THE GOSHOGAKE MUD VOLCANO FIELD, TOHOKU, NORTHERN JAPAN: AN ACIDIC, HIGH-TEMPERATURE SYSTEM RELATED TO MAGMATIC VOLCANISM. G. Komatsu[1], R. Ishimaru[2], N. Miyake[2], K. Kawai[3], M. Kobayashi[4], and H. Sakuma[5], [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]Department of Earth and Planetary Environmental Science, University of Tokyo, Hongo 7-3-1, Bunkyo, Tokyo 113-0033, Japan. [5]Research Center for Functional Materials, National Institute for Materials Science, 1-1 Namiki, Tsukuba, 305-0044 Japan.

Introduction: Mud volcanism is widespread in various geologic settings in the world. Large-scale mud volcanoes are well known for example along the Alpine orogenic belt of the Mediterranean, Caspian and Black Sea regions [e.g., 1, 2, 3, 4, 5]. The most studied mud volcanism sites are related to sedimentary processes at relatively low temperatures. For example, in Azerbaijan the temperatures of fluids consisting of mud, water, gas, and oil are up to 2–3 ºC above the ambient temperature [6] although some large-scale eruptive events emplace deep-sourced mud flows on the surface as hot as 70 ºC [7, 8]. On the other hands, mud volcanism has also been observed in association with magmatic volcanism such as at Mt. Etna [9], Yellowstone [10], and Iceland [11]. Such volcanism sites tend to be characterized by high temperatures typically over 80 ºC to near the boiling point and low pH values [e.g., 10]. Nonetheless, mud volcanoes associated with magmatic volcanism are generally small (normally up to meter scale) and simple, and rarely exhibit the suite of mud volcano morphologies commonly observed at those in sedimentary settings. Some mud volcano edifices in sedimentary settings of Azerbaijan and Pakistan exceed kilometers in horizontal scale and hundreds of meters in height [4, 12].

The Goshogake mud volcano field: We here introduce the Goshogake mud volcano field in Tohoku, Japan, where the mud volcanoes are fed with high-temperature fluid related to magmatism of the Nasu volcanic belt (**Fig. 1**). This area is also a part of the Sengan geothermal field [13]. The geomorphological features observed in Goshogake are rather complex for mud volcanism in magmatic settings, and include salses (water-dominated ponds), gryphons (mound-shaped vent structures of mud and gas, made of accumulated sediment), and mud pots (wide vent structures of mud and gas, filled with watery mud) (**Fig. 2**). These features are mostly at the meter scale. The watery mud associated with the mud volcano features exhibits a temperature range of approximately 30 ºC to the near boiling point. The circulating water in the field is strongly acidic, with a pH range between 2 and 3, which is not common to sedimentary mud volcano systems [e.g., 14, 15].

We present documentation of the Goshogake mud volcano features, and data from field measurements of temperature of emitted watery mud and methane abundance, as well as from laboratory analyses for pH of collected watery mud and isotope ratios of water phase, mineralogical composition of deposited solid phases, collected gas composition and microbiology [16, 17, 18].

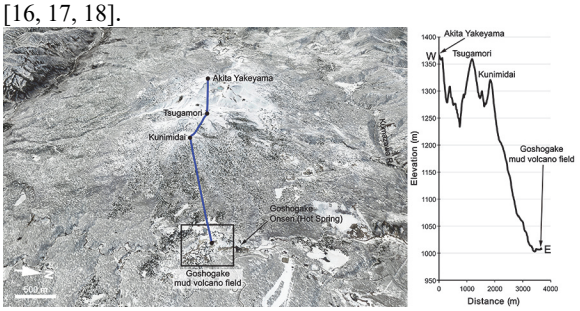

Fig. 1. Spatial relationships between the Akita Yakeyama volcano, its flank volcanoes (Tsugamori, Kunimidai), and the Goshogake mud volcano field.

Fig. 2. Oyunuma (Grand hot pond) and its surroundings. a) Oyunuma is a 70 x 60 m wide steamy salse. A gryphon field is visible next to Oyunuma and a small group of mud pots are located beyond Oyunuma. b) View of the gryphon field.

The gryphon in the foreground is about 0.5-m high. c) Active mud pot (2–3 m wide) bubbling with steam.

Mud sources and driving mechanisms: The identified mineralogy of the sampled mud includes quartz group, opal, muscovite, kaolinite, pyrite, and sulfur. The presence of high-temperature polymorphs of quartz (tridymite and cristobalite) and an amorphous form of silica (opal) in the mineralogy indicates that the mud volcano system likely involves high temperatures and/or hydrothermal alteration. Although the source of the mud is not clearly determined, possible options include 1) alteration products of host rocks and sediments, 2) fine-grained sedimentary layer(s) at depth, or 3) a combination of 1) and 2) (**Fig. 3**).

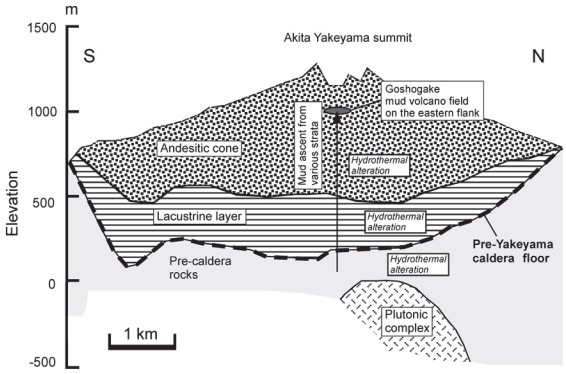

Fig. 3. Schematic cross-section across the Akita Yakeyama volcano complex. The cross-section shows an ancient caldera structure and lacustrine sediment filling the caldera underneath the present andesidic Akita Yakeyama volcano cone. The Goshogake mud volcano field, situated on the eastern flank of the Akita Yakeyama volcano at the elevation of approximately 1010 m a.s.l., may have derived its mud from hydrothermal alteration of host rocks and/or from the lacustrine layer. The cross-sectional stratigraphy of the Akita Yakeyama volcano is based on [13, 19] with reference to drill-hole observations.

Regarding its driving mechanisms, buoyancy of muddy sediment, high fluid pressure in overpressured or undercompacted conditions due to rapid sedimentation, together with the presence of a gas phase in the sediment, could be key factors. Historical records are inconclusive about the relationship between earthquakes and the Goshogake mud volcano field activity. In conclusion, the Goshogake mud volcano field is a hybrid system of sedimentary volcanism strongly influenced by its surrounding magmatic volcanism.

Terrestrial analog: Some extraterrestrial landforms have recently been hypothesized to be mud volcanoes on Mars [20, 21, 22, 23, 24]. Although currently there is not sufficient information about the nature of the purported mud volcanism conditions on Mars, it is assumed that the Martian mud volcanism is sedimentary in nature for the majority of cases. Nevertheless, abundant volcanic zones are known on Mars from geomorphological studies [25]. Furthermore, clay minerals [e.g., 26] and opaline silica likely related to hydrothermal conditions [27] have been reported by orbital spectroscopy and rover instrument. Thus, as in the case of the terrestrial analogs, it is not a far-fetched idea that we will find certain localities on Mars where mud volcanism was driven by magmatic volcanism. In this context, understanding of relatively less studied terrestrial high-temperature mud volcano systems may have insightful implications for their Martian counterparts and also for search for life and its traces associated with them [28, 29, 30].

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