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Utility of trace elements in apatite for discrimination and correlation of Quaternary ignimbrites and co-ignimbrite ashes, Japan

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A B S T R A C T

Apatite is a common accessory mineral in intermediate and felsic igneous rocks. Because apatite has a wide range of trace-element compositions as well as strong resistance to diagenetic alteration, the trace-element composition of apatite has been used for tracing petrogenetic processes of plutonic bodies as well as the tephrochronology of Paleozoic tephras. However, it has been little used in Quaternary volcaniclastic deposits. Our studies of apatite trace-element compositions in representative Quaternary ignimbrites and their corresponding co-ignimbrite ashes in Japan demonstrated that such compositions are not affected by welding and can be successfully used for discrimination of, and correlation between, tephras and ignimbrites. We also could distinguish different tephra deposits and ignimbrites from the same caldera. Although most apatite trace-element compositions did not change throughout the succession of ejecta from a single eruption, the Fe contents in apatite varied across stratigraphic horizons. Consequently, we were able to correlate the Fe contents of apatite phenocrysts in specific ignimbrite horizons and their corresponding co-ignimbrite ashes and thus identify the phase of the eruption during which the major part of a co-ignimbrite ash was released.

1. Introduction

Apatite, a common accessory mineral in intermediate to felsic igneous deposits, exhibits a wide variation in its trace-element compositions, and studies have demonstrated a clear relationship between the contents of several elements in apatite and the nature of its host magmas (e.g., Hoskin et al., 2000; Prowatke and Klemme, 2006; Chu et al., 2009; Miles et al., 2014). Therefore, trace-element compositions of apatite have been used to evaluate petrogenetic processes of igneous rocks (e.g., Piccoli and Candela, 2002; Chu et al., 2009). Another notable feature of apatite is its strong resistance to diagenetic and pedogenic alteration, weathering, and diffusion processes (e.g., Morton and Hallsworth, 2007; Churchman and Lowe, 2012), which has enabled researchers to establish tephrochronology in highly altered Ordovician bentonites (Carey et al., 2009; Sell and Samson, 2011a, 2011b; Sell et al., 2015).

Despite its utility and widespread application, apatite chemistry has been little used in Quaternary volcanic and volcaniclastic deposits. Sell and Samson (2011a) determined apatite trace-element compositions of several Quaternary tephras and demonstrated its utility in tephrochronology. However, they noted that their tephras were obtained from different tectonic settings around the world, and the possibility of using this means to discriminate among tephras from the same tectonic setting and source region is unconfirmed. Here we present apatite trace-element compositions from Quaternary ignimbrites and their co-ignimbrite ashes in Japan and address four points: (1) the effect of welding upon apatite trace-element compositions, (2) the stratigraphic changes in trace-element compositions of apatite within ignimbrite successions, (3) the possibility of using apatite trace-element compositions to discriminate among different ignimbrites from the same caldera, and (4) the possibility of correlating ignimbrites and their distal co-ignimbrite ashes based on apatite trace-element compositions.

2. Samples investigated

Three representative Quaternary calderas in Japan were selected because the widespread co-ignimbrite ashes derived from them are

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important tephras for age determination of Quaternary sediments in Japan (e.g., Matsuzaki et al., 2014) and because they contain abundant apatite phenocrysts. Samples were taken from the ignimbrites and corresponding co-ignimbrite ashes that are the product of explosive caldera-forming eruptions (Fig. 1). Sample details are listed in Table 1. Eruption volumes given below are minimum estimates because they were based on the volume of ejecta with various degrees of welding.

2.1. Aso Caldera

Aso Caldera, the largest caldera (18 × 25 km) in southwestern Japan, is in the center of Kyushu Island (Fig. 1). Four major series of eruptions in this caldera from 266 to 89 ka are named the Aso-1 to Aso-4 eruption cycles in ascending order (Fig. 2; Ono et al., 1977). By “eruption cycle” we mean a series of many eruptive pulses with only short time gaps between them (Kaneko et al., 2007).

The products of the Aso-1 eruption cycle (266 ± 14 ka) consist of pumice fall deposits and overlying densely welded pyroclastic flow deposits of pyroxene rhyolite that contain abundant obsidian lenses (Ono et al., 1977). The total eruption volume is estimated at 50 km^3 (Committee for Catalog of Quaternary Volcanoes in Japan, 1999).

Ejecta of the Aso-2 eruption cycle (141 ± 5 ka) is divided into subunits Aso-2TL, Aso-2A, Aso-2B, and Aso-2T in ascending order (Fig. 2; Ono et al., 1977). These are rhyolitic plinian pumice fall deposits, densely welded rhyolitic pyroclastic flow deposits, andesitic scoria flow deposits, and andesitic scoria fall deposits, respectively. The total eruption volume is estimated at 50 km^3 (Committee for Catalog of Quaternary Volcanoes in Japan, 1999).

Ejecta of the Aso-3 eruption cycle (123 ± 6 ka) is divided into subunits Aso-3W, Aso-3A, Aso-3B, and Aso-3C (Fig. 2; Ono et al., 1977). Aso-3W is a rhyolitic pumice fall deposit. Aso-3A is a rhyolitic pumice flow deposit that varies from non-welded to densely welded tuff. Aso-3B and Aso-3C are both andesitic scoria flow deposits; the scoria of Aso-3B is aphyric whereas the scoria of Aso-3C contains abundant phenocrysts. The total eruption volume is estimated at more than 150 km^3 (Committee for Catalog of Quaternary Volcanoes in Japan, 1999).

The Aso-4 eruption cycle (89 ± 4 ka) was one of the largest Quaternary eruptions in Japan, and its co-ignimbrite ash covered most of the Japanese islands (e.g., Aoki, 2008). Its ejecta is divided into subunits Aso-4A, Aso-4T, and Aso-4B (Ono et al., 1977; Kamata, 1997). Aso-4A consists of dacitic pumice flow deposits that range from non-welded to densely welded. Aso-4T is a lithic-rich pumice flow deposit consisting of altered orange pumice and coarse breccia. Aso-4B is a densely welded tuff except at its top. The total eruption volume is estimated at more than 600 km^3 (Committee for Catalog of Quaternary Volcanoes in Japan, 1999).

Bulk rock samples (in welded and non-welded facies) and samples of single pumice clasts (in non-welded facies) were taken from each subunit of all four eruption cycles.

2.2. Shishimuta Caldera

Shishimuta Caldera, in northeastern Kyushu Island (Fig. 1), had two eruption cycles during the Quaternary (Fig. 2; Kamata, 1989a, b; Kamata et al., 1994a, b; Kamata and Hoshizumi, 1996). The first eruption cycle (990 ± 30 ka) created the Yabakei pyroclastic flow deposit, and the second (850 ± 30 ka) created the Imaichi plinian pumice fall and Imaichi pyroclastic flow deposits.

The Yabakei pyroclastic flow deposit consists of hornblende dacite pumice flows and has a volume greater than 110 km^3 (Kamata, 1989a). Most parts are densely welded, and its uppermost part is non-welded to partly welded in the studied section.

The Imaichi pyroclastic rocks consist of basal plinian pumice fall deposits overlain by several pyroclastic flow deposits, with a total volume greater than 90 km^3 (Kamata et al., 1994b). The lower and upper parts of these deposits are non-welded to partly welded, and

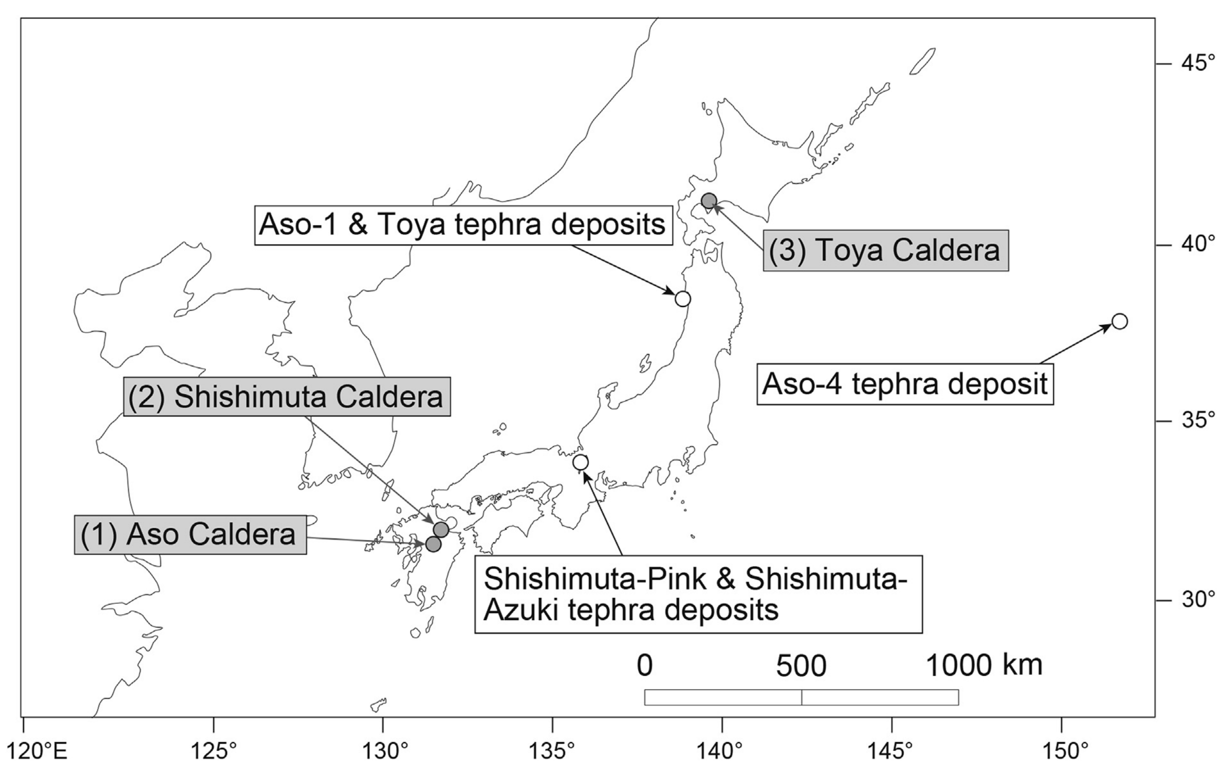

Fig. 1. Locality map showing Aso, Shishimuta, and Toya calderas and the sample sites of the Aso-1, Aso-4, Shishimuta-Pink, Shishimuta-Azuki, and Toya tephras.