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A 90,000-year tephrostratigraphic framework of Aso Volcano, Japan

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ABSTRACT

A detailed 90,000-year tephrostratigraphic framework of Aso Volcano, southwestern Japan, has been constructed to understand the post-caldera eruptive history of the volcano. Post-caldera central cones were initiated soon after the last caldera-forming pyroclastic-flow eruption (90 ka), and have produced voluminous tephra and lava flows. The tephrostratigraphic sequence preserved above the caldera-forming stage deposits reaches a total thickness of 100 m near the eastern caldera rim. The sequence is composed mainly of mafic scoria-fall and ash-fall deposits but 36 silicic pumice-fall deposits are very useful key beds for correlation of the stratigraphic sequence. Explosive, silicic pumice-fall deposits that fell far beyond the caldera have occurred at intervals of about 2500 years in the post-caldera activity. Three pumice-fall deposits could be correlated with lava flows or an edifice in the western part of the central cones, although the other silicic tephra beds were erupted at unknown vents, which are probably buried by the younger products from the present central cones. Most of silicic eruptions produced deposits smaller than 0.1 km^3, but bulk volumes of two silicic eruptions producing the Nojiri pumice (84 ka) and Kusasenrigahama pumice (Kpfa; 30 ka) were on the order of 1 km^3 (VEI 5). The largest pyroclastic eruption occurred at the Kusasenrigahama crater about 30 ka. This catastrophic eruption began with a dacitic lava flow and thereafter produced Kpfa (2.2 km^3). Total tephra volume in the past 90,000 years is estimated at about 18.1 km^3 (dense rock equivalent: DRE), whereas total volume for edifices of the post-caldera central cones is calculated at about 112 km^3, which is six times greater than the former. Therefore, the average magma discharge rate during the post-caldera stage of Aso Volcano is estimated at about 1.5 km^3/ky, which is similar to the rates of other Quaternary volcanoes in Japan.

1. Introduction

Aso Volcano in central Kyushu, southwestern Japan, is a composite volcanic system comprising Aso caldera and post-caldera central cones. The Aso caldera, 25 km north–south and 18 km east–west (Fig. 1), was formed by four gigantic pyroclastic-flow eruptions of andesitic to rhyolitic magma from ca. 270 ka to 90 ka (Ono et al., 1977; Matsumoto et al., 1991). Post-caldera central cones were formed soon after the last caldera-forming eruption (90 ka) and have produced large volumes of fallout tephra and lava flows. Nakadake Volcano, which is the only active central cone, is one of the most active volcanoes in Japan. At the post-caldera cones, explosive eruptions have frequently occurred although they have been much smaller than the caldera-forming stage eruptions.

This paper presents an integrated stratigraphy of thick fallout tephra deposits preserved mainly above the Aso pyroclastic-flow plateau around the caldera. Based on the constructed tephrostratigraphic framework, this paper discusses the eruptive history of the post-caldera central cones over the last 90,000 years and the magma discharge rate of the post-caldera activity of Aso Volcano.

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2. Geological setting

Aso Volcano is one of the largest caldera volcanoes in the world (Fig. 1). The caldera-forming Aso pyroclastic-flow deposits are divided into four units: Aso-1 (270 ka), Aso-2 (140 ka), Aso-3 (120 ka) and Aso-4 (90 ka) in ascending order (Ono et al., 1977). The flows successively flowed into valleys between the basement mountains, filled them up and formed pyroclastic-flow plateaus. Between each of the four large pyroclastic-flow units, eruptions produced numerous tephra fallout layers. Nekodake, formerly thought to be a post-caldera central cone, is now interpreted to be a deeply dissected stratovolcano near the eastern rim of the caldera formed between the Aso-2 and Aso-3 eruptions (Ono and Watanabe, 1985; Matsumoto et al., 1991).

Post-caldera cones have arisen near the center of the caldera since the Aso-4 eruption at ca. 90 ka (Ono and Watanabe, 1985). The central cones have produced voluminous fallout tephra layers and lava flows. At least 17 cones are visible on the surface, but many more edifices, consisting of both lava and pyroclastics, have been detected under the present central cones by boreholes (Uto et al., 1994; Hoshizumi et al., 1997). The shapes and structures of the central cones vary depending on their chemistry, which ranges from basalt to rhyolite (Ono and Watanabe, 1985). Takanoobane lava dome (568 m a.s.l.; Watanabe, 2001) of biotite rhyolite was constructed near the western rim of the caldera at 51 ka (Matsumoto et al., 1991).

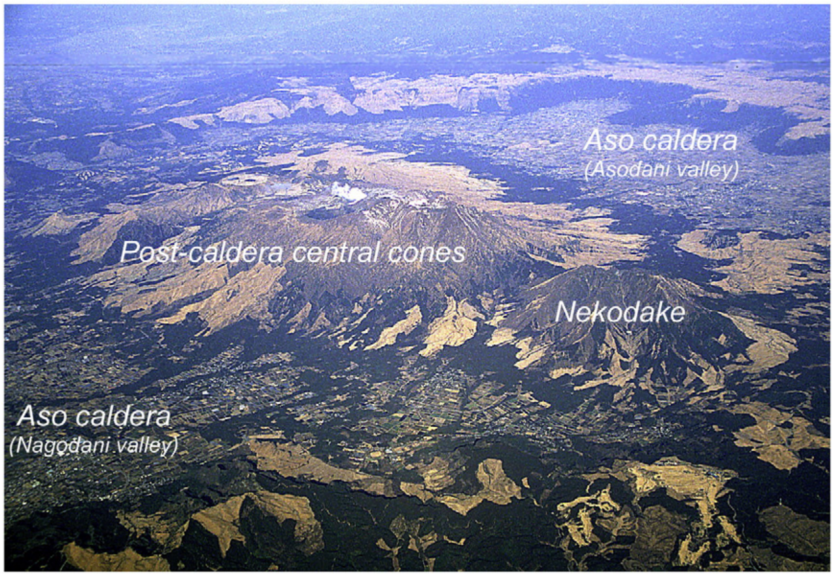

Fig. 1. Oblique view of Aso caldera and post-caldera central cones from the south.

Kusasenrigahama Volcano of pyroxene dacite is a welded pumice cone with a 1 km-diameter crater that produced one of the largest plinian pumice-fall deposits of the central cones. Eboshidake (1337 m) and Okamadoyama (1153 m) are stratovolcanoes of pyroxene andesite. Yomineyama (913 m), Washigamine, Naraodake (1331 m) and Takadake (1592 m: the highest peak of Aso Volcano) are stratovolcanoes of olivine–pyroxene andesite to basalt. They are composed of piles of agglutinate or welded spatter near their summits and lava flows near their bases. Janoo (754 m), Kishimadake (1326 m), Ojodake (1238 m) and Komezuka (954 m) are Holocene scoria cones of pyroxene–olivine basalt.

Nakadake Volcano (1506 m) is the only active central cone in Aso caldera, and is a composite volcano of basaltic andesite to basalt. Nakadake became active from ca. 22–21 ka (Miyabuchi et al., 2004a), and has formed an old edifice (agglutinate and lava), a young edifice (pyroclasts and lava) and a still younger pyroclastic cone (Ono and Watanabe, 1985).

3. Outline of tephrostratigraphic sequence

A thick tephra sequence erupted from the post-caldera central cones is preserved above the Aso pyroclastic-flow plateau, especially east of the caldera, because tephra dispersal is affected by the prevailing west to southwest wind direction in Japan. The total thickness of fallout tephra deposits after the Aso-4 eruption (89 ka; Matsumoto et al., 1991) reaches about 100 m at the eastern caldera rim (Watanabe and Fujimoto, 1992). Although the magma chemistry of the post-caldera central cones has a wide range from basalt to rhyolite, basaltic to basaltic andesitic magmas have dominated (Ono, 1989). Most of tephra layers distributed in and around Aso caldera are therefore mafic scoria-fall and ash-fall deposits. It is very difficult to distinguish these mafic tephra layers in the field because they are voluminous and so similar in appearance. In contrast, three key marker beds were known to be present in this complicated monotonous stratigraphy (e.g. Watanabe and Takada, 1990). They are Kikai Akahoya ash (K-Ah) and Aira Tn ash (AT), which are representative widespread tephra from southern Kyushu (Machida and Arai, 1983), and Kusasenrigahama pumice (Watanabe et al., 1982). Moreover, a recent tephrochronological study (Miyabuchi et al., 2003) identified 36 pumice beds around the caldera and revealed that they are very useful for correlation of complex stratigraphic units at separated localities. However, on the floor of Aso caldera these tephra deposits are buried under the subsequent thick tephra. Even east of the caldera, tephra deposits older than 10 ka are extremely limited in exposure. Fortunately, since 1995 several 10-m-high road cuts were created during construction of a forestry road that runs north to south about 5 km east of the eastern caldera rim (Fig. 2). New field examination of tephra stratigraphic sections located mainly east of Aso caldera, including these road cuts, was conducted. The locations of all measured stratigraphic sections are shown in Fig. 3.

On the basis of key pumice beds and two widespread ash-fall deposits from southern Kyushu, numerous tephra deposits distributed around the Aso caldera have been correlated between separated localities (Fig. 4). An integrated stratigraphy of the thick sequence of tephra fallout deposits above the Aso-4 pyroclastic-flow deposit has been constructed (Fig. 5). Tephra marker beds from the post-caldera cones are summarized in Table 1.

4. Description of major tephra deposits

Bulk volumes of major tephra beds have been calculated by using their isopach data according to the Fierstein and Nathenson (1992) method. Mineral assemblages of ash or crushed lapilli samples for all major tephra layers were determined by observation under a binocular microscope (Table 1). Major element analyses of coarse lapilli or blocks included in representative tephra beds were performed using X-ray fluorescence techniques at the National Agricultural Research Center for Kyushu Okinawa Region (Table 1).

4.1. Nojiri pumice (NjP)

Nojiri pumice (NjP) occurs about 2.5 m above the top of the Aso-4 pyroclastic-flow deposit and reaches a maximum thickness of 132 cm at a representative section (site A0218) about 6 km SE of the caldera rim. There are several minor scoria-fall deposits between the Aso-4 deposit and NjP. NjP is the lowermost key tephra of the constructed pyroclastic sequence to the southeast of Aso caldera (Miyabuchi et al., 2003). The tephra is divided into lower and upper parts by an olive-brown (2.5Y4/6; Munsell color) 10-cm-thick silty ash (Fig. 6A). The lower part (77 cm thick) is composed of light yellow (2.5Y7/3) to pale-yellow (2.5Y8/4) weathered pumice clasts with small amounts of lithic and dark colored pumice, and divided into at least four fall units by differences in grain size and color. The maximum size of pumice (MP; average long-axis diameter of the three largest pumice clasts at