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Subaqueous landslides in earthquake-prone South-Central Chile: The role of ash and quick clay on slope failure

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Submarine slope failures represent one of the most frequent, dynamic and devastating geohazards along active margins concerning onshore and offshore infrastructure as well as coastal communities. 'In situ' geotechnical characterization of submarine slopes located in active geological settings is therefore compulsory for the understanding of submarine landslide initiation. Lakes have been shown to represent "small-scale model oceans" with a regionally constrained area where most of the governing factors are known. Other than in the marine realm, sliding surfaces, i.e. 'weak layers' are easily and cost effectively accessible with conventional coring rigs and 'in situ' geotechnical devices. Lake Villarrica is such a natural laboratory for landslide initiation studies in a seismically and volcanically active area. It is a large glacigenic lake (ca. 20 x 10 km) located at the foot of Villarrica Volcano in the Andes, in south-central Chile. High magnitude earthquakes occur regularly due to the subduction of the Nazca plate under the South American continent. Seismic reflection and side scan sonar data of this lake reveal numerous slope failures characterized by two main sliding surfaces at two distinct levels in the stratigraphy. The MARUM free fall shallow-water CPT has been deployed in order to investigate the geotechnical properties of these lithological units. Cone resistance, sleeve friction and pore pressure have been measured on a plateau of unfailed slope material down to a depth of ~ 8.1 m, reaching both stratigraphic units that act as sliding surface on the slope. Cores of ~ 8 m length have been taken for further geotechnical laboratory experiments and sediment characterization. The upper $\sim$7 m of unfailed sediment mainly consist of biogenic opal alternating with tephra layers. The lower part of the core contains quick clay with a sensitivity > 500. At ~ 3 m depth a drastic decrease in cone resistance gradient has been noted. One of the sliding surfaces is located right above a sandy-silt tephra layer that is susceptible to liquefy as confirmed by cyclic triaxial tests. The second sliding surface is located within the unit of quick clay. None of the sliding surfaces has been identified as being particularly weak in terms of static drained shear strength. However, the undrained shear strength deduced from cone resistances data indicate an overall overconsolidation of the sediment except the quick clay.

We present a broad set of 'in situ' and laboratory geotechnical data (CPT, MSCL, SEM, XRD grain-size distribution, moisture and density, vane shear, direct shear, cyclic triaxial shear) that characterize the sliding surfaces of a subaqueous slide in much detail. This data set, combined with seismic and side scan data of sediment involved in large lake-bottom sliding processes, allows for detailed location and analysis of a 'weak layer' and contributes to a better understanding of slope failure initiation applicable to the marine realm.