

Diffuse methane seep in the upper bathyal zone from the lower Pliocene Tamugigawa Formation, Niigata Prefecture

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"Diffuse seeps" are characterized by scattered occurrences of small carbonate concretions and cold-seep bivalve fossils, and interpreted to be caused by ephemeral and weak fluid flow (Nesbitt et al., 2013). Although they are expected to preserve infaunal or semi-infaunal fossils *in situ* in the sediments not fully cemented with carbonates and also help to understand how seeping fluids diffuses through low permeable sediments, they have not been well described and studied compared with large methane-seep carbonate bodies.

In the Japan Sea borderland, some fossil vesicomid bivalves occur from the Neogene marine sediments associated with small carbonate concretions, which suggest diffuse cold seeps. This study reports an ancient diffuse methane seep from the lower Pliocene Tamugigawa Formation in Niigata Prefecture. At Matsunoyama-Matsuguchi, Tokamachi City, various shaped, pebble-sized small carbonate concretions are scattered with vesicomid, lucinid, and thyasirid bivalve fossils in the grey siltstone exposed along the Koedo River. The shapes and distributions of the concretions as well as fossils were recorded by drawing a sketch of the outcrop, and the carbon and oxygen stable isotopic compositions of some concretions were analyzed and plotted on the sketch. The molluscan fossils from this outcrop consist of remarkably diverse taxa, such as protobranch bivalves, naticid, buccinid, and other small gastropods, and scaphopods as well as cold-seep bivalves including vesicomids. Infaunal lucinids and thyasirids occur in the upper part of the outcrop as articulated valves retaining their living positions. The vesicomid bivalves, including at least two species, *Archivesica kannoi* and *Calyptogena cf. pacifica*, constitute only 27% of the species composition (n=54). The low abundance of vesicomids and also the presence of naticid drill hole suggest relatively shallow environment (cf. Kiel, 2010; Amano et al., 2010), consistent with the inferred depositional depth of the Tamugigawa Formation based on molluscan fossil assemblage (upper bathyal zone, 200-500 m: Amano et al., 1991; Amano, 1994). The concretions occur mostly in the middle part of the outcrop and they are irregular-shaped, globular, funnel-shaped, or tortuous like burrows. They are light grey colored, or dark grey colored in the lowermost part of the outcrop, and composed of micritic low-Mg calcite. The $\delta^{13}\text{C}$ values of them are low (-46.0 to -24.3 ‰), suggesting that they are mainly derived from anaerobic oxidation of methane (AOM), which is also suggested by the presence of a lipid biomarker pentamethylcosane (PMI) in the micrite. The concretions contained close to one another or in about the same horizon in the outcrop have similar $\delta^{13}\text{C}$ values (± 6 ‰), which may suggest that they formed in the same AOM zone. It is concluded that this outcrop represents a diffuse methane seep in a relatively shallow environment, upper bathyal zone, in the early Pliocene where seeping fluids diffused through some pore spaces such as burrows in the silty sediment. It may be possible to recognize ancient AOM zones in outcrops of diffuse seeps by analyzing the isotopic composition of each concretion scattered in the outcrop as this study.

Keywords: diffuse methane seep, Niigata, Pliocene, upper bathyal zone