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Research paper

Characterization of hydrate and gas reservoirs in plate convergent margin by applying rock physics to high-resolution seismic velocity model

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ABSTRACT

Gas hydrates are widely distributed in the Kumano forearc basin, which is located above accretionary prism in the Nankai margin off the Kii peninsula, Japan. Bottom-Simulating Reflector (BSR) at the base of gas hydrate stability zone has been imaged as a strong acoustic impedance contrast on the reflection seismic profiles. In order to better define the accumulations of gas hydrates and free gases, we performed a high-resolution seismic velocity analysis to 3D seismic data using a method of conventional semblance spectra via automatic velocity picking algorithm. The results revealed that gas hydrate-bearing sediments above the BSR and free gas-bearing sediments below the BSR are characterized by P-wave velocities of 1900–2500 m/s and 1000–1800 m/s, respectively. Then, the velocity model was converted into gas hydrate and free gas saturation using rock physics approaches. The results indicated that saturation of gas hydrates ranges from 0% to 45% in the pore space, and highly concentrated around the outer ridge where faults are densely developed. Additionally, concentrations of free gas ranging from 0% to 20% in the pore space are widely distributed below BSRs and are considerably high above ridge structure generated by displacement of large fault splayed from the deep plate boundary décollement. Based on these results, we suggest that the gas hydrates concentrated due to the free gas influx which migrated upward through the steeply dipping strata and faults (or fractures) cutting through the basin. The accumulations of gas and/or hydrates are further controlled by fault movements in the accretionary prism beneath the forearc basin. Therefore, these factors generated by intensive tectonic movements in the plate subduction zone control the distribution and saturation pattern of gas hydrate and free gas formations.

1. Introduction

Gas Hydrate is crystalline solids like ice bonding both water and gas molecules. In gas hydrate, mainly methane is trapped within water molecules forming as a rigid lattice cages. They occur in the permafrost region and deep water sediments where are high pressure and low temperature condition (Kvenvolden, 1993; Sloan and Koh, 2007). Significant amount of hydrocarbon clogged in the hydrate phase represents the unconventional and potential energy resources (Milkov, 2004). One cubic foot of gas hydrate approximately yields 163 cubic feet of gas (Hardage and Roberts, 2006). The gas hydrates contribute to global climate change and potential drilling hazards (Ruppel and Kessler, 2017; Kretschmer et al., 2015; Hovland et al., 2001). Furthermore, the destabilized gas hydrate seepage in marine sediments could cause geologic hazards such as submarine slumps and induced earthquakes (Xu and Germanovich, 2006; Kvenvolden, 1993; Sloan and Koh, 2007; Waite et al., 2009). Therefore, characterization of hydrocarbon reservoirs is also crucial to predict future climate change and geohazards.

The methane hydrate is widely distributed in the forearc basin of the plate convergent margins. Kumano forearc basin is located to the southeast of the Kii Peninsula, Japan, overlying the accretionary prism in the Nankai Trough where the Philippine Sea plate is subducting beneath the Japanese islands (Fig. 1). Various seismic profiles show that the BSRs are widespread in this region (Ashi et al., 2002; Baba and Yamada, 2004; Matsumoto et al., 2004; Uchida et al., 2004; Jia et al., 2016). Seismic characteristics of BSR are recognized as a continuous strong reflection event with negative polarity. The presence of a BSR thus allows us to define the boundary between high velocity gas hydrate-bearing sediments and the underlying low velocity free gas-bearing sediments (Shipley et al., 1979; Hyndman and Spence, 1992;

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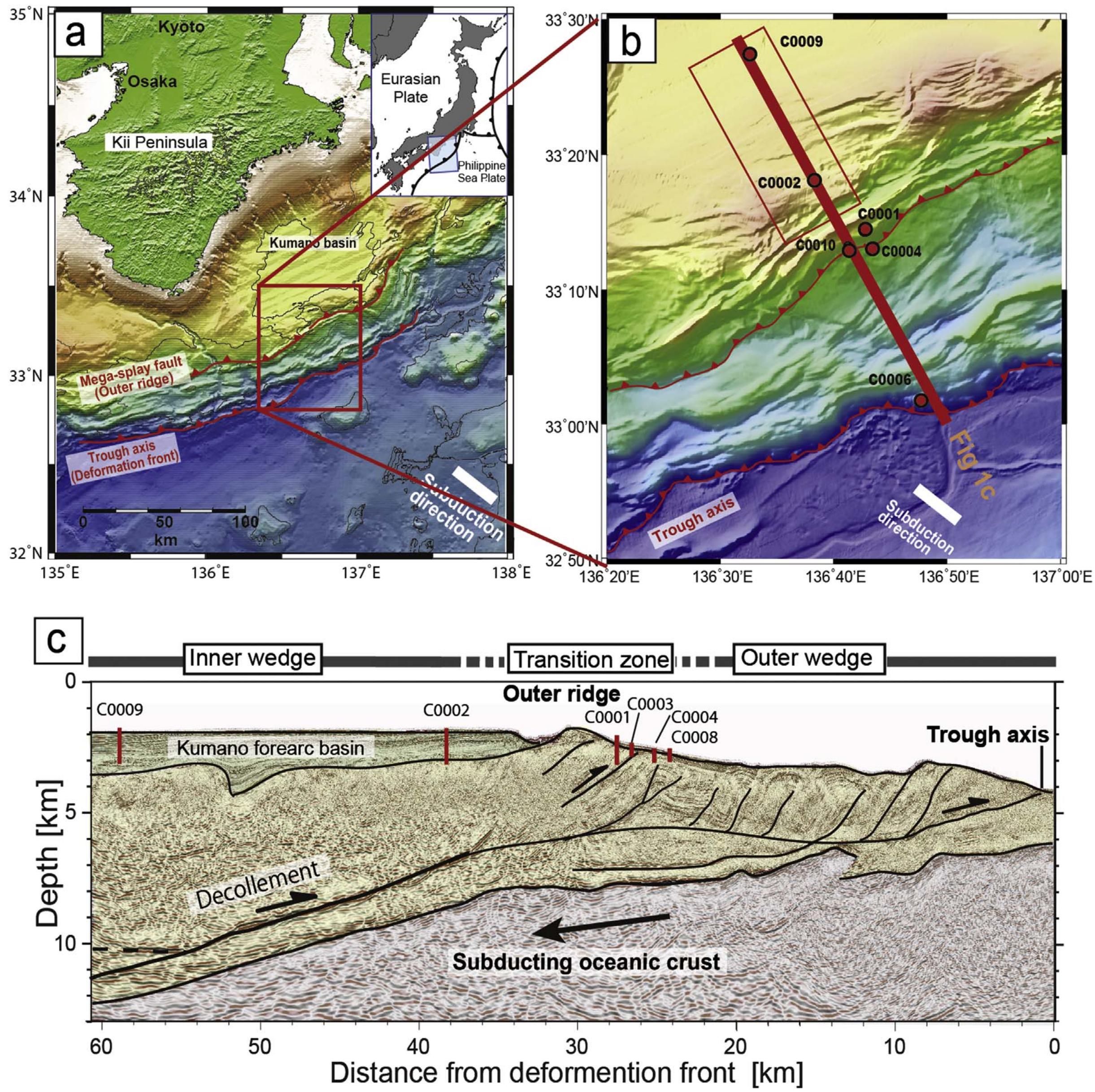

Fig. 1. (a) The Kumano forearc basin of the Nankai Trough area. (b) An enlarged map around 3D seismic data area (Expedition 319 Scientists, 2010). Red rectangle indicates our study area (or northern part of 3D seismic area). (c) Seismic reflection profile and interpretation of the fault system in the Nankai accretionary prism (Tsuji et al., 2015). The profile location is shown in panel (b). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Vargas-Cordero et al., 2010). The estimation of total methane amount contained in gas hydrate-bearing sediments in the eastern Nankai Trough has been quantified to be 40 trillion cubic feet (Fujii et al., 2008).

There have been numerous studies on hydrate-bearing sediments in the Kumano forearc basin using several methods. For example, Miyakawa et al. (2014) studied gas hydrate saturation at Site C0002, IODP Expeditions 314 and 315, in the Kumano forearc basin of the Nankai Trough by applying Archie's equations and a three-phase Biot-type equation on logging data; Taladay and Moore (2015) studied concentrated gas hydrate deposits in the Kumano forearc basin using the seismic attributes; Jia et al. (2016) studied gas hydrate distribution in the same region using acoustic impedance inversion for post-stack seismic data. In this study, we implemented a high-resolution seismic velocity analysis using an algorithm of automatic optimum velocity picking to effectively map gas hydrate distribution as well as gas reservoirs underneath hydrate layers in the Kumano forearc basin. With the high-resolution P-wave velocity model from the automatic seismic velocity determination, the spatially high concentration and distribution of hydrate and gas reservoirs in the Kumano forearc basin are well-defined. Many studies quantified gas hydrate saturation from acoustic impedance and water-filled porosity relations (Lu and McMechan, 2002; Wang et al., 2011); however, from our 3D seismic velocity model, we can benefit to connect this empirical relation to the P-wave seismic velocity instead of acoustic impedance inversion heavily relying on many well data. As a result, we can elucidate formation processes of hydrocarbon gas formation, accumulations and their stratigraphic, structural and tectonic control in the Kumano forearc basin of Nankai accretionary prism.

2. Data

2.1. Seismic data

Studied 3D multichannel seismic reflection data were acquired in the Nankai Trough in 2006. The coverage area is approximately