Geomorphology 312 (2018) 51–59

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Continuous and large sediment supply in a steep landslide scar, Southern Japanese Alps

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ARTICLE INFO

Article history:
Received 23 October 2017
Received in revised form 6 March 2018
Accepted 4 April 2018
Available online 05 April 2018

Keywords:
Sediment supply
Denudation
Weathering
Channel
The Southern Japanese Alps
Airborne light detection and ranging

ABSTRACT

Continuous sediment supply in the Aka-kuzure landslide scar, in the tectonically active alpine Southern Japanese Alps, was investigated using airborne light detection and ranging data in 2000, 2003, 2007 and 2012. In addition, we focused on the spatial variability of denudation patterns based on topographical analyses using DEMs. Denudation volume for the past 12 years reached about 10^6 m^3 and mean annual denudation rate ranged from 0.25 to 0.31 m/yr. Topographical analyses revealed that sediment supply in the scar consists of a combination of two denudation types, sporadic-deep and wide-thin. These denudation types have different roles in the topographical development of the landslide scar. Sporadic-deep type supplies less volume than wide-thin type but still contributes to channel development, as it mainly occurs on lower-order streams and tends to change the convex slope into a concave slope. In contrast, although denudation depth of the wide-thin type is thin, the area affected by this type extends to the whole landslide scar. Consequently, the wide-thin type accounts for most of the total volume lost, for which detachment by frost shattering is suggested as an important role.

1. Introduction

Mountain areas in humid, tectonically active regions, such as the Himalayas, Taiwan, and Japan, have experienced competition between tectonic uplift and incision by fluvial processes (e.g. Imaizumi et al., 2017). A high relief created by uplift and incision is denudated by various hillslope processes. In such mountain areas, landslides are recognized as one of the major processes which support high denudation rates in catchments (e.g. Hovius et al., 1997; Korup et al., 2010; Larsen and Montgomery, 2012). Hovius et al. (1997) pointed to the large contribution of high-magnitude low-frequency landslide events to erosion.

Many studies have addressed the impact of landslide events, because the occurrence of landslides not only supplies a large amount of sediment into a river at once but also affects hillslope evolution, river networks, ecosystems and human activities (e.g. Korup et al., 2010; Remondo et al., 2008; Sartori et al., 2003; Chigira et al., 2013). However, the quantitative evaluation of the continuity of sediment supply in landslide scars following the initial failure is extremely limited (Gallo and Lavè, 2014; Imaizumi et al., 2015). In the High Himalayan Khudi catchment, sediment supplied into the river by the enlargement of a landslide played a dominant role on erosion in the catchment (Gallo and Lavè, 2014). Therefore, in such tectonically active regions, continuous sediment supply from landslide scars may be large, and thus cannot be ignored. Moreover, denudation components on landslide scars are expected as a combination of various hillslope processes including surface erosion, mass movement, and weathering. However, the relative contribution of these processes to topographical evolution in landslide scars has not been clarified. Therefore, evaluating the evolution of landslide scars is important in understanding sediment supply processes in catchments.

The Southern Japanese Alps (SJA), located in a tectonically active region, has many bare landslide scars. Among them, the Aka-kuzure landslide appears to be a good representative of highly erodible landslide scars, because the alluvial fan below the landslide has shown repeated growth and reduction due to sediment supplied from the landslide and fluvial erosion, respectively (Ikeda et al., 1993; Chigira and Kiho, 1994). Thus, the Aka-kuzure is a suitable site to examine the continuity of sediment supply and consequent topographical change to the landslide scar. Although an investigation of slope retreat on a limited area of the Aka-kuzure found parallel retreat along the dip direction (Imaizumi et al., 2015), the sediment production, including other hillslope processes within the Aka-kuzure, remains uncertain.

The overall aim of this study was to evaluate impact of continuous sediment supply in a landslide scar after the failure in a tectonically active and humid alpine region. We examined denudation volume in the Aka-kuzure landslide using airborne light detection and ranging

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https://doi.org/10.1016/j.geomorph.2018.04.002
0169-555X/

(LiDAR) data in four periods (2000—2012). The specific objectives of this study were (1) to interpret continuity of sediment supply from the huge landslide scar using Digital Elevation Models (DEM); (2) to assess spatial distribution of denudation patterns based on topographical analyses; and (3) to discuss contribution of each denudation pattern to topographical development, as well as to the continuity of the sediment supply, over a long period.

2. General setting of the study site

The SJA which mainly consists of Cretaceous accretionary complexes has been uplifted throughout the Quaternary (Dambara, 1971; Moriyama and Mitsuno, 1989). The uplift rate during the last century, based on the geodetic observation, is estimated to be about 4 mm/yr (Sagiya and Inoue, 2003). Such uplift of the accretionary complexes causes high dip strata, rock mass fracture and increased rock jointing. In addition to such geological situations, heavy rainfall and frequent earthquake events can induce the occurrence of landslides leading to many landslide scars in the SJA.

The Aka-kuzure landslide is located at the southern end of the SJA, in the upper basin of the Oi River (Figs. 1 to 3). There is no record of the initial failure event of the Aka-kuzure landslide, however, a (1:50000) map published in 1913 shows the presence of the landslide scar. Thus, the landslide scar has been sustained for at least 100 years. The total volume lost and landslide scar area were estimated to be about 2.7 × 10^7 m^3 and 4.1 × 10^5 m^2, respectively (Chigira, 1989). The bedrock consists of sandstone, alternations of sandstone and shale, and shale (Chigira and Kiho, 1994). Thickness of the sandstone is up to about 5 m depending on the locations within the landslide, while shale thickness is relatively consistent at about 0.2 m (Ikeda et al., 1993). The dip of strata trending NE–SW shows 20° to 40° eastward (back slope) in the landslide scar and 40° to 80° westward (dip slope) in its tip (Chigira and Kiho, 1994). Such geological structures and the distribution of multiple uphill and down-hill facing scarps on the middle to upper slopes suggest that the surrounding slope, including the landslide, has experienced deep-seated gravitational slope deformation (Chigira and Kiho, 1994). The surface of the landslide scar is finely dissected by deep gullies, which resembles a badland landscape (Lin and Oguchi, 2004) (Fig. 3c). The slope inclination, except for the valley bottoms, is more than the angle of repose (about 35°), thus preventing plants from taking root on the steep rock slope. On dry days, surface flows are limited to running along the valley in the center of the landslide, while on wet days surface flows appear in a wider area. The alluvial fan just below the landslide scar extends to the Oi River (Fig. 3d). The occurrence of debris flows in the channels due to heavy summer rainfall controls the development of the alluvial fan. Active sediment transportation on the alluvial fan is revealed based upon the interpretation of aerial photographs and on-site surveys (Aniya, 1980; Ikeda et al., 1993;

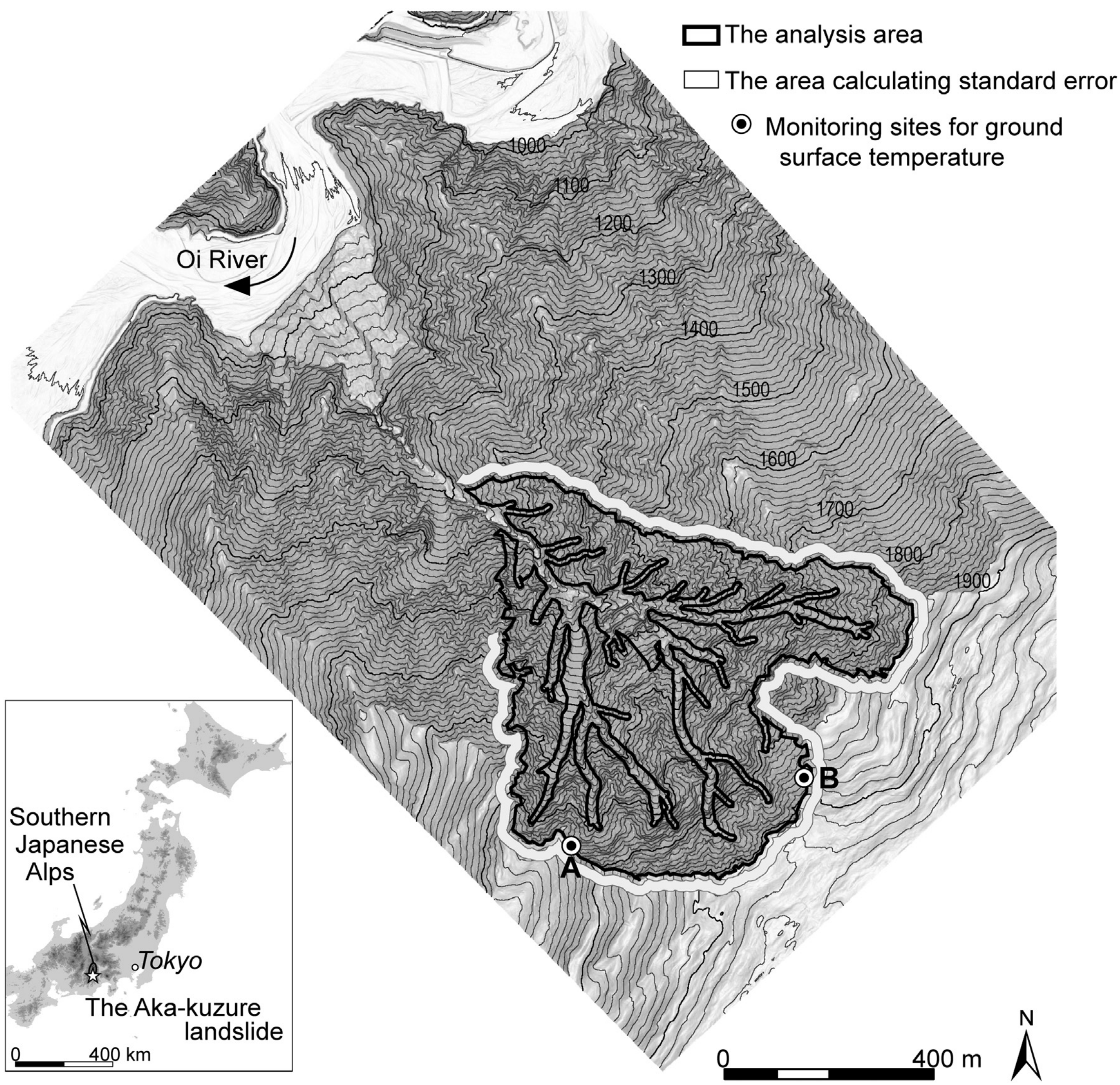

Fig. 1. Topographical map of the Aka-kuzure landslide. Contour interval is 10 m.