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Large slope instabilities in Northern Chile and Southern Peru

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Deep canyon incision into Tertiary paleosurfaces and large slope instabilities along the canyon flanks characterize the landscape of western slope of the Andes of northern Chile and South Peru. This area belongs to the Coastal Escarpment and Precordillera and is formed by coarse-grained clastic and volcanoclastic formations. The area is characterized by intense seismicity and long-term hyperaridity (Atacama Desert). Landslides along the canyon flanks affect volumes generally up to 1 km^3 and locally evolved in large rock avalanches. We prepared a landslide inventory covering an area of about 30,000 km^2, extending from Iquique (Chile) to the South and Tacna (Peru) to the North. A total of 606 landslides have been mapped in the area by use of satellite images and direct field surveys, prevalently including large phenomena. The landslides range from 1 10^{-3} km^2 to 464 km^2 (Lluta landslide). The total landslide area, inclusive of the landslide scarp and of the deposit, amounts to about 2,130 km^2 (about 7% of the area).

The mega landslides can be classified as large block slides that can evolve in large rock avalanches (e.g. Minimini landslide). Their initiation seems to be strongly associated to the presence of secondary faults and large fractures transversal to the slope. These landslides show evidence suggesting a re-incision by the main canyon network. This seems particularly true for the Lluta collapse where the main "landslide" mass is masked or deleted by the successive erosion. Other landslides have been mapped along the Coastal Escarpment and some of the major tectonic escarpments with an E-W trend. We examined area-frequency distributions of landslides by developing logarithmically binned, non-cumulative size frequency distributions that report frequency density as a function of landslide planar area A. The size frequency distribution presents a strong undersampling for smaller landslides, due to the extremely old age of the inventory. For landslides larger than 2 000 m^2, the distribution exhibits a power-law behaviour with scaling exponent, β, equal to -2.24. For comparison, we analysed the power-law behaviour of other earthquake-induced landslide inventories, obtaining similar results, although the geological and seismic conditions may have been very different (Buller, New Zealand, β = -2.42; Iningahua, New Zealand, β = -2.53; Northridge, USA, β = -2.39; Chi-Chi, Taiwan, β = -2.30; Wenchuan Earthquake, China, β = -2.19). Volume estimates and slope stability modelling have been completed to characterize the phenomena and the possible triggering mechanisms. For volume estimate, we reconstructed the pre-failure surface for tens of landslides, in order to characterize the area-volume relationship. By using this relationship, we assigned a volume to all landslides of the inventory. The study area is subject to a high seismicity associated to earthquakes of different type: interplate (superficial and intermediate depth), subduction zone earthquakes, and earthquake along the Coastal Escarpment. By analysing the frequency size relationships for earthquake-induced landslides from literature, it is possible to observe that the higher the earthquake Magnitude, the higher the frequency density curve. To quantify this observation, we used the power-law relationships derived for each inventory to calculate the frequency density associated to selected areas, and we plotted these frequencies as a function of the magnitude of the respective earthquakes. By fitting these values, we derived the expected Magnitude required to generate the landslide distribution of the study area. In conclusion, we argue that the evolution of these landslides is controlled by: deep valley incision, canyon walls undercutting and lateral migration of the river controlled by valley flank instabilities, the Presence of weak lithologies and weak basal layers, the river incision debuttressing the slope toe and especially brings to daylighting the weak basal layers observed at some landslide sites, the possible deep groundwater flow above the deep impermeable formations and clay layers, the movement along sub-horizontal basal shear zones which can be locally extruded at the slope toe, the river damming because of the strong lateral components of displacement and successive reincision by the river with dam failure, the possible sequence of reactivations by reincision of the deposit, and the occurrence of high magnitude (8-9) earthquakes.