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Origin and mode of emplacement of lithic-rich breccias at Aso Volcano, Japan: Geological, paleomagnetic, and petrological reconstruction

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ABSTRACT

Takajosan breccia rocks are distributed around the southwestern caldera rim of the Aso Volcano in Japan. They are characterized by coarse lithic breccias with a pumiceous matrix. The proximal coarse lithic breccias are divided into the lower massive unit and the upper stratified unit. The lower massive lithic breccias tend to transform laterally into tuff breccias and pumiceous lapilli tuffs. Paleomagnetic results showed that all of the deposits were deposited at high temperatures of 175–560 °C. This was also supported by geological characteristics such as spatter clasts, clasts with a bread-crust texture, and weakly welded parts. These features clearly show that the deposits originated from pyroclastic density currents (PDCs). The dense lithic-rich lithofacies, low vesicularity of pumice, lack of plinian fall deposits, and radial distribution indicate that the deposits were derived from boil-over PDCs rather than plinian column-collapse PDCs. The SiO_2 contents of the matrix glasses of the proximal lower massive breccia showed a progressive decrease from the bottom toward the upper part. We interpret that this chemical variation corresponds to chemical zonation of the magma chamber. This indicates that the massive deposits aggraded progressively from the base upwards (progressive aggradation), rather than through en masse freezing. The vertical lithofacies changes of the proximal breccias from the lower massive to the upper stratified units indicate that a sustained current in a quasi-steady state switched to an unsteady current with the progression of the volcanic activity.

1. Introduction

Coarse lithic breccias created as a result of several processes constitute a large portion of a volcanic edifice (e.g., Grubensky et al., 1998; Smith et al., 1999). Therefore, an accurate interpretation of the emplacement mode of such breccias can lead towards a better understanding of volcano development. Previous researchers have proposed the following emplacement modes for lithic breccias: (1) co-ignimbrite lag breccias related to pyroclastic density currents originated from magmatic (e.g., Druitt and Sparks, 1982; Walker, 1985; Branney and Kokelaar, 1997) or phreatomagmatic explosions (e.g., Perez-Torrado et al., 1997; Gómez-Tuena and Carrasco-Núñez, 2000); (2) block-and-ash flows derived from a gravitational collapse of lava domes (e.g., Yamamoto et al., 1993; Sarocchi et al., 2011); (3) re-sedimented volcaniclastic deposits (e.g., Fisher, 1960; Kataoka et al., 2008); (4) coarse rockfall or rock avalanche deposits related to caldera collapses (Lipman, 1976); and (5) autoclastic breccias originating from lava flows (e.g., Hackett and Houghton, 1989; Grubensky et al., 1998; Smith et al., 1999). These emplacement modes can be distinguished by the emplacement temperature, which can be revealed by paleomagnetic or geological studies, the clast shapes, compositions of the clast and matrix, lithofacies variation and others. However, the resulting deposits in these cases may be texturally similar, and distinguishing between the different modes can be difficult (Bardot, 2000). Therefore, careful investigation of the lithic breccias is needed in order to accurately reconstruct the emplacement mode.

The emplacement process of sediments in fluvial, marine and volcanic environments is generally deduced from geological evidence. In addition, paleomagnetic and petrological information can potentially assist in determining the emplacement mode of volcanic sediments. For example, the emplacement temperature of a volcanic deposit can be recorded in magnetic minerals, thereby providing evidence of the emplacement mode. Volcanic products, which are evacuated from a chemically zoned magma chamber, change the compositions of erupted

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materials over time. Therefore, the vertical chemical variation of a deposit can provide information of the emplacement process (Branney and Kokelaar, 1997; Carrasco-Núñez and Branney, 2005). Although each method is individually useful for the reconstruction of the emplacement mode of volcanic sediments, no previous studies have combined all these methods for lithic-rich breccias. The combination of geological, paleomagnetic, and petrological methods to investigate the emplacement mode of volcanic sediments should provide more comprehensive information and interpretations.

A large amount of coarse lithic breccias is distributed around the southwestern caldera rim of the Aso Volcano in Japan. Based on geological data, Ono and Watanabe (1985) have suggested that these lithic breccias are pre-caldera volcanic products. However, the emplacement mode of the breccias has not been revealed. In this study, we report on the geological, paleomagnetic, and petrological characteristics of these coarse lithic breccias in order to reconstruct the emplacement mode.

2. Aso Volcano

The Aso Volcano is located in central Kyushu, southwestern Japan (Fig. 1a). Its eruptive history is characterized by four gigantic pyroclastic eruptions, which are called Aso-1, Aso-2, Aso-3, and Aso-4 (Ono et al., 1977). The K–Ar age (Matsumoto et al., 1991) and volume (Watanabe, 2001) of Aso-1, Aso-2, Aso-3, and Aso-4 are 266 ± 14 ka and >30 km^3, 141 ± 5 ka and >25 km^3, 123 ± 6 ka and >40 km^3, and 89 ± 7 ka and >80 km^3, respectively. These large pyroclastic eruptions resulted in the formation of a large caldera (25 km north–south and 18 km east–west) (Matumoto, 1943), although the caldera structure corresponding to each eruption is ambiguous. Post-caldera central cones were formed

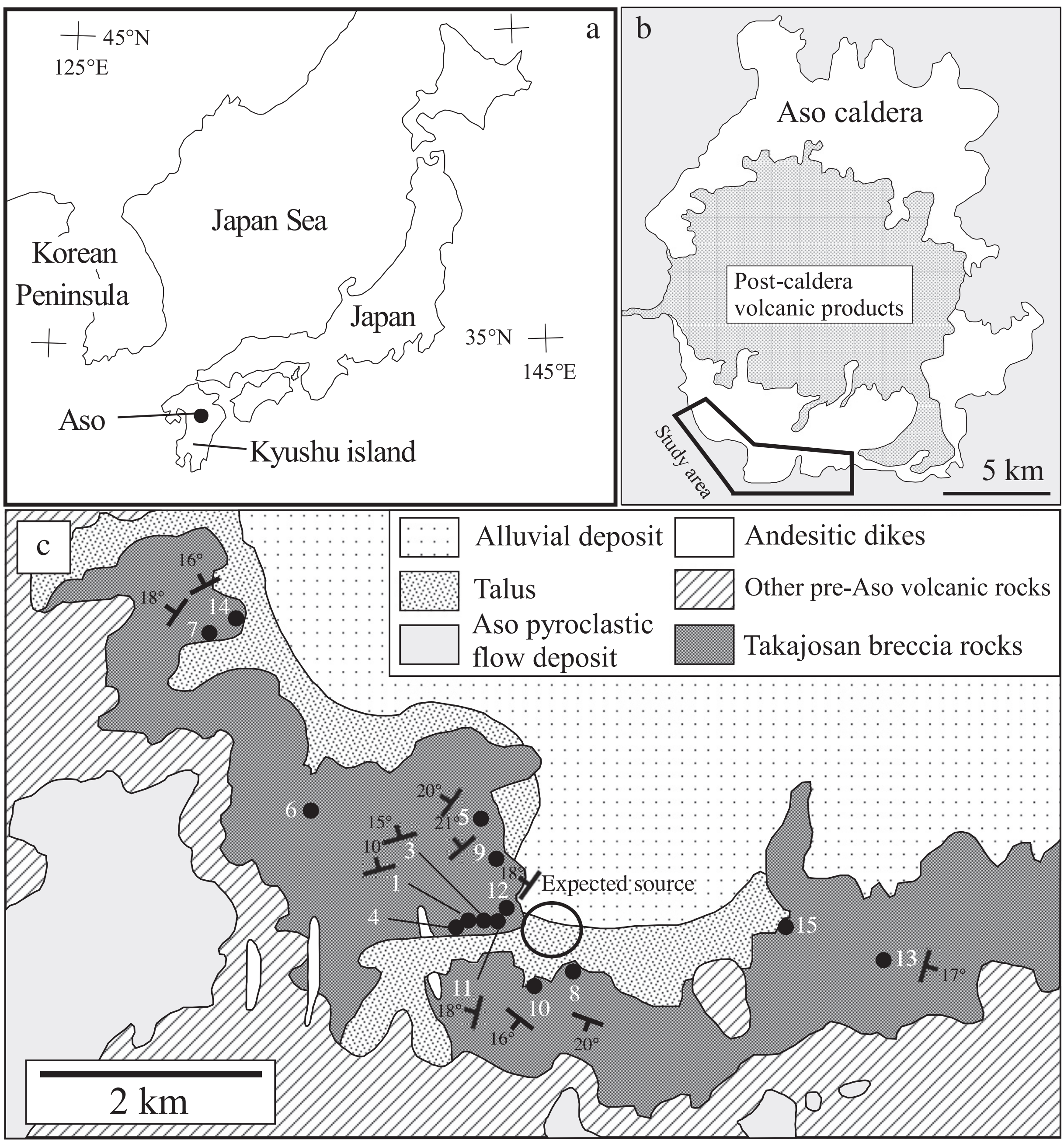

Fig. 1. (a) Sketch map of Japan and the adjacent area. (b) Simplified map of the Aso caldera showing the location of the studied area. (c) Simplified geological map modified from Hase et al. (2008), which shows the distribution of Takajosan breccia rocks and site localities with their strike and dip of stratification.