

Cascading hillslope disasters by earthquake and subsequent heavy rainfall: geological factors affecting co-seismic and post-seismic landslides in the Noto Peninsula

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This presentation reports the results of an engineering-geological analyses of landslides caused by earthquake and subsequent heavy rainfall in 2024 in the Noto Peninsula, Japan. The spatial density and morpho-dynamics of the landslides differed clearly depending on the topographic and geological conditions. Subsurface structures of the bedrock weathering zone and their regulation on the hillslope hydrological characteristics seemed to be the critical factors that controlled the landslide diversity. Typical geological conditions are pyroclastic rocks, siliceous mudstones, and alternating beds of sandy and muddy rocks. We examined the mechanisms and processes of landslides based on geospatial analyses, ground-based survey, hydrological observations, and physicochemical analyses of hillslope materials.

In the area underlain by pyroclastic rocks, landslides of shallow layers including soil and heavily weathered bedrock occurred at high elevations of the mountainous terrain by the earthquake, and the debris flowed down along river channels for long distances. During the subsequent heavy rainfall at eight months later, new landsliding, expansion of existing scars, and reworking of the deposits in the channels resulted in large amounts of sediment and driftwood discharge into the lowlands. The pyroclastic rock is characterized by a hard unweathered portion and a significant decline in wet strength due to weathering through hydration of glassy matrix and clay mineral formation. The contrasting behavior in response to the seismic motions and vertical discontinuous profiles of hydraulic properties within the weathered zone seemed to have strongly influenced on the co-seismic and post-seismic mass movements.

In the areas where siliceous mudstones are distributed, the co-seismic landslides showed contrasting morpho-dynamics depending on the conditions of anti-dip or dip slopes for the beddings, which are characterized by shallow topsoil collapses and rockfalls in steep hillslopes or deep translational sliding in relatively gentle slopes. The weathered bedrock colored yellowish-white to reddish-brown includes numerous open fractures, whereas the underlying dark-gray, pyrite-bearing parent rock is often exposed on sliding surfaces of the deep landslides. This situation suggested that the interactions of sulfuric acid formation by water-rock reactions associated with mineral dissolution and elemental leaching, and the deposition of iron (hydro)oxides with swelling and shrinkage during wet-and-dry cycles, resulted in progressive rock fragmentation and mass-strength loss, contributing to the occurrence of the mass movements. Comparison of landslide inventories between earthquakes and heavy rainfall suggests that changes in predisposing conditions, such as reduced bulk stiffness and improved drainage capability due to the bedrock body by seismic shaking, may provide both positive or negative effects on the landslide susceptibility.

In the hillslopes composed of sandstone-mudstone alternating beds, despite the small number of co-seismic landslides, the post-earthquake heavy rainfall induced many landslides with a high spatial density. In this geology, the sandy strata become plastic through weathering, while the muddy parts retain some elasticity and brittle state. Such piled alternating properties invoke a hypothesis of seismic isolation by the weathered geological structure, in which these layers function to suppress the seismic motion near surface. Even if the preceding earthquake did not cause any visible landslide, the energy of the seismic motion may have flawed the weathered bedrock, and increased the room for pore pressure build-up in

the crack networks by rainwater infiltration, which then contributed to the anomalous landsliding.

Keywords: landslides, post-earthquake heavy rainfall, complex cascading disaster, bedrock weathering, seismic isolation by geological structure