

Three types of cold-seep carbonates from Miocene sediments in the Shin'etsu basin of the Japan Sea region

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During the opening of the Japan Sea in the early to middle Miocene, deep sedimentary basins were formed by rapid subsidence. The Neogene sediments, which deposited in these basins and are now exposed in the Japan Sea borderland, host carbonate blocks associated with fossil vesicomid bivalves, suggesting that cold seeps have prevailed in the Japan Sea since its formation. Although some of them are interpreted to be methane-seep carbonates (Ishimura et al., 2005; Amano et al., 2010), many vesicomid-bearing carbonates in this region remain geochemically unstudied. Researches on geochemical and physical properties, and evolution of the cold seep in the Japan Sea are prerequisite for further understanding of the cold seep system in this region under different tectonic setting from that of the Pacific side subduction zone.

This study investigated the textures, stable isotopic compositions of carbon and oxygen, and biomarker contents of the carbonate concretions associated with vesicomid fossils from three localities in the Neogene Shin'etsu sedimentary basin. Three distinct types of cold seep carbonates are observed in this basin, as follows.

At Loc. 1, Sorimachi in Matsumoto City, pebble- to cobble-sized concretions are scattered with articulated vesicomid fossils, *Adulomya* sp. A, in the dark-grey siltstone of the middle Miocene Bessho Formation exposed along the Hofukuji River. They are mainly composed of micritic low-Mg calcite. The low $\delta^{13}\text{C}$ values (-34.6 to -23.6 ‰) and a lipid biomarker pentamethylcosane (PMI) extracted from the micrite suggest that these concretions are derived from anaerobic oxidation of methane (AOM), and they can represent a diffuse methane seep.

At Loc. 2, Nakanomata in Joetsu City, a float of concretion yielding disarticulated and fragmented vesicomid fossils, *Adulomya* sp. C, as well as bathymodiolidin mussels, *Bathymodiolus akanudaensis*, was found along the Nakanomata River where alteration of fine sandstone and siltstone of the upper Miocene Nodani Formation crops out. The concretion is considered to be derived from the Nodani Formation based on the diatom fossil assemblage. It is composed of micritic aragonite crosscut by abundant vein-like voids and cavities rimmed with acicular aragonite crystal aggregates. The low $\delta^{13}\text{C}$ values of them (-41.1 to -23.8 ‰), and the presence of PMI and crocetane in the micrite suggest that the concretion is derived from AOM, and interpreted to have been formed by rapid and active methane seepage.

At Loc. 3 which is close to Loc. 2, pebble-sized small concretions and pipe-like concretions are contained with articulated and disarticulated vesicomid fossil, *Calyptogena pacifica*, in the dark grey siltstone just below oily sandstone of the upper Miocene Nodani Formation. They are composed of micrite and bladed to fibrous calcite lining voids. The $\delta^{13}\text{C}$ values of them are -24.8 to -13.2 ‰, and typical biomarkers of anaerobic methanotropic archaea such as PMI and crocetane are absent in the micrite. These concretions are considered to be sulfate reduction- or oil-derived, and may represent a non-seep, sulfide-rich habitat or an oil seep. Analyses of carbon stable isotopes of these biomarkers would provide further evidence for it.

The difference among these three types of carbonate concretions from the Neogene Shin'etsu sedimentary basin suggests the variety of seepage rates, intensity, or source material of the cold seeps which prevailed there. Such environmental variation is also represented in associated faunal compositions. During the middle to late Miocene, the stress field of the Japan Sea region was tensional (Sato, 1994; Takano, 2002), and it is suggested from this study that geochemically and physically different cold seeps developed under tensional stress field within a limited interval of time and space in this time in the Japan Sea region.

Keywords: Japan Sea, Shin'etsu basin, Miocene, cold seep