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菊池, 瞭平

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Doctoral Dissertation

Generation and evolution processes of voluminous
magmas in the large silicic eruptions at Aso volcano:
petrological and geochemical investigations based on
micro-scale analysis

(阿蘇火山の大規模珪長質噴火における大量のマグマの生成と進化プロセス：微小領域分析に基づく岩石学的・地球化学的研究)

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Graduate School of Science, Kobe University

KIKUCHI ryohei

菊池 瞭平

Abstract

Caldera volcanoes are common in continental arcs and continental hot spots. The activity is characterized by formation of voluminous silicic magma reservoir at the upper crust and large eruption that ejects the voluminous silicic magma ($>10^3 \text{ km}^3$). It is important to understand magmatic system of the caldera volcano because it is an endmember of various volcanic activities, contributes evolution of the continental crust by generation of the voluminous silicic magma, and impacts environment and human society by the large eruption. To understand the caldera volcanic systems, it is most important to elucidate generation of the voluminous silicic magma that characterizes the caldera volcanoes. We investigated this problem for Aso volcano in SW Japan, which is one of the largest caldera volcanoes in the world. The Aso volcano repeated large eruptions four times, which are Aso-1, Aso-2, Aso-3, and Aso-4. The large eruptions ejected voluminous silicic magma and a small amount of mafic magma as pumice and scoria, respectively. Compositions of the silicic and mafic magmas are dacitic to rhyolitic and basaltic andesitic to andesitic, respectively, in High-K series proposed in Gill (1981). Sr isotopic compositions of the silicic and mafic magmas are identical, indicating the source material of the two magmas is the same. Based on the petrological similarity in the High-K series and Sr isotopic composition between the silicic and mafic magmas, previous studies proposed two main generation models for the silicic and mafic magmas assuming a single magma source. One is that the silicic and mafic magma are generated by partial melting of a single mafic rock. The other is that the silicic and mafic magmas are generated by crystallization of a single magma. In both the models, basaltic magma is thermally and materially involved in the generation of the voluminous magma. To clarify validity of the generation models, we focus on a micro-scale analysis of melt inclusion (MI) and groundmass (GM). The MI is a glass in phenocryst, and GM is matrix glass in ejecta. The MI and GM glasses can record melt composition in various stages from magma generation to eruption. Therefore, we can reveal magma generation and evolution process by the compositional analysis of the MI and GM.

Our research goal is to reveal a magma plumbing system of the large eruptions in the Aso volcano, especially petrogenetic relationship between the silicic and mafic magmas.

For this goal, we analyzed MI and GM in the pumices (silicic magma) and scoriae (mafic magma) of the Aso-2, 3, and 4 eruptions. In addition, we also analyzed MI in basaltic scoriae of Aso-4/3 Z-20 and Z-15 and Aso-CC Ksh small basaltic eruptions, which occur before and after the large eruptions, to clarify a role of basaltic magma in generation of the voluminous magma. Analysis of major and trace element compositions is performed using SEM-EDS at Kobe University and Laser ablation ICP-MS at ETH Zürich, respectively.

We summarize important petrological and geochemical features of the Aso magma for magma generation, as revealed by our analytical results and previous studies.

- (1) The pumices and scoriae of the large eruptions are dacitic to rhyolitic and basaltic andesitic to andesitic, respectively, in the High-K series, and have the same Sr isotopic compositions, as reported in previous works. These features indicate that the silicic and mafic magma were generated from the same mafic material.
- (2) MI and GM glasses in the pumice and scoria of the three large eruptions are classified into three types based on the major element composition obtained in our study: High-K Silicic type (HK-S), High-K Mafic type (HK-M), and Medium-K (MK) type.
 - (a) The HK-S glasses are found in the pumices and quenched melts of the silicic magmas. Compositions of the HK-S glasses are dacitic to rhyolitic in the High-K series.
 - (b) The HK-M glasses are found in the scoriae and quenched melts of the mafic magmas. Compositions of the HK-S glasses are basaltic andesitic to dacitic in the High-K series.
 - (c) The MK glasses are found in the Aso-3 and Aso-4 scoriae. Compositions of the MK glasses are andesitic in the Medium-K series and different in the K series from the whole rock composition of the Aso-3 and 4 scoriae, indicating that the MK glasses do not have a genetic relationship with the mafic magma by simple fractionation.

- (3) The HK-S, HK-M, and MK glasses are also clearly distinguished in normalized contents of middle to heavy rare earth elements (MREE to HREE). The HK-S glasses show that the contents of MREE are lower than those of HREE values. The HK-M glasses show that the contents of MREE are roughly equal to those of HREE. The MK glass in the Aso-3 scoria has lower contents of MREE and HREE than the HK-M glasses, while the MK glass in the Aso-4 scoria has higher content of those than the HK-M glasses.
- (4) MI in the Z-20, Z-15, and Ksh basaltic scoriae (B-MI) are basaltic to andesitic in the Medium to High-K series and form a continuous trend with the HK-M glasses in major and trace elements, indicating a petrogenetic relationship between the B-MI and HK-M glasses.

We discuss petrogenesis of melts of the HK-M and HK-S glasses (called HK-M and HK-S melts) that explains Feature 3 by crystallization of the basaltic B-MI melt. Our assumption of basaltic B-MI melt as a source material of the HK-M and HK-S melts is based on Feature 1 and Feature 4. Examination method is to calculate composition of melt based on phase proportion of crystallization and elemental distribution coefficients of the minerals. The proportions of crystallized minerals are determined by two independent methods: one is results of equilibrium and fractional crystallization experiments of basaltic magma in previous studies, and the other is an estimation by mass balance calculation from the change of major elemental composition from the basaltic B-MI to HK-S.

Results of the examination suggest that the HK-M melt can be generated by equilibrium and fractional crystallization of the basaltic B-MI melt with a small amount of amphibole. In addition, it can be also produced by equilibrium partial melting of a mafic rock with the basaltic B-MI melt composition because equilibrium crystallization and equilibrium partial melting are reverse processes. On the other hand, the HK-S melt was generated by only fractional crystallization of the HK-M melt with apatite and a small amount of amphibole. Unlike the HK-M melt, the HK-S melt cannot be generated by partial melting since there is no melting process corresponding to the reverse process of fractional crystallization.

We also discuss petrogenesis of the MK melts in the Aso-3 and 4 scoriae by mass balance calculation based on the compositions. It is concluded that both the melts were generated by melting plagioclase and apatite with/without amphibole. The petrogenesis can be interpreted by remelting of crystal mush in a shallow magma reservoir by heat from a high-temperature magma supplied to the reservoir.

We propose a magma plumbing system for the Aso volcano based on the petrogenesis of the HK-M, HK-S, and MK melts. Hereafter, the three melts are referred to as magmas (e.g., HK-M magma). First, mantle-derived basaltic magma is supplied to the lower crust. The basaltic magma is differentiated into the HK-M magma. At the same time, heat from the basaltic magma melts the lower crust, which was formed by solidification of previously injected basaltic magma, producing the HK-M magma. Second, the HK-M magma ascends through the crust and forms a shallow magma reservoir. Third, the HK-M magma is differentiated into the HK-S magma by fractional crystallization. Last, a new HK-M magma is supplied to the magma reservoir from the lower crust again. The HK-M magma is emplaced under the HK-S magma body and forms a compositionally stratified reservoir. At this time, the MK magma is generated by remelting of crystal mush by heat from the HK-M magma.

Our study provides two important new insights into generation of voluminous magma in caldera volcanoes. One is that mafic magma (i.e., HK-M magma) initially forms a shallow magma reservoir, then the mafic magma is differentiated into voluminous silicic magma (i.e., HK-S magma). The other is that both the crystallization of basaltic magma and partial melting of the basaltic crust contribute to generation of the mafic magma. The simultaneous occurrence of these generation processes is efficient in producing magma and, thus, reasonable for the generation of voluminous magma.

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1. Introduction

Caldera volcanoes are common in continental arcs and continental hot spots (Cole et al., 2005). The volcanic activity is characterized by formation of voluminous silicic magma reservoir at the upper crust and large eruption that eject the voluminous magma ($>10^3 \text{ km}^3$) as VEI-6 to 8 (Volcanic Explosivity Index proposed in Newhall and Self (1982)) as pyroclastic fall and flow forming thick volcanic deposits (Ignimbrite). Rapid discharge of the voluminous magma by the large eruption makes the shallow magma reservoir empty and collapses the crust above the reservoir, resulting in a caldera formation (Lipman, 1997). We consider that research of the caldera volcano is important in the following scientific and social perspectives.

- (1) The caldera volcanoes are an endmember of volcanic activities in continental arc because of their magma volume and evolved composition. Therefore, understanding the caldera volcanism and comparing it to mafic endmember (i.e., basaltic activity) and intermediate activities (i.e., andesitic activity) are important to elucidate volcanic diversity.
- (2) The caldera volcanism is the largest silicic activity on the Earth and probably contributes to growth of the continental crust because granite in the upper crust is formed by solidification of the silicic magma (Bachmann et al., 2007). Thus, investigating generation process of voluminous magma in the caldera volcano can provide new insights into evolution of the Earth.
- (3) The large eruptions have a significant impact on global environment (e.g., volcanic winter) and human society, by ejecting large amounts of volcanic ash and aerosols over a wide areas and catastrophic pyroclastic flow (Newhall et al., 2018). We can contribute to disaster prevention by basic research to understand the caldera volcanism and to predict long-term activity of the caldera volcano.

Our primary concern is to understand generation of the voluminous silicic magma, which is the most important feature of the caldera volcanoes. To understand the magma generation, we analyzed micro-scale volcanic glass in ejecta for the Aso volcano, Japan, which is one of the largest caldera volcanoes in the world. We first introduce previous studies about the caldera volcano and background of our study in this chapter. Next, we explain the Aso volcano and the research method in Chapters 2 and 3, respectively. Analytical result and discussion are shown in Chapters 4 and 5, respectively. Finally, Chapter 6 summarizes this study.

1.1.Previous studies

Caldera volcanoes have been studied by many geological, petrological, geochemical, and geophysical researches, and various information have been revealed from magma generation to eruption (Bachmann and Huber, 2016). We summarize important insights for generation and evolution of voluminous magma below.

Structure of magma plumbing system in caldera volcanoes

Many previous studies have proposed a magmatic system from magma generation to eruption, called magma plumbing system (e.g., Bachmann and Huber, 2016) (Fig. 1). This system is generally considered to have the following processes. First, basaltic magma is generated by partial melting of the upper mantle. Second, the basaltic magma is supplied to the lower crust. The basaltic magma produces evolved magma by its own crystallization and partial melting of surrounding crust at the lower crust (deep crustal hot zone (Annen et al., 2006; Solano et al., 2012)). Third, the evolved magma at the lower crust rises to the upper crust, form a shallow reservoir, and evolve further. Last, the accumulated magma discharge from the shallow reservoir. System of the shallow reservoir is becoming understood, because a lot of information of the reservoir is recorded in ejecta as crystals and glasses. On the other hand, the magma generation and evolution in the crust are still controversial (see below).

Shallow magma reservoirs of caldera volcanoes have been studied by many previous works (Bachmann et al., 2007; Bachmann and Bergantz, 2008; Cashman and Giordano, 2014; Bachmann and Huber, 2016). The reservoirs are considered to be composed of melt-rich zone (melt pocket, lens, or chamber) surrounded by high-crystallinity (≥ 40 wt.%) zone (crystal mush) by geological and petrological researches and physical models (e.g., Bachmann and Bergantz, 2004; Hildreth, 2004). Depths of the magma reservoirs in many caldera volcanoes are estimated about 2 ± 0.5 kbar by geophysical and petrological studies (Huber et al., 2019). Time scale for some processes in the magma reservoir has been estimated by radiometric dating (e.g., U-Pb and U-Th dating of zircon) and diffusion geochronometry (e.g., Mg in plagioclase) in recent years (e.g., Wilson and Charlier, 2009; Costa et al., 2020). The former generally shows a long time scale ($\sim 10^4$ - 10^5 years) of magma reservoir growth and storage in the crust, and the latter shows a short time scale (hours to years) of magma reactivation, remobilization, and mixing process by input of new hot magma in reservoir.

Nature of magma in caldera volcanoes

Nature of magma in caldera volcanoes has been revealed by descriptions of ejecta in geological investigations and compositional analysis of whole rock and phenocryst in petrological and geochemical studies. Based on the previous works, we summarize four important points about magma generation and evolution.

- (1) Large eruptions can be largely classified into two categories: One is eruptions of mainly silicic (rhyodacitic to rhyolitic) magma followed by ejection of mafic (mostly basaltic andesitic to andesitic) magma (e.g., K-Ah, Kikai (Maeno and Taniguchi, 2007); Bishop Tuff, Long Valley (Hildreth and Wilson, 2007); Crater Lake (Bacon and Druitt, 1988); Huckleberry Ridge Tuff, Yellowstone (Wilson, 2008); Carpenter Ridge Tuff, Bachelor caldera (Bachmann et al., 2014)). Erupted volumes of the silicic magmas are usually significantly larger than that of the mafic magmas. The other is eruptions of silicic (rhyodacitic to rhyolitic) magma only (e.g., Toya ignimbrite, Toya (Goto et al., 2018); AT, Aira (Aramaki, 1984); K-Th, Kikai (Ono, 1982); Oruanui, Taupo (Wilson et al., 2006)).
- (2) The large eruptions repeatedly occur in many caldera volcanoes at intervals of tens of thousands to a million years (e.g., Kikai, Japan; Taupo, New Zealand; Toba, Indonesia; and Yellowstone, the USA) (Ono, 1982; Wilson et al., 1995; Perkins and Nash, 2002; Chesner, 2012).
- (3) The silicic magmas in both the above two eruption types are generally poor in crystals (<10-20 wt.%) and homogeneous in composition, except for a few crystal-rich (up to 45 wt.%) dacitic magmas called “monotonous intermediates” (e.g., Fish Canyon Tuff (Bachmann et al., 2002); Antana ignimbrite (Lindsay et al., 2001)).
- (4) Even in cases without direct eruption of mafic magma, traces of less differentiated components are always found in the silicic magma, such as high-An content plagioclase (e.g., AT, Aira (Nishihara et al., 2024); K-Th, Kikai (unpublished data of authors)) and some banded pumice and/or mafic enclave (e.g., Toya ignimbrite, Toya (Goto et al., 2018); Fish Canyon Tuff, La Garita caldera (Bachmann et al., 2002); Oruanui, Taupo (Wilson et al., 2006)).

From these points, the caldera volcanism is mainly dominated by the silicic magmas. However, the mafic magma is commonly present in the silicic magma system and should have important roles in the system, such as magma generation and evolution.

Magma generation

We would like to understand generation processes of the silicic and mafic magmas in caldera volcanoes, which are still under discussion. Two endmember models have been proposed for the generation of silicic magma in which mantle-derive basaltic magma contributes materially or thermally: crystallization of the basaltic magma as the source material of the silicic magma, or partial melting of crustal rock by basaltic magma as a thermal source. The crystallization of basaltic magma is a fundamental process in magmatic differentiation and can explain petrological features of many silicic magmas (Gill, 1981; Musselwhite et al., 1989; Sisson and Grove, 1993; Mortazavi and Sparks, 2004; Sisson et al., 2005; Ulmer et al., 2018). The crustal melting occurs by heat from high-temperature magma (e.g., mantle-derived basaltic magma). The melting model is supported by physical models under specific condition (e.g., Huppert and Sparks, 1988; Koyaguchi and Kaneko, 2000) and petrological studies (e.g., Beard and Lofgren, 1991; Tamura and Tatsumi, 2002; Chen and Grapes, 2007; Nishihara et al., 2024). Determining validity of the two models is not easy, because equilibrium crystallization is reverse process of equilibrium melting, meaning when one process can explain magma generation the other can also explain it. On the other hand, Rayleigh fractional crystallization, which remove crystals from magma, and melting are irreversible processes. If we can detect the fractional processes, we determine which of these processes occurred in magma generation. However, it is difficult to detect the processes because original property of magma at generation is largely lost from erupted magma due to evolution processes in the crust, such as crystallization, fractionation, remelting, magma mixing, and contamination of crustal material.

Problems to solve

To reveal the generation process of voluminous silicic magma, we focus chemical composition of micro volcanic glass in ejecta. The glass records many magmatic processes such as crystallization and melting (e.g., Wolff et al., 2020). Thus, original nature of magma at generation can be revealed by extracting detailed magmatic processes from the glass. Details of the analysis are described in Section 1.2 In addition, we should discuss petrogenetic relationship between the silicic magma, mafic, and mantle-derive basaltic magma in caldera volcanoes.

1.2 This study

Micro-scale analysis of Melt inclusion and Groundmass

We focus a micro-scale analysis of melt inclusion (MI) in phenocryst and groundmass (GM), which are volcanic glasses in ejecta. The MI is a glass that is quenched melt in phenocryst captured during crystallization of host mineral in magma (Roedder, 1979, 1984). Size of the MI is generally 10s μm (Fig. 2). The MI maintain its composition at the time of capture because host crystal prevents transport of the melt to the outside after the capture. Thus, the MI has a potential to record changes in melt composition during crystallization and mixing of magma. The GM is composed of glass and fine-grained crystal (from “devitrification”) and is interpreted as a melt in the magma reservoir just prior to eruption. Therefore, the MI and GM can be regarded as material snapshots of magma plumbing systems, recording melt compositions at various stages from magma generation to eruption.

Analysis method and previous studies of the MI are summarized in many review papers and books (e.g., De Vivo and Bodnar, 2003; Cannatelli et al., 2016; Rose-Koga et al., 2021). The analysis mainly measures major element, trace element, and volatile contents by EPMA, LA-ICP-MS, SIMS, and FT-IR. Previous studies have revealed water content of primitive magma, depth of magma reservoir, and degassing processes at shallow depth, based on the volatile content and its saturation (e.g., Anderson et al., 1989; Sobolev and Chaussidon, 1996; Roggensack et al., 1997; Saito et al., 2001). MI studies have also been conducted on caldera volcanoes and mainly clarified shallow process in magma reservoir (e.g., Chabiron et al., 2001; Saito et al., 2001; Chesner and Luhr, 2010). We focus on the generation of voluminous magma and analyze major and trace element composition of MI and GM.

The Aso volcano and Research purpose

The Aso volcano in central Kyushu, SW Japan is one of the largest caldera volcanos in the world (Fig. 3), and its eruptive activity began about 270 ka. The Aso volcano repeated large eruptions of VEI-6 to 7 four times, referred to as the Aso-1, Aso-2, Aso-3, and Aso-4 eruptions, and ejected voluminous silicic magma and small amount of mafic magma. Small eruptions (< VEI-5) have also occurred before and after the large eruptions and sometimes ejected basaltic magmas. A number of geological and petrological studies are conducted on the Aso volcano, and basic data have been accumulated, including geological description of volcanic deposits and petrographic descriptions and geochemical compositions of ejecta (Ono et al., 1977; Ono and Watanabe, 1985; Hunter, 1998; Miyoshi et al., 2005; Kaneko et al., 2007, 2015; Miyabuchi, 2009; Hoshizumi et al., 2022). Geophysical studies are also

conducted, and the current crustal structure beneath the Aso volcano is becoming understood (e.g., Sudo and Kong, 2001; Abe et al., 2010, 2017; Hata et al., 2016).

Purpose of our study is to understand magma plumbing system of the large eruptions in the Aso volcano. To do it, we focus on the following points.

- (1) Petrogenetic relationship between the silicic and mafic magmas.
- (2) Compositional feature of basaltic magmas, which likely contributes materially and/or thermally to generation of the silicic magma, and comparing them to those of the silicic and mafic magmas.
- (3) Factors and processes in generation of the voluminous silicic magma.

To do them, we analyze MI and GM in the silicic and mafic magmas of the Aso-2, 3, and 4 eruptions and MI in basaltic magma of the small eruptions to discuss a role of the basaltic magmas. The activity of the Aso volcano and nature of these magmas are described in the next section.

2. Geological and petrological backgrounds of the Aso volcano

This chapter describes backgrounds of the Aso volcano, focusing on the Aso-2, Aso-3, and Aso-4 large eruptions and basaltic small eruptions of Aso-4/3 and Aso-CC activities, which are the target of our research.

2.1. Large eruptions: the Aso-2, Aso-3, and Aso-4 eruptions

Eruptive activities and ejecta

The Aso volcano has undergone four large eruptions, the Aso-1, Aso-2, Aso-3, and Aso-4 eruptions (see Fig. 2, for cumulative volume step-diagram). Their eruption ages are estimated to be 266 ± 14 , 141 ± 5 , 123 ± 6 , and 86.4 ± 7 ka, respectively, by K-Ar and Ar-Ar dating (Matsumoto et al., 1991; Albert et al., 2019). Estimated volume of these large eruptions are 32, 32, >100, and >465 DRE (Dense Rock Equivalent) km³, respectively (Committee of catalog of Quaternary volcano in Japan, 1999; Kaneko et al., 2015; Yamamoto, 2015; Takarada and Hoshizumi, 2020). These large eruptions are characterized by discharge of voluminous silicic magma invariably followed by ejection of mafic magma (Lipman, 1967;

Ono et al., 1977; Watanabe, 1978; Tajima et al., 2017). The silicic magmas were erupted as pumice pyroclastic flows and/or falls, and the mafic magmas were ejected as scoria pyroclastic flows and/or falls (Fig. 5a). The pyroclastic deposits are widespread around the caldera rim (Fig. 3b) (Ono et al., 1977; Kamata, 1997; Hoshizumi et al., 2023), reaching up to about 150 km from the rim (Suzuki-Kamata and Kamata, 1990).

This study analyzed MI and GM in pumice and scoria of the Aso-2, Aso-3, and Aso-4 eruptions (Table 1). Pumice and scoria of the Aso-2 eruption for the analysis are collected from Aso-2TL pumice fall deposit and Aso-2T scoria fall deposit, respectively (Ono et al., 1977; Kamata, 1997). Aso-3 pumice for the analysis is sampled from Aso-3W pumice fall deposit and Aso-3A pumice flow deposit, and Aso-3 scoria is collected from Aso-3C scoria flow deposit (Ono et al., 1977). Petrological feature of the Aso-3W and Aso-3A pumices are the same (Kaneko et al., 2015). Aso-4 pumice and scoria are collected from Aso-4I-1 pumice flow deposit and Aso-4I-3 scoria flow deposit (Ono et al., 1977; Watanabe, 1978; Kamata, 1997; Kaneko et al., 2007). The naming of the Aso-4 ejecta is based on Kaneko et al. (2007).

Mineral assemblage of the Aso-2 and Aso-3 pumices is clinopyroxene, orthopyroxene, plagioclase, and Fe-Ti oxide (Table 1). The Aso-4 pumice contains these minerals, amphibole, and very small amount of olivine. Crystallinity of these pumices are less than 10 vol. % (Kaneko et al., 2007, 2015; (Kaneko et al., 2007, 2015; unpublished data of authors for the Aso-2 eruption). The Aso-2 scoria contains olivine, clinopyroxene, orthopyroxene, plagioclase, and Fe-Ti oxide. The Aso-3 scoria contains the same minerals as the Aso-2 scoria except olivine. The Aso-4 scoria contains the same minerals as the Aso-2 scoria and amphibole. Crystallinity of the scoriae are 20-30 vol. % (Kaneko et al., 2007, 2015; (Kaneko et al., 2007, 2015; unpublished data of authors for the Aso-2 eruption).

Whole rock chemical composition of the pumices and scoriae have been reported in many previous works (Ono et al., 1977; Watanabe, 1979; Ono and Watanabe, 1985; Kamata, 1997; Hunter, 1998; Kaneko et al., 2007, 2015; Keller et al., 2021) (Fig. 6). The pumices and scoriae are dacitic to rhyolitic and basaltic andesitic to andesitic, respectively, in High-K series proposed in Gill (1981). The high K₂O content in the ejecta is characteristic of the Aso volcano. In other active volcanoes in Kyushu, their ejecta belong to Medium-K series (e.g., Ohat et al., 1990; Inoue et al., 1994; Imura and Kobayashi, 2001; Miyoshi et al., 2010; Shibata et al., 2013; Kawanabe et al., 2015; Yamasaki et al., 2016) (Fig. 6). Whole rock Sr isotopic compositions of the pumices and scoriae of the Aso-2, Aso-3, and Aso-4 eruptions are concentrated within narrow range of 0.7040-0.7043 throughout the Aso-2 to Aso-4 (Hunter, 1998; Kaneko et al., 2007, 2015). Mineral composition of the scoriae are less evolved than that of the pumices (i.e., high Mg# and An content) (Kaneko et al., 2007, 2015; unpublished data of authors for the Aso-2 eruption).

Magma plumbing system beneath the Aso volcano

On the basis of the order of eruption from silicic to mafic magma during the large caldera-forming eruptions (Lipman, 1967; Watanabe, 1979; Kaneko et al., 2007, 2015), the magma reservoirs are often considered to have a zoned structure, with silicic magma (i.e., source of the pumices) overlying a more mafic and crystal-rich layer (i.e., source of the scoriae). Ishibashi et al. (2018) suggests the presence of crystal mush in the Aso-4 magma reservoir and disruption of it just prior to the Aso-4 eruption based on amphibole chemistry. Keller et al. (2021) infers a supply of high temperature mafic magma to the reservoir of the Aso-4 eruption just prior to the eruption based on reverse chemical zoning in phenocrysts and presence of mafic mineral in the silicic and mafic magmas. Depth of the Aso-4 magma reservoir is estimated to be ~10 km by amphibole geobarometer and high-pressure experiment (Ishibashi et al., 2018; Ushioda et al., 2020).

Magma generation at the Aso volcano has also been investigated in previous works. Three models for the magma generation have been proposed, assuming that the silicic and mafic magma were derived from a single source material based on the petrological similarities, such as the same Sr isotopic composition and the High-K series.

- 1) a crustal melting model in which the silicic and mafic magmas were generated by partial melting of the same mafic crust (Kaneko et al., 2015). The difference in composition between the two magmas is explained by different degrees of partial melting. Namely, the silicic magma was generated by low degree of partial melting, and the mafic magma was generated by high degree of partial melting. This model is based on the fact that Ni content in the silicic magma is higher than or not different from Ni content in the mafic magma. The relationship of the Ni contents means that the silicic magma cannot be generated by simple crystallization differentiation of the mafic magma because Ni content in magma generally decreases with crystallization.
- 2) A model dominated by fractional crystallization in which the crystal-poor, silicic endmember was produced by melt extraction from crystal mush of intermediate composition in the upper crustal reservoir magma reservoir (Keller et al., 2021). In this mode, the mafic scoria represents the cumulative crystal leftovers formed by melt extraction of the silicic endmember (complemented by some mixing with mafic recharge). This generation process is based on whole rock, glass, and mineral chemical composition and mass balance modeling reproducing the silicic and mafic

magma compositions by crystal-melt separation from a parent of intermediate composition.

- 3) Degassed crystallization model based on volatile content in melt (Miyagi et al., 2023). This model estimates the following process for the generation of the voluminous silicic magma: (I) volatile rich basaltic magma ascends to near the surface and degas there, (II) this degassed magma migrates back to depths of ≥ 12 km in the crust, (III) crystallization the degassed basaltic magma generates the silicic magma.

As described above, the magma generation processes of the three models are fundamentally different from each other. Our goal is to gain new insights into the magma generation process by MI and GM analysis and to update the models based on the insights.

2.2. Small eruptions: Aso-4/3 and Aso-CC eruptions

Small eruptive activities ($\leq$ VEI 5) occurred many times between the large eruptions and after the Aso-4 eruption (Ono et al., 1977; Miyabuchi, 2009, 2011; Miyoshi et al., 2013; Hoshizumi et al., 2022). The small activities are called the following: Aso-2/1 between the Aso-1 and Aso-2 eruptions, Aso-3/2 between the Aso-2 and Aso-3 eruptions, Aso-4/3 between the Aso-3 and Aso-4 eruptions, and Aso-CC after the Aso-4 eruption. The Aso-4/3 and Aso-CC activities have been well investigated in previous geological and petrological works because of their newer eruption ages which make it easy to survey and analyze the deposits (e.g., Miyoshi et al., 2005, 2011, 2012; Kawaguchi et al., 2021; Keller et al., 2023a, 2023b). We analyze MI in basaltic magmas of the Aso-4/3 and Aso-CC activities to clarify a role of the basaltic magmas in the generation of the silicic and mafic magmas in the Aso volcano. The Aso-4/3 and CC activities are described in detail below.

The Aso-4/3 activity discharged basaltic to rhyolitic magmas more than 40 times (Ono et al., 1977; Miyoshi et al., 2013; Hoshizumi et al., 2022). During the early stage of the Aso-4/3 activity (133 to 109 ka), mainly basaltic to basaltic andesitic magmas were ejected as scoriae (Ono et al., 1977; Hoshizumi et al., 2022). We focus on basaltic and basaltic andesitic scoria fall deposits of Z-20 and Z-15 eruptions in this early stage (Fig. 5b). Mineral assemblage in both the scoriae is olivine, clinopyroxene, plagioclase, magnetite, and slightly orthopyroxene (Table 1). Whole rock chemical composition of the Z-20 and Z-15 scoriae are basaltic andesitic and basaltic, respectively, in the Medium-K series (Fig. 6) (Hoshizumi et al., 2022). Whole rock Sr isotopic compositions of the Z-20 and Z-15 scoriae have not been

measured. Whole rock Sr isotopic compositions of the Z-20 and Z-15 scoriae have not been reported.

The Aso-CC activities ejected various magmas from basaltic to rhyolitic (Ono and Watanabe, 1985; Miyoshi et al., 2005, 2011, 2012, 2013; Miyabuchi, 2009, 2011; Kawaguchi et al., 2021). Latest 20,000 years, basaltic to basaltic andesitic magmas were mainly erupted. We focus on scoria fall deposit ejected from volcanic activity of Kishima-dake (Ksh) at 4 ka (Fig. 5c). Mineral assemblage of the Ksh scoria is olivine, clinopyroxene, plagioclase, magnetite, and slightly orthopyroxene. Whole rock composition of the Ksh scoria is basaltic in the High-K series (Fig. 6) (Miyoshi et al., 2005). Whole rock Sr isotopic compositions of the Ksh scoriae has not been measured. Miyoshi et al., 2011 reported that Sr isotopic compositions of some basaltic magmas of the Aso-CC activity are 0.7040-0.7041. The Sr isotopic compositions overlap with those of pumices and scoriae of the large eruptions.

3. Method

3.1. Preparation of analytical samples

Sampling points of the ejecta are summarized in Table 2. We collected quenched ejecta at the lowest or uppermost part of pyroclastic deposits whenever possible. Phenocrysts were separated by crushing the ejecta, panning its fragments, and heavy-liquid separation with sodium polytungstate. The phenocrysts were mounted on a glass slide and polished to a flat surface. Finally, we observed exposure of MI under optical microscope. GM analytical sample were fragments obtained from the crushing of ejecta and prepared by the same method as for the MI sample.

3.2. Compositional analysis

Major element composition was analyzed by JEOL JSM-6480 LA II Scanning Electron Microscope (SEM) equipped with JEOL EX-54165JMH Energy Dispersive Spectrometer (EDS) system using W and LaB6 filaments at Kobe University. Operating conditions were set to 15 kv acceleration voltage, 0.4 nA beam current, and counting times of 180-300 s with ZAF correction. To minimize Na loss, beam irradiation area was set to larger than 10×10 μm. Elemental mapping was performed for some ejecta. Elements measured are Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, P, and S.

Trace element composition was measured by a 193 nm Resonetics Resolution 155 excimer laser ablation system coupled to a Thermo Element XR sector field mass spectrometer (i.e., Laser ablation ICP-MS) at ETH Zürich. A spot size was set to 19 μm . Elements measured are Li, B, Na, Mg, Al, P, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Zn, Rb, Sr, Y, Zr, Nb, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, Pb, Th, and U.

We analyzed MI and GM for the Aso-2, 3, and 4 eruptions, and MI for the Z-20, Z-15, Ksh eruptions. Host mineral species of MI that we analyzed are olivine, clinopyroxene, orthopyroxene, amphibole, and plagioclase.

4. Result

4.1. Major element composition

4.1.1. Pumice and scoria of the Aso-2, Aso-3, and Aso-4 eruptions

MI and GM compositions of the Aso-2, 3, and 4 pumices are similar and concentrated in 67-68, 69-71, and 70-72 wt.% SiO_2 in the High-K series, respectively (Fig. 7). Host minerals of the MIs are clinopyroxene, orthopyroxene, and plagioclase in Aso-2 and 3 pumices, and are orthopyroxene, amphibole, and plagioclase in Aso-4 pumice. The MI and GM compositions are close to whole rock chemical composition of each pumice; they have the high SiO_2 content and belong to the High-K series. Small number of andesitic MIs are found in clinopyroxene in the Aso-3 pumice and olivine, clinopyroxene, orthopyroxene, and amphibole in Aso-4 pumice. The andesitic MI compositions are similar to MI composition of the Aso-3 and Aso-4 scoriae described below. Thus, the host phenocrysts of the andesitic MIs can be interpreted as phenocryst in the scoria mixed into the pumice and we treat them as ones in the scoria.

The scoriae have wider variation in MI and GM compositions than those of the pumices. The MI and GM compositions of the Aso-2 scoria are concentrated in 57-61 wt.% SiO_2 in the High-K series and forms a compositional trend with whole rock composition (Fig. 7a). Host phenocrysts are olivine, clinopyroxene, orthopyroxene, and plagioclase. The MI and GM of the Aso-3 scoria have a K_2O content variation from about 1 to 4 wt.% in range of 59-63 wt.% SiO_2 (Fig. 7b); unlike the Aso-2 scoria, the Aso-3 scoria has the MI and GM belonging to both the High-K and Medium-K series. The MIs of High-K series are found in all kinds of the phenocryst, whereas ones of Medium-K series only in plagioclase. The GM is heterogeneous in composition; elemental mapping of the Aso-3 scoria GM reveals mingling textures of the High-K and Medium-K glasses, indicating that two kinds of melts

coexisted and mixed in scoria magmas (Fig. 8a). The MI and GM in High-K series have SiO₂ contents of 59-63 wt.%. K₂O content of the High-K glasses increases from 2.5-4 wt.% with the SiO₂ content and forms a compositional trend with the whole rock composition of the Aso-3 scoria. On the other hand, K₂O content of the MI and GM in Medium-K series varies from about 1 to 3 wt.% in a range of 59-62 wt.% SiO₂.

The Aso-4 scoria has a similar variation of MI and GM compositions from the High-K to Medium-K to the Aso-3 scoria. Composition of MI in the High-K series 55-68 wt.% SiO₂, and K₂O content increase from about 2 to 4.5 wt.% with the SiO₂ content. The High-K MI form a compositional trend with whole rock composition of the Aso-4 scoria. Host minerals of the MI in High-K series are olivine, clinopyroxene, orthopyroxene, amphibole, and plagioclase (An₅₀₋₆₀; An = $\text{Ca}/(\text{Ca}+\text{Na}+\text{K}) \times 100$ in mole for plagioclase). On the other hand, MI in the Medium-K series has SiO₂ content of 59-62 wt.%, and K₂O content varies from about 0.5 to 2 wt.%. Host mineral species of the MI in the Medium-K series are olivine and plagioclase (An₈₀₋₉₀). Small number of rhyolitic MIs are captured in low-Ca content plagioclase (An₃₀₋₅₀) and similar to the MI compositions of the Aso-4 pumice. As well as the andesitic MIs in the pumices, the host plagioclase of the rhyolitic MIs can be interpreted as phenocryst in the pumice mixed into the scoria and we treat them as ones in the pumice. GM has variation in SiO₂ content of about 60-69 wt.%. K₂O content in the GM increase from about 1 to 4 (i.e., the Medium-K to High-K) with the SiO₂ content. The GM in the High-K series with 66-69 wt.% SiO₂ is close to the MI in the High-K series. On the other hand, the GM in the Medium-K series has a SiO₂ range of 60-66 wt.%, with the low SiO₂ ones (around 60 wt.%) like the MI in the Medium-K series. We perform elemental mapping of the Aso-4 scoria observe mingling textures of the High-K and Medium-K glasses, indicating that two types of melts coexisted and mixed in scoria magmas (Fig. 8b).

4.1.2. Classification of the MI and GM glasses into three types

The MI and GM glasses of the three large eruptions can be classified into three types: High-K Silicic type (HK-S), High-K Mafic type (HK-M), and Medium-K type (MK) (Fig. 7). The HK-S type glasses are found in the Aso-2, Aso-3, and Aso-4 pumice and are dacitic to rhyolitic in the High-K series shown in red areas in Figure 7. The HK-M type glasses are found in all the scoriae and are basaltic andesitic to dacitic in the High-K series shown in blue area in Figure 7. The MK type glasses are found in the Aso-3 and Aso-4 scoriae and are andesitic in the Medium-K series shown in green area in Figure 7. We defined the distinction

between the HK-M and MK type by whether glass compositions are continuous with the whole rock chemical composition of the scoriae.

4.1.3. Scoria of the Z-20, Z-15, and Ksh eruptions

MI compositions of the Z-20, Z-15, and Ksh scoriae are basaltic to andesitic, concentrated in 49-60, 50-58, and 48-60 wt.% SiO₂, respectively, in the Medium-K to High-K series (Fig. 9). The composition forms continuous trends with the composition of the HK-M glasses in the Aso-2, 3, and 4 scoriae. The compositions of less evolved MI (around 50 wt.% SiO₂) are similar in all the Z-20, Z-15, and Ksh scoriae. The whole rock compositions of the three scoriae almost overlap with the MI composition in the variation diagram, although that of the Z-15 scoria has lower K₂O content than the MI. Hereafter, these basaltic to andesitic MIs are referred to as B-MI.

4.2. Trace element composition

We analyze trace elemental composition of the HK-S, HK-M, MK, and B-MI types (Fig. 10, 11). This section does not distinguish between MI and GM glass data for each glass type because the compositions of the MI and GM are almost identical. Firstly, we show Thorium (Th) and Gadolinium (Gd; Middle-REE) contents in the glasses because the Th-Gd relationship is clearly different for each glass type. Th and Gd are incompatible trace elements with many minerals in igneous rocks (Luhr and Carmichael, 1980; Fujimaki et al., 1984; Fujimaki, 1986), and their contents in melt generally increase with crystallization. Based on the Th-Gd relationship, we show averaged REE patterns representing each type.

4.2.1. Thorium vs. Gadolinium

The Aso-2, 3, and 4 pumices have similar Th and Gd contents of the HK-S glass (red areas in Fig. 10); their Th contents are 13-19, 13-16, and 13-15 ppm, respectively, and their Gd contents increase with the Th content from 5 to 8, 5 to 6, and 4 to 6 ppm, respectively.

The scoriae contain the HK-M and MK glasses. The HK-M glasses in the Aso-2, 3, and 4 scoriae have similar Th and Gd contents (blue areas in Fig. 8). The Th contents of the HK-M glasses are lower than the HK-S glasses, but their Gd contents are not different from the

HK-S glasses. On the other hand, feature of Th and Gd contents of MK glasses in the Aso-3 and 4 scoriae are different. We describe the composition of the HK-M and MK glasses for each eruption. In the Aso-2 scoria, Th content in HK-M glass of the Aso-2 scoria is 7-11 ppm and Gd content increase with the Th content from 4 to 6 ppm. In the Aso-3 scoria, Th and Gd contents of HK-M and MK glasses are shown as a blue and green areas in Figure 10b, respectively, and are not clearly different in the Th-Gd relationship. Th content of the Aso-3 HK-M and MK glasses is 7-11 ppm and Gd content increase with the Th content from 5 to 6 ppm and 4 to 6 ppm, respectively. In the Aso-4 scoria, feature of Th and Gd contents in HK-M and MK glasses is different. The content of HK-M glass is concentrated in 6 to 10 ppm, and Gd content increase from 4 to 6 ppm with the Th content shown as blue area in Figure 10c. Some HK-M type MI in olivine, clinopyroxene, and orthopyroxene has high Gd content (7 to 8 ppm) than the other HK-M glass. Th content of the MK glass is 5 to 7 ppm, and Gd content roughly decrease from 7 to 5 ppm with the Th content.

The B-MI in the Z-20, Z-15, and Ksh scoriae are similar to each other in the Th-Gd relationship. Th contents of the three scoria is concentrated in 2-8, 2-4, and 2-12 ppm, respectively, and Gd contents increase with the Th content. The B-MI compositions form trends with the HK-M type in the three scoriae.

4.2.2. REE spider diagram

We show averaged REE compositions of glasses in the pumice and scoriae of the large eruptions and the basaltic scoriae by spidergram in Figure 11. The average compositions are obtained by the following way. Shown compositions of the HK-S glasses in the Aso-2, 3, and 4 pumices and the HK-M glass in the Aso-2 scoria are average composition of the MI and GM. Compositions of the HK-M and MK glasses in the Aso-3 and 4 scoriae are average composition of only the MI to remove noise of the heterogeneity in the GM compositional from the HK-M to MK. In addition, the HK-M type MI with high Gd content captured in olivine, clinopyroxene, and orthopyroxene in the Aso-4 scoria were not used in the calculation of the average (Fig. 10c). Shown composition of the Z-20, Z-15, and Ksh scoriae are averages of the basaltic MI (> 52 wt.% SiO₂) because we focus on primitive nature of the basaltic glasses, not their evolution.

The less evolved B-MI glasses in the Z-20, Z-15, and Ksh scoriae show the same negative slope from LREE to HREE in primitive mantle normalized REE patterns (Fig. 11a). Primitive mantle values are taken from Sun and McDonough (1989).

REE patterns of the HK-S, HK-M, and MK glasses of the Aso-2, 3, and 4 eruptions normalized by average of the less evolved B-MI glasses show different features for each type (Fig. 11b). The HK-S glasses in all the three pumices show negative slope from LREE to MREE and positive slope from MREE to HREE in the REE pattern. On the other hand, the HK-M glasses in the three scoriae show a negative slope from LREE to MREE and a flat pattern from MREE to HREE. The MK glasses show different REE patterns in the Aso-3 and 4 scoriae. The Aso-3 MK glass shows a negative slope pattern from LREE to MREE and flat pattern from MREE to HREE. The MREE and HREE content in the Aso-3 MK glass are a little lower than the HK-M glass of the Aso-3 eruption. The Aso-4 MK glass shows a downward gentle slope pattern from LREE to HREE. The REE content in the Aso-4 MK glass are higher than those of the Aso-4 HK-M glass, especially in MREE.

4.3. Summary of the analytical results

We summarize important petrological and geochemical features of the Aso magma for magma generation, as revealed by our analytical results and previous studies.

- (1) MI and GM glasses in the pumice and scoria of the three large eruptions are classified into three types based on the major element composition: HK-S, HK-M, and MK types.
 - (a) The HK-S glasses are found in the pumices and are dacitic to rhyolitic in the High-K series.
 - (b) The HK-M glasses are found in the scoriae are basaltic andesitic to dacitic in the High-K series.
 - (c) The MK glasses are found in the Aso-3 and Aso-4 scoriae are andesitic in the Medium-K series.
- (2) The HK-S, HK-M, and MK glasses are also clearly distinguished in contents of Th and Gd. Th content of the HK-S glasses is higher than that of the HK-M glasses, while Gd contents of the HK-S and HK-M glasses is not much different. Th and Gd content of the Aso-3 MK glass is similar to the Aso-3 HK-M glass, while Gd content in the Aso-4 MK glass is higher than that of the Aso-4 HK-M glasses at the same Th content.
- (3) REE patterns of the HK-S, HK-M, and MK glasses also have different characteristics, respectively. The HK-S glasses show the upward slope from MREE to HREE. The HK-M glasses show flat patterns from MREE to HREE. The Aso-3 MK glass shows a flat pattern from MREE to HREE, and the MREE and HREE contents are lower than the Aso-3 HK-M glasses. The Aso-4 MK glass shows a downward gentle slope pattern

from LREE to HREE and higher MREE and HREE contents than the Aso-4 HK-M glass.

- (4) MI in the Z-20, Z-15, and Ksh basaltic scoriae (B-MI) are basaltic to andesitic in the Medium to High-K series and form a continuous trend with the HK-M glasses in major and trace elements.

5. Discussion

The compositional analyses of the MI and GM reveal the presence of the HK-S glass in the pumices and the HK-M and MK glasses in the scoriae of the large eruptions. Since the HK-S and HK-M glasses mainly constitute the groundmass of the pumice and scoria, respectively, we conclude that these glasses correspond to melts of the silicic (origin of the pumice) and mafic magmas (origins of the pumice and scoria) in the crust, respectively. The MK glass has lower K₂O content than the HK-M glass, suggesting that melt of the MK glass is not directly derived from the silicic and mafic magmas. In Section 5.1, we approach the generation process of the silicic and mafic magma by clarifying the petrogenesis of the HK-M and HK-S glasses, which are representative melts of both magmas. For generation of the MK glass, the source material and process are discussed based on the petrogenesis of the HK-S and HK-M glasses in Section 5.2. Hereafter, each glass will be denoted as a melt (e.g., the HK-S melt).

5.1. Causes of the REE variation in the HK-S and HK-M melts

The compositions of the HK-S and HK-M melt are discrete in the Th-Gd relationship (Fig. 10), and the shapes of the REE patterns of the two melts are different on the spidergram (Fig. 11b). On the other hand, the Sr isotopic ratios of the silicic and mafic magmas, corresponding to the HK-M and HK-S melts, are the same (Hunter, 1998; Kaneko et al., 2007, 2015). This isotopic feature suggests that the two melts were generated from the same magma source. We investigate whether the REE compositions can be reproduced by the crystallization or partial melting of a single material. A method is to calculate REE composition of melt based on phase proportion at various degrees of crystallization and elemental distribution coefficients between minerals and the melts. The proportions of crystallized minerals are determined by two independent methods: one is result of crystallization experiments in previous studies (see Section 5.2.1), and the other is an estimation by mass balance calculation from the change of major elemental composition (see Section 5.2.2).

5.1.1. REE calculation from phase proportions in the crystallization experiments

The phase proportions used in the calculation are from crystallization experiments of basaltic magma in an equilibrium process (Blatter et al., 2013) and a fractional process (Nandedkar et al., 2014). The two experiments are referred to as EQ and FC, respectively. In the FC experiment, the fractionation process is reproduced by step-by-step experiments in temperature; melt composition in an experiment is a starting material composition for the next experiment at a lower temperature than in the pre-experiment.

Starting materials of the experiments are hydrous high-Mg arc basalts (Table 3). Water contents in the starting materials are 2.1 and 3.0 wt.% for the EQ and FC experiments, respectively. The measured Aso basaltic melts are more differentiated in MgO content compared to the starting materials (Table 2). However, estimated composition of Aso' primitive basalt calculated by adding olivine composition to the differentiated basalts (Tatsumi et al., 1983) ((g) in Table 2) is close to the starting materials in (Fe+Mg)/Si and Ca/Si ratio, which affect crystallized mineral phases in primitive stage. In addition, water content in the Aso's basaltic melts has been reported about 1.3-4.9 wt.% by analysis of melt inclusions (Kawaguchi et al., 2021; Miyagi et al., 2023) and is close to the content in experiments. Therefore, the results of the experiments are applicable to the Aso magma. REE composition of the starting material for the calculation is set to the average composition of basaltic B-MI measured in this study. (Roeder and Emslie, 1970)

Figure 12 shows the phase proportions of the experiments. The EQ experiments were conducted in series of 9, 7, and 4 kbar, the FC experiments were conducted at 7 kbar. The phase proportions indicate that behavior of amphibole crystallization is clearly different between the EQ and FC experiments. In the EQ experiments, the proportion of amphibole rapidly increases with cooling after the onset of amphibole crystallization. At the coolest condition in each experiment series, about fifty percent of mineral phases is amphibole. In the FC experiments, the proportion of amphibole rapidly increases to ~10% after the onset of its crystallization and then increases little. This difference in the amphibole crystallization is due to the generation of amphibole by the reaction of clinopyroxene and/or orthopyroxene with melt (Blatter et al., 2013). These crystallization behaviors have a significant effect on the REE content in melt since amphibole has higher D_{REE} , especially MREE, than other minerals (Fig. 13).

Crystallization of apatite, which also has high D_{REE} (Fig. 13), is reported only in the FC experiments. The amount of the crystallized apatite is 0.2% from 860 to 700 °C. In this

temperature range, crystallization rate of apatite decreases with temperature decrease due to depletion of P₂O₅ in the melt. On the other hand, the apatite crystallization is not evaluated in the EQ experiments. However, P₂O₅ content in melt decreased between 975° and 950° at 7 kbar, suggesting apatite crystallization. Thus, we calculate that the amount of crystallized apatite is ~0.1 % from the decrease in P₂O₅ content in the melt. The EQ experiments at 9 and 4 kbar do not have P₂O₅ decrease because they were not carried out down to a temperature at which apatite crystallization begins (Fig. 12).

Calculation method for REE composition: equations and distribution coefficients

We calculate the REE compositions using the following equations (1) for the equilibrium crystallization and melting processes and (2) for the fractional crystallization process. These equations are described in many papers and textbooks of petrology (e.g., Rollinson, 2014). Content of elements in melt (C_L) at a melt fraction (F) is given by

$$\frac{C_L}{C_{L0}} = \frac{1}{(F + D - FD)} , \quad (1)$$

$$\frac{C_L}{C_{L0}} = F^{(D-1)} . \quad (2)$$

C_{L0} is initial content of elements in melt, and D is bulk distribution coefficient. The calculation of the FC experiments is performed step by step at each temperature using equation (2) as follows: C_L at a temperature is estimated from equation (2) using mineral phase amounts (i.e., $1-F$) at the temperature, a bulk distribution coefficient calculated from the amount of mineral phase (i.e., D), and melt composition at a previous temperature. By repeatedly using this calculation, change of melt composition by progress of crystallization is evaluated.

The distribution coefficients of REE for the minerals are shown in Figure 13. Those of olivine, clinopyroxene, orthopyroxene, amphibole, and plagioclase are from Fujimaki et al. (1984), magnetite is from Luhr and Carmichael (1980), and apatite is from Fujimaki (1986). Since D_{Gd} and D_{Er} for magnetite are not available, we estimate D_{Gd} as the mean value between D_{Eu} and D_{Dy} , and D_{Er} as the mean value between D_{Dy} and D_{Yb} , and these values are also shown in Figure 11. Th is a highly incompatible element in each mineral (e.g., Luhr and Carmichael, 1980; Mahood and Stimac, 1990), except for apatite. Therefore, the D_{Th} is uniformly set to 0.01 for all the minerals except apatite. D_{Th} for apatite is set to 1.6 reported

in Mahood and Stimac (1990), but its amount of crystallization in the experiments is so small that it has little effect on the calculated Th content in melt.

Results of the REE calculations

Figure 14a shows the calculated Th and Gd contents in the melts. An increase in Th content represents progress of crystallization since Th is highly incompatible. The change in Gd contents with crystallization is clearly different between the EQ and FC experiments. The results of the EQ experiments at the three pressures show that the Gd content initially increases until the Th content is up to 5 ppm. Then, the Gd content of the EQ experiments at the 9 and 4 kbar does not significantly change, and that at the 7 kbar decreases, with the Th content. The change of the trend at 5 ppm Th is due to the onset of amphibole crystallization (Fig. 10 a, b, c) with high D_{Gd} of amphibole (Fig. 13). The results of the FC experiments show that the Gd content increases with crystallization, whereas temporarily decreases at two points. The first decrease occurs at about 5 ppm Th (1010 °C) due to the onset of amphibole crystallization (Fig. 12d). Thereafter, the Gd content increased again because of the slow increase in the amount of amphibole (Fig. 12d). The second decrease at about 9 ppm (830 °C) is caused by the onset of apatite crystallization because of high D_{Gd} of apatite (Fig. 13). The Gd content increases again because apatite crystallization is reduced due to the depletion of P in the melt.

REE spidergram in Figure 12b shows REE patterns of least evolved HK-S and HK-M observed in this study and calculated REE patterns from the experimental results of the EQ at 7 kbar and FC experiments (Figs. 12b, d). The Th content of the primitive HK-M and HK-S melts is low among each compositional variation (7.9 and 13.3 ppm, respectively). The compositions of the calculated patterns are chosen to be close to the least evolved HK-M and HK-S melts in the Th contents; Th content of the EQ experiments is 7.3 and 12.9 ppm (1025 and 1000 °C) referred to as Low-Th, and that of FC experiments is 7.3 and 12.8 ppm (950 and 730 °C) referred to as High-Th.

The REE pattern of the observed HK-M melt is close to the calculated Low-Th melts of both the EQ and FC experiments in the flat shapes from MREE to HREE and the contents. These shapes are formed by apatite-free crystallization. The values in MREE and HREE are reproduced by the low amount of amphibole crystallization with high D_{MREE} and D_{HREE} of amphibole in both the EQ and FC experiments. The observed HK-S melt is close to the calculated High-Th melt of the FC experiments in the upward slope from MREE to HREE in the REE pattern and these contents. The pattern shape is formed by the crystallization of

apatite, which has higher D_{MREE} than D_{HREE} . The high MREE and HREE values in the observed HK-S melt are reproduced by the smaller amount of amphibole crystallization in the FC experiments than in the EQ.

5.1.2. Calculation of REE composition based on mass balance calculation

We calculate REE compositions of the HK-M and HK-S melts based on mass balance calculation. The mass balance determines a crystallized mineral proportion that reproduces the compositional change in major elements. Using the obtained proportion, the REE composition is calculated by the same method as in Section 5.2.1.

Crystallized mineral proportion evaluated by the mass balance calculation

The mass balance calculation determines crystallized mineral proportions in the following two compositional intervals: (A) from the basaltic B-MI to the HK-M melt, and (B) from the HK-M melt to the HK-S melt (Table 4). Mineral species and the compositions used in the calculations are olivine (Fo80), clinopyroxene (Mg#75), orthopyroxene (Mg#73), amphibole (Mg#70), plagioclase (three different An contents), magnetite (XUsp28), apatite. We use an ideal composition of Fo80 olivine, which occurs in the Aso basalt, only for Interval A. The compositions of clinopyroxene, orthopyroxene, amphibole, plagioclase, and magnetite are the compositions in the Aso-4 pumice and scoria. Apatite of $\text{Ca}_5(\text{PO}_4)_3(\text{OH})$ is used for the Interval B. An content of plagioclase may somewhat change during crystallization so that we use three An contents to allow some range of composition for crystallized plagioclase. Plagioclases of An80 and An60 are used for the Interval A and An60 and An40 for the Interval B. Additionally, the calculations were performed without amphibole in the Interval (B) as in the case of the Aso-2 and Aso-3 eruptions whose pumices do not contain amphibole, whereas with amphibole in the case of the Aso-4 eruption whose pumice has amphibole. This mass balance calculations were conducted with a modeling software provided by Cabero et al. (2012). This software determines the crystallized mineral proportion from the changes in the major elemental composition using the least-squares method.

Calculated phase proportions are shown in Figure 15a. The compositional change in the Interval A is reproduced by ~68 wt.% crystallization of predominantly clinopyroxene (20 wt.%), plagioclase (6 wt.% An80, 32 wt.% An60), and magnetite (7 wt.%), with amphibole-free. In Interval B, the compositional change is reproduced by ~32 wt.% crystallization, with clinopyroxene (2 wt.%), orthopyroxene (2 wt.%), amphibole (5 wt.%), plagioclase (13 wt.% An60, 5 wt.% An40), magnetite (4 wt.%), and apatite (1 wt.%). The calculation without

amphibole in Interval B (i.e., for Aso-2 and Aso-3) shows that the compositional change is reproduced by ~38 wt.% crystallization, with clinopyroxene (3 wt.%), clinopyroxene (4 wt.%), orthopyroxene (4 wt.%), plagioclase (14 wt.% An60, 6 wt.% An40), magnetite (4 wt.%), and apatite (1 wt.%). The residual sums of squares are sufficiently small in all the calculations: 0.2 in Interval A, 0.01 or 0.1 in Interval B with/without amphibole, respectively.

The calculated results indicate that the amount of amphibole crystallization is small or none in crystallization differentiation from the basaltic melt to the HK-S melt. The crystallized mineral proportions are close to the experimental result of the FC rather than that of the EQ in Section 5.2.1.

Calculation of REE and Th contents from the mineral proportions

The REE and Th contents are calculated as in Section 5.1.1 based on the obtained mineral proportions and the distribution coefficients for minerals. The equation (1) and (2) in Section 5.1.1 are used to calculate change in melt composition in the equilibrium and fractional crystallization processes, respectively.

Figure 15b shows the Th and Gd contents of the calculated HK-M melts determined by the equilibrium and fractional equations. They are close to the Th and Gd contents of the observed HK-M melt, although the Gd content calculated by the fractional equation is slightly higher than that of the observed HK-M melt. The REE patterns of the calculated HK-M melts are shown in Figure 15c. The pattern shapes are flat from MREE to HREE and reproduce the characteristic pattern of the observed HK-M melt. On the other hand, Th and Gd contents of the calculated HK-S melt are close to that of the observed HK-S melt (Fig. 15b). REE patterns of the calculated HK-S melts show an upward slope from MREE to HREE, which is the feature of the observed HK-S melt (Fig. 15d). These characteristics of the REE patterns are formed by the crystallization of apatite with higher distribution coefficients of MREE than HREE (Fig. 13). Amphibole crystallizes only in a small amount and affects little on change in the REE content. In summary, the REE and Th contents of the observed HK-M and HK-S melts can be reproduced by the crystallization estimated by the mass balance calculation in major elements. The difference between the equilibrium and fractional crystallization is small.

5.1.3. Petrogenesis of the HK-S and HK-M melts

We show in Section 5.1.1 that the least evolved HK-M melt, which has the low Th content in our observation, can be generated by the equilibrium or fractional crystallization of the basaltic melt as suggested by the calculation results of the experiments at 7 kbar. This HK-M melt can also be generated by equilibrium partial melting of a rock with the same composition as the basaltic melt because the equilibrium crystallization is simply the reverse process of the crystallization in equilibrium. Either of the crystallization and melting produced the HK-M melt, or both the processes simultaneously occurred and generated it.

The least evolved HK-S melt can be generated by the fractional crystallization of the least evolved HK-M melt at 7 kbar, but not the equilibrium crystallization. Unlike the HK-M melt, the HK-S melt cannot be generated by partial melting since there is no melting process corresponding to the reverse process of fractional crystallization. In addition, the calculated REE patterns in the equilibrium partial-melting (i.e. crystallization) case are largely different from the observed the HK-S melt by the large amount of amphibole crystallization (Fig. 14b). The generation model of the HK-S melt at 7 kbar may be applicable for the more shallow depth because suppression of amphibole crystallization, which is the cause of the REE compositional feature of the HK-S melt, is observed at 2-6 kbar in polybaric fractional crystallization experiments (Marxer et al., 2022). The proportion of amphibole in the low-pressure experiments is less than 20 wt.% when melt proportion is about 20-30 wt.%, which is close to the proportion of the 7 kbar fractional experiment. The petrogenesis of the HK-M and HK-S melts is not contradictory to the examination of the mass balance calculations in Section 5.1.2.

Compositional variation of the observed HK-S melt can be roughly explained only by the fractional crystallization (Fig. 14). On the other hand, the experiments do not explain the evolved HK-K melt. It is probably generated by crystallization without amphibole and apatite, which Gd is largely distributed in, after the formation of the less evolved HK-M melts.

5.2. Petrogenesis of the MK melt: melting of plagioclase, apatite, and amphibole crystals

The MK melts are observed in the Aso-3 and Aso-4 scoriae and characterized by the K-poor composition (Fig. 7b, c). In addition, they are enriched in Na₂O and have a high P₂O₅/K₂O ratio (Fig. 16a, b), and form continuous trends with the HK-M melts in their major-element variations; Na₂O content and P₂O₅/K₂O value increase as K₂O content decreases. The relationship between Na₂O and K₂O, which is linear on the variation diagram, is inconsistent with simple crystallization, suggesting that the MK melt variation is formed by mixing of the HK-M melt and some materials. Independently, the groundmass texture of

the scoriae in Aso-3 and Aso-4 eruptions suggests variation of the MK melt by the mixing; the mingling textures of the MK and HK-M melts in the scoria groundmass (Fig. 8). We examine whether the mixing can generate the MK melt.

The endmember material for the MK melt variation is clearly different from the Aso's basaltic melt (i.e., the B-MI melts) (Fig. 16a), and must be poor in K and enriched Na and P. On the other hand, REE features are different between the Aso-3 and Aso-4 MK melts; the Aso-3 MK melt has lower MREE and HREE values than the Aso-3 HK-M melt, while the Aso-4 MK melt has higher MREE values than the Aso-4 HK-M melt (Fig. 10b). Namely, endmember materials for the MK melts are different so that each of them must be estimated respectively.

We assume a mixture of plagioclase, apatite, and amphibole as the endmember material; plagioclase is rich in Na, apatite rich in P and REE, and amphibole rich in REE. The mineral compositions are as follows: those of plagioclase and amphibole are the phenocryst compositions in Aso-4 scoria in Keller et al. (2021), that of apatite is an average composition in diorite and granodiorite in Mao et al. (2016) and O'Sullivan et al. (2020). The P₂O₅ content in plagioclase and amphibole is assumed to be 0, and the K₂O and Na₂O contents in apatite to be 0. We estimate two mixing endmembers for the Aso-3 and 4 MK melt: one has proportions of 99 wt. % plagioclase (An₄₅), 1 wt. % apatite, and 0 wt. % amphibole (Endmember 1 for the Aso-3 MK melt), and the other 89 (An₃₅), 1, and 10 wt.% (Endmember 2 for the Aso-4 MK melt). We determine the compositionally closest mixture of the plagioclase, apatite, and amphibole to the averaged MK melt in the REE and K by least square method.

Calculation results are shown in Figure 16 and indicate that the Aso-3 and Aso-4 MK melt can be generated by the mixing of the HK-M melts and the endmember materials proposed by our calculation. Mixing lines 1 and 2 are consistent with the variations of the Aso-3 and Aso-4 MK melts, respectively (Fig. 16a, b). The REE pattern of the Aso-3 MK melt is reproduced with a mixing ratio between the averaged Aso-3 HK-M melt and Endmember 1 is 78:22, and that of the Aso-4 MK melt is reproduced with a mixing ratio between the averaged Aso-4 HK-M melt and Endmember 2 is 54:46 (Fig. 16c, d).

We infer that the endmembers are generated by melting of crystal mush composed of plagioclase, apatite, and amphibole. This genesis is suggested by the following two points. One is that Keller et al. (2021) shows a supply of high-temperature mafic magma to magma reservoir of Aso-4 eruption just prior to the eruption. This hot magma could be the heat source for the melting of crystals. The other is that plagioclase, apatite, and amphibole are relatively easy to molten because these minerals generally crystallize at low temperature (Fig. 12). A

number of previous studies have reported dissolution of these minerals in remelting of crystal mush (Ellis et al., 2023).

Miyagi et al. (2023) also observed K-poor melts, presumably corresponding to the MK melt in our study and concluded that the melt was generated by crystallization differentiation of a hydrous basaltic magma. This crystallization model does not discuss the contents of Na₂O, P₂O₅, and REE in the MK melts. On the other hand, our study conclude that the MK melt is a secondary melt by remelting of crystals by new input of hot magma. This interpretation is consistent with that eruptions of the MK melt are rare at the Aso volcano.

5.3. A model of magma plumbing system of the large eruptions in the Aso volcano

We want to model a magma plumbing system for the Aso volcano based on the shown genetic processes of the Aso's magmas. Hereafter, magmas with HK-M and HK-S melts are referred to as HK-M and HK-S magma (i.e., the mafic and silicic magmas), respectively, and a magma with the MK melt is MK magma. We summarize features of the large eruptions in Aso volcano which are important for the modeling.

- (1) The HK-M magma can be generated by differentiation of a mantle-derived magma and/or partial melting of the crust with basaltic composition.
- (2) The HK-S magma can be generated by differentiation of the HK-M magma at the lower to upper crust.
- (3) Depth of the magma reservoir of the Aso-4 eruption is estimated to be ~10 km (Ishibashi et al., 2018; Ushioda et al., 2020).
- (4) The HK-M magma erupted in the three large eruptions, meaning that the HK-M magma is directly supplied to the shallow reservoir.
- (5) The reservoirs are layered with the HK-S magma overlying on the HK-M magma.
- (6) Presence of a crystal mush within the magma reservoir is suggested (Ishibashi et al., 2018).
- (7) It is interpreted that the MK magma is generated by melting of crystal mush and that the generation occurred just prior the large eruptions.

Figure 17 shows a model of the magma plumbing system in the Aso volcano based on the features shown above. We assume that lower crust beneath the Aso volcano is gabbroic crust which was formed by solidification of mantle-derived magmas (i.e., primitive B-MI melt)

previously injecting and may be partially molten. First, mantle-derived basaltic magmas were newly supplied to the lower crust (Fig. 17a). They were differentiated into the HK-M magma and/or simultaneously heated and melted the lower crust to produce the same magma as the HK-M magma (Feature 1). Second, the HK-M magma ascended through the crust and formed a shallow reservoir (Features 3, 4) (Fig. 17b). Third, then, the HK-M magma was differentiated into the HK-S magma by fractional crystallization (Feature 2) and formed a voluminous HK-S magma body and crystal mush (Feature 6) (Fig. 17c). Last, a new HK-M magma was supplied to the magma reservoir from the lower crust again and emplaced between the HK-S magma body and the crystal mush to form a compositionally stratified reservoir (Feature 5) (Fig. 17d). At this time, the HK-M magma remelted surrounding crystal mush, partly mixed with it, and generated the MK magma (Feature 7) (Fig. 17d), although the MK magma is not observed in the Aso-2 ejecta.

We supplement two points about the generation of the HK-M and MK magmas. First, the generation of the HK-M magma by both the crystallization of magma and crustal melting can occur in “hot zone”, which is formed by repeated inputs of mantle-derived basaltic magma (Annen and Sparks, 2002; Annen et al., 2006; Solano et al., 2012). The simultaneous occurrence of the crystallization and melting is efficient to produce magma and, thus, reasonable for the generation of voluminous magma. Second, it is inferred that the MK magmas were generated just prior the large eruptions because the MK and HK-M magmas were erupted before they are homogenized (Fig. 8). The timing of the generation may mean that it triggered the large eruptions such as crystal mush rejuvenation by melting (e.g., Burgisser and Bergantz, 2011).

Our idea on the magma generation of the Aso volcano updates ones proposed by the previous works. Kaneko et al. (2015) proposed that the HK-M and HK-M magma were generated by partial melting of mafic crust. While our model is partly consistent with the genesis of the HK-M magma, it indicates that the HK-S magma cannot be generated by the crustal melting in the trace element composition. Keller et al. (2021) presented that the HK-M and HK-S magmas in the Aso-4 eruption are cumulate mush and crystal-poor melt pocket, respectively, formed by fractional crystallization from an intermediate magma. We generally agree with this model in the Aso-4 eruption as a stage between Figure 15b and c. However, it is likely that the HK-M magma in the Aso-2 and Aso-3 eruptions were newly supplied magma because melt and phenocrysts compositions of the HK-M magmas in the Aso-2 and Aso-3 eruptions are clearly more mafic from those of the HK-S magma (Fig. 7) (Kaneko et al., 2015 and unpublished data of others). Miyagi et al. (2023) insists that the MK magma is primary magma generated in the mantle beneath the Aso volcano and is a magma source of the HK-S magma. The interpretation for the MK magma’ genesis is fundamentally

different from our idea, and it is impossible that the HK-S magma is generated from the MK magma based on the trace element composition.

We have two important new insights into generation of voluminous magma in caldera volcanoes. One is that mafic magma (i.e., the HK-M magma) initially form a shallow magma reservoir, then the mafic magma is differentiated into voluminous silicic magma (i.e., the HK-S magma). Namely, we have shown one example that mafic magma, which is often found in caldera volcanoes, is direct source material in generation of voluminous silicic magma. The other is that both the crystallization of basaltic magma and partial melting of the basaltic crust contribute to generation of the mafic magma. The simultaneous occurrence of these generation processes is thermally efficient in producing magma and, thus, reasonable for the voluminous silicic magmatism.

6. Conclusions

We analyze major and trace elements composition of the MI and GM in the pumices and scoriae of the Aso-2, 3, and 4 eruptions, and the basaltic scoriae of the Aso-4/3 Z-20 and Z-15 and Aso-CC Ksh eruptions. The analytical results are summarized below.

- (1) MI and GM of the Aso-2, 3, and 4 eruptions are classified into three types: HK-S, HK-M, and MK. The HK-S is a melt of the silicic magma with high SiO₂ and K₂O content. The HK-M is a melt of the mafic magma with low SiO₂ and high K₂O content. The MK is a Medium-K₂O melt found in the Aso-3 and 4 mafic magmas.
- (2) The HK-M magma was generated by crystallization of basaltic magma and/or partial melting of basaltic crust.
- (3) The HK-S magma was formed only by fractional crystallization of the HK-M magma.
- (4) The MK magma generation is explained by mixing the HK-M magma with some melt of apatite and plagioclase with/without amphibole. This melt may be generated by melting crystal mush in the shallow reservoir due to new injection of the HK-M magma.
- (5) The magma plumbing system of the Aso volcano is considered as follows. The HK-M magma is generated at the lower crust by crystallization and crustal melting. Next, the HK-M magma ascended and form a shallow magma reservoir. The HK-S magma is generated by crystallization of the HK-M magma in the shallow reservoir. Sometimes, the MK magma is generated by remelting of crustal mush by supply of a new magma.

Our study provides two important insights into generation of voluminous magma in caldera volcanoes. One is that the mafic magma (i.e., HK-M magma) is initially supplied to the shallow magma reservoir then is differentiated into voluminous silicic magma (i.e., HK-S magma) there. The other is that the mafic magma is generated by both the crystallization of basaltic magma and partial melting of the basaltic crust. The simultaneous occurrence of the crystallization and melting processes is possible at the hot zone and thermally reasonable for generation of the voluminous magma.

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Figures

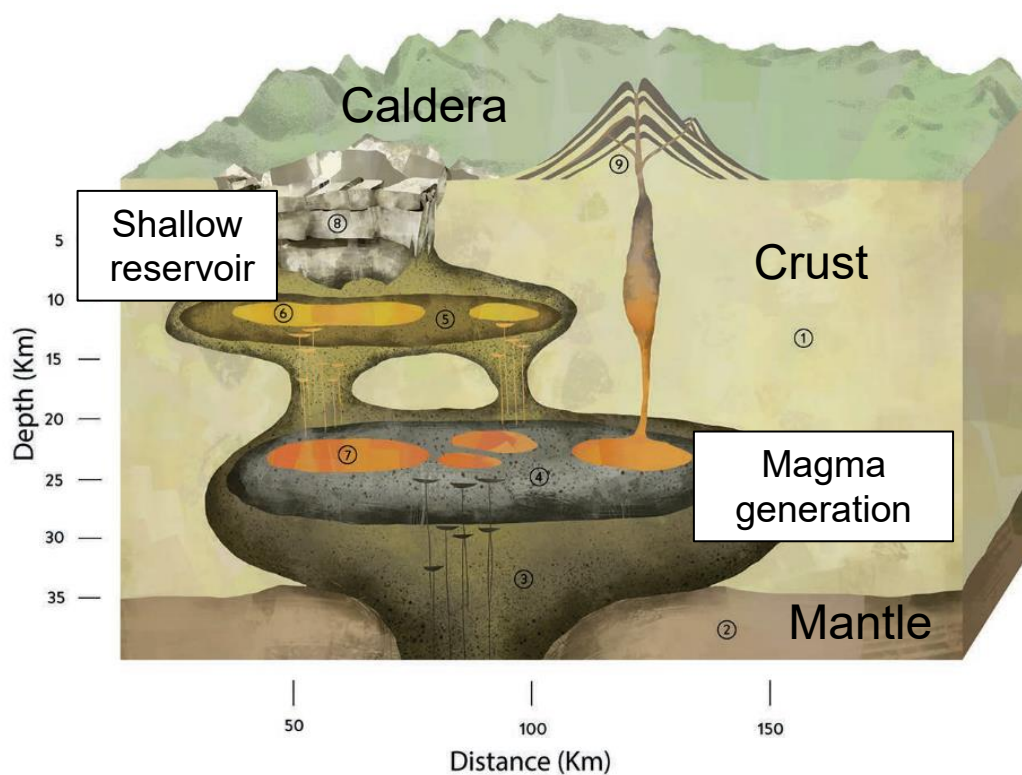


Figure 1 Schematic diagram of magma plumbing system modified from Bachmann and Huber (2016). Basaltic magma produced in the mantle is supplied to the lower crust (deep crustal hot zone). Differentiated magma is generated in the lower crust. The differentiated magma rises and forms a shallow magma reservoir.

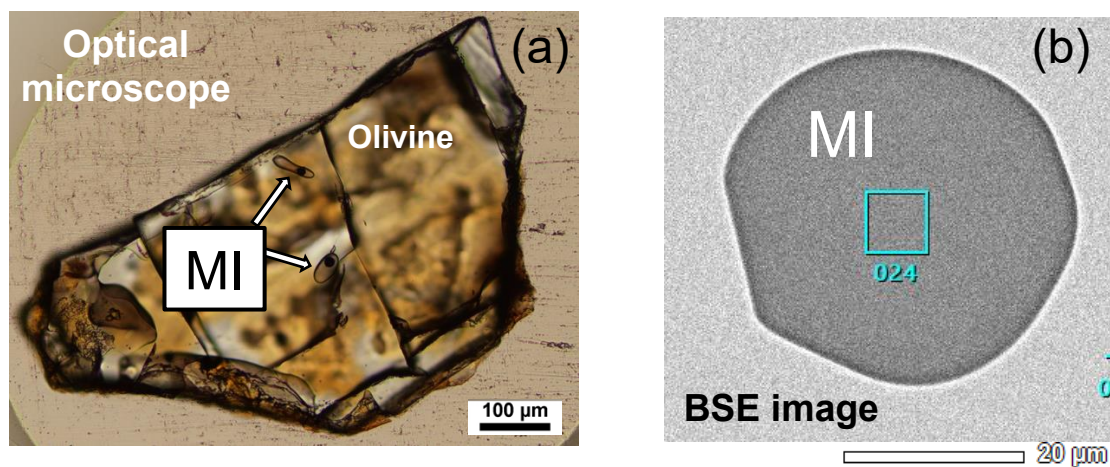


Figure 2 Images of melt inclusion (MI). (a) is MI captured in an olivine crystal under optical microscope. (b) is a BSE image of MI by SEM.

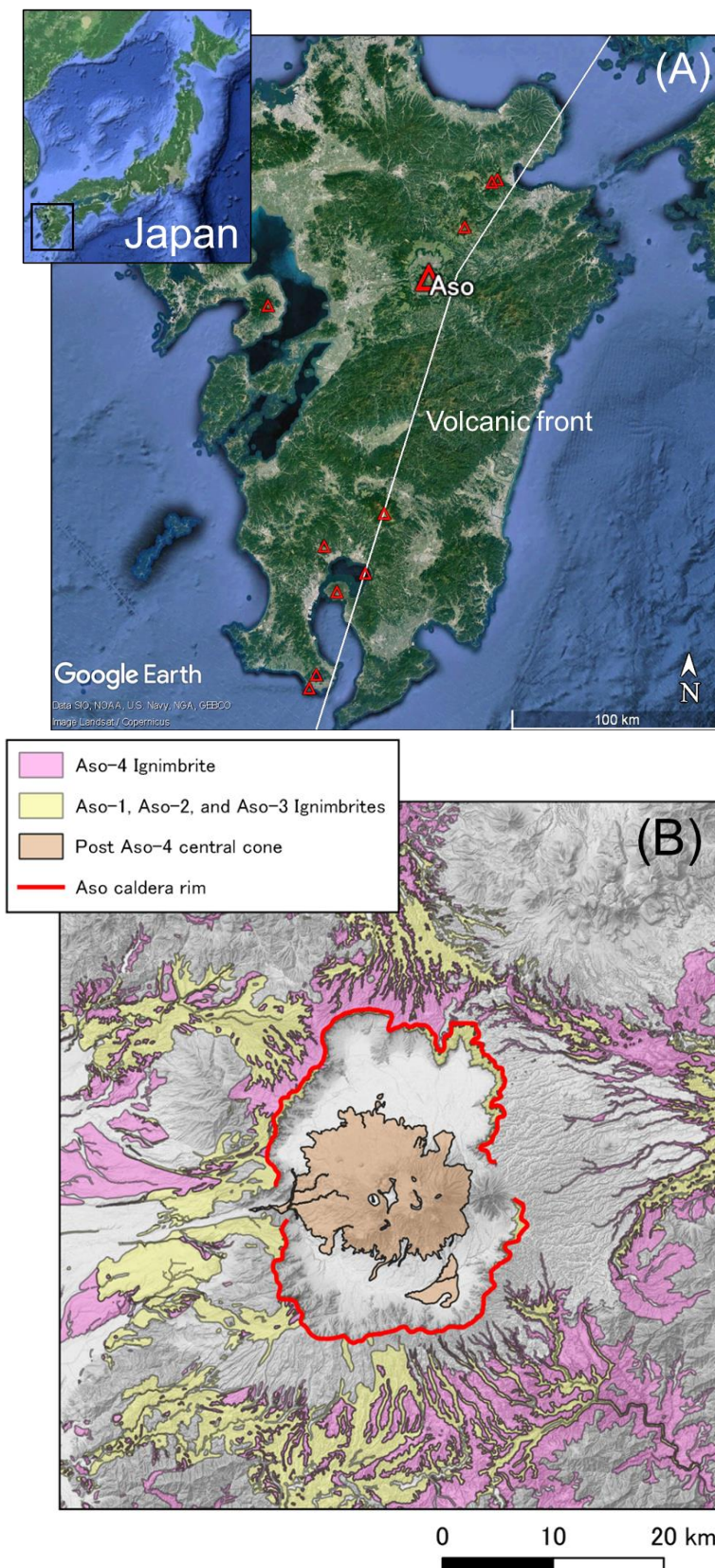


Figure 3 Location of the Aso volcano in Kyushu area (A) is caldera structure and distribution of pyroclastic deposits (Ignimbrite) (B). Red triangles in (A) indicate active volcanoes and a white line is a volcanic front in the Kyushu area. Colored area in (B) shows distributions of volcanic deposits of the Aso-1, Aso-2, Aso-3, and Aso-4 eruptions and post-Aso-4 central cone activity (Aso-CC). (B) is based on Hoshizumi et al. (2023).

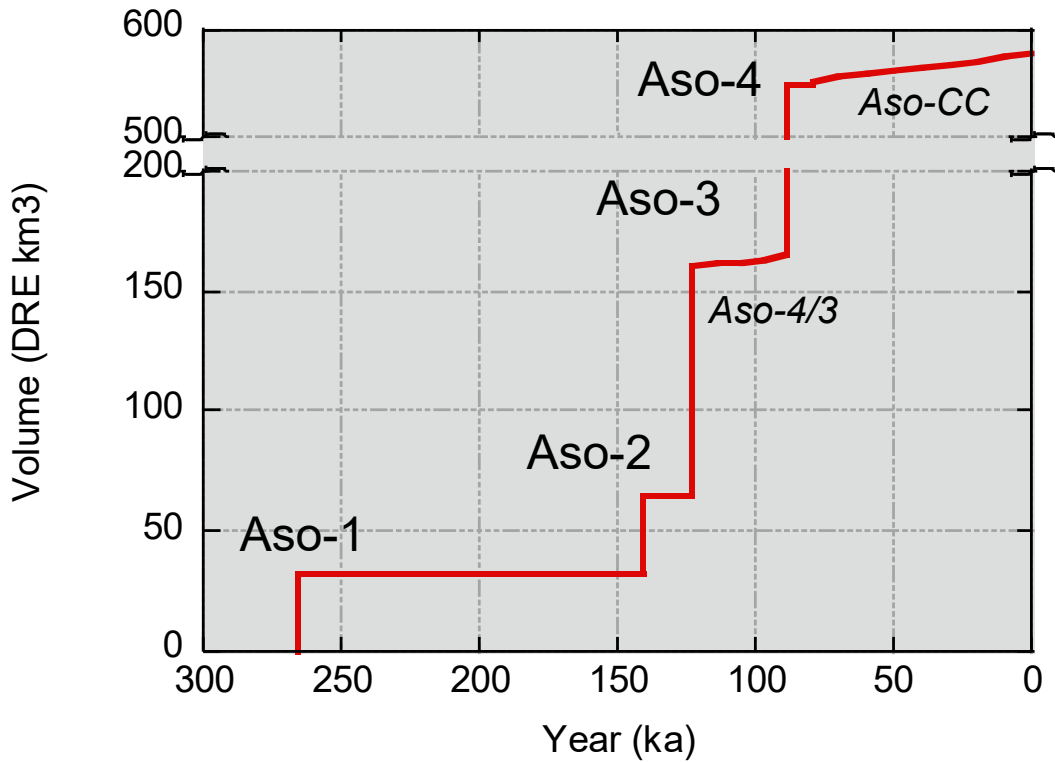


Figure 4 Cumulative volume step-diagrams for the erupted magmas in the Aso volcano. The eruption age is based on Matsumoto et al. (1991) and the DRE volume is referred from Yamamoto et al. (2015). The Aso-1, Aso-2, Aso-3, and Aso-4 eruptions are large-scale silicic eruptions. The Aso-4/3 and Aso-CC are small eruptive activities. The eruptive volume of the Aso-4/3 and CC activities is expressed as an average value of the total volume divided by the period from the Aso-3 to Aso-4 eruptions and from the Aso-4 eruption to the present, respectively.

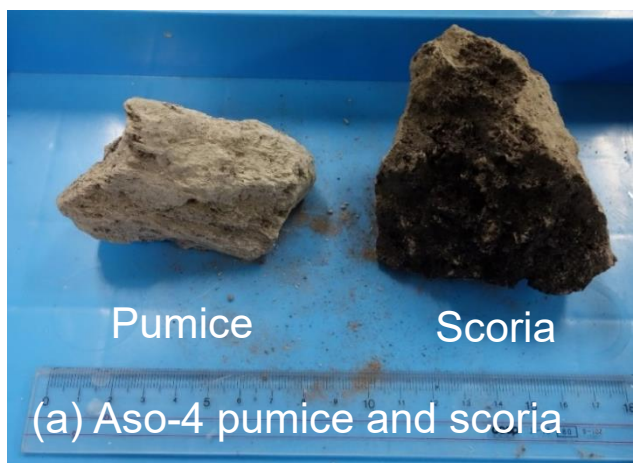


Figure 5 Pumice and scoria of the Aso-4 eruption (a), and scoriae of Aso-4/3 Z-15 eruption (b) and Aso-CC Ksh eruption (c). Z-20 scoria is similar in appearance to the Z-15 scoria. The scale of every image is in cm.

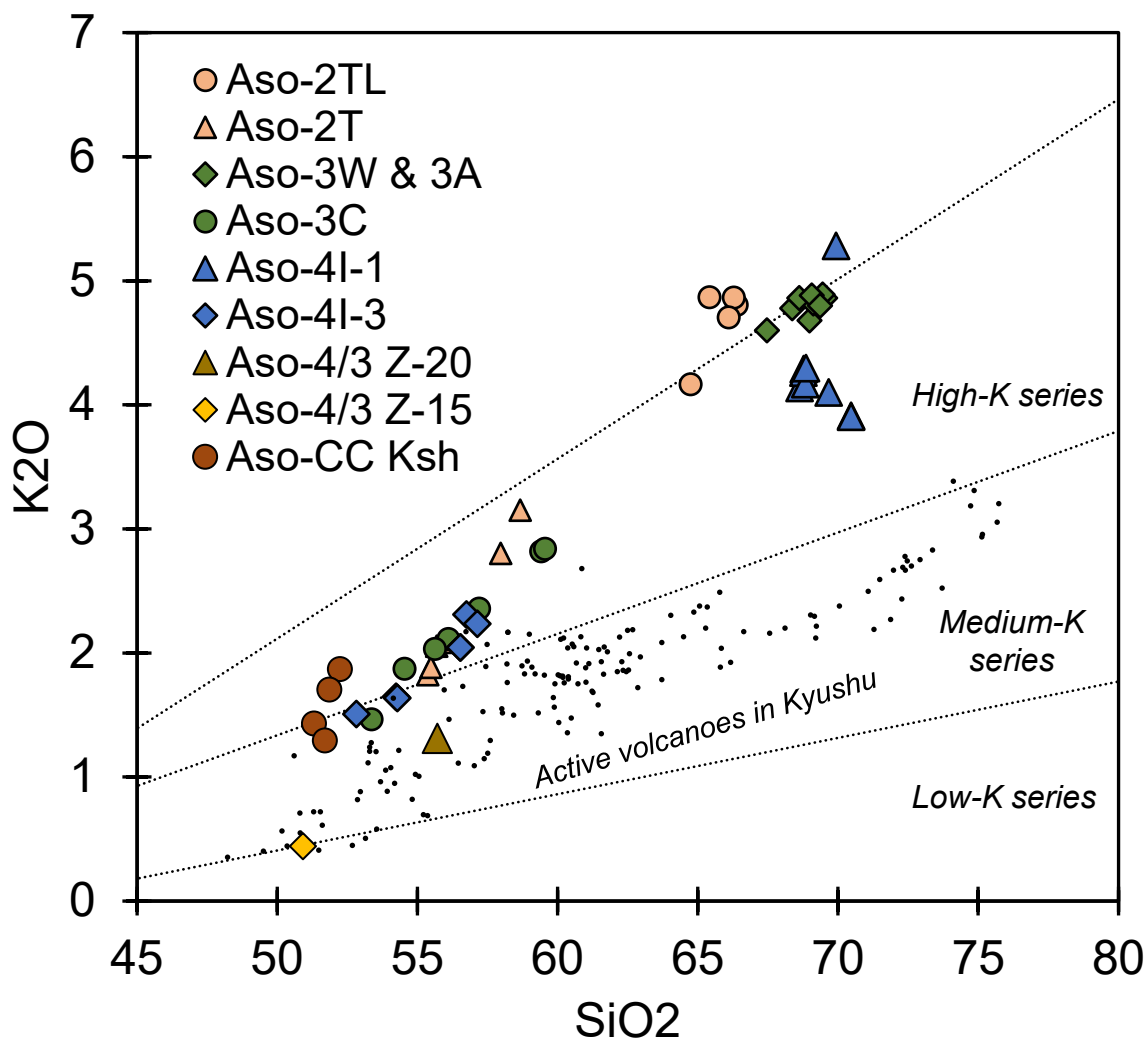


Figure 6 Whole rock chemical compositions of the pumices and scoriae of the Aso-2, Aso-3, and Aso-4 eruptions, and those of the scoriae of the Aso-4/3 Z-20, Z-15, and Aso-CC Ksh eruptions. The data of the Aso-3 eruption is referred from Kaneko et al. (2015), the Aso-4 eruption is referred from Kaneko et al. (2007), the Aso-4/3 Z-20 and Z-15 eruption are Hoshizumi et al. (2022), and the Aso-CC Ksh are from Miyoshi et al. (2005). The Aso-2 data are unpublished data of the authors. Black dots are compositions of the other active volcanoes on the Kyushu volcanic arc (Ohta et al., 1990; Inoue et al., 1994, Imura and Kobayashi, 2001, Miyoshi et al., 2010; Shibata et al., 2013, Kawanabe et al., 2015, Yamazaki et al., 2016 and unpublished data of the authors. Dotted lines represent High to Low-K series in Gill (1981), extended to high and low SiO_2 content.

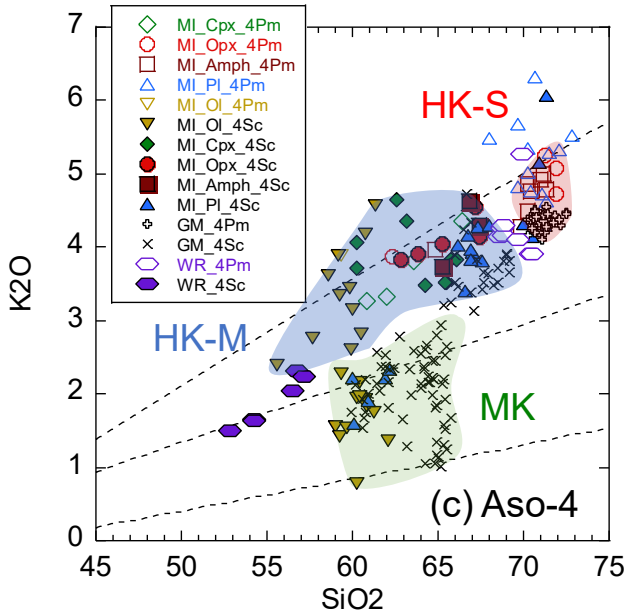
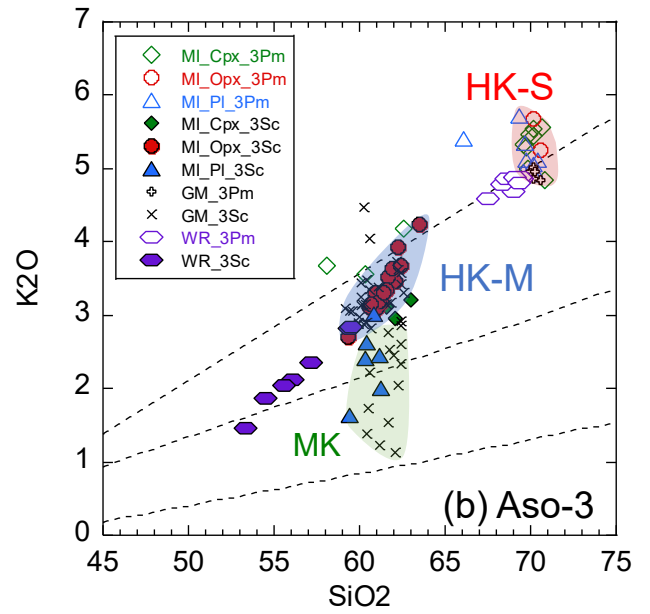
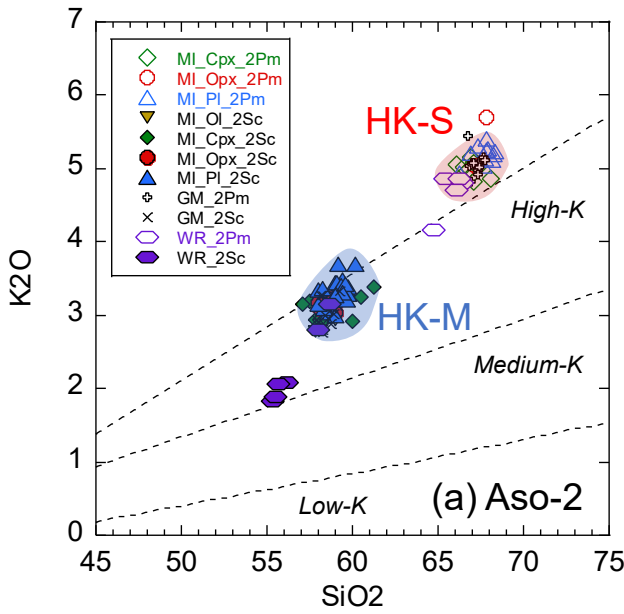


Figure 7 SiO₂ and K₂O contents in MI and GM of the Aso-2, 3, and 4 pumices and scoriae. Symbols of MI show host mineral species. The whole rock chemical compositions (WR) of the pumice and scoria are also plotted. Dashed lines represent the K series (Gill, 1981). Colored area indicates glass types: red for HK-S, blue for HK-M, and green for MK. Details of the type classification are given in the text.

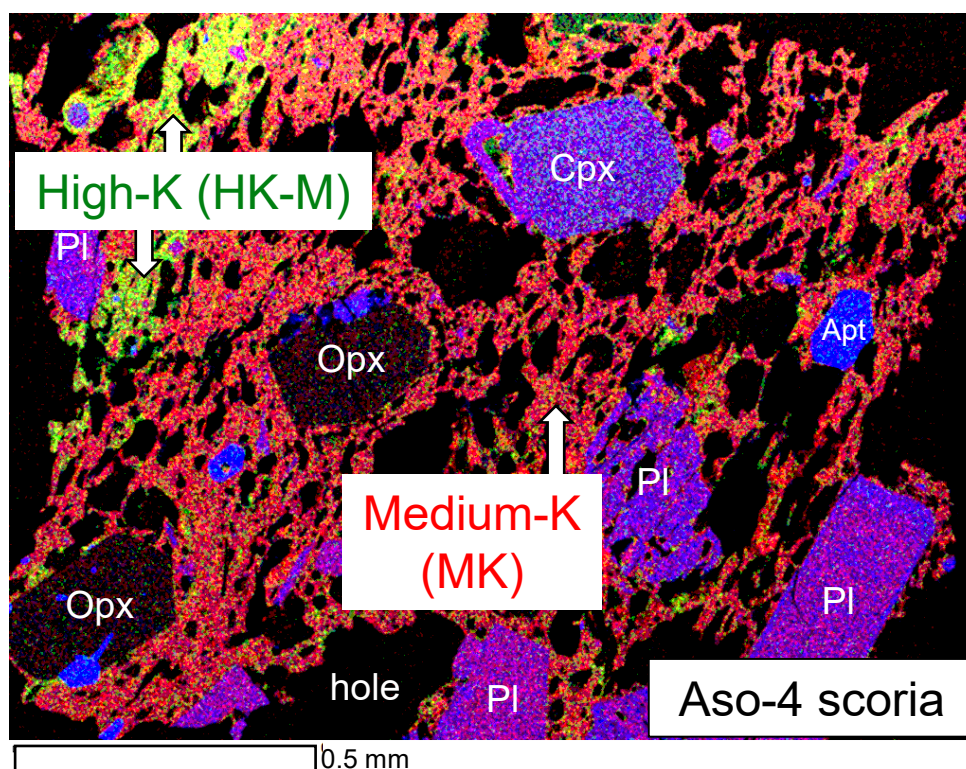
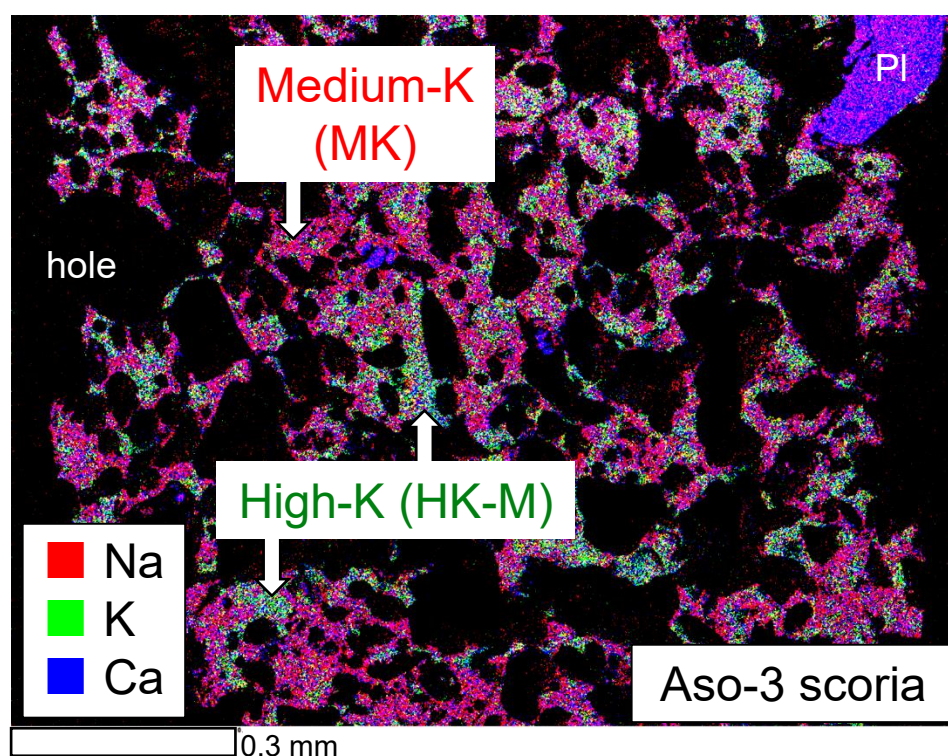


Figure 8 Results of elemental mapping for the Aso-3 and Aso-4 scoriae. Colors represent concentration of elements: red for Na, green for K, and blue for Ca. GM in green area is the High-K series (HK-M) composition and the red region is the Medium-K series (MK-M) composition.

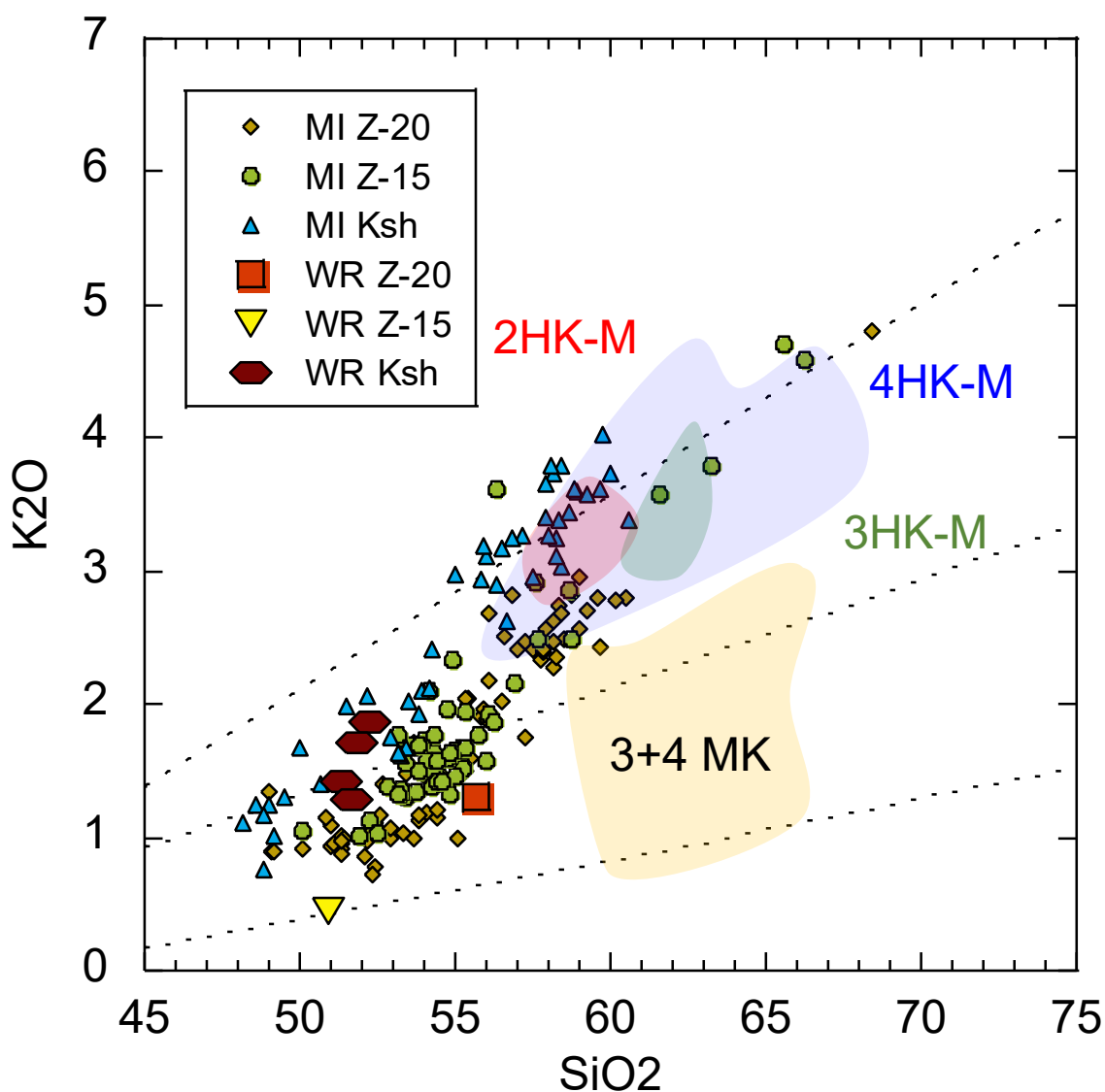


Figure 9 MI composition of the Aso-4/3 Z-20, Z-15, and Aso-CC Ksh scoriae. Whole rock chemical composition (WR) and MI and GM composition of the Aso-2 (red area), Aso-3 (green area), and Aso-4 (blue area) scoriae are also shown.

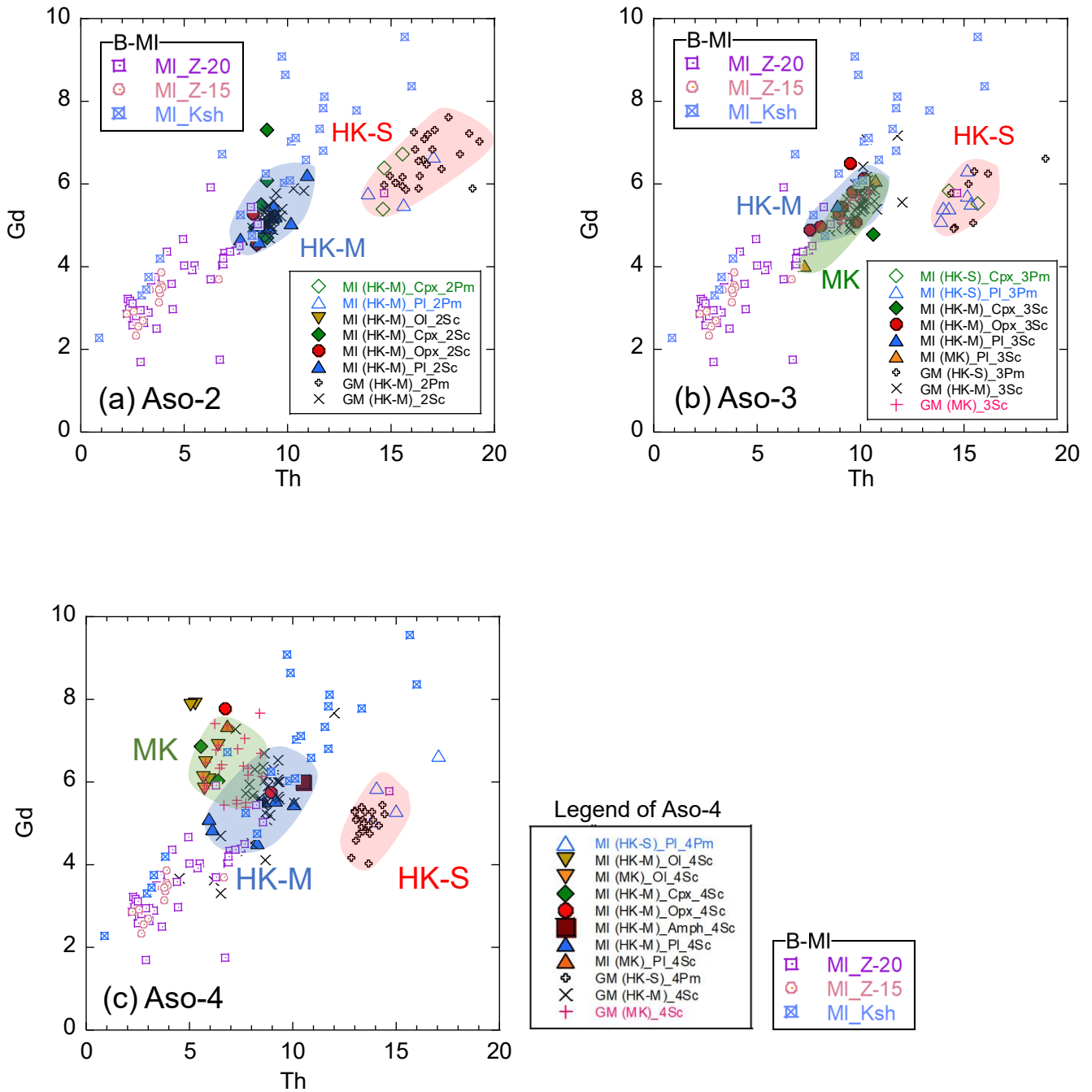


Figure 10 Th and Gd content in MI and GM of the Aso-2 (a), Aso-3 (b), and Aso-4 (c) eruptions. MI compositions of the Z-20, Z-15, and Ksh scoriae are plotted on the figures. Colored areas show the glass types.

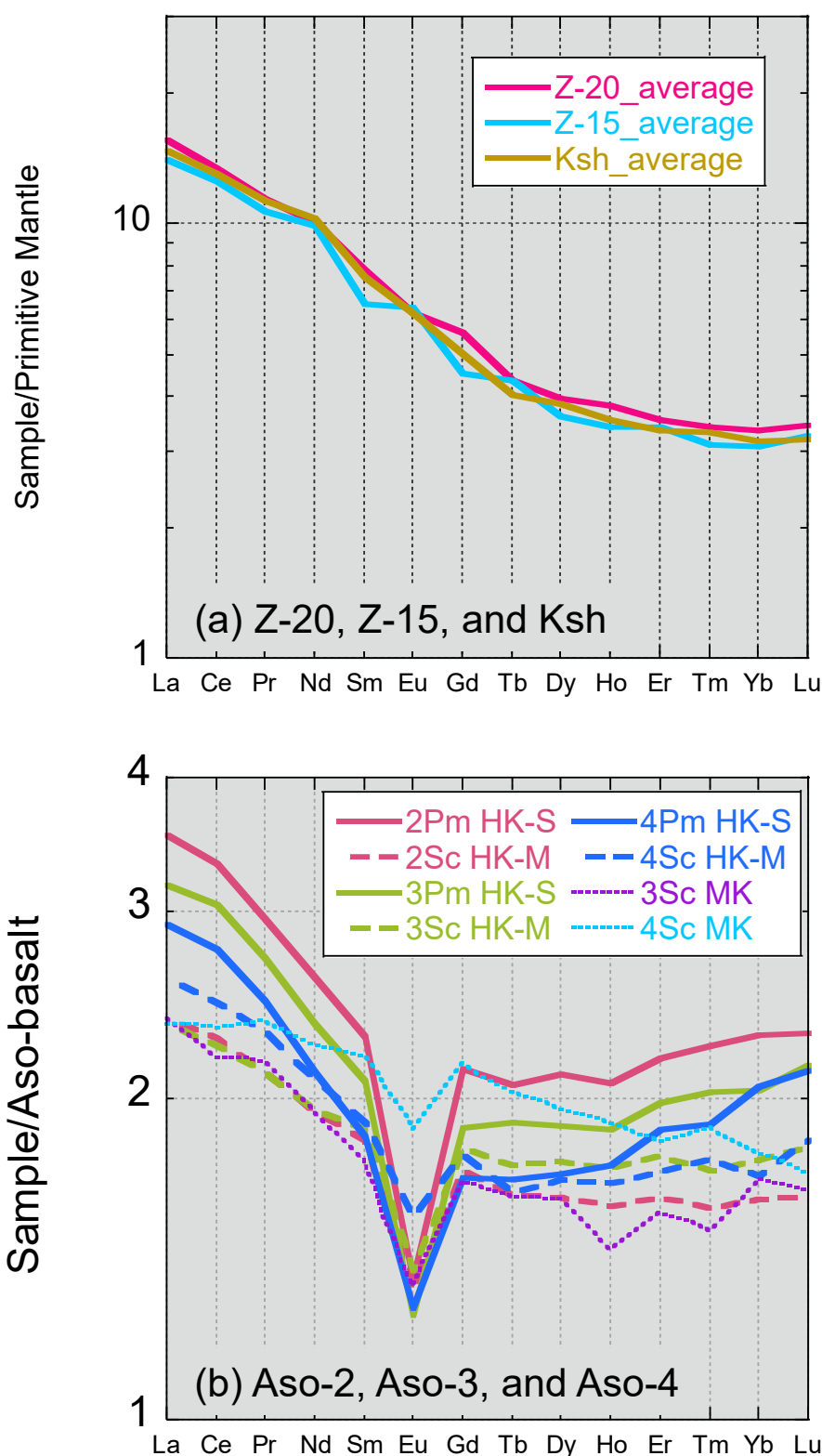


Figure 11 Spidergram of REE compositions. (a) shows average compositions of less evolved B-MI glasses (<52 wt.% SiO₂) for the Aso-4/3 Z-20, Z-15, and Aso-CC Ksh scoriae, normalized by the primitive mantle (Sun and McDonough, 1989). (b) shows average compositions of the HK-S, HK-M, and MK glasses of the Aso-2, Aso-3, and Aso-4 eruptions, normalized by average of the three less evolved B-MI glasses composition shown in (a).

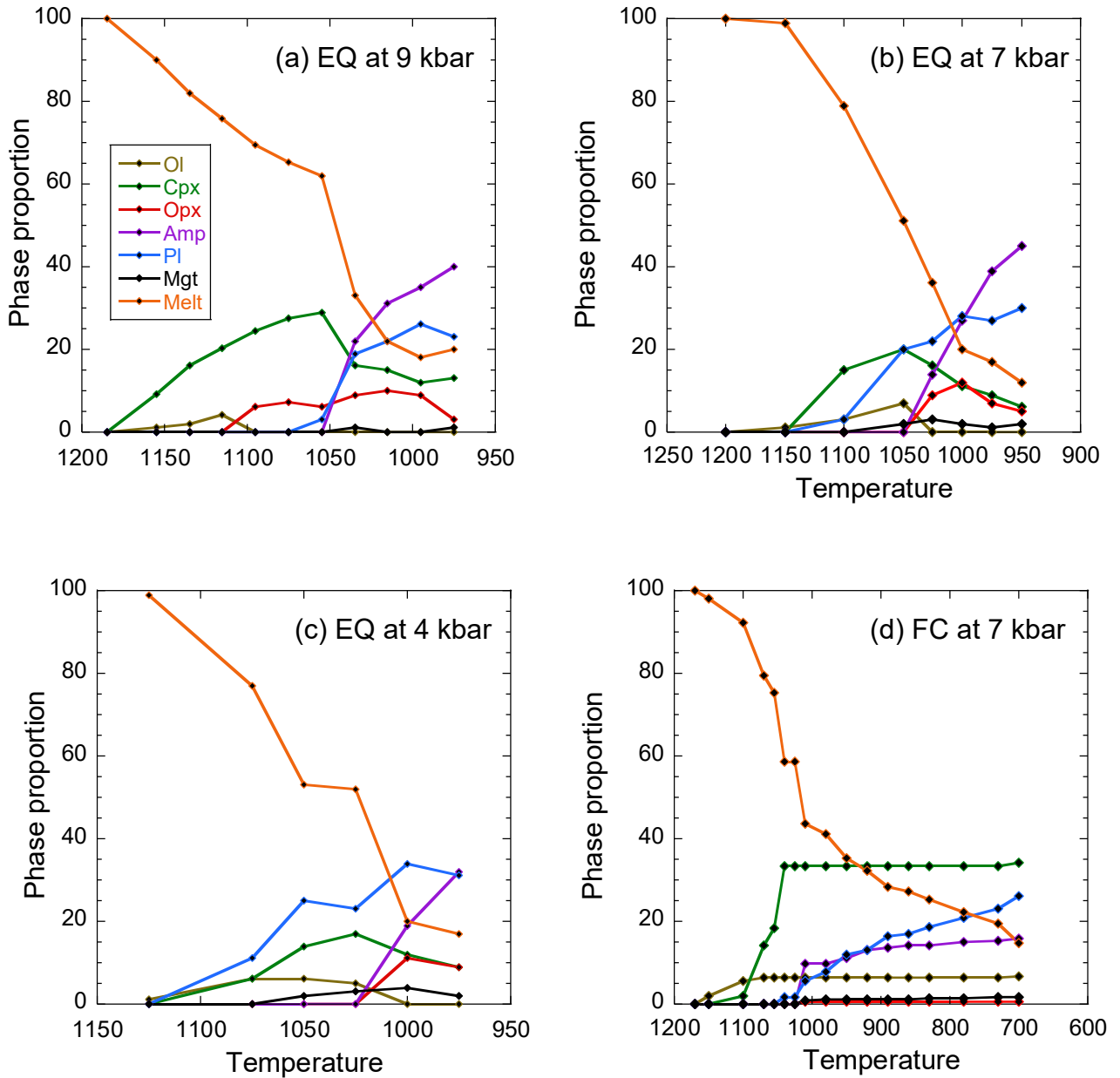


Figure 12 Phase proportion of the EQ and FC experiments (Blatter et al., 2013; Nandedkar et al., 2014). (A) to (C) are the proportions of the EQ experiments at 9 kbar, 7 kbar, and 4 kbar, respectively. (D) is the FC experiment. The phases shown in the figures are olivine, clinopyroxene, orthopyroxene, amphibole, plagioclase, magnetite, and melt. Proportions of apatite are not shown in the figures because the amounts are very small; see the text for the proportions. A few accessory minerals (e.g., spinel) crystallized in the experiments. The shown data have been recalculated to 100 % excluding the accessory minerals.

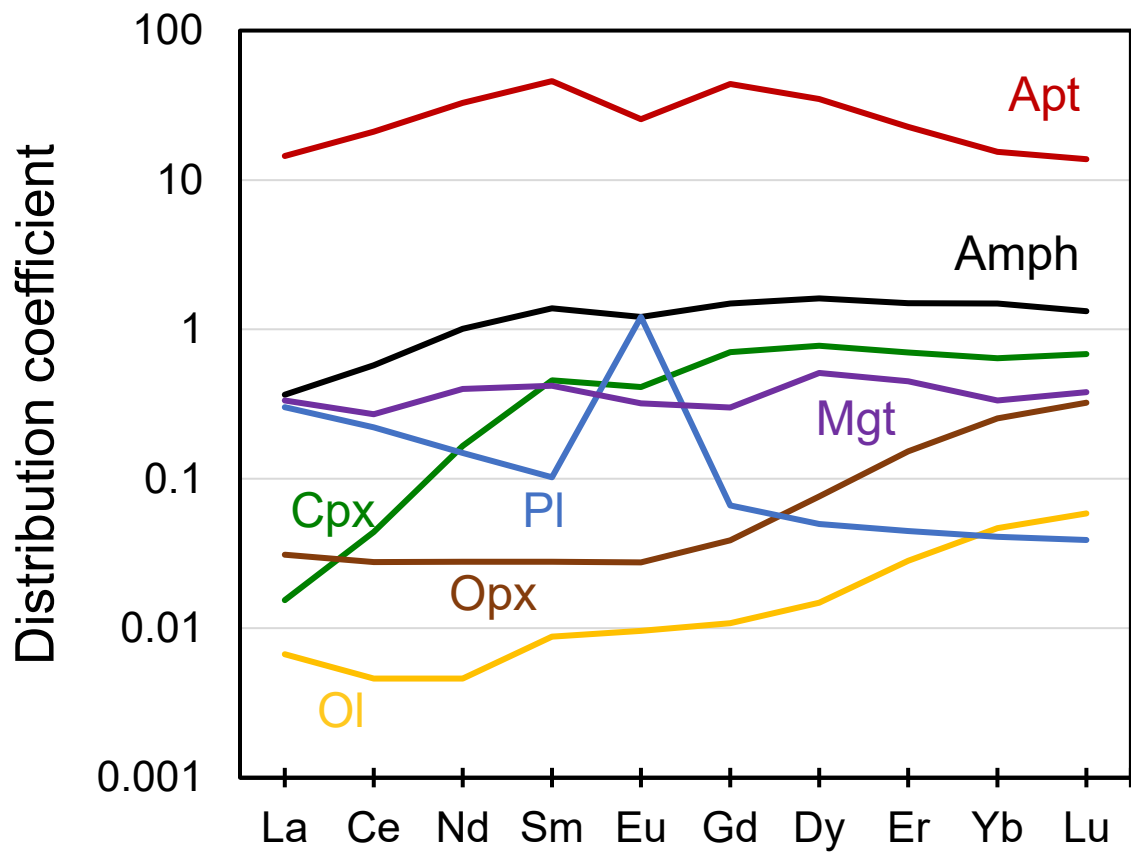


Figure 13 Distribution coefficients of REE for minerals. Those of olivine, clinopyroxene, orthopyroxene, amphibole, and plagioclase are in Fujimaki et al. (1984), magnetite is in Luhr and Carmichael (1980), and apatite is in Fujimaki (1986).

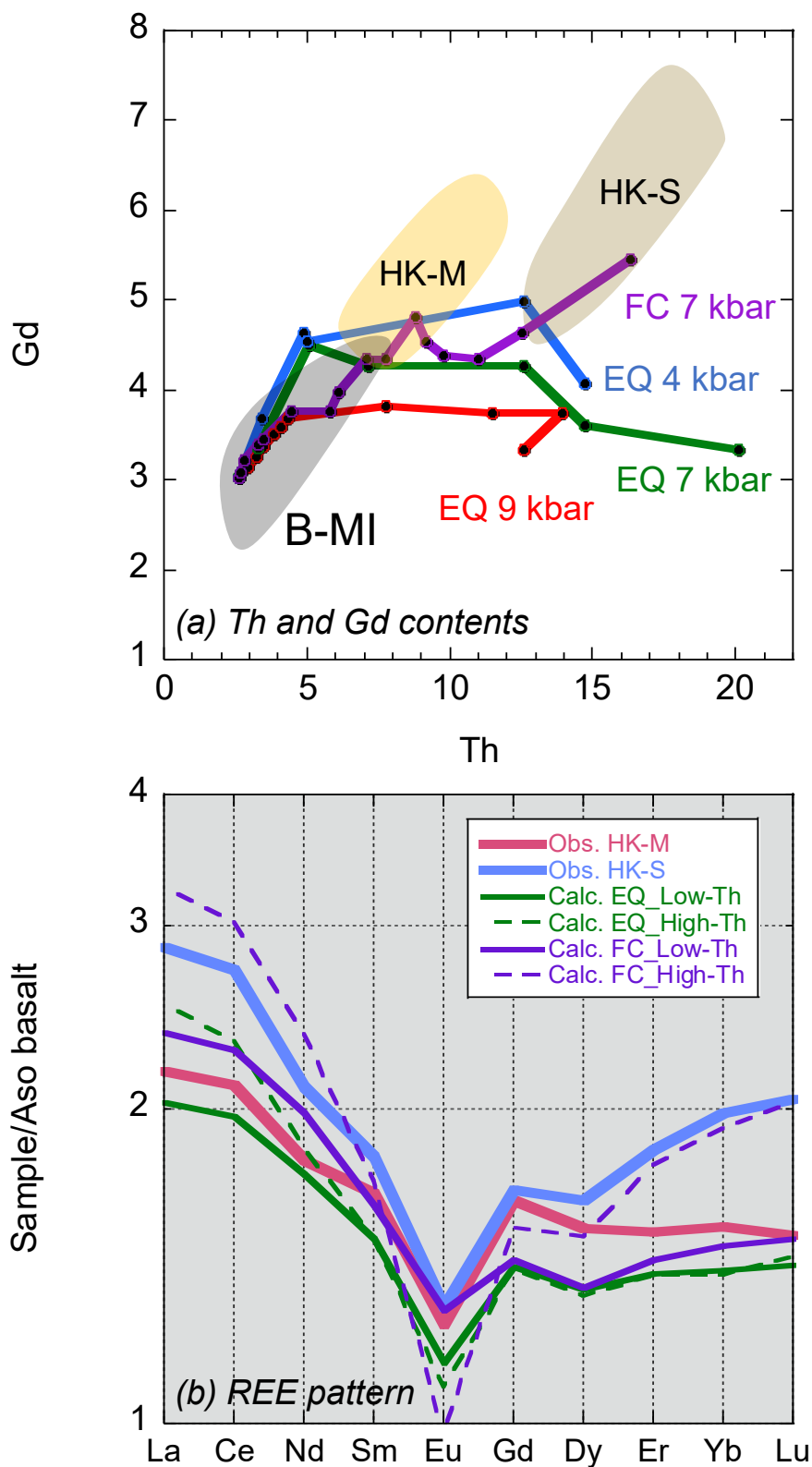


Figure 14 Calculation results of REE and Th contents. (a) is Th-Gd relationship. An increase in Th content indicates progressive crystallization. Colored areas indicate compositional variations of the HK-S, HK-M, and B-MI melts. (b) spidergram of REE pattern normalized by the Aso basalt. This figure shows calculated melt compositions of low Th content close to the composition of the HK-M melt and those of high Th content close to the HK-S melt.

(a)

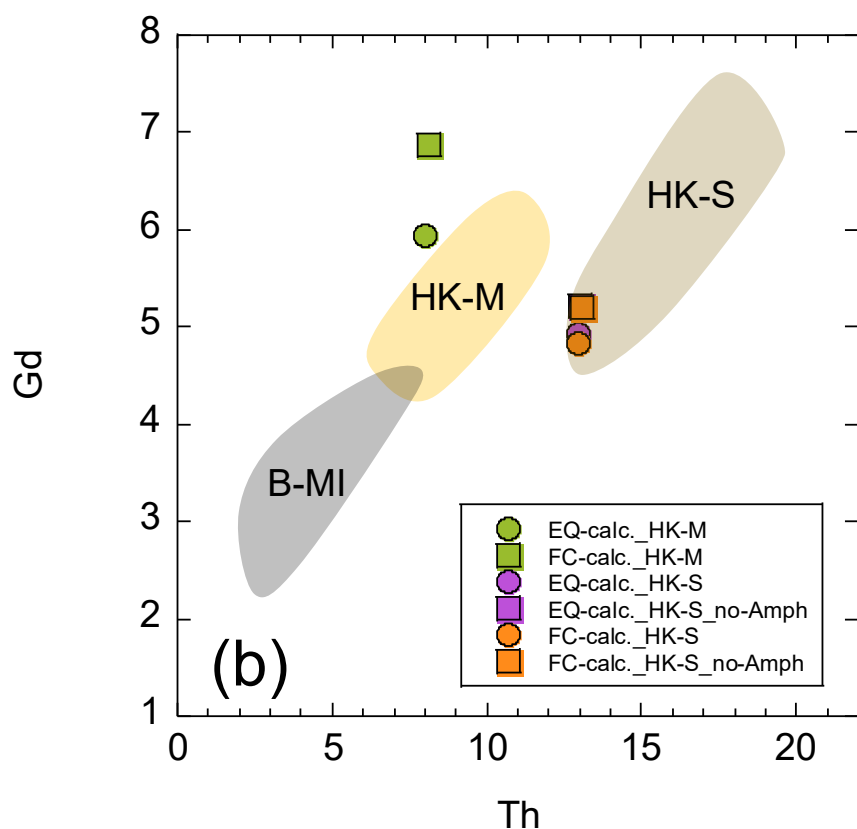
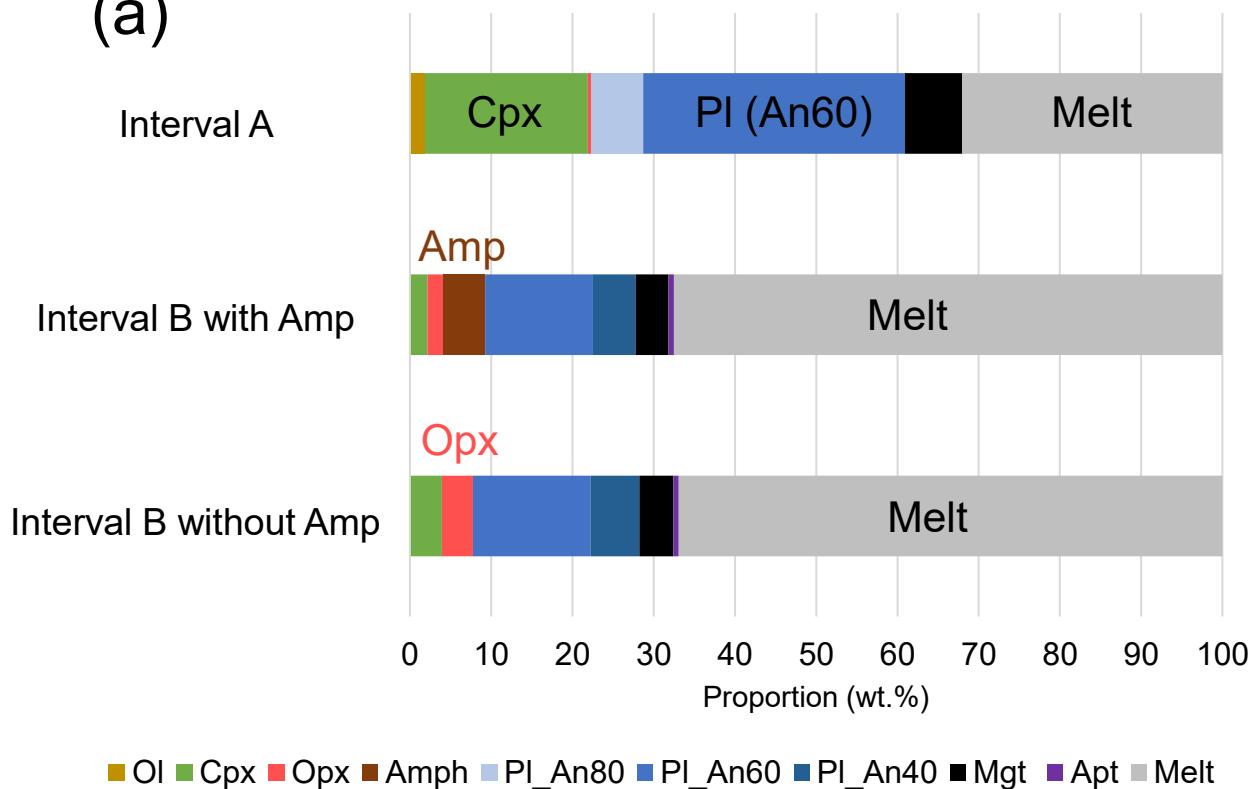


Figure 15 Calculated phase proportions shown by bar graphs (a), Th and Gd contents in calculated HK-M and HK-S melts (b), and REE pattern of the melts (c, d). Colored areas in (b) indicate the observed compositional variations of the HK-S, HK-M, and B-MI melts. no-Amph in the legends indicates the calculation without amphibole in (b) and (d).

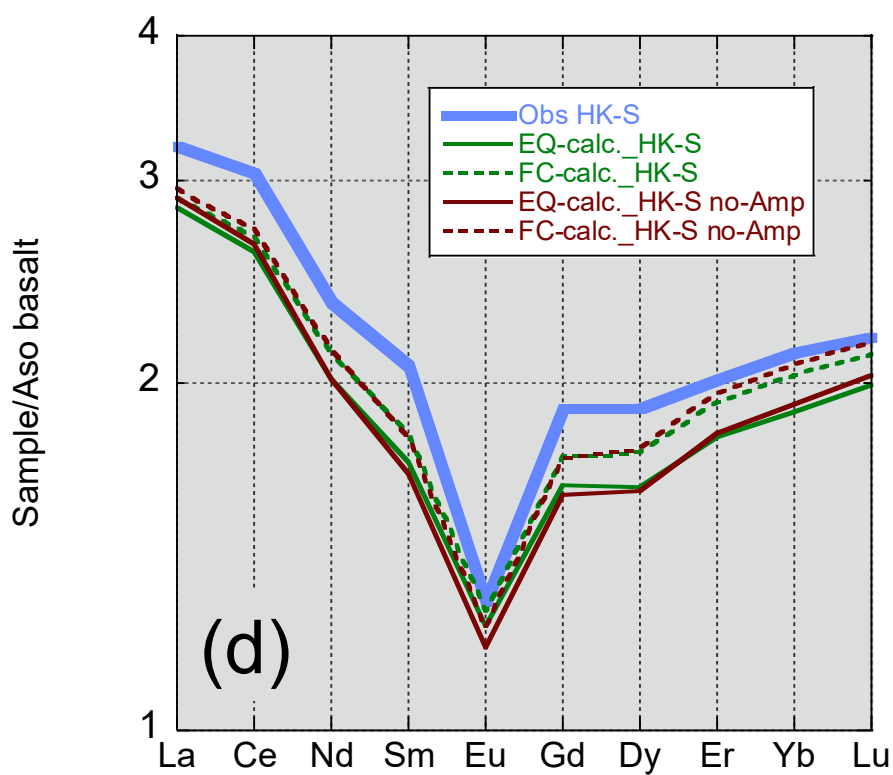
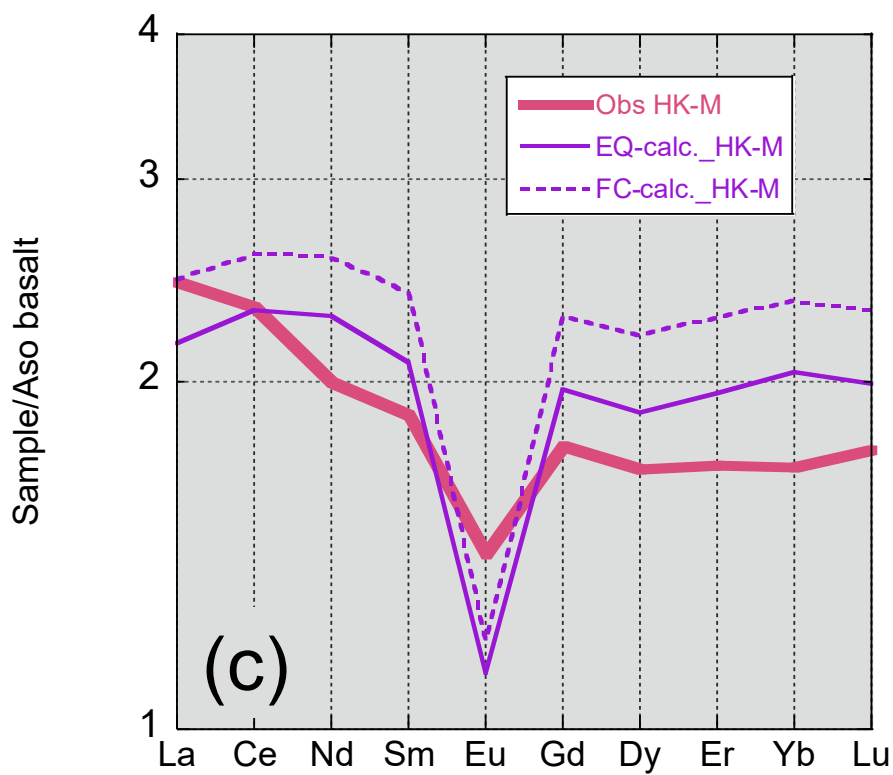


Figure 15 Continued

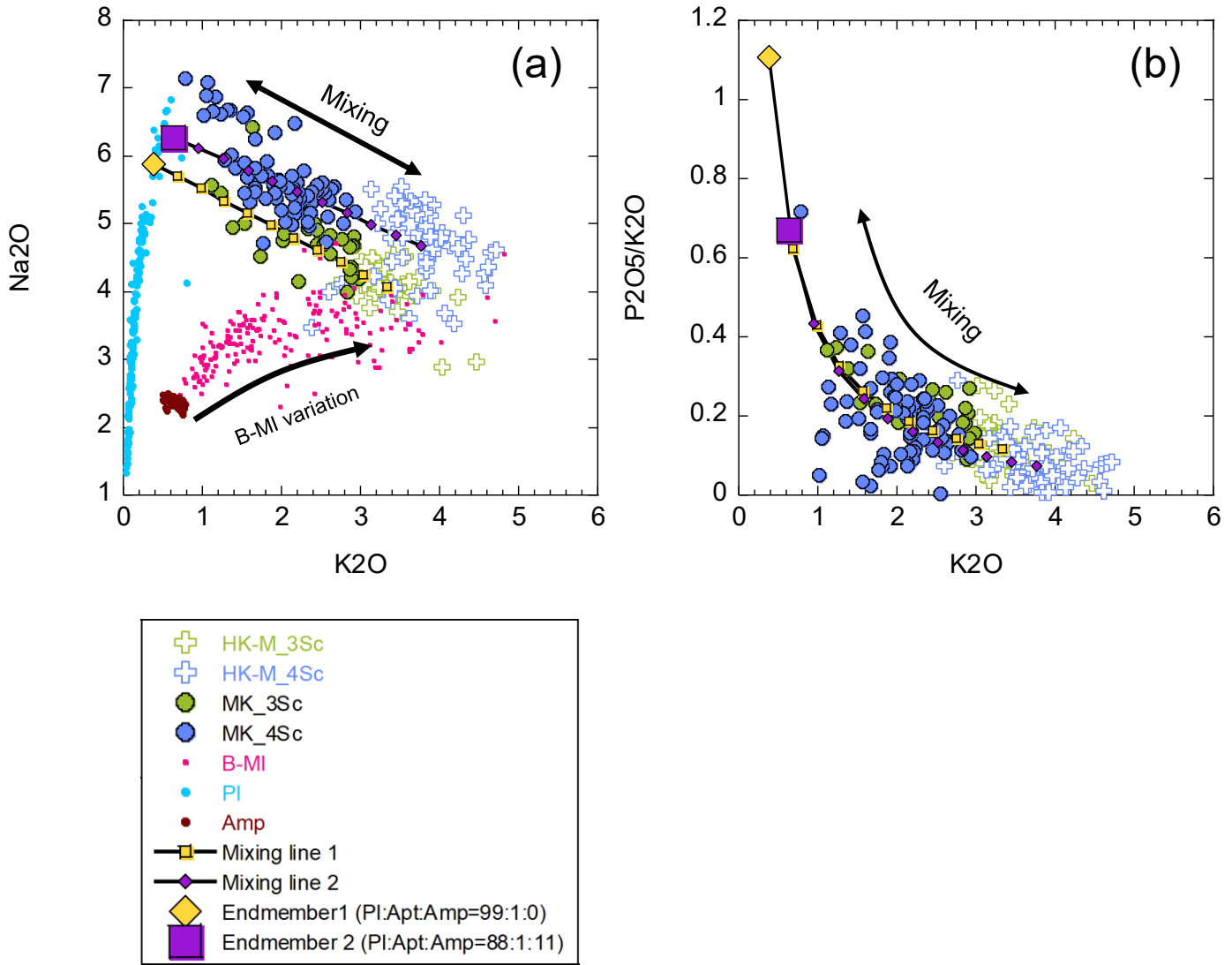


Figure 16 Compositional feature of the MK melts and calculation results indicating petrogenesis of the melts. (a) and (b) are Na₂O-K₂O and P₂O₅/K₂O-K₂O variation diagrams. The figures show compositions of the MK and HK-M melts in the Aso-3 and 4 and calculated endmembers. Lines are mixing lines between the endmembers and average of the HK-K melt compositions. Compositions of plagioclase and amphibole in the Aso-4 scoria and the B-MI melt are also shown in (a). (c) and (d) are REE patterns of the endmembers and the calculated MK melts of the Aso-3 and Aso-4, respectively. Yellow and green dotted lines are the calculated MK melt compositions of the Aso-3 and 4, respectively, and solid lines are the observed MK melt compositions.

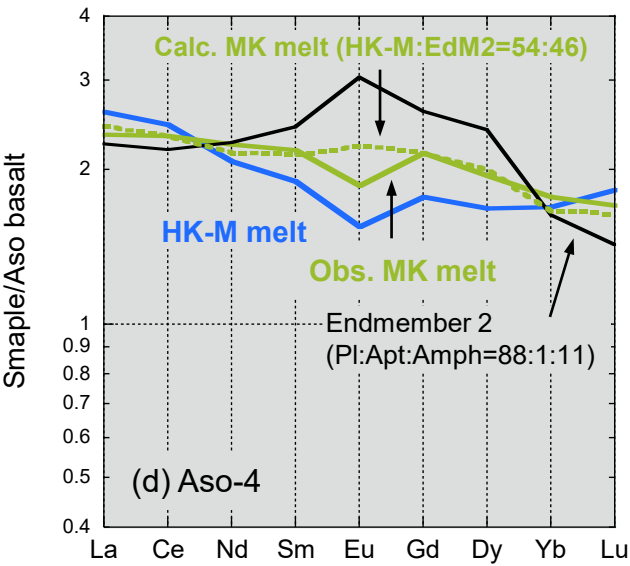
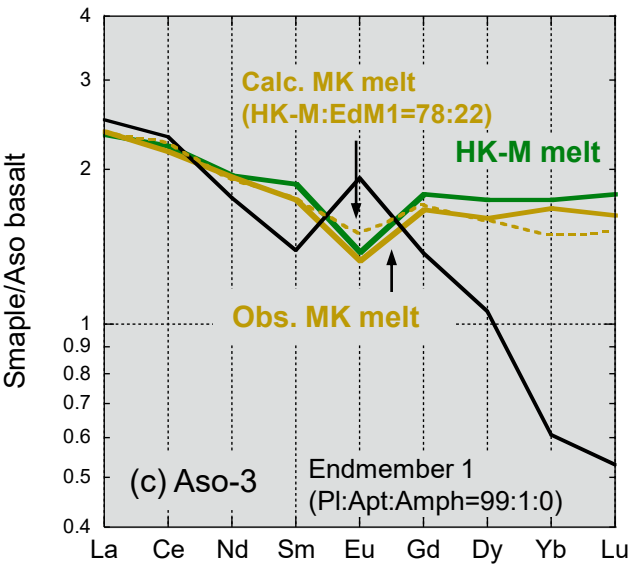


Figure 16 Continued

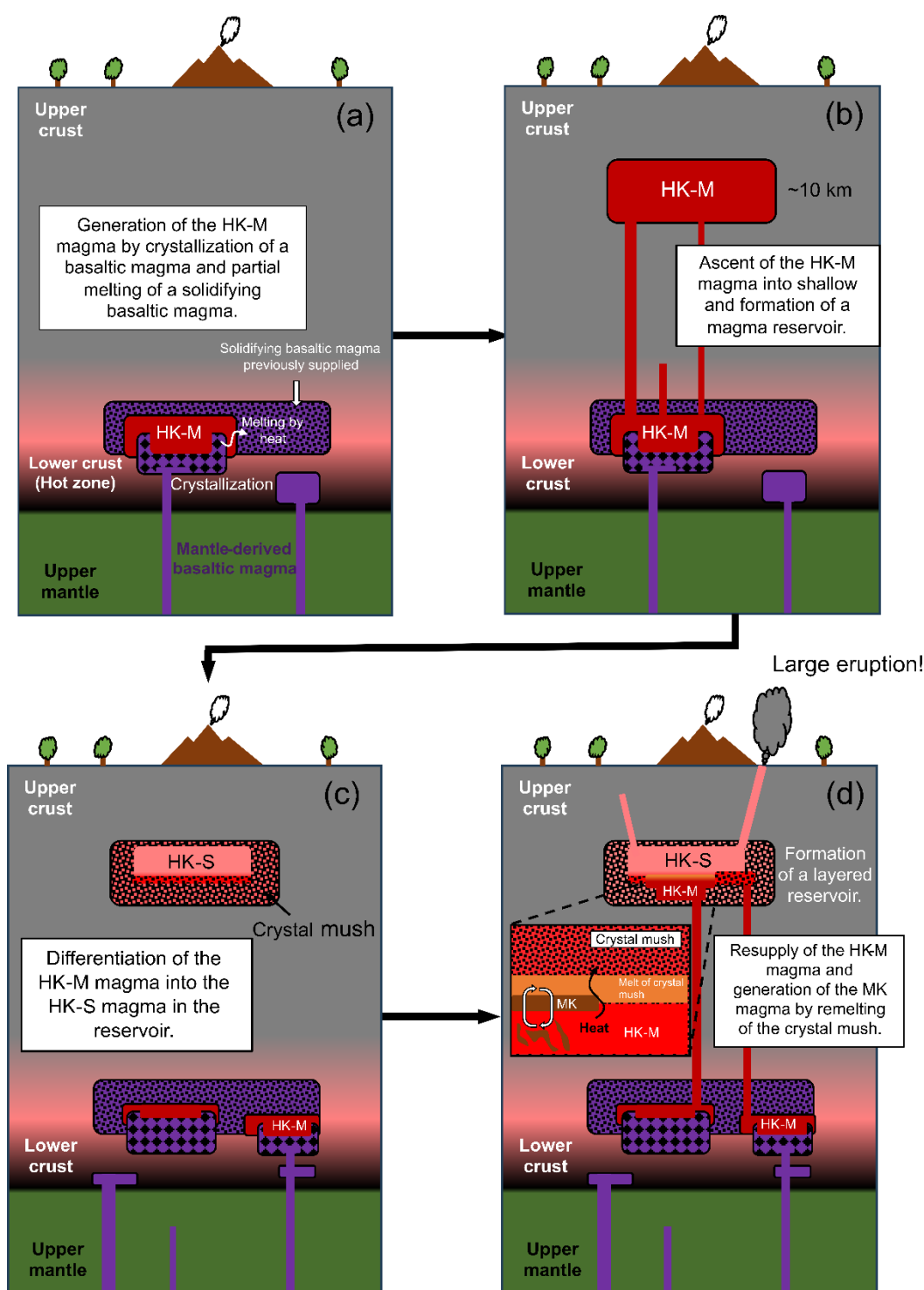


Figure 17 Schematic diagram of the magma plumbing system model in the Aso volcano proposed by our study. (a) Basaltic magma is supplied to the lower crust to produce the HK-M magma by its own crystallization and melting of the surrounding crust. (b) The HK-M magma rises into the upper crust and forms a shallow magma reservoir. (c) The HK-M magma in the shallow reservoirs is differentiated into the HK-S magma by crystallization. (d) New HK-M magma is supplied into the shallow reservoir, resulting in a layered magma reservoir. At this time, remelting of crystal mush occurs and the MK magma is formed.

Tables

Table 1 Petrographic description of the ejecta.

	Unit	Rock type	Mineral assemblage						Analysis
			Ol	Cpx	Opx	Amp	Pl	Mgt	
Aso-CC	Ksh	Scoria	○	○	△	-	○	○	MI
Aso-4	4I-3	Scoria	△	○	○	○	○	○	MI, GM
	4I-1	Pumice	-	△	○	○	○	○	MI, GM
Aso-4/3	Z-15	Scoria	○	○	△	-	○	○	MI
	Z-20	Scoria	○	○	△	-	○	○	MI
Aso-3	3C	Scoria	-	○	○	-	○	○	MI, GM
	3W, 3A	Pumice	-	○	○	-	○	○	MI, GM
Aso-2	2T	Scoria	○	○	○	-	○	○	MI, GM
	2TL	Pumice	-	○	○	-	○	○	MI, GM

Mineral abbreviations are as follows: Ol olivine, Cpx clinopyroxene, Opx orthopyroxene, Amp amphibole, Pl plagioclase, Mgt magnetite. Circles indicate that the mineral is present in the ejecta, triangles indicate that the mineral is present in small amounts, and the hyphens show that the mineral is not present in the ejecta. Column of analysis indicates the MI and GM glass type we analyzed.

Table 2 Location of sampling sites.

Eruption		Aso-2				Aso-3			Aso-4/3		Aso-4		Aso-CC
Unit		2TL	2T	3W	3A	3C	3C	3C	Z-20	Z-15	4I-1	4I-3	Ksh
Ejecta		Pumice	Scoria	Pumice	Pumice	Scoria	Scoria	Scoria	Scoria	Scoria	Pumice	Scoria	Scoria
Loc. (degree)	Lat.(N)	32.96609	32.96609	32.90188	32.90587	32.94161	32.89326	32.90366	131.33681	131.33681	32.94065	32.95596	32.53343
	Long.(E)	131.38972	131.38972	131.32788	131.34945	131.15450	131.31656	131.33681	32.90366	32.90366	131.31090	130.86158	131.03293

Table 3 Compositions of starting materials in the experiments and the basaltic B-MI.

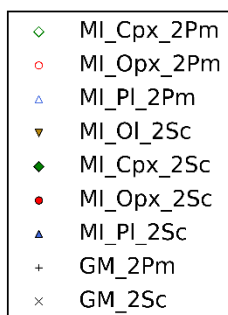
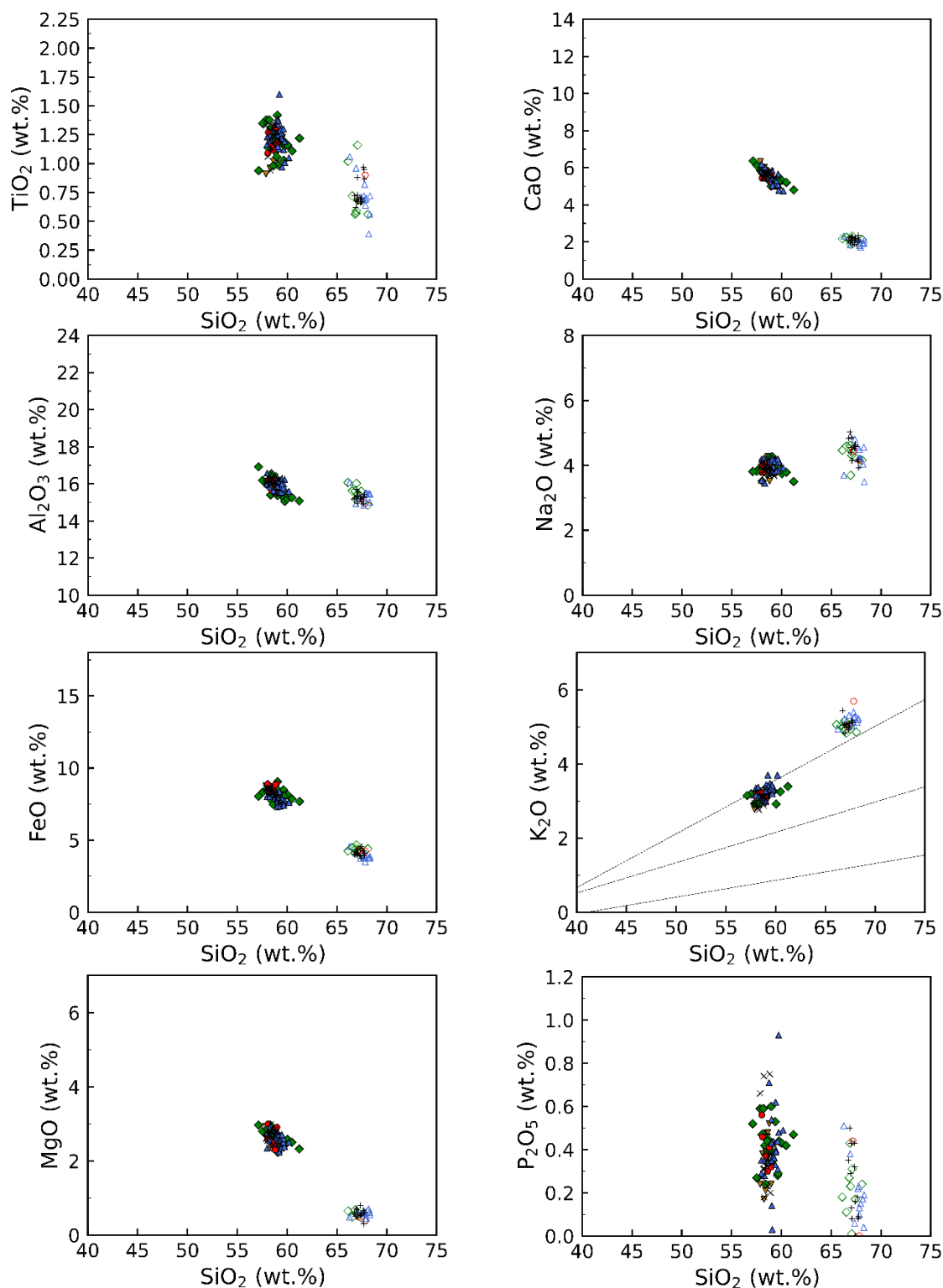
Sample	SiO ₂	TiO ₂	Al ₂ O ₃	FeO*	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	FeO/MgO	(Fe+Mg)/Si	Ca/Si
<i>Starting material of the experiments</i>													
(a) EQ	49.9	1.25	17.0	9.28	0.16	8.67	10.0	3.02	0.49	0.22	1.07	0.41	0.21
(b) FC	50.02	0.70	15.69	8.39	0.15	10.46	11.95	1.92	0.61	0.10	0.80	0.45	0.26
<i>Observed basaltic magmas in the Aso volcano</i>													
(c) Z-20	51.34	1.16	17.54	10.06	0.19	4.68	10.43	3.07	1.10	0.23	2.15	0.29	0.20
(d) Z-15	50.75	1.00	17.60	10.79	0.19	4.85	10.52	2.84	1.01	0.16	2.22	0.31	0.21
(e) Ksh	49.43	1.18	18.42	10.79	0.21	4.09	11.07	2.95	1.29	0.33	2.64	0.30	0.22
(f) Average	50.51	1.11	17.85	10.55	0.20	4.54	10.67	2.95	1.13	0.24	2.32	0.31	0.23
<i>Calculated primitive basaltic magma in the Aso volcano</i>													
(g)	49.12	0.96	15.35	10.66	0.17	10.63	9.18	2.54	0.98	0.21	1.00	0.50	0.20

Table 3 Compositions of starting materials in the experiments and the basaltic B-MI. (a) is starting composition of the equilibrium crystallization experiment at 4, 7, and 9 kbar (Blatter et al., 2013), (b) is that of the fractional experiment at 7 kbar (Nandedkar et al., 2014). These shown compositions are recalculated to 100 wt.% H₂O free. (c) to (e) are the composition of the basaltic B-MI in the Aso volcano measured in this study, and (f) is an average of (c) to (e). Estimated composition of primitive basaltic magma in the Aso volcano is shown in (g). This composition is estimated by adding olivine composition to the average composition (f) as in Tatsumi et al. (1983). In this calculation, Mg/Fe exchange partitioning between olivine and melt (K_D) is 0.3 (Roeder and Emslie, 1970), and $Fe^{3+}/(Fe^{2+}+Fe^{3+})$ ratio is 0.62 determined by the composition of olivine phenocryst and the basaltic melts.

Table 4 Major element composition of melt used for the calculations in section 4.3.

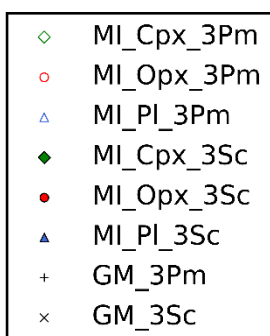
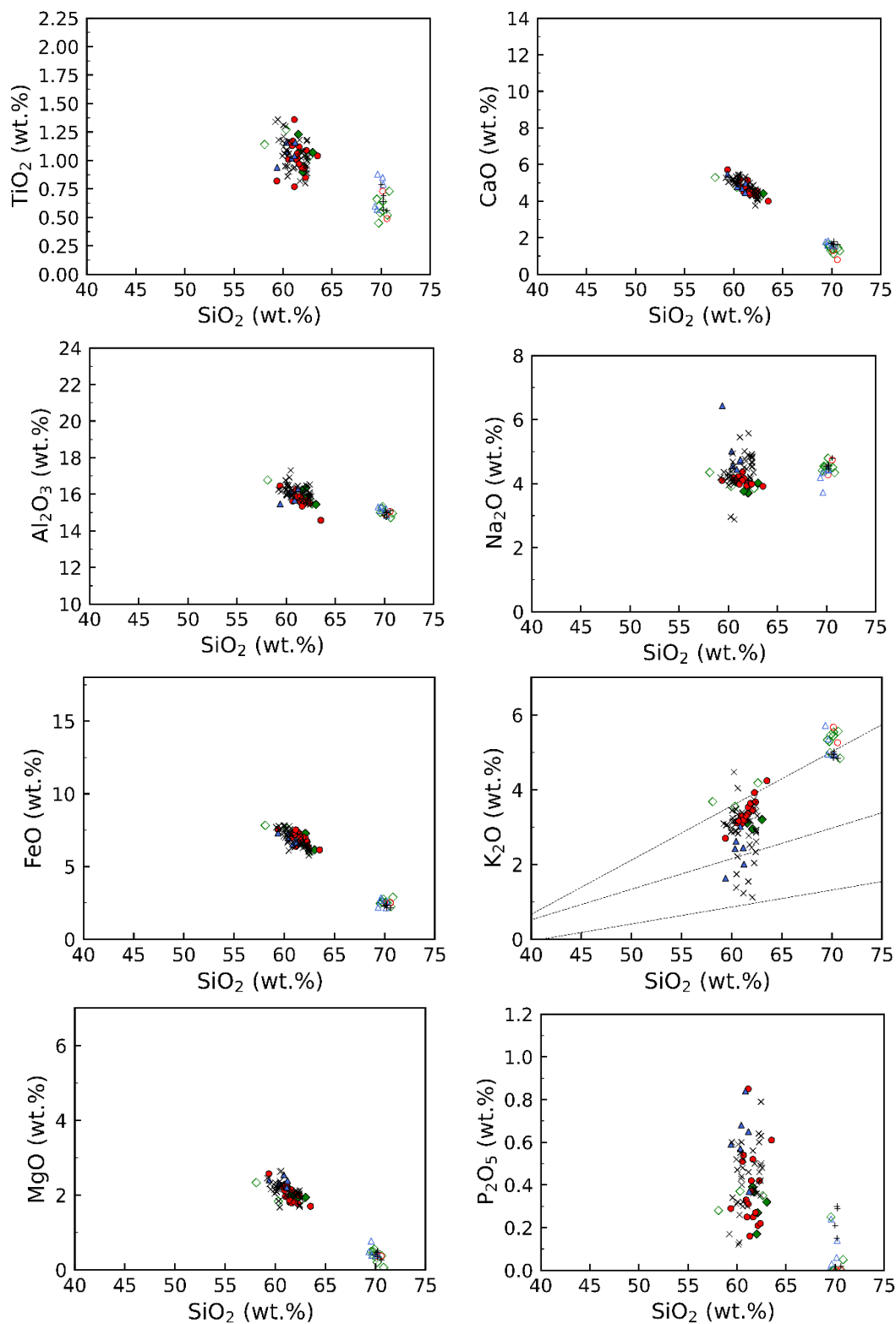
	SiO2	TiO2	Al2O3	FeO	MgO	CaO	Na2O	K2O	P2O5
Basaltic B-MI	50.73	1.12	17.93	10.59	4.56	10.72	2.97	1.14	0.24
HK-M	61.54	1.01	16.33	6.55	1.96	4.65	4.16	3.44	0.37
HK-S	69.54	0.63	15.23	2.79	0.45	1.69	4.60	4.94	0.13

Appendix

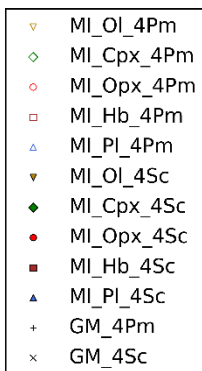
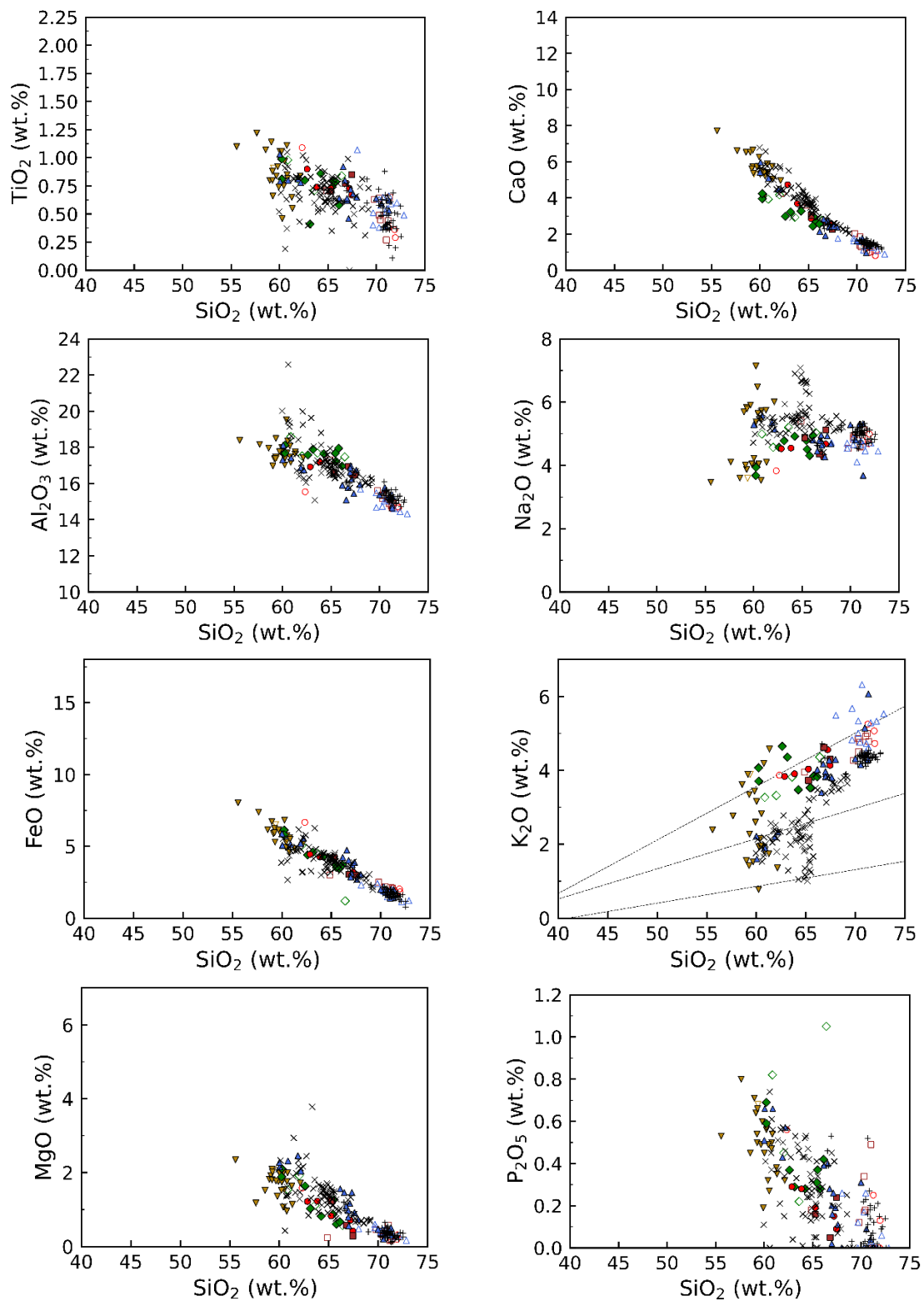


Appendix A Variation diagrams of major element composition of MI and GM in each ejecta: (a) Aso-2, (b) Aso-3, (c) Aso-4, (d) Z-20, Z-15, and Ksh, (e) all.

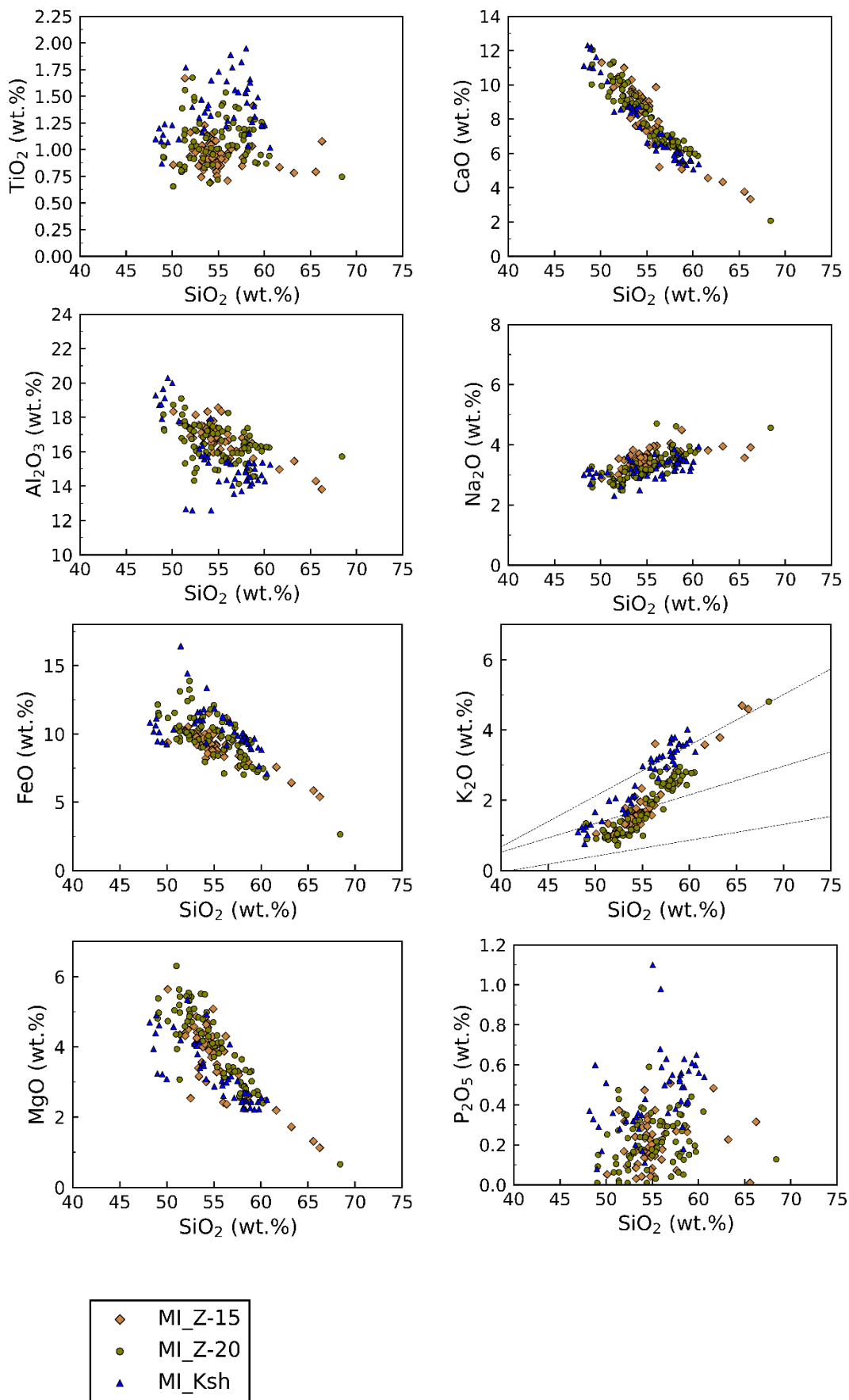
(a) Aso-2



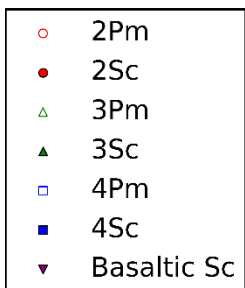
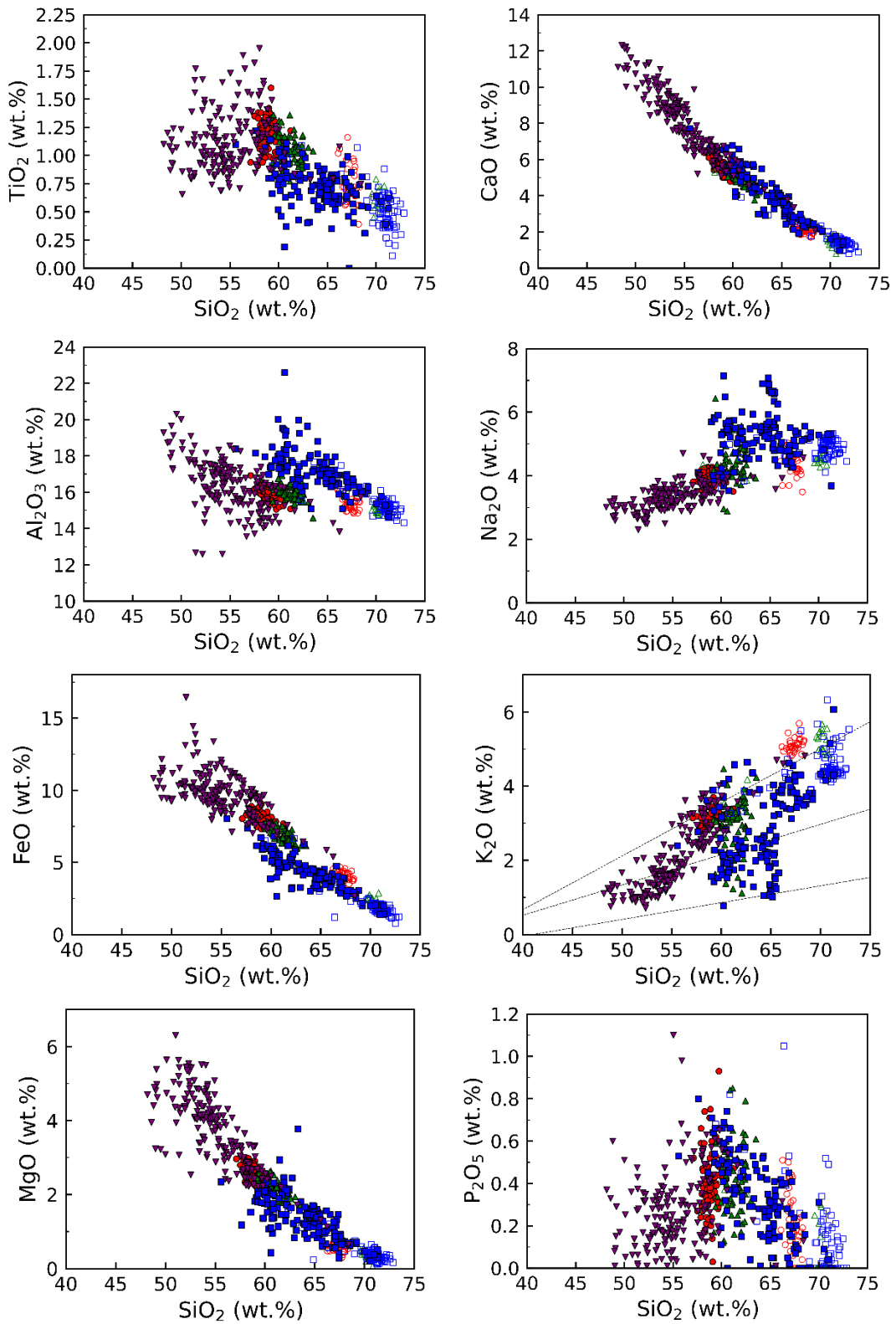
(b) Aso-3



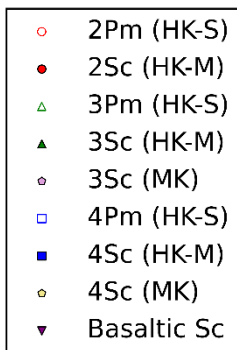
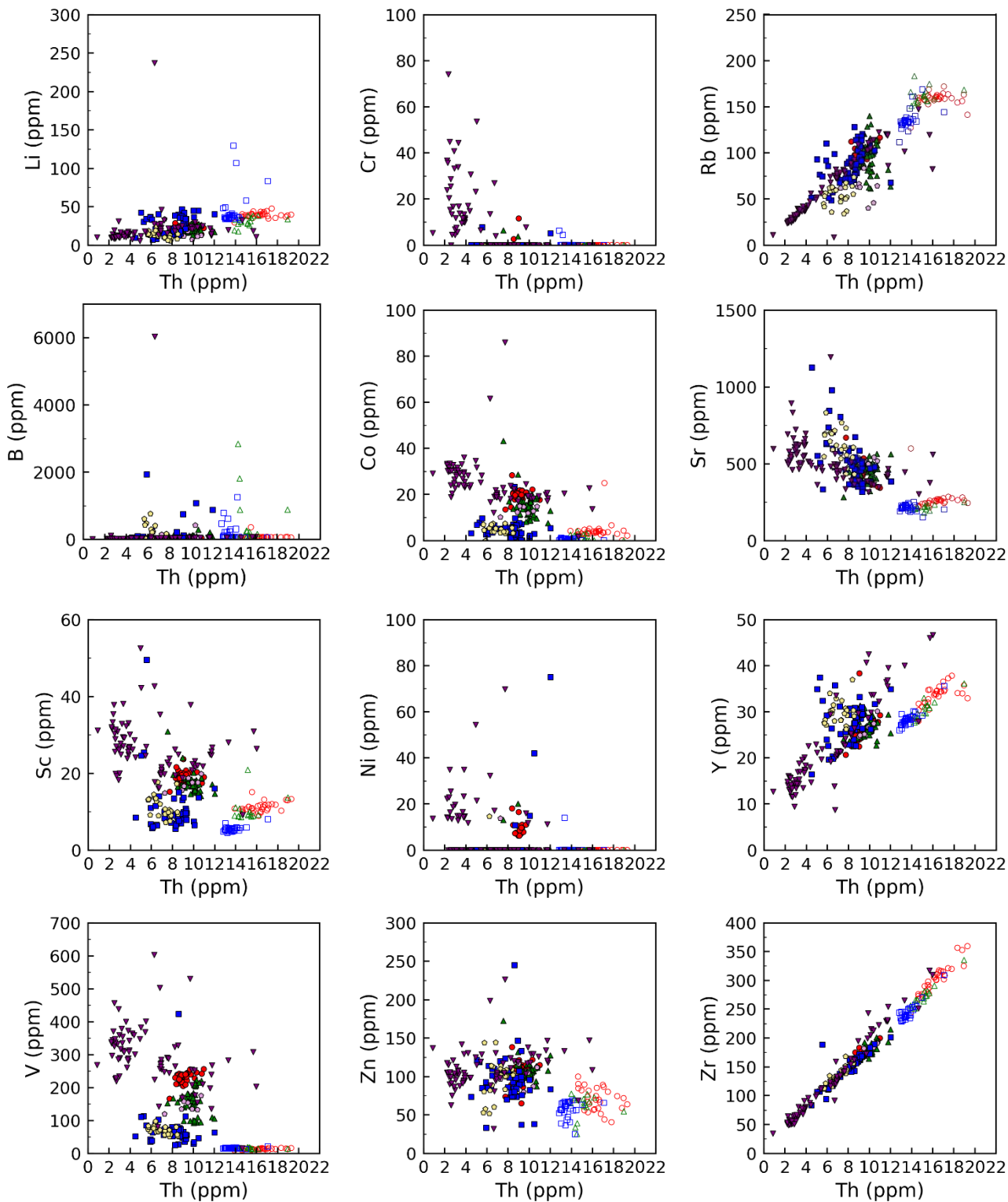
(c) Aso-4



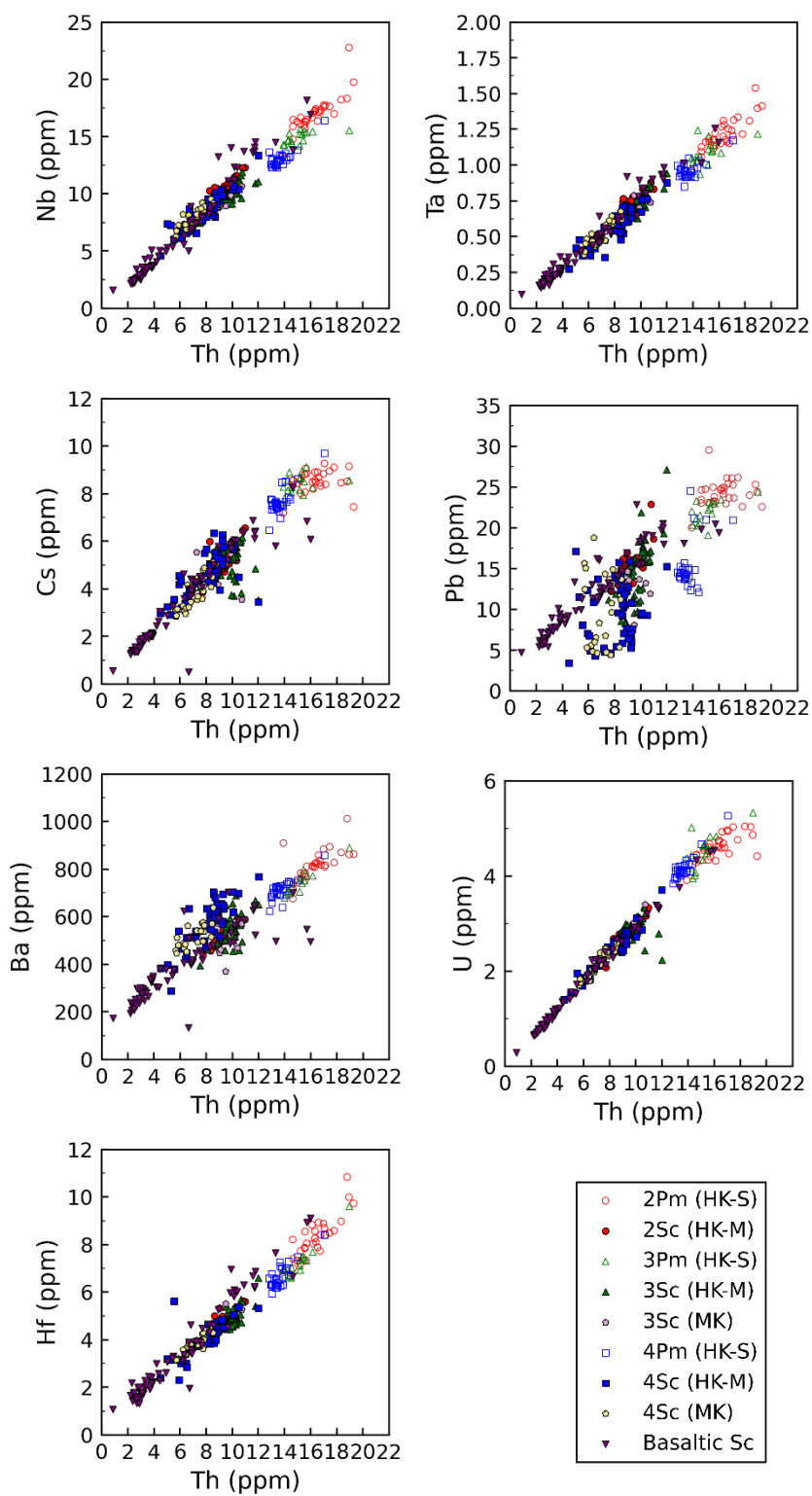
(d) Z-20, Z-15, and Ksh

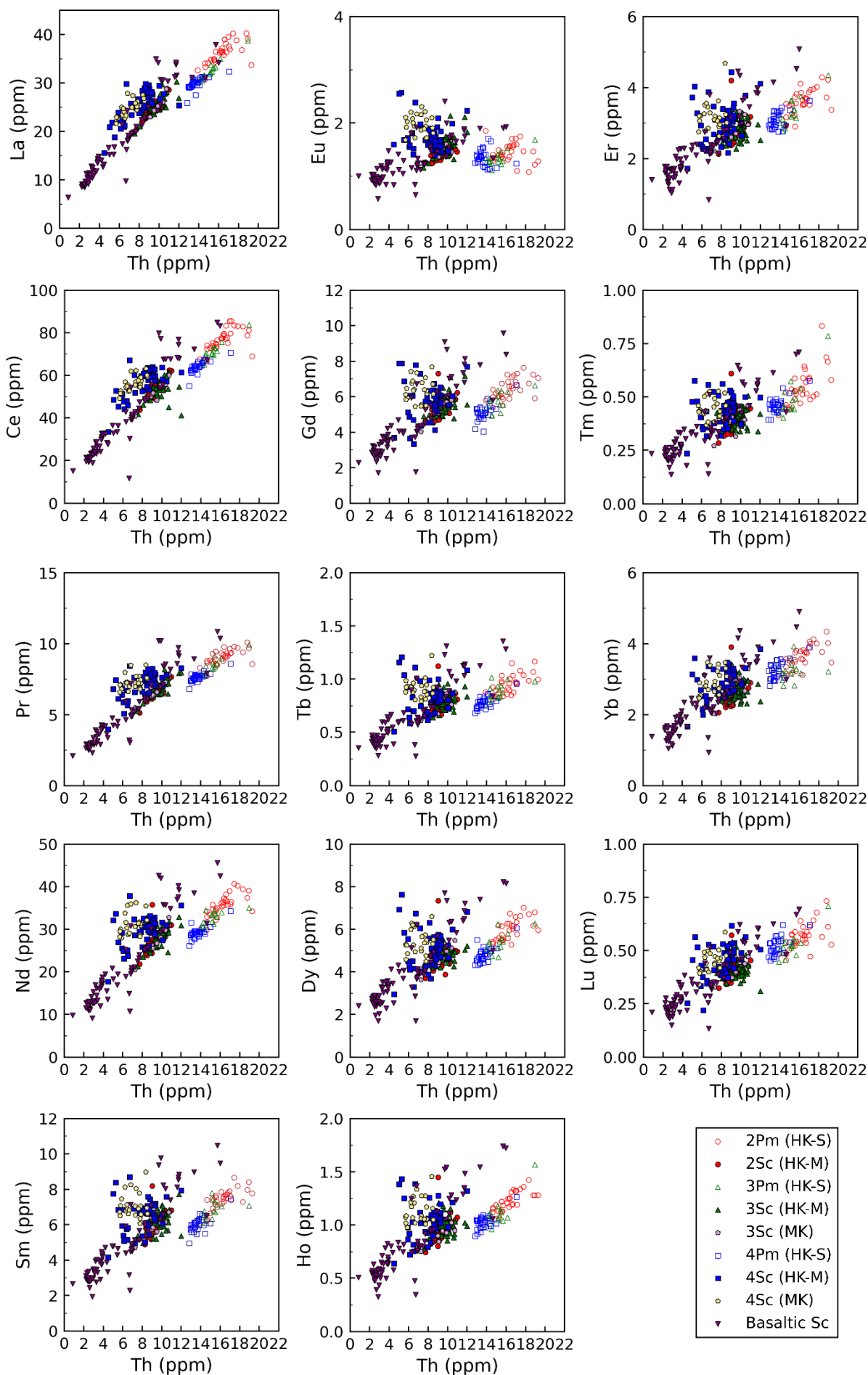


(e) All



Appendix B Variation diagrams of trace element composition of MI and GM in each ejecta





Appendix C Tables of major element composition of MI and GM of the large eruptions and the basaltic scoriae

	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL
Ejecta	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice
Glass type	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
Host mineral	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Op	Op	Pl	Pl	Pl	Pl	Pl	Pl
Sample number	B-01	B-02	B-03	C-01	C-02	F-02a	F-02b	F-02c	Op	Op	A-01a	A-01b	B-01a	B-01b	B-02	C-02	C-03	E-01a
Compositional type	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S
Analysis time (s)	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
Fo, Mg#, An# of host	66.1	66.5	65.8	0.0	66.8	67.6		66.0		59.8	59.8	44.9	39.5	48.6	43.9	43.9	45.2	45.9
Weight (wt. %)																		
SiO ₂	62.5	63.26	63.84	62.8	65.55	65.16	66.57	63.03	64.77	65.26	66.44	63.96	66.01	65.73	64.78	66.06	66.48	66.43
TiO ₂	0.53	0.53	0.69	0.97	1.13	0.66	0.55	0.64	0.57	0.66	0.88	0.6	0.38	0.94	1.04	0.68	0.55	0.7
Al ₂ O ₃	14.15	14.78	14.99	15.27	15.09	15.02	14.52	14.58	15.5	14.8	14.66	14.63	14.98	14.67	15.71	15.07	14.63	15.04
FeO	4.11	3.87	4.3	4.04	4.14	4.21	4.3	3.97	4.51	4.18	4.14	3.58	3.62	4.03	4.46	3.9	3.66	3.71
MnO	0.31	0.3	0.12	0.01	0.11	0	0.04	0.02	0.2	0.09	0.02	0	0.19	0	0.03	0	0.04	0.12
MgO	0.54	0.64	0.46	0.62	0.55	0.53	0.61	0.44	0.57	0.48	0.37	0.56	0.69	0.66	0.47	0.44	0.59	0.57
CaO	1.98	2.02	2.16	2.06	1.95	2.24	2.07	1.89	1.82	2.02	1.75	1.85	1.85	1.82	2.27	1.66	1.9	2.01
Na ₂ O	4.31	4.27	4.4	4.24	4.21	4.28	4.06	3.96	3.57	4.31	4.07	3.97	3.91	4.82	3.61	4.09	4.43	4.73
K ₂ O	4.59	4.72	4.82	4.81	4.97	4.69	4.75	4.7	4.99	4.9	5.57	4.96	4.96	5.13	4.83	5.13	5.06	5.24
P ₂ O ₅	0.4	0.26	0.11	0.17	0.01	0.3	0.23	0.16	0.22	0.43	0	0.12	0.16	0.37	0.5	0.15	0.04	0.06
S	0	0.02	0.07	0.01	0.04	0	0.05	0.09	0.03	0	0.05	0.03	0.07	0.05	0.05	0.03	0	0
Total	93.42	94.67	95.96	95	97.75	97.09	97.75	93.48	96.75	97.13	97.95	94.26	96.82	98.22	97.75	97.21	97.38	98.61

Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL
Pumice	Pumice	Pumice	Pumice	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
Pl	Pl	Pl	Pl	Ol	Ol	Ol	Ol	Ol	Ol	Ol	Ol	Ol	Ol	Ol	Ol	Ol	Cpx	Cpx
E-01c	F-04a	F-04b	F-04c	A-04	D-02	E-02	E-03	Op_D-04	Op_E-03	03_01	03_03	03_04	03_05	03_06	03_08	03_09	B-01	B-02a
HK-S	HK-S	HK-S	HK-S	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M
240	180	180	240	180	180	180	180	180	180	300	300	300	300	300	300	300	180	180
43.7	44.6	46.2	44.7	68.8	70.5		71.3	69.5	68.5	71.0	71.4	71.3	68.6	70.9	71.5	71.9	71.1	73.6
64.7	66.73	65.98	64.62	58.39	58.08	56.76	57.55	57.21	57.29	56.62	56.17	55.89	55.75	56.27	56.17	55.71	57.05	57.22
0.66	0.81	0.7	0.68	1.21	1.25	1.15	1.05	1.17	1	1.22	0.93	1.17	0.88	1.03	1.22	1.16	1.36	1.01
14.76	14.97	14.47	14.61	15.97	15.5	15.58	15.74	15.48	15.75	15.73	15.86	15.47	15.48	15.68	15.4	15.24	15.77	15.7
3.34	3.78	3.85	3.65	8.02	8.12	8.33	7.95	7.9	7.71	8.36	8.21	7.86	8.47	8.05	8.21	7.91	8.36	8.33
0.26	0.03	0.2	0.07	0.11	0.33	0.27	0.12	0	0.27	0.31	0.18	0.24	0.16	0.07	0.12	0.06	0.07	0.23
0.43	0.62	0.62	0.51	2.34	2.52	2.27	2.47	2.5	2.6	2.49	2.41	2.54	2.82	2.35	2.29	2.62	2.7	2.59
1.71	2.09	2.05	1.99	5.59	5.39	5.44	5.34	5.27	5.41	5.73	5.81	5.29	6.1	5.42	5.42	5.46	5.77	5.4
4.27	4.15	4.44	3.3	4.25	4.09	4	4.13	4.06	4.04	3.67	3.63	3.78	3.64	3.36	3.57	3.82	3.88	4.04
5.15	5.06	4.9	4.95	3.06	2.9	2.83	3.01	3.09	3.01	2.86	2.88	3.07	2.68	2.94	2.94	3.02	2.89	3.03
0.1	0.23	0.21	0.18	0.46	0.24	0.4	0.31	0.51	0.47	0.37	0.16	0.38	0.23	0.36	0.41	0.2	0.58	0.58
0	0	0.06	0.03	0.22	0.07	0.14	0.16	0.12	0.16	0.05	0.15	0.1	0.14	0.18	0.1	0.18	0.16	0.18
95.38	98.47	97.48	94.59	99.62	98.49	97.17	97.83	97.31	97.71	97.41	96.39	95.79	96.35	95.71	95.85	95.38	98.59	98.34

Appendix C Continued

Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T
Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx
B-03	C-01	C-02	C-03a	C-03b	D-02a	D-02b	D-03a	D-03b	D-03d	D-03e	F-01a	F-01b	03_02a	03_02b	03_02c	03_03	03_05	Opx_E-04a	Opx_E-04b
HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M
180	180	180	180	180	180	180	180	180	180	180	180	180	300	300	300	300	300	180	180
72.2	75.5				74.0		70.3	70.3	70.3	83.0	75.1		75.3			72.6	74.5	73.2	73.2
56.89	58.22	58.24	57.96	57.49	57.8	57.77	56.55	57.57	57.36	55.57	58.34	58.93	56.08	56.43	55.65	58.59	57.82	58.44	58.4
1.28	1.12	1.23	1.22	1.38	0.97	1.17	1.33	1.23	1.14	0.91	1.17	1.14	1.1	0.94	1.2	1.17	1.06	1.05	1.16
15.03	14.67	15.22	15.09	15.16	15.82	16.07	15.92	15.74	16.15	16.46	15.49	14.91	15.61	15.81	15.76	14.43	14.59	15.57	15.28
8.34	7.85	7.89	8.9	8.09	7.48	7.57	8.17	8.17	7.6	7.82	8.22	7.99	8.56	7.21	7.7	7.35	7.51	8.49	7.89
0	0.25	0.27	0	0.11	0.09	0.02	0.27	0	0.37	0	0.41	0.39	0.22	0.24	0.12	0.15	0	0.43	0.23
2.89	2.37	2.34	2.47	2.41	2.65	2.58	2.75	2.79	2.66	2.89	2.2	2.53	2.75	2.64	2.56	2.22	2.39	2.39	2.36
5.67	5.34	5.12	5.06	5.28	5.14	5.46	6.01	5.58	5.35	6.2	5.28	5.22	5.58	5.6	5.36	4.59	4.98	4.97	5.1
3.85	3.85	4	3.89	3.81	4.18	4.18	3.76	3.95	4	3.71	3.97	3.67	3.39	4	3.79	3.35	3.62	4.14	3.86
3	3.19	3.15	3.08	3	3.3	3.14	3.14	2.92	3.01	3.06	3.16	2.87	2.84	2.92	2.81	3.24	3.11	3.08	3.16
0.41	0.43	0.52	0.33	0.58	0.38	0.44	0.27	0.37	0.34	0.51	0.42	0.42	0.45	0.42	0.23	0.45	0.4	0.42	0.28
0.16	0.15	0.09	0.2	0.14	0.08	0.13	0.14	0	0.14	0.15	0.12	0.1	0.02	0.12	0.1	0.16	0.14	0.17	0.15
97.52	97.44	98.07	98.2	97.45	97.89	98.53	98.31	98.32	98.12	97.28	98.78	98.17	96.6	96.33	95.28	95.7	95.62	99.15	97.87

Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T
Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
Opx	Opx	Opx	Opx	Opx	Opx	Opx	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl
A-02a	A-02b	B-02a	B-02b	D-03a	D-03b	F-02	A-01	A-02	B-01	B-03	B-04a	B-04b	C-02a	C-02b	C-03a	C-03b	D-03a	D-03b	F-03
HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M
180	180	180	180	180	180	300	180	180	180	180	180	180	180	180	180	180	180	180	180
73.2	72.9	73.1	71.9	71.1	70.3	73.1	71.9	56.9	72.0	71.1	70.6	75.1	68.7	68.7	77.5	77.5	70.8	61.5	69.9
56.87	57.68	56.31	57.3	57.75	56.85	56.06	58.35	58.44	56.8	58.8	58.31	57.79	57.61	58.15	58.34	57.82	59.11	57.24	57.91
1.24	1.11	1.08	1.14	1.29	1.07	1.12	1.11	1.58	1.15	1.3	1.26	0.98	1.31	1.23	1.2	1.36	1.03	1.33	1.26
15.84	15.16	15.54	15.33	15.49	15.63	15.09	15.58	15.32	16.25	15.38	15.46	15.72	15.59	15.92	15.27	15.96	15.33	15.43	15.48
8.23	8.73	8.13	8.53	8.69	8.7	7.6	8.01	8.26	7.84	7.64	7.88	7.45	7.49	7.29	7.54	7.18	7.5	7.56	7.2
0	0	0.09	0.08	0.03	0.22	0.13	0.22	0.23	0.14	0.17	0.28	0	0	0.08	0.3	0.02	0.09	0.26	0.28
2.94	2.41	2.33	2.47	2.26	2.54	2.77	2.44	2.21	2.29	2.54	2.61	2.32	2.5	2.45	2.3	2.58	2.46	2.67	2.45
5.49	5.44	5.2	5.39	5.21	5.32	5.16	5.2	4.94	5.7	5.16	5.48	4.87	5.15	5.17	5.06	5.15	4.67	4.89	5.24
3.71	3.89	3.83	4.02	4.04	3.92	3.79	3.91	3.72	4.1	4.16	4.1	3.8	4.12	3.74	4.08	4.02	3.85	4.05	4.02
3.02	3.05	3.09	3.16	2.99	3.12	2.88	3.24	3.65	3.28	3.4	3.06	3.27	3.36	3.35	3.42	3.19	3.64	3.33	3.32
0.45	0.33	0.29	0.36	0.4	0.55	0.3	0.43	0.37	0.34	0.33	0.7	0.46	0.42	0.39	0.61	0.53	0.48	0.03	0.35
0.1	0.1	0.18	0.16	0.1	0.04	0.16	0.14	0	0.07	0.11	0.1	0.1	0.05	0.08	0.07	0.18	0.1	0.1	0.14
97.89	97.9	96.07	97.94	98.25	97.96	95.06	98.63	98.72	97.96	98.99	99.24	96.76	97.6	97.85	98.19	97.99	98.26	96.89	97.65

Appendix C Continued

Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T
Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
PI	PI	PI	PI	PI	PI	PI	PI	PI	PI
F-04a	F-04b	03_01	03_02	03_03a	03_03b	03_04	03_05	03_06	03_07
HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M
180	180	300	300	300	300	300	300	300	300
73.6	73.6	71.7	65.5	76.3	64.9	75.5	67.9	74.3	70.9
57.56	58.09	56.58	56.62	57.07	58.07	56.75	56.3	57.27	56.29
1.15	1.27	1.2	1.24	1.17	1.09	0.93	1.19	1.21	1.1
15.16	15.4	15.62	15.11	15.51	15.57	15.26	15.54	15.41	15.41
7.5	7.37	7.8	7.9	8.41	7.23	7.49	8.28	7.93	7.62
0	0	0.13	0.18	0.15	0.13	0.14	0.22	0.1	0
2.3	2.44	2.48	2.75	2.89	2.54	2.59	2.68	2.58	2.6
4.62	4.94	5.52	5.59	5.89	5.51	5.07	6.02	5.25	5.59
3.96	4.09	4.11	3.85	3.38	3.74	3.64	3.44	3.73	3.62
3.17	3.33	3.27	2.94	3.03	3.12	3.16	3.07	3.18	2.85
0.9	0.43	0.34	0.33	0.27	0.3	0.37	0.28	0.34	0.13
0.06	0.07	0.11	0.08	0.12	0.07	0.04	0.08	0.11	0.14
96.38	97.43	97.16	96.59	97.89	97.37	95.44	97.1	97.11	95.35

Appendix C Continued

	Aso-3W	Aso-3W	Aso-3W	Aso-3W	Aso-3W	Aso-3W	Aso-3W	Aso-3W	Aso-3W	Aso-3W	Aso-3W	Aso-3W	Aso-3W	Aso-3A	Aso-3A	Aso-3A	Aso-3A	Aso-3A	Aso-3A	Aso-3A
Ejecta	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice
Glass type	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
Host mineral	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Opx	Pl	Pl	Pl	Pl	Cpx	Cpx	Cpx	Cpx	Opx	Pl	Pl
Sample number	B-04	C-03	D-01	D-04	E-01	E-02	Pl_C-03a	Pl_C-03b	A-04	D-04	E-04	G-03	C-02	C-03a	C-03c	F-02a	D-01	A-04	B-03	
Compositional type	HK-S	HK-S	HK-S	HK-S	HK-M	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-M	HK-M	HK-S	HK-S	HK-S	HK-S	
Analysis time (s)	240	240	240	240	240	240	240	240	240	240	240	240	240	180	180	180	180	180	180	180
Fo, Mg#, An# of host	75.9	75.0	76.1	73.1	73.0	72.9	71.4	70.0	45.3	71.1	48.0	46.8	75.5	70.6	73.4	75.2	70.9	43.9	49.0	
Weight (wt.%)																				
SiO2	68.17	68.36	68.01	70.66	62.71	68.59	68.65	68.72	69.97	65.37	69.53	70.36	70.32	57.23	58.72	67.96	67.57	66.91	66.11	
TiO2	0.44	0.65	0.58	0.52	1.03	0.55	0.63	0.72	0.69	1.15	0.82	0.56	0.54	1.12	1.24	0.7	0.47	0.75	0.84	
Al2O3	14.89	14.75	14.94	14.73	15.49	14.62	14.54	14.57	14.93	15.53	14.77	15.18	15.12	16.53	15.77	14.36	14.42	14.14	14.53	
FeO	2.49	2.42	2.49	2.23	6.03	2.44	2.51	2.41	2.33	3.97	2.44	2.66	2.77	7.71	7.42	2.76	2.4	2.48	2.7	
MnO	0.19	0.15	0.09	0.03	0.41	0.15	0.09	0.19	0.04	0.07	0.14	0	0.07	0.22	0.18	0.04	0.19	0.02	0	
MgO	0.38	0.48	0.47	0.37	1.86	0.2	0.31	0.36	0.28	0.85	0.5	0.43	0.55	2.29	1.78	0.06	0.35	0.43	0.37	
CaO	1.46	1.63	1.55	1.44	4.17	1.1	1.33	1.26	1.39	2.25	1.71	1.51	1.31	5.21	4.62	1.23	0.77	1.49	1.74	
Na2O	4.45	4.33	4.4	4.5	3.86	4.68	4.46	4.18	4.61	4.09	4.53	4.56	4.43	4.28	3.81	4.16	4.54	4.22	3.53	
K2O	5.17	5.24	4.86	5.56	4.19	5.42	5.32	5.55	5.08	5.35	5.09	5.07	5.5	3.62	3.46	4.64	5.04	4.72	5.08	
P2O5	0	0.25	0	0	0.35	0	0	0	0.01	0.21	0	0	0	0.28	0.36	0.05	0	0.13	0.03	
S	0.11	0	0.03	0	0.04	0.01	0.03	0	0.09	0.02	0.1	0	0							
Total	97.75	98.26	97.42	100.04	100.14	97.76	97.87	97.96	99.42	98.86	99.63	100.33	100.61	98.49	97.36	95.96	95.75	95.29	94.93	

Aso-3A	Aso-3A	Aso-3A	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C
Pumice	Pumice	Pumice	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
PI	PI	PI	Cpx	Cpx	Cpx	Cpx	Cpx	Opx	Opx	Opx	Opx	Opx	Opx	Opx	Opx	Opx	Opx	Opx	Opx
B-04_connected	E-05a	E-05b	P-04a	P-04b	Q-01a	Q-01b	Q-01c	N-03a	N-03b	N-03c	O-02	P-01a	P-01b	P-01c	Q-01	S-04a	S-04b	06_01a	
HK-S	HK-S	HK-S	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M
	180	180	180	240	240	240	240	240	240	240	240	240	240	240	240	240	240	300	
	46.5	46.6	41.8	72.8	73.3	73.1	73.1	75.1	73.3	73.3		71.8	70.9	70.9		70.9	72.9		72.6
	66.27	66.17	66.46	61.15	60	59.92	60.19	60.02	58.97	58.7	59.7	60.93	59.44	59.75	60.88	61.09	59.85	59.35	61.54
	0.8	0.57	0.54	1.04	0.87	1.2	0.92	1.05	0.98	0.81	1.33	1.01	0.98	1.15	0.91	1.11	1.11	0.75	1.01
	14.39	14.61	14.42	14.98	15.83	15.4	15.36	15.81	15.7	16.28	15.3	15.44	15.33	15.94	15.36	15.56	15.63	15.43	14.13
	2.04	2.09	2.56	5.97	6.46	7.03	7.06	6.46	6.88	7.49	6.25	7.2	7.16	7.04	6.8	6.84	7.22	7.31	5.96
	0.15	0.34	0.18	0.21	0.19	0.1	0.09	0.12	0.16	0.13	0.16	0.12	0	0.07	0.19	0.24	0	0.1	0.08
	0.36	0.46	0.74	1.88	1.86	1.95	1.82	1.9	2.2	2.54	2.25	1.79	2.11	1.92	1.98	1.77	2.08	2.13	1.65
	1.55	1.7	1.51	4.29	4.27	4.52	4.36	4.25	4.73	5.66	4.44	4.51	4.53	4.42	4.3	4.48	4.67	4.66	3.88
	4.2	4	4.15	3.9	3.59	3.66	3.81	4.02	4.07	4.05	4.12	4.33	4.08	4.13	3.88	4.07	3.95	3.86	3.8
	4.65	5.46	4.73	3.11	3.35	3.03	2.86	3.28	3.03	2.67	3.16	3.27	3.08	3.04	3.39	3.5	3.24	3.1	4.11
	0.06	0	0.23	0.31	0.16	0.38	0.26	0.36	0.5	0.29	0.83	0.42	0.16	0.24	0.21	0.25	0.32	0.3	0.59
				0.2	0.2	0.15	0.21	0.08	0.17	0.26	0.12	0.13	0.11	0.23	0.11	0.19	0.17	0.09	0.14
	94.47	95.4	95.52	97.04	96.78	97.34	96.94	97.35	97.39	98.88	97.66	99.15	96.98	97.93	98.01	99.1	98.24	97.08	96.89

Appendix C Continued

Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C
Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
Opx	Opx	Opx	Opx	Opx	Opx	PI	PI	PI	PI	PI	PI
06_01b	06_02	06_03a	06_03b	06_04	06_05	T-0401	N-0102	U-02a02	U-02b	W-01	W-02
HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	MK	MK	MK	MK	MK
300	300	300	300	300	300	240	240	240	240	240	240
71.9	72.4	72.8	72.7	72.3	71.2	70.4	74.6	76.5	80.0	76.4	78.6
59.72	60.2	58.68	59.9	59.23	59.15	60.87	59.34	60.4	60.34	60.98	61.11
0.91	0.82	1.12	1.05	0.93	1.02	1.02	0.94	1.08	1.16	1.04	1.16
15.02	15.06	15.11	14.88	14.76	15.31	15.69	15.47	16.18	16.07	16.22	16.28
6.79	6.48	6.73	6.09	6.78	6.37	6.56	7.32	6.95	7.24	6.79	6.66
0.24	0.05	0.18	0.14	0.23	0.08	0.22	0.17	0.24	0.02	0.14	
1.76	1.71	2.18	1.91	2.06	1.79	2.54	2.4	2.3	2.31	2.19	2.39
4.33	4.14	5.02	4.37	4.21	4.95	4.7	5.49	4.84	4.78	4.46	4.98
3.8	3.88	3.98	3.83	4	3.95	4.45	6.43	4.56	5.01	4.69	4.74
3.51	3.79	3.06	3.52	3.22	3.18	3.02	1.63	2.62	2.42	2.44	2.01
0.26	0.41	0.52	0.21	0.5	0.36	0.84	0.59	0.68	0.57	0.65	0.37
0.17	0.12	0.15	0.13	0.22	0.13	0.12	0.16	0.09	0.09	0.1	0.11
96.51	96.66	96.73	96.03	96.14	96.29	100.03	99.94	99.94	100.01	99.7	99.81

Appendix C Continued

	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1
Ejeceta	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice
Glass type	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
Host mineral	Cpx	Cpx	Cpx	Cpx	Opx	Opx	Opx	Opx	Hb	Hb	Hb	Hb	Hb	Hb	Hb	Hb	PI	PI	PI	PI
sample_no.	B-0102	D-0302	E-03	E-05	C-02	H-01a	H-01b	J-01	F-01	I-03	#13	#14	#15	#16a	#16b	I-02	G-01	H-01	H-02	I-01a
Compositional type	HK-M	HK-M	HK-M	HK-M	HK-M	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-M	HK-S	HK-S	HK-S	HK-S
analysis_time(min.)	180	180	180	180	180	180	180	180	240	240	120	120	120	120	120	240	240	240	240	240
Fo, Mg#, An# of host	79.1	79.2	79.6	0.0	72.3	72.4	73.4	73.3	69.9	72.3	70.2	69.6	70.6	66.3	69.5	72.6	29.0	35.9	39.9	48.7
Weight (wt.%)																				
SiO2	60.49	60.84	62.21	65.27	61.48	70.53	69.26	71.38	70.87	71.39	68.32	69.19	70.33	69.14	69.13	65.76	71.84	72.74	69.28	67.36
TiO2	0.97	0.78	0.69	0.83	1.08	0.38	0.35	0.29	0.44	0.65	0.62	0.44	0.27	0.63	0.48	0.72	0.48	0.61	0.54	1.06
Al2O3	18.48	17.19	17.29	17.17	15.33	14.46	14.18	14.54	14.7	14.89	15.27	15.09	14.74	14.92	15.09	17.54	14.13	14.57	14.65	15.54
FeO	4.88	4.95	4.4	1.18	6.58	2.05	1.96	1.82	2.06	1.95	2.47	2.16	2.13	1.95	1.86	3.05	1.2	1.15	1.96	2.29
MnO	0.12	0.2	0.21	0.3	0.27	0.18	0.23	0.05	0.13	0	0	0.06	0	0.14	0.2	0.48	0	0.19	0.06	0.17
MgO	1.53	1.88	1.09	0.56	1.57	0.26	0.19	0.31	0.17	0.18	0.45	0.31	0.56	0.41	0.36	0.24	0.17	0.3	0.34	0.48
CaO	3.91	4.09	2.87	2.72	4.19	0.96	0.78	1.06	1.26	1.01	2	1.29	1.1	1.84	1.34	3.66	0.89	1.1	1.32	1.74
Na2O	4.96	4.48	5.09	4.95	3.78	4.73	4.52	4.95	4.94	5.13	4.45	4.87	4.54	4.75	4.81	5.49	4.39	4.74	4.65	4.67
K2O	3.25	3.26	3.74	4.29	3.82	5.2	4.89	4.69	4.98	4.78	4.18	4.68	4.88	4.43	4.78	4.01	5.45	5.38	4.61	5.44
P2O5	0.82	0.44	0.22	1.03	0.55	0.25	0	0.13	0	0	0.12	0.18	0.49	0.17	0.33	0.18	0	0.06	0	0.26
S									0.03	0.11						0.26	0.08	0.04	0.04	0.02
Total	99.41	98.11	97.81	98.3	98.65	99	96.36	99.22	99.58	100.09	97.88	98.27	99.04	98.38	98.38	101.39	98.63	100.88	97.45	99.03

Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3
Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI
I-01b	I-02a	I-02b	I-03a	I-03b	K-01	K-04	#03	#04	E-02	#09	#14	#16	C-02	AJ-03a	AJ-03b	13_01	13_03a	13_03b	
HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M
240	240	240	240	240	240	240	120	120	180	300	300	300	180	240	240	300	300	300	
42.9	40.3	40.8	37.1	46.5	46.5	47.5	46.1	74.2	74.8	73.3	74.2	75.2	74.5	74.5	71.9	73.0	73.2		
71.03	69.11	70.16	71.3	71.64	68.76	69.55	69.32	70.13	57.88	58.52	58.39	56.06	57.89	59.42	59.75	61.19	58.27	59.42	
0.52	0.37	0.58	0.66	0.66	0.39	0.51	0.62	0.58	0.89	1.07	0.87	1.11	1.23	0.73	0.96	0.55	1.12	1.05	
15.29	15.12	14.32	15.28	15.39	15.28	14.65	14.54	14.96	16.98	17.95	17.21	18.54	18.25	17.85	18.12	17.71	17.11	17.41	
1.73	1.85	1.68	1.51	1.47	2.36	2.41	2.13	1.82	6.35	6.17	6.14	8.11	7.42	5.99	5.68	4.84	5.8	5.74	
0.23	0.14	0.2	0	0.2	0.18	0.12	0	0.13	0.23	0.28	0.4	0.19	0.1	0.27	0.27	0.05	0.19	0.16	
0.33	0.39	0.26	0.46	0.39	0.5	0.6	0.37	0.45	2.02	1.52	2.06	2.37	1.19	1.75	1.52	1.14	1.89	1.97	
1.49	1.55	1.24	1.12	1.35	1.76	1.63	1.63	1.66	5.19	6.53	5.64	7.78	6.64	6.22	5.15	5.03	5.54	5.26	
4.77	4.78	4.38	4.15	4.69	4.64	4.53	4.59	4.79	3.5	3.6	3.81	3.5	4.13	3.97	4	4.09	3.95	4.19	
4.5	4.93	5.19	6.38	4.64	4.77	5.67	5.27	4.75	3.79	3.62	3.3	2.41	2.78	2.58	2.79	4.57	3.83	3.13	
0.03	0	0	0	0	0	0.12	0.17	0.26	0.66	0.45	0.49	0.53	0.8	0.19	0.27	0.35	0.63	0.45	
0.07	0.11	0.09	0.05	0.04	0.08	0.05			0.23	0.21	0.29			0.22	0.24	0.26	0.19	0.22	
99.99	98.35	98.1	100.91	100.47	98.72	99.84	98.64	99.53	97.49	99.94	98.52	100.89	100.43	99.19	98.75	99.78	98.52	99	

Appendix C Continued

Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3
Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI
13_05	13_06	C-0302	G-03	L-01a	L-01b	L-01c	L-02	L-04	P-03a	P-03b	R-01	AB-01a	AB-01b	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx
HK-M	HK-M	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK	HK-M	HK-M	HK-M	HK-M
300	300	180	180	180	180	300	180	180	180	180	180	300	300	300	300	300	300	300	300
73.6	73.7	74.8	75.0	73.4	72.8	74.7	74.8	73.5	73.1	74.1	73.8	73.1	73.8	76.4	79.6	79.4	80.0	78.2	78.1

59.29	59.24	60.11	58.86	60.64	60.7	59.48	61.82	58.39	58.05	58.43	56.55	61.35	60.38	64.28	63.79	61.76	60.21	59.6	63.19
1.08	0.91	1.06	0.8	0.46	0.85	0.8	0.84	0.79	0.65	0.82	0.74	0.65	0.75	0.77	0.78	0.83	0.99	0.8	0.71
17.65	17.59	17	16.93	17.52	17.46	16.79	17.34	17.11	18.11	17.4	18.29	17.66	17.68	17.54	16.78	16.97	17.7	17.93	17.06
4.49	5.92	5.98	6.72	6.87	5.59	5.39	5.14	5.88	5.2	6.04	4.62	4.85	5.29	3.38	3.45	4.13	6.13	5.74	3.64
0.16	0.16	0.21	0.18	0.04	0.26	0.11	0.07	0.37	0.06	0.12	0.27	0.31	0.24	0.1	0.13	0.12	0.19	0.32	0.25
0.94	1.35	1.52	1.82	1.76	1.76	1.96	1.71	1.78	1.98	1.74	1	1.64	2.02	0.6	1.24	0.79	2.11	1.87	0.85
5.74	5.7	5.47	6.52	5.41	5.38	5.3	4.94	6.54	5.27	5.61	3.78	5.76	5.41	2.62	2.89	3.15	3.96	4.2	2.36
3.45	4.01	7.13	5.68	5.41	5.47	5.6	5.98	5.74	5.67	5.79	6.07	5.76	5.64	4.21	4.39	4.73	3.68	3.9	4.63
4.09	3.41	0.78	1.56	1.95	1.92	1.78	1.35	1.4	2.23	1.5	2.02	1.75	1.96	3.75	3.44	3.35	4.07	3.67	3.41
0.46	0.59	0.56	0.71	0.57	0.5	0.53	0.32	0.53	0.65	0.48	0.3	0.38	0.49	0.27	0.36	0.27	0.69	0.58	0.3
0.25	0.19					0.04						0.03	0.06	0.22	0.13	0.06	0.25	0.35	0.17
97.6	99.07	99.82	99.78	100.63	99.89	97.78	99.51	98.53	97.87	97.93	93.64	100.14	99.92	97.74	97.38	96.16	99.98	98.96	96.57

Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3
Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
Cpx	Cpx	Cpx	Opx	Opx	Opx	Opx	Opx	Hb	Hb	Hb	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI
N-02	R-01	04_02	Hb_E-04	B-05a	B-05b	Cpx_O-04a	CpxO-04b	A-03	C-05	G-04	B-01	B-03a	B-03b	C-02a	C-02b	C-04	D-02	E-01a	E-01b	E-03
HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M
300	300	300	240	240	240	300	300	240	240	180	300	240	240	180	180	240	240	240	240	240
78.4	76.5	79.0	75.9	76.6	76.9	73.4	73.6	71.1	0.0	69.5	54.1	52.1	54.1	59.5	57.7	56.5		58.4		

63.12	61.14	64.63	65.07	63.14	62.54	66.3	67.27	64.52	63.69	66.8	65.65	64.42	66.74	65.09	64.94	66.13	66.25	65.77	65.04	66.24
0.41	0.78	0.57	0.73	0.73	0.9	0.66	0.73	0.69	0.73	0.84	0.45	0.61	0.62	0.7	0.9	0.63	0.67	0.79	0.63	0.63
17.89	17.18	16.58	16.61	17	16.84	16.27	16.47	16.43	16.17	16.3	15.88	16.32	16.58	14.93	14.72	15.53	16.41	15.55	15.64	16.68
4.6	4.3	3.64	4.2	4.21	4.43	3.02	3.22	4.16	2.91	2.96	3.63	3.02	2.89	3.76	4.61	2.96	2.65	3.96	4.16	2.84
0.16	0.15	0.07	0.21	0.18	0.05	0.31	0.15	0.1	0.05	0.03	0.07	0.16	0.4		0.16	0.18	0	0.27	0.03	0.13
1.03	1.6	0.65	0.83	1.22	1.21	0.41	0.71	1.23	0.55	0.29	1.14	0.54	0.79	1.41	1.42	0.71	0.9	1.07	1.53	0.97
3.23	2.92	2.5	2.85	3.65	4.72	2.48	2.54	3.02	2.59	2.24	2.35	2.59	2.66	2.33	2.76	2.31	2.39	1.89	2.11	2.71
4.78	4.46	4.83	4.86	4.5	4.51	4.6	4.27	4.82	4.16	5.07	4.59	4.46	4.75	4.13	4.34	4.55	4.83	4.7	4.72	4.91
4.36	4.54	3.74	4.03	3.87	3.82	4.07	4.57	3.69	4.4	4.26	3.8	3.77	3.96	4.14	3.32	4.18	3.73	4.11	3.95	3.79
0.29	0.36	0.41	0.19	0.28	0.29	0.09	0.15	0.16	0.05	0.24	0.25	0.15	0.2	0.18	0.39	0	0.11	0.28	0.38	0.02
0.12	0.24	0.12	0.14	0.12	0.22	0.13	0.04	0.04	0.04		0	0.08	0.08			0.1	0.08	0.15	0.13	0.01
99.99	97.67	97.74	99.72	98.9	99.53	98.34	100.12	98.86	95.34	99.03	97.81	96.12	99.67	96.67	97.56	97.28	98.02	98.54	98.32	98.93

Appendix C Continued

Aso-4I-3	Aso-4I-3	Aso-4I-3	Aso-4I-3	Aso-4I-3	Aso-4I-3	Aso-4I-3	Aso-4I-3	Aso-4I-3	Aso-4I-3
Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
PI	PI	PI	PI	PI	PI	PI	PI	PI	PI
#03	#04	#04	#05	D-03	F-01	OI_H-02a	OI_H-02b	OI_H-0401	OI_P-01
HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	MK	MK	MK	MK
120	120	120	120	180	180	180	180	180	180
37.8	46.6	45.5	35.2	46.4	87.0	84.4	84.3	87.2	81.8
71.32	69.63	69.47	71.41	68.05	60.27	58.64	59.67	59.58	60.14
0.53	0.61	0.64	0.39	0.57	0.79	0.77	0.78	1.02	0.75
14.79	14.31	15.26	15.37	15.23	16.44	17.7	17.06	17.19	16.21
1.99	1.39	1.98	1.41	1.99	5.08	4.95	5.05	5.84	5.4
0.01	0.4	0	0.17	0	0.25	0.27	0.2	0.05	0.17
0.31	0.5	0.47	0.38	0.2	2.4	2.11	2.27	2.26	1.98
1.33	1.44	1.61	0.97	1.71	4.38	5.83	5	5.38	4.32
3.68	5.2	5.24	5.35	4.64	5.22	5.19	5.47	5.25	4.97
6.07	4.2	4.29	5.19	4	2.15	1.56	1.86	2.2	2.25
0	0	0.31	0.04	0.09	0.42	0.64	0.65	0.51	0.55
100.03	97.68	99.27	100.68	96.48	97.4	97.66	98.01	99.28	96.74

Appendix C Continued

	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20
Ejecta	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte
Host	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	Cpx	Cpx	Cpx
Glass type	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
Sample number	A-04a	A-04b	A-04c	B-01	B-03a	B-03b	B-04	C-01	C-04	D-01	D-04	E-01a	E-01b	F-03a	F-03b	Opx01_F-02a	Opx01_F-02b	A-03a	A-03b	A-03c	
Analysis time (s)	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	
Fo, Mg#, An# of hc	79.3			80.2	74.9		81.6	81.8		80.4				79.0				73.3	79.7	75.1	
Weight (wt.%)																					
SiO2	49.79	49.46	49.14	48.5	47.76	52.24	48.89	48.43	51.69	51.34	49.71	51.06	48.98	50.35	52.39	55.91	56.08	55.98	52.77	56.12	
TiO2	0.79	0.81	1.04	1.12	1.01	0.81	0.92	0.75	0.89	0.94	0.88	1.2	1.33	0.88	0.98	1.01	1.11	1.38	1.11	1.24	
Al2O3	17.13	17.11	17.77	16.54	16.85	16.07	17.16	15.94	16.32	16.25	16.56	16.88	17.42	16.89	15.7	15.61	15.5	15.07	16.89	16.63	
FeO	9.92	9.83	9.3	8.94	11.23	10.17	11.3	9.14	9.3	8.63	9.77	9.09	10.03	9.25	9.34	9.6	8.94	9.43	8.87	8.97	
MnO	n.d.	0.19	0.3	0.14	0.43	0.31	0.25	0.04	0.34	n.d.	0.26	0.13	0.04	0.06	0.02	n.d.	0.21	0.09	0.36	n.d.	
MgO	5.04	4.19	2.94	4.7	5.24	4.37	4.95	5.99	4.69	5.28	4.39	3.92	3.78	4.86	4.82	3.35	3.23	3.23	4.09	3.32	
CaO	10.03	10.87	10.86	10.72	10.89	8.73	11.98	10.63	9.19	9.02	9.94	9.78	10.09	9.77	8.76	6.38	6.35	6.7	9.17	6.64	
Na2O	2.66	2.58	2.67	2.57	2.52	3.26	2.74	2.62	2.96	2.83	2.52	3.07	2.89	2.65	2.84	3.62	3.42	3.33	3.32	3.39	
K2O	0.98	0.91	0.87	0.83	0.87	1.44	0.89	0.88	0.99	0.95	1.24	0.96	0.92	1.07	1.36	2.36	2.35	2.77	1.1	2.49	
P2O5	0.46	0.02	0.41	0.06	0.09	0.19	0.15	0.13	0.29	0.31	0.34	0.16	0.1	0.07	0.23	0.04	0.21	0.38	0.38	0.29	
S	0.22	0.35	0.38	0.28	0.41	0.13	0.28	0.38	0.22	0.18	0.1	0.18	0.32	0.27	0.18	0.14	0.09	0.07	0.02	0.05	
Total	97.02	96.32	95.68	94.4	97.3	97.72	99.51	94.93	96.88	95.73	95.71	96.43	95.9	96.12	96.62	98.02	97.49	98.43	98.08	99.14	

Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20
Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte
Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx
MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
A-04a	A-04b	A-05	B-01	B-02a	B-02b	B-02c	B-02d	B-03	B-04a	B-04b	B-05a	B-05b	C-01	C-02	C-04	C-05	D-01	D-02a	D-02b	D-02c
180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
81.9	86.8	78.5	83.5	74.8	73.5	73.5	76.8	85.8	76.7				79.5	76.0		80.7	72.5	75.7		78.4
51.31	49.71	51.82	48.44	51.02	54.88	52.45	48.8	51.1	51.44	53.81	50.79	50.73	55.04	50.77	54.75	47.88	52.76	50.56	50.54	51.78
0.81	0.65	0.95	0.82	1.14	1.15	1.27	1.48	0.65	0.82	1.39	1.63	1.15	0.93	1	1.01	0.91	1.13	1.41	1.44	1.07
19.22	18.59	16.36	16.85	14.58	14.85	14.23	14.55	16.66	15.12	15.3	15.22	15.71	17.92	15.49	15.43	17.74	14.44	14.25	13.81	15.42
10.51	11.09	9.69	11.01	12.24	10.01	11.55	12.46	7.52	10.76	9.92	12.08	10.83	6.98	9.78	9.41	11.87	11.39	13.4	12.78	10.18
0.3	0.2	0.17	0.19	0.06	0.04	0.17	0.19	0.19	0.02	0.05	0.27	0.25	0.25	0.07	0.02	0.07	0.42	0.34	0.36	0.28
4.39	4.7	3.79	4.81	4.57	3.17	3.55	5.16	5.2	4.58	3.7	4.6	4.77	3.08	5.24	3.34	4.7	3.93	4.7	5.13	4.23
9.64	9.86	7.13	8.88	8.59	6.76	7.33	8.59	8.51	8.48	7.86	8.83	9.06	6.31	9.66	7.21	9.79	7.48	8.29	9.02	8.42
3.27	3.04	2.86	2.88	3.14	3.21	3	2.51	3.03	2.78	3.06	2.43	2.74	4.62	3	3.46	3.2	2.89	2.56	2.4	3
1.1	0.9	0.93	1.1	1.35	1.67	1.55	0.95	1.13	1.11	1.55	0.95	1.09	2.64	1.13	1.96	1.31	1.39	0.76	0.69	1.65
n.d.	0.25	0.3	0.06	0.14	0.11	0.14	0.01	0.36	0.17	0.18	0.34	0.14	0.31	0.13	0.25	0.01	0.57	n.d.	0.1	0.23
0.1	0.23	0.11	0.28	0.11	0.04	0.14	0.26	0.2	0.3	0.11	0.18	0.23	0.09	0.25	0.04	0.2	0.17	0.23	0.22	0.24
100.65	99.22	94.11	95.32	96.94	95.89	95.38	94.96	94.55	95.58	96.93	97.32	96.7	98.17	96.52	96.88	97.68	96.57	96.5	96.49	96.5

Appendix C Continued

Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20
Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte	Basalte
Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	PI	PI	PI	PI
MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
D-02d	D-03a	D-03b	E-01a	E-01b	E-01c	E-01d	E-03a	E-03b	E-03c	E-03d	F-01	F-04	F-05a	F-05b	F-05c	A-01a	A-01b	A-03a	A-03b
180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
	78.8	79.6	80.5	82.1			80.8	70.8	72.8	72.8	72.8	82.2	77.3	83.2		76.4	76.4	81.8	81.8
51.14	53.04	51.22	51.95	49.29	52.79	53.6	54.07	53.72	54.53	54.13	55.29	53.33	50.11	49.05	50.11	56.12	57.21	58.78	58.44
0.97	1.12	0.9	0.82	0.86	0.69	1.08	1.38	1.15	1.5	1.26	1.02	0.98	1.03	1.09	0.99	0.87	0.97	1.28	1.18
15.35	15.97	16.06	16.68	16.18	16.39	16.61	15.1	14.85	15.31	15.1	17.11	15.49	15.61	15.89	16.11	16.65	17.09	14.5	14.48
10.78	8.18	9.29	9.05	9.38	8.16	8.13	11.2	10.71	9.63	10.53	8.74	10.18	9.48	10.13	9.75	7.45	6.91	9.34	9.49
0.27	0.35	n.d.		0.02	0.15	0.17	0.09	0.09	0.25	0.21	0.04	0.3	0.13	0.16	0.19	0.06	0.13	0.26	0.38
4.92	4.15	4.22	4.11	5.14	4.52	3.99	3.35	3.01	4.04	3.83	3.21	3.99	5.31	5.39	5.24	2.48	2.41	3.3	3.26
8.83	8.2	8.2	8.36	9.16	8.37	7.8	6.84	6.53	6.89	6.55	7.18	8.07	10.14	9.74	9.85	6.92	6.52	5.4	5.47
2.82	3.1	2.84	3.07	2.68	3.03	3.07	3.47	3.2	3.35	3.2	3.69	3.09	2.57	2.57	2.75	3.88	4.54	3.59	3.44
1.03	1.43	1.09	1.16	0.97	1.55	1.98	1.99	2.09	1.86	1.9	1.86	1.53	1	0.93	0.83	2.41	2.24	2.94	2.8
0.27	0.16	0.07	0.01	0.22	0.17	0.21	0.03	0.22	0.29	0.31	0.21	0.35	0.01	0.26	0.3	0.15	0.16	0.15	0.4
0.31	0.16	0.26	0.26	0.14	0.26	0.15	0.17	0.02	0.12	0.02	0.05	0.08	0.37	0.36	0.22	0.11	0.05	0	0.07
96.69	95.86	94.15	95.49	94.17	96.1	96.71	97.69	95.75	97.73	96.87	98.66	97.22	95.79	95.6	96.21	97.17	98.36	99.66	99.41

Appendix C Continued

	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15		Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15		Z-15	Z-15
	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt		Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt		Basalt	Basalt
Glass type	MI	MI	MI	MI	MI	MI	MI	MI		MI	MI	MI	MI	MI	MI	MI	MI		MI	MI
Host mineral	OI	OI	OI	OI	OI	OI	OI	OI		OI	OI	OI	OI	OI	OI	OI	OI		OI	OI
Sample number	A-02a	A-02b	A-02c	A-03	A-04	B-01a	B-01b	B-02_mgtinc		B-04a	B-04b	B-04c	B-05	C-01a	C-01b	C-01c	C-05	D-02_mgtinc	E-01	E-02
Analysis time (s)	180	180	180	180	180	180	180	180		180	180	180	180	180	180	180	180		180	180
Mg# (Fo) of host min.	76.5	78.1	76.9	77.6	77.2	78.0	77.1	76.5		77.7	76.7	76.7		77.8				77.3	77.3	
Weight (wt.%)																				
SiO2	52.73	53.32	52.33	52.56	52.57	52.52	52.57		53.83	51.46	52.03	50.19	51.14	49.44	50.04	51.17	53.01		49.56	52.41
TiO2	0.92	0.82	0.9	1.05	1.05	1.05	0.95		0.93	0.78	0.93	0.96	0.9	0.89	0.93	1.12	0.67		1.61	0.93
Al2O3	15.42	15.99	15.97	15.99	15.9	16.17	16.7		15.99	15.86	15.84	16.14	16.39	16.52	17.29	16.75	16.13		16.96	16.04
FeO	8.84	8.82	9.03	8.88	9.3	8.99	8.72		8	9.92	8.92	10.11	9.24	9.75	9.44	9.26	8.28		10.11	8.68
MnO	n.d.	0.27	0.14	n.d.	0.23	0.26	0.36		0.23	0.36	0.09	0.29	0.14	0.18	0.06	0.05	n.d.		0.03	0.05
MgO	3.85	3.73	3.78	3.96	3.8	3.85	2.92		3.72	3.99	4.52	4.32	3.26	4.18	2.42	3.03	2.29		4.2	3.8
CaO	8.63	8.45	8.86	8.93	8.51	8.36	9.21		7.29	9.41	8.77	9.6	9.87	9.96	10.47	9.2	9.34		9.51	8.32
Na2O	3.49	3.41	3.29	3.38	3.32	3.46	3.6		3.81	3.13	3	3.08	3.11	2.87	3.33	3.43	3.22		2.73	3.53
K2O	1.47	1.47	1.4	1.41	1.38	1.57	1.42		1.85	1.25	1.45	1.09	1.28	0.96	0.99	1.49	1.49		1.29	1.39
P2O5	0.04	0.14	0.16	0.16	0.33	0.3	0.46		0.17	n.d.	0.23	0.09	0.31	0.16	n.d.	0.1	0.12		0.36	0.08
S	0.11	0.07	0.08	0.2	0.13	0.1	0.15		0.18	0.19	0.17	0.21	0.2	0.32	0.29	0.2	0.12		0.1	0.08
Total	95.5	96.49	95.94	96.52	96.52	96.63	97.06		96	96.35	95.95	96.08	95.84	95.23	95.26	95.8	94.67		96.46	95.31

Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15
Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt
MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI
E-03	F-04	F-05	Opx_E-02	Opx_F-03	Opx_F-04	F-01	E-03a	E-03b	E-02a	E-02b	E-02c	D-03a	D-03b	D-01a	D-01b	D-01c	C-04a	C-04b	C-03	
180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
81.4	78.1											70.7	70.7				84.2	81.9	81.2	
47.95	51.06	50.52		53.1	53.44	57.93	52.08	55.01	54.48	53.32	51.65	51.55	63.79	65.1	50.21	51.94	52.15	51.7	50.48	50.84
0.82	0.86	1.13		1.05	0.87	1.39	0.84	0.99	1	0.93	0.81	0.83	0.77	1.06	0.98	0.76	0.86	0.66	0.81	0.71
17.55	16.21	16.43		16.38	15.89	15.39	17.59	15.5	15.13	16.61	16.65	16.83	13.91	13.58	16.47	16.44	17.3	17.01	16.77	16.37
8.98	9.63	9.87		8.98	9.37	9.25	7.95	9.19	8.93	9.88	9.38	9.48	5.69	5.3	9.66	9.44	8.3	7.85	9.59	9.37
n.d.	n.d.	0.53		0.02	0.28	0.01	0.05	0.04	n.d.	0.13	0.25	n.d.	0.02	0.13	0.53	0.19	0.23	0.1	n.d.	0.15
5.4	4.23	4.2		3.6	3.16	2.39	3.62	3.24	4.17	3.17	4	3.83	1.28	1.11	4.16	3.83	3.3	4.64	4.38	4.66
10.81	9.17	9.82		8.64	7.11	5.01	7.1	6.73	7.61	6.27	7.37	7.11	3.67	3.28	7.6	7.35	6.96	8.22	8.62	8.73
2.76	3.18	3.44		3.41	3.8	4.43	3.39	3.23	3.23	3.77	3.35	3.05	3.47	3.85	3.15	3.26	3.23	3.31	3.1	3.2
1	1.27	0.98		1.55	1.7	2.45	1.56	2.09	1.8	1.87	1.31	1.35	4.57	4.52	1.28	1.25	1.58	1.5	1.32	1.26
0.05	0.03	0.31		0.22	0.21	0.26	0.24	0.49	0.29	0.36	0.13	0.31	0.01	0.31	0.08	0.07	0.16	0.13	0.15	0.23
0.38	0.25			0.07	0.05	0.06	0.32	0.08	0.2	0.11	0.24	0.32	0.1	0.05	0.2	0.23	0.2	0.4	0.28	0.15
95.7	95.89	97.23		97.02	95.88	98.57	94.74	96.59	96.84	96.42	95.14	94.66	97.28	98.29	94.32	94.76	94.27	95.52	95.5	95.67

Appendix C Continued

Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15
Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt
MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl
C-02a	C-02b	C-02c	B-03a	B-03b	B-02	A-04a	A-04b	A-04c	A-01a	A-01b	A-01c	A-01d	A-01e	A-01f	A-02a	A-02b	Opx_F-04	
180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
77.8	79.1	75.7	79.1	78.8	82.8	83.1	78.6	73.7	86.5	86.5	86.5	86.5	86.5	86.5	53.5	53.5		
55.78	55.55	56.25	51.42	51.17	50.85	52.11	52.04	52.22	51.29	51.95	51.65	51.94	51.29	51.51	61.44	59.82		54.97
0.82	0.89	0.99	1.18	0.96	0.86	0.9	1.02	1.11	1.08	0.75	0.71	0.88	0.99	0.8	0.76	0.81		0.98
16.27	15.57	15.82	16.75	16.86	17.32	16.05	16.41	15.3	16.25	15.98	16.25	16.22	15.85	14.96	15.02	14.53		15.76
7.34	8.1	7.62	8.81	8.86	8.73	9.76	9.62	11.05	9.2	8.4	8.25	8.19	8.87	9.37	6.25	7.35		10.88
n.d.	0.17	0.15	0.17	0.35	0.43	0.08	0.05	0.4	0.15	0.29	0.03	0.34	0.28	0.09	n.d.	0.17		0.28
3.19	3.09	2.49	3.91	4.09	3.78	4.06	3.94	3.74	4.18	4.06	4.05	4.36	4.39	4.77	1.68	2.13		2.31
6.2	6.59	5.8	8.42	8.36	7.19	7.53	7.95	7.25	8.02	7.9	8.31	8.16	7.29	6.86	4.21	4.43		5.08
3.92	3.77	3.63	3.68	3.51	3.31	3.28	3.33	2.86	3.28	3.4	3.09	3.42	3.2	2.87	3.84	3.7		3.45
2.83	2.4	2.74	1.63	1.71	1.41	1.35	1.66	1.52	1.62	1.86	1.54	1.69	1.99	2.19	3.68	3.48		3.52
0.26	0.07	0.28	n.d.	0.16	0.27	0.18	0.16	0.28	0.04	0.04	0.13	0.24	0.22	0.19	0.22	0.47		0.25
0.24	0.19	0.13	0.13	0.18	0.32	0.14	0.11	0.18	0.16	0.18	0.17	0.15	0.27	0.18	0.08	0.18		0.05
96.85	96.39	95.9	96.1	96.21	94.47	95.44	96.29	95.91	95.27	94.81	94.18	95.59	94.64	93.79	97.18	97.07		97.53

Appendix C Continued

	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL
Electa	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice
Glass type	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM
Sample number	A01	A01	A01	A01	B01	B01	B01	B01	B01	C01	C01	C01	C01
	Aso-2TL_A01a	Aso-2TL_A01b	Aso-2TL_A01c	Aso-2TL_A01d	Aso-2TL_B01a	Aso-2TL_B01b	Aso-2TL_B01c	Aso-2TL_B01d	Aso-2TL_B01e	Aso-2TL_C01a	Aso-2TL_C01b	Aso-2TL_C01c	Aso-2TL_C01d
Compositional type	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S
Analysis time(s)	180	180	180	180	180	180	180	180	180	180	180	180	180
Weight (wt.%)													
SiO2	63.87	63.7	64.29	63.29	64.07	64.84	64.21	64.24	63.95	64.08	63.77	64.35	64.85
TiO2	0.59	0.66	0.63	0.64	0.84	0.71	0.69	0.64	0.66	0.9	0.64	0.92	0.83
Al2O3	14.58	14.34	14.51	14.87	14.66	14.48	14.61	14.32	14.54	14.44	14.78	14.19	14.77
FeO	3.99	3.54	3.73	3.94	3.79	3.89	3.87	4.35	4.17	3.88	4.08	4.05	3.78
MnO	0.06	0.27	0.06	0	0.2	0.18	0	0	0	0	0.26	0.02	0
MgO	0.48	0.52	0.76	0.68	0.52	0.66	0.58	0.56	0.5	0.28	0.51	0.64	0.58
CaO	1.86	2.07	2.01	2.1	2.17	1.97	2.05	2.01	1.8	2.23	2.18	1.89	2.03
Na2O	4.79	4.39	4.39	4.15	4.35	4.7	4.65	4.35	4.29	3.9	3.94	3.98	3.76
K2O	4.81	4.81	4.75	4.57	4.85	4.89	5.24	4.78	4.67	4.85	4.82	4.91	4.9
P2O5	0.48	0.15	0.31	0.27	0.12	0.42	0.34	0	0.41	0.08	0.08	0.17	0.09
S	0	0.04	0.01	0.02	0	0.01	0	0	0	0	0.02	0	0.14
Total	95.51	94.49	95.45	94.53	95.57	96.75	96.24	95.25	94.99	94.64	95.08	95.12	95.73

Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T
Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM
A01	A01	A01	A01	B01	B01	B01	B01	C01	C01	C01	C01	D01	D01	D01	D01
Aso-2T_A01a	Aso-2T_A01b	Aso-2T_A01c	Aso-2T_A01d	Aso-2T_B01a	Aso-2T_B01b	Aso-2T_B01c	Aso-2T_B01d	Aso-2T_C01a	Aso-2T_C01b	Aso-2T_C01c	Aso-2T_C01d	Aso-2T_D01a	Aso-2T_D01b	Aso-2T_D01c	Aso-2T_D01d
HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M
180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
58.78	58.12	58.38	57.97	58.26	58.79	57.04	57.86	57.99	57.81	58.41	58.29	58.21	58.57	58.3	57.9
1.27	1.14	1.23	1.35	1.29	1.23	1.04	1.11	1.2	0.93	1.34	1.16	1.32	1.17	1.18	1.32
15.82	16.09	15.98	15.9	16.18	16.6	16.08	15.84	15.84	15.9	16.27	16.21	15.93	15.94	16.04	16.26
8.21	8.63	8.18	7.98	8.55	8.26	8.44	8.18	8.54	8.38	8.67	8.22	8.07	7.8	7.76	8.23
0.42			0.16	0.3	0.45	0.25	0.3	0.19	0.05	0.03			0.3		
2.78	2.78	2.83	2.67	2.68	2.75	2.51	2.85	2.68	2.95	2.62	2.83	2.63	2.76	2.42	2.4
5.61	5.49	5.34	5.61	5.67	5.49	5.68	5.57	5.49	5.65	5.94	5.7	5.32	5.77	5.35	5.49
3.84	3.95	3.88	3.66	3.85	3.74	4.03	3.83	4.1	3.89	3.99	3.86	3.63	3.92	3.61	3.71
2.88	3.26	3.07	3.07	2.76	2.84	2.84	2.97	3.25	3.18	2.97	2.95	3.08	2.99	3.28	3.1
0.37	0.18	0.38	0.34	0.31	0.75	0.27	0.48	0.31	0.34	0.67	0.32	0.74	0.2	0.42	0.23
	0.08		0.02	0.09	0.05	0.1	0.02	0.1	0.02					0.01	0.09
99.98	99.72	99.27	98.73	99.94	100.95	98.28	99.01	99.69	99.1	100.91	99.54	98.93	99.42	98.37	98.73

Appendix C Continued

	Aso-3A	Aso-3A	Aso-3A	Aso-3A	Aso-3A	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C
Glass type	Pumice	Pumice	Pumice	Pumice	Pumice	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
Sample name	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM
	A	A	A	A	A	B	B	B	B	B	B	B	B	HS20072002	HS20072002	HS20072002	HS20072002	HS20072002	HS20072002
	A-01a	A-01b	A-02a	A-02b	A-03	B-01a	B-01b	B-02a	B-02b	B-03a	B-03b	01a	01b	01c	01d	01e	02a	02b	02b
	HK-S	HK-S	HK-S	HK-S	HK-S	HK-M	MK	MK	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M
Analysis time (s)	180	180	180	180	180	180	180	180	180	180	180	180	180	240	240	240	240	240	240
Weight (wt.%)																			
SiO2	68.68	68.05	68.56	68.04	68.78	60.49	58.99	60.18	59.11	61.68	60.8	62.29	63.19	63.1	63.26	62.66	60.19	61.02	
TiO2	0.54	0.62	0.77	0.55	0.68	1.07	0.84	1.04	1.07	0.94	1.09	0.8	1.18	1.04	1.06	0.89	1.12	1.07	
Al2O3	14.69	14.59	14.57	14.52	14.46	16.63	16.89	16.83	16.57	16.57	16.36	15.86	15.75	16.02	15.71	16.08	16.3	16.02	
FeO	2.11	2.27	2.23	2.29	2.11	7.03	5.94	7.12	6.52	6.41	6.8	6.36	6.35	6.03	6.68	6.03	7.57	7.23	
MnO		0.1	0.26	0.04	0.15	0.19		0.18	0.07	0.29	0.24	0.1	0.01	0.28	0.22	0.11	0.03	0.22	
MgO	0.26	0.45	0.4	0.33	0.5	2.11	1.63	2.05	1.8	2.01	2.21	2.08	1.99	1.92	2.11	1.74	2.16	2.25	
CaO	1.59	1.6	1.66	1.58	1.76	5.16	5.29	5.25	4.89	5.23	5.13	4.27	4.15	4.27	3.82	4.06	5.03	4.99	
Na2O	4.67	4.44	4.44	4.43	4.37	4.11	4.57	4.34	4.29	4.18	4.08	4.15	4.58	4.39	4.28	4.56	4.31	4.09	
K2O	4.71	4.71	4.85	4.87	4.85	3.26	2.83	2.88	3.1	3.42	3.5	3.61	3.61	3.33	3.8	3.43	3.14	3.36	
P2O5	0.02	0.15	0.21	0.29	0.28	0.59	0.59	0.52	0.54	0.3	0.43	0.46	0.35	0.48	0.65	0.79	0.32	0.48	
S												0.06	0.09		0.09		0.06		
Total	97.27	96.98	97.95	96.94	97.94	100.64	97.57	100.39	97.96	101.03	100.64	100.04	101.25	100.86	101.68	100.35	100.23	100.73	

Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C
Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM
HS20072002	HS20072002	HS20072002	HS20072002	HS20072002	HS20072002	HS20072002	HS20072002	HS20072002	HS20072002	HS20072002	HS20072002	HS20072002	HS20072002	HS20072002	HS20072003	HS20072003
02c	02d	02e	03a	03b	03c	03d	03e	04a	04b	04c	04d	04e	B02a	B02b		
MK	HK-M	MK	MK	HK-M	HK-M	HK-M	HK-M	MK	MK	MK	MK	MK	MK	MK	MK	MK
240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240	240
59.88	59.75	61.19	59.67	59.77	59.27	60.67	59.49	61.71	61.63	62.49	62.43	60.97	62.36	61.96		
1.31	1.37	1.32	1.16	1.05	1.17	1.37	1.2	1.17	0.94	1	0.92	1.07	1.09	0.96		
15.96	16.23	16.77	16.18	16.31	16.11	16.65	15.78	15.65	15.73	15.45	16.11	15.94	16.55	15.74		
7.35	7.82	7.23	7.76	7.56	7.5	7.89	7.76	5.7	6	6.11	6.21	6.48	6.38	6.47		
0.09	0.13	0.1	0.06	0.22	0.32	0.29	0.05	0.1	0.22	0.2	0.11	0.01	0.22	0.24		
2.32	2.31	2.18	2.13	2.07	2.14	2.51	2.21	1.72	1.69	2.12	2.03	1.87	2.11	2.03		
5.17	5.06	5.02	5.13	4.89	5.21	5.41	4.93	4.31	4.51	4.51	4.15	4.62	4.63	4.63		
4.18	4.14	4.43	4.18	4.18	4.34	4.29	3.91	4.75	4.78	4.65	4.68	4.64	5.6	4.83		
2.97	3.06	2.92	2.88	3.14	3.05	3.17	3.41	2.89	2.58	2.86	2.91	2.5	1.13	2.03		
0.47	0.6	0.26	0.31	0.12	0.34	0.17	0.32	0.78	0.49	0.63	0.42	0.49	0.41	0.6		
0.05	0.01	0.13	0.09	0.06	0.08	0.04		0.04	0.12	0.06	0.09	0.09		0.04		
99.75	100.48	101.55	99.55	99.37	99.53	102.46	99.06	98.82	98.69	100.08	100.06	98.68	100.48	99.53		

Appendix C Continued

Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C
Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM
HS20072003	HS20072003	HS20072003	HS20072003	HS20072003	TM20072101	TM20072101	TM20072101	TM20072101	HS20072003	HS20072003	HS20072003	HS20072003
B02c MK	B04a MK	B04b MK	B04c MK	B04d MK	C01a HK-M	C01b HK-M	C02a MK	C02a MK	B04e HK-M	B04h HK-M	B04f MK	B04g MK
240	240	240	240	240	240	240	240	240	240	300	300	300
62.76	60.69	62.17	60.34	60.77	62.3	61.95	61.98	62.49	59.42	59.73	59.35	60.24
1.04	1.17	1.19	1.04	1.17	1.03	1.05	1.08	0.83	0.88	0.94	0.93	0.93
16.63	16.04	16.08	15.8	16	16.4	15.74	15.61	16.29	15.62	15.87	16.01	16.21
6.34	7.18	7.12	7.74	7.56	6.32	6.58	6.46	6.55	7.2	7.49	7.33	6.62
	0.19		0.18	0.07	0.04	0.17	0.25	0.11	0.11	0.05	0.18	0.18
1.7	2.3	2.14	2.61	2.65	2.08	2	1.98	2.05	2.23	2.18	2.33	1.93
4.32	5.13	5.04	5.31	5.26	4.46	4.79	4.87	4.88	5.34	5.31	5.36	5.25
4.95	4	5.05	4.51	4.16	4.49	4.53	4.9	4.83	2.82	2.94	4.85	5.37
2.34	2.83	1.55	1.74	2.22	3.19	3.17	2.45	2.81	3.96	4.43	1.35	1.21
0.49	0.52	0.36	0.4	0.3	0.38	0.56	0.36	0.38	0.31	0.13	0.43	0.45
0.01	0.05	0.13	0.09	0.16		0	0.02	0.05	0.14	0.1	0.04	0.07
100.58	100.1	100.83	99.76	100.32	100.69	100.54	99.96	101.27	98.03	99.17	98.16	98.46

Appendix C Continued

	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1
Ejecta	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice
Glass type	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM
Smample name	181106	181106	181106	181106	181106	190123	190123	190123	190123	190123	190123	190123	NJ01-04	NJ01-04	NJ01-04	K-OG181125-02	K-OG181125-02	K-OG181125-02
Compositional type	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	a	b	c	B-01a	B-01b	B-02a
Analysis time (s)	120	120	120	120	120	120	120	120	120	120	120	120	180	180	180	180	180	180
Weight (wt.%)																		
SiO2	69.35	68.9	69	69.22	69.51	69.1	67.99	68.12	68.03	68.46	68.96	67.78	67.71	67.66		68.82	69.03	68.29
TiO2	0.39	0.51	0.57	0.86	0.71	0.41	0.41	0.42	0.1	0.66	0.6	0.57	0.34	0.34		0.48	0.29	0.54
Al2O3	15	14.94	15.06	14.73	15.23	14.52	14.93	14.32	14.87	14.21	14.6	14.6	14.54	14.59		14.03	14.36	14.08
FeO	1.59	1.8	2.12	1.57	1.7	1.37	1.64	1.51	1.62	1.41	1.6	1.99	1.93	1.62		1.54	1.13	0.74
MnO	0.26	0.18	0.13	0.37	0.4	0.37	0.16		0.02		0.63	0.1	0.11	0.26		0.14	0.01	0.13
MgO	0.54	0.63	0.49	0.5	0.29	0.4	0.12	0.27	0.29	0.22	0.37	0.41	0.31	0.11		0.36	0.25	0.34
CaO	1.69	1.19	1.59	1.53	1.6	1.29	1.36	1.46	1.45	1.44	1.49	1.55	1.57	1.42		1.26	1.1	1.2
Na2O	4.55	4.43	4.72	4.43	4.99	4.79	4.76	4.58	4.45	4.89	4.64	4.77	4.74	4.7		4.51	4.75	4.55
K2O	4.26	4.41	4.32	4.24	4.34	4.41	4.01	4.13	4.13	4.17	4.15	4.22	4.01	4.15		4.09	4.26	4.19
P2O5	0.14	0.51	0.03	0.26	0.22	0.18	0.07	0.2	0.02		0.06	0.08	0.19			0.1		0.13
S																		
Total	97.77	97.5	98.03	97.71	98.99	96.84	95.45	95.01	94.98	95.46	97.1	96.07	95.45	94.85		95.33	95.18	94.19

Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1
Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice
GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM
K-OG181125-02	K-OG181125-02	K-OG181125-02	no-name03	no-name03	no-name03	no-name03	no-name03	no-name03	no-name03	no-name03	no-name03	180926-01	180926-01	180926-01	181019-04	181019-04	181019-04	181019-04
B-02b	B-02c	B-02d	a	b	c	d	e	f	g	a	b	c	a	b	c	d	e	
HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S
180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
68.41	67.92		68.46	69.27	68.69	69.37	68.63	69.17	68.93	68.11	69.08	68.06	69.4	70.25	69.87	69.39	69.33	69.19
0.49	0.19		0.35	0.48	0.39	0.54	0.35	0.4	0.57	0.46	0.6	0.47	0.39	0.54	0.38	0.66	0.36	0.37
14.53	14.2		14.54	14.86	15.05	15.31	15.13	14.93	15.15	15.56	14.58	15.03	15.01	14.95	14.55	15.12	14.98	15.13
1.23	1.46		1.14	1.62	1.64	1.76	1.56	1.45	2.14	1.56	1.94	1.73	1.8	2	1.7	1.42	1.74	1.95
0.12	0.19		0.11	0.14	0.03	0.11	0.2		0.25	0.17	0.13	0.18		0.17		0.14	0.1	0.16
0.27	0.29		0.18	0.39	0.23	0.24	0.4	0.36	0.26	0.27	0.4	0.35	0.31	0.4	0.23	0.23	0.36	0.27
1.3	1.22		1.36	1.43	1.49	1.44	1.54	1.63	1.63	1.56	1.32	1.43	1.37	1.5	1.42	1.4	1.48	1.43
4.47	4.82		4.61	5	5.11	5.11	4.8	5.18	5.11	4.85	4.88	4.9	4.96	5.01	5.03	5.07	4.84	5.06
4.22	4.1		4.16	4.31	4.16	4.13	4.36	4.25	4.09	4.11	4.34	4.23	4.33	4.06	4.23	4.24	4.24	4.29
0.14			0.09			0.04	0.11	0.16		0.02	0	0.06	0.22			0.18		
95.18	94.39		95	97.5	96.83	98.12	97.13	97.37	98.15	96.65	97.33	96.6	97.57	98.88	97.41	97.85	97.43	97.85

Appendix C Continued

Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3
Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM
181019-04	181019-04	190104-03	190104-03	190104-03	190104-03	190104-03	190123	190123	190123	190123	190123	190123	190123	190123	190123	190123	Bn1	Bn1
f	g	a	b	c	d	e										a	b	c
HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M
180	180	180	180	180	180	180	180	120	120	120	120	120	120	120	120	180	180	180
69.11	69.45	69.73	69.64	69.61	69.62	69.2	67.75	67.24	66.97	66.98	67.53	67.58	67.56	66.87	63.45	63.42	62.64	63.19
0.62	0.59	0.22	0.48	0.65	0.37	0.38	0.73	0.71	0.58	0.79	0.54	0.3	0.79	0.52	0.74	0.67		0.57
15.29	14.71	14.86	14.83	14.68	14.88	15.29	16.17	15.64	15.87	15.66	15.84	15.65	15.56	15.74	15.9	15.19	15.41	15.26
1.55	1.5	1.77	1.59	1.52	1.4	1.59	2.93	1.92	2.23	2.44	2.72	2.99	2.12	2.12	3.62	3.09	3.64	3.43
0.21	0.05	0.19	0.16	0.03	0.18	0.3		0.13			0.08			0.17		0.05		0.18
0.36	0.3	0.4	0.33	0.41	0.14	0.34	0.69	0.66	0.39	0.63	0.61	0.71	0.73	0.7	0.94	1.09	1.24	1.14
1.53	1.27	1.4	1.22	1.42	1.54	1.4	2.44	1.97	2.27	2.2	2.24	2.13	2.11	1.98	2.8	2.41	2.19	2.36
4.96	5.17	4.92	5.12	5.16	4.96	5.01	5.05	5.21	4.97	5.43	5.07	5.08	5.16	5.04	4.62	4.26	4.12	4.41
4.3	4.15	4.18	4.35	4.33	4.35	4.31	3.45	3.7	3.78	3.44	3.67	3.74	3.83	3.53	3.74	4.11	3.57	4.03
0.01		0.12	0.04							0.16	0.25		0.03		0.28	0.5	0.38	0.44
97.94	97.19	97.79	97.76	97.81	97.44	97.82	99.21	97.18	97.06	97.73	98.55	98.18	97.89	96.67	96.09	94.79	93.19	95.01

Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3	Aso-4-1-3
Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM
Bn1	Bn2_Ol-rich	Bn2_Ol-rich	Bn2_Ol-rich	Bn2_Ol-rich	Bn2_Ol-rich	181125-01a	181125-01a	181125-01a	181125-01a	181125-01a	181125-01a	181125-01a	181125-01a	181125-01a
e	D-01a	D-01b	D-04a	D-04b	D-04c	a-01a	a-01b	a-01c	a-02a	a-02b	a-03a	a-03b	a-04a	a-04b
HK-M	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK	MK
180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
63.08	59.6	59.69	59.16	60.28	59.67	60.09	59.92	60.02	61.04	59.94	60.74	59.46	57.75	60.35
0.58	0.65	0.79	1.02	0.8	0.8	0.91	0.36	0.62	0.95	0.79	0.82	0.7	0.66	0.99
15.29	16.47	16.22	17.86	15.79	17.12	18.38	19.09	18.92	15.89	16.13	16.14	17.78	17.13	15.52
3.29	4.61	4.82	4.8	5.42	4.53	4.63	4.29	4.9	4.82	5.2	6.07	4.54	5.32	5.59
0.1	0.39	0.26	0.37	0.34	0.42	0.25	0.16	0.09	0.11	0.19	0.32	0.1	0.27	0.27
0.93	2.24	2.86	1.57	2.06	1.85	1.36	1.38	1.34	2.38	2.1	1.96	1.41	2.24	2.09
2.17	4.4	5.03	4.62	4.31	4.85	5.39	5.7	5.4	4.12	4.08	4.41	5.49	5.43	4.27
4.37	5.11	4.59	5.21	5.23	5.34	5.14	5.62	5.48	4.86	5.34	5.09	4.84	4.79	4.8
4.47	2.29	2.5	2.13	2.27	2.08	1.97	1.73	1.65	2.7	2.44	2.33	1.98	2.05	2.27
0.37	0.48	0.36	0.59	0.45	0.5	0.55	0.36	0.44	0.42	0.55	0.55	0.2	0.39	0.55
94.65	96.24	97.12	97.33	96.95	97.16	98.67	98.61	98.86	97.29	96.76	98.43	96.5	96.03	96.7

Appendix C Continued

Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3
Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM
181125-01b	181125-01b	181125-01b	181125-01b	181125-01b	181125-01b	181125-01b	181125-01b	181125-01b	181125-01b	181125-01b	181125-01b	181125-01b	181125-01b	181125-01b	181125-01b	181125-01b	181125-01b	181125-01c
b-01a	b-01b	b-01c	b-02a	b-02b	b-02c	b-02d	b-02e	b-02f	b-02g	b-02h	b-03a	b-03b	b-03c	b-04a	b-04b	b-04c	b-04c	c-01a
HK-M	MK	MK	MK	MK	MK	MK	MK	HK-M	MK	MK	MK	MK	MK	HK-M	MK	HK-M	HK-M	HK-M
180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
64.67	59.49	63.47	63.71	62.62	64.41	62.15	62.58	64.94	63.71	62.58	62.73	64.13	60.63	64.22	61.57	63.97	64.36	
0.6	0.89	0.71	0.62	0.74	0.82	0.68	0.75	0.96	0.6	0.82	0.85	0.67	0.62	0.61	0.7	0.73	0.61	
16.09	19.1	16.08	16.69	17.04	16.07	14.8	17.2	15.75	16.31	17.87	16.42	15.98	18.8	16.01	16.51	15.06	16.23	
3.67	3.91	4.24	3.65	3.31	3.95	6.14	3.12	3.15	4.15	4.1	4.27	4.44	3.16	3.64	3.39	3.46	4.32	
0.2	0.05	0.15	0.18	0.07	0.16	0.27	0.05	0.19	0.15	0.01	0.16	0.03	0.16	0.03	0.09	0.04	0.15	
1.01	1.08	1.64	0.74	1.32	1.08	3.71	1.09	0.84	1.68	1.3	1.43	1.26	1.44	1.25	1.54	1.2	1.51	
2.77	5.74	3.93	3.83	4	3.59	2.86	4.06	2.58	3.92	4.51	3.62	3.6	5.5	3.38	4.23	2.85	3.06	
4.95	5.35	5.57	5.64	5.45	5.51	4.93	5.41	5.35	5.83	5.88	5.32	5.5	5.03	5.11	5.14	4.59	4.93	
3.39	1.89	1.8	1.62	1.92	2.48	2.29	2.59	3.03	1.78	1.28	2.14	2.16	2.11	3.17	2.14	3.23	3.16	
0.39	0.73	0.19	0.25	0.41	0.4	0.32	0.52	0.19	0.13	0.52	0.23	0.2	0.33	0.24	0.26	0.43	0.21	
97.74	98.23	97.78	96.93	96.88	98.47	98.15	97.32	96.84	98.3	99.01	97.02	98.1	97.65	97.63	95.57	95.56	98.54	

Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3
Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM
181125-01c c-01b MK	181125-01c c-01c MK	181125-01c c-01d MK	181125-01c c-01e MK	181125-01c c-02a MK	181125-01c c-02b MK	181125-01c c-02c MK	181125-01c c-03 MK	181125-01c c-04a MK	181125-01c c-04b MK	181125-01d d-01a MK	181125-01d d-01b MK	181125-01d d-01c MK	181125-01d d-02 MK	181125-01d d-03a MK	181125-01d d-03b MK	181125-01d d-03c MK	
180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
63.45	64.17	64.1	64.9	62.99	62.83	63.93	62.03	62.98	62.3	59.2	62.95	62.29	63.65	60.69	60.78	62.31	
0.69	0.77	0.56	0.61	0.53	0.71	0.6	0.59	0.59	0.63	0.51	0.9	0.72	0.62	0.42	0.39	0.54	
16.7	17.09	16.21	17.28	16.96	16.66	16.16	16.86	16.56	16.74	19.76	16.31	16.82	16.37	19.54	18.95	17.66	
4.46	3.8	3.72	3.55	3.81	4.45	4.15	4.27	3.92	4.14	3.81	4.49	4.71	3.74	3.11	3.16	4.14	
0.11	0.14		0.2	0.29	0.14	0.02	0.14	0.1	0.24	0.2	0.22	0.29	0.21		0.22	0.01	
1.61	1.13	1.46	1.44	1.46	1.27	1.57	1.77	1.57	1.4	2.06	1.64	1.54	1.43	1.26	0.81	1.16	
3.53	3.64	3.46	4.08	4.24	3.72	3.4	3.94	4.05	3.72	6.7	3.94	3.93	3.65	5.61	5.31	4.04	
5.41	5.44	5.4	5.59	5.12	5.23	5.09	4.99	5.03	5.25	4.66	5.45	5.46	5.56	5.25	5.29	5.3	
2.35	2.42	2.58	2.46	2.11	2.54	2.87	2.52	2.13	2.27	1.74	2.05	1.95	2.09	1.76	1.6	2.08	
0.51	0.32	0.33	0.28	0.23	0.27	0.27	0.45	0.34	0.42	0.11	0.42	0.48	0.17	0.15	0.04	0.16	
98.82	98.92	97.82	100.39	97.74	97.82	98.06	97.56	97.27	97.11	98.75	98.37	98.19	97.49	97.79	96.55	97.4	

Appendix C Continued

Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3
Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM
181125-01d	no-name-01	no-name-01	no-name-01	no-name-01	no-name-01	no-name-02	no-name-02	no-name-02	181130-03	181130-03	181130-04	181130-04
d-04	01a	01b	01c	01d	01e	02a	02b	02c	03a	03b	04a	04b
MK	MK	MK	MK	MK	MK	HK-M	HK-M	HK-M	MK	MK	MK	MK
180	180	180	180	180	180	180	180	180	180	180	180	180
62.23	65	64.7	64.36	65.07	65.14	66.74	67.24	66.89	65.45	65.17	65.48	65.56
0.79	0.68	0.8	0.77	0.59	0.7	0.49	0.65	0.4	0.75	0.77	0.8	0.52
16.58	17.2	17.02	16.66	16.84	17.01	16.14	15.82	16.39	17.09	16.77	16.65	16.91
3.76	4.53	3.91	3.84	4.29	4.13	2.83	2.79	3	4.29	4.09	3.96	3.99
0.2	0.45	0.05	0.39	0.18	0.12	0.16	0.38		0.13	0.19	0.31	0.3
1.32	1.49	0.96	1.44	1.26	1.36	0.75	0.67	0.65	1.4	1.3	1.43	1
3.72	3.62	3.64	3.59	3.69	3.65	2.56	2.5	2.57	3.65	3.19	3.48	3.22
5.33	6.98	6.6	7.03	6.89	6.67	5.23	5.29	5.25	6.64	6.62	6.62	6.24
2.07	1.06	1.3	1.05	1.17	1.13	3.61	3.6	3.49	1.01	1.57	1.24	1.66
0.45	0.15		0.16	0.27	0.31	0.1	0.09	0.2	0.05	0.05		0.28
96.45	101.16	98.98	99.29	100.25	100.22	98.61	99.03	98.84	100.46	99.72	99.97	99.68

Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3	Aso-41-3
Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM
181130-04	181130-04	181130-04	181228	181228	181228	181228	181228
04c	04d	04e	04a	04b	04c	04d	04e
MK	MK	MK	MK	MK	HK-M	HK-M	MK
180	180	180	180	180	180	180	180
65.04	64.58	65.11	62.63	59.75	64.14	65.06	64.01
0.71	0.64	0.35	0.51	0.19	0.81	0.55	0.69
16.91	16.94	17.15	18.41	22.27	16.48	16.07	17.69
3.43	4.15	3.71	2.94	2.62	3.17	2.56	3.13
0.03	0.01	0.38	0.06		0.13	0.13	0.02
1.12	1.24	1.1	0.92	0.42	0.92	0.85	0.9
3.86	3.71	3.4	4.58	6.48	2.86	2.49	3.82
6.54	6.65	6.31	5.35	5.39	5.15	5.21	5.28
1.5	1.34	1.91	2.5	1.51	3.42	3.3	2.77
0.29	0.25	0.14	0.01		0.15	0.07	0.32
99.43	99.51	99.56	97.91	98.63	97.23	96.29	98.63

Appendix D Tables of trace element composition of MI and GM of the large eruptions and the basaltic scoriae

[illegible]

Appendix D Continued

Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2TL	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T
Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
GM	GM	GM	GM	GM	GM	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M
ASQ01_PN_001 - 5	ASQ01_PN_001 - 6	ASQ01_PN_001 - 7	ASQ01_PN_001 - 8	ASQ01_PN_001 - 9	ASQ01_PN_001 - 10	ASQ01_PN_001 - 11	ASQ01_PN_001 - 12	ASQ01_PN_001 - 13	ASQ01_PN_001 - 14	ASQ01_PN_001 - 15	ASQ01_PN_001 - 16	ASQ01_PN_001 - 17	ASQ01_PN_001 - 18	ASQ01_PN_001 - 19	ASQ01_PN_001 - 20	ASQ01_PN_001 - 21	ASQ01_PN_001 - 22	ASQ01_PN_001 - 23	ASQ01_PN_001 - 24	ASQ01_PN_001 - 25	ASQ01_PN_001 - 26	ASQ01_PN_001 - 27	ASQ01_PN_001 - 28
39.1	37.2	34.5	35.9	39.1	38.8	24.3	21.4	24.1	23.5	24.8	24.9	25.0	22.2	22.8	22.9	23.0	22.0	24.4	23.6	24.5	22.1	23.8	23.3
61.4	62.7	58.4	61.4	57.1	61.2	35.1	38.3	39.0	38.9	38.0	36.9	37.8	38.1	40.6	34.6	36.1	34.9	38.3	37.4	36.7	47.8	37.3	37.5
29566.0	29315.7	24839.2	29286.0	27780.3	29201.9	25790.2	26011.1	26843.7	26935.0	25846.6	26589.6	26171.4	25400.3	26906.9	26825.4	26478.4	23290.7	26088.0	26186.0	26786.3	24760.5	26243.6	26426.7
3628.3	3449.1	3481.9	3287.1	3490.3	3351.6	12655.9	11700.9	11146.0	11880.6	12817.1	13191.6	13283.5	12136.9	11395.3	12135.0	12833.2	22102.8	11490.0	12022.2	12217.7	10265.6	12703.6	11380.7
81066.6	77674.8	82397.3	73694.3	80131.7	75556.8	72684.0	73151.5	74317.5	76709.2	73287.5	74835.8	74837.0	70862.7	75116.2	75576.9	73717.4	69742.3	73135.4	74369.0	81803.5	73225.2	75692.7	74877.7
498.4	648.9	558.5	669.9	568.7	610.4	1437.9	1499.4	1511.6	1545.0	1438.6	1492.0	1492.8	1555.9	1490.9	1509.0	1483.2	1313.4	1520.8	1456.8	1511.3	1801.5	1446.9	1551.4
39046.4	38344.8	38368.4	38750.6	37938.0	38312.1	22469.7	23652.9	24151.3	24035.5	22200.7	22571.6	22820.0	23096.2	24166.9	23474.8	23140.3	20917.4	23270.6	23332.4	24251.5	27610.6	23299.8	26521.7
16637.9	15136.6	14835.9	14397.7	14762.7	14670.5	35466.6	33330.7	33938.8	35000.4	36551.5	37259.8	37609.2	36591.5	34895.3	34921.9	34811.0	33240.8	34110.8	35361.4	35672.3	31608.3	36713.3	32647.5
8.9	11.3	11.8	10.3	11.2	10.6	19.6	18.6	19.8	18.6	18.7	20.8	19.8	23.7	18.0	17.6	18.0	21.6	17.1	17.9	18.4	19.0	17.9	18.0
3952.2	3795.3	4130.7	3606.6	3805.2	3643.5	5621.4	5524.9	5662.9	5474.5	5535.3	5642.7	5747.6	5830.4	5644.9	5605.8	5429.5	5372.4	5627.4	5855.0	5878.9	6592.7	5613.0	5806.5
134	130	157	130	153	137	238.7	217.4	205.5	213.5	233.1	239.3	241.5	204.4	224.6	229.0	211.5	210.2	218.8	232.9	222.9	255.7	237.2	219.5
BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD
836.4	819.9	1447.5	770.7	815.5	776.3	1007.8	1038.1	1081.5	925.1	1002.5	1068.1	1039.2	1197.5	946.6	988.1	990.7	1375.2	1050.6	981.9	973.0	1029.7	1003.2	977.0
28801.2	28190.4	28371.9	26460.5	28914.9	27205.5	55308.1	53089.4	53477.4	49647.8	53234.0	53963.9	53369.2	53741.0	52536.3	53921.5	51057.2	62508.1	52764.0	52111.5	50771.3	54122.3	53973.0	52119.5
3.3	2.8	24.9	2.8	4.7	2.9	20.8	19.1	19.1	18.9	20.2	19.3	21.2	17.9	18.7	18.3	20.2	28.3	19.4	19.5	18.7	17.7	20.4	18.7
BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD
57.3	89.4	43.9	84.6	55.9	82.0	106.9	99.7	109.2	101.9	102.3	107.9	110.5	121.5	102.4	101.5	100.6	138.2	112.9	107.2	105.8	114.8	102.4	102.2
159.4	157.1	158.6	159.8	157.9	159.9	91.8	98.6	101.3	99.2	91.8	94.4	93.9	95.9	99.4	97.9	94.7	84.9	96.7	95.5	98.2	116.6	95.1	107.1
260.8	240.3	251.6	225.1	242.2	238.1	400.5	401.8	407.2	422.6	408.4	418.9	418.0	384.8	404.9	412.4	401.4	383.9	395.3	410.5	430.3	342.4	413.7	377.5
33.9	32.1	34.8	30.3	31.8	31.1	24.1	25.3	28.9	22.5	23.0	24.7	24.4	38.4	24.3	23.2	23.0	25.4	25.2	24.0	25.4	29.2	23.7	24.4
304.9	277.3	308.4	273.0	290.0	278.0	155.6	162.0	171.4	160.3	152.1	156.2	155.5	183.2	166.0	159.0	155.9	157.5	162.4	157.4	171.2	200.2	155.2	169.9
17.0	16.1	17.7	16.5	16.6	16.3	9.4	9.9	10.2	10.2	9.5	9.5	9.6	10.0	10.2	9.7	9.5	9.2	9.6	9.8	10.0	12.3	9.1	10.4
8.2	8.5	8.4	8.6	8.0	8.4	4.7	5.2	5.5	5.3	5.1	4.9	5.0	5.2	5.3	5.2	5.0	4.6	5.2	5.1	5.2	6.5	4.8	5.6
808.8	761.5	815.6	736.0	783.2	743.6	476.9	493.2	500.4	505.6	467.1	484.6	480.8	489.5	511.2	489.1	471.0	457.0	484.1	478.9	534.5	588.7	482.0	519.2
36.6	34.7	36.9	33.2	34.7	34.1	23.1	23.8	25.3	23.8	22.4	23.0	22.6	26.6	23.9	22.9	22.9	22.2	23.3	23.9	25.4	28.5	22.9	24.7
77.3	75.2	85.5	72.3	73.7	72.7	49.6	52.2	55.9	51.4	48.9	50.3	50.6	63.4	53.2	49.6	49.4	49.2	51.7	50.2	54.7	62.1	48.9	53.6
8.9	9.3	9.3	8.6	8.7	8.8	6.2	6.4	7.1	6.1	5.9	6.1	6.2	8.2	6.5	6.2	6.1	6.0	6.3	6.2	6.7	7.6	6.2	6.6
35.3	35.7	36.4	32.9	34.7	33.4	23.9	26.2	29.9	24.3	24.4	25.1	25.6	35.7	26.6	25.1	25.4	24.4	25.5	25.2	27.0	31.0	26.0	26.7
7.2	7.5	7.4	6.3	6.9	6.6	5.6	6.2	6.5	5.5	5.7	5.7	6.2	5.9	5.7	5.3	5.8	5.5	5.5	6.4	6.8	5.4	5.9	6.2
13.3	15.1	11.1	13.3	14.3	13.3	1.3	1.4	1.6	1.4	1.3	1.3	1.4	1.6	1.5	1.4	1.3	1.2	1.4	1.4	1.5	1.5	1.4	1.4
6.8	6.0	7.3	6.0	6.0	6.2	4.9	5.5	6.1	4.7	4.8	4.5	4.8	7.3	5.0	4.8	4.6	5.3	5.0	4.9	5.5	6.2	4.9	5.2
0.9	0.8	1.0	0.8	0.9	0.9	0.7	0.7	0.8	0.7	0.7	0.8	0.7	1.1	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.7	0.7
5.6	6.2	5.8	5.3	5.6	5.5	4.4	4.4	5.2	4.3	4.1	4.4	4.7	7.3	4.6	4.3	4.0	4.9	4.7	4.3	4.6	5.0	4.2	4.4
1.2	1.1	1.2	1.1	1.1	1.2	0.9	1.0	1.1	0.8	0.8	0.9	0.8	1.4	0.9	0.9	0.8	0.9	0.9	0.9	0.9	1.1	0.9	0.9
3.8	3.5	3.9	3.2	3.3	3.5	2.5	2.7	3.2	2.4	2.6	2.8	2.4	4.2	2.5	2.7	2.6	2.7	2.6	2.5	2.4	3.2	2.6	2.5
0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.3	0.3	0.4	0.4	0.6	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.3	0.4
3.6	3.2	4.0	3.1	3.4	3.5	2.7	2.6	2.9	2.2	2.2	2.3	2.3	3.9	2.8	2.3	2.4	2.7	2.6	2.3	2.8	2.9	2.3	2.6
0.6	0.6	0.5	0.5	0.6	0.5	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.6	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.3	0.4
8.0	7.2	8.4	7.0	7.7	7.3	4.2	4.8	4.8	4.5	4.4	4.3	4.3	5.3	4.7	4.3	4.2	4.2	4.3	4.1	4.5	5.6	4.4	4.9
1.3	1.2	1.3	1.1	1.2	1.2	0.7	0.7	0.7	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.7	0.6	0.7	0.7	0.7	0.8	0.7	0.7
24.8	29.5	23.6	24.6	23.1	24.7	14.7	15.2	15.7	15.6	14.6	15.4	14.8	15.2	15.5	15.1	14.3	13.9	15.2	15.0	15.5	18.6	14.9	15.7
16.2	15.2	17.1	14.7	15.2	15.0	8.5	8.7	9.0	9.0	8.4	8.5	8.7	9.0	9.1	8.6	8.5	8.4	8.7	8.6	9.3	11.0	8.5	9.2
4.6	4.5	4.5	4.4	4.6	4.3	2.5	2.7	2.8	2.7	2.5	2.6	2.5	2.7	2.7	2.6	2.6	2.5	2.8	2.6	2.8	3.3	2.5	2.9

Appendix D Continued

Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	
Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	
MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	
PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	PI	
HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	
3_B04a-1 Aso-2T_P0_C03a-3 Aso-2T_P0_D03a-1 Aso-2T_P0_F03-1 Aso-2T_P0_F04a-1 Aso-2T_P0_F04b-1 Aso-2T_P0_F04c-1 Aso-2T_P0_F04d-1 Aso-2T_P0_F04e-1 Aso-2T_P0_F04f-1 Aso-2T_P0_F04g-1 Aso-2T_P0_F04h-1 Aso-2T_P0_F04i-1 Aso-2T_P0_F04j-1 Aso-2T_P0_F04k-1 Aso-2T_P0_F04l-1 Aso-2T_P0_F04m-1 Aso-2T_P0_F04n-1 Aso-2T_P0_F04o-1 Aso-2T_P0_F04p-1 Aso-2T_P0_F04q-1 Aso-2T_P0_F04r-1 Aso-2T_P0_F04s-1 Aso-2T_P0_F04t-1 Aso-2T_P0_F04u-1 Aso-2T_P0_F04v-1 Aso-2T_P0_F04w-1 Aso-2T_P0_F04x-1 Aso-2T_P0_F04y-1 Aso-2T_P0_F04z-1																													
21.3	21.8	18.4	22.6	24.6	17.8	24.4	22.7	24.0	21.7	21.3	24.1	22.5	23.0	22.1	22.6	23.3	25.6	28.6	23.1	23.5	22.9	22.6	27.2	24.0					
36.1	31.3	26.9	38.1	36.8	28.0	39.5	38.1	36.8	41.3	37.1	36.4	37.1	39.8	41.2	33.3	36.6	36.5	42.0	38.5	39.3	37.8	40.2	38.9	36.6					
26732.0	26499.5	25639.5	26147.7	26171.1	25146.8	26832.9	27089.7	26730.6	25575.2	26522.9	26242.0	26347.7	26686.7	26081.1	22209.8	25788.2	25623.7	18225.6	25343.2	25834.5	26564.5	25769.7	26991.6	26744.3					
11654.9	10983.4	10175.1	10791.9	11067.1	8726.5	11736.5	13085.9	12818.9	12777.3	13271.8	11874.1	13033.1	13348.1	12728.9	11525.7	13423.0	14042.9	9671.1	12913.3	12914.4	12722.4	12570.4	14391.1	12995.0					
74923.1	74316.4	94033.2	71859.5	73896.4	109550.3	74603.8	79388.3	77919.0	79213.3	79099.9	78057.7	78753.6	78068.6	78664.1	77122.4	77581.1	83363.3	81444.2	76196.9	76686.6	80233.6	76393.0	84758.7	77102.4					
1544.2	1412.7	1346.5	1695.5	1525.5	1051.7	1484.7	1552.1	1478.5	1517.3	1580.7	1330.5	1541.7	1500.8	1522.8	1233.8	1505.4	1464.7	1517.0	1429.9	1542.5	1397.6	1352.1	1426.0	1396.8					
25098.9	24720.7	20173.3	24830.3	24668.2	17329.4	23740.7	25165.3	25257.5	24773.2	23705.6	22846.5	23880.2	23876.2	24515.8	22491.4	23331.4	23607.1	20212.7	23450.4	23732.0	22612.4	23901.0	24044.6	24097.1					
33874.4	31921.5	47139.6	31916.4	32243.9	58274.9	35272.0	37816.9	37364.6	39152.5	38507.7	35638.5	38416.6	38079.2	36517.5	35089.1	39037.4	40761.0	30289.8	37376.3	36903.9	39804.8	36880.8	44218.8	37494.0					
17.6	18.5	18.0	17.7	18.0	15.2	17.8	19.5	20.2	19.1	19.8	19.2	20.7	19.1	18.5	18.4	19.2	20.3	18.7	19.0	19.5	19.2	18.0	20.3	18.9					
5637.2	5726.0	5981.9	6034.8	5823.9	4588.7	5618.4	6012.5	5980.1	5888.0	6027.4	5760.1	6029.7	5906.9	5980.7	5921.2	5900.0	6276.5	6269.9	5770.4	5934.5	5750.8	5823.9	6552.6	5908.8					
213.3	228.4	241.0	228.0	221.3	166.0	228.4	240.9	237.4	231.5	236.9	216.8	238.2	239.1	238.3	208.1	237.3	239.7	229.6	232.0	237.4	234.1	230.5	246.1	233.3					
BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD				
1012.5	928.3	825.4	905.5	933.6	717.4	981.3	1064.9	1034.7	1016.9	1052.6	940.6	1050.6	1053.8	1023.7	907.8	1099.3	1066.5	1031.4	1044.3	1033.6	1018.8	1121.9	1034.1						
53128.1	49852.9	45159.3	47833.0	49878.9	38472.2	53416.0	55820.6	54493.2	53854.1	54825.2	53548.3	56808.0	55805.4	53469.1	50004.7	57743.1	56790.5	58519.9	55428.4	55043.9	55258.2	53851.9	60097.0	56492.0					
18.9	17.9	16.0	17.1	18.0	13.5	18.7	21.8	19.4	19.7	21.2	18.0	21.0	20.7	20.8	18.0	20.8	20.8	14.5	19.0	21.3	20.7	20.2	22.1	21.8					
BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD				
105.1	95.5	86.4	95.3	96.3	73.8	104.7	115.0	107.4	111.7	109.3	74.7	108.5	112.7	103.7	65.0	113.6	88.8	109.7	119.3	107.1	104.3	121.8	108.4						
102.0	104.7	84.5	104.7	102.2	73.6	99.2	99.9	99.8	97.7	96.2	98.3	96.8	95.2	97.2	94.6	93.9	93.3	112.3	93.8	96.6	92.7	99.2	98.9	96.9					
394.3	372.6	536.7	361.5	376.4	669.3	407.2	430.6	422.7	435.3	434.3	403.6	443.5	440.9	421.7	418.6	438.6	453.9	374.4	422.6	417.6	479.1	418.2	477.5	433.8					
24.8	24.5	25.2	25.6	24.6	20.6	24.1	25.4	24.8	24.6	25.1	23.8	25.0	26.2	25.3	24.8	24.8	26.7	22.5	24.1	24.9	24.5	25.0	28.4	25.4					
166.9	160.3	167.9	164.3	170.8	139.4	164.3	168.2	172.4	168.8	171.7	169.8	169.3	172.7	167.0	176.7	166.4	171.6	155.9	162.0	164.5	162.8	164.2	187.1	167.7					
10.0	10.0	9.8	11.4	10.7	7.6	9.9	10.3	10.5	10.1	10.4	10.0	10.4	10.1	10.1	10.3	9.7	10.5	10.3	9.8	10.3	10.0	9.9	11.6	10.2					
5.5	5.5	4.7	6.0	5.5	3.8	5.2	5.5	5.2	5.1	5.2	5.1	4.8	5.2	4.9	4.9	4.9	5.1	6.0	4.9	5.3	4.9	5.3	5.2	5.0					
512.5	519.4	510.3	519.8	515.6	440.7	497.6	519.5	515.0	510.8	501.9	505.3	520.0	511.9	509.2	540.8	506.4	536.3	554.2	496.8	508.9	505.1	496.5	565.3	517.9					
23.6	23.8	24.8	24.8	24.0	20.5	24.0	24.8	24.9	24.1	24.7	23.5	24.6	25.3	24.6	26.2	23.5	26.1	21.9	23.4	24.1	23.8	23.9	26.7	24.4					
52.3	51.1	53.6	52.9	53.7	43.8	51.8	53.9	54.6	52.1	53.4	49.7	54.2	55.4	53.1	49.0	52.9	56.9	49.0	52.4	53.2	52.3	51.3	58.9	53.4					
6.3	6.5	6.5	6.5	6.5	5.1	6.4	6.8	6.6	6.5	6.7	6.3	6.5	6.9	6.5	6.9	6.5	6.6	6.1	6.4	6.5	6.5	6.2	7.2	6.6					
25.8	25.9	27.4	27.6	27.5	21.8	24.7	27.7	27.2	27.1	26.6	25.3	27.5	27.8	26.7	29.2	26.3	28.1	25.0	26.0	27.5	25.6	25.3	30.1	27.2					
5.9	5.6	5.6	6.2	5.9	5.2	5.4	6.4	6.2	5.7	5.8	5.5	6.2	6.2	6.0	6.2	5.6	6.2	4.9	5.8	6.0	5.5	5.8	6.8	5.6					
1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.4	1.5	1.4	1.4	1.4	1.4	1.3	1.5	1.3	1.4	1.3	1.5	1.4	1.4	1.4	1.4	1.7	1.5					
4.9	4.6	5.2	5.1	5.2	4.7	4.9	5.6	5.0	5.1	4.9	5.0	5.2	5.3	5.1	5.0	5.0	5.4	4.9	4.9	5.4	5.1	5.3	5.9	5.2					
0.7	0.7	0.8	0.7	0.7	0.8	0.7	0.8	0.8	0.7	0.7	0.8	0.8	0.7	0.8	0.7	0.7	0.8	0.8	0.7	0.7	0.7	0.7	0.8	0.8					
4.5	4.4	4.3	4.4	4.3	3.7	4.4	4.8	4.6	4.5	4.7	4.4	4.6	4.9	4.5	4.7	4.4	3.9	4.7	4.4	4.7	4.2	4.5	4.8	4.4					
0.8	0.9	0.9	0.9	0.9	0.7	0.9	1.0	1.0	0.9	0.9	1.0	1.0	0.9	1.0	0.9	1.0	0.9	0.8	0.9	0.9	0.9	0.9	1.1	0.9					
2.4	2.5	2.8	2.5	2.7	2.1	2.7	2.6	2.8	2.5	2.6	2.4	2.6	2.8	2.9	2.7	2.6	2.7	2.5	2.8	2.6	2.5	2.7	2.9	2.6					
0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.4	0.4	0.5	0.4	0.3	0.4	0.3	0.4	0.4	0.4	0.3					
2.4	2.3	2.6	2.6	2.6	2.1	2.4	2.6	2.6	2.3	2.6	2.4	2.4	2.6	2.3	2.6	2.7	2.5	2.3	2.5	2.7	2.6	2.4	2.9	2.6					
0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.3	0.4	0.4	0.4	0.4					
4.5	4.6	4.6	5.1	4.6	3.9	4.4	4.6	4.8	4.6	4.8	4.6	4.7	4.8	5.0	4.4	4.4	4.3	4.5	4.5	4.5	4.4	4.6							

Appendix D Continued

Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T	Aso-2T
Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM
HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M	HK-M
QOT_Sc_D014b-3	ASOT_Sc_D014-1	ASOT_Sc_D014-2	ASOT_Sc_D014-3	ASOT_Sc_D014-1	ASOT_Sc_D014-2	ASOT_Sc_D014-3	ASOT_Sc_D014-1	ASOT_Sc_D014-3	ASOT_Sc_D014-2	ASOT_Sc_D014-3	ASOT_Sc_D014-1	ASOT_Sc_D014-3
23.3	25.2	23.4	22.3	24.0	23.5	24.2	14.3	26.4	23.2	21.8	24.9	23.9
36.7	36.3	36.1	37.2	39.3	37.4	39.2	47.8	37.7	39.1	35.0	39.3	36.8
27054.8	27083.7	26402.9	27373.6	27073.6	26706.9	27083.9	27781.1	25709.2	25741.1	25022.7	26981.1	25451.1
12655.5	13231.4	12644.1	12301.0	13116.5	13186.5	12658.7	9901.5	13214.0	12862.7	12718.8	13023.8	11912.9
78085.6	81893.6	78179.3	78006.2	79160.0	77950.6	78472.0	77698.6	82125.3	78611.3	78682.2	79010.3	78962.6
1468.8	1456.6	1409.1	1452.0	1353.1	1417.8	1409.2	1552.3	1388.1	1404.7	1354.0	1416.7	1460.3
24749.1	24170.8	24580.3	24768.6	24291.8	24318.0	24675.1	24094.8	25097.7	23660.5	22663.2	24560.5	23291.3
36992.1	39343.6	37664.2	36237.6	38403.1	38630.7	36673.7	32398.1	38718.3	37629.5	36088.3	37138.8	36543.0
18.9	19.9	19.2	18.5	19.8	18.6	18.3	17.5	18.3	19.5	18.9	19.6	18.7
5898.7	6081.1	5949.0	5875.7	5967.6	5890.4	5966.9	6643.8	6416.0	5827.1	5868.0	5946.6	5687.2
239.5	244.8	233.4	232.8	239.0	242.3	238.1	242.4	255.2	237.9	223.3	239.9	224.9
BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD
1018.6	1051.7	1001.3	993.8	1051.9	1060.5	1038.1	961.1	1078.5	1041.0	1004.5	1038.9	968.5
54867.4	56413.1	53915.3	53603.8	56595.2	57394.4	56088.7	54125.5	59208.1	56218.1	56799.9	56488.8	55673.9
20.0	20.6	18.3	19.7	20.6	21.6	20.1	18.3	20.9	20.4	19.1	19.8	19.7
BelowLOD	7.9	8.6	BelowLOD	BelowLOD	9.7	6.3	BelowLOD	11.1	BelowLOD	BelowLOD	9.8	7.3
104.4	112.0	99.4	102.4	113.0	112.3	107.1	111.3	115.1	105.8	107.3	111.3	104.3
96.5	95.4	99.4	99.6	98.2	98.3	100.5	112.4	99.5	96.0	97.7	99.8	97.6
424.4	462.2	434.8	423.9	442.6	437.8	429.5	350.4	446.1	440.8	417.6	431.1	437.0
24.8	26.4	25.1	24.7	24.7	24.8	24.0	27.8	26.2	24.9	24.9	24.7	24.0
167.3	174.6	169.4	167.6	167.9	168.4	169.2	195.6	178.5	166.8	175.2	166.1	160.9
10.2	10.1	10.3	10.3	10.3	10.3	10.2	12.3	10.9	10.2	10.5	10.1	10.1
5.2	5.2	5.2	5.4	5.2	5.3	5.4	6.5	5.4	5.1	5.0	5.4	5.1
510.9	531.3	519.3	503.5	507.5	512.5	510.8	585.5	545.6	512.7	534.1	517.4	497.3
24.1	25.5	24.4	23.6	24.0	24.9	24.6	28.8	26.2	24.4	23.7	24.2	23.4
52.0	55.3	52.6	52.0	52.9	52.8	53.4	62.4	56.5	52.8	51.8	53.5	50.3
6.3	6.7	6.7	6.4	6.5	6.5	6.4	7.6	6.8	6.7	6.4	6.7	6.4
27.1	27.9	27.0	26.4	27.9	26.1	26.5	30.9	29.3	26.6	26.8	26.6	25.4
5.2	6.6	6.1	5.7	6.2	6.0	6.0	6.7	6.5	5.7	5.9	6.1	6.1
1.4	1.5	1.4	1.4	1.4	1.4	1.4	1.5	1.4	1.5	1.4	1.3	1.3
4.9	5.8	4.7	5.1	5.5	5.2	5.0	5.8	5.2	5.2	4.9	5.2	4.9
0.7	0.8	0.7	0.7	0.8	0.7	0.8	0.9	0.9	0.7	0.7	0.8	0.7
4.3	4.7	4.8	4.5	4.8	4.6	4.7	5.0	4.9	4.3	4.5	4.6	4.4
0.9	1.0	0.9	1.0	1.0	0.9	0.9	1.0	1.0	0.9	1.0	0.9	0.9
2.7	3.1	2.5	2.7	2.6	2.6	2.8	3.0	2.7	2.8	2.6	2.5	2.6
0.3	0.4	0.4	0.4	0.4	0.4	0.3	0.5	0.4	0.4	0.4	0.4	0.3
2.5	2.7	2.5	2.6	2.5	2.6	2.3	2.7	2.7	2.4	2.4	2.7	2.4
0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
4.8	4.9	4.7	4.5	4.7	4.5	4.7	5.6	4.9	4.6	5.0	4.6	4.3
0.7	0.8	0.7	0.8	0.7	0.7	0.7	0.9	0.7	0.7	0.8	0.8	0.7
15.2	16.1	15.1	15.9	15.5	15.7	16.0	22.9	16.4	15.7	16.0	15.8	16.1
8.9	9.4	9.1	9.3	9.0	9.3	9.1	10.8	9.7	8.9	8.7	9.3	8.7
2.7	2.7	2.6	2.7	2.7	2.7	2.7	3.2	2.9	2.6	2.6	2.7	2.6

Appendix D Continued

	Aso-3W	Aso-3W	Aso-3W	Aso-3W	Aso-3W	Aso-3A	Aso-3A	Aso-3A	Aso-3A	Aso-3A	Aso-3A	Aso-3A	Aso-3A	Aso-3A	Aso-3A	Aso-3A	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C	Aso-3C
Ejecta	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria	Scoria
Glass type	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
Mineral	Cpx	Cpx	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx
Compositional type	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S
Sample number	Aso-3W_Qp01_C-03	Aso-3W_Qp01_D-04	Aso-3W_P01_A04-2	Aso-3W_P01_C-03a_Cen-2	Aso-3W_P01_D03-2	Aso3A_P01_A04-3	Aso3A_P01_B04-1	Aso3A_P01_B04a-1	Aso3A-SC_glass_A03	Aso3A-SC_glass_A03	Aso3A-SC_glass_A03a-1	Aso3A-SC_glass_A03a-2	Aso3A-SC_glass_A03a-3	Aso3A-SC_glass_A03a-4	Aso3A-SC_glass_A03a-5	Aso3A-SC_glass_A03a-6	Aso3C_Qp04_C-01c	Aso3C_Qp04_C-01c	Aso3C_Qp04_H-03a	Aso3C_Qp04_H-03b	Aso3C_Qp04_H-03c	Aso3C_Qp04_H-03d	Aso3C_Qp04_H-03e	Aso3C_Qp04_H-03f	Aso3C_Qp04_H-03g	Aso3C_Qp04_H-03h
ppm																										
Li	27.6	37.9	26.0	28.7	27.7	19.2	17.8	33.0	35.6	38.1	30.9	33.6	38.2	32.9	31.0	29.8	25.2	19.9	22.3	23.8	19.2	20.1	17.4			
B	71.3	59.2	66.9	251.5	53.6	52.5	60.3	50.7	77.0	152.9	215.2	879.5	238.8	2836.3	876.0	1805.0	38.3	35.2	33.4	38.0	36.0	35.7	23.9			
Na	27663.0	29440.9	29614.7	26198.0	30186.9	28742.6	28533.9	29801.8	30910.4	31003.2	30796.0	31264.3	29862.2	30081.5	29534.9	30425.2	26929.8	27795.5	27201.7	28641.7	27292.0	28157.9	17664.3			
Mg	2959.0	2432.2	2606.4	8129.2	2222.2	2579.4	2512.0	2961.5	2778.5	2896.8	2783.3	3003.0	2752.0	2648.8	2854.2	2896.7	8588.6	10127.3	11503.7	8857.5	10083.4	9133.7	51859.9			
Al	70678.8	75560.2	74629.0	69336.2	75288.2	73895.8	71979.9	73185.3	80228.9	79746.4	79936.3	88065.4	80037.3	83375.4	79001.1	80708.4	78403.8	74247.5	77005.8	74305.0	78129.3	81340.7	55585.8			
P	351.1	364.0	362.0	306.6	291.4	432.2	382.7	521.8	415.4	443.3	335.8	299.8	437.8	276.6	437.0	328.9	1580.1	2576.9	1430.1	1663.1	1342.1	1332.8	997.0			
K	41039.4	43559.9	39671.6	39404.8	39787.0	39339.8	38625.0	38223.7	39590.7	39727.6	38007.6	41818.8	41315.8	42130.2	38958.7	38469.4	27051.2	24277.7	22385.9	26272.2	24278.2	24836.7	17352.7			
Ca	10358.8	9066.9	10593.4	17478.3	11130.8	11319.8	11406.1	11267.4	12111.2	11490.7	11507.7	14108.8	12054.3	10234.2	11735.6	10950.4	29223.4	31918.5	36897.7	30316.3	33263.0	34273.4	26700.0			
Sc	8.7	8.8	9.9	20.9	9.0	8.9	8.8	11.1	8.7	9.2	9.1	13.7	9.4	10.8	9.5	8.5	15.5	18.8	19.6	18.0	18.1	30.8				
Ti	2970.2	2996.4	3173.4	2935.8	2835.8	3375.0	3019.4	3706.1	3270.3	3378.7	3230.7	3708.0	3402.6	3298.5	3090.1	3254.6	4864.4	4774.3	4742.5	4877.3	5675.9	5295.6	4530.4			
V	14.3	12.7	18.0	18.6	12.5	18.0	16.0	15.1	13.7	14.8	14.6	13.7	16.2	13.9	14.1	14.1	159.3	98.9	167.2	157.8	179.6	175.2	151.5			
Cr	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	6.4		
Mn	719.8	673.9	688.8	1025.9	656.0	677.1	670.8	724.3	721.7	748.4	725.9	799.8	742.6	715.9	748.0	759.4	902.8	1303.8	1146.6	998.8	1027.9	970.5	2195.2			
Fe	17464.3	15968.9	17183.1	21019.2	15225.7	16103.5	18396.5	17708.1	16286.2	16136.0	16930.2	17411.6	15956.2	16503.1	17156.4	16554.3	44018.4	44266.2	50380.0	47031.1	48719.3	46770.0	80808.0			
Co	2.0	BelowLOD	BelowLOD	2.5	BelowLOD	2.5	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	4.0	BelowLOD	13.9	11.2	16.9	13.7	15.4	15.6	43.2	
Ni	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	13.0	
Zn	69.3	66.6	63.1	70.6	61.8	65.6	71.7	77.4	76.9	72.6	60.2	54.5	66.1	33.6	38.9	25.1	93.7	114.7	102.3	98.4	105.2	100.2	172.5			
Rb	183.3	174.8	166.9	163.3	161.9	168.0	153.9	150.9	156.1	158.7	156.6	168.5	161.3	161.6	155.0	155.9	110.6	98.8	90.8	106.9	99.9	100.1	72.2			
Sr	206.2	193.7	203.4	180.2	217.0	202.4	205.2	222.8	224.4	233.4	232.8	250.3	222.0	206.0	213.5	213.1	404.8	438.6	444.0	464.7	461.9	483.2	283.1			
Y	27.7	30.8	29.7	33.0	29.7	28.3	29.1	29.3	31.4	32.0	31.4	36.1	31.0	28.1	29.7	28.5	22.7	31.3	23.7	29.4	30.7	26.5	24.0			
Zr	251.5	278.0	273.0	263.5	268.9	256.2	251.3	251.6	281.2	290.7	273.3	335.3	281.1	265.6	265.8	266.1	182.5	161.7	152.6	186.2	192.4	178.7	144.7			
Nb	14.6	15.3	15.2	14.2	15.2	14.3	14.7	14.2	15.4	15.4	14.6	15.5	15.6	15.3	14.4	14.6	11.0	9.3	8.2	10.0	10.1	10.1	7.5			
Cs	8.6	9.1	8.9	8.2	8.6	8.3	8.1	7.8	8.5	8.2	7.9	8.5	8.7	8.9	8.3	8.1	6.0	5.3	4.8	5.6	5.2	5.3	4.1			
Ba	707.3	770.6	739.3	704.2	752.9	735.4	701.5	678.6	751.2	770.0	795.8	889.0	761.5	694.3	723.0	740.9	564.4	507.4	462.2	539.8	538.2	543.3	393.6			
La	31.1	33.2	32.2	31.8	32.2	30.2	30.7	30.2	33.1	34.9	32.9	38.7	33.7	30.5	31.6	31.3	25.2	24.6	21.0	24.2	25.7	26.1	19.5			
Ce	66.5	71.3	70.1	69.8	65.1	66.8	65.2	72.6	75.5	72.7	83.6	72.5	64.9	70.4	69.4	53.6	54.4	46.0	53.7	58.1	56.3	41.8				
Pr	7.9	8.6	8.2	8.2	8.2	7.7	7.7	7.8	8.4	8.9	9.1	9.9	8.6	7.8	7.9	8.4	6.5	6.8	5.8	6.5	7.2	7.0	5.2			
Nd	30.6	32.9	31.2	33.3	31.7	29.5	31.6	30.1	33.7	33.9	34.4	35.0	33.2	30.0	30.6	34.4	24.6	28.5	23.5	27.5	30.8	29.7	21.2			
Sm	6.4	7.1	6.8	7.8	6.3	6.4	6.6	6.1	6.7	7.0	7.3	7.1	7.4	6.8	6.1	6.2	5.7	6.0	5.0	6.4	6.9	6.3	5.4			
Eu	1.3	1.3	1.3	1.4	1.3	1.3	1.3	1.3	1.2	1.5	1.5	1.7	1.4	1.3	1.1	1.2	1.3	1.7	1.2	1.5	1.6	1.5	1.2			
Gd	5.8	5.5	5.5	6.3	5.7	5.1	5.4	5.4	6.3	6.3	5.1	6.6	6.0	5.8	4.9	4.9	4.8	5.4	5.0	5.8	6.5	5.1	4.9			
Tb	0.8	0.9	0.9	0.9	0.8	0.7	0.8	0.8	0.9	1.0	0.8	1.0	0.8	0.9	0.8	1.0	0.7	0.9	0.7	0.9	0.9	0.8	0.7			
Dy	5.4	5.4	5.4	6.2	5.1	5.0	5.3	5.0	5.6	5.8	5.2	6.3	4.7	5.1	4.7	5.0	4.3	5.6	4.4	5.2	5.5	4.8	4.3			
Hb	1.1	1.0	1.1	1.2	1.0	1.1	1.1	1.0	1.1	1.1	1.1	1.6	1.1	1.1	1.0	1.0	0.9	1.2	0.9	1.1	1.2	1.0	0.8			
Er	2.8	3.1	3.2	3.6	3.2	3.2	3.1	3.0	3.4	3.7	3.4	4.3	3.6	2.8	3.0	2.8	2.5	3.4	2.4	3.3	3.1	2.9	2.6			
Tm	0.5	0.5	0.5	0.6	0.4	0.4	0.5	0.4	0.4	0.5	0.5	0.8	0.4	0.4	0.4	0.5	0.4	0.5	0.3	0.5	0.5	0.4	0.4			
Yb	3.0	3.3	3.3	3.6	3.1	3.4	3.2	3.3	2.8	3.2	3.9	3.2	3.4	2.8	3.2	3.1	2.3	3.4	2.4	2.9	3.2	2.8	2.6			
Lu	0.6	0.5	0.5	0.5	0.5	0.4	0.5	0.5	0.5	0.5	0.6	0.7	0.5	0.5	0.5	0.5	0.4	0.5	0.4	0.5	0.5	0.4	0.4			
Hf	7.0	7.3	7.5	7.3	7.1	6.9	6.6	7.0	7.5	7.7	7.4	9.6	6.9	6.7	7.0	6.6	5.0	4.6	4.2	4.7	5.4	5.0	3.9			
Ta	1.0	1.1	1.1	1.0	1.1	1.0	1.1	1.0	1.1	1.1	1.1	1.2	1.2	1.2	0.9	1.1	0.8	0.7	0.6	0.7	0.7	0.7	0.6			
Pb	21.1	22.9	22.4	19.0	22.2	22.0	23.2	20.3	23.2	23.4	21.7	24.4	23.1	20.2	21.5	20.5	16.9	15.0	11.9	15.7	16.2	15.7	11.1			
Th	14.3	15.7	15.3	15.2	15.2	13.9	14.3	14.0	15.5	16.2	15.4	19.0	15.2	14.4	14.6	14.5	10.6	9.1	8.1	9.6	9.5	9.8	7.5			
U	4.4	4.8	4.7	4.3	4.6	4.4	5.0	4.2	4.5	4.8	4.5	5.3	4.6	3.9	4.1	4.0	3.3	2.9	2.5	3.0	2.9	2.9	2.3			

Appendix D Continued

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Appendix D Continued

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Appendix D Continued

	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1	Aso-41-1
Ejecta	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice	Pumice
Glass type	MI	MI	MI	MI	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM	GM
Mineral	PI	PI	PI	PI	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S
Compositional type	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S	HK-S
n number	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2	Aso-41_PJ2_H11-2
ppm																						
Li	57.7	83.5	106.8	129.1	48.0	35.0	41.3	33.0	36.4	34.3	37.8	37.1	34.4	34.3	33.5	38.5	36.2	35.6	35.9	38.6	34.6	
B	51.8	59.5	47.5	50.2	465.0	210.9	301.8	75.5	108.0	60.9	48.9	303.4	51.3	50.1	53.7	78.2	238.0	1249.7	44.2	58.2	79.7	
Na	30658.0	31431.3	26245.7	30073.3	27855.8	32553.0	29496.4	33235.0	32910.7	33358.0	33333.0	32987.0	31912.4	32527.0	33064.2	31768.5	32247.2	32799.8	33222.6	32792.9	32203.5	
Mg	1787.3	2469.9	2162.4	2193.3	2156.1	2269.1	1969.8	2316.5	2293.8	2367.2	2278.4	2139.5	2074.2	2253.3	2130.0	2108.9	1979.0	2228.4	2150.2	2027.7	1920.5	
Al	75865.5	77098.3	77479.5	76558.9	98157.5	78994.8	92782.8	77600.9	79597.6	77619.6	79004.7	81704.7	76555.4	75622.5	77149.7	79527.9	75823.6	78389.0	83101.8	75924.7	77845.1	79566.0
P	192.3	407.2	339.8	343.4	309.7	268.8	281.1	261.5	288.3	286.4	295.7	273.8	281.5	261.1	294.8	295.5	280.6	277.1	240.5	256.5	292.6	282.3
K	42194.5	36444.7	49610.0	35568.1	30463.6	33560.8	31659.0	35061.0	32339.1	32231.5	32560.2	32571.4	32955.7	33245.9	32914.1	33527.1	32416.3	32970.0	34014.9	32602.9	33398.9	34803.0
Ca	7450.5	10086.2	8606.5	8914.6	8365.2	10216.1	8882.6	8941.2	10622.3	10505.1	11553.5	10932.5	9799.0	9450.2	9988.3	10691.3	9862.1	9979.8	10463.0	9555.8	9943.8	9762.6
Sc	5.8	8.0	5.9	5.7	4.8	5.9	5.6	5.8	5.4	4.4	5.1	5.7	4.7	5.3	5.1	5.1	5.3	4.7	5.1	5.1	5.3	5.0
Ti	2159.9	2999.1	2630.3	2676.0	2677.8	2449.5	2747.8	2406.7	2504.4	2438.5	2520.6	2585.8	2427.0	2426.5	2440.2	2518.8	2405.5	2425.9	2558.5	2437.9	2484.0	2448.5
V	12.6	20.5	17.2	17.9	15.0	15.4	14.2	13.6	16.1	16.4	15.5	15.7	15.3	15.4	16.2	15.9	14.9	15.1	15.1	15.6	15.3	15.4
Cr	BelowLOD	BelowLOD	BelowLOD	BelowLOD	6.3	BelowLOD	BelowLOD	BelowLOD	BelowLOD	4.4	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD
Mn	708.1	784.8	756.6	787.2	728.9	850.4	754.6	829.0	885.8	864.1	887.4	888.9	794.3	777.9	820.5	817.8	834.1	831.1	816.9	858.2	851.3	752.3
Fe	11120.2	13240.8	11782.1	12318.6	11997.2	11844.0	11414.8	9593.4	12175.5	12434.5	12139.6	11935.0	11112.0	11070.0	11585.1	10689.3	11252.3	10430.7	8337.2	11407.1	8880.4	6436.4
Co	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	0.7	0.8	0.5	0.9	0.4	0.7	0.7	0.4	0.7	0.5	0.4	0.4	BelowLOD
Ni	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD
Zn	62.9	65.6	69.0	67.2	52.3	56.2	47.2	56.1	64.2	65.4	66.3	55.5	62.3	61.2	61.8	61.3	56.6	43.6	24.9	64.5	58.1	40.5
Rb	168.8	144.2	161.0	148.1	111.7	130.0	123.3	134.2	134.4	131.5	134.1	136.1	135.7	135.5	135.5	138.2	134.1	133.5	140.1	132.1	132.4	137.0
Sr	149.9	202.9	201.2	188.1	188.7	217.6	196.6	189.2	232.7	226.2	235.3	250.2	214.9	208.4	220.7	222.6	207.9	215.9	228.2	214.3	215.5	214.2
Y	29.2	35.6	29.0	28.8	26.0	27.7	27.3	28.5	28.4	27.5	28.3	30.1	27.0	27.9	27.3	28.4	27.1	28.6	29.9	26.3	27.4	28.2
Zr	270.3	309.2	253.7	251.9	244.1	240.5	250.2	254.8	238.1	230.4	239.2	248.6	235.9	232.6	236.7	237.8	234.2	240.6	257.6	229.1	239.5	234.8
Nb	13.8	16.4	13.5	13.3	13.6	12.3	13.4	13.2	12.9	12.6	12.9	12.9	12.7	12.5	12.5	13.0	12.5	12.9	13.2	12.9	12.6	13.3
Cs	8.6	9.7	8.5	8.5	6.4	7.5	6.9	7.7	7.4	7.3	7.5	7.6	7.5	7.7	7.4	7.7	7.2	7.8	7.5	7.5	7.5	
Ba	753.1	856.5	689.6	638.3	621.9	719.6	690.4	744.0	723.4	700.7	729.0	735.5	692.8	696.0	725.5	723.7	682.5	716.3	746.4	691.5	713.4	718.4
La	31.1	32.3	29.5	29.4	25.8	29.2	27.4	30.7	30.6	29.1	30.0	31.0	29.5	29.8	29.3	30.1	29.1	30.3	31.2	29.0	30.1	30.6
Ce	66.4	70.5	64.5	63.9	54.9	64.1	60.4	67.5	64.3	62.5	66.4	65.7	63.2	62.4	63.5	64.2	62.3	62.8	67.0	62.6	64.5	63.8
Pr	7.8	8.6	7.7	7.8	6.8	7.2	7.3	7.7	7.6	7.6	7.6	7.7	7.5	7.7	7.4	7.7	7.4	7.7	8.1	7.4	7.5	7.5
Nd	30.5	34.2	29.3	29.3	26.1	29.1	28.5	28.9	29.1	28.9	28.9	30.3	27.7	28.8	29.6	29.4	28.5	28.8	29.3	27.1	29.0	28.2
Sm	6.0	7.4	6.2	6.3	4.9	5.8	6.2	5.5	6.1	5.9	5.7	6.5	6.0	5.9	6.1	6.1	5.7	5.4	6.0	5.6	6.6	5.9
Eu	1.2	1.2	1.1	1.2	1.2	1.3	1.2	1.7	1.4	1.3	1.4	1.7	1.4	1.4	1.4	1.3	1.4	1.6	1.1	1.3	1.4	1.2
Gd	5.3	6.6	5.9	5.1	4.2	5.1	4.0	5.2	5.1	4.8	4.8	5.0	4.8	4.9	5.4	5.3	4.9	5.5	4.6	5.1	5.3	
Tb	0.8	1.0	0.8	0.8	0.7	0.8	0.8	0.7	0.8	0.7	0.8	0.9	0.8	0.8	0.7	0.8	0.8	0.7	0.8	0.7	0.7	0.8
Dy	5.1	6.1	4.8	4.8	4.3	4.3	5.2	5.1	5.0	4.7	4.4	4.5	4.6	4.9	4.4	4.7	4.5	4.6	4.9	4.6	4.7	5.0
Ho	1.0	1.3	1.1	1.0	0.9	1.0	1.0	1.0	0.9	1.0	1.0	1.1	1.0	1.1	1.0	1.1	1.0	1.0	1.0	0.9	1.0	1.0
Er	3.4	3.6	3.3	3.3	2.9	3.0	3.1	3.0	3.3	2.8	3.3	3.4	3.0	3.0	2.8	2.9	2.9	3.0	2.8	3.1	3.2	2.8
Tm	0.5	0.6	0.5	0.5	0.4	0.4	0.4	0.4	0.5	0.5	0.4	0.5	0.4	0.5	0.4	0.5	0.5	0.5	0.5	0.4	0.5	0.4
Yb	3.6	3.9	3.6	3.4	3.2	3.4	3.5	3.0	3.2	3.2	3.5	3.4	3.3	2.9	3.2	3.0	2.8	3.4	3.5	3.0	3.1	3.2
Lu	0.5	0.6	0.5	0.6	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.5	0.6	0.6	0.5	0.5	0.5
Hf	7.5	8.4	6.9	7.0	6.6	6.3	7.1	6.7	6.5	6.6	6.2	7.0	6.2	6.4	6.2	6.3	6.3	6.5	7.3	5.9	6.3	6.6
Ta	1.0	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9	0.9	0.9
Pb	20.9	20.9	21.1	24.5	14.4	14.4	13.8	12.1	15.0	14.8	14.8	14.8	14.0	13.7	13.7	14.2	13.9	12.8	12.6	13.8	13.2	12.3
Th	15.0	17.1	14.1	13.8	12.8	13.1	13.7	14.4	13.4	13.2	13.7	14.2	13.4	13.4	13.4	13.5	13.0	13.6	14.3	13.1	13.9	13.9
U	4.7	5.3	4.3	4.3	3.8	3.9	4.1	4.4	4.1	4.1	4.2	4.1	4.1	4.1	4.1	4.1	4.0	4.1	4.2	4.1	4.1	4.1

Appendix D Continued

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[illegible]

Appendix D Continued

Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41-3		Aso-41	
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Appendix D Continued

Aso-41/3		Aso-41/3		Aso-41/3		Aso-41/3		Aso-41/3	
Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM	Scoria GM
HK-M A50 403_GJ_Scoria_181220 2086-2	HK-M A50 403_GJ_Scoria_181220 2086-3	MK A50 403_GJ_Scoria_181220 2086-4	MK A50 403_GJ_Scoria_181220 2086-5	HK-M A50 403_GJ_Scoria_181220 2086-6	MK A50 403_GJ_Scoria_181220 2086-7	HK-M A50 403_GJ_Scoria_181220 2086-8	MK A50 403_GJ_Scoria_181220 2086-9	HK-M A50 403_GJ_Scoria_181220 2086-10	HK-M A50 403_GJ_Scoria_181220 2086-11
33.9	35.2	6.1	9.0	21.3	5.6	36.3			
746.9	41.2	26.1	27.6	28.0	26.6	35.7			
30280.5	32238.0	44834.3	43627.7	39772.7	44729.3	34391.6			
4997.0	5568.7	7122.2	6922.7	6342.4	6981.3	4309.0			
81985.0	79748.1	86590.1	83644.9	84981.1	87277.1	80994.1			
887.0	1086.7	1231.1	1181.4	1142.5	1224.4	806.6			
24708.1	25347.4	7318.1	11484.8	20280.7	8157.2	27288.4			
17987.7	19277.4	27696.4	23598.5	20676.3	26751.7	1722.8			
10.3	9.9	9.9	9.1	9.3	10.2	6.5			
343.9	3596.2	3563.0	3489.5	2477.1	3622.3	3113.6			
54.4	56.8	58.1	56.8	52.0	57.8	33.7			
BelowL02	BelowL02	BelowL02	BelowL02	BelowL02	BelowL02	BelowL02	BelowL02	BelowL02	BelowL02
949.5	1011.1	1239.9	1216.7	1220.5	1232.5	1000.1			
22709.1	24085.5	28397.6	26651.2	26434.8	27679.0	18340.4			
3.2	3.7	3.9	3.5	3.6	3.8	2.0			
BelowL04	BelowL04	BelowL04	BelowL04	BelowL04	BelowL04	BelowL04	BelowL04	BelowL04	BelowL04
37.0	89.2	107.1	100.6	106.7	109.1	82.1			
92.5	95.5	34.2	52.2	90.3	37.0	106.2			
368.9	385.5	614.8	471.5	364.1	557.1	382.9			
29.4	29.4	29.6	29.2	29.2	30.4	26.1			
168.2	164.9	143.5	143.0	147.5	145.6	183.3			
9.8	9.3	8.7	8.9	9.2	8.4	10.7			
5.0	5.2	4.1	4.9	5.7	4.2	5.8			
577.0	581.3	539.3	563.5	633.3	537.7	618.0			
25.6	26.2	25.8	25.6	26.2	26.2	26.7			
57.3	59.4	57.6	57.5	59.5	59.1	58.0			
7.1	7.5	7.2	7.2	7.4	7.5	7.0			
28.8	30.7	31.5	30.8	30.5	31.3	27.4			
6.7	6.9	6.6	6.6	6.7	7.1	6.0			
1.6	1.5	1.9	1.7	1.9	2.1	1.5			
0.7	6.2	6.4	6.2	5.7	6.3	5.5			
0.9	0.9	0.9	0.9	0.9	0.9	0.7			
5.3	5.4	5.4	5.4	5.6	5.5	4.7			
1.1	1.1	1.1	1.1	1.1	1.2	1.0			
3.2	3.1	3.1	3.0	3.1	3.1	2.6			
0.4	0.5	0.5	0.4	0.4	0.4	0.4			
3.1	3.1	3.2	2.8	2.9	3.1	2.8			
0.5	0.5	0.5	0.5	0.4	0.4	0.5			
4.5	4.5	3.9	3.9	4.1	3.9	5.0			
0.7	0.7	0.6	0.6	0.6	0.6	0.8			
0.7	12.6	13.7	14.9	13.5	13.2	9.5			
9.3	9.0	7.6	7.8	8.0	7.8	10.1			
2.6	2.7	2.4	2.3	2.4	2.4	3.1			

Appendix D Continued

	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20	Z-20
Ejecta	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt
Glass type	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
Mineral	OI	OI	OI	OI	OI	OI	OI	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx	Cpx
Sample number	ASD- 4_3620_0601_B00-1	ASD- 4_3620_0601_C01	ASD- 4_3620_0601_A04+1	ASD- 4_3620_0601_B01-2	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03	ASD- 4_3620_0601_F03
ppm																							
Li	14.3	8.5	10.0	9.9	11.1	10.2	11.0	27.3	9.8	10.3	9.7	19.5	13.8	10.5	30.8	11.1	16.7	15.8	7.6	14.1	16.3	16.6	
B	13.0	13.6		13.9	13.3	13.3	12.4	17.4	76.0	11.8	11.6	13.7	16.0	19.7	15.8	14.5	14.5	18.3	20.0	20.7	27.1	22.3	
Na	17057.0	16703.0	17740.1	17720.1	19399.9	18630.0	20070.3	37550.7	17106.3	17999.1	17547.1	17219.5	19165.0	20939.7	20358.3	20836.8	21156.0	20502.3	21638.1	21641.2	23387.3	20991.6	
Mg	22220.2	28545.3	22767.0	18844.2	24272.7	24479.8	22545.1	42495.8	24581.8	23628.3	24524.6	23054.6	24007.4	21195.6	21454.5	21734.8	19689.2	19728.3	18603.8	18056.3	15606.2	18339.2	
Al	81616.1	79218.3	82804.6	81176.8	80849.3	77183.4	75801.8	184016.7	77044.3	77670.6	78026.4	78807.4	73354.3	70515.8	85303.9	84311.3	84103.0	79148.0	77068.6	79434.4	73319.0	79732.0	
P	603.5	573.2	780.7	666.1	565.9	1068.1	955.4	1450.8	561.7	587.4	590.0	608.0	702.3	738.0	590.5	632.7	719.6	821.5	860.1	784.5	1028.8	1053.6	
K	7178.8	7538.7	8486.4	7900.1	8681.7	7888.1	10533.5	17904.5	8686.0	7586.6	7656.7	7508.0	9349.4	10389.6	8399.0	9459.1	9941.8	11961.6	11509.9	12098.8	15803.2	15303.2	
Ca	75020.1	67206.6	65615.4	72104.2	61546.5	59093.2	56122.8	119407.8	61030.5	59903.0	63801.4	58533.3	60229.4	52605.2	62014.7	54501.0	54958.1	53191.0	51838.4	51458.8	44044.9	49760.9	
Sc	35.3	30.3	27.7	31.4	28.9	27.0	29.2	42.6	32.0	33.3	37.8	25.5	29.4	32.3	26.0	18.2	24.9	23.8	26.2	28.6	26.9	24.1	
Ti	4423.5	4181.0	4025.8	4391.6	4592.0	4643.1	5048.0	9244.3	4330.5	4470.3	4375.0	4694.0	4586.3	5571.9	4871.6	3193.1	4256.0	3958.9	5888.6	5156.3	6491.6	4400.4	
V	344.2	324.3	289.5	336.4	347.0	228.9	307.4	602.8	338.0	296.6	370.0	456.0	335.0	399.0	437.4	285.1	316.6	260.1	364.4	359.5	401.0	300.3	
Cr	74.1	44.7	11.8	25.5	28.7	13.4	13.8	13.5	23.9	35.7	20.4	15.4	33.8	9.5	33.2	40.7	7.5	11.6	17.1	14.8	BelowLOD	30.7	
Mn	1348.6	1136.0	1161.1	1122.0	1189.6	1112.0	1140.3	2345.4	1302.7	1242.6	1247.9	1278.4	1250.3	1545.7	1223.4	923.6	1172.7	1072.1	1331.5	1153.0	1289.2	1115.2	
Fe	70840.9	61093.6	62200.0	59486.3	63519.8	58349.0	60615.8	130912.2	70261.0	66160.9	65363.9	65370.2	67737.3	81609.1	63507.7	49590.6	62473.1	58030.3	72370.0	59360.8	74337.2	59217.8	
Co	29.8	33.4	28.3	24.0	30.6	30.2	29.0	61.5	32.7	30.3	31.8	30.1	30.4	33.1	26.5	24.9	27.8	26.7	28.2	23.0	28.3	24.0	
Ni	BelowLOD	34.8	BelowLOD	BelowLOD	25.5	13.5	14.8	32.3	14.2	13.8	22.9	16.4	12.7	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	16.5	11.8	BelowLOD	BelowLOD	BelowLOD
Zn	115.1	90.0	95.5	98.7	99.3	91.0	87.8	198.4	117.6	105.1	99.3	105.2	106.7	141.9	104.0	86.9	112.6	91.3	130.7	98.4	128.8	98.4	
Rb	24.3	26.7	30.1	27.2	29.7	27.6	38.3	74.3	23.6	25.9	26.0	26.5	34.2	36.4	30.6	32.5	33.1	41.9	43.0	47.5	62.2	56.0	
Sr	578.2	535.0	559.4	560.1	534.0	459.9	504.4	1194.3	510.2	493.7	520.7	542.7	498.4	502.7	609.1	588.9	600.9	544.0	514.0	505.0	454.3	488.6	
Y	13.1	12.6	13.4	13.1	14.1	13.3	17.0	29.4	14.9	16.1	15.8	15.6	14.4	19.6	14.6	9.4	14.3	13.5	22.6	18.0	21.9	14.7	
Zr	48.7	50.2	55.9	54.0	55.1	55.8	70.9	123.0	53.6	64.2	57.2	58.0	65.3	77.5	66.1	50.5	66.6	67.7	96.3	87.2	113.3	83.4	
Nb	2.1	2.2	2.7	2.6	2.5	3.4	3.4	5.6	2.2	2.4	2.5	2.4	3.2	3.6	2.9	2.9	3.6	4.4	4.1	4.5	5.9	5.0	
Cs	1.4	1.3	1.6	1.5	1.6	1.3	2.0	4.6	1.2	1.4	1.4	1.4	1.8	1.9	1.5	1.8	1.9	2.1	2.4	2.6	3.3	3.0	
Ba	221.4	207.2	257.4	218.0	233.6	223.5	280.4	622.2	192.6	204.8	212.7	212.7	245.9	263.9	236.0	255.7	276.6	334.7	303.6	301.5	373.9	378.3	
La	9.0	8.4	10.3	9.0	8.8	9.6	10.9	21.4	8.5	8.8	8.8	9.1	10.4	11.6	9.7	9.1	11.0	11.8	14.0	12.7	16.7	13.1	
Ce	20.8	19.3	23.0	20.4	20.0	21.0	24.4	42.7	19.5	21.2	20.2	21.3	23.2	26.8	22.8	18.8	23.8	24.1	32.6	28.4	36.4	27.7	
Pr	2.7	2.5	2.9	2.6	2.6	2.6	3.1	5.9	2.6	2.8	2.7	2.8	2.9	3.6	3.0	2.3	3.0	2.9	4.2	3.6	4.5	3.4	
Nd	11.4	11.0	13.2	11.4	11.2	11.1	13.3	25.2	11.5	12.5	11.9	13.0	13.1	15.9	12.7	9.1	12.7	11.9	19.5	15.4	19.4	13.6	
Sm	2.8	2.8	3.5	2.9	2.8	2.8	3.3	5.9	3.1	3.3	3.0	3.3	2.7	3.9	3.0	1.9	3.2	2.9	4.7	3.9	4.6	3.3	
Eu	1.0	0.9	0.9	0.9	0.9	0.8	1.0	1.8	0.9	1.0	1.0	0.9	1.0	1.1	0.9	0.6	0.9	0.8	1.3	1.0	1.3	0.8	
Gd	3.0	2.6	2.9	2.9	2.7	2.8	3.7	5.9	2.9	3.2	3.2	3.1	2.9	3.8	2.9	1.7	2.6	2.5	4.4	3.6	4.0	3.0	
Tb	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.9	0.4	0.4	0.4	0.5	0.4	0.6	0.4	0.3	0.4	0.4	0.7	0.5	0.7	0.4	
Dy	2.5	2.4	2.5	2.5	2.8	2.6	3.0	5.1	2.7	2.8	2.9	2.9	2.5	3.5	2.6	1.7	2.5	2.3	4.1	3.5	4.1	2.5	
Ho	0.5	0.5	0.5	0.5	0.6	0.5	0.6	1.2	0.6	0.6	0.6	0.5	0.6	0.8	0.6	0.3	0.5	0.5	0.8	0.7	0.8	0.6	
Er	1.6	1.3	1.5	1.4	1.4	1.4	2.0	2.7	1.8	1.7	1.8	1.5	1.5	2.2	1.6	1.0	1.6	1.3	2.3	2.0	2.4	1.6	
Tm	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.2	0.3	0.3	0.2	0.2	0.3	0.3	0.1	0.3	0.2	0.3	0.3	0.4	0.2	
Yb	1.3	1.3	1.5	1.2	1.5	1.4	1.8	3.1	1.6	1.6	1.7	1.6	1.6	2.0	1.4	1.2	1.5	1.4	2.3	1.9	2.3	1.7	
Lu	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.3	0.3	0.2	0.2	0.2	0.4	0.2	0.1	0.3	0.2	0.4	0.3	0.3	0.2	
Hf	1.4	1.6	1.7	1.5	1.6	1.5	2.1	3.1	1.7	2.2	1.8	1.8	2.0	2.5	2.0	1.3	1.8	1.9	3.0	2.6	3.3	2.3	
Ta	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	
Pb	7.1	5.8	7.0	6.2	6.5	5.8	7.8	13.0	5.4	5.8	5.6	6.1	7.3	7.8	5.4	7.0	7.7	10.1	8.2	8.8	11.2	9.2	
Th	2.4	2.5	3.0	2.6	2.6	2.7	3.4	6.3	2.2	2.3	2.4	2.5	3.3	3.6	2.9	2.9	3.1	3.7	4.2	4.4	5.5	4.5	
U	0.7	0.7	0.8	0.7	0.8	0.8	1.0	1.8	0.6	0.7	0.7	0.7	0.9	1.0	0.9	0.9	1.0	1.2	1.2	1.4	1.7	1.3	

Appendix D Continued

Z-20		Z-20		Z-20		Z-20		Z-20		Z-20		Z-20		Z-20		Z-20		Z-20		Z-20		Z-20	
Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	
MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	
Cpx	Cpx	Cpx	Cpx	Cpx	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	Pl	
ASD ASD																							
4_3020_Cpvt_B00a_4_3020_Cpvt_C_4_3020_Cpvt_E_4_3020_Cpvt_F_4_3020_Cpvt_G_4_3020_P001_D00a_4_3020_P001_D00b_4_3020_P001_D00c_4_3020_P001_D00d_4_3020_P001_D00e_4_3020_P001_D00f_4_3020_P001_D00g_4_3020_P001_D00h_4_3020_P001_D00i_4_3020_P001_D00j_4_3020_P001_D00k_4_3020_P001_D00l_4_3020_P001_D00m_4_3020_P001_D00n_4_3020_P001_D00o_4_3020_P001_D00p_4_3020_P001_D00q_4_3020_P001_D00r_4_3020_P001_D00s_4_3020_P001_D00t_4_3020_P001_D00u_4_3020_P001_D00v_4_3020_P001_D00w_4_3020_P001_D00x_4_3020_P001_D00y_4_3020_P001_D00z		B00b_2		B00c_1		1		1		1		1		1		1		1		1		1	
17.8	13.4	11.9	5.5	46.1	22.8	19.0	15.3	27.8	236.9	21.0	17.9	18.3	21.9	22.4	32.1	32.1							
25.5	35.3	24.4	22.3	27.8	26.9	26.1	32.1	28.9	27.1	30.5	32.4	30.4	31.0	38.8	39.5	50.1							
23841.6	31544.1	18697.1	2023.6	24115.0	24412.5	23618.9	21473.1	24466.9	30516.3	24548.3	22242.5	24507.8	22291.0	20352.9	25055.6	30391.1							
16310.9	15332.5	27368.3	30245.9	12827.0	13715.7	12767.3	15070.0	13342.3	11470.7	12907.7	15878.8	12544.9	13572.3	14038.1	11593.1	3418.5							
74715.7	86107.0	61879.4	70195.4	84294.0	80889.6	79458.6	73324.0	77737.8	82747.9	76318.4	76310.3	73644.2	83381.2	71511.3	78496.5	79869.3							
1048.7	1508.3	839.8	875.3	998.6	1034.3	1007.7	1100.3	1060.8	979.6	1057.6	1189.6	1149.5	1111.2	1367.8	1102.2	577.8							
14735.3	21272.4	13163.2	13201.8	17554.3	18320.9	17658.3	19386.8	18832.2	18417.2	18794.6	21172.3	18660.2	19934.1	22302.2	19553.7	33995.1							
45047.0	40082.9	59262.4	71868.5	44805.1	43681.4	42116.3	38964.1	40475.8	43223.5	39243.9	39039.8	37260.7	44824.0	35487.0	39038.3	15327.9							
24.6	16.3	4.2	5.5	20.5	21.6	19.7	22.8	22.8	21.0	21.7	20.1	26.2	19.6	24.9	19.7	81.1							
5976.8	3864.4	5832.2	6084.5	5085.0	52680.0	49235.5	5559.5	5357.6	4603.7	5126.4	6336.4	5184.2	5711.7	6131.7	5115.9	3372.3							
368.1	42.1	382.8	347.2	255.1	274.2	257.5	290.5	284.4	223.8	270.9	323.2	263.0	287.6	327.3	247.0	15.3							
6.4	26.9	53.6	23.2	BelowLOD	BelowLOD	4.0	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD							
1229.0	853.0	1384.4	1563.9	1035.2	1110.5	1018.2	1216.9	1062.0	943.6	1061.9	1289.6	1020.2	1133.6	1228.2	1010.9	708.7							
69673.2	48203.4	69653.4	74889.1	54416.5	57911.6	54593.4	63036.3	57126.0	49389.1	56176.6	65770.0	53719.5	59405.8	65148.6	51900.3	19357.6							
25.1	18.9	31.7	34.6	18.9	20.5	19.2	22.8	19.8	16.7	19.6	23.7	18.7	20.6	22.3	17.9	1.7							
BelowLOD	17.0	21.4	54.3	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD	BelowLOD							
59.3	80.6	115.0	124.7	99.0	104.9	92.6	116.9	102.1	68.7	99.7	124.1	96.5	104.6	120.2	98.1	68.7							
156.1	75.7	57.8	48.2	72.0	73.2	74.2	81.8	75.4	68.1	72.9	88.6	77.5	80.4	92.6	78.7	147.4							
477.7	564.7	362.2	461.2	494.4	459.4	475.3	405.1	451.9	452.6	481.9	489.4	450.7	389.4	431.0	462.0	362.4							
11.7	8.7	21.1	22.9	20.5	21.4	20.2	23.0	20.8	19.2	20.8	25.2	21.4	22.6	28.4	21.3	27.9							
193.9	19.7	102.1	98.3	126.3	128.3	120.3	141.0	128.7	116.1	126.2	154.7	133.1	141.4	162.0	134.7	251.1							
5.4	7.5	5.3	4.9	6.8	6.7	6.7	7.5	7.0	6.3	7.0	8.2	7.7	7.9	8.9	7.4	13.8							
3.2	4.0	2.9	2.4	3.8	3.9	3.7	4.5	4.0	3.6	3.9	4.7	4.3	4.4	5.0	4.3	8.2							
352.8	508.6	330.6	376.4	410.3	412.0	398.1	455.5	415.2	404.2	408.1	474.2	417.9	438.9	479.0	446.4	698.8							
15.2	16.2	15.2	16.6	18.4	18.5	18.0	19.8	19.0	17.4	18.1	22.4	19.1	19.8	22.7	19.5	31.0							
33.4	30.2	32.9	36.5	40.1	39.3	39.2	43.0	40.7	38.1	40.1	48.0	41.6	44.5	48.9	42.8	67.1							
4.2	3.0	4.2	4.7	4.9	4.9	4.9	5.4	5.0	4.6	4.9	5.8	5.0	5.1	5.4	5.1	5.2							
16.9	10.7	18.3	20.8	20.5	20.5	19.5	22.4	20.8	18.9	20.2	25.1	21.0	23.2	25.7	21.1	31.4							
4.3	2.3	4.8	4.8	4.5	4.8	4.5	4.5	4.7	4.4	4.6	6.0	4.9	5.1	5.6	5.1	6.5							
1.0	0.6	1.1	1.4	1.2	1.3	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.3							
3.9	1.8	4.0	4.7	4.3	4.3	4.0	4.4	4.2	3.7	4.0	5.5	4.2	4.5	5.0	4.4	5.8							
0.6	0.3	0.6	0.6	0.6	0.6	0.6	0.6	0.7	0.6	0.6	0.7	0.6	0.7	0.6	0.7	0.6							
3.7	1.7	4.0	4.3	3.9	3.8	3.7	3.9	4.1	3.3	3.7	4.7	4.0	4.0	4.9	3.9	5.0							
2.1	0.8	2.4	2.2	2.1	2.2	2.1	2.4	2.3	2.2	2.2	2.2	2.8	2.4	2.5	2.8	2.4							
0.3	0.1	0.3	0.3	0.3	0.4	0.3	0.4	0.3	0.4	0.3	0.3	0.4	0.4	0.3	0.4	0.3							
2.2	0.9	2.3	2.5	2.1	2.0	2.1	2.0	2.2	2.2	2.1	2.5	2.4	2.3	2.7	2.2	2.3							
0.3	0.1	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.4	0.3	0.4	0.5							
2.3	2.0	3.1	2.6	3.5	3.5	3.5	3.9	3.6	3.4	3.6	4.3	3.4	3.7	4.6	3.9	6.1							
0.4	0.5	0.4	0.3	0.5	0.5	0.5	0.6	0.5	0.4	0.5	0.6	0.5	0.6	0.5	0.6	0.6							
9.9	11.0	9.8	13.3	11.8	12.0	11.5	13.2	12.0	11.4	12.1	14.0	12.6	12.8	14.6	12.5	19.8							
5.4	6.7	5.0	4.9	7.0	6.9	6.8	7.5	6.9	6.3	6.9	8.2	6.9	7.7	8.5	7.2	14.6							
1.5	2.1	1.5	1.4	2.0	2.0	2.0	2.2	2.1	1.9	2.0	2.4	2.2	2.4	2.7	2.2	4.4							

Appendix D Continued

	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15	Z-15
Ejecta	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt
Glass type	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI	MI
Mineral	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	OI	PI	PI	PI	PI
Sample number	ASD- 4_3015_001_B01	ASD- 4_3015_001_C01	ASD- 4_3015_001_D04	ASD- 4_3015_001_A00A-1	ASD- 4_3015_001_B01A-1	ASD- 4_3015_001_A04	ASD- 4_3015_001_A00B-1	ASD- 4_3015_001_B01	ASD- 4_3015_001_B01	ASD- 4_3015_001_A00	ASD- 4_3015_001_A00B-1	ASD- 4_3015_001_A00B-1	ASD- 4_3015_001_A00B-1	ASD- 4_3015_001_A00B-1	ASD- 4_3015_001_A00B-2
	8-1	8-1	8-1	8-1	8-1	8-1	8-1	8-1	8-1	8-1	8-1	8-1	8-1	8-1	8-1
ppm															
Li	9.2	12.7	13.7	8.5	14.2	12.8	14.9	12.6	14.7	13.3	10.8	12.1	26.7		
B	12.0	13.6	14.4	107.9	17.4	16.6	15.7	17.0	17.8	18.0	20.7	11.7	6030.1		
Na	20149.8	20048.2	20864.2	16476.8	23549.1	21931.9	22855.6	22605.8	23232.0	22858.6	18831.9	19954.8	16618.5		
Mg	28019.6	24491.1	17922.0	15322.9	17215.8	25388.6	18620.0	21559.1	19035.2	18179.5	16853.1	17586.3	2195.4		
Al	91121.2	85783.8	79947.7	120965.1	79150.9	77513.1	84848.0	76900.6	80641.2	79186.8	105162.7	91292.1	141485.5		
P	681.8	708.8	780.5	503.7	953.9	1092.6	906.9	911.1	982.6	924.4	562.1	620.0	745.8		
K	7765.9	8908.4	10211.7	7423.7	12274.5	11300.5	11793.2	11761.6	12061.9	11754.4	9187.7	10632.1	1863.0		
Ca	77032.8	70902.7	61306.4	84416.5	56487.6	56435.3	63730.1	55912.1	58899.7	57696.8	71036.3	61447.3	44985.3		
Sc	31.5	30.9	27.0	19.8	26.9	26.3	30.0	24.8	26.6	25.6	19.3	20.0	16.1		
Ti	4356.3	4451.6	4564.7	3578.0	5162.0	4902.7	5352.7	5092.6	5224.2	5039.1	3582.4	3569.9	3587.1		
V	333.7	332.1	312.0	226.0	312.8	280.4	341.8	288.0	308.6	284.2	218.2	233.8	79.9		
Cr	36.7	16.7	16.8	BelowLOD	10.0	13.3	11.1	10.1	11.8	11.2	4.5	6.8	BelowLOD		
Mn	1183.9	1317.6	1194.0	888.1	1115.1	1199.2	1187.0	1113.4	1166.2	1120.3	942.8	1008.3	151.4		
Fe	64883.5	67686.2	61496.6	45881.6	56277.9	63402.1	61019.4	57727.8	59317.2	57438.0	48908.4	52910.8	48073.4		
Co	33.2	32.8	24.2	18.8	22.9	36.0	23.7	29.0	25.5	23.9	20.5	22.7	12.0		
Ni	22.2	18.7	BelowLOD	BelowLOD	BelowLOD	34.8	BelowLOD	23.3	14.6	14.3	BelowLOD	BelowLOD	BelowLOD		
Zn	105.1	120.9	102.9	62.5	94.4	104.9	101.2	95.0	98.6	93.3	75.0	82.4	31.9		
Rb	24.3	26.5	33.8	24.8	39.1	36.8	37.4	38.7	38.7	38.4	27.9	32.3	8.6		
Sr	691.8	665.6	622.2	893.6	625.3	622.8	696.2	615.6	661.2	637.7	831.8	721.2	497.7		
Y	14.1	14.5	15.3	11.7	17.2	17.4	18.4	16.9	17.3	16.7	11.5	12.0	13.8		
Zr	51.3	63.8	66.2	50.5	77.1	74.3	80.3	76.7	78.2	76.8	50.9	53.9	120.6		
Nb	2.1	2.7	3.1	2.4	3.7	3.5	3.6	3.6	3.7	3.7	2.7	2.5	5.0		
Cs	1.3	1.3	1.8	1.4	2.1	2.0	2.0	2.1	2.1	2.1	1.6	1.6	0.5		
Ba	238.8	250.3	281.6	251.8	341.0	323.2	349.0	331.5	334.6	329.5	296.4	300.5	132.6		
La	9.1	10.3	11.9	9.6	14.1	13.5	14.8	13.8	14.1	13.5	11.3	11.0	9.7		
Ce	21.4	23.5	26.5	21.8	31.2	30.1	32.8	31.0	32.2	29.8	23.3	24.1	11.6		
Pr	2.9	3.0	3.4	2.8	4.0	4.0	4.2	4.0	4.0	4.0	3.0	3.0	3.2		
Nd	12.8	14.1	14.4	11.4	17.2	17.0	18.7	17.4	17.8	16.4	12.6	12.7	14.9		
Sm	2.9	2.9	3.5	2.4	4.3	3.7	4.2	4.0	4.4	3.8	3.0	3.0	3.2		
Eu	1.0	1.1	1.1	0.9	1.2	1.2	1.5	1.2	1.3	1.1	1.0	0.9	0.8		
Gd	2.9	2.6	3.4	2.9	3.6	3.4	3.5	3.4	3.9	3.1	2.3	2.7	3.7		
Tb	0.5	0.5	0.4	0.4	0.5	0.5	0.6	0.5	0.5	0.5	0.3	0.4	0.4		
Dy	2.6	2.7	3.3	2.0	3.4	3.3	3.4	3.3	3.1	2.4	2.0	2.9			
Ho	0.6	0.6	0.6	0.5	0.7	0.6	0.6	0.6	0.7	0.6	0.4	0.4	0.5		
Er	1.6	1.7	1.6	1.3	1.7	1.7	1.9	2.0	1.8	1.7	1.1	1.1	1.9		
Tm	0.2	0.2	0.3	0.2	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2		
Yb	1.6	1.4	1.6	1.0	1.8	1.7	2.1	1.8	1.9	1.8	1.3	1.1	1.3		
Lu	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.3		
Hf	1.6	2.0	2.0	1.6	2.2	2.1	2.2	2.4	2.2	2.1	1.3	1.5	3.9		
Ta	0.2	0.2	0.2	0.2	0.3	0.2	0.3	0.3	0.3	0.3	0.2	0.2	0.5		
Pb	6.1	6.4	7.6	5.7	9.0	8.4	8.7	8.8	8.7	8.9	6.4	6.9	16.2		
Th	2.2	2.8	3.3	2.6	3.9	3.8	3.9	3.8	3.9	3.8	2.7	3.0	6.6		
U	0.7	0.9	1.0	0.7	1.1	1.1	1.2	1.1	1.2	1.1	0.8	0.8	2.2		

Appendix D Continued

	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh	Ksh
Ejecta Glass type Mineral	Basalt OI MI	Basalt OI MI	Basalt OI MI	Basalt OI MI	Basalt OI MI	Basalt OI MI	Basalt OI MI	Basalt Cpx	Basalt Cpx	Basalt Cpx	Basalt Cpx	Basalt Cpx	Basalt Cpx	Basalt Cpx	Basalt Cpx	Basalt Cpx	Basalt Cpx	Basalt Cpx	Basalt PI	Basalt PI	Basalt PI	Basalt PI	Basalt PI	Basalt PI	Basalt PI
Sample number	ASD-co- nah-01_022 - nah-01_022-1	ASD-co- nah-01_029 - nah-01_029-1	ASD-co- nah-01_031 - nah-01_031-1	ASD-co- nah-01_035 - nah-01_035-1	ASD-co- nah-01_036 - nah-01_036-1	ASD-co- nah-01_037 - nah-01_037-1	ASD-co- nah-01_038 - nah-01_038-1	ASD-co- nah-01_039 - nah-01_039-1	ASD-co- nah-01_040 - nah-01_040-1	ASD-co- nah-01_041 - nah-01_041-1	ASD-co- nah-01_042 - nah-01_042-1	ASD-co- nah-01_043 - nah-01_043-1	ASD-co- nah-01_044 - nah-01_044-1	ASD-co- nah-01_045 - nah-01_045-1	ASD-co- nah-01_046 - nah-01_046-1	ASD-co- nah-01_047 - nah-01_047-1	ASD-co- nah-01_048 - nah-01_048-1	ASD-co- nah-01_049 - nah-01_049-1	ASD-co- nah-01_050 - nah-01_050-1	ASD-co- nah-01_051 - nah-01_051-1	ASD-co- nah-01_052 - nah-01_052-1	ASD-co- nah-01_053 - nah-01_053-1	ASD-co- nah-01_054 - nah-01_054-1	ASD-co- nah-01_055 - nah-01_055-1	ASD-co- nah-01_056 - nah-01_056-1
ppm																									
Li	10.2	9.7	13.1	22.0	20.4	21.7	23.2	15.1	17.7	22.0	12.2	22.6	24.2	24.8	22.4	29.5	20.7	24.9	14.0	10.4	18.5	19.6	17.0		
B	9.5	13.2	12.9	42.8	28.0	31.9	44.2	15.7	17.4	43.2	45.2	32.3	39.8	45.2	41.1	43.7	41.1	38.7	44.5	64.9	61.0	47.5	61.		
Na	16892.9	18623.6	1959.3	21802.6	17581.9	23992.7	24793.9	21061.1	22071.3	22650.0	42963.9	24191.0	24146.7	22786.5	24645.2	23962.4	22861.2	21069.6	22000.9	16030.6	20313.9	19822.2	22888.7		
Mg	20208.4	20836.7	20513.1	15297.5	6238.0	14434.9	11932.8	24233.8	20613.9	11805.8	10983.7	11192.0	12164.7	11631.0	12243.7	11610.1	10388.6	10906.2	13243.9	7397.6	13765.2	12264.0	9922.8		
Al	87270.7	88322.0	84905.9	76066.5	60681.0	68897.5	73466.7	68695.9	78662.7	77371.6	75451.3	85035.1	70772.4	71930.1	71108.3	72126.6	70256.4	71109.9	73184.3	104958.4	68144.4	78791.5	83178.0		
P	776.1	933.7	870.2	1870.3	1312.4	2027.5	2196.3	1019.0	1146.2	2361.3	2266.8	1476.6	1876.6	2352.9	1968.1	2252.4	2067.3	2518.0	2499.8	3245.7	3198.1	2634.6	2327.1		
K	5058.3	8824.2	11597.4	20297.7	18917.4	22524.0	22822.0	10868.0	11981.0	27801.2	28937.3	24247.3	27918.2	24981.6	26789.4	26789.4	29093.1	13849.8	23807.5	23807.5	21767.2	20752.5	21767.2		
Ca	73886.9	67463.3	62542.1	47651.5	35871.9	46767.5	34715.6	61555.9	57803.5	39800.0	37169.3	46803.0	38172.7	35637.0	38603.9	35395.3	34628.9	35788.1	38776.1	55341.6	40789.1	46010.4	42893.8		
Sc	31.2	26.4	32.9	37.8	23.9	35.3	22.0	38.1	33.0	24.9	24.5	74.2	19.6	21.8	23.2	21.5	22.4	18.7	25.7	26.4	30.9	28.0	26.7		
Ti	3784.4	5125.3	5246.3	9653.3	5610.2	9374.7	6055.6	5522.8	6118.1	7434.5	7752.1	6056.4	6426.8	7196.5	6572.8	6798.1	7607.6	6405.5	6393.4	6723.1	8788.4	7663.7	8290.3		</