Metabolic capacity of anaerobic methanotrophy and organic cycling in a sulfate-depleted, ferruginous terrestrial mud volcano

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Terrestrial mud volcanoes are considered an important natural source of methane emission and represent a surface expression of conduits transporting deeply-seated organic matters, gases and fluids to surface. While terrestrial environments are generally deprived of sulfate, how microbial communities regulate methane cycling and sequester organic carbon in such methane-rich environments remains largely unknown. In this study, cored sediments were retrieved from a ferruginous mud volcano in Taiwan and applied with geochemical, incubation and molecular analyses. Our results demonstrated inverse correlations between Fe/Mn/DIC and methane along depth. The methanotrophic zones were interlayered with methanogenic zones in a reversible sequence, and characterized by elevated abundances of ANME-2a and Desulfuromonadales members. The detected ANME-2a members possessed a full suite of genes required for methanogenesis. Genes classified into Geobacter and potentially accounting for electron transport of iron reduction were abundant in the methanotrophic zones as well. These geochemical and genetic patterns were consistent with active anaerobic methanotrophy possibly coupled with Fe/Mn reduction. Incubations of mud slurries further demonstrated that anaerobic methanotrophy could be stimulated at least by methane alone, or by methane with iron oxide. The isotopic (^{13}C and ^{14}C) and abundance variations of TOC indicated the incorporation of both atmosphere- and methane- derived carbon into organic matters at various proportions along depth. As being reflected from the DOC and gene profiling, these complex organic matters could be hydrolysed and decomposed by various genes into smaller organic entities in the methanogenic zone, providing readily utilized precursors for methane production. Overall, a complex metabolic network imposed by various physical and chemical factors appears to control methane emission and other elemental cycling in terrestrial mud volcanoes.