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Submarine landslide identified in MD179 cores, off-Joetsu area, eastern margin of the Sea of Japan

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ABSTRACT

Gas hydrate is exposed on the sea floor and is buried in shallow sediments in the off-Joetsu area at the eastern margin of the Sea of Japan. Sediment cores recovered from topographic highs of the Joetsu Knoll and Umitaka Spur show pockmarks and mounds formed by gas hydrate dissociation, but those from the Un-named ridge have no such topographic features. All topographic highs and pockmarks mainly comprise bioturbated layers interbedded with thinly laminated (TL) layers, which are common Sea of Japan sediments. Recovered sediments are, however, mostly disturbed by submarine landslides, showing tilted horizons, faults, slump folds, and breccia, except that from the Un-named ridge. The timing of events is well constrained by identification of the number of TL layers in some sediment cores. Landslides occurred both during the cold glacial period of the late MIS3 to the last glacial maximum (LGM) and during the warm interglacial period of the post-LGM. All were caused by the explosive rise of gas hydrate formed at very shallow depths of the sea bottom by the supply of gas from the depth of the gas hydrate stability zone through gas chimney passages developed under the pockmarks. Seismic activity demands consideration as a factor because the off-Joetsu area is tectonically active.

1. Introduction

Gas hydrate warrants investigation for its potential as both an energy resource and for its connection with future natural disasters. Large-scale submarine landslides shown on topographical maps, such as the Storegga Slide, which is associated with a tsunami, are being studied in conjunction with dissociation of gas hydrate (Bugge et al., 1987; Mienert et al., 1998, 2005; Vogt and Jung, 2002; Sultan et al., 2004). Gas hydrate is stable under low-temperature and high-pressure environments and is sensitive to their changes. Therefore, its dissociation and the consequent release of gas are suspected to result from a rise in temperature, such as that by global warming (Nisbet, 1990; Haq, 1998; Kennett et al., 2002; Mienert et al., 2005), or by a decrease in pressure that might occur with a falling sea level (Kayen and Lee, 1991; Haq, 1998; Maslin et al., 1998; Rothwell et al., 1998) or a landslide triggered by seismic activity (Mau et al., 2007). Consequently, two contrasting climate modes are presumed to be related with the dissociation of gas hydrate; either a decrease in pressure by a decline in sea level during a cold interval or a rise in temperature during a warm interval.

Gas hydrates are exposed on the bottom of the sea and exist within sediments at the eastern margin of the Sea of Japan (Matsumoto, 2005, 2009; Matsumoto et al., 2009). Nineteen sediment cores were recovered during the Sea of Japan cruise of R/V Marion Dufresne during summer 2010 from the west of Okushiri Island in the north to the off-Joetsu area in the south, mainly targeting the investigation of gas hydrates (Fig. 1). The recovered sediments extend from the recent to the previous warm interval via the cold glacial interval when the sea level had lowered (Kakuwa et al., 2013a,b). Detailed examination of the sediment cores of MD179 clarified that numerous submarine landslide events disturbed an orderly succession of horizontal layers.

This report describes the sediments deposited on the topographic highs of Umitaka Spur, Joetsu Knoll, and the Un-named ridge in the off-Joetsu area (Fig. 1), and presents discussion of the timing and causes of submarine landslides identified in the area.

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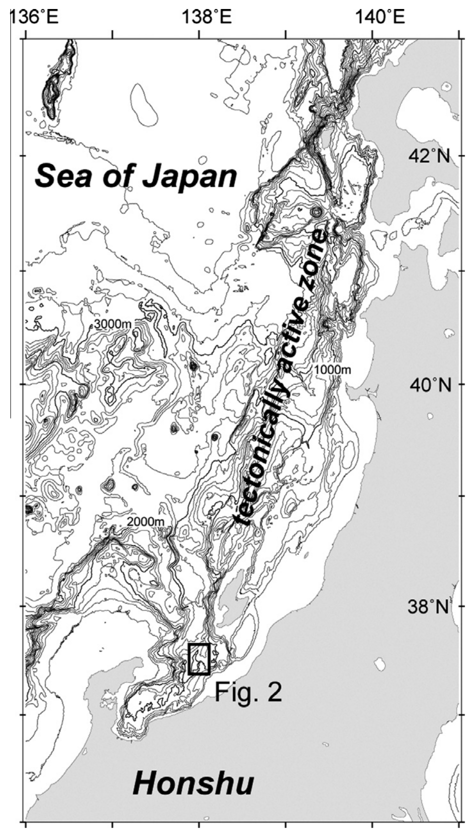

Fig. 1. Index map shows the locality of the off-Joetsu area where the sediment cores of MD179 are recovered. The tectonically active zone runs NNE to SSW from the west of Hokkaido to the off-Joetsu area, eastern margin of the Sea of Japan.

2. Topography and sub-bottom seismic profiles of core sites

The Sea of Japan started to form around 20–25 million years ago by rifting of the eastern margin of the Asian continent (Tamaki, 1986; Tamaki and Isezaki, 1996; Yanai et al., 2010). Spreading of the back arc basin turned to compression around 2–3 million years ago. The deformation was concentrated in the eastern margin of the Sea of Japan, producing north–northeast to south–southwest trending folds and reverse faults that engendered numerous ridges and basins (Tamaki and Honza, 1985; Sato, 1994; Sato et al., 2004). The Umitaka Spur and the Joetsu Knoll in the off-Joetsu area were also formed by the tectonic movements described above (Matsumoto et al., 2009).

The Umitaka Spur, which is 8 km long northeast to southwest, 2 km wide east–west and 250 m high, is bounded by a steep slope in the south from a shallow shelf of Honshu Island (Fig. 2). Pockmarks, which are rounded to oval depressions of 350–600 m in diameter and 30–50 m deep, and mounds, which are 5–30 m high, are aligned in a north–northeast to south–southwest trend on the top of the Umitaka Spur. Both the pockmarks and the mounds were formed by dissociation of gas hydrate (Matsumoto et al., 2009).

The Joetsu Knoll, situated in the northwest of the Umitaka Spur, which is elongated northeast to southwest, is bounded by a steep cliff in the northeast and by a gentle cliff in the northwest (Fig. 2). Several pockmarks and mounds are aligned on the top of the knoll parallel to the elongated direction (Matsumoto et al., 2009).

The 3.5 kHz sub-bottom profiler records were obtained using the Sea Falcon II system of R/V Marion Dufresne. The sub-bottom profile (SBP) of each core site shows fine stratification in general, but it is disturbed or interrupted by structureless columnar zones, 0.5–1 km in diameter, under pockmarks and mounds (Fig. 3). These images are called a gas chimney structure, which is assumed as a passage of deep-rooted gas in the Cascadia margin off Vancouver (Chapman et al., 2002) and the Sea of Okhotsk (Shoji et al., 2005).

MD179-3296 is from the inside of a pockmark on the Umitaka Spur (Fig. 2). The water depth at the core site is 914 m. The pockmark is a broad bean-like shape that is elongated north–northwest. The long axis and the short axis of the pockmark are, 610 m and 210 m, respectively. The depth is around 10 m. The SBP shows development of fine stratification disturbed by a blank chimney structure of the pockmark (Fig. 3).

MD179-3299 is cored at the lower foot of the Umitaka Spur (Fig. 2). The site water depth is 1000 m. Pockmarks and mounds are situated 3 km west of the core site. Stratification is clear in the eastern slope of the Umitaka Spur on the SBP, but it disappears on the east of the core site. The gas chimney structure develops under the mounds (Fig. 3).

MD179-3301 is cored at the lower foot of the Umitaka Spur (Fig. 2). The water depth is 1046 m. The SBP shows that the core site is situated in the transitional part from the stratified gentle slope to a poorly stratified slope (Fig. 3).

MD179-3304 is cored at the southern edge of a pockmark on the ridge of the Umitaka Spur (Fig. 2). The water depth is 896 m. The diameter and the depth of the pockmark are 640 m and 20 m, respectively. The SBP shows that stratification develops well in the south of the pockmark, although it develops poorly in both the pockmark and mounds in the east of the core site (Fig. 3).

MD179-3312 is cored on the ridge of the Un-named ridge (Fig. 2). The water depth is 1026 m. No pockmark or mound is visible on the ridge. Stratification is developed well in the SBP of this core (Fig. 3).

MD179-3317 is cored in a pockmark on the ridge of the Joetsu Knoll where mounds and pockmarks are arranged in a direction of northeast to southeast (Fig. 2). The water depth is 1021 m. The SBP of the coring site and its surrounding area show that stratification develops in the surface part of the Joetsu Knoll, but the gas chimney structure below the pockmark interrupts it (Fig. 3).

3. Sediments of the Sea of Japan

Late Quaternary sediments deposited on the bottom of the Sea of Japan between the Asian Continent and the Japanese Islands are characterized by repeated finely laminated dark and bioturbated light-colored layers (Oba et al., 1991; Tada et al., 1992; Föllmi et al., 1992; Nakajima et al., 1996; Tada et al., 1999). The laminated dark layers and bioturbated light-colored layers respectively represent the intervals of poorly oxygenated and highly oxygenated conditions that prevailed at the sea-bottom of the Sea of Japan (Nakajima et al., 1996; Tada et al., 1999; Watanabe et al., 2007).

The laminated dark layer is named the thinly laminated (TL) layer (Tanaka, 1984). Subsequent layers are numbered sequentially as TL1, TL2 from the top separated by bioturbated layers. The TL layers are recognized up to 25 horizons during the last glacial period to recent in the areas off Akita and off Oki Islands for example (Itaki et al., 2007). Those TL layers are regarded as having been deposited almost simultaneously in the whole of the Sea of Japan, which is supported by several widespread tephras from the Tsushima Basin in the south to the Yamato Basin and west of Hokkaido in northwest of the Sea of Japan (Tada et al., 1992; Nakajima et al., 1996). Therefore the TL layers substitute roughly for a time marker or a baseline in the Sea of Japan.

The recovered sediments of the MD179 cores are also composed mostly of the repeated TL layers within a bioturbated succession, which is common for the Sea of Japan. Each TL layer is identified