Original Article

Change of sediment yield by sheet erosion caused by the ebb of volcanic activity on the flank covered with the broad-leaved forest of Sakurajima Volcano

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Summary

Field surveys were carried out in order to clarify the differences in sediment yield by sheet erosion caused by periods of both heightened (between April and October 1985) and low volcanic activity (between April and October 2005) in addition to the factors governing the differences in sediment yield over two time periods on the flank of Sakurajima Volcano covered with broad-leaved forest. The results were as follows:

(1) When rainfall intensities were constant, sediment yields were much smaller during periods of low volcanic activity than during periods of heightened activity.

(2) The amounts of individual sediment yield during periods of low volcanic activity in Sheet A (experimental catchment with a 34 degree slope inclination) and Sheet B (experimental catchment with a 43 degree slope inclination) were about 0.4 % and 0.5 % of those measured during periods of heightened activity. The reason for this large decrease in sediment yield by sheet erosion during periods of low volcanic activity was thought to be due to the increase of infiltration capacity and the decrease in the magnitude of the surface runoff caused by the recovery of the vegetation following the ebb of volcanic activity.

Key Words: Sakurajima Volcano, volcanic activity, sediment yield by sheet erosion

1. Introduction

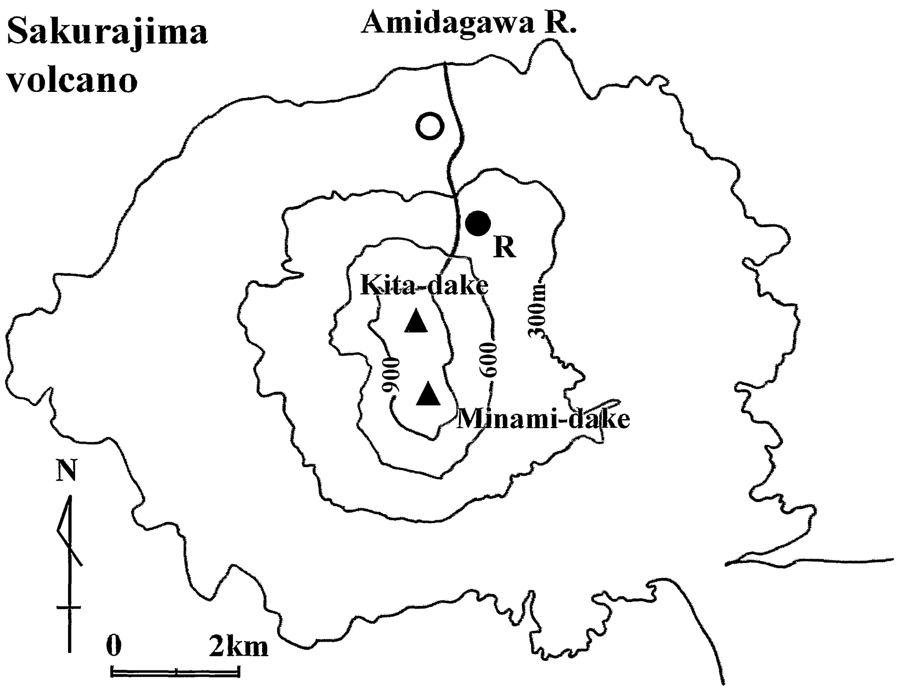
Volcanic eruptions create a radical alteration of the hydrologic and erosion regime of the surrounding areas. The hydrologic and erosion phenomena caused by volcanic eruptions have been investigated at many volcanoes, including Mount Usu (Chinen, 1986), Sakurajima Volcano (Shimokawa & Jitousono, 1987a, 1987b), Mount St. Helens (Collins & Dunne, 1986; Pierson, 1986), Mount Merapi (Shimokawa et al., 1996; Jitousono et al., 1996) and Mount Yakedake (Okuda et al., 1980; Suwa et al., 1989). Sediment yield and sediment discharge have been found to decrease with time except for volcanoes with continued volcanic activity, such as Sakurajima Volcano. However, much sediment flows out on the flank of Sakurajima Volcano every year, continuing presently with the volcano's present volcanic activity.

The ebb and flow of volcanic activity has an effect upon the hydrologic and erosion regime of the surrounding areas. Regarding the flank of Sakurajima Volcano, rainfall induced surface runoff and debris flow, the total runoff, and the peak discharge of surface runoff and debris flow during heightened volcanic activity were found to be greater than during low activity (Jitousono & Shimokawa, 1989, 1991). Moreover, Teramoto et al. (2005a, 2005b) demonstrated that the yearly depth of the volcanic ash layer and the yearly erosion rate during heightened volcanic activity (between 1972 and 1992) were much greater than during low activity (between 1993 and 2003) on the northern flank of Sakurajima Volcano.

The purpose of this study is to clarify the change of sediment yield by sheet erosion caused by the ebb of volcanic activity, governed by various factors, on the flank of Sakurajima Volcano.

2. Study area and methods

The study area is a part of the Amida River located on the northern flank of Sakurajima Volcano, as shown in **Fig. 1**. To measure sediment yield by sheet erosion and surface runoff, experimental catchments were established at 400 m above sea level in the Amida River (Fig. 1, **Fig. 2**). Each experimental catchment was a square 5 m long and 2 m wide. The squares



● Experimental catchments (Sheet A and Sheet B) and volcanic ash fall gauge station
O Volcanic ash fall gauge station (Kagoshima Prefecture)
R Rain gauge station (Kagoshima Regional Forestry Management Office)

Fig. 1 Location of the study area.

Canopy **Undergrowth**

Fig. 2 Condition of experimental catchments.

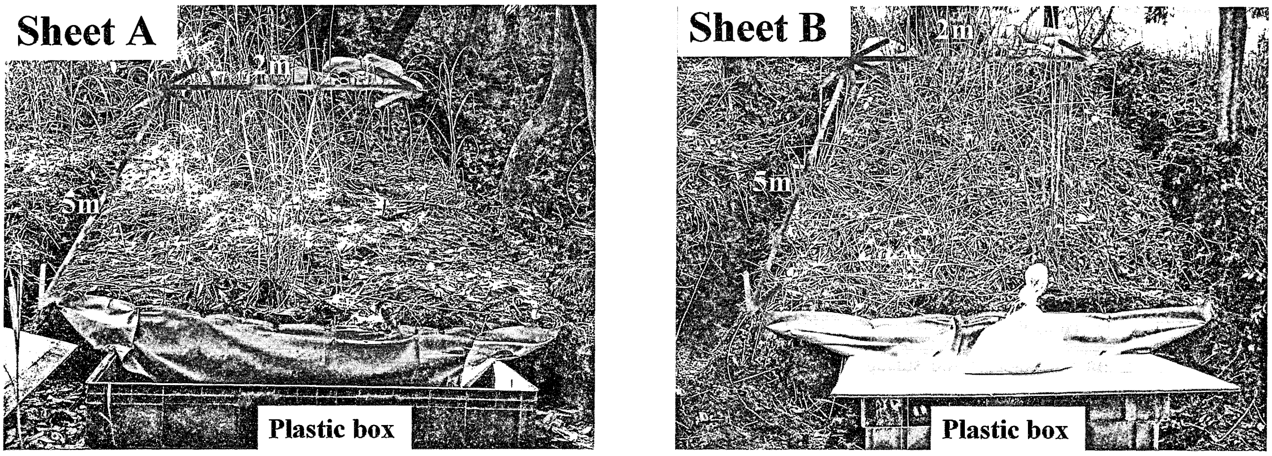


Fig. 3 Condition of Sheet A and Sheet B.

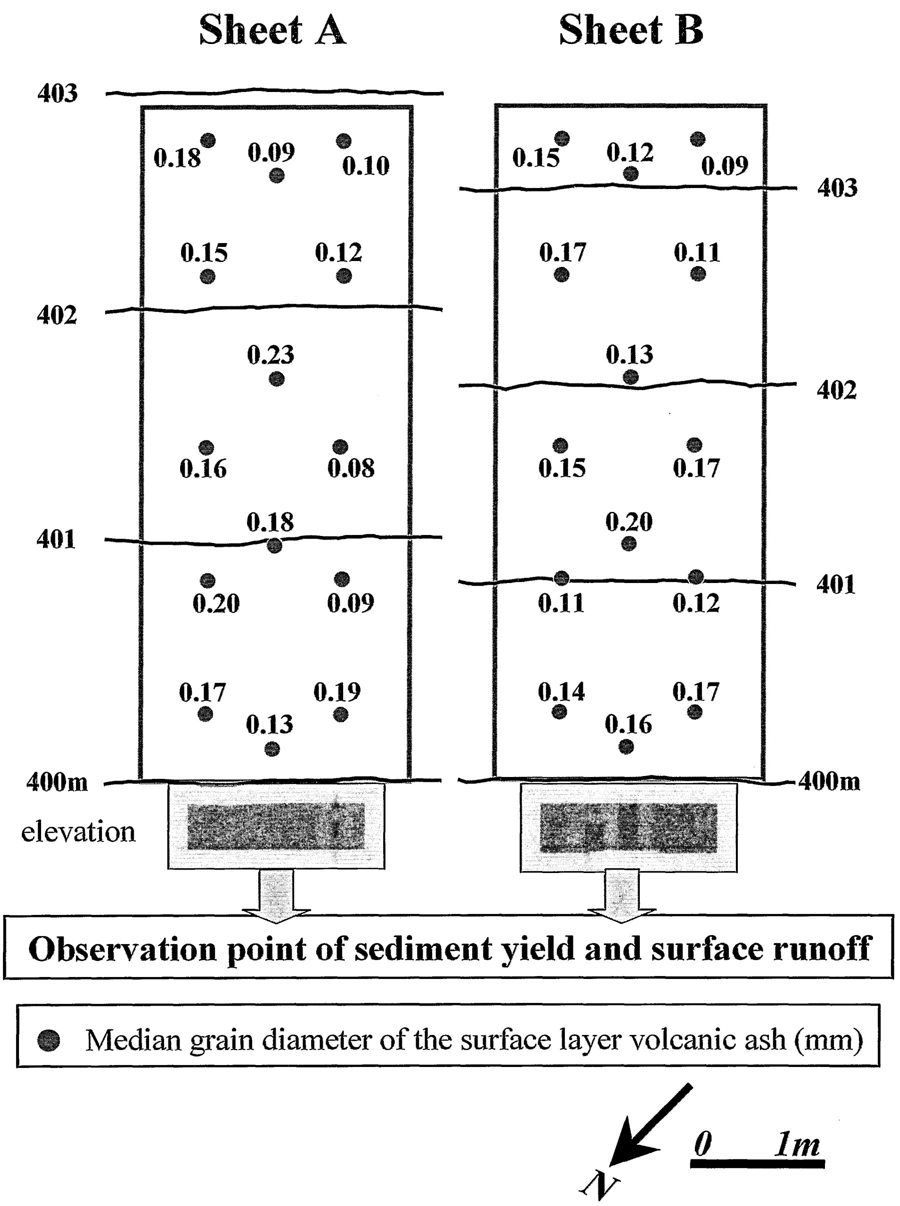


Fig. 4 Topography and distributions of the median grain diameter of the surface layer volcanic ash in Sheet A and Sheet B, measured on the 21st of April, 2005.

were installed on two slopes, one with a 34 degree and one with a 43 degree inclination, covered with broad-leaved forest (**Fig. 3**). In the lowest part of the experimental catchments, a plastic box for measuring sediment yield by sheet erosion and surface runoff was installed (Fig. 3). Measurement began on the 21st of April, 2005. In this paper, we refer to the experimental catchment with a 34 degree slope inclination as "Sheet A" and the experimental catchment with a 43 degree slope inclination as "Sheet B" (Fig. 3). Both the topographies and the distributions of the median grain diameter of the surface layer volcanic ash measured on the 21st of April, 2005, in Sheet A and Sheet B are shown in **Fig. 4**. The mean value of the median grain diameter is 0.15 mm in Sheet A and 0.14 mm in Sheet B. The sediment yield by sheet erosion in Sheet A and Sheet B were also measured between 1984 and 1986. Moreover, the amounts of volcanic ash fall were also measured between 1984 and 1986 at a location nearby Sheet A and Sheet B (Shimokawa & Jitousono, 1987a).

At the same time, in order to clarify the specific gravity of grains, bulk density, and grain size distributions, the sediment yields by sheet erosion in Sheet A and Sheet B were collected. Moreover, in order to clarify the dry density of the surface volcanic ash layer in the experimental catchments, undisturbed samples were collected by metallic cylinders 55 mm in diameter and 60 mm in height. In addition, the infiltration capacities of the soil were measured by the simplified sprinkling infiltration capacity test proposed by Shimokawa and Jitousono (Shimokawa & Jitousono, 1987a).

The amount of volcanic ash fall was measured at a location nearby Sheet A and Sheet B (Fig. 1). This measured point is the same point at which Shimokawa and Jitousono (Shimokawa & Jitousono, 1987a) conducted measurements between 1984 and 1986. Moreover, from 1978 onward, Kagoshima Prefecture measured the amount of volcanic ash fall in the lower reach of the Amida River (Fig. 1). The rainfall data used in this paper was collected by the Kagoshima Regional Forestry Management Office at a location less than 1 km away from Sheet A and Sheet B (Fig. 1).

The geological composition of the study area consists of a 1914 Taisho pumice layer covered with a volcanic ash layer.

3. Change of annual amount of volcanic ash fall

Fig. 5 shows the change in the annual amount of volcanic ash fall in the lower reach of the Amida River as measured by Kagoshima Prefecture between 1978 and 2005 (Kagoshima Prefecture, 1978－2005). The annual amount of volcanic ash fall between 1978 and 1993 was large. Moreover, the amount of volcanic ash fall in 1985 was approximately 65 kg/m², the largest annual value for the period of 1978 to 2005. Since 1994, the annual amount of volcanic ash fall has been decreasing remarkably.

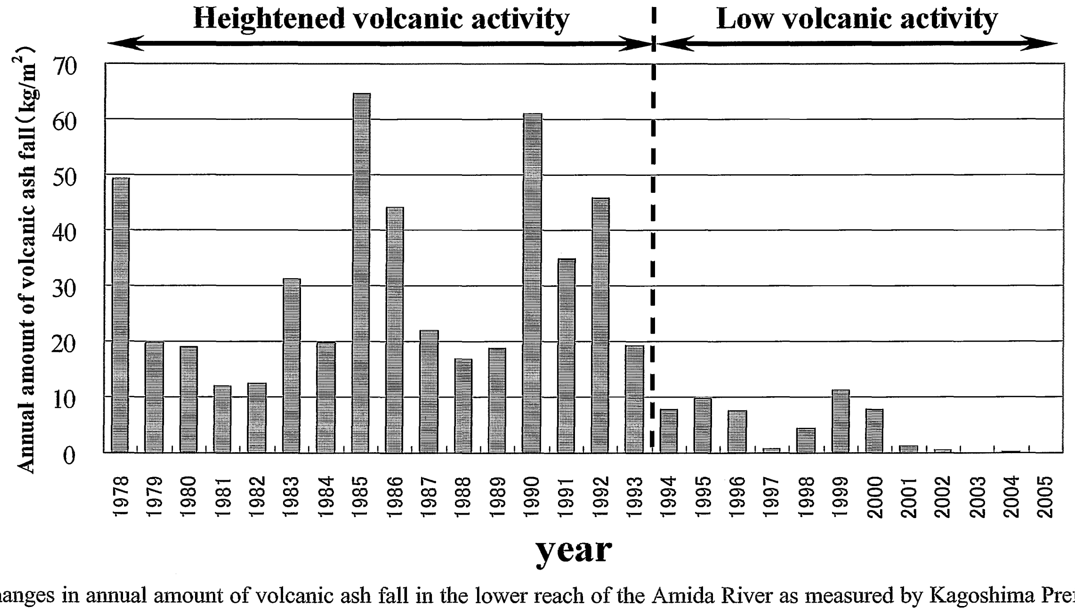


Fig. 5 Changes in annual amount of volcanic ash fall in the lower reach of the Amida River as measured by Kagoshima Prefecture between 1978 and 2005.

4. Sediment yield by sheet erosion caused by the ebb of volcanic activity on the flank of Sakurajima Volcano

We investigated the results measured during low volcanic activity (between April and October 2005).

Fig. 6 shows the relationship between the amount of individual rainfall and sediment yield by sheet erosion (a) and surface runoff (b), and **Fig. 7** shows the relationship between maximum rainfall per 60 minutes and sediment yield by sheet erosion (a) and surface runoff (b). Sediment yield and surface runoff became larger with increased rainfall intensities. In cases where rainfall intensities were of the same degree, sediment yield and surface runoff were greater in Sheet B than in Sheet A. The surface runoff percentage for each runoff in Sheet A was between 2.2 % and 10.8 % (average 5.2 %), and for Sheet B it was between 3.6 % and 10.8 % (average 6.0 %).

Fig. 8 shows the relationship between maximum rainfall per 60 minutes and the median grain diameter in sediment yield by sheet erosion. The median grain diameter became larger with increased maximum rainfall per 60 minutes. The median grain diameter for each runoff in Sheet A was between 0.09 mm and 0.42 mm (average 0.21 mm), and for Sheet B it was between 0.07 mm and 0.44 mm (average 0.23 mm). The relationship between the maximum rainfall per 60 minutes and the 10, 30, 70, and 90 percent grain diameter in the grain size distribution curve

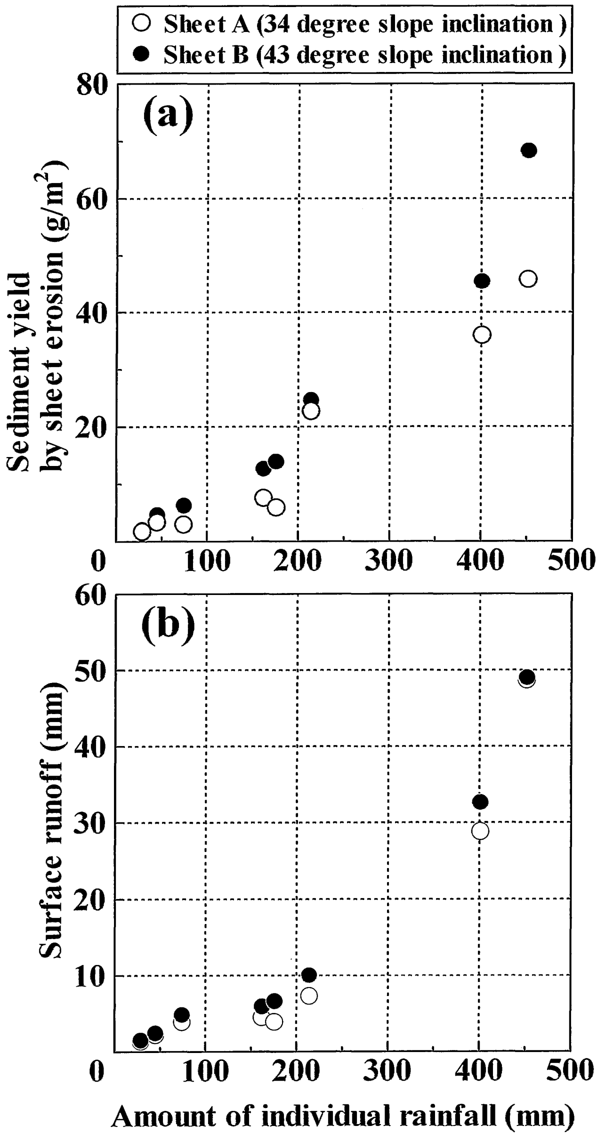


Fig. 6 Relationship between amount of individual rainfall and sediment yield by sheet erosion (a) and surface runoff (b).

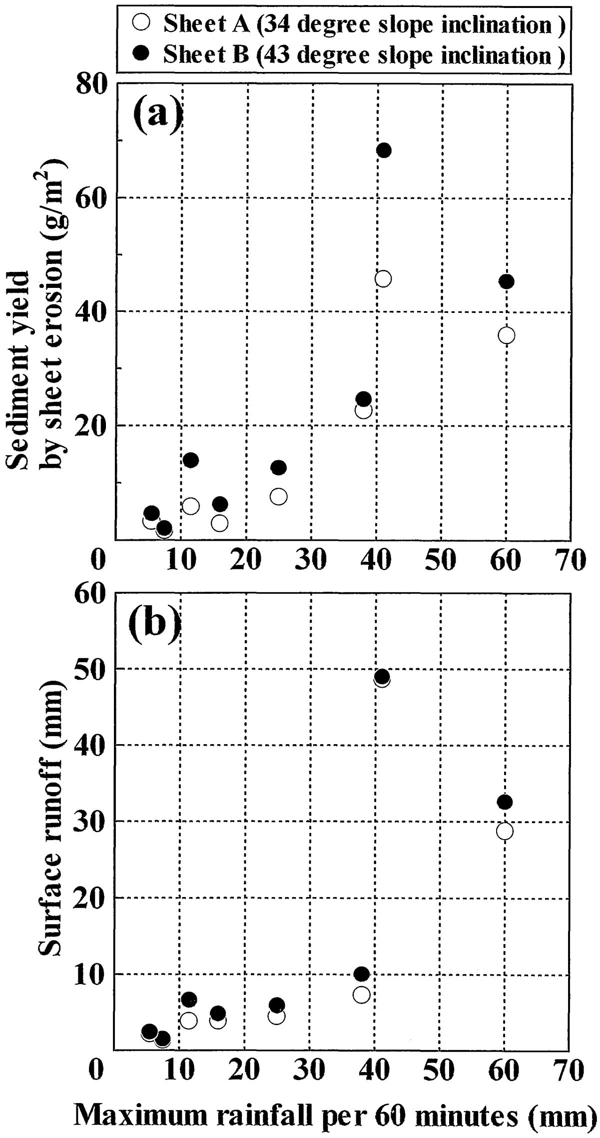


Fig. 7 Relationship between maximum rainfall per 60 minutes and sediment yield by sheet erosion (a) and surface runoff (b).

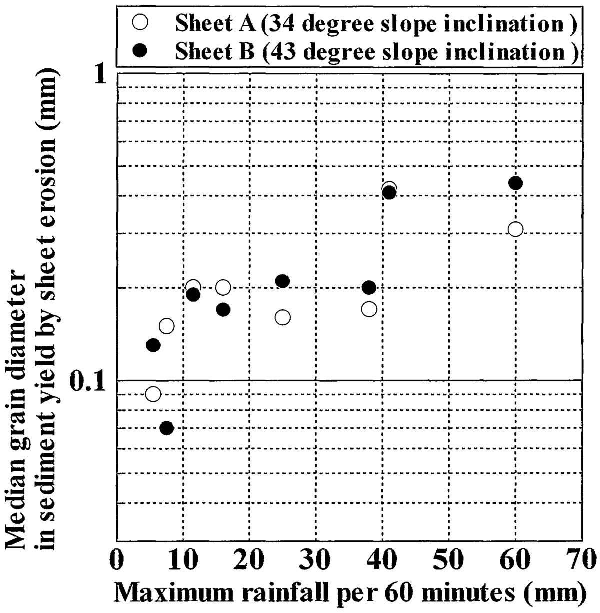


Fig. 8 Relationship between maximum rainfall per 60 minutes and the median grain diameter in sediment yield by sheet erosion.

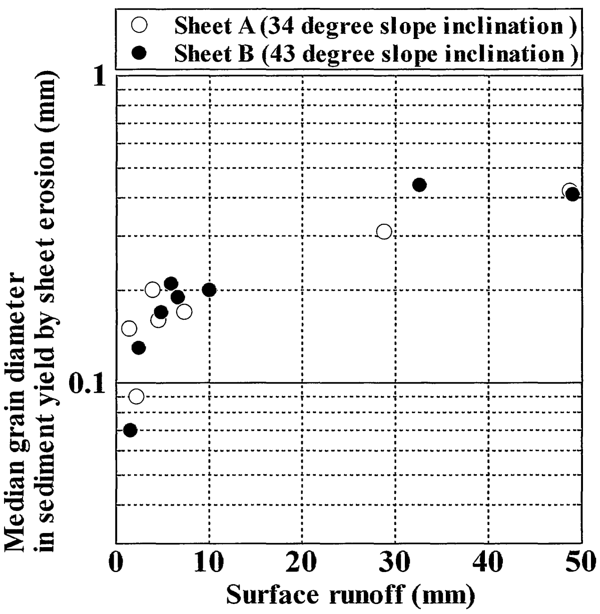


Fig. 9 Relationship between surface runoff and the median grain diameter in sediment yield by sheet erosion.

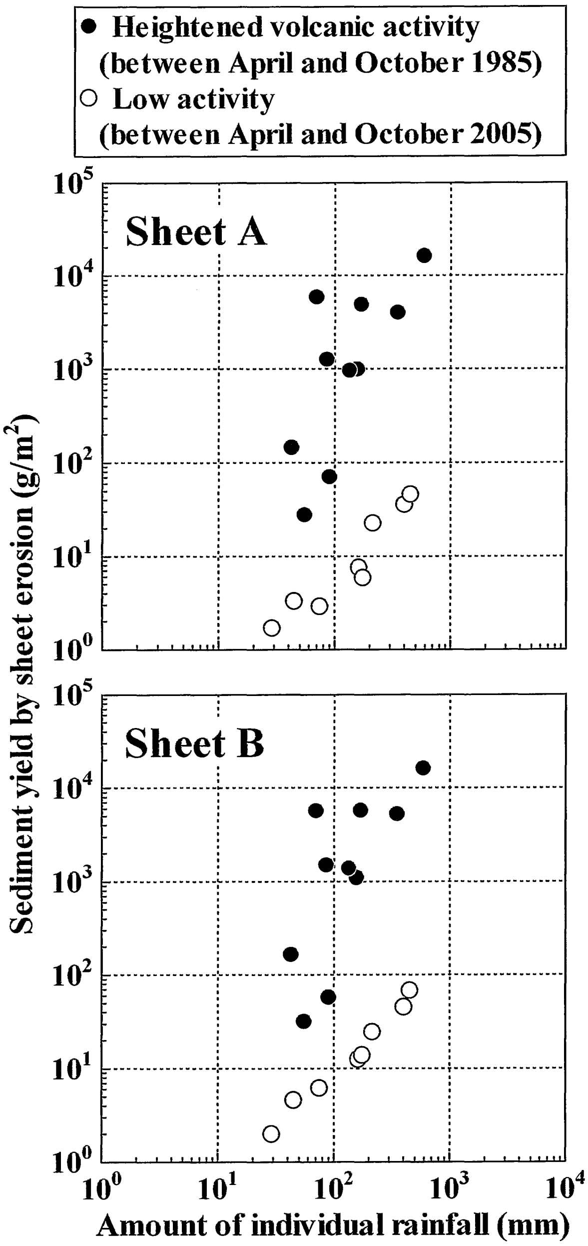


Fig. 10 Relationship between amount of individual rainfall and sediment yield by sheet erosion in Sheet A and Sheet B during periods of both heightened (between April and October 1985) and low volcanic activity (between April and October 2005).

in the sediment yield showed the same tendency as the relationship between the maximum rainfall per 60 minutes and the median grain diameter.

Fig. 9 shows the relationship between the surface runoff and the median grain diameter in sediment yield by sheet erosion. The median grain diameter became larger with increased surface runoff. Further, the increment of the median grain diameter caused by the increment of surface runoff was found to be related to the increment of tractive force caused by the increment of surface runoff.

5. Change in sediment yield by sheet erosion caused by the ebb and flow of volcanic activity on the flank of Sakurajima Volcano

Fig. 10 shows the relationship between the amount of individual rainfall and sediment yield by sheet erosion, and **Fig. 11**

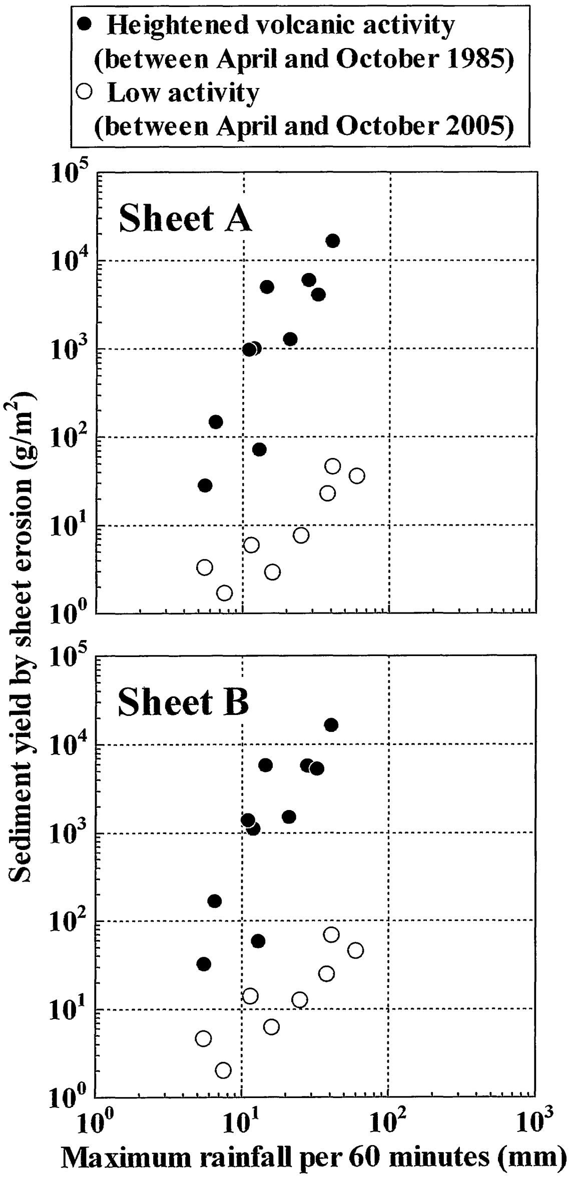


Fig. 11 Relationship between maximum rainfall per 60 minutes and sediment yield by sheet erosion in Sheet A and Sheet B during periods of both heightened (between April and October 1985) and low volcanic activity (between April and October 2005).

shows the relationship between the maximum rainfall per 60 minutes and sediment yield by sheet erosion in Sheet A and Sheet B during two periods of heightened volcanic activity (between April and October 1985) (Shimokawa & Jitousono, 1987) and two periods of low activity (between April and October 2005). Compared with the same experimental catchments, sediment yield during the two periods became larger with increased rainfall intensities. Moreover, in cases where rainfall intensities were of the same degree, sediment yield was much smaller during low volcanic activity than during heightened activity.

Table 1 shows a comparison of the amount of individual sediment yield by sheet erosion in Sheet A and Sheet B, and volcanic ash fall at a location 1 m^2 away from Sheet A and Sheet B, with the amount of individual rainfall during periods of both heightened (between April and October 1985) (Shimokawa & Jitousono, 1987) and low volcanic activity (between April and October 2005). The amount of individual volcanic ash fall at the 1 m^2 location during low volcanic activity was about 12.5 % of that measured during heightened activity. Moreover, the amount of individual sediment yield during low volcanic activity in Sheet A and Sheet B was about 0.4 % and 0.5 % of that measured during heightened activity.

According to the measured value of the yearly erosion rate by sheet erosion estimated by a comparison of the thickness of volcanic ash accumulated in the broad-leaved forest of the northern flank of Sakurajima Volcano, the yearly erosion rates during periods of low volcanic activity (between 1994 and 2003) was about 40 % of those measured during periods of heightened activity (between 1972 and 1986) (Teramoto et al., 2005a). This result is in harmony with the results of the current study.

Table 2 shows a comparison of the dry densities of the surface volcanic ash layers and infiltration capacities measured nearby Sheet A and Sheet B during periods of both heightened

Table 1 Comparison of the amount of individual sediment yield by sheet erosion in Sheet A and Sheet B, and volcanic ash fall at an area 1 m^2 away, with the amount of individual rainfall during periods of both heightened (between April and October 1985) and low volcanic activity (between April and October 2005).

Experimental catchment	Observed period	Amount of volcanic ash fall (kg/m^2)	Amount of sediment yield by sheet erosion (kg/m^2)	Amount of rainfall (mm)
Sheet A	During April 1985 and October 1985 (Heightened volcanic activity) (Shimokawa and Jitousono, 1987)	65.1	34.8	1742
Sheet B			37.4	
Sheet A	During April 2005 and October 2005 (Low volcanic activity)	0.52	0.13	1517
Sheet B			0.18	

Table 2 Comparison of the dry density of the surface volcanic ash layer and the infiltration capacity measured nearby Sheet A and Sheet B during periods of both heightened (between April and October 1985) and low volcanic activity (between April and October 2005).

Observed period	Dry density of surface volcanic ash layer (g/cm^3)	Slope inclination (degree)	Infiltration capacity (mm/hr)
1985 (Heightened volcanic activity) (Shimokawa and Jitousono, 1987)	1.42～1.49 (Average 1.46)	23	74
		33	70
2005 (Low volcanic activity)	1.12～1.28 (Average 1.19)	22	112
		35	103

(between April and October 1985) (Shimokawa & Jitousono, 1987) and low volcanic activity (between April and October 2005). The dry density measured during the periods of low volcanic activity was smaller than that measured during heightened activity. The infiltration capacity during low volcanic activity was, however, much greater than that measured during heightened activity.

Thus, the reason for the large decrease of sediment yield by sheet erosion during low volcanic activity is considered to be because of the increase of infiltration capacity and the decrease in the magnitude of the surface runoff caused by the recovery of the vegetation following the ebb of volcanic activity.

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広葉樹林で覆われた桜島の荒廃斜面における噴火活動の衰退に伴う表面侵食土砂量の変化

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要　旨

桜島の広葉樹林で覆われた斜面において，噴火活動が活発な時期（1985年４月～同年10月）と穏やかなそれ（2005年４月～同年10月）における表面侵食土砂量を比較した。さらに，２つの時期における表面侵食土砂量の違いを支配している要因についても検討した。得られた結果は以下の通りである。

(1) 降雨強度が同程度の場合で比較すると，噴火活動が穏やかな時期の表面侵食土砂量は，活発な時期のそれに比べ非常に小さくなっていた。

(2) Sheet A試験地（斜面傾斜34度）およびSheet B試験地（斜面傾斜43度）における噴火活動が穏やかな時期の表面侵食土砂量の合計値は，活発な時期のそれのそれぞれ約0.4%，0.5%であった。噴火活動が穏やかな時期の表面侵食土砂量の方が，活発な時期のそれに比べ非常に小さくなった理由として，噴火活動の衰退に伴う植生回復によって斜面の浸透能が増加したこと，浸透能の増加により表面流の発生条件が緩和され，表面流の発生頻度と規模が減少したことが挙げられる。

キーワード：桜島，噴火活動，表面侵食土砂量