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Grain Size Distribution of the Sediments from the 24 ka Sector Collapse of Asama Volcano, Japan

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Abstract

The large-scale sector collapse of Asama volcano, Japan, at around 24 ka distributed large amounts of debris to surrounding areas. We studied the grain size distribution of the sediments, the "Nakanojo mudflow deposits" and the "Maebashi mudflow deposits", from Asama as one of the physical properties which have been never described. The analytical results show that the grain size distribution is similar among the Asama samples, especially for the finer fractions. And it resembles that of other debris avalanche deposits rather than that of cohesive debris flow deposits. This observation is consistent with the idea that the sediments transported over a distance of more than 70 km, as a single granular flow with some properties of debris avalanche.

Key words: *grain size, sector collapse, debris avalanche, Asama volcano, Japan*

Introduction

Japan is in a tectonically active and warm-humid region characterized by a high erosion rate such that debris from mountains formed depositional plains during the late Quaternary. Moreover, the Japanese Islands have many active volcanoes. Only a few geomorphologic studies have focused on the role of volcanoes as a significant source of sediment to depositional plains (Machida, 1984). However, especially after the sector collapse of Mount St. Helens in 1980 (Voight et al., 1983; Glicken, 1996), the geomorphic significance of catastrophic volcanic events has been re-evaluated, and volcanologic studies have progressed dramatically all over the world (Ui, 1983, 1987; Siebert, 1984; Siebert et al., 1987; Cendrero and Dramis, 1996; Shimazu and Oguchi, 1996; Thouret, 2005; Ponomareva et al., 2006; Schuster and Highland, 2007).

Among Japanese large-scale sector collapses, those of Bandai volcano in 1888 (Nakamura, 1978; Moriya, 1988) and of Unzen-Mayuyama in 1792 (Inoue, 1999) are the best known. In the latter case, a tsunami caused by the sector collapse was responsible for the death or disappearance of as many as 15,000 people, making it the worst

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volcanic disaster in Japanese history. Thus, large-scale volcanic sector collapses should be researched with associated debris transport from the viewpoint of hazard assessment (Siebert et al., 1987; Koarai et al., 1996; Carrasco-Núñez et al., 2006; Inokuchi, 2006). However, except for studies of some typical examples such as Mount St. Helens and a few others (Mimura et al., 1982; Takarada et al., 1999), only a small number of studies have adequately addressed such catastrophic sediment transport in Japan. It is highly desired the examination and data accumulation from various viewpoints, in order to evaluate the effects of debris transport resulting from volcanic sector collapses. Especially focusing on catastrophic hazardous nature of the debris avalanches, they have low "equivalent" coefficient of friction responsible for extraordinary long travel distances (Siebert, 1984, Ui, 1987). Although there are some ideas for its explanation, in general, debris avalanche matrix is highly likely to contribute to a generation of low frictional condition of debris avalanche (Ui et al., 2000). Therefore, it is important to examine the physico-chemical properties of the debris avalanche matrix.

This paper, then, shows the grain size distribution of the deposits from the 24 ka Asama volcano sector collapse with a few comparative discussions. The data will become useful for future understanding the catastrophic debris transport processes, together with other findings to be obtained.

Study area

We researched sediment transport associated with a sector collapse event of Asama volcano, northwestern Kanto district, central Japan, which occurred during the late Pleistocene (Aramaki, 1963). Asama volcano is one of the most active Quaternary stratovolcanoes in Japan. It collapsed at around 24,000 years ago, according to previous tephrochronological research (Aramaki, 1963; Unozawa and Sakamoto, 1972; Nakamura et al., 1997; Takemoto and Kubo, 2003). Deposits originating from this large-scale sector collapse should have been widely distributed (Fig. 1). By reconstruction of the morphology of the volcanic edifice before and after the collapse, the volume of the lost sector has been calculated to be about 4 km^3 (Yoshida and Sugai, 2007a). The estimated depositional volume in the northwestern Kanto Plain, which is more than 70 km from Asama volcano, is at least 2.6 km^3, based on hundreds of borehole columns (Yoshida, 2006).

The debris from the northern flank of Asama volcano traveled to the northwestern Kanto Plain via the Agatsuma River valley without significant time lag (Fig. 1; Takemoto and Kubo, 2003; Yoshida and Sugai, 2006, 2007b; Yoshida et al., 2006). In other words, it is not recognized the formation of a temporary lake at the Agatsuma River valley, and then, the debris avalanche emplaced a large amount of debris on the northwestern Kanto Plain where the current inhabitants exceeds 0.6 million. Hence, it has recently become of great interest to determine how such a large amount of debris was transported from its origin to this distant area, not only from the viewpoint of

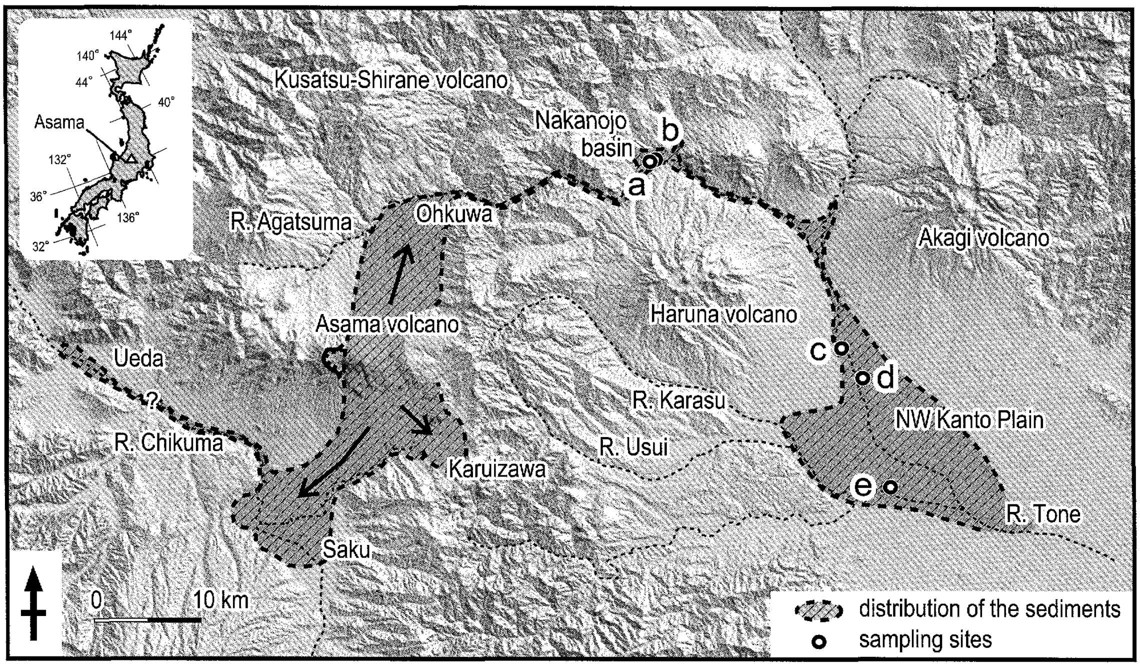

Fig. 1. Reconstructed distribution of deposits derived from the 24 ka sector collapse of Asama volcano and sampling site locations (a–e).

geomorphology but also from that of volcanic hazard assessment. Namely, this Asama case is regarded as good one for discussion of catastrophic sediment transport. We need to accumulate sedimentological data which have never been investigated for such a reason.

Grain size distribution of the Asama sediments

At five locations in Nakanojo basin (distance from source ca. 45 km), the middle reaches of the Agatsuma River, and the northwestern Kanto Plain (ca. 70–90 km from the source), we obtained a total of eight sediment samples of Asama sector collapse origin (Fig. 1). They are named as the "Nakanojo mudflow deposits" and the "Maebashi mudflow deposits", respectively. The outcrops have already introduced by Yoshida and Sugai (2007a). Each sample weighed 2 – 3 kg and consisted of materials with diameter smaller than ca. 3 cm (approximate -5ϕ), following Glicken (1996), who studied the debris avalanche deposits of Mount St. Helens. In the laboratory, we used a set of standard sieves and a laser diffraction particle size analyzer (SALD-3000S, Shimadzu Corporation, Kyoto, Japan) to determine the grain size distribution. As a result, the $\leq$ 3-cm (-5ϕ) fraction of most Asama sediments showed a bimodal grain size distribution (Fig. 2 and Table 1). And for particles finer than 2 mm ($-1\ \phi$), the Asama sediments well resemble that of the debris avalanche deposits from Mount St. Helens (Fig. 3 and Table 1).

For a triangular diagram showing the proportions of total gravel, sand, and mud in the

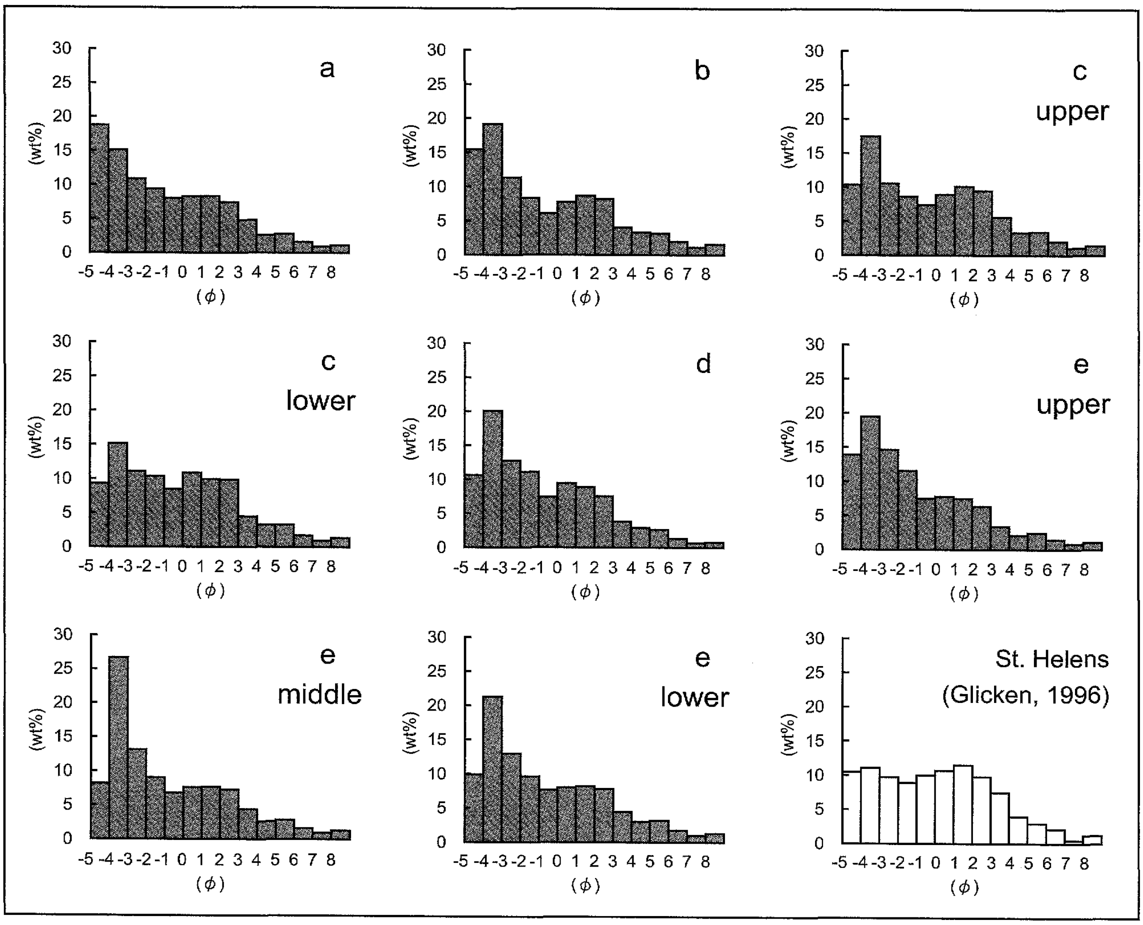

Fig. 2. Grain size distributions for the ≦3-cm (less than -5ϕ) fractions of the Asama sediments. For comparison, the grain size distribution of the debris avalanche deposits from Mt. St. Helens in 1980 (average; Glicken, 1996) is also shown.

Table 1. Grain size distribution of clasts from the Asama deposits compared with that of the debris avalanche deposits from Mt. St. Helens.

	φ		a		b		c-upper		c-lower		d		e-upper		e-middle		e-lower		St. Helens (Glicken, 1996)	
	to	from	<−5φ	<−1φ	<−5φ	<−1φ	<−5φ	<−1φ	<−5φ	<−1φ	<−5φ	<−1φ	<−5φ	<−1φ	<−5φ	<−1φ	<−5φ	<−1φ	<−5φ	<−1φ
	−5	−4	18.8		15.4		10.4		9.3		10.6		13.9		8.2		9.9		10.5	
	−4	−3	15.1		19.1		17.5		15.1		20.1		19.5		26.7		21.3		11.0	
	−3	−2	10.9		11.3		10.6		11.1		12.8		14.6		13.1		12.9		9.7	
Gravel	−2	−1	9.4		8.3		8.6		10.4		11.1		11.5		9.0		9.6		8.9	
	−1	0	8.0	17.5	6.1	13.3	7.4	14.0	8.5	15.7	7.4	16.4	7.5	18.5	6.8	15.8	7.6	16.5	10.0	16.6
	0	1	8.3	18.1	7.7	16.9	8.9	16.9	10.9	20.1	9.5	20.8	7.8	19.2	7.6	17.7	8.0	17.3	10.7	17.8
	1	2	8.3	18.1	8.6	18.9	10.1	19.1	10.0	18.4	8.9	19.5	7.5	18.5	7.7	17.8	8.2	17.7	11.4	19.1
	2	3	7.4	16.2	8.2	17.9	9.5	17.9	9.9	18.2	7.6	16.6	6.4	15.7	7.3	16.9	7.8	16.8	9.8	16.3
Sand	3	4	4.8	10.5	4.0	8.8	5.6	10.6	4.5	8.3	3.8	8.4	3.4	8.4	4.4	10.2	4.4	9.6	7.4	12.4
	4	5	2.6	5.6	3.3	7.3	3.4	6.4	3.3	6.0	2.9	6.4	2.1	5.3	2.6	6.1	3.0	6.5	3.9	6.6
	5	6	2.8	6.0	3.2	6.9	3.5	6.5	3.3	6.0	2.6	5.8	2.5	6.1	2.8	6.6	3.2	6.9	2.9	4.9
	6	7	1.6	3.5	2.0	4.3	2.1	3.9	1.7	3.1	1.3	2.9	1.5	3.6	1.6	3.8	1.7	3.8	2.1	3.5
Silt	7	8	0.9	2.0	1.1	2.5	1.1	2.0	0.9	1.7	0.6	1.4	0.9	2.1	1.0	2.2	1.0	2.2	0.5	0.8
Clay	≦8		1.1	2.4	1.5	3.4	1.4	2.7	1.3	2.4	0.8	1.7	1.1	2.7	1.3	3.0	1.3	2.8	1.2	2.0

(wt%)

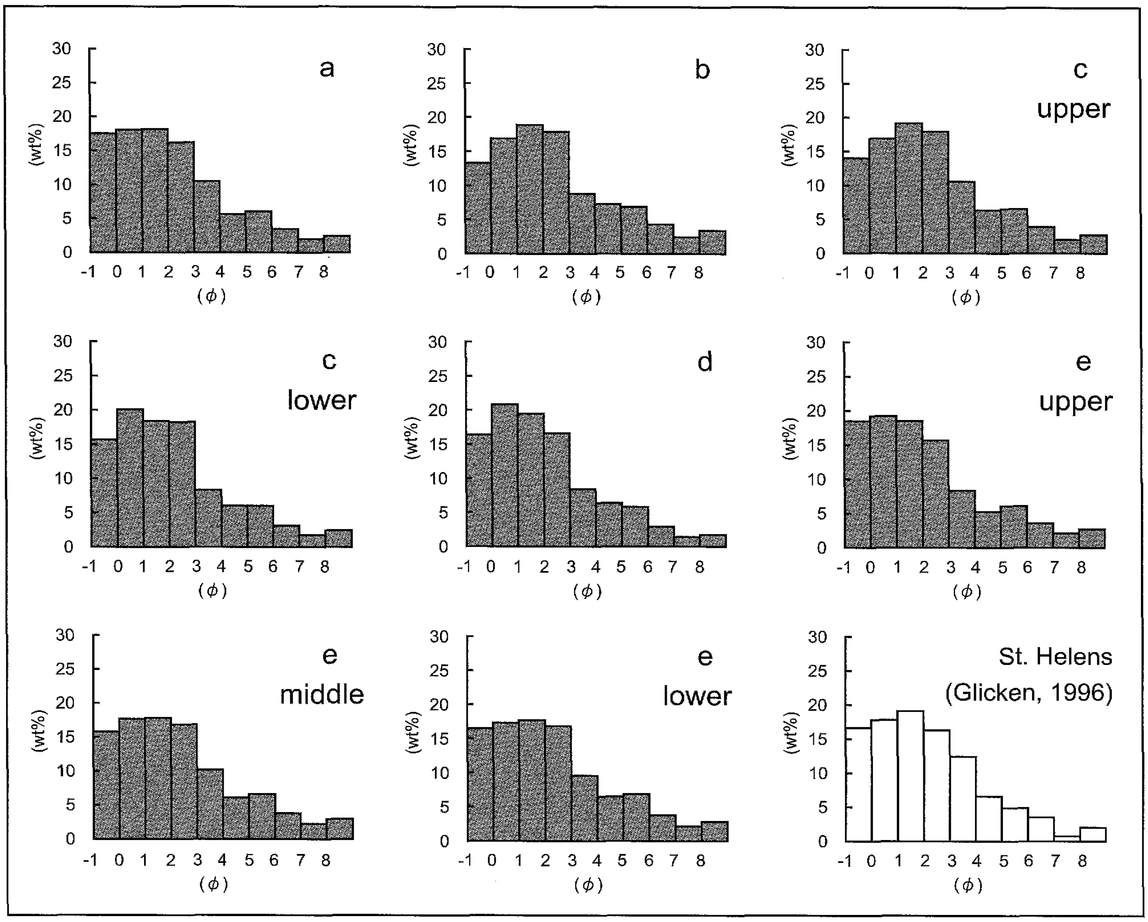

Fig. 3. Grain size distributions for the $\leq$2-mm (less than -1ϕ) fractions of the Asama sediments. For comparison, the grain size distribution of the debris avalanche deposits from Mt. St. Helens in 1980 (average; Glicken, 1996) is also shown.

Asama sediments, it is also necessary to estimate the quantity of clasts larger than ca. 3 cm (-5ϕ) in diameter. Then, we computed the weight percentages of clasts larger than ca. 3 cm using their volume percentages which has been estimated by Yoshida and Sugai (2007a), from the plane-projected areal ratio of the clasts larger than ca. 3 cm to the area of the exposure which within they reside. This is based on the assumption that the plane-projected areal ratio can be replaced by the volumetric ratio (Chayes, 1956; Glicken, 1996). And we set the density of clasts larger than ca. 3 cm is constantly 2.4 g cm^{-3}, and the bulk density of finer particles than ca. 3 cm is 1.6 g cm^{-3} (Yoshida and Sugai, 2007a). Based on the above, we obtained the result showing that the proportions of gravel, sand, and mud in the Asama sediments were plotted within the debris avalanche field on a triangular diagram (Fig. 4). Figure 4 also shows the proportion of gravel slightly decreases in the Kanto Plain, farther areas from the source. This possibly affects the decrease of sand fraction, not mud (silt and clay) fraction. Although such above grain size data is still just one of the key parameters for understanding the sediment transport, the similar grain size distribution among all samples suggests that the debris

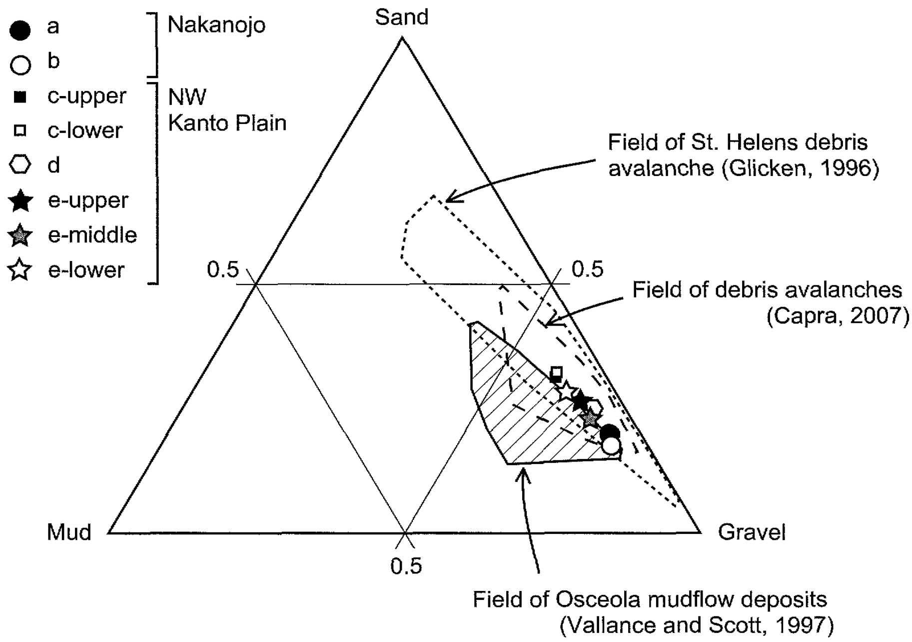

Fig. 4. Triangular diagram showing the proportions of gravel, sand, and mud of sediments from the Asama sampling locations (this study), the Mt. St. Helens debris avalanche deposits (Glicken, 1996), and the Osceola mudflow deposits (Vallance and Scott, 1997). For comparison, the proportions of typical debris avalanche deposits (Capra, 2007) are also shown.

could be transported over a distance of more than 70 km, as a single granular flow. And the similarity with the other debris avalanche deposits (Fig. 4) suggests that the Asama flow also kept some properties of debris avalanche till emplacement (Yoshida and Sugai, 2006; Yoshida et al., 2006).

Additionally, in its volumetric magnitude and wide-distribution of the deposits, the Asama example might be comparable to the Osceola mudflow (total volume, 3.8 km^3) from Mount Rainier, which is considered a typical cohesive debris flow (Vallance and Scott, 1997). However, the particle size distributions of the Asama and Mt. Rainier deposits differ considerably. The proportion of mud in the Asama sediments is around 8% at most relative to the total quantity of materials (Fig. 4), whereas the Mt. Rainier sediments have even 25% of mud (Fig. 4, Osceola mudflow deposits; Vallance and Scott, 1997).

We need further investigations to paint a more precise picture of the debris transport event from Asama volcano, combined with detailed facies analysis and other approaches. Also, similar efforts should be shared for other many events to have never been fully described.

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浅間火山における2.4万年前の大規模山体崩壊に由来する堆積物の粒度組成

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要　　旨

約2.4万年前に浅間火山で発生した大規模山体崩壊に由来する堆積物のうち，長距離土砂移動を考える上で示唆に富む「中之条泥流堆積物」と「前橋泥流堆積物」の粒度分析を行ったので報告する．粒度組成は堆積物の物理的性質を示す基本的な情報であり，上記の堆積物についてこれまでに報告例はなかった．細粒分に着目した全量分析の結果，二つの「泥流」堆積物の粒度組成は比較的類似していることが判明した．また，粘着性の高い土石流の粒度組成というよりは，セントヘレンズ火山をはじめとする諸岩屑なだれの組成に近く，上記の「泥流堆積物」を岩屑なだれ堆積物とみる考えと矛盾しないことが分かった．

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