SEDIMENTARY RECORDS OF ANCIENT MUD VOLCANISM: HOW DO WE IDENTIFY MUD VOLCANOES IN THE STRATIGRAPHY OF MARS? G. Komatsu[1,2], R. Ishimaru[2], K. Kawai[3], N. Miyake[2], M. Kobayashi[3], H. Sakuma[4], and T. Matsui[2], [1]International Research School of Planetary Sciences, Università d'Annunzio, Viale Pindaro 42, 65127 Pescara, Italy (goro@irsps.unich.it), [2]Planetary Exploration Research Center, Chiba Institute of Technology, 2-17-1 Tsudanuma, Narashino-shi, Chiba 275-0016, Japan, [3]Department of Earth and Planetary Science, University of Tokyo, Hongo 7-3-1, Bunkyo, Tokyo 113-0033, Japan, [4]Research Center for Functional Materials, National Institute for Materials Science, 1-1 Namiki, Tsukuba, 305-0044 Japan.

Introduction: Mud volcanism is typically defined as a phenomenon in which fluid-rich, fine-grained sediments ascend within a lithologic succession and it tends to produce landforms on the surface by the extruded mud [e.g., 1, 2]. On Earth, land-based mud volcanism is widespread in various geologic settings in the world. Mud volcanoes are well known for example along the Alpine orogenic belt of the Mediterranean, Caspian and Black Sea regions [e.g., 1, 3, 4, 5, 6] as well as in countries such as Indonesia [7], China [8] and Trinidad [9].

These mud volcanoes are identifiable based on the clear morphological expressions of emplaced muddy deposits on the surfaces. However, ancient mud volcanism may leave traces also in stratigraphy. As more in-situ outcrop observation has become feasible in recent Mars exploration, opportunities for identifying mud volcanoes in stratigraphy is increasing. In this sense, exploration of clay-rich sedimentary deposits with Mars rovers will particularly be relevant. As some of future rover missions such as Mars 2020 and ExoMars 2020 will target clay-bearing outcrops, terrestrial analogs of mud volcanoes embedded in stratigraphy would likely to give hints on what to search in Martian outcrop data.

Evidence for ancient mud volcanism exposed in Kii Peninsula: We here introduce field sites along the coasts of Kii Peninsula, western Japan (Wakayama Prefecture), where ancient mud volcanism is preserved and exposed in sedimentary sequences (**Fig. 1**) [10, 11]. Coarse-grained shallow marine sediment sequences of the Miocene upper Tanabe Group and Kumano Group (exposed along the west and east coast respectively) are intruded into by the underlying fine-grained sediment. The fine-grained sediment is considered to have originated from Asso Formation (lower Tanabe Group) and Paleogene Muro Group underlying Kumano, respectively. The intruding mudstone deposits exhibit diverse types of stratigraphic features: mud dikes intruding into overlying layers (**Figs. 2, 3**), diapirs in contact with surrounding strata (**Figs. 4, 5**).

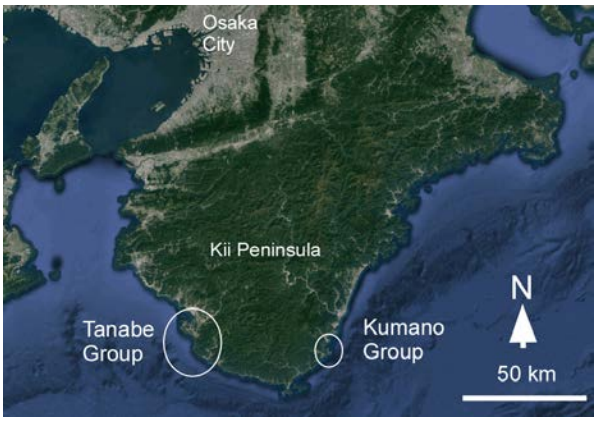

Fig. 1. Locations of field sites along the coasts of Kii Peninsula, western Japan.

Fig. 2. Mud dike intruded into the Kanayama Formation, the upper most part of the Tanabe Group. Gongenzaki, western Kii Peninsula.

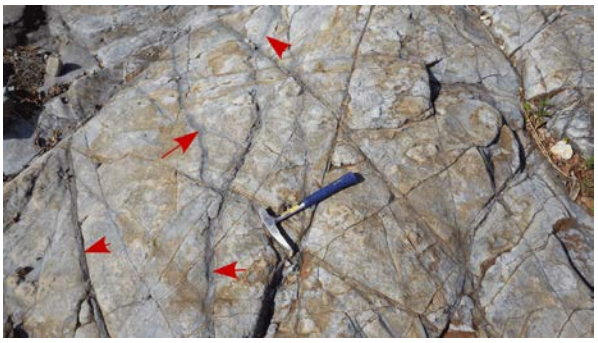

Fig. 3. Criss-crossing mud or sandstone dikes (arrows). Ichie-minami, western Kii Peninsula. At the Ichie area, diapirs intrude into S1 Member of Shirahama Formation (upper Tanabe Group).

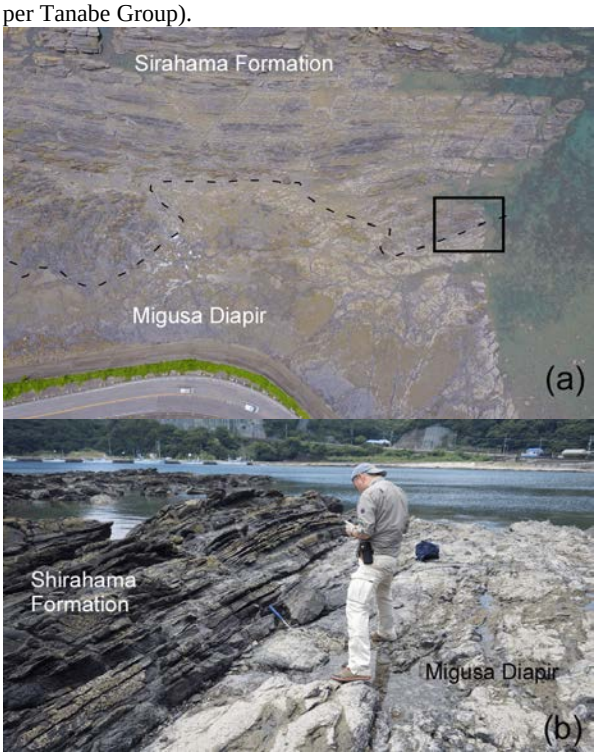

Fig. 4. Migusa Diapir in contact with S3 Member of Shirahama Formation. (a) Drone view of the Migusa Diapir and S3 member. The rectangular frame shows the location of (b). Cars at the bottom for scale. (b) Ground view of the Migusa Diapir and S3 member. Migusa, western Kii Peninsula.

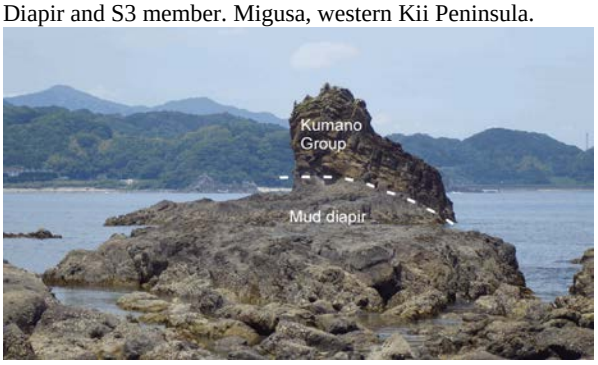

Fig. 5. Mud diaper pushed upward sedimentary layers of the Kumano Group stratum. Nanki Kumano Geopark, eastern Kii Peninsula.

Implications for Mars outcrop studies: Mud volcanism has been proposed to be an interesting target for future Mars exploration including astrobiological investigation [12, 13]. There are many recent reports on the possible identification of mud volcano landforms on the surface of Mars [14, 15, 16, 17, 18]. Furthermore, features indicative of clastic pipes have been interpreted from the orbital remote sensing [19] and at the outcrop scale [20]. However, no clear evidence for mud volcanoes in stratigraphy of Mars has been found to date. This situation may change with future landing missions.

Future Research: The ancient mud volcanoes preserved in the stratigraphic sequences of coastal areas along Kii Peninsula could provide ample opportunities for studying how the fine-grained sediment (i.e., constituents of the mud volcanoes) has maintained clues on past life. Along the line of this reasoning, we plan to analyze collected samples from the consolidated mud sediment for the evaluation of preserved organic matters. Sedimentary deposits have good potential for preserving biomarkers [21], and we intend to examine the collected mud sediment for verifying this aspect.

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