Potential interactions between prior earthquakes and later landslide initiation – evidence from Central Asia and Japan

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1. INTRODUCTION

Factors affecting earthquake-initiated landslides include earthquake magnitude, focal depth, and seismic wave propagation and attenuation. Landslides triggered by earthquakes often occur on convex slopes and near ridgelines, while landslide initiated by rainfall or snowmelt usually occur on hillslope locations where subsurface water accumulates (e.g., geomorphic hollows, locations downslope where subsurface water accumulates) (Sidle and Ochiai, 2006). Evidence is presented from Fergana Basin in Kyrgyzstan and the area west of the Mount Aso in Kumamoto Prefecture, Japan, on how fissures developed during earthquakes may promote subsequent initiation of rainfall-triggered landslides. Such fissures have been recognized in areas that have experienced large earthquakes, but these have not been directly associated with later landslide initiation.

2. RESULTS AND DISCUSSION

More than 1800 recent major landslides in hilly terrain and soft sediments of the Fegana Basin have been largely attributed to accumulation of heavy rainfall and snowmelt (Haberland et al., 2011). Most of these landslides have occurred near ridgelines and/or on convex slopes – not typical locations of rainfall-initiated mass failures. While no recent large earthquakes have occurred in the Fergana Basin, smaller earthquakes have generated fissures near ridgelines and on convex slopes (Figure 1a). The connection of fissures, developed years or decades before slope failure, with preferential transport of rainwater and runoff into the soil has not been previously investigated. Fissures have been observed to expand with time, particularly during subsequent minor earthquakes, further promoting preferential infiltration. Because the soil mantle is rather homogeneous, the position and depth of these fissures may control the location and depth of slope failures. Zones in the soil where

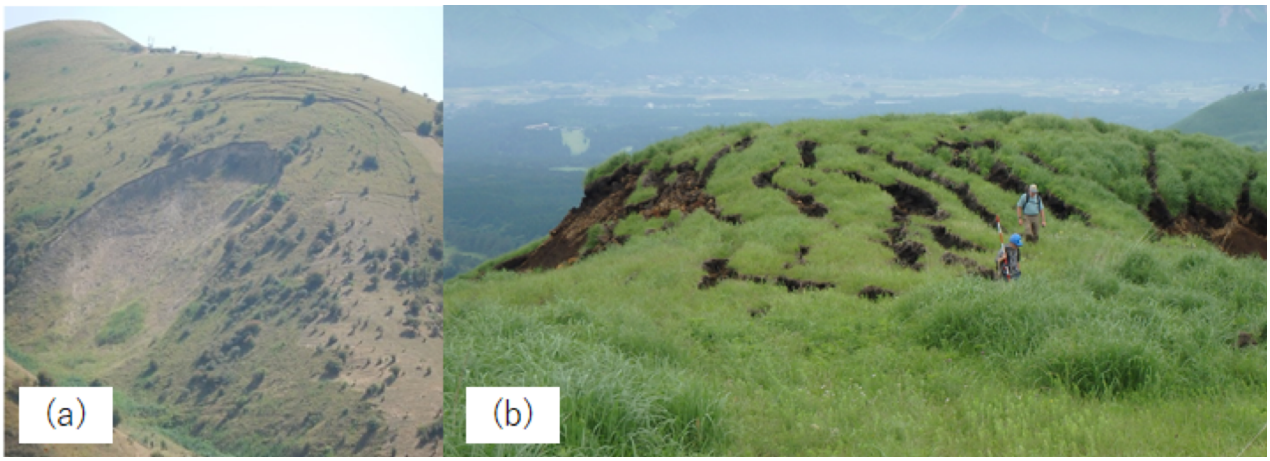

Figure1. Earthquake generated fissures on ridgelines near areas of landslide initiation or potential new landslides: (a) landslides that occurred in 2003 near Uzgen, Kyrgyzstan, with fissures upslope; (b) multiple fissures along a ridgeline near Mt. Aso where a landslide occurred during 2016 earthquake.

surficial inputs of water are preferentially transported, augment natural subsurface accumulation of antecedent rainfall and snowmelt. Many landslides in the eastern Fergana Basin occur after several months of accumulated precipitation, and shallow groundwater has been observed emerging on critical hillside locations prior to slope failure.

An unusual temporal series of earthquakes struck the area near Kumamoto, Japan in April 2016. A large (M 6.5) foreshock on April 14th was followed 28 hours later by the major (M 7.3) tremor (e.g., Kawase et al., 2017). The earthquakes had shallow focal depths (about 10-12 km) and generated shaking intensities of 7, the highest on the Japanese scale. The most intense ground shaking occurred on the west side of Mount Aso causing numerous landslides. Although a few longer runout landslides/debris flows occurred, most landslide deposits accumulated on hillslopes or within headwater channels. Many landslides initiated along ridgelines or on convex and planer slopes due to amplifications of seismic waves. Within the Tokosegawa-Nigorigawa basins (total area 13 km^2) that we examined, forested areas occupied steeper terrain than grasslands; however, grasslands with slope gradients > 30° had a larger percentage of land disturbed by landslides compared to forests. Large displaced soil blocks were common in the landslides and were thrust to the surface on ridgelines during the intense shaking. Despite the many landslides that occurred during the earthquakes, much of the damage from mass wasting may be realized later. Future landslides along ridgelines will likely occur where large fissures (1-2 m deep) appeared during the earthquakes (Figure 1b).

As noted, fissures can preferentially route rain water and runoff into the soil mantle, thus augmenting pore water pressures that may trigger landslides in future periods of heavy or accumulated rainfall. Additionally, landslide sediment stored in headwater channels because to the limited mobility of many of the 2016 earthquake-initiated failures poses a risk for future debris flows during large storms (Lin et al., 2006). Surface erosion from landslide scars together with new landslides along ridgelines will exacerbate sediment accumulation in these headwaters. As channels accumulate sediment, they become increasingly vulnerable to debris flows during large flow events (Sidle and Ochiai, 2006). This scenario represents a cascading sequence of hydrogeomorphic events that generate future environmental and human risks, including impacts on water quality, sediment disasters in rural communities, and damage to buildings and infrastructure.

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