Grain Size Distribution of the 1926 Volcanic Mudflow at Mt. Tokachi, Japan

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In May 1926, a volcanic mudflow triggered by the eruption of Mt. Tokachi, referred to as "the 1926 mudflow," ran through the Furano and Biei rivers in Hokkaido, Japan, killing 144 residents. This study analyzed the grain size distribution of this mudflow to determine the reason why it sustained such a large force across a gentle plain. The mudflow deposits were sampled and analyzed along the Furano River. To compare the results with those of previous studies, the grain size distribution of deposits were identified in eight different sections. Then the distribution was categorized into three groups: very fine (<0.1 mm in diameter), fine (0.1–2 mm in diameter), and coarse (≥2 mm in diameter). In each section, the proportion of grains in each group were multiplied by the net volume of the mudflow deposition provided by *Nanri et al.* [2009] to estimate the volume of each grain group. At the downstream end of the source and scouring zones, the very fine group comprised 54% of the transported sediment. This increased to 61% at the end of the transport zone, and reached 85% at the downstream end of the deposition zone. Hence, the 1926 mudflow contained a large amount of very fine materials and the resulting high gap density of the fluid in the mudflow enabled it to extend for more than 20 km from its point of origin across a gentle plain. The large fluid dynamic force resulted in extensive damage to buildings on the plain.

Key words: the 1926 mudflow, mudflow contents, mudflow volume, deposition sampling, mudflow behavior

1. INTRODUCTION

Following the eruption of Mt. Tokachi on May 24, 1926, a volcanic mudflow occurred. Referred to as "the 1926 mudflow," the event is considered the worst volcanic disaster in Japan in the 20th century. It ran through the Furano and Biei rivers in Hokkaido, Japan (**Fig. 1**), killing 144 residents [*Tokachidake Explosion Afflicted Relief Committee*, 1929; *Ishikawa et al*., 1971]. Immediately after the event, the details of the eruption, inundation area, injuries and fatalities among residents, and damage caused to buildings were documented by various researchers and organizations [*Tada and Tuya*, 1927; *Tanakadate*, 1926; *Tokachidake Explosion Afflicted Relief Committee*, 1929]. *Tada and Tuya* [1927] reported that deep snow layers melted by a hot debris avalanche from the crater contributed to the massive volume of the mudflow, which was estimated to be approximately 2.0 million m^3. The mudflow that ran through the Furano River was estimated to have a volume of 0.45 million m^3 (**Table 1**) [*Nanri et al*., 2009]. Later *Ikari* [1940] reexamined the event and revised the inundation area, depth of sediment deposit, and material sizes along the course of the mudflow. More recently, *Nanri et al*. [2016] estimated that the fluid dynamic force of the mudflow reached more than 10^2 KN/m, even on a gentle plain where the gradient was just 1:100, leading to the complete destruction of buildings in the path of the mudflow. The strong force was attributed to the fine grain sizes that comprised the extremely heavy flow, the density of which was estimated to be 1.6 to 1.7×10^3 kg/m^3 [*Nanri et al*., 2004]. Such a heavy and destructive mudflow is not unusual for an event initiated by a volcanic eruption. For example, the mudflow produced by the eruption and subsequent debris avalanche at Mount St. Helens, USA, in 1981 was equivalent to the 1926 mudflow, with a density of 1.7×10^3 kg/m^3 [*Takahashi*, 1981]. The flow was

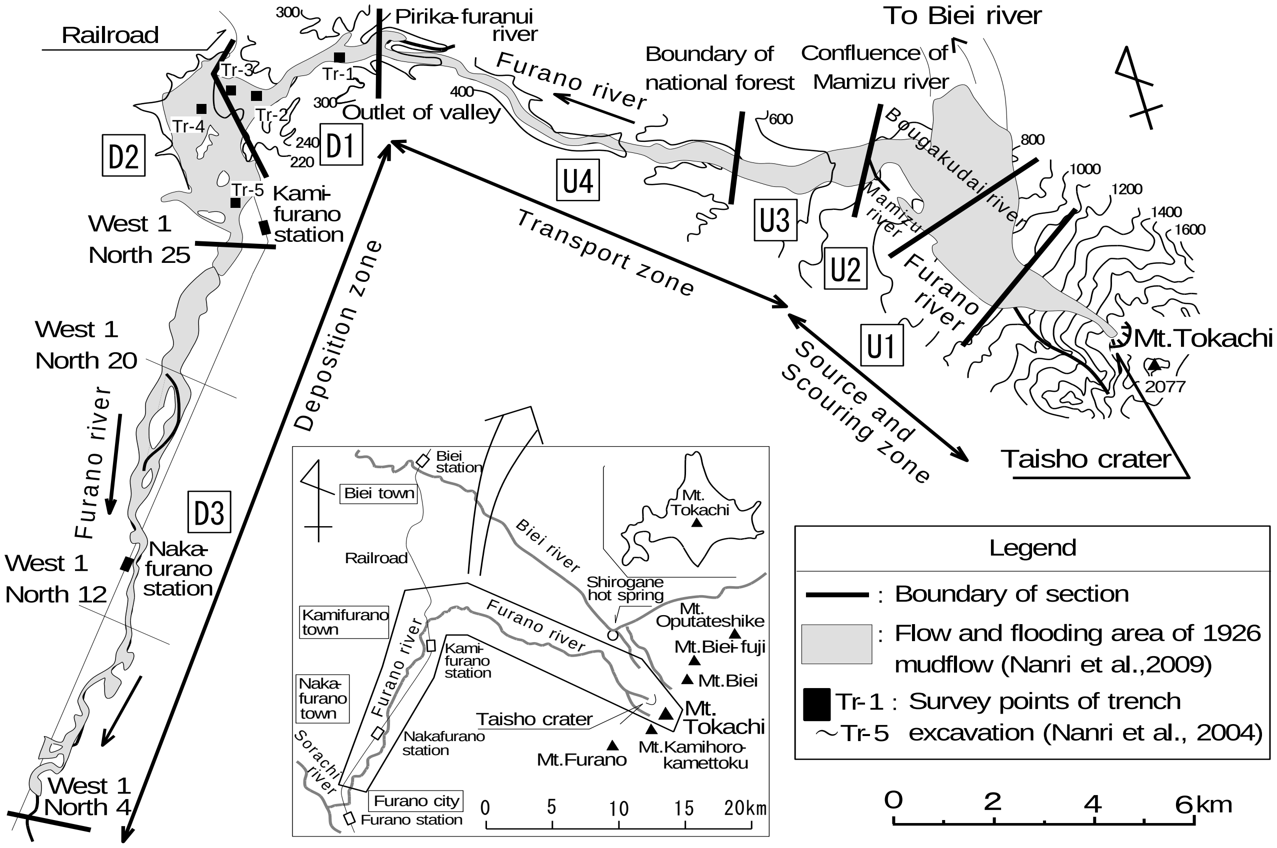

Fig. 1 Location of the study areas and the area affected by the 1926 mudflow

reported to resemble a cement paste in the Toutle River, 64 km from its point of origin, and also caused major damage to properties in the area. Previous studies have indicated that the materials within mudflows become finer with distance. To examine spatial changes in grain size distribution of the mudflow downstream, we sampled and analyzed the mudflow deposits that still remain along the Furano River.

2. METHODS

2.1 Study area

The 1926 mudflow was initiated from the Taisho Crater on Mt. Tokachi when it erupted (**Fig. 1**). It traveled down to the confluence of the Mamizu River, scoring the adjacent ground (source and scouring zone: U1 and U2 sections in **Fig. 1**). The average channel slope of each section was greater than 1:12. *Nanri et al.* [2009] estimated that in these zones, 3.35 million m^3 of sediment was produced and 0.45 million m^3 was deposited in total (**Table 1**). Then the flow ran along a gorge to the junction of the Furano and Pirika-furanui rivers at the outlet of the valley (transport zone: U3 and U4 sections in **Fig. 1**), where it eroded a volume of 0.65 million m^3 and deposited 0.5 million m^3 of sediment [*Nanri et al.*, 2009]. The channel bed gradients in this section ranged from 1:20 to 1:50. After passing through the gorge, the flow deposited approximately 1.55 million m^3 of sediment (deposition zone: D1, D2, and D3 sections in **Fig. 1**), while a volume of 1.5 million m^3 traveled further downstream [*Nanri et al.*, 2009]. The channel slope was 1:50–1:120 for D1, 1:130–1:460 for D2, and 1:300–1:500 for D3. The mudflow spread across a plain in D2 and then converged in the downstream part of the section (**Fig. 1**), where it partially destroyed the Kamifurano Bridge [*Nanri et al.*, 1995]. The volume of erosion and deposition per distance of each section is presented in **Fig. 2**. In this study, the components of the mudflow passing the downstream end of U4 (outlet of the valley) were assumed to be similar to the eroded materials in the U1 to U4 sections.

Nanri et al. [2004] examined the stratigraphy of the 1926 mudflow deposits in the D1 and D2 sections. They found that the deposition presented only a single layer in D1, while two layers were identified in D2. The upper layer was distinctly finer than the lower layer. An equilibrium experiment on

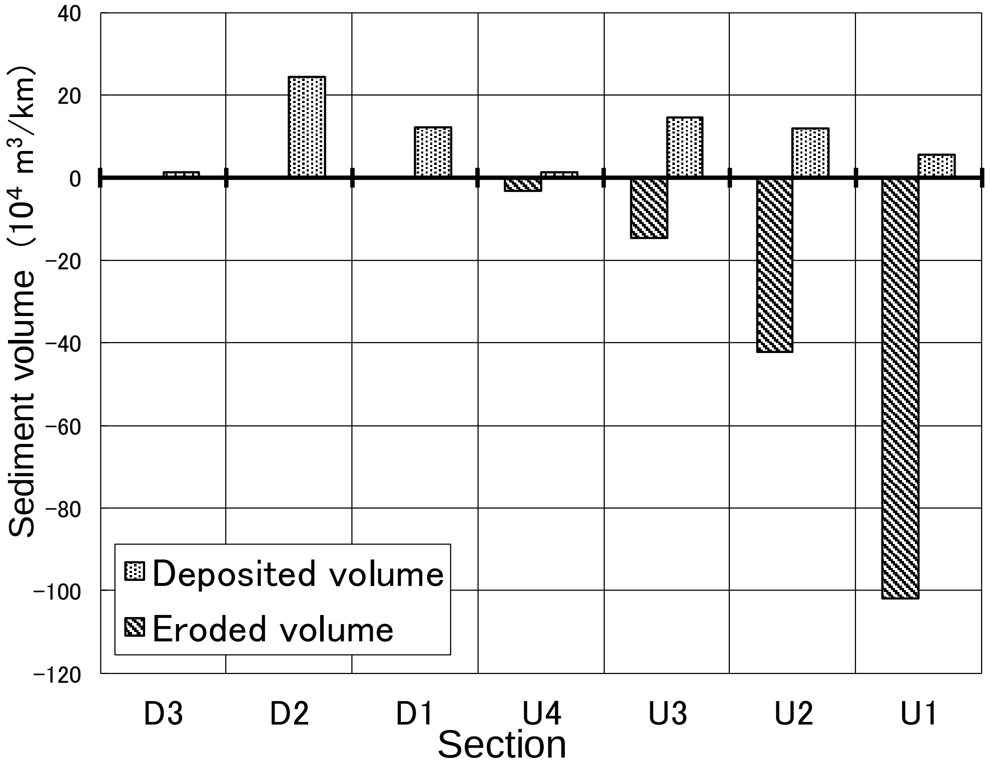

Fig. 2 Longitudinal changes in deposited and eroded sediment volume per unit stream length following the 1926 mudflow
※The data used in this diagram were obtained from *Nanri et al.* [2009].

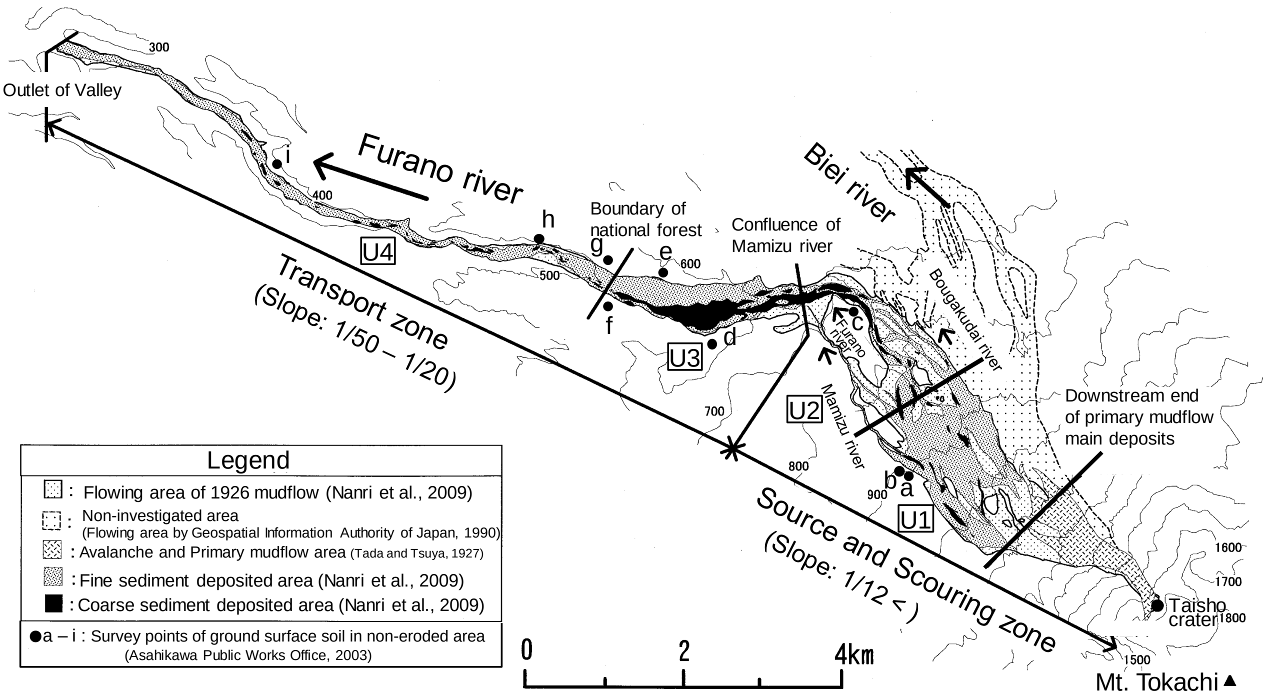

Fig. 3 Distribution of sediment remnants and survey points of ground surface soil in the non-eroded area
※This figure was revised from *Nanri et al.* [2009].

the separation of the fluid and solid phase was conducted by *Nanri et al.* [2009]. From these results, two possible interpretations for the phenomena were proposed: successive flow was finer than the first flow that arrived in the section, or the mudflow itself had two layers.

2.2 Methods

The materials of the 1926 mudflow deposits were collected from the U1, U2, U3, and U4 sections by

Table 1 Volume of each grain size group of sediment deposited, eroded, and transported by the 1926 mudflow

($10^4 m^3$)

Zone	Location / Section	※1 Deposited volume	Grain size			※1 Eroded volume	Grain size			※1 Transported volume	Grain size		
			Very fine	Fine	Coarse		Very fine	Fine	Coarse		Very fine	Fine	Coarse
Source and Scouring zone	Crater												
						※2 45	21	11	13				
	EL 1,100m									45	21	11	13
	U1	9	2	3	4	163	81	39	43				
	Prefectural road									199	100	47	52
	U2	36	6	7	23	127	63	30	34				
Transport zone	Confluence of Mamizu river									290	157	70	63
	U3	38	1	1	36	38	19	9	10				
	Boundary of national forest									290	175	78	37
	U4	12	3	3	6	27	13	6	8				
Deposition zone	Outlet of valley									**305**	185	81	39
	D1	37	7	9	21								
	Railroad									268	178	72	18
	D2	100	46	36	18								
	North 25 road									168	132	36	0
	D3	18	4	14	0								
	North 4 road									150	128	22	0
Downstream of Deposition zone	Outflow volume from Deposition zone	150	128	22	0								
Total volume		400	197	95	108	400	197	95	108				

※1 : Nanri et al. (2009)

※2 : The volume of debris avalanche around 1926 crator (Taisho crator)

the *Hokkaido Asahikawa Public Works Office* [2002, 2003], from the D1 and D2 sections by *Nanri et al.* [2004], and from the D3 section by *Ikari* [1940]. Samples were obtained by *Hokkaido Asahikawa Public Works Office* [2002, 2003] from five sites in U1, five in U2, three in U3, and six in U4. A grid line method was applied to sample surface materials, while subsurface materials were sieved. For other sections, the sampled materials were sieved and sedimentation analyses were applied to collect fine materials. *Nanri et al.* [2004] excavated five trenches, Tr1–Tr5 (**Fig. 1**), with depths of approximately 2 m. The samples in D2 (Tr4 and Tr5) were obtained from each layer. In addition, surface soil was collected from the ground at all nine sites at locations close to the mudflow course (non-eroded area) (**Fig. 3**). These samples were used to determine any differences between the original soils and mudflow deposits. They were subjected to the same analyses as those conducted by *Nanri et al.* [2004].

The material composition obtained from the sampling sites was averaged for each section. The sampled components were classified into three groups: coarse (≥2 mm in diameter), fine (from 0.1 to 2 mm in diameter), and very fine (<0.1 mm in diameter). After the proportion of each group at each site was obtained, it was multiplied by the deposition and erosion volumes of the mudflow following *Nanri et al.* [2009] (**Table 1**).

3. GRAIN SIZE DISTRIBUTION

The grain size distribution is presented in **Fig. 4**. Coarse materials accounted for 95% of the deposits, with the D_{60} and D_{95} being 200 and 1,000 mm, respectively, in U3. *Nanri et al.* [2009] reported that deposits of similar components were widely spread out over this section (**Fig. 3**). On the other hand, deposits in U1, U2, and U4 were much finer, with 35–60% of them being in the fine and very fine groups.

In the deposition zone, D1 consisted of mainly coarse deposits (55%) (**Fig. 4**). On the other hand, less than 20% of the sampled materials in D2 and D3 were in the coarse group, while materials from the very fine group accounted for 45% and 20% of the materials in D2 and D3, respectively. It was estimated that 85% of the mudflow consisted of very fine materials when it traveled downstream of D3 (**Fig. 4**).

The results shown in **Table 1** indicate that deposited sediment was distributed mainly throughout the deposition zone and downstream of the deposition zone. All eroded sediment was supplied from the transport zone and the source and scouring zone. It was estimated that at the outlet of the valley the volume of the mudflow reached 3.05 million m^3, with 61% of all materials being from the very fine group (**Table 1**). The material composition of the original ground soil was compared to the

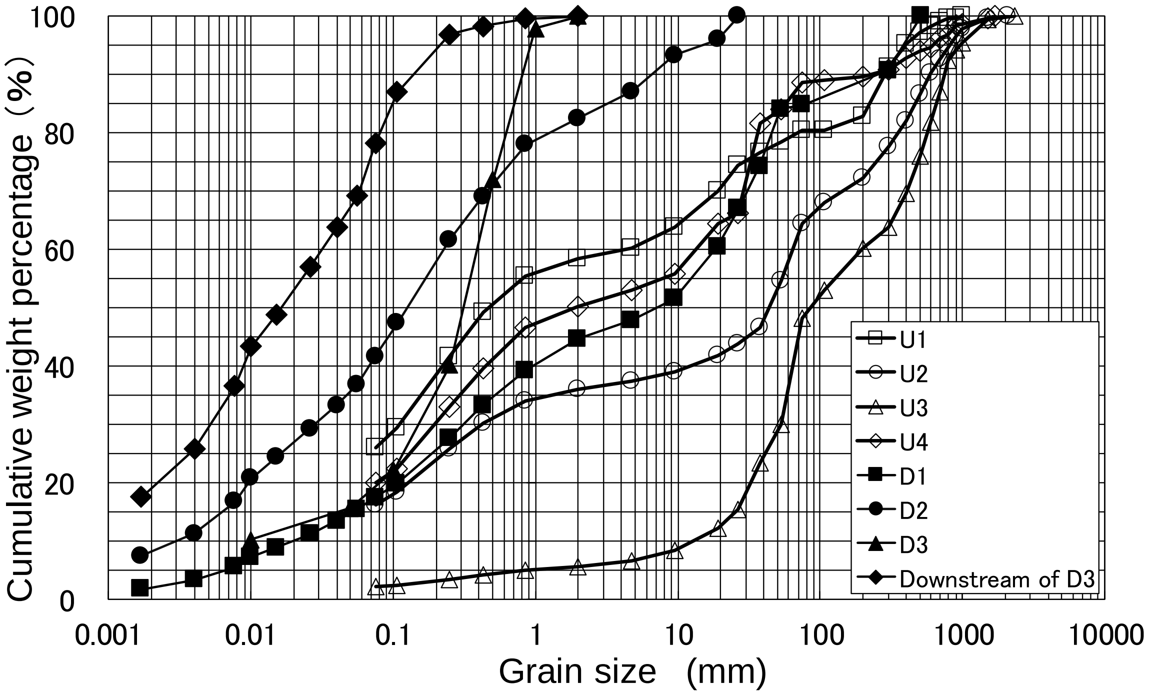

Fig. 4 Grain size distribution of 1926 mudflow deposits
※The data for the U1, U2, U3, and U4 sections, and the D1, D2, and D3 sections, and downstream of D3 sections were obtained from the *Hokkaido Asahikawa Public Works Office* [2002, 2003], *Nanri et al.* [2004], and *Ikari* [1940].

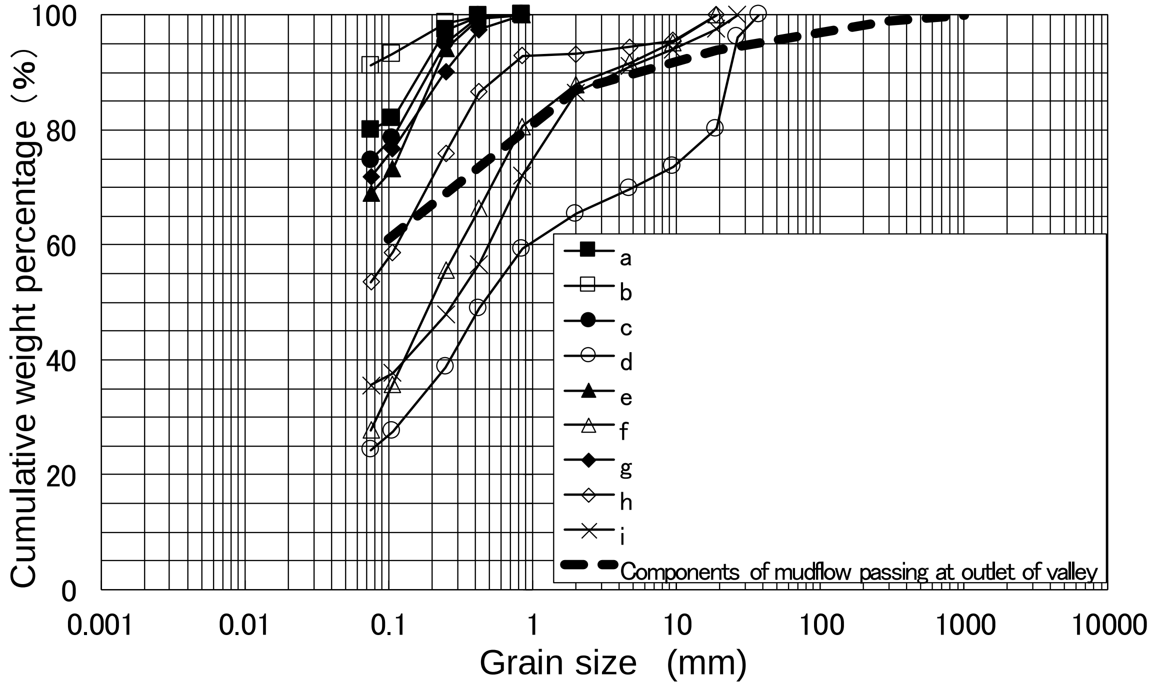

Fig. 5 Comparison of the grain size distribution in sediments from the 1926 mudflow at the outlet of the valley and ground surface soil in a non-eroded upstream area
※The data for a–i were obtained from *the Hokkaido Asahikawa Public Works Office* [2003].

deposited sediment (**Fig. 5**). The ‘f’ and ‘i’ samples in the transport zone were similar to the coarse group materials.

As shown in **Fig. 6**, at the downstream end of the source and scouring zone, very fine materials accounted for 54% of the transported sediment. This increased to 61% at the end of the transport zone and reached 85% at the downstream end of the deposition

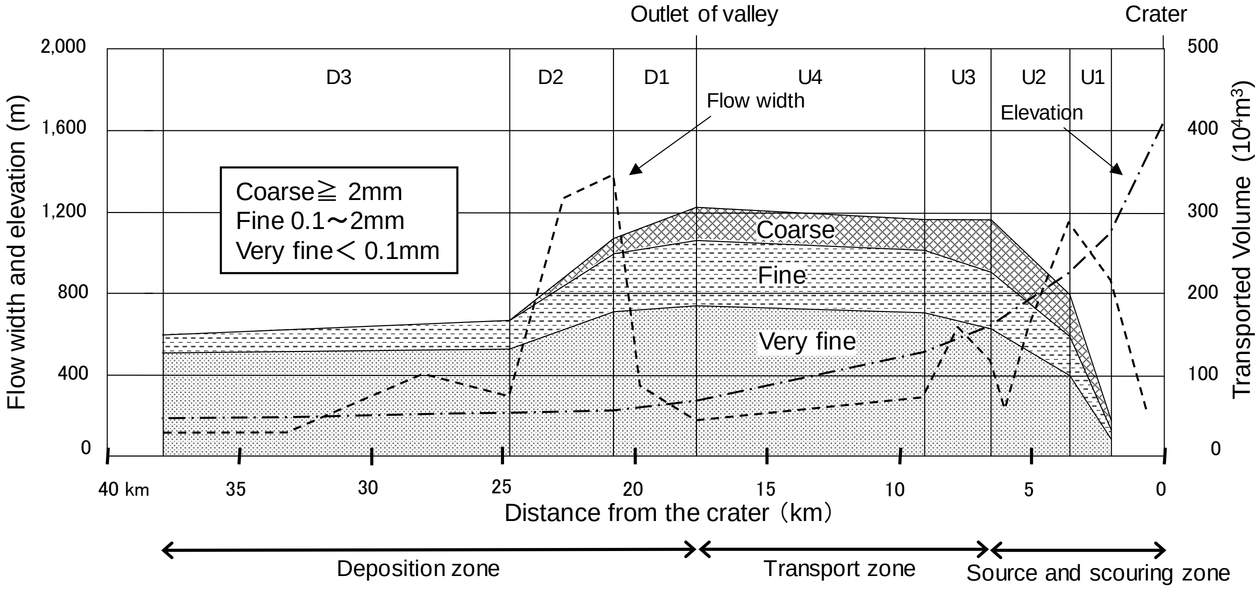

Fig. 6 Spatial changes in grain size components of sediment transported by the 1926 mudflow

zone.

4. CONCLUSIONS

We analyzed the grain size distribution of the 1926 mudflow and found that the grains rapidly became finer throughout the D2 section. This would have produced a dense fluid that could have yielded a large dynamic force of more than 10^2 KN/m, accounting for the extensive damage to houses across the gentle plain more than 20 km from the 1926 crater. The material composition at the downstream end of the U4 section (outlet of the valley) was similar to the original ground soil. Hence, it is possible that the materials present in the channel course could be used to estimate the fluid dynamic force in the flood plain, which would help create a hazard map in preparation for possible future disasters.

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