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Volcanic and environmental influences of Mt. Fuji on the $\delta^{13}C$ of terrestrially-derived *n*-alkanoic acids in sediment from Lake Yamanaka, central Japan

Shinya Yamamoto [a,*], Takashi Uchiyama [a], Yosuke Miyairi [b], Yusuke Yokoyama [b]

[a] Mount Fuji Research Institute, Yamanashi Prefectural Government, 5597-1 Kenmarubi, Kamiyoshida, Fujiyoshida, Yamanashi 403-0005, Japan
[b] Atmosphere and Ocean Research Institute, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8564, Japan

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ABSTRACT

The recognition of vegetation changes induced by volcanic eruption is particularly important for paleoenvironmental studies in volcanic regions. In this study, we examined the molecular and stable carbon isotopic compositions ($\delta^{13}C$) of sedimentary leaf wax *n*-alkanoic acids from Lake Yamanaka at the northeastern foot of Mt. Fuji, central Japan, to distinguish volcanic effects on biomarker $\delta^{13}C$ proxies from other environmental influences over the past 15,000 years. The $\delta^{13}C$ values of C_{30} acids showed a significant positive correlation with average chain length (ACL_{24-30}), suggesting that $\delta^{13}C$ reflects plant physiological responses to changes in water availability for C_3 plants. The $\delta^{13}C$ values of C_{30} acids showed patterns similar to those of Holocene stalagmite $\delta^{18}O$ records in Chinese caves, indicating that variations in hydroclimate at the northeastern foot of Mt. Fuji are controlled by large-scale changes in Asian monsoon activity. In contrast, the $\delta^{13}C$ values of C_{24}–C_{28} acids increased abruptly at ca. 1750 and 1100 cal yr BP, which coincide with eruptive events at the northeastern flank of Mt. Fuji. This suggests an increase in input from C_4 plants, likely reflecting an increase in C_4 *Miscanthus* grass, a pioneer species on volcanic deposits, following by the devastation of forest by the eruptions.

1. Introduction

Volcanic eruptions have profound effects on the terrestrial ecosystems around volcanoes. The impacts of volcanic eruptions on terrestrial vegetation are especially severe and vary depending on the magnitude and style of eruption along with the distance from the eruption source. For example, high-temperature lava flows and pyroclastic flows generally cause high mortality of vegetation in the area near the volcano (Dale et al., 2005), whereas pyroclastic falls can damage a wider area of vegetation via the accumulation of tephra and thermal effects (Endo, 1991; Dale et al., 2005). Volcanic eruptions also provide a catalyst for changes in vegetation through fire episodes that are triggered by increased fuel as a result of vegetation killed by tephra deposition (Long et al., 2011). Therefore, it is important to determine the effects of volcanic eruptions on terrestrial vegetation to better understand paleoenvironmental changes in volcanic regions.

Mt. Fuji is the largest active volcano in Japan, and its activity began ca. 100,000 yr BP (Takada et al., 2016). The presence of tree molds and fossilized forests buried under tephras and pyroclastic flow deposits at the foot of the mountain provides evidence for the destruction of forests in association with past volcanic activity (Miyaji et al., 1985; Kitagaki et al., 2007). Pollen analyses on Ohnuma-aisawa lake deposits at the eastern foot of Mt. Fuji revealed a deteriorating ground condition after the fallout of Yu-2 tephra at ca. 2200 yr BP (Miyaji and Suzuki, 1986). However, our knowledge on the volcanic impact on terrestrial vegetation at Mt. Fuji is still limited because pollen assemblages in lake sediment, which are modified during transportation and sedimentation processes (Kosugi et al., 1993), are usually sensitive to climate changes in addition to volcanic eruptions.

The stable carbon isotopic composition ($\delta^{13}C$) of plant leaf waxes such as high-molecular-weight *n*-alkanes, *n*-alkanols, and *n*-alkanoic acids (Eglinton and Hamilton, 1967) are commonly used to reconstruct past changes in the environment and vegetation (e.g., Freeman and Colarusso, 2001; Feakins et al., 2005, 2007, 2013; Huang et al., 2007; Tipple and Pagani, 2010;Yamamoto et al., 2010a, 2010b, 2010c, 2014) because these compounds are ubiquitous in sedimentary settings, and their $\delta^{13}C$ values sensitively reflect ecological and physiological responses to environmental changes (Farquhar et al., 1982; Arens et al., 2000;

* Corresponding author.
E-mail address: s.yamamoto@mfri.pref.yamanashi.jp (S. Yamamoto).

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Diefendorf and Freimuth, 2017) along with taxonomic variations within plant communities (Arens and Jahren, 2002). In addition, the molecular distributions of plant leaf waxes are also sensitive to changes in the plant's growing environment (e.g., changes in temperature and aridity) (Poynter et al., 1989; Kawamura et al., 2003; Schefuβ et al., 2003; Rommerskirchen et al., 2003; Sachse et al., 2006); thus, combining $\delta^{13}C$ with the molecular distribution of plant leaf waxes can make it possible to distinguish volcanic and non-volcanic environmental effects on terrestrial vegetation.

Lake Yamanaka is the largest volcanic-dammed lake on the northern foot of Mt. Fuji. Since the lake has been affected by numerous tephras as a result of the prevailing westerly winds (Koshimizu and Uchiyama, 2002), the sediment from Lake Yamanaka provides a good opportunity to examine the volcanic and environmental impacts using biomarker proxies for vegetation and environmental changes. In this study, we present the molecular and stable carbon isotopic compositions of sedimentary leaf wax *n*-alkanoic acids in a borehole core from Lake Yamanaka to distinguish volcanic effects from other natural factors over the last 15,000 years.

2. Study area and samples

Lake Yamanaka (35°25′N, 138°52′30″E, 980.5 masl) is the largest lake (area = 6.9 km^2) at the northern foot of Mt. Fuji and is ca. 13 km from the summit (Fig. 1). The lake is shallow, with maximum and average water depths of 13.3 and 9.4 m, respectively (Koshimizu et al., 2007). The basin floor of the lake is roughly crescent shaped, with the concave side facing toward the south. The catchment of the lake covers an area of 62.1 km^2, which is primarily vegetated with some barren surface in the uppermost part of the catchment on the slope of Mt. Fuji (Adhikari, 2011). The vegetation around Lake Yamanaka is dominated by substitutional communities in the *Fagetea crenatae* region (*Castanea crenata-Quercus mongolica* var. *grosseserrata* and *Galium verum* var. asiaticum-*Miscanthus sinensis* communities) and *Larix kaempferi* plantation (Environmental Agency, 1985). Pollen assemblages in the borehole core from the lake revealed anthropogenic impacts since ca. 1000 years BP (Kosugi et al., 1993).

The borehole core YA-1 is 17.65 m long and was obtained from the deepest part of the lake in 1998 (Fig. 1) (Koshimizu and Uchiyama, 2002). At depths greater than 11.4 m, the core consists entirely of scoria fallout deposits; above 11.4 m, the core is characterized by 669-cm-thick silty sediments with intercalations of scoria fallout and debris flow deposits (Fig. 2). The 28 scoria fallout horizons with various thicknesses (2–62 cm) indicate that at least 28 volcanic events occurred in the 7000-year history of Lake Yamanaka (Adhikari, 2011). The core can be divided into five units based on lithology and diatom assemblage (Fig. 2) (Yoshizawa et al., 2004; Adhikari et al., 2005; Adhikari, 2011). Unit I (lake bottom to a depth of 2.4 m) consists of dark-brown clayey silt with two scoria layers characterized by a high percentage of planktic diatoms. Unit II (depth = 2.4–6.1 m) consists of silty clayey sand with a large number of intercalations of scoria fall deposit. This unit is characterized by a high percentage of epiphytic and benthic diatoms. Unit III (depth = 6.1–9.33 m) consists of clayey sandy silt with intercalations of scoria layers and debris flow deposits characterized by the dominance of planktic diatoms. Unit IV (depth = 9. 33–11.4 m) consists of silty sand with scoria layers defined by a high percentage of periphytic diatoms. Unit V (depth = 11.4–17.6 5 m) primarily consists of scoria deposits with intercalations of sand and silt layers. The interval between 11.4 and 13.5 m mainly consists of black volcanic ash soil, which may be correlated to the Fuji-black soil layer (Kuroboku), with intercalations of thin volcanic ash layers. Variations in particle-size distribution and diatom assemblage from Units I–IV indicate alternation of lake and river/swamp environments over the last 7000 years (Supplementary Fig. 1) (Yoshizawa et al., 2004; Adhikari et al., 2005; Adhikari,

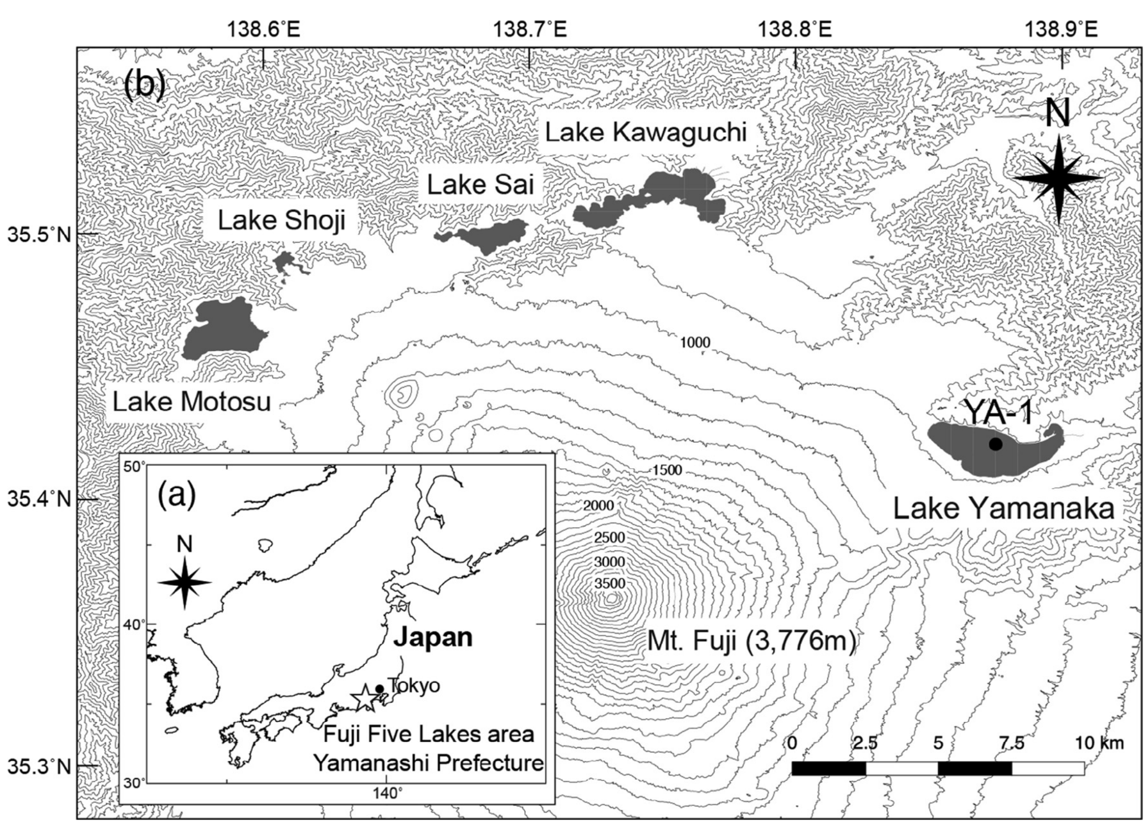

Fig. 1. Map showing the location of (a) the Fuji Five Lakes area, Yamanashi Prefecture, Japan, and (b) Lake Yamanaka and the coring position of the YA-1 core.