EXPLOSIVE ACTIVITIES OF HARUNA VOLCANO
AND THEIR IMPACTS ON HUMAN LIFE
IN THE SIXTH CENTURY A.D.

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Abstract Explosive activities with VEIs of 5 happened twice in the 6th century A.D. from Haruna volcano, central Japan. Their impacts were large enough to cause strong damage in the area, which is reconstructed by a study of volcanology combined with archeology. The first eruption occurred in the beginning of the 6th century, and was characterized by a repetition of phreatomagmatic eruptions forming fine ash fall and block and ash flow deposits. An observation at archeological sites suggests that three kinds of volcanic hazards impacted human life and their environment: fallout of phreatomagmatic ash that devastated cultivated land, block and ash flows that blew down and burned houses, and lahar that buried cultivated land. The second eruption occurred in the middle of the 6th century. This event mainly consists of pumice-falls from plinian eruptions with alternation of pyroclastic flows and falls, and phreatomagmatic ash falls in the later stage. The deposition of pumice-falls and subsequent outwash of lahars damaged the villages and cultivated land. An ancient farm village was restored by archeological excavations. Through these studies, it was clarified that not only a burial beneath thick tephra fallout but also a destruction caused by even thin pyroclastic flow made heavy impacts on human life, and possibly human society. Secondary disasters caused by outwash lahars devastated extensively for a long period.

Key words: Haruna volcano, fallout tephra, pyroclastic flow, lahar, volcanic disaster

1. Introduction

The investigations on when and how natural disasters occurred in the past provide an essential key to forecast disasters in the future. Even though a past natural disaster was recorded in historical documents, geological and archeological observations are essential to reconstruct what happened in detail, because historic records tend to be scarce and incomplete in the earlier historic age. This paper intends to show how geological study combined with archeology is useful for reconstructing the two undocumented 6th century eruptions of Haruna volcano, and their impacts on human

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environments.

2. General Geology of Haruna Volcano

Haruna volcano is a large stratovolcano with a small summit caldera, located in central Japan (Fig. 1). A highly dissected volcanic cone and many lava domes show a rugged topography with the highest peak of Mount Karasugadake (1,449 m a.s.l.). In contrast, smooth and gentle volcanic alluvial fans occur on the eastern foot (Fig. 2).

Haruna volcano started its activity in the Middle Pleistocene. In the earlier stage, repeated eruptions of tephra and lava built up a large stratovolcano. In the later stage,
there erupted two ignimbrites, of which older ignimbrite, Muroda pyroclastic flow deposit with approximate volume of >1.1 km$^3$ (Soda. 1990). may have induced a collapse of Himuro caldera (Oshima, 1986) between 300 ka and 150 ka.
After the formation of a small stratovolcano in Himuro caldera, a plinian eruption produced Hassaki tephra including younger ignimbrite, Shirakawa pyroclastic flow deposit with an approximate volume of more than 2.7 km³ in 41–44 ka (Suzuki, 1976; Oshima, 1986). These large tephra ejections may have resulted in the formation of the Haruna caldera at the summit (Arai, 1962).

This activity was followed by extrusion of many lava domes constructed inside and outside of the caldera. Of them, Mount Futatsudake (1,343 m a.s.l.) is the youngest dome. Explosive activities were recorded three times associated with this dome-formation: the eruptions of Arima Ash (Hr-AA), Shibukawa Tephra Formation (Hr-S) and Ikaho Tephra Formation (Hr-I) from older to younger (Machida et al., 1984; Soda, 1989). There is no historic records on these eruptions. Archeological chronology, however, gives reliable ages for them: the 5th century A.D. the beginning of the 6th century A.D. and the middle of the 6th century A.D., respectively (Machida et al., 1984; Sakaguchi, 1986, 1993). The Futatsudake lava dome was formed immediately after the eruption of Hr-I.

An analysis of human footprint patterns preserved on the paddy field covered with Hr-S and Hr-I suggests that both eruptions occurred in early summer (Harada and Noto, 1984). This interpretation is based on the observation of human footprint patterns on paddy field, controlled by seasonally changing soil wetness and farming.

3. Eruption of the Shibukawa Tephra Formation and Its Effects on Human Life

Eruption sequence

In the beginning of the 6th century A.D., an eruption occurred from the vent about 2 km southwest of Ikaho spa, producing 15 tephra members including pyroclastic flow deposits (Fig. 3). The tephra formation called as the Shibukawa Tephra Formation (Hr-S) includes two deposits previously described as the Futatsudake ash-fall deposit (FA) and the Futatsudake pumice flow deposit-1 (FPF-1) by Arai (1979). Essential ejecta include hornblende and orthopyroxene as heavy minerals. The tephra sequence indicates that eruptions were of phreatomagmatic type as a whole, mainly producing block and ash flows with large projectiles.

The eruption started with an ejection of large quantity of pink-brown and fine-grained volcanic ash (S₁), which fell on the eastern flank of Haruna volcano. This layer contains a lot of accretionary lapilli, indicating a phreatomagmatic explosion. Grain size and thickness distribution suggest that the vent may have been to the southwest of Ikaho spa. Many small-scale phreatomagmatic explosions followed, forming fine-grained ash fall deposit (S₂) around the vent.

A small-scale pyroclastic flow (S₃) followed S₂. This pyroclastic flow deposit is distributed in a small area on the southeastern foot of Haruna volcano. The eruption of S₃ was succeeded by an ejection of white pumice (S₄) and brown finely grained ash (S₅) originated in smaller-scale phreatomagmatic explosions. After the eruption of S₅, a phreatomagmatic explosion accompanying with cock's tail jets occurred. The impact
structures by coarse projectiles ($S_4$) are observed in the layers $S_1 - S_5$ on the eastern foot. The ejection of $S_6$ proceeded to an ejection of a pyroclastic flow ($S_7$). This pyroclastic flow deposit consists of several flow units alternated with ash fall deposits originated from ash-clouds. The layer $S_8$ includes a large quantity of lithic fragments of grey dacite. These characteristics indicate that this member is of a block and ash flow type.

The layer $S_7$ reached the southern foot of Komochi volcano and the western foot of Akagi volcano (Fig. 4). An emplacement is ascribed to high mobility of the flow occurring in valleys and hills. Relatively well-sorted and laminated beds are found on higher places and poorly sorted and massive ones in valley-fills.

After this eruption, grey coarse volcanic ash rich in lithic fragments ($S_4$), brown finely grained volcanic ash ($S_8$), and white pumice and grey lithic fragments ($S_{10}$) were ejected. An ejection of yellow fine-grained volcanic ash ($S_{11}$) followed them. Highly mobile pyroclastic flows ($S_{12}$) occurred again. This member is similar to $S_7$ in lithology. that is, both contain a large amount of grey lithic fragment. This flow reached beyond the distribution limit of the flow $S_7$. In distal area, $S_{12}$ is composed of grey coarse ash in the lower part and pink fine ash in the upper part.

The layer $S_{12}$ is covered with a yellow-brown fine ash fall deposit ($S_{13}$). In the
vicinity of the Athletic Field of Shibukawa City (Loc. 2) about 3 km east-northeast of the vent, an ash-fall deposit (S13) containing a large amount of accretionary lapilli with the maximum diameter of 8 mm is found. Some segregation pipe structures originated in the layer S12 are recognized running through S13, suggesting that the time-interval was very short. The layer S13 is most likely an ash-cloud derived from the flow S12.

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**Fig. 4** Distribution map of the Shibukawa Tephra Formation (revised from Soda, 1989)
Along the Takisawa River, a pink pyroclastic flow deposit \( S_{14} \) is exposed with abundant pumice lumps. This member is covered with a brown-grey, finely stratified, coarse volcanic ash fall deposit \( S_{15} \).

The air-fall components of \( Hr-S \), ejected by phreatamagmatic and co-ignimbrite-forming eruptions, can be found in almost area of the Kanto Plain. The thickness of \( Hr-S \) near the Ozegahara moor (Fig. 1) about 60 km northeast of Haruna volcano and that at the Kita-Takashimadaira site about 110 km southeast of Haruna volcano are 3 mm and 2 mm, respectively. The pyroclastic flow deposits covered an area of ca. 300 km². Bulk volumes of air-fall tephra and pyroclastic flow deposits are estimated to be 0.3 km³ and 0.5 km³, respectively.

Severe destruction of vegetation might have been induced by frequent lahars, because the \( Hr-S \) tephra is commonly found immediately below sandy lahar deposits on the eastern foot of Haruna volcano.

Volcanic disasters found by archeological excavations

It is inferred that more than 27 archaeological sites have been suffered from the volcanic hazard related to the eruption of \( Hr-S \) (Kojima, 1990). These sites have been discovered on the eastern foot of Haruna volcano, the Maebashi Upland and adjacent areas. The following three sorts of volcanic disasters can be recognized: burial by tephra fallout, destruction and burning by pyroclastic flow and burial by lahar.

An excavation of Dodo site. 14 km south-southeast from the source, revealed that paddy fields were covered with \( Hr-S \). At this site, many so-called "mini paddy fields" which are characterized by very small individual field as large as 4 m² were discovered in 3,000 m² (Gunma Archeological Research Foundation, 1983; Noto, 1989). The thickness of \( Hr-S \) was 3–8 cm. A dry farm 150 m² in area was discovered at the Hiraishi site group about 8 km east-southeast of the vent. At this site, the dry farm was discovered from the horizon just below \( S_{1} \) (Educational Board of Yoshioka Village, 1988). The width and height of the furrows in this dry farm are 36–100 cm and about 5 cm, respectively.

A destroyed and burned house by the pyroclastic flow was discovered at the Nakasuji site which is 8 km east of the vent. The Nakasuji site is an ancient village comprising of surface and pit dwellings with religious services, farms, tracks and ditches (Educational Board of Shibukawa City, 1988). The surface dwelling-1 was blown down to the flow direction and charred by the pyroclastic flow (\( S_{7} \), Fig. 5). \( S_{1} \) and \( S_{2} \) fell out and covered the floor shortly before the roof collapsed down on it. This fact suggests that the roof collapse was resulted from the weight of layers \( S_{1} \) and \( S_{2} \), possibly with a higher density by containing much water.

Another evidence indicating the destructive power of the pyroclastic flows \( S_{7} \) was found at the Shiroi site group: the Shiroi-Niiya site, the Shiroi-Minaminakamichi site, the Shiroi-Omiya site, the Shiroi-Kitanakamichi site, which are located about 10 km east-northeast of the vent. At these sites, trunks of trees were detected, standing in the layers \( S_{1} – S_{4} \) and blown off by the pyroclastic flow \( S_{7} \) (Iijima et al., 1991; Shimojo et al., 1991; Ishikita et al., 1991; Gunma Archeological Research Foundation, 1994). The tree-casts were filled with laminated and relatively well-sorted pyroclastic flow deposits \( S_{7} \).

The direction of fallen trees, NE, indicates the direction of the pyroclastic flow \( S_{7} \).
Frequency of fallen tree-traces decreases with an increase in distance from the vent. The depositional features indicate that pyroclastic flow S, was low in density and high in mobility. Occurrence of many fragments of charcoals indicates that the temperature of pyroclastic flows was high enough to burn the surface of the trees (>250 °C). Charred fragments of trees were identified with *Quercus* sect. *Pirinus* (Palaeoenvironment Research Institute Co., Ltd., 1993).

Many cultivated lands buried by the lahars were discovered along the streams on the eastern foot of Haruna volcano. An example is found at the Shinpotanaka-Muramae site of the Maebashi Upland located about 10 km southeast of the vent. At this site, a total of 341 divisions of "mini paddy fields" were excavated (Gunma Archeological Research Foundation. 1990). These paddy fields are covered by lahar deposit with thickness of about 70 cm. The deposit was so thick that the field was abandoned. Judging from the fact that no further cultivation is found on the surface of the lahar deposits.
4. Eruption of Ikaho Tephra Formation and Associated Disasters

Eruption sequence

In the middle of the 6th century A.D., the eruption forming the Ikaho Tephra Formation (Hr-l) took place approximately 20–30 years after the eruption of Hr-S. The length of this time-interval is estimated by the thickness of peat layer in the Ozegahara moor (Arai, 1979) and the archeological chronology (Haji and Sue-ki; Sakaguchi, 1993). There are several evidences that devastated fields were recovering during this time on the flank of Haruna volcano and its adjacent areas excluding the area where thick Hr-S had accumulated and lahars occurred frequently. The Hr-l forming eruption occurred from a relatively wide crater, which is now almost filled with the Futatsudake lava dome.

Hr-l consists of the Futatsudake pumice fall (FP) and the pumice flow-2 (FPF-2) (Arai, 1979). This tephra can be divided into 19 layers (Fig. 6). Silica contents of pumice from air-fall tephra and lava range from 60.5 to 61.26 wt.% and from 59.92 to 60.27 wt.% in bulk chemistry, respectively (Oshima, 1975). Pumice includes hornblende and orthopyroxene as heavy minerals.

The eruption of Hr-l began with a small-scale ejection of grey pumice (I_1). Then, fine pink volcanic ash and grey pumice were ejected repeatedly. The alternation of grey pumice and grey pumice coated with pink ash (I_2-I_5) is observed in the northeast side. After the eruption of I_5, white pumice including small amount of banded pumice (I_5) was ejected.

An ejection of pink fine-grained volcanic ash (I_6) followed. The intermediate-scale ejections of white pumice (I_7) can be divided into eight fall units. After the event of I_7, the eruption became more explosive. An increase in size of pumice and lithic fragments (I_8) is recognized at many localities. The layer I_8 can be divided into three units and was followed by the ejection of pink fine ash (I_9).

A powerful ejection of white pumice (I_10) recurred. The layer I_10 is divided into five fall units. Following this eruption, the pyroclastic flow (I_11) containing a large amount of white pumice occurred. A pink finely grained volcanic ash layer I_12, rich in brown lithic fragments originated in an ash-cloud, covered the flow deposit. This was followed by the intermediate-scale ejections of white pumice (I_13), which can be divided into three units. A pyroclastic flow (I_14) and a pink finely grained ash layer (I_15) of ash-cloud origin followed. Furthermore, small-scale ejections of pumice (I_16) and a pyroclastic flow (I_17) occurred.

The products of these eruptions are covered with finely stratified volcanic ash layers (I_18 and I_19) rich in accretionary lapilli. The layer I_18 is a layer composed of pink fine ash. The layer I_19 is a finely-stratified yellow fine ash layer, and is composed of more than twenty fall units near the crater. These deposits suggest that the intermittent phreatomagmatic explosions occurred. After these explosive activities, magma extruded forming a lava dome of Futatsudake in the crater.

The air-fall tephras are mostly distributed to the northeast (Fig. 7). The distal tephra layers found in Soma City (Fig. 1) about 240 km to the northeast far from Haruna volcano are with thickness of 3 cm. Fallout tephra and pyroclastic flow deposit are about 1.3 km³ and 0.3 km³ in bulk volume, respectively. Also, lava dome is estimated to be
Fig. 6  Schematic columnar section of the Ikaho Tephra Formation
Three pyroclastic flow deposits were added to the section of Kitamaki (Loc. 3), about 10 km northeastward from the vent.
Fig. 7 Distribution map of the Ikaho Tephra Formation (revised from Soda, 1989)
about 0.1 km².

Lahar deposit can be recognized not only along the ignimbrite-filled valleys but also in floodplain of the Tone River. The most distal locality where this lahar deposit is found is the Odachi-Baba site about 60 km downstream of the Tone River (Iida et al., 1988). A thin layer of humic soil is usually found between I₁ and the lahar deposits, indicating that there was some hiatus between them.

Type of disaster detected by archeological excavations

Some archaeological evidences for the disasters have been described at 12 sites in the northeastern foot of Haruna volcano (Kojima, 1990). The volcanic disasters are classified into two types: 1) burial of villages and farms by fallout tephra, and 2) burial of farms by lahar deposits.

A burial of village is represented by the Kuroimine site (Fig. 8) about 10 km northeast of the Futatsudake crater. This village of the middle 6th century was perfectly reconstructed by removing the 190 cm-thick fallout pumice layers. The residential area is surrounded by a fence made of grass. Pit dwellings, surface dwellings, raised floor buildings, a shed for animals and remains of religious services were found. Outside the fence, paddy fields and farms, a spring and some tracks connecting with them were excavated. Finding of small plant-opals of rice from soil of small dry field suggests that the eruption occurred in growing season (Noto et al., 1990). Noto et al. (1990) consider that these small farms were dry rice nurseries.

The process of the burial and collapse of houses is clarified for the case of the surface dwelling-1 at the Kuroimine site. The fallout pumice rolled over the roof, and did not stay on it during the earlier stage of the eruption. During the eruption of I₁, a burial by tephra attained to the lower end of the roof. Then the roof began to bury. A pumice fall of I₁ with the largest clast of 280 mm in diameter broke the roof soon. No remains of human beings were detected in the eruptive materials. From the section of pumice fall deposit which buried a pit dwelling B-91, Ishii and Umezawa (1994) recognized the traces of human beings who were suspected to call help after I₁.

The Dodo site is a representative site where many mini paddy fields were excavated under the lahar deposits about 100 cm thick. At the Odachi-Baba site along the Tone River about 60 km far from Haruna volcano, farms were also discovered under the 80 cm thick lahar deposit.

At the Shiroi site group, dry fields with many hoof-prints of horses were detected. From the soil, much of the plant-opal of eulalia (Miscanthus sinensis) were detected. Noto and Aso (1993) and Gunma Archeological Research Foundation (1994) considered that the possibility of three rotation cultivating system — stock-farming, dry field-farming and fallow-lying — may have been performed at this site.

At an outcrop in Ohinata (Fig. 7. Loc. 4) about 4 km northeast of the crater near Ikaho Spa, hollow impressions of trees and charred branches are found in the very coarse air-fall pumice layers with a thickness more than 400 cm. The pyroclastic flow deposits also include many charcoal fragments. Thus the vegetation in the proximal area must have been devastated by the accumulation of air-fall pumice.
5. Discussion and Conclusion

The author will discuss about the human behavior against various volcanic disasters caused by the two Haruna-Futatsudake eruptions. In the area covered by the thick Hr-S, destructive burial of architectures occurred as shown in the case of Nakasuji site. A fatal destruction was mainly brought by pyroclastic flows. It is possible to estimate that there were heavy casualties, though no human remains have been found yet.
In the area covered with air-fall tephras, it is most likely that the recovery of cultivated land had much difficulties owing to the complicated system of cultivation. Noto (1989) suggested that paddy fields at the Dodo site were recovered by the residents quickly, based on the coincidence of large divisions between the paddy fields just below Hr-S and those just below lahar deposit originated in Hr-I. Moreover, he referred to the existence of a society which made great account of a rice crop and system to bind farmers in a local society.

A trace of countermove against the volcanic disasters was discovered in the Shiroi-Kita-nakamichi site. That is the trace of three rotation system of cultivations as the author mentioned above. At this site, there detected no traces of cultivation just before the Hr-S event. It is also considered that there was forest, because many charcoals were found in the pyroclastic flow deposit S_r. Excavations reveal that this devasted area was cultivated after the event. This ancient society accepted the influence of eruption not on a losing side but a plus side. Such detailed studies of volcanic disasters and process of recoveries will give many suggestions to various important and interesting problems.

In conclusion, it is disclosed that a study of geology combined with archeology is very effective for clarifying the pre-historic eruptions, volcanic disasters that attacked the ancient human life and behavior of human beings against the volcanic event.

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Notes

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Period. *Noko no Gijutsu*, 12, 21-46.*


(*: in Japanese, **: in Japanese with English abstract)