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EFFECTS OF LANDSLIDES ON LANDSCAPE EVOLUTION IN ALPINE ZONE OF MOUNT SHIROUMA-DAKE, NORTHERN JAPANESE ALPS

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Abstract This paper describes the characteristics of landslide topographies in the alpine zone of Mount Shirouma-dake based on aerial photo interpretation as well as on-site geological/ geomorphological investigations. A comparison between a geomorphological map and a physiographic vegetation map has helped to reveal the relationship between landslide topographies and vegetation patterns. Landslide topographies coincide with vegetation mosaics on and around the landslide masses. It appears that landslide topographies and their development have controlled the microenvironments on and near the ground surface conditions through snow depth, soil moisture, slope processes, and other factors. The importance of landslide activities on landscape development should be studied in greater detail in the Japanese alpine zone.

Key words: landslide, landscape evolution, alpine zone, Japanese Alps

1. Introduction

Landslide activities (in this paper, the term "landslide" is used to describe rotational or translational movements of rock as well as mass rock creep) could influence the surface or near-surface natural environments of slopes through the development of topographical features such as scars, ridges, depressions, ponds, and drainage channels. The development of such features may in turn induce changes in the slope process, soil stratigraphy, microclimate, and groundwater conditions. Miyagi (2002) reported that complex natural environments formed in and around landslide topographies can produce rich biodiversity in low relief mountains and hills. In his paper, he presented geomorphological and vegetation maps of the large-scale landslide topographies in the montane zone in the Tohoku District, Japan. He also discussed the interaction between landslide topographies and landscape structures. The effects of landslide activities on landscape evolution in the alpine zone of Japanese high mountains have not yet been investigated, although active and inactive landslide topographies have developed in these regions (Shimizu *et al.* 1980; National Research Institute for Earth Science and Disaster Prevention 2000; Sato and Kariya 2005).

In this paper, we describe examples of large- to middle-scale landslide topographies in the alpine zone of Mount Shirouma-dake (2,932 m ASL), and briefly discuss the relationships between the development of

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landslide topographies and landscape evolution.

2. Study Area

Shirouma-dake is situated in the northern Japanese Alps (also called as the Hida Mountains, Fig. 1). The main ridge runs from the south to the north and bifurcates to the northeast and the northwest at Sangokuzakai Col 1 km north of Shirouma-dake. A major spur is derived from Shirouma-dake to the west. Nagaike-daira is surrounded by these ridges and the spur. Miniature cirques and U-shaped valleys, formed during MIS4 and 2 or before, as well as active or relict periglacial forms are also present (Koaze *et al.* 1974; Iwata 1983). This area comprises Paleozoic–Mesozoic sedimentary and metamorphic rocks as well as Neogene igneous rocks and Quaternary unconsolidated deposits (Nakano *et al.* 2002). Currently, the climate of this area is characterized by abundant snow and rain, and approximately half the annual precipitation falls as snow. Except for the ridges, snow is generally several meters thick, and may be as deep as 30 m on slopes that are leeward of the westerlies prevailing in the winter. Late-lying snow disappears in mid June to early August. The mean annual air temperature and precipitation around the summit of Shirouma-dake are estimated to be 0 ℃ and >4,000 mm, respectively (The Research Group for Alpine Geomorphology 1978; Iwata 1983). It would appear that no mountain permafrost exists in the present climate, as indicated by our unpublished rock temperature data. The tree line of the forest consisting of *Alnus maximowiczii* and *Betula ermanii* ends at 2,300–2,400 m ASL. Above the tree line, an alpine landscape comprising rubble slopes, grasslands, and dwarf tree communities (*e.g.*, *Pinus pumila*) is dominant (Fig. 2).

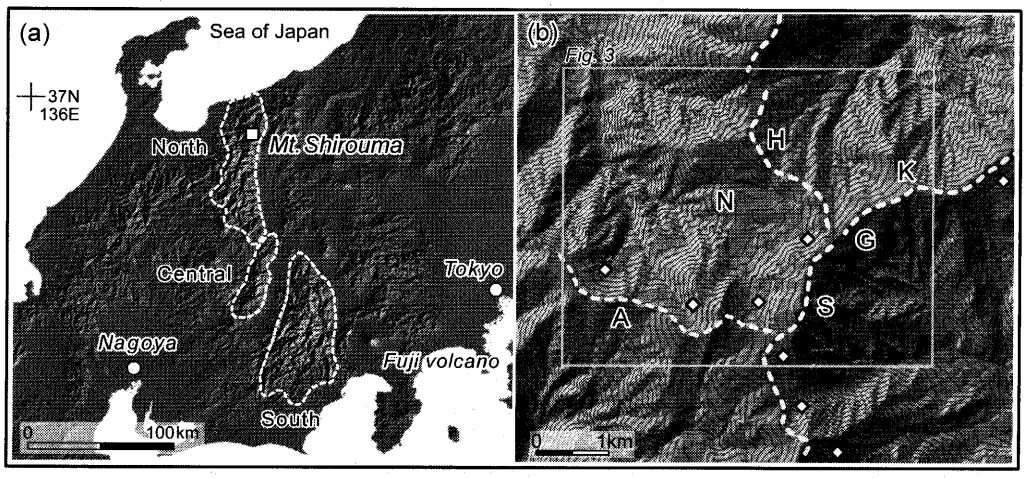

Fig. 1 (a) Japanese Alps (north, central and south sectors) in central Honshu Island. (b) Location of Shirouma-dake, Nagaike-daira and their surrounding mountains. A: Mt. Koasashi-dake (2,636 m ASL), S: Mt. Shirouma-dake (2,932 m), G: Sangokuzakai Col (2,751 m), N: Nagaike-daira, K: Mt. Korenge-yama (2,769 m), H: Mt. Hachigatake (2,563 m). A closed diamond shows a possible glacial cirque. Contour interval is 50 m. A shade-relief map was generated from 10 m DEM by using KASHIMIR3.

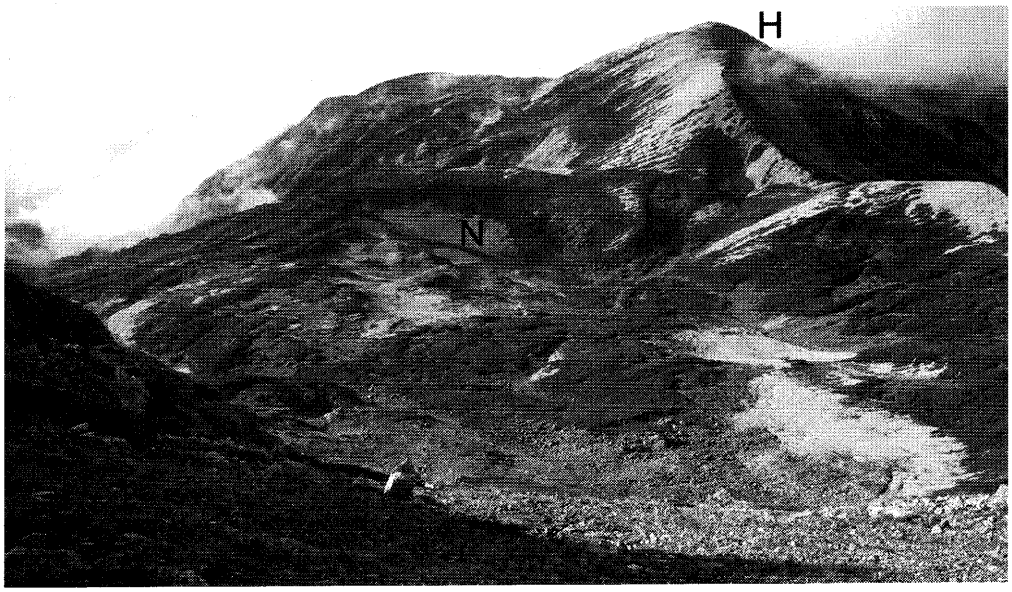

Fig. 2 Landscape of Nagaike-daira, viewed from EES. H: Mt. Hachigatake, N: Nagaike pond. (photographed by YK on Sep. 27 2004)

3. Methods

Aerial photo interpretation and on-site geological/ geomorphological investigations were carried out to define landslide topographies, especially for detecting scars, ridges, depressions, valley-side bulges, and unsteady drainage networks. Buried soil was explored for its chronology. The landscape of the study area was partly referred to from the work by Iwata (1986).

4. Results

Landslide topographies

Figure 3 shows the distribution of landslide topographies in and around Shirouma-dake. Most of the topographies are of a rotational slide type or mass rock creep type. Although some landslide topographies are considered to originate from the mass wasting of moraines, many are considered to originate from bedrock deformations.

Based on the latest geological map (1:50,000; Nakano *et al.* 2002) of this area, slipping surfaces of some landslide topographies are considered to coincide with distinctive geologic faults and/ or bedding planes of sandstone or shale. Although landslide topographies have a tendency to occur on any slope independently, a concentration of landslide bodies that forms a landslide complex is recognized. For example, a landslide complex whose estimated volume exceeds 10^6 m^3 is present in Nagaike-daira and Mount Koasahi-dake. In particular, the Nagaike-daira landslide

complex (NLC) has a distinct westing landslide body. Landslide-induced topographies such as compressive ridges and tensional depressions are common in the NLC. An empirical estimation of the relationship between the topographic dimensions (width, area, and length) and depth of slipping surface by Ueno (2001) revealed that the average depth of a slipping surface within the underlying bedrock and the volume of the landslide mass of the NLC were 110 m and 7.5×10^7 m^3, respectively. It could be considered that the westward migration of the landslide body of the NLC induced the occurrence of other landslides on the northern slopes of Shirouma-dake and the southern slopes of Mount Hachigatake. Although the age of landslide activities in the NLC is less, folded buried soil found in the northern shore of Nagaike Pond (Loc. 1; Fig. 3) indicates a date of 7433 cal BP (at a two sigma confidence error level calculated by CALIB4–IntCal04), suggesting landslide activity in the early Holocene epoch.

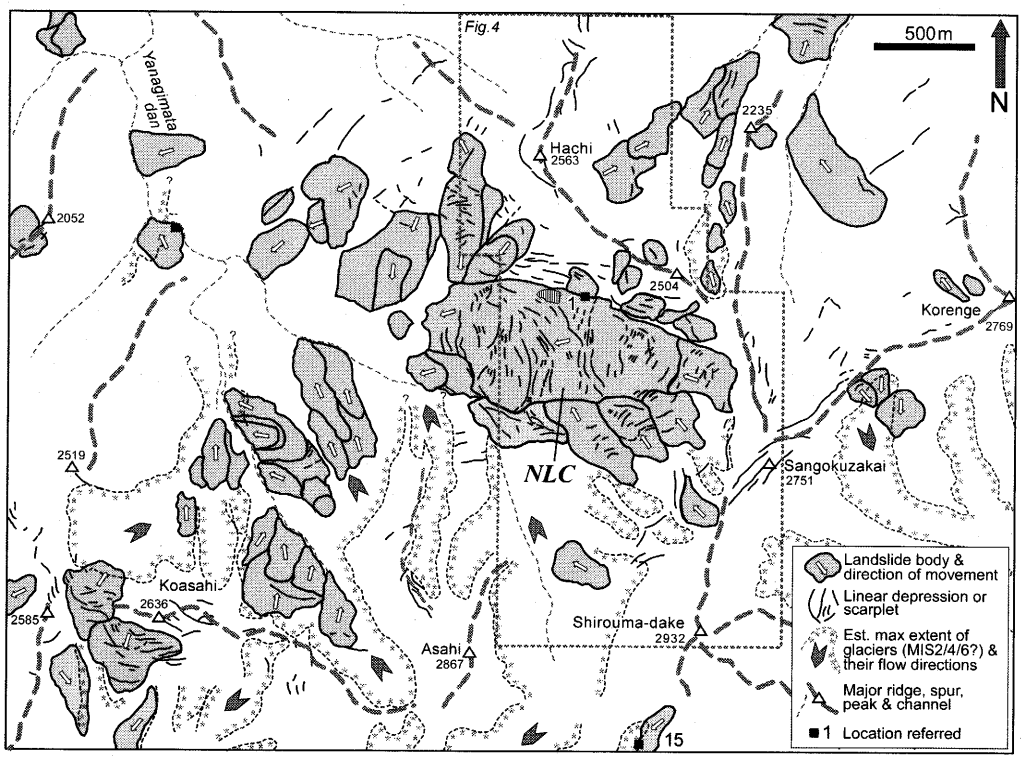

Fig. 3 Geomorphological map of landslide and glacial topographies in and around Mt. Shirouma-dake and Nagaike-daira. NLC: Nagaike-daira Landslide Complex.

Landscape of Nagaike-daira

Figure 2 shows the landscape of the alpine zone of Shirouma-dake, taking Nagaike-daira as an example. A mosaic texture comprising wind-blown or snow-induced vegetation-free rubble slopes,

wind-blown or snowpatch meadows, *Pinus pumila* patches, dwarfed broadleaf tree communities (e.g., *Alnus maximowiczii*), and sparse stands of subalpine conifers (e.g., *Abies mariesii*) is evident. Koaze *et al.* (1974), Iwata (1974, 1986) and the Research Group for Alpine Geomorphology (1978) reported the distribution of periglacial patterned grounds and related vegetation mosaics in Nagaike-daira (Fig. 4). Koaze *et al.* (1974) and Iwata (1974, 1986) also suggested that the physiographic differences in snow depth, rate and type of slope processes, lithology, and microclimates on any given slopes were one of the primary causes of mosaic formation.

5. Discussion

In order to examine the relationship between landslide topographies and the pesent landscape, a part of the landslide bodies and landslide-induced scarps shown in Fig. 3 was superimposed on the physiognomic vegetation map prepared by Iwata (1986) (Fig. 4). This superimposed chart indicates that the landslide topographies and vegetation mosaics exhibit good agreement with some of the parts with a linear or curved pattern (e.g., south of Nagaike pond, northwest of Sangokuzakai Col), while vegetation mosaics were found to be related to non-landslide topographies such as gullies and ridges (e.g., north of Hachigatake). The mechanisms of this agreement between the topographies and vegetation mosaics can be explained in that the landslide topographies accompanied by a convexo-concave surface primarily control the snow accumulation and microclimate on slopes. In turn, these factors affect the soil thermal regime, soil moisture, and properties of slope materials. Finally, these factors decide the types and rates of slope processes and soil thickness. Furthermore, the presence or absence of landslide slip surfaces could affect the mobility of groundwater and the depth of the groundwater table. The presence of landslide topographies and their importance in the development of the landscape in Shirouma-dake and Nagaike-daira has hardly been studied. However, it is evident that landslide topographies determine the surface and near-surface environments of slopes, as discussed above. This also suggests that the landscape evolution in Shirouma-dake and Nagaike-daira has been affected not only by global or semiglobal changes in climate but also by local to site environmental changes induced by past or ongoing landslide activities.

In addition, the geomorphic contribution of landslide activities to slope evolution appears to be more important than those of periglacial processes in many locations of Nagaike-daira. Given that the main landslide body of the NLC has moved westward by 300 m parallel to the ground surface and it has a slip surface that is 110 m deep, the estimated value of the long-term average of the annual vertical mass transfer (Rapp 1960) is 1.7×10^{6} ton m km^{-2} a^{-1}. This is three orders of magnitude higher than the evaluated ranges for the periglacial domain including a nivation hollow ($0.6–12.8\times10^{3}$ ton m km^{-2} a^{-1}, The Research Group for Alpine Geomorphology 1978; Iwata 1983) around Nagaike-daira.

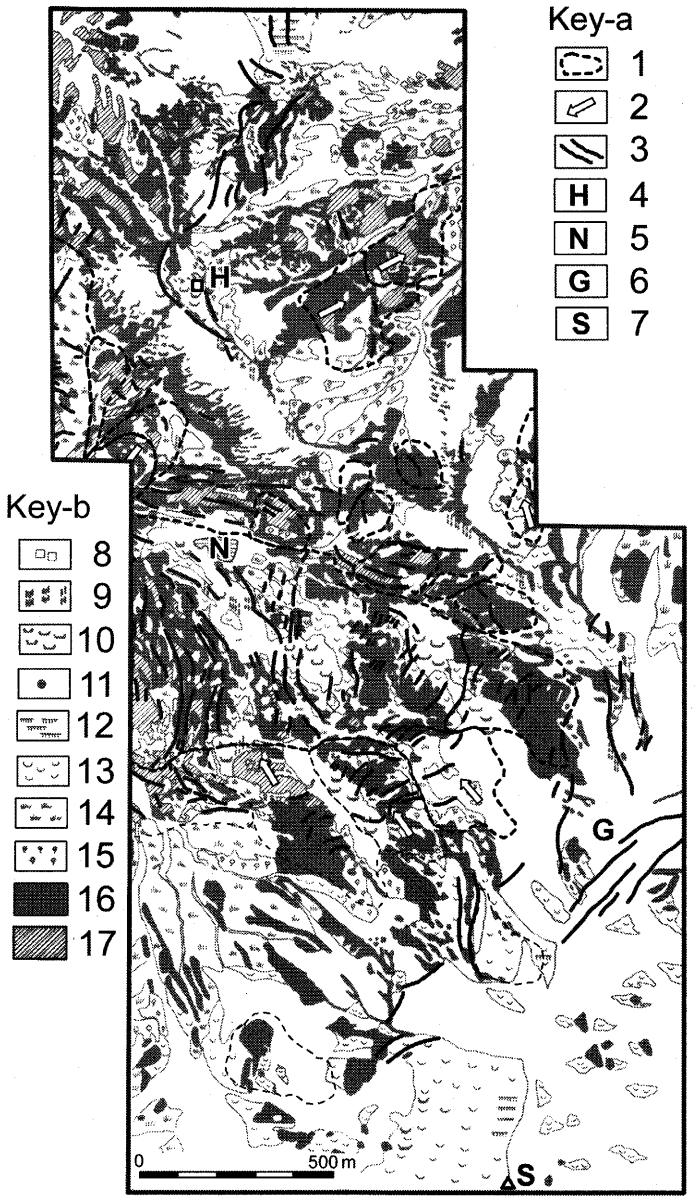

Fig. 4 Landscape structures and landslide topographies in and around Nagaike-daira (reproduced partly from Iwata, 1986). 1: Landslide bodies, 2: Movement direction of landslides, 3: scarps related to landslide activities, 4: Hachigatake, 5: Nagaike pond, 6: Sangokuzakai col, 7: Shirouma-dake, 8: Sorted net, 9: Sorted stripes, 10: Sorted lobes (stone-banked lobes), 11: vegetation covered lobes, 12: turf-banked terraces, 13: turf-banked lobes, 14: alpine meadow, 15: broad-leaved shrub, 16: *Pinus pumila* shrub, 17: forest. Keys from 8 to 17 were cited and partly toned from the figure by Iwata (1986). The area of this map is shown in Fig. 2.

6. Concluding Remarks

Unlike the case of other areas such as the Himalayas and the Karakoram (Hewitt 1999), landslide activities and their causal effects on landscape evolution in the alpine zone have not been investigated in Japan. The landscape evolution of the alpine zone has been mainly discussed from the viewpoint of climatic geomorphology. However, landslide topographies and their development cause local environmental changes, and they are considered to be an important factor in the development of landscape mosaics. Landslide topographies and their development should be studied in greater detail in order to consider the overall scheme of landscape development in high mountains in Japan.

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(* : in Japanese, **: in Japanese with English abstract)