Sediment yield and topographic change after major volcanic activity

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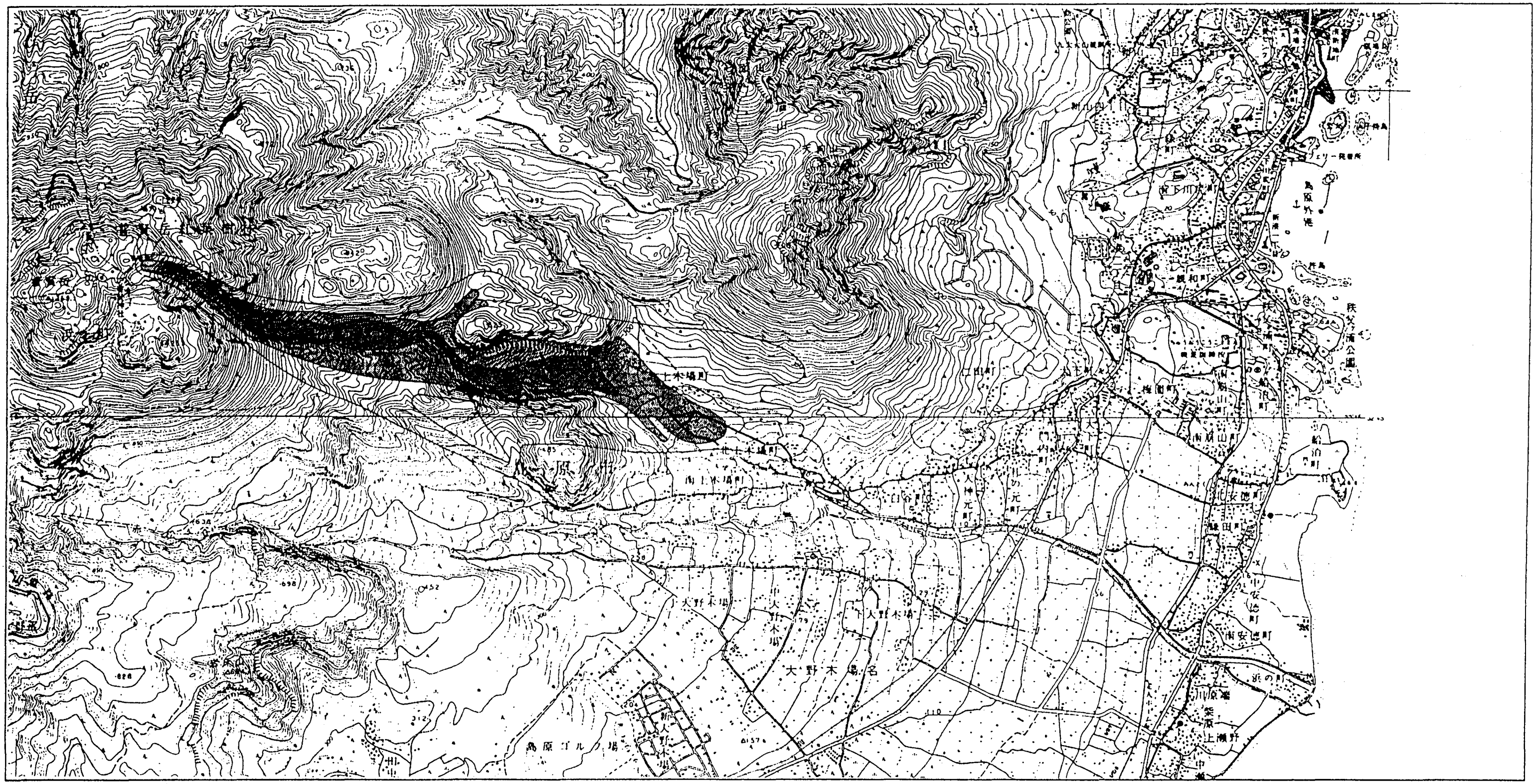
Abstract Mount Unzen in Kyushu, the western island of Japan, erupted in November 1990. Many pyroclastic flows have taken place since May 1991 and the ground level downstream has been raised on average by approximately 40 m. Recently, volcanic activity has subsided. The fresh pyroclastic material has been intensively eroded by subsequent rainfall, with the sediment being transported as debris flows. Topographic changes, such as the development of gullies and alluvial fans and changes in river bed elevation have been investigated using remote sensing techniques. The fairly rapid changes in river bed elevation can be explained using a sediment routing method. The analysis provided estimates of the threshold rainfall needed to generate debris flows, and these were found to be time dependent. Erosion rates have also changed through time. The changes in erodibility are suggested to provide an interesting topic for further research.

DEPOSITION OF PYROCLASTIC FLOW

When Mount Unzen Fugendake, which is located on Kyushu, the western island of Japan erupted in November 1990, magma appeared at its summit. The magma did not flow down the slopes but formed lava domes. New lava cooled and subsequently cracked. Parts of the lava domes collapsed and tumbled down the slopes, turning into pyroclastic flows. These pyroclastic flows travelled progressively further. The flow which occurred on 3 June 1991 was of high magnitude and unexpectedly flowed far downstream, killing 42 people, including news reporters, taxi drivers and some volcanologists. Figure 1 shows the depositional area of the 3 June pyroclastic flow. Figure 2 provides a longitudinal profile of the deposit. The pyroclastic flow resulted in fan-shaped deposits several tens of metres thick. The June 8 pyroclastic flow was larger than that of 3 June and its extent is indicated in Fig. 2. Figure 3 shows the volume of magma supplied to the summit during the period of the eruption and Fig. 4 shows the incidence of pyroclastic flows during the period 1991-1995. Pyroclastic flows occurred frequently in 1991 and continued until early 1995. The supply of magma halted in mid 1994. Pyroclastic flows stopped as the magma supply stopped. The total volume of volcanic sediment produced since 1990, including the lava domes was 162 200 000 m^3. Half of it, 88 800 000 m^3, remains at the summit in the lava domes. The elevation of the summit rose by 126 m.



Range of the main body of deposited pyroclastic flow
Range of the pyroclastic flow (of less density portion)
Range effected by the dust storm of pyroclastic flow

Fig. 1 The extent of the deposit associated with the pyroclastic flow which occurred on 3 June 1991 (produced by the Erosion Control Department, Public Works Research Institute, Ministry of Construction).

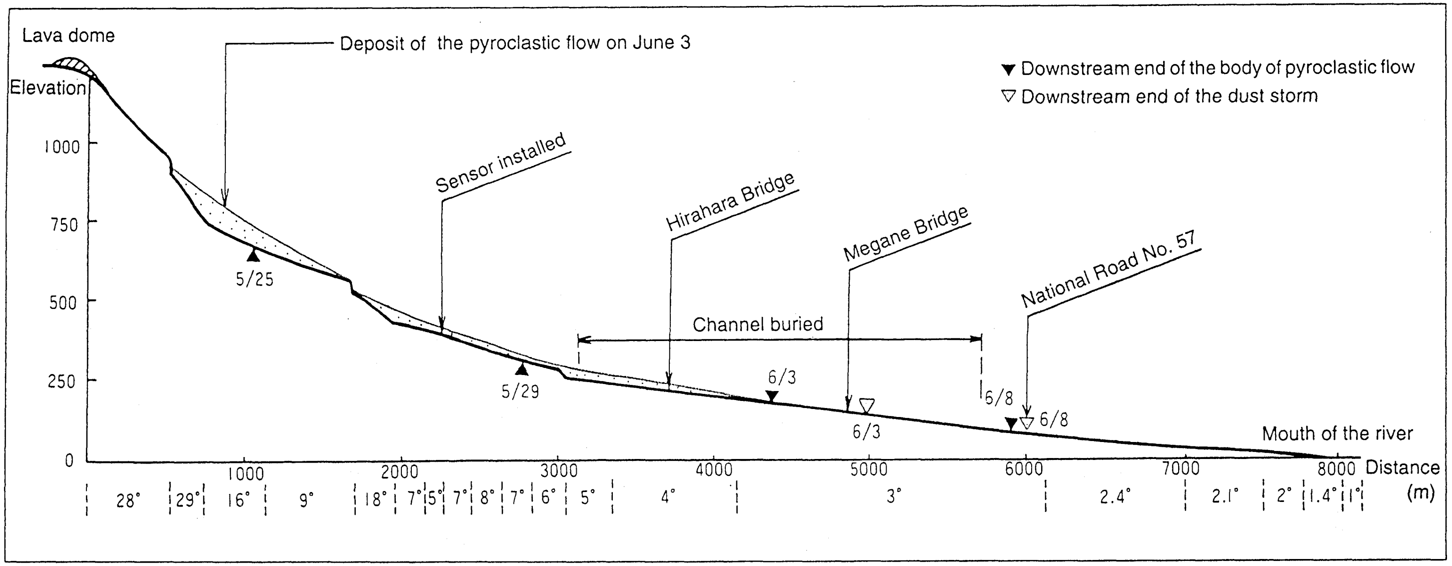


Fig. 2 A longitudinal profile of the Mizunashi River showing the deposition associated with the pyroclastic flows which occurred on 3 June and 8 June 1991 (produced by the Erosion Control Department, Public Works Research Institute, Ministry of Construction).

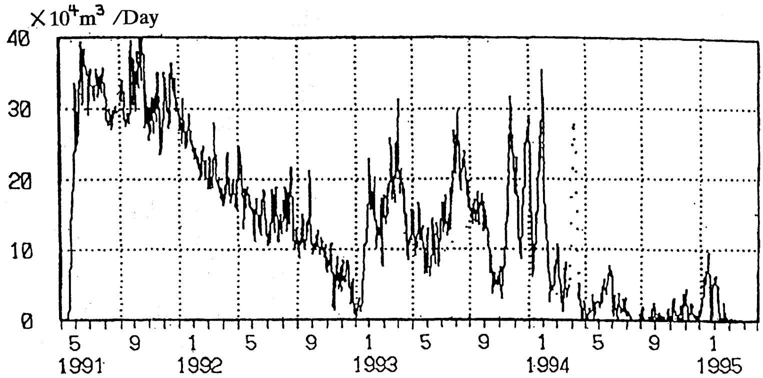


Fig. 3 Daily magma supply rates estimated by Yamashita & Matsushima.

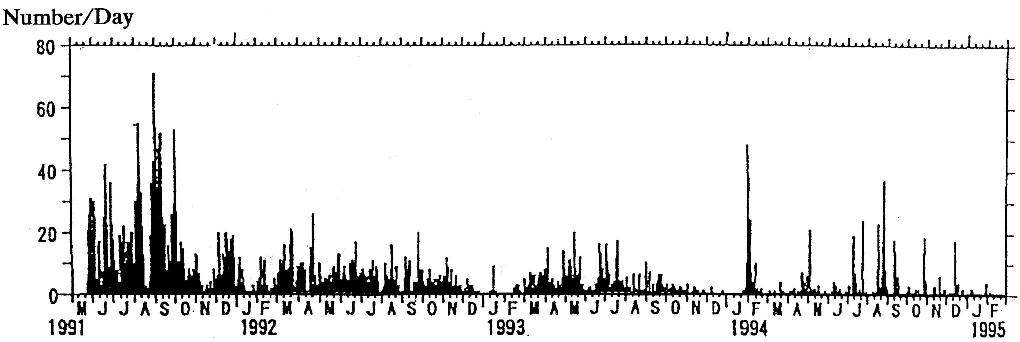


Fig. 4 The number of pyroclastic flows recorded by the Self-Defence Forces during the period 1991-1995.

EROSION BY DEBRIS FLOWS

Debris flows occurred frequently due to the large amounts of unstable sediment deposited on the steep slopes by pyroclastic flows and the covering of the surface of the deposits by a thin impermeable layer composed of fine clay-sized sediment. The saturated infiltration rate decreased from *ca.* 110 mm h^{-1} before the eruption to 14 mm h^{-1} after the eruption (Hendrayanto *et al.*, 1995; Ikeya *et al.*, 1995). Low rainfall intensities, in excess of 14 mm h^{-1}, have been sufficient to trigger debris flows since the eruption started. Table 1 lists the number of debris flows occurring, the amount of annual rainfall and the annual sediment volume discharged from the Mizunashi river basin between 1991 and 1995. The year 1993 was unusual in terms of its very high rainfall. The mean annual rainfall in this area is 2739 mm, $year^{-1}$, based on 40 years of data. Monthly sediment discharges are shown in Fig. 5. 1994 had low rainfall but 1995 was a more normal year, with only slightly less rainfall than the average. The sediment discharge decreased markedly between 1993 and 1994. Figure 6 shows the maximum hourly rainfall intensities for the main rainfall events in each year. Solid dots indicate that debris flows occurred due to the rainfall, whereas circles indicate that debris flows

Table 1 Annual debris flow totals and annual rainfall, 1991-1995.

	Number of debris flows	Annual rainfall (mm)	Annual sediment discharge (m^3)
1991	6	2676	719 300
1992	13	2247	876 000
1993	8	4772	3 940 000
1994	2	1573	233 000
1995	0	2268	279 000

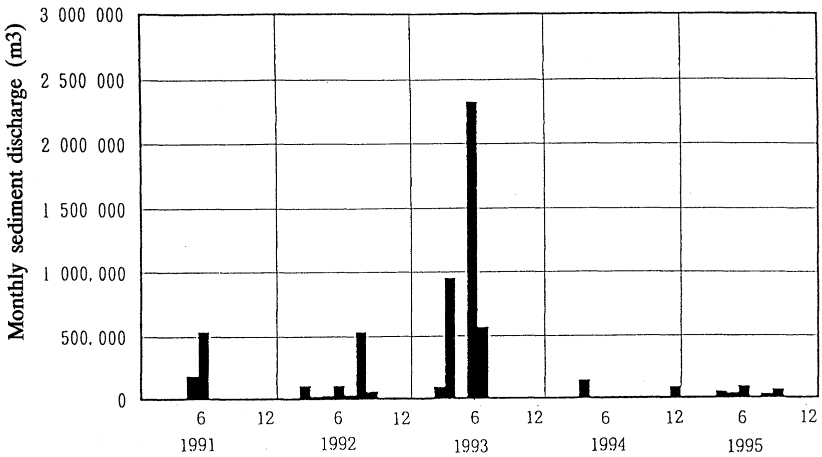


Fig. 5 Monthly sediment discharges of the Mizunashi River.

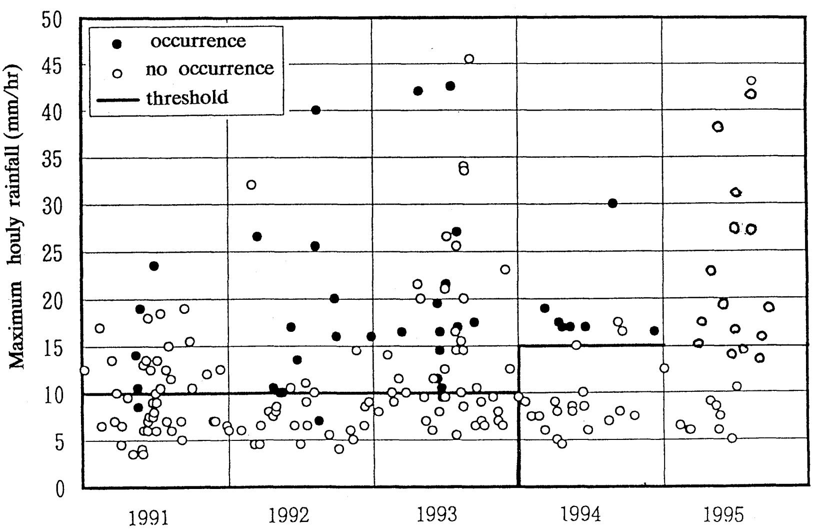


Fig. 6 The relationship between maximum hourly rainfall intensity and the occurrence of debris flows.

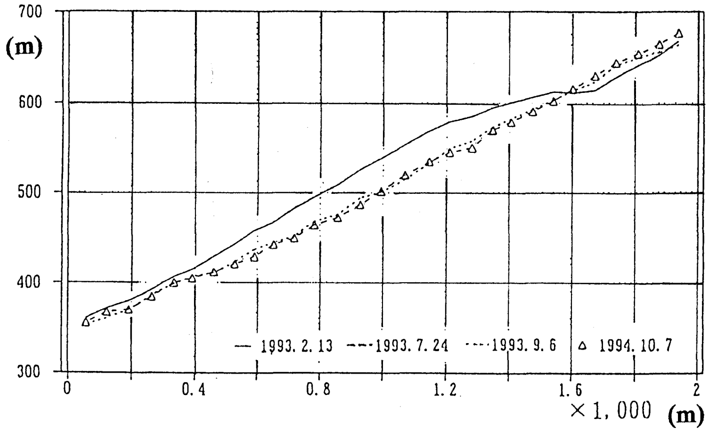


Fig. 7 Change in the longitudinal profile of the Akamatsu-dani.

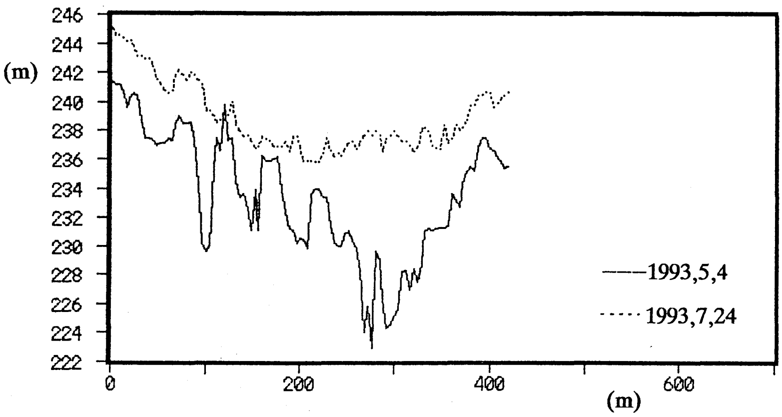


Fig. 8 An example of cross sectional change.

did not occur. It was found that debris flow activity was triggered by a threshold rainfall intensity. This threshold increased towards the end of the period, because the fine pyroclastic sediment which covered the slopes had been mostly washed away and the infiltration rate returned to that which existed before the eruption.

Figure 7 shows the changes that occurred in the longitudinal profile of the Akamatsu-dani, the south branch of the Mizunashi River. The river bed dropped rapidly by July 1993 and it has not changed greatly since then. The change of the river bed elevation in 1993 was accounted for by using a sediment transport equation. (Mizuyama *et al.*, 1995). Erosion in the upstream reach caused some deposition downstream. Figure 8 provides an example of the change in the cross section. These data were obtained using remote sensing techniques, because entering the area was prohibited when the volcano was active. Figure 9 shows the relationship between the total amount of rainfall and sediment discharge. Less sediment was transported by the same amount of rainfall in 1995.

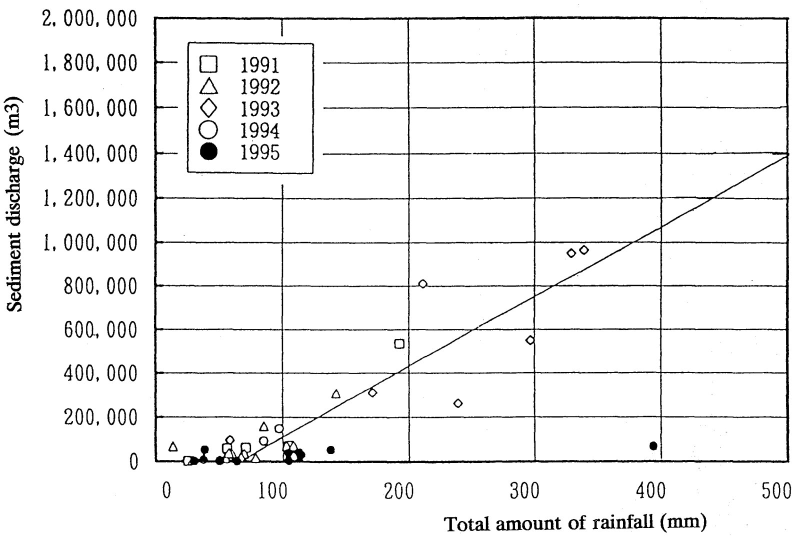


Fig. 9 The relationship between total rainfall and sediment discharge for individual storm events during the period 1991-1995.

Prediction of future sediment discharges is necessary to produce an effective sabo (erosion control) plan. It is, however, difficult, because this is our first encounter with such drastic topographic changes produced by volcanic activity. A comparative study of Mount St Helens and Mount Pinatubo is planned.

Acknowledgement The authors thank Mr Nobuo Anyoji, Sabo Technical Centre, Japan for providing the latest information and data concerning the sediment discharge from Mount Unzen. The authors would also like to express their thanks to Mr Munehiro Matsui and Mr Kozo Mikami from the Unzen Restoration Work Office of the Ministry of Construction for their cooperation and support for this research.

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