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Leakage of magmatic–hydrothermal volatiles from a crater bottom formed by a submarine eruption in 1989 at Teishi Knoll, Japan

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ABSTRACT

A submarine eruption occurred off the Izu Peninsula of Japan on 13 July 1989, forming Teishi Knoll, which has a diameter of 450 m and a height of ca. 10 m above the surrounding 90–100 m deep seafloor. Immediately after the eruption, intense gas release was observed from two vents in the crater. The gas bubbling gradually decreased and apparently ceased in 1990. Given that no survey has been undertaken to examine volatile release from the crater of Teishi Knoll, we collected seawater samples at three different sites from just above the crater bottom on 17 July 2012, in order to detect signs of magmatic volatile release. Seawater samples from the crater bottom have dissolved CH_4 contents and $\delta^{13}C$ values higher than those of shallower (50–100 m deep) seawater samples. Total inorganic carbon contents from the bottom seawater samples are also higher, and $\delta^{13}C$ and $\Delta^{14}C$ values lower than those of shallower seawater samples. These data indicate the addition of minor CH_4 and CO_2 of hydrothermal or magmatic origin to the bottom seawater from the crater. $^{3}He/^{4}He$ ratios and total organic carbon data are also consistent with the leakage of magmatic fluids. The most prominent CH_4 and CO_2 anomalies were observed at the site located closest to one of the bubbling gas sites of the 1989 eruption. As such, volcanic gas emissions still continue today at extremely low levels, 23 years after eruption of this monogenetic volcano. The monitoring of ultra-trace amounts of chemical components in seawater is a prospective method to monitor temporal changes in magmatic activity at such submarine volcanoes.

1. Introduction

The subduction of the Pacific plate beneath the Philippine Sea plate causes intensive volcanic activity forming many volcanoes belonging to the Izu–Ogasawara volcanic arc in the southeastern part of Japan, parallel to the two plates boundary. Most of the volcanoes are polygenetic stratovolcanoes (e.g., Fuji or Izu–Oshima), apart from one volcano group consisting of >100 monogenetic volcanoes in the 40 × 30 km area covering both the eastern part of Izu Peninsula and the western part of Open Sea, Sagami, Japan. This volcano group has been named the “Izu–Tobu Volcanoes” by the Japan Meteorological Agency (2005).

In the evening of 13 July 1989, a submarine eruption occurred off the Izu Peninsula, near the northern boundary of the area of the Izu–Tobu Volcanoes. This eruption formed Teishi Knoll (34°59.6′N, 139°07.8′E), which is ca. 450 m across and protrudes ca. 10 m above the surrounding 90–100 m deep seafloor (Oshima et al., 1990, 1991). The summit crater of Teishi Knoll is ca. 200 m across and is ca. 30 m deep. The shallowest and deepest points of this knoll are 81 and 122 m below sea level, respectively. Although earthquake swarms in the vicinity of the Izu–Tobu Volcanoes have been noted in historical records and frequently observed since 1978, the 1989 eruption occurred after a 2700-year-long dormant period (Japan Meteorological Agency, 2005). As such, this represents our first opportunity to observe the birth of a monogenetic volcano. Fig. 1 shows the location of Teishi Knoll along with other Izu–Tobu monogenetic volcanoes and neighboring polygenetic volcanoes (Fuji, Hakone, and Izu–Oshima) along the Izu–Ogasawara volcanic arc. The figure also shows the epicenter distribution of seismic swarms associated with the eruption.

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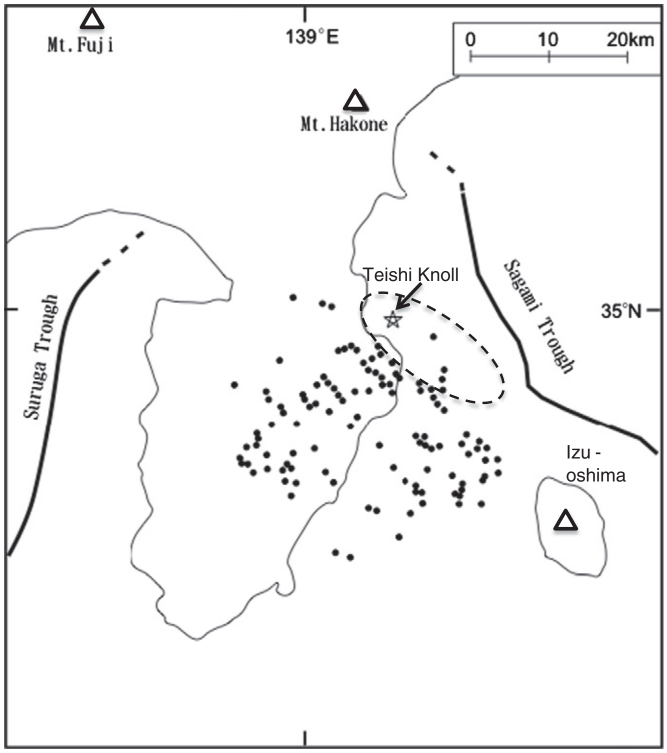

Fig. 1. Locations of Teishi Knoll and other monogenetic volcanoes of the Izu–Tobu Volcanoes (modified after Fig. 1 of Ohno et al. (2011)). The star symbol marks Teishi Knoll and the area surrounded with dashed line shows the epicenter distribution of seismic swarms associated with the Teishi eruption. The solid circles indicate the locations of monogenetic volcanoes (Koyama and Umino, 1991). Nearby polygenetic volcanoes (Fuji, Hakone, and Izu–Oshima) that belong to the Izu–Ogasawara volcanic arc are shown as open triangles.

Immediately after the eruption, intense release of gas bubbles was observed from two crater vents (Oshima et al., 1991). The emission of gas bubbles then gradually decreased and ceased in 1990 (Naka, 1994). The chemical composition of the gas, collected using the unmanned probe *Dolphin 3K* of JAMSTEC (Japan Marine Science and Technology Center) on 27 September 1989, was measured and determined to be 23.8% CO_2, 14.0% H_2, 49.0% N_2, 10.6% O_2, and 1.8% CH_4 (Ossaka et al., 1992). The seawater temperature at the bubbling site reached 90–100 °C in September 1989 and the sediment temperature in the crater bottom was >70 °C at two sites in August 1990, and decreased to 30 °C in March 1994 (Naka, 1994). After the visible gas bubbling stopped, no subsequent surveys have been carried out to examine volatile release from the crater bottom of Teishi Knoll, although seismic and geodesic monitoring has been continued by the Japan Meteorological Agency (http://www.seisvol.kishou.go.jp/tokyo/316_Izu-TobuVG/316_index.html), and surface seawater color observations have been undertaken by the Japan Coast Guard (http://www1.kaiho.mlit.go.jp/GIJUTSUKOKUSAI/kaiikiDB/kaiyo5-2.htm).

Since the discovery of hydrothermal fluids at the spreading center of the Galapagos Ridge in 1977 (Edmond et al., 1979), many sites of emissions of hydrothermal fluids have been reported globally at mid-ocean ridges, back arc basins, submerged island arc volcanoes, and submarine hotspot volcanoes (German and Von Damm, 2003; Tivey, 2007). In the Izu–Ogasawara arc, hydrothermal fluids were first observed at Kasuga Seamount (McMurtry et al., 1993). Moreover, at Suiyo Seamount (Tsunogai et al., 1994, 2005; Toki et al., 2008), Myojin Knoll (Tsunogai et al., 2000), and Oomurodashi (Tani et al., 2012) along the same arc, hydrothermal fluids are characterized by enrichments in dissolved CO_2, CH_4, H_2S, and He, as well as metal ions like Mn^{2+} and Fe^{2+} relative to seawater. Such dissolved species originate from oceanic crust interacting with circulating hydrothermal fluids and/or from magma or hot igneous rock degassing beneath the vent (German and Von Damm, 2003; Tivey, 2007). In the case of Teishi Knoll, despite the fact there is no visible hydrothermal fluid venting, it is possible that trace amounts of dissolved gas from magmatic or hydrothermal processes may be detectable and related to present volcanic activity, even though it is 23 years since the last eruption. Furthermore, dissolved organic carbon (DOC) contents in seawater can be used as an indicator of hydrothermal activity, given that hydrothermal fluid venting affects DOC contents at the Juan de Fuca ridge system (Lang et al., 2007).

Dissolved inorganic carbon (DIC) and CH_4 in seawater consist of several carbon species of different origins. The carbon isotope composition of CO_2 and CH_4 is an excellent tracer to identify the source(s) of these carbon species (Hoefs, 2009). The $\delta^{13}C$ values of CO_2 or carbonates are distinctly different between marine and magmatic origins, and $\delta^{13}C$ values of CH_4 can be used to discriminate among biogenic, thermogenic, and abiogenic CH_4. The $\Delta^{14}C$ values of DIC can also be used as a tracer to investigate hydrothermal fluid dynamics. For example, Walker et al. (2008) demonstrated that $\Delta^{14}C$ values of DIC in hydrothermal fluids on the Juan de Fuca Ridge show a mixing relationship between pure high-temperature hydrothermal fluid consisting of dead carbon with $\Delta^{14}C = -1000‰$, and bottom seawater with $\Delta^{14}C = -250‰$. It is also known that $^3He/^4He$ ratio is an excellent tracer to identify the magmatic component in gases dissolved in seawater (e.g., Lupton and Craig, 1981; Ruth et al., 2000; Schlosser and Winckler, 2002; Srinivasan et al., 2004). It is possible to detect the magmatic component because $^3He/^4He$ values of magmatic gas are higher than those of ambient seawater, which are almost atmospheric in composition (1.4×10^{-6}, denoted as R_A) within analytical error of ~$0.01R_A$ at depths of <200 m (Takahata et al., 2010).

The objective of our study was to investigate magmatic volatile release 23 years after the submarine eruption of Teishi Knoll in 1989. We attempted to do this through comprehensive chemical and isotopic analyses of seawater samples collected just above the crater bottom. In addition, we discuss the present magmatic activity at Teishi Knoll and the long-term change in volcanic activity after eruption of this monogenetic volcano, in terms of magmatic volatile release.

2. Sample collection and analytical procedures

2.1. Seawater sampling locations

Seawater was sampled on 17 July 2012 from the deck of the small fishing boat *Minoru-maru*. After approaching the sea area above Teishi Knoll, seawater sampling locations were selected by comparing the seafloor morphology observed by a fishing radar installed on the boat with a detailed submarine topographic map of this area made after the 1989 eruption (Oshima et al., 1990, 1991).

Fig. 2 shows the locations of six seawater samples collected in this study. Three samples (A, B, and C) were collected at three different sites a few tens of centimeters above the crater bottom of Teishi Knoll. During the seawater sampling, which typically took 20–30 min, the boat attempted to maintain the same position on the sea surface despite the ocean currents and winds. In fact, the spatial position and depth of each sampling site may have moved slightly during sampling. The water depths to the crater bottom at the three sites were 113–114 m (A), 114–115 m (B), and 107–108 m (C). Site C was located as close as possible to the 1989 eruption bubbling sites. For comparison, shallow seawater samples from three different depths above the Teishi Knoll crater were also collected. These samples were D (98–99 m water depth), E (79–80 m), and F (48–49 m).

2.2. Seawater sampling procedures

The seawater sampling procedures followed the lake water sampling system of Yoshida et al. (2010), which has been applied to water sampling to depths of 210 m at Lakes Nyos and Monoun, Cameroon.