

## Geological precursors of catastrophic landslides induced by earthquakes

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Recent earthquakes, the 2011 Tohoku earthquake, the 2009 Padang earthquake, the 2008 Wenchuan earthquake, the 2008 Iwate-Miyagi Inland earthquake, the 2005 northern Pakistan earthquake, and the 2005 Mid Niigata prefecture earthquake, gave us lessons about where and why large, catastrophic landslides are induced by earthquakes: those landslides had specific preparatory processes, mechanical or chemical, to be induced by earthquakes.

The 2011 Tohoku earthquake induced long run out catastrophic landslides in pyroclastic fall deposits with a sliding surface in halloysite-rich paleosol, which once was made by chemical weathering and has been resiltified so that gibbsite changed to halloysite. Halloysite is very fragile against shaking and has been a major component of sliding surface materials of landslides during many earthquakes including the 2009 Padang earthquake. Dissolution of carbonate by groundwater was another chemical preparatory process of landslides induced by the 2008 Wenchuan earthquake.

Mechanical preparation for earthquake-induced large landslides is deep-seated gravitational slope deformation, which preceded many landslides involving the Daguobao landslides by the Wenchuan earthquake and the Chiu-fen-erh-shan and the Tsaoling landslides during the Chi-Chi earthquake. Deep-seated gravitational slope deformation deteriorates rocks, which would become more susceptible to earthquake tremor. River erosion that undercut previous landslides, once collided to the opposite slope, is another important mechanical preparation for the landslides reactivated by earthquakes. There occurred many such catastrophic landslides during the Mid Niigata prefecture earthquake and the northern Pakistan earthquake.

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