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Formation of gas discharging from Taketomi submarine hot spring off Ishigaki Island in the southern Ryukyu Islands, Japan

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ABSTRACT

Taketomi submarine hot spring lies off Ishigaki Island in the southern Ryukyu Islands and vents hot spring waters at temperatures up to ~50 °C from the seafloor at a depth of 20 m. We investigated the chemical and isotopic composition of gases discharging from Taketomi hot spring. The gases were composed mainly of methane, with secondary nitrogen at higher than atmospheric concentration. Carbon and hydrogen isotope data suggest that the methane in the discharging gases was derived mainly from thermal decomposition of organic matter. Helium isotopes were enriched in ^{3}He relative to the atmosphere, suggesting a supply of mantle-derived helium to the discharging gases. The mantle-derived gases transfer the deep-originated thermal energy to the hot spring and thermogenesis of organic matter. The hydrocarbons in the venting gas could be sourced from sedimentary rocks of the Yaeyama or Shimajiri Groups, or Yaeyama metamorphic rocks, and added to the ascending gases as they pass through those source rocks on their way to the surface. Because the Pleistocene rocks of the Ryukyu Group beneath the hot spring have been altered by the spring activity, the Taketomi hot spring began venting after the Pleistocene.

1. Introduction

Methane is abundant in reductive environments, such as in sediments, the Earth's crust, and animal and human intestines. When methane is emitted from a reductive environment into the atmosphere it undergoes photochemical reactions and absorbs infrared radiation, thus having a strong role in the greenhouse effect, a role that is exceeded only by atmospheric water vapor and carbon dioxide (Lelieveld et al., 1993). Methane seeps from sedimentary basins can occur on the seafloor or on land, and such emissions are 10 times larger than those from geothermal and volcanic areas (Etiope and Milkov, 2004). Total worldwide methane emissions from micro-seepages have been estimated to be 40–60 Tg per year (Etiope and Klusman, 2010; Kvenvolden and Rogers, 2005) and correspond to about 9% of total methane emissions of 580 Tg per year (Denman et al., 2007). To consider the methane budget in the total earth system, the processes by which methane moves between sources and sinks must be better understood.

Around the Ryukyu arc, gas seeps of mainly methane have been observed at several sites, and it is important to investigate the distribution of these seeps in order to understand the budget of greenhouse gases in a global context (Toki, 2013). Fukuta et al. (1969) reported that gases discharging from Taketomi hot spring are composed mainly of methane (70.9–74.6%) on the basis of the 4th phase survey of natural gas resources in the Ryukyu Islands (conducted by the Geological Survey of Japan). A research group from the University of the Ryukyus showed that the maximum temperature of the discharging fluids was 37.5 °C at the vent mouth at that time, which is higher than the average ambient temperature (25 °C) of seawater (Kaneshima et al., 1983). Carbon isotope ratios of methane and helium isotope ratios that they determined indicated a magmatic heat source (Oomori et al., 1991, 1993). Tsunogai et al. (2010) pointed out that hydrocarbons in the gases discharging at Taketomi hot spring were thermogenic gases derived from Miocene Yaeyama Group (Kaneshima et al., 1983) and that active volcanic activity during Miocene would be a heat source for thermogenic gases in the Taketomi gases (Kawano and Ueda, 1966) similar to natural gases containing mantle-derived helium discharging from Miocene rocks in northwestern Taiwan (Poreda et al., 1988).

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We report on carbon isotope ratios of heavy hydrocarbons and hydrogen isotope ratios of methane in samples of gases discharging from Taketomi hot spring that support a thermal origin of the hydrocarbons, and consider the heat source for those hydrocarbons with reference to recent seismic tomographic data from the southern Ryukyu arc.

2. Geological setting

The Ryukyu Islands are a 600-km-long arcuate chain of about 160 islands (Fig. 1a) lying between the East China Sea and the Ryukyu Trench and stretching from south of the Japanese island of Kyushu to Taiwan. From north to south they are known as the Okinawa Islands (including Okinawa Island), the Miyako Islands, and the Yaeyama Islands (including Ishigaki and Iriomote Islands) (Fig. 1b). The northern islands include both volcanic and non-volcanic islands, whereas the islands south of Aguni and Kume islands (where there was volcanic activity during the Miocene and Pliocene) are all non-volcanic (Konishi, 1965). However, seafloor hydrothermal activity has been identified along the volcanic arc at Hatoma Knoll (Watanabe, 2001), Yonaguni Knoll IV (Matsumoto et al., 2001), and Iriomote submarine volcano (Kato, 1982), whereas Taketomi hot spring lies south of the volcanic arc, meaning that the spring is located at non-volcanic front (Fig. 1b and c).

This study focuses on Taketomi submarine hot spring off Taketomi Island in the Yaeyama Islands (Fig. 1c). The basement rocks of the Yaeyama Islands are the Fusaki and Tomuru Formations, which are referred to collectively as the Yaeyama metamorphic rocks (Fig. 2). The Fusaki Formation represents a Jurassic accretionary prism, and the Tomuru Formation corresponds to the Triassic–Jurassic Sangun metamorphic rocks of mainland Japan (Isozaki and Nishimura, 1989). The

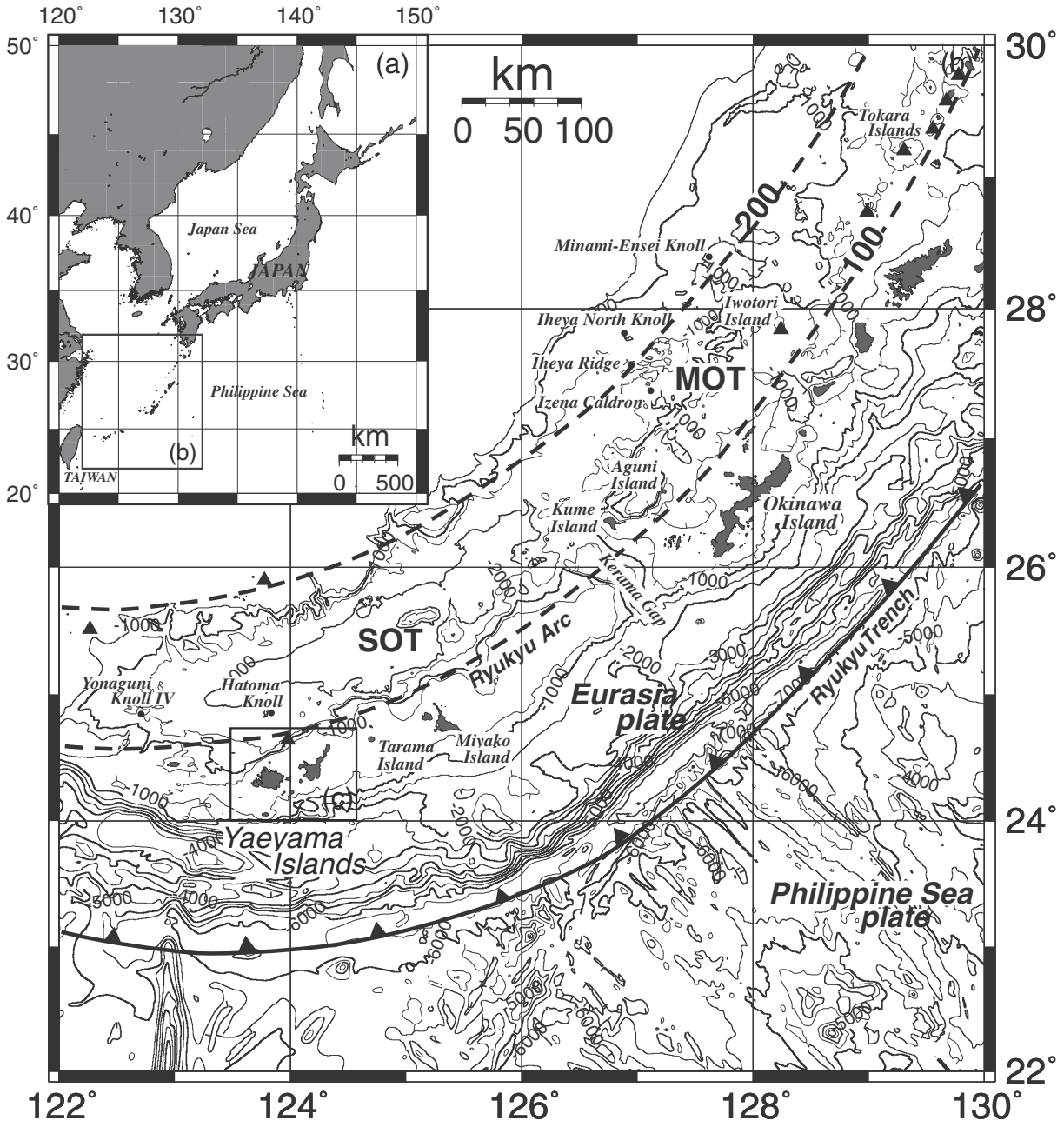

Fig. 1. (a) Regional map of the Japanese Islands and (b) map of the Ryukyu Islands. Solid triangles indicate Quaternary volcanoes, and solid circles indicate known active hydrothermal fields. Bathymetric contour interval is 200 m. Heavy dashed lines are depth contours (km) of the Wadati-Benioff zone (Letouzey and Kimura, 1986; Pezzopane and Wesnousky, 1989). MOT and SOT indicate middle Okinawa Trough and southern Okinawa Trough, respectively. (c) Map of Yaeyama Islands showing the location of Taketomi submarine hot spring.

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