalline substance formed by water and gas molecules (mainly methane) at low temperature and high pressure (Milkov and Sassen, 2001). Gas hydrates have been identified along many continental margins and in permafrost regions and are gradually becoming recognized as a potential source of energy for the coming decades.

The eastern Nankai Trough, located offshore of central Japan, is considered to be an attractive potential resource-rich area of gas hydrates (Fujii et al., 2008; Yamamoto et al., 2010). In this area, bottom simulating reflectors (BSRs) have been widely observed and interpreted as representing lower boundaries of gas-hydrate-bearing deposits (Aoki et al., 1983; Ashi et al., 2002; Hayashi et al., 2010). Previous studies reported that gas hydrate has developed in the pore spaces of unconsolidated sandy sediments within the deep submarine fan system (Nakamizu et al., 2004; Takahashi et al., 2001; Tsuji et al., 2004; Uchida et al., 2004). In some locations in the eastern Nankai Trough, gas hydrate has selectively accumulated in turbidite sediments (Fujii et al., 2008, 2009). According to 2D/3D seismic surveys, 16 concentrated zones have been found in the eastern Nankai Trough survey area. Using a combination of 3D seismic and well data, Noguchi et al. (2011) evaluated the reservoir architectures of gas-hydrate-bearing turbidite channels in one concentrated zone.

Reservoir engineering studies, such as history matching and prediction of performances by using production test results, require fine-scale geological model to evaluate the gas hydrate dissociation behavior in each thin sand bed. The fine-scale geological model should contain detailed information about lithology and sedimentology associated with petrophysical properties obtained from core samples. In contrast to 3D seismic and physical log data, core samples could provide high-resolution geological information that that 3D and logging are unable to. In some cases, 3D seismic and physical log data may not exactly reflect the lithofacies of reservoirs because of the poor resolution of BSRs and borehole damage,

* Corresponding author. Tel.: +81 43 276 9289; fax: +81 43 276 4062.
E-mail address: komatsu-yuhei@jogmec.go.jp (Y. Komatsu).

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respectively. Previous studies included relatively little detailed sedimentological analyses of core samples at the reservoir scale.

To obtain data an understanding reservoir properties at the first offshore production test site, pressure core-sampling operations were conducted from June to July 2012 (Fujii et al., 2015). In this paper, we show that sedimentary facies and paleoenvironments identified from core samples have important implications for the interpretation of reservoir properties. This paper provides a regional case study that contributes to characterizing reservoir heterogeneity in terms of depositional architectures. The results will be used to aid in the interpretation of subsurface data and to quantitatively constrain geological models, thereby reducing uncertainties in plans for the development of reservoirs.

2. Geological setting

The study area is located in the Tokai–Kumano forearc basins along the 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. A large number of active faults have been identified by the KAIKO–Tokai survey (Research Group for Active Submarine Faults off Tokai, 1999; Soh and Tokuyama, 2002). The stratigraphy of the forearc basin of the eastern Nankai Trough comprises the Late Pliocene to Early Pleistocene Kakegawa Group (Atsumi-oki Group) and the Ogasa Group (Hamamatsu-oki Group) (Fig. 2) (Hiroki et al., 2004; Arai et al., 2006; Takano et al., 2009, 2010). The Kakegawa Group unconformably overlies the underlying units with a certain time gap, indicating a different phase of forearc basin tectonics, and the Ogasa Group unconformably overlies the Kakegawa Group, indicating a tectonic event between depositions of the two groups.

Takano et al. (2009, 2010) used 2D/3D seismic surveys and well data (including cores and logs) to conduct a seismic sequence stratigraphic analysis and to reconstruct the depositional processes of submarine fan turbidites in the eastern Nankai Trough area. They

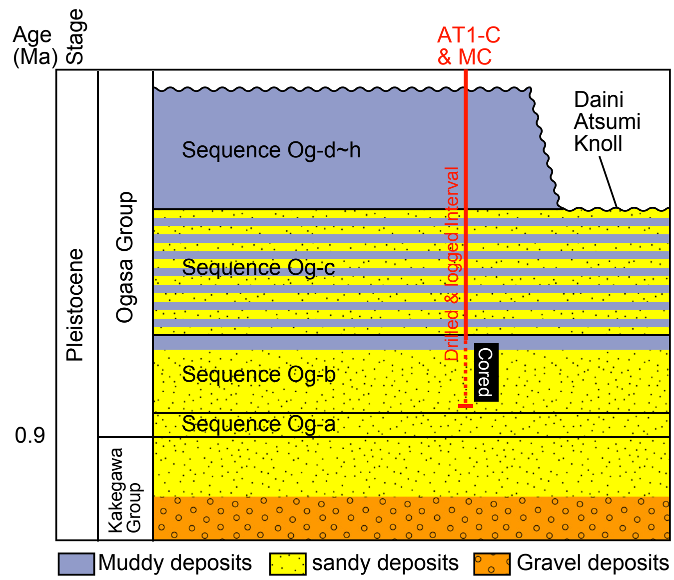

Figure 2. Stratigraphic columns for the Daini–Atsumi Knoll (modified Takano et al., 2009) to reflect the stratigraphic interval penetrated at the AT1-C well based on the results of this study. The cored interval from the AT1-C well recovered Eocene to Late Paleocene turbidite sediments of the Ogasa group.

classified the Kakegawa and Ogasa Groups into 17 sequence units: Kg-a to -h and Og-a to -i, based on well data and seismic reflection terminations, such as onlaps and truncation surfaces on the seismic sections. Furthermore, they interpreted the depositional system of the turbidites using seismic facies via a seismic geomorphological analysis (e.g., Arato and Takano, 1995). The depositional system suggests that submarine fan architecture was intermittently transformed through time. Some spatial differences in depositional patterns between the Tokai-oki, Atsumi-oki, and Kumano-nada

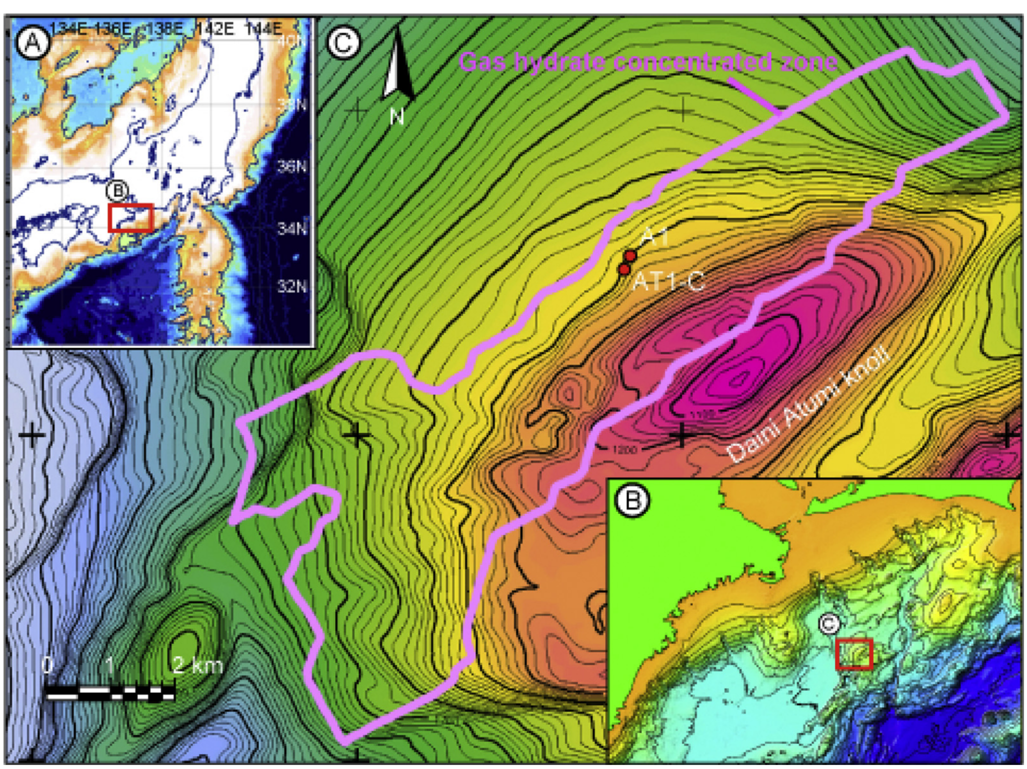

Figure 1. Reference map showing the location of the AT1-C well relative to the concentrated zone of the Daini–Atsumi Knoll.