Textures of the Eruptive Products of Asama-Maekake Volcano from the 12\textsuperscript{th} Century:
Indicator of Eruptive Processes

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1. Introduction

Asama-Maekake volcano (Figs. 1a and 2e) has been active for about 10,000 years. Large-scale eruptions (e.g., the 1783 eruption) and small-scale eruptions (e.g., the 2004 eruption) have repeatedly occurred throughout its eruptive history. The large-scale eruptions have generated geologically detectable eruptive products including lava flows, pyroclastic flow deposits, pyroclastic fall deposits, and pyroclastic cones in the proximal area. On the other hand, the ash emitted from individual small-scale eruptions is too small in volume to be recognized in the field. However, ash particles have accumulated in the black humus soil layers. These products have various textures at the macro- and microscales. In particular, eutaxitic textures are often observed in the above eruptive products, suggesting the welding of pyroclasts. Therefore, to obtain information on the eruptive processes, the textures of the pyroclasts are focused on in this study. The younger eruptive products of the large-scale eruptions that occurred in the 12\textsuperscript{th} C and 18\textsuperscript{th} C are described in this paper. Ash particles contained in the soil that formed after the 1783 eruption are also described.

2. Outline of the eruptive history of Asama volcano

The geology of Asama Volcano has been studied for a long time by many researchers (e.g., Yagi, 1936, and Ara-
maki, 1963). An outline of the eruptive history was compiled in a recent study (Takahashi and Yasui, 2013). Asama volcano consists of three major volcanic edifices: Kurofu (ca. 100~20 ka), Hotokeiwa (ca. 20~10 ka), and Maekake (ca. 10 ka to the present). The dominant rock type is andesitic for Kurofu and Maekake, whereas it is dacite to rhyolite for Hotokeiwa. Concerning Maekake volcano, although the exact number of large-scale eruptions has not yet been revealed, more than ten pumice fall deposits have been detected, implying repeated pyroclastic eruptions throughout its eruptive history. The latest large-scale eruption occurred in AD1783, during which sub-Plinian pumice fall deposits, pyroclastic flow deposits, and clastogenic lava flow were generated and a pyroclastic cone was formed on the summit (Yasui and Koyaguchi, 2004). The total volume of the eruptive products was estimated to be ca. 0.5 km$^3$ DRE. The largest eruption is considered to have occurred in AD1108 (Aramaki, 1993). The pyroclastic fall deposits and eruption ages are denoted as As-A for AD1783, As-B’ for AD1128, and As-B for AD1108. The total distributions of these deposits are shown in Figs.1b, 1c, and 1d, respectively. On the basis of a recent geological survey, each isopach map has been modified using the maps produced by Yasui (2015). These deposits consist of many fall units (e.g., Figs.1e and 2a). The stratigraphic relations between As-A, As-B’, Red ash and As-B are shown in Fig.1e using a photo taken on the ESE flank. The distributions of pyroclastic flow deposits and lava flows were originally studied by previous studies (e.g., Aramaki, 1963). There are many flow units in the pyroclastic flow deposits from the 1108 and 1783 eruptions. For distributions of the 1783 products, Agatsuma pyroclastic flow (APF), Onioshidashi lava flow (ONI) and Kamayama pyroclastic cone (KM) from the 1783 eruption are labeled on the map (Fig.1b). For the 1108 products, Oiwa pyroclastic flow deposit (OPF), Kamino-butai lava flow (KB) and Makekake pyroclastic cone (MK) are on Fig.1d.

After the 1783 eruption, numerous small-scale eruptions have repeatedly occurred (Miyazaki, 2003), with intensity varying from gigantic explosions with detonation to relatively gentle ash emissions without detonation. These activities have generated ballistic blocks in the proximal area and ash fall onto the flank slope to the foot of the volcano.

3. Occurrence of the eruptive products of Asama-Maekake volcano from the 12th Century

Eruptive products from the 12th century are broadly divided into three; pyroclastic fall deposits, pyroclastic flow deposits, and welded pyroclastic rocks.

3-1. Pyroclastic fall deposits

Eruptive products from the 12th and 18th C show various occurrences in the field. Regarding the pyroclastic fall deposits, units of pumice fall and ash fall can be observed in many localities. In case of As-B from the 1108 eruption, at least eight fall units (B-1 to B-8) have been recognized on the ESE flank slope (Yasui, 2015). On the other hand, As-A has 24 units and As-B’ has 7 units. For instance, occurrence of the pyroclastic fall deposit (As-B) is shown in Fig.2a. Fall units B-2 and B-4 are pumice fall deposits, whereas that of B-3 is an ash fall deposit. The pumice grains are generally lapilli size. The color of the 1783 pumice is pale-gray, whereas that of the 1108 pumice is light-brown (Fig.3a). As-B’ contains abundant heterogeneous clasts including banded pumice. Bulk-rock chemical compositions of the eruptive products of Asama-Maekake volcano were shown by Takahashi et al. (2007). According to their list, the range of the SiO$_2$ content (wt.%) of the products are as follows; 1783 eruption: 60.2-63.6, 1128 eruption: 58.6-62.5, 1108 eruption: 59.5-60.8. Dark-brown part of heterogeneous clasts in As-B’ is more mafic (SiO$_2$ 58.8-59.5 wt.%), whereas pale-gray part of those is more silicic (61.1-62.3%) (Yasui, 1994).

Lithic fragments are also contained in many fall units of pumice fall deposits. For instance, some lithic fragments in B-4 are marked by circles in Fig.2a. Kichise et al. (2008) analyzed the bulk-rock chemical composition of these lithic fragments contained in As-A, As-B’, and As-B and compared the results with juvenile pumice clasts. They revealed that there are no differences between them, respectively. Thus, most of these lithic fragments are considered to be juvenile materials. These fragments are mostly angular, massive, and dark-gray volcanic rock (Fig.3d). Although there have been some examples of gradual changes of vesicularity into porous parts, lithic fragments are seldom coated by a vesicular part.

The units of ash fall generally consist of pumiceous vesicular grains, crystal debris, and lithic fragments. The
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Fig. 1  Index map of Asama volcano and the distributions of eruptive products of the 12\textsuperscript{th} and 18\textsuperscript{th} Centuries. Isopach maps were modified after Fig. 9 of Yasui (2015). a: Index map. b: Isopach map of As-A (total). The Agatsuma pyroclastic flow deposit (APF) and Onioshidashi lava flow (ONI) are also shown. c: Isopach map of As-B\textsuperscript{'} (total). d: Isopach map of As-B (total). Isopach lines of Red ash are also shown on the map. The Owake pyroclastic flow deposit (OPF) and Kaminobutai lava flow (KB) are also shown. +: Localities where pyroclastic fall deposit As-B cannot be found on the pyroclastic flow deposit (OPF). e: Photograph and columnar section showing the stratigraphic relationship of As-A, As-B\textsuperscript{'}, Red ash, and As-B. The locality is on the ESE flank slope and the distance from the summit crater (SC) is about 8 km. The locality is shown on the maps in b, c, and d by large solid star. Representative fall units are labeled on the photograph. Thickness of As-B\textsuperscript{'} at this locality is small because of the marginal part of the distribution (see Fig. 1c).

AVO: Asama volcano Observatory, University of Tokyo, M: Miyota, OW: Owake, NK: Naka-karuizawa, K: Karuizawa, Y: Yokokawa, KK: Kita-karuizawa, O: Omae, N: Naganohara
Fig. 2  Variation in occurrence of the eruptive products of Asama-Maekake volcano from the 12th century.
For details, see the text in Sect. 3.
a: Representative occurrence of pyroclastic fall deposit observed in As-B from the 1108 eruption on the ESE flank slope. The distance from the crater is about 7 km. b: (1) Close-up of black humus soil between As-A and As-B’ on the eastern flank. The distance from the...
Fig.2 (continued)
crater is about 4.4 km. (2) Typical bread-crust bomb on the eastern foot. Scale: 15 cm.
c: Thick agglutinate on the Nishimaekake crater wall. d: Typical section of Agatsuma pyroclastic flow deposit from the 1783 eruption on the ENE flank slope. The distance from the crater is about 2.8 km. e: Aerial photograph of Asama volcano from the north. Broad Onioshidashi lava flow (ONI) from the 1783 eruption can be clearly observed on the northern flank slope. The Kamayama pyroclastic cone (KM) is situated in the ellipsoidal crater of the Mount Maekake. Mount Maekake itself is a composite large pyroclastic cone (MK). The upper part of MK is considered to have formed through the 1108 eruption (Yasui and Takahashi, 2015). Kaminobutai lava flow (KB) from the 1108 eruption can be seen. A horseshoe-shaped crater and amphitheater can be seen on the right. Although the amphitheater has been half-buried by the younger Maekake cone, it is obvious topographic evidence of the large-scale sector collapse of Kurofu volcano. The area with a gentle slope on the left is Hotokeiwa, which is composed of thick lava flows. f: Typical Oiwake pyroclastic flow deposit from the 1108 eruption on the southern flank slope. Characteristic rugged blocks are contained in the non-welded matrix ash. Scale: 39 cm. g: Surface features of the Onioshidashi lava flow in the midstream. (1) Blocky surface. (2) Close-up of a surface block of Onioshidashi lava. Scale: 39 cm.
The degree of welding varies vertically and flat-erned blocks can be recognized in the lower part. Columnar joints have developed. A reddish-brown oxidized zone can be seen on the uppermost part. Fig.2f shows a typical Oiwake pyroclastic flow deposit (OPF) from the 1108 eruption. Characteristic rugged blocks are contained in the non-welded matrix ash. Sometimes lithic fragments are also contained in the deposits (Figs.3e and 3f).
Sugaya et al. (2016) reported that the blocks of APF have a crust impregnated with very fine (1-10 µm) ash particles and interstitial opal. They also found that weakly welded ash particles exist between the opal-bearing crust and the inner core.
3-3. Welded pyroclastic rocks
Welded pyroclastic rocks are observed, particularly in the proximal area. A thick agglutinate can be observed on the crater walls in the summit region. Fig.2c shows the thick agglutinate on the Nishi-Maekake crater wall. According to Yasui and Takahashi (2015), units 1, 2, and 3 are products of the 1108 eruption. Columnar joints have developed in Unit-1. These agglutinates form the upper part of the Maekake pyroclastic cone (MK). Kamayama (KM) pyroclastic cone occupies the Maekake crater (Fig.2e). The thick agglutinate on the crater wall of KM indicates that a large amount of pyroclasts were deposited during the 1783 eruption. Yasui and Koyaguchi (2004) reported that the northern crater wall coincides with the Onioshidashi lava flow (ONI) on the northern flank slope, suggesting the syn-eruptive generation of clastogenic lava during a sub-Plinian eruption to form the pyroclastic cone around the crater.
Fig.2g-1 shows the surface features of the Onioshidashi lava flow. It is not easy to walk through the rugged terrain covered with huge lava blocks. Fig.2g-2 shows a close-up of a block of ONI and individual spatter can be seen in the upper part. As Inoue (2002) pointed out, the degree of welding increases in the downward direction. As seen in Fig.3c, the section of the lava is highly heterogeneous. Figures 3c-1 and 2 show the appearance of the
Fig. 3  Photographs of hand specimens of the eruptive products of Asama-Maekake volcano from the 12th century. 

a: Representative pumice clasts: (1) As-A, (2) As-B', and (3) As-B. b: Block contained in the Oiwake pyroclastic flow deposit on the southern flank slope. The left block shows the rugged surface morphology and the right block shows the inner structure containing some vesicles. c: Sections of Onioshidashi lava: (1) Drilling core sample taken at a depth of 12.2 m. The upper oxidized vesicular part gradually changes into the massive gray part in the hand specimen. (2) Drilling core sample taken at a depth of 52.3 m. Alternate dark-gray and reddish-brown streaks can be seen, suggesting densely welding. The upward direction of the drilling core is shown by the arrows in photographs 1 and 2. For details of the drilling core sample, see Yasui and Koyaguchi (2004). (3) Section of a hand specimen from the surface part of the lava. A complex heterogeneous distribution with a reddish-brown vesicular part and a dark-gray massive part can be observed. d-f: Lithic fragments contained in As-B (fall unit B-4). e and f: Lithic fragments contained in the Oiwake pyroclastic flow deposit on the southern flank slope. These samples were taken at the same locality as those in Fig. 3b. The right sample in Fig. 3f shows the densely welded structure. g: Lapilli-size lithic fragments contained in the black soil overlying the 1783 pyroclastic fall deposit. Labels of Types 1-5 correspond to those in Fig. 8.
drilling core samples. It is rich in the oxidized part and contains markedly elongated fiamme and some accessory lithic fragments. These features are unusual for coherent lava. ONI is considered to be clastogenic lava on the basis of their nature of the welded pyroclastic rock (Yasui and Koyaguchi, 2004).

4. Textures of the eruptive products of Asama-Maekake volcano

The textures of the eruptive products of Asama-Maekake volcano were observed mainly under a microscope in this study. For the preparation of thin sections, porous grains such as pumice and/or fine-grained clasts were hardened using epoxy regin before polishing. In the description of the textures observed under the microscope, the term “phenocryst” is used for crystals larger than 0.5 mm, and crystals smaller than 0.5 mm are called “groundmass crystals” in this study.

4-1. Pumice clasts and free crystals

Pumice fall deposits consist of porous pumice clasts (e.g., Figs.4a and 6a) and free crystals (Fig.6b). The colors of the groundmass and the crystallinity of the pumice clasts of As-A, B’, and B are diverse. In particular, As-B’ has the greatest heterogeneity. Banded and patchy patterns at the macro- and microscales are also widespread (Fig.3a), suggesting magma mingling (Yasui, 1994). Most of the free crystals have broken surfaces. Examples of broken crystals are indicated by orange lines in Fig.6b. On the other hand, pumice clasts have much fewer broken crystals. Details were described in Yasui (2012).

4-2. Composite blocks in the pyroclastic flow deposits

Lapilli- and block-size clasts contained in the pyroclastic flow deposits (APF and OPF) commonly show a characteristic morphology both at both the macro- and microscales. In terms of outline, they have rugged shape (Figs.3b, 5d, 5e, 5g, 5h, 7e, 7g, 7i). They are composed of multiple domains, as can be seen in a two-dimensional (2-D) section. The grain in Fig.6c is composed of four domains. Domain 1 is an angular brown glassy fragment with vesicles. Domain 2 is composed of many grains of glass shards and crystal debris. Relatively large brown glass shards similar to domain 1 are contained in domain 3. Domain 4 is massive and cryptocrystalline. In the grain shown in Fig.7a, an area rich in crystal debris can be observed (Fig.7d) and distinctive broken plagioclase phenocrysts are shown in Fig.7c. It has dents filled with ash particles on its edge. Another grain has a domain with a fluidal-shaped dark-brown glass shard and surrounding ash particles (Figs.7e and 7f). Figs.7f, 7g and 7h show detailed features of a weakly welded rim composed of ash particles.

4-3. Proximal agglutinates and lava flows

Proximal agglutinates (KM and MK) and lava flows (ONI and KB) have almost the same features under a microscope. A distinctive eutaxitic texture and abundant broken crystals and crystal debris are commonly observed (Figs.4c-4f, 6d, and 6e). Yasui and Koyaguchi (2004) also showed the proportion of the broken plagioclase phenocrysts in ONI being more than 70% and they regarded these features as evidence of clastogenic lava.

4-4. Lithic fragments

As described in Sect. 3-1, lithic fragments appear in the products of both large-scale pyroclastic eruptions and small-scale eruptions (e.g., Figs.3d and 3g). Lithic fragments associated with large-scale eruptions have a densely welded eutaxitic texture (Figs.4g, 4h, 4i, 5c, 5f, 5i, 6g, and 6h). Abundant crystal fragments are observed and their distribution in a single thin section is complex. Sometimes areas rich in crystal debris are seen (Figs.4h and 6h).

Fig.4 Enlarged photographs of thin sections of eruptive products of Asama-Maekake volcano from the 12th century. Labels of Types 1-5 correspond to those in Fig.8. The ID of each thin section is given as (TA-x). a: Pumice clast from the 1783 eruption (As-A-21, TA-370). The lower-half photograph was taken with a polarizing plate and shows the distribution of phenocrysts and vesicles. b: Lapilli-size grains contained in the Oiwake pyroclastic flow deposit (TA-400). c: Onioshidashi lava from the terminal cliff of the northeastern branch (TA-262). d: Kaminobutai lava from the terminal cliff (TA-265). e: Welded pyroclastic rock (agglutinate) from the 1108 eruption on the southern flank slope (TA-435) (Takahashi et al., 2010). f: Unit-1 of the 1108 agglutinate on the Nishimaekake crater wall (TA-273). g: Lithic fragment contained in the pumice fall deposit (Fall unit: As-B-4, TA-289). h: Lithic fragment contained in the Oiwake pyroclastic flow deposit (TA-378). The lower-half photograph was taken with a polarizing plate. i: Lithic fragment contained in the Oiwake pyroclastic flow deposit (TA-381).
For captions, see page 43.
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Fig.5 Enlarged photographs of thin sections of eruptive products of Asama-Maekake volcano from the 12th century. Labels of Types 1-5 correspond to those in Fig.8. The ID of each thin section is given as (TA-x). a: Grains ejected during the Feb 2, 2009 eruption. Most of them are massive gray lithic fragments. The grain size is 1 to 2 mm (TA-376). b: Grains contained in the humus soil overlying the 1783 pyroclastic fall deposit on the eastern flank slope. The grain size is 2 to 4 mm (TA-166). c: Grains from the lithic fragment fall deposit (Fall unit: As-B'-6). The grain size is 4 to 8 mm. These grains are mostly angular massive lithic fragments (TA-146). d: Lapilli-size grains from the 1783 Agatsuma pyroclastic flow deposit. The grain size is 4 to 8 mm (TA-414). e: Lapilli-size grains from the 1783 Agatsuma pyroclastic flow deposit. The grain size is 2 to 4 mm (TA-413). f: Lithic fragments contained in the 1783 pyroclastic fall deposit (As-A-21). The grain size is 4 to 8 mm. (TA-361). g: Lapilli size grains from the 1108 Oiwa pyroclastic flow deposit. The grain size is 4 to 8 mm (TA-419). h: Lapilli size grains of the 1108 Oiwa pyroclastic flow deposit, The grain size is 2 to 4 mm (TA-420). i: Lithic fragments consisting of Red ash (TA-339). The grain size is 4 to 8 mm.
Fig. 6 Photomicrographs of the eruptive products of Asama-Maekake volcano from the 12th century. Labels of Types 1-5 correspond to those in Fig. 8. The ID of each thin section is given as (TA-x). Photographs were taken with open nichols except for photo b (crossed nichols). Examples of broken crystals are indicated by orange lines. a: Pumice clast from the 1783 eruption (Fall unit: As-A-21). Note the euhedral plagioclase on the right (TA-370). b: Free crystals from the 1783 pyroclastic fall deposit (As-A-21). The broken surfaces of the crystals shown by orange lines are distinctive (TA-362). c: Pyroclast from Agatsuma pyroclastic flow deposit. Labels on the photograph correspond to the names of the domains described in Sect. 4-2 (TA-413). d: Agglutinate from the 1783 eruption from the NNW outer slope of Kamayama just below the crater rim (TA-253). e: Eutaxitic texture...
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Fig.6 (continued)

and preferred orientation of crystals observed in the Onioshidashi lava. Note that most of the crystals are broken (TA-262). f: Angular lithic fragments with eutaxitic textures. This is an enlargement of the area shown by a circle in Fig.5c (As-B', TA-146). g: Lithic fragment with distinctive eutaxitic texture. This is an enlargement of the area shown by a circle in Fig.5f. (As-A-21, TA-361). h: A lithic fragment contained in the Oiwake pyroclastic flow deposit. This is an enlargement of part of Fig.4h. The area is rich in fine-grained crystal debris (TA-378). i: Ash particle ejected in the Feb 2, 2009 eruption (TA-376). No broken crystals can be seen in this grain.

Fig.7 Photomicrographs of Type-2 grains contained in the Oiwake pyroclastic flow deposit.
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5.

5-1. Classification of eruptive products on the basis of textures

As described in Sect. 4, juvenile materials of the eruptive products of Asama-Maekake volcano show diversity in texture and can be broadly divided into five types (Figs. 5a, 5b, and 6i).

\[
\begin{array}{|c|c|c|}
\hline
\text{Occurrence} & \text{Type} & \text{Example} & \text{Figure} \\
\hline
\text{Angular lithic fragment} & 5 & \text{Post 1783 ejecta (e.g., 2009 Feb. eruption)} & 2b, 3g, 5a,b, 6i \\
\hline
\text{Welded pyroclastic rock} & 4 & \begin{itemize} 
\item Lithic ash fall (B'-6, B-3, B-7, Red ash) 
\item Lithics in PFA (ex. B-4, B'-4) 
\item Lithics in PFL (OPF, B’ scoria flow) 
\end{itemize} & 2a, 3d,e,f, 4g-i, 5c,f,i, 6f,g,h \\
\hline
\text{Pumice clast} & 3 & \begin{itemize} 
\item Proximal agglutinate (KM, MK) 
\item Clastogenic lava (ONI, KB) 
\end{itemize} & 2c,g, 3c, 4c-f, 6d,e \\
\hline
\text{Welded pyroclastic rock} & 2 & \begin{itemize} 
\item Blocks contained in the pyroclastic flow deposits (APF, OPF) 
\end{itemize} & 2d,f, 3b, 4b, 5d,e,g,h, 6c, 7a-i \\
\hline
\text{Pumice fall deposit} (Fall unit: e.g., As-A-21, A-19, B'-3, B-2, B-4, B-6, B-8) & 1 & 2a, 3a, 4a, 6a,b \\
\hline
\end{array}
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Fig. 8 Classification of eruptive products of Asama-Maekake volcano.
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(Fig.8). Among them, two contrasting groups in terms of appearance are lithic fragments (Types 4 and 5) and porous pumice clasts (Type-1). Types 4 and 5 are angular and massive and contain very small amounts of vesicles. In addition, there are other types (Types 2 and 3). Type-2 comprises clasts contained in the pyroclastic flow deposit, which are characterized by their rugged surface and being partly surrounded by a rim composed of weakly-welded ash particles. Type-2 blocks contain ash particles and sometimes have a complex welding texture. Owing to these features, Type-2 is distinctive among the eruptive products of Asama-Maekake volcano. Type-3 materials correspond to the proximal agglutinate and lava flow, and have a eutaxitic texture and abundant broken crystals. Since Type-4 has the same features, Type-4 is regarded as continuous with Type-3 in terms of welding texture.

5-2. Origin of individual type

Type-1 comprises porous pumice clasts, indicating the fragmentation of intensely vesiculated magma through sub-Plinian eruption, whereas Types-4 and 5 are angular, dense, massive lithic fragments, indicating fragmentation by brittle fracture. Type-4 has a distinctive eutaxitic texture and is rich in broken crystals (e.g., Figs.6g and 6h), whereas Type-5 does not have such features (Fig.6i). Since Type-5 was generated from small-scale eruptions after the 1783 eruption, it is considered to originate from solidified coherent magma that filled the shallow conduit or the crater. Types 1, 2, 3, and 4 are associated with large-scale pyroclastic eruptions. Type-3 is characterized by various welding textures. Types 3 and 4 are continuous in terms of the degree of welding. Type-4 is considered to have been derived from the densely welded part. The angular shape of Type-4 indicates brittle fracture, similarly to Type-5, implying some kind of a Vulcanian eruption. Consequently, to explain the existence of Types 1 to 4, processes of the vigorous pyroclastic eruptions with intense vesiculation of magma and its fragmentation, the deposition of pyroclasts in the proximal area to form welded pyroclastic rocks, and a Vulcanian explosion in some occasions are needed.

For Type-2, its distinctive features described in Sect. 4-2 are explained as follows. Because most of the clasts are not a single grain but an aggregate of multiple grains, and ash-size clasts also exist, the origin of Type-2 cannot be explained by a simple process such as the fragmentation of vesiculated magma in the conduit. Instead, some syn-eruptive complex processes including the fragmentation, aggregation, and welding of pyroclasts to form composite blocks are needed. In other words, the partial collapse of the Plinian eruption column cannot account for the pyroclastic flow deposits composed of Type-2 clasts. Part of the rim was composed of ash particles filling the dents of a composite block. Sugaya et al. (2016) observed an opal coating on the block surface of Agatsuma pyroclastic flow deposit (APF) and discussed postdepositional weathering. On the other hand, dent-filling, weakly-welded ash particles are often form rim on the blocks. Since these ash particles are also often observed inside the clasts, the formation of this rim cannot be explained by an ascending eruption cloud and/or the transport of pyroclastic flow.

6. Summary

The eruptive products of Asama-Maekake volcano described in this study can be divided into five types (Types 1 to 5). The coherent lava appears only as Type-5 clasts that have been generated by the small-scale eruptions from after the 1783 eruption to the present day. The products of the large-scale eruptions in the 12th and 18th centuries are Types 1, 2, 3, and 4. These types indicate a wide range of processes such as the fragmentation of magma, and the aggregation and welding of pyroclastic materials. The recognition of such diversity will be important for obtaining a more detailed understanding of the syn-eruptive processes in a large-scale pyroclastic eruption.

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