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Geomorphological and Geological Features of The Collapsing Landslides Induced by The 2009 Padang Earthquake.

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The Mw7.6 Padang earthquake in 2009 attacked the northwest of Sumatra, Indonesia, and triggered many landslides, which killed at least 130 people at one village. We made satellite image interpretations, field investigations, and laboratory tests to identify the geomorphological and geological features of these landslides. As a result, we found that the number of landslides was 159, materials that slid were pumice fall deposits, and their sliding surface was made within the base of the pumice layer where pumice grains were mixed with underlying lahar and heavily weathered. These landslides had the following characteristics: 1) they occurred in the areas with pumice beds with $>$3 m thickness, which was controlled by the distance from their source; 2) the pumice fall deposits had a slope-parallel layering, which had been cut at the foots of slopes; and 3) the mixed layer at the base of the pumice beds was heavily weathered to be clayey materials with abundant halloysite.

We made an isopach map of the pumice fall deposits, which is so-called Qhpt and believed to be from Maninjau Caldera. The isopach contours, however, showed that Qhpt is from Tandikat Volcano, and that landslides occurred in clusters in the areas with pumice beds thicker than 3.5 m.

Qhpt beds had slope-parallel bedding, but they were undercut by subsequent river incision. Interpretations of stereoscopic satellite images and field surveys showed that there are four terraces along the Magung River, and Qhpt covers widely distributed higher terraces (Lh) of lahar younger than 80 ka and middle terraces (Lm) but are cut by lower terraces (Ll1 and Ll2) as well as small nearby tributary gullies. This undercutting likely reduced the support of Qhpt beds from downslope.

The mixed layers, in which sliding surfaces were formed, were heavily weathered and very weak; weaker than the main Qhpt above and the lahar below. XRD analyses showed that pumice grains of the main part of Qhpt scarcely had halloysite but pumice grains and weathered lahar in the mixed layers were rich in halloysite. The formation of halloysite could be attributed to the interaction between the materials of the mixed layers and the water coming through Qhpt beds; water, which gets Si and other chemical components from the volcanic glass of pumice, may become stagnant in the mixed layers because they are much less permeable than the Qhpt beds above. This would be a preferable condition of halloysite formation.

Infinite slope stability analysis using geotechnical parameters, pumice bed thickness, and slope angles, which we obtained, suggested that landslides with sliding surfaces within the mixed layers could be triggered by the shaking of the 2009 Padang earthquake. The natural water contents of the materials of the mixed layers exceeded their liquid limits, which suggests that they would behave like a liquid after remolding.

The geological history, which is volcanic eruption, weathering, and undercutting by river incision as stated above, is typical in tropical volcanic areas. That means we can make a hazard map of such a catastrophic landslide induced by earthquakes on the basis of geological development.

Keywords: 2009 Padang earthquake, Halloysite, Collapsing landslide, pumice fall deposits, weathering