A cold-seep assemblage associated with authigenic carbonate from the middle Pleistocene Kakinokidai Formation, Kazusa Group, Japan

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A cold-seep assemblage associated with authigenic carbonates greately depleted in ^{13}C ($d^{13}C$ = -48.82 to -62.29 per mill) occurs in outer shelf facies of the Middle Pleistocene Kakinokidai Formation of the Kazusa Group, in Kawayatsu, Chiba Prefecture, central Japan. The Kakinokidai Formation in this site is intensely bioturbated and contains molluscs that suggest a paleodepth 100 to 150m (Shibasaki and Majima, 1997). The Kakinokidai Formation has been dated in 0.6 to 0.7 Ma based on magnetostratigraphy (Niitsuma, 1997), microfossil biostratigraphy (Takayama and Sato, 1987; Sato and Takayama, 1992; Okada and Niitsuma, 1989; Pickering et al., 1999), and fission-track dating (Watanabe and Kashihara, 1996). This assemblage is the youngest and the shallowest cold-seep depended fossil assemblage that consists of large invertebrates.

In Kawayatsu, the cold-seep assemblage occurs sporadically in three locations (named as Tunnel 1, Tunnel 2, and Outcrop 1) that are aligned in NNE-SSW direction: Tunnel 2 that Shibasaki and Majima (1997) studied in detail; Tunnel 1 locating in about 50m NNE of Tunnel 2; and Outcrop 1 being situated on about 170m NNE of Tunnel 2. The strata exposed at the three locations stratigraphically locate between a few m above and below of the Ka2.3 tephra layer. A bored core (Core No. 2), 68m in length, was drilled beside the Tunnel 2 to underneath of the cold-seep assemblage and shows that no seep evidence is observed in the subsurface below the Tunnel 2.

Outcrop1 covers a stratigraphic interval 1.5m above to 2.5m below of the Ka2.3, and consists of massive muddy sandstone bearing sporadic ariticulate bivalves *Lucinoma* sp., with many burrows of 2-1.5cm in diameters. These burrows are randomly oriented, sporadic or aggregated, probably crustacean in origin, and always enclosed by authigenic carbonates that consist of HMG-calcite and dolomite. The inner walls of burrows may be fringed or filled by aragonite layers. Some of the isolated burrows look like a chimney on exposure surfaces.

We also observed carbonate concretion layers in northern 12m part of Tunnel 1 (50m in length) where massive muddy sandstone 1.5-3.3m stratigraphic above of Ka2.3 is exposed and *Archarax* sp. occurs sporadically. All carbonate concretions are composed of dolomite that are not so depleted in ^{13}C ($d^{13}C$=-22.4 to -18.5 per mill). These isotope data suggest that the carbonate concretions had been precipitated below the zone of anaerobic oxidation of methane (AOM). In SEM observations, some foraminifer tests are entirely dissolved within the carbonate concretions but very fine structures of their tests are elaborately preserved as outer and inner molds.

To compare activate timings of seepage that had maintained the assemblage with global warming events, we observe exposures and a core (Core No. 1) obtained from the study area. The core, 80m in depth, is bored normal to general bedding of the study area, N66 degree E in strike and 7 degree NW in dip, and covers the lowermost horizon of the Kakinokidai Formation, massive muddy sandstones, and the upper part of the Kokumoto Formation, alternation of sandstones and muddy sandstones. We measure $d^{18}O$ of *Globorotaria inflata* in the Core No. 1 (upper part of the Kokumoto Formation and lowermost part of the Kakinokidai Formation) and the exposures (lower and middle part of the Kakinokidai Formation) and can designate MIS (marine isotope stage) 18 at stratigraphic horizon 32.99m below of Ka2.3 and MIS 17 at 26.79m above of Ka2.3. This result evidently suggests that methane seepage that had maintained the cold-seep assemblage of Kawayatsu had been activated in a global warming timing.