7th International Conference on Debris-Flow Hazards Mitigation

Landslides and debris flows in volcanic rocks triggered by the 2017 Northern Kyushu heavy rain

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Abstract

About 200 landslides and debris flows occurred in Northern Kyushu during heavy rain at Asakura City, Toho Village, Hita City on July 5th to 6th, 2017. At Hita City, the total precipitation during this two-day event was 402.5 mm. At Asakura city, underlain by granitic rocks and schist, shallow landslides dominated. Whereas, at Toho Village and Hita City, which is underlain by volcanic rocks, the number of landslides and debris flows are fewer, are larger and deeper, than those at Asakura City.

We examined the geomorphology and geology at 19 landslides in volcanic rocks, 11 of which mobilized as debris flows. We studied the initiation mechanism of landslides underlain by volcanic rocks. The geology consists of pyroclastic rocks and lava flows in ascending order. The lava flows are distributed at ridges and contain vertical cooling joints. Scarps of landslides caused by the 2017 rain are located near the boundary of pyroclastic rocks and lava flows. The sliding surfaces of these landslides are at the contact between the lava flows and the pyroclastic rocks. We consider, therefore, that the trigger for these landslides was a decrease of strength at the contact caused by an increase in groundwater pressure caused by infiltration of rain water through the cooling joints in lava flows. Therefore, we conclude that the landslides caused by the 2017 heavy rain at volcanic rock fields are cap rock type landslide. Furthermore, the curvature of the hillsides downslope from landslides is concave, which may be a required condition for debris-flow mobilization.

"Keywords: landslide ; heavy rain fall ; volcanic rocks ; cap rock"

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1. Introduction

About 200 landslides and debris flows occurred in Northern Kyushu during heavy rain at Asakura City, Toho Village, and Hita City on July 5th to 6th, 2017. The event, which was named “the 2017 Northern Kyushu heavy rain” by the Meteorological Agency of Japan, was induced by back building storms that caused heavy rain fall (Tsuguchi, 2017). The morphology of northern Kyushu Mountains including the Seburi Mountains and the Samgun Mountains, contributed to concentration and intensification of rains in the training (Tsuguchi, 2017). The training occurred at east end of the Seburi Mountains and traversed to the east into Asakura, Toho and Hita. Therefore, the amount of rainfall was greater at Asakura City than in Hita and Toho districts. The precipitation during the two days at Asakura area was 150% of that in the Hita and Toho districts.

At Asakura City in Fukuoka Prefecture, many debris flows, which initiated from landslides and contained a large quantity of fallen trees, occurred along rivers. These debris flows entered downstream town areas and caused huge damages. The source of debris flows at Asakura City was many small, shallow landslides with a few large landslides (Nishimura et al., 2018). In contrast, large landslides were the source of debris flows at the Hita and Toho districts (Nishimura et al., 2018). The geology of Asakura City area consists of metamorphic rocks and granitic rocks. On the other hand, volcanic rocks underlie the Hita and Toho areas. Therefore, at the Hita and Toho areas, large landslides occurred without small landslides in spite of only receiving two-thirds of the amount of rainfall of the Asakura area.

We examined the factors contributing to the occurrence of large landslides caused by a smaller amount of rainfall at Hita and Toho. This paper reports the characteristics of rainfall and the topographical and geologic conditions at

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landslide sites in Hita City. We also discuss the initiation conditions for landslides that occur in areas underlain by volcanic rocks.

2. Regional Topography and Geological Settings at the Hita and Toho districts

The Chikugo River runs trough the area whrere many landslides and debris flows occurred (Fig. 1). The Hita Basin and the Ryochiku Plain are adjacent to the river. The Samgun Mountains and the Hiko Mountains are on northern side of the river and contain some peaks of 1000 m in elevation. Tributary rivers such as the Oohi River and the Ono River join the Chikugo River from the north (Yada, 2018). The landslide and debris flow event occurred along the tributary rivers.

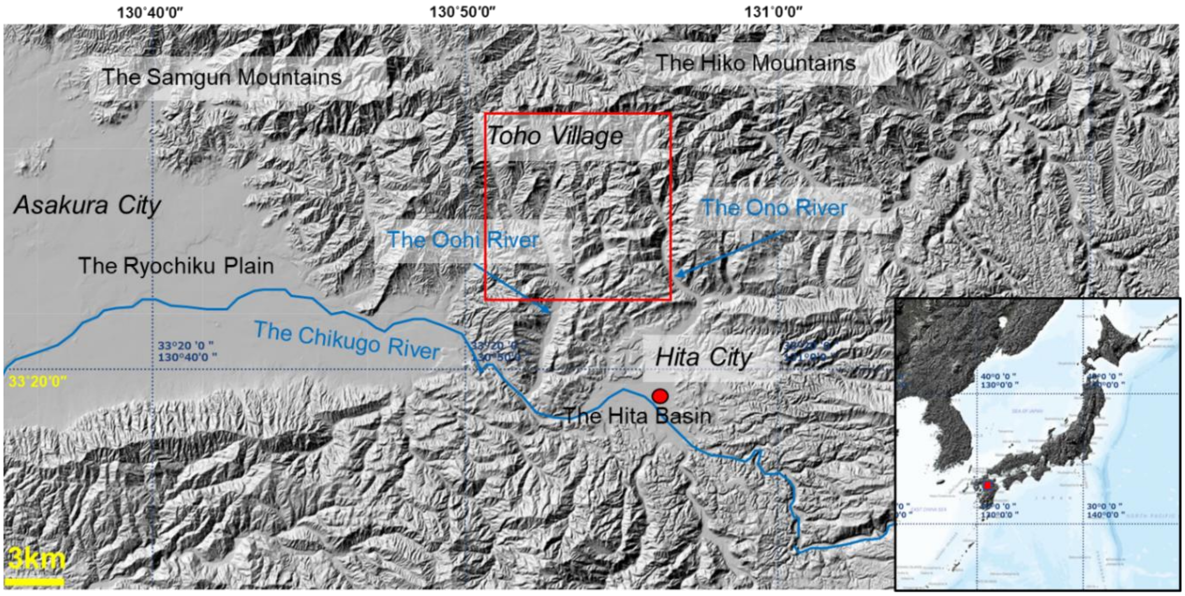

Fig. 1. Topographical map around the Hita, Toho, and Asakura area. This map is based on the digital map published by the Geospatial Information Authority of Japan. The red frame shows a field survey area of Fig. 6. Red point shows the Hita AMeDAS point.

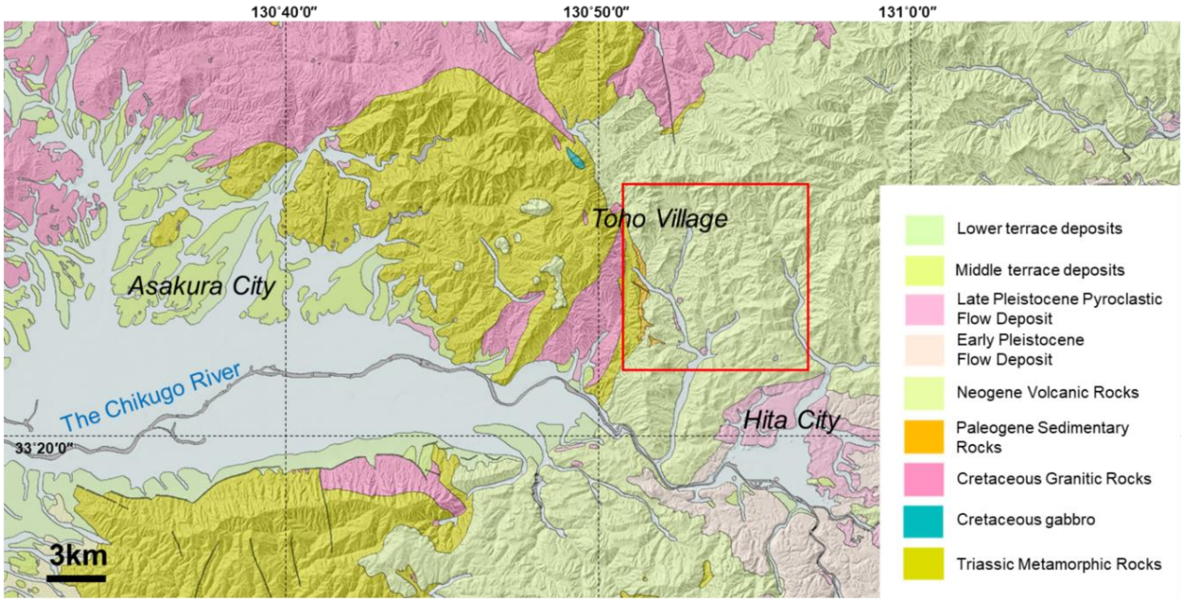

Fig. 2. Geological map around the Hita, Toho, and Asakura area (Geological Survey of Japan, AIST, 2015). The red frame shows a field survey area of Fig. 6.

Asakura City is underlain by metamorphic and granitic rocks (Fig. 2). The metamorphic rocks are part of the Samgun Metamorphic Belt and consist of pelitic schist and sandy schist with a small amount of green schist (Yada, 2018). The granitic rocks consist of mainly biotite hornblende granodiorite, which are part of the Soeda Granodiorite. The granitic rocks intruded into the metamorphic rocks, therefore the metamorphic rocks adjacent to the granitic rocks transformed to hornfels by contact metamorphism (Yada, 2018).

In the Hita and Toho districts on the eastern side of the Oohi River, Neogene and Quaternary volcanic rocks are distributed widely. The volcanic rocks consist of lavas, pyroclastic flows, and pyroclastic fall deposits. At the top of some peaks in Asakura City, there are also volcanic rocks (Yada, 2018).

3. Precipitation on July 5th to 6th at Hita City

At Hita City, the observed maximum hourly rainfall on July 5 and 6 at the AMeDAS (Automated Meteorological Data Acquisition System) point was 74 mm, the maximum 3 hour rainfall was 180.5 mm and the maximum 24 hour rainfall was 369.5 mm (Fig. 3). The total precipitation during this two-day event was 402.5 mm. The precipitation at Hita was smaller than that at the Asakura AMeDAS point, where the maximum hourly rainfall was 129.5 mm, the maximum 3 hour rainfall was 261 mm, and the maximum 24 hour rainfall was 545.5mm (Tsuguchi, 2017). However, the two days of precipitation at Hita was the most that had occurred there in the past seven decades, and the precipitation in two days exceeded 400mm that had occurred only two times during same seven decades.

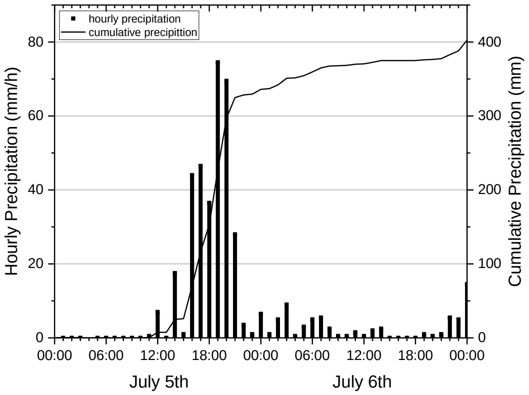

Fig. 3. Observed precipitation at Hita AMeDAS point.

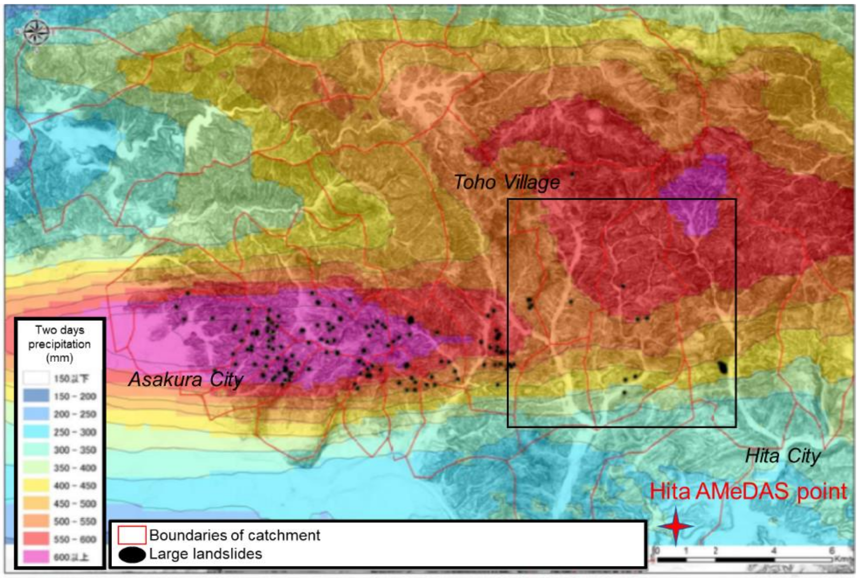

Fig. 4. Distribution of two days of precipitation and large landslides in the Hita, Toho, and Asakura area (Nishimura et al., 2018). The black frame shows a field survey area of Fig. 6.

Fig. 4 shows the distribution of two days precipitation in the Asakura, Toho, Hita districts, which was estimated by meteorological radar (Nishimura et al., 2018). In the mountainous areas, the radar estimated that precipitation during the two day period exceeded 550 mm. In areas near Asakura City, the distribution of landslides corresponded to a huge precipitation zone, whereas the landslide distribution in Hita City did not agree with the estimated precipitation (Fig. 5).

4. Distribution of Landslides and Debris Flows at Hita City

Fig. 5 shows the distribution of landslides and debris flows in the Asakura, Toho and Hita districts (Geographical Survey Institute, 2017). Numerous landslides and debris flows occurred in the mountainous area of Asakura City that coincides with the zone of high precipitation (Fig. 4) and the location of metamorphic and granitic rocks. In the Hita and Toho districts, where volcanic rocks are locates, there were fewer landslides and debris flows than at Asakura City.

Nishimura et al. (2018) interpreted 189 landslides in Fig. 5, which had areas of 1,000 m^2 or more. Thirty-five landslides exceeded 6,000 m^2 in area. Six landslides with areas of 10,000 m^2 or more were detected (Nishimura et al., 2018), and two landslides of the six were in volcanic rocks. Furthermore, they said that twenty landslides were located in volcanic rocks, 142 landslides were located in metamorphic rocks, twenty-three landslides in granitic rocks and four landslides in sedimentary rocks. Nishimura et al. (2018) show that small landslides were dominant in areas underlain by metamorphic and granitic rocks, and that large landslides were dominant in areas underlain by volcanic rocks. In the volcanic rocks, there were 15 landslides with areas of 1,000 m^2 or more, and six landslides in volcanic rocks had areas of 6,000 m^2 or more. The median values of landslide areas in volcanic rocks, metamorphic rocks and granitic rocks are 4895 m^2, 3830 m^2 and 4081 m^2 respectively.

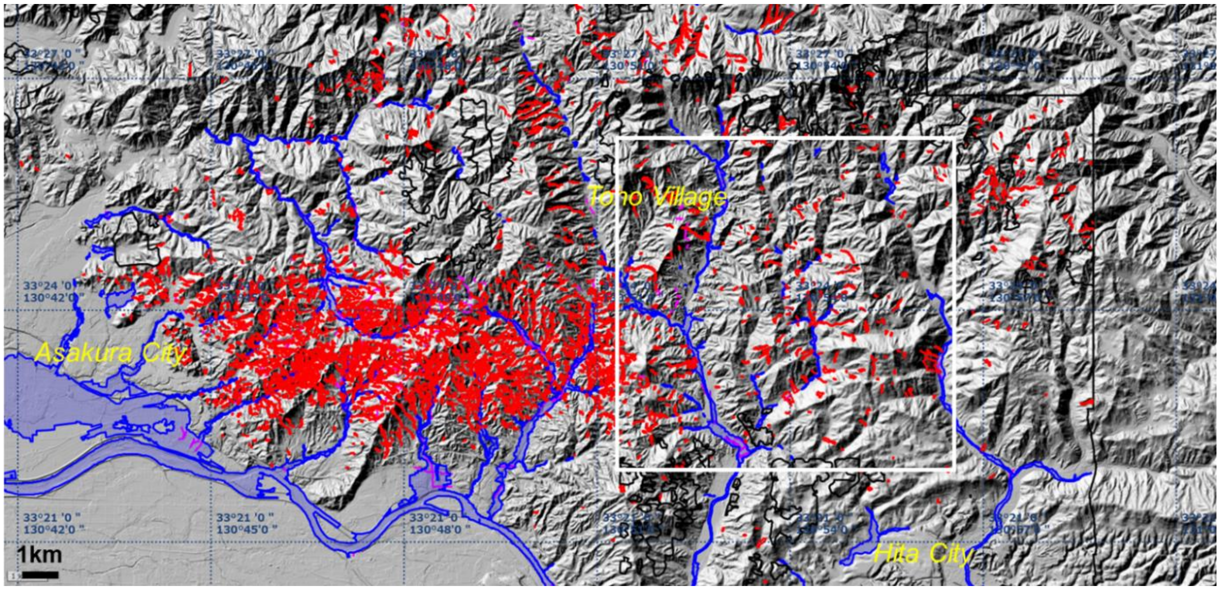

Fig. 5. Distribution of landslides, debris flows and floods in the Hita, Toho, and Asakura area (Geographical Survey Institute, 2017). Red: landslides and debris flows, Blue: flood area. The white frame shows a field survey area of Fig. 6.

5. Geomorphological and Geologic Features at landslide and debris flow sites in volcanic rocks

We interpreted the geomorphological features at 19 landslides in volcanic rocks with two days precipitation estimated by meteorological radar (Table 1). Eleven of 19 landslides triggered debris flow. It did not depend on a landslide area, the elevation of the scarp, the form at scarp and precipitation whether a landslide became the trigger of the debris flow. If landslides were followed by debris flow, the curvature of the hillsides downslope from landslides is concave. Occurrence of landslide were not controlled by geomorphology, because the form at scarp were various.

Table 1. The geomorphological features of landslides in volcanic rocks

No.	Landslide area (m^2)	Scarp elevation (m)	Two days precipitation (mm)	With or without debris flow	Form of at scarp		Form of the hillsides downslope from landslides	
					Vertical	horizontal	Vertical	horizontal
1	1,300	503	600	without	convex	straight	convex	straight
2	1,815	432	500	with	convex	ridge	concave	valley
3	3,214	334	550	without	convex	straight	rectilinear	straight
4	7,915	388	500	with	convex	valley	concave	valley
5	2,963	423	550	with	convex	ridge	concave	valley
6	6,381	252	400	without	convex	valley	convex	valley
7	67,600	379	400	without	concave	ridge	convex	ridge
8	12,732	236	350	without	convex	straight	rectilinear	straight
9	6,979	386	450	with	convex	valley	concave	valley
10	6,285	681	550	with	rectilinear	valley	concave	valley
11	5,479	544	600	with	convex	straight	concave	valley
12	4,942	526	600	with	convex	ridge	concave	valley
13	4,895	573	600	with	rectilinear	ridge	concave	valley
14	4,727	323	550	with	rectilinear	straight	concave	valley
15	4,701	652	550	with	convex	ridge	concave	valley
16	4,276	315	500	without	convex	straight	convex	straight
17	3,601	391	500	without	concave	valley	concave	valley
18	3,302	319	300	without	convex	straight	rectilinear	valley
19	1,072	575	500	with	rectilinear	valley	concave	valley

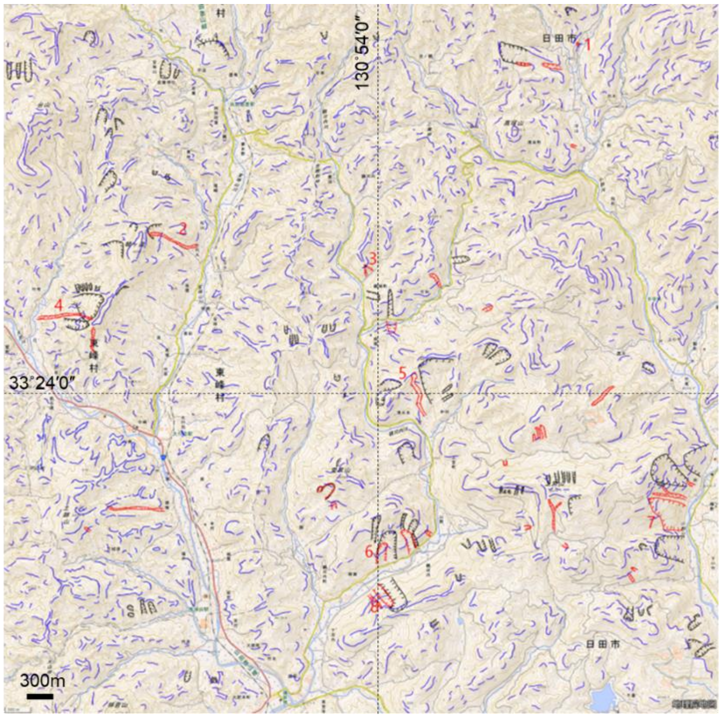

Fig. 6. Geomorphological features in the surveyed area. Red symbols are landslides by the 2017 event, black symbols are scarps recognized from aerial photographs taken before the 2017 event, and blue symbols are knick lines. Numbers are same as Tables 1, 2, and show representative landslides.

We analyzed the geomorphology and geology at eight landslides in detail. Detailed geomorphology at landslides was interpreted from aerial photographs which were taken before and after the event. Ground surveys were done to determine geologic units at representative 8 landslide sites. Fig. 6 shows the locations of analyzed landslides and results from the geomorphologic analysis. The geologic units at each landslide are shown in Fig. 7. The geomorphological features and geology are listed in Table 2. The results from these investigations suggest that;

1) Existing landslide morphology will influence the occurrence of new landslides, because 6 of 8 landslides investigated were situated near the older landslide scarps.

2) At 6 of 8 landslides investigated rigid lava flow with cooling joints cover pyroclastic flow deposits which have low permeability. Therefore, it is suggested that the geologic structure at scarp of landslides are cap rock structure. Furthermore, landslides occurrence did not be influenced by mineral assemblage of cap rock lava, because 2 of 6 lavas consist of hornblende-two-pyroxene andesite and other lavas consist of two-pyroxene andesite.

3) Hydrothermal alteration of rocks is prevalent in the northeastern part of the study area, because only few landslides were located in the northeastern part of the study area in spite of huge rainfall (Fig. 4).

4) The geomorphological features such as the elevation and slope angle at scarp, the slope angle at sliding surface, did not control whether a landslide triggered the debris flow.

Table 2. The geomorphological features and geology of representative eight landslides

Landslide No.	1	2	3	4	5	6	7	8
Landslide area (m^2)	1,300	1,815	3,214	7,915	2,963	6,381	67,600	12,732
Scarp elevation (m)	503	432	334	388	423	252	379	236
Slope angle at scarp (˚)	37	41	38	49	17	21	21	37
Slope angle at sliding surface (˚)	46	37	34	37	24	31	24	36
Running distance of debris flow (m)	non	900	non	800	1,000	non	non	non
Two days of precipitation (mm)	600	500	550	500	550	400	400	350
Geology	strongly hydrothermally altered andesite lava	bi-hb-2px andesite lava flow cap with pyroclastic flow deposits under layer	strongly hydrothermally altered andesite lava	2px andesite lava flow cap with pyroclastic flow deposits under layer	hb-2px andesite lava flow cap with pyroclastic flow deposits under layer	2px andesite lava flow cap with pyroclastic flow deposits under layer	2px andesite lava flow cap with pyroclastic flow deposits under layer	2px andesite lava flow cap with pyroclastic flow deposits under layer
Geomorphological feature	not close to an old scarp	close to an older scarp	rectilinear slope, not close to an old scarp	close to an older scarp	close to an older scarp	close to an older scarp	close to an older scarp	close to an older scarp

Landslide Numbers are same as Fig. 6. bi: biotite, hb: hornblende, px: pyroxene

6. Discussion

Landslides by 2017 event in volcanic rocks have some common features of geomorphology and geology (Table 1,2). Those are that the scarp of new landslides is located close to an older scarp and that the cap rock andesite lava covers low permeable pyroclastic flow deposits at the scarp. The width of joints in lavas near older scarp maybe spread due to slope instability caused by old landslide. It is easy to infiltrate rain water through the spread joints in lava. Therefore, we suggest that the cap rock structure might contribute to the occurrence of new landslides because rain water would infiltrate through the jointed lava flows and pool on top of the pyroclastic deposits, thus increasing pore pressure, and promoting landslide initiation and sliding at the contact.

There are only few landslides in the northeastern part of the study area in which hydrothermal altered volcanic rocks are distributed. At this area, the permeability of lavas maybe decreased by hydrothermal argillation. Therefore, at 2017 event rain water could not infiltrate into ground and ran off on slope surface, then only shallow and narrow landslides occurred.

Eleven debris flows were observed in volcanic rocks at 2017 event. From the interpretation of aerial photographs and ground surveys, we cannot find out the significant factors which will control to trigger a debris flow from a landslide (Fig. 8). However, if landslide had high elevation at scarp and high two-days precipitation, debris flow will be easy to occur. At all hillsides downslope from landslides in volcanic rocks, at which debris flow ran down, form of the hillsides was concave-valley type. The curvature of the hillsides downslope from landslides is concave, which may be a required condition for debris-flow mobilization.

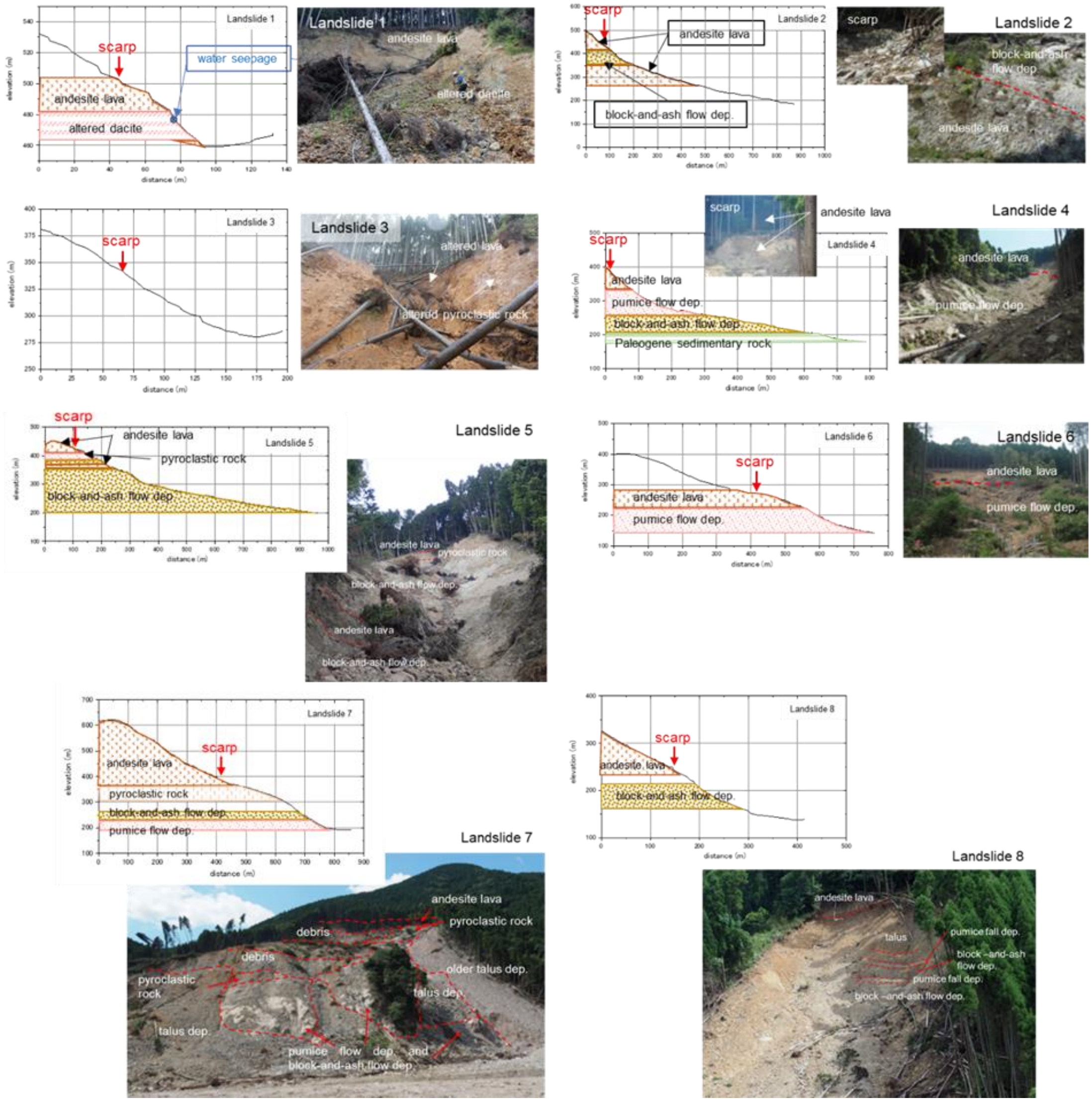

Fig. 7. Geology at each landslide.

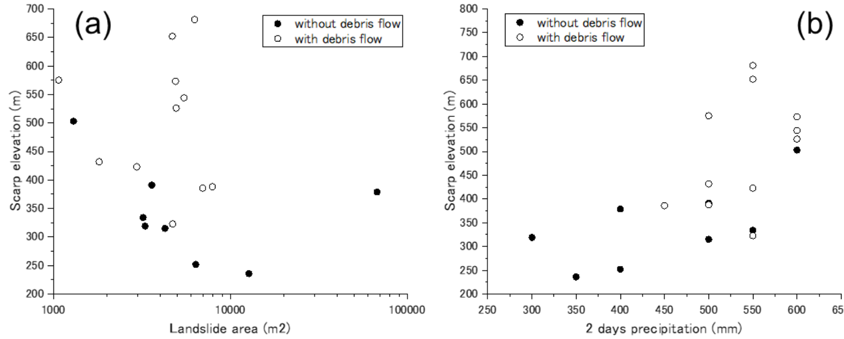

Fig. 8. Geomorphology and precipitation at landslides and debris flows. (a) the relationship between landslide area and scarp elevation, (b) the relationship between two days precipitation and scarp elevation.

7. Conclusions

We investigated landslides and debris flows which occurred in volcanic rocks in Hita and Toho districts in Northern Kyushu. These landslides and debris flows were triggered by heavy rain on July 5th and 6th , 2017. We mapped geomorphological and geological features of these land slide from aerial photointerpretation and ground surveys. The results from these investigations suggest that;

1) Existing landslide morphology will influence the occurrence of new landslides, because 6 of 8 landslides investigated were situated near the older landslide scarps.

2) At 7 of 8 landslides investigated rigid lava flow with cooling joints cover pyroclastic flow deposits which have low permeability. Therefore, we suggest that the cap rock structure might contribute to the occurrence of new landslides because rain water would infiltrate through the jointed lava flows and pool on top of the pyroclastic deposits, thus increasing pore pressure, and promoting landslide initiation and sliding at the contact.

3) Hydrothermal alteration of rocks is prevalent in the northeastern part of the study area. Only few landslides were located in the northeastern part of the study area. Therefore, it seems that altered rocks were minimally susceptible to land sliding during the 2017 rainfall event.

4) We cannot find out the significant factors which will control to trigger a debris flow from a landslide. However, the curvature of the hillsides downslope from landslides is concave, which may be a required condition for debris-flow mobilization.

Acknowledgements

We are deeply appreciation to members of the 2017 Northern Kyushu Heavy Rain Disaster Research Mission of JSEG for useful discussions about landslides. This work was supported partly by the Cabinet Office, Government of Japan, Cross-ministerial Strategic Innovation Promotion Program (SIP). This article was greatly improved by the comment of the reviewer.

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