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MORPHOLOGIC DESCRIPTION OF THE PUNTA COLA ROCK AVALANCHE AND ASSOCIATED MINOR ROCKSLIDES CAUSED BY THE 21 APRIL 2007 AYSÉN EARTHQUAKE (PATAGONIA, SOUTHERN CHILE).

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INTRODUCTION

On 21 April 2007 the Aysén fjord earthquake (Mw 6.2) in southern Chile, triggered hundreds of landslides in the epicentral area along the fjord coast and surroundings (Figure 1). The seismicity was associated with tectonic activity in the Liquiñe-Ofqui Fault Zone (LOFZ), a major structural feature of the region. The landslides included rock slides and avalanches, rock falls, shallow soil and soil-rock slides, and debris flows [Sepúlveda and Serey, 2009]. Some of the major rock slides and rock avalanches caused large tsunami waves that impacted the fjord coasts.
Our project aims to understand the condition factors controlling size and distribution of earthquake triggered landslides. This includes detailed structural analysis of fault zones in the Aysén fjord region, on-site engineering geological and structural mapping, terrestrial laser scanning and photogrammetric analysis of selected rockslide sites as well as the elaboration of detailed digital elevation models prior to and after the 2007 earthquake.
This study focuses on the morphologic and structural analysis of the 12 Mm^3 Punta Cola rock avalanche [Sepúlveda and Serey, 2009] (Figure 2) based on a high-resolution digital elevation model (HR-DEM) provided by terrestrial laser scanning. This dataset will enable precise volume estimations, kinematic interpretations and dynamic back-analyses of rock slope failures and detailed run-out analyses of high mobility rock slope failures.

TERRESTRIAL LASER SCANNING

Terrestrial laser scanning (TLS) is based on the reflectorless and contactless acquisition of a point cloud of the topography using the time-of-flight distance measurement of an infrared laser pulse. The Optech ILRIS-3D used for this study has a wavelength of 1500 nm and a range in practice of about 600 to 1000 m on rock slopes.
TLS is widely used nowadays in landslide studies, such as rockfall quantification and back-analyses [e.g. Rosser et al., 2005; Abellán et al., 2006], structural analyses [e.g. Jaboyedoff et al., 2007; Sturzenegger and Stead, 2009] or the measurement of displacements [e.g. Oppikofer et al., 2008; 2009; Teza et al., 2008; Abellán et al., 2009].
A total of 58 scans have been acquired in January 2010 from 11 viewpoints on the Punta Cola rock avalanche deposits (Figure 3) in order to cover as completely as possible the study area.
The TLS datasets were treated and analyzed using the PolyWorks software. The procedure includes a manual cleaning of the raw point clouds, their co-registration (or alignment) and georeferencing using the GPS coordinates of the scanner locations (see Oppikofer et al., 2009 for a detailed description of the methodology). Finally, a HR-DEM with a cell size of 25 cm and a hillshade (view-shaded relief representation) are created (Figure 3).

ROCKSLIDE MORPHOLOGY

ROCKSLIDE SCAR ZONE

The scar of the Punta Cola rock avalanche is nearly 1 km long and up to 760 m wide (Figure 3). The height difference between the crown and the toe of the basal failure surface is more than 530 m. The basal failure surface is exposed in the north-eastern part of the rockslide scar and displays a complex morphology using several pre-existing discontinuities, but also newly formed fractures (Figure 2a). The rockslide scar is delimited to the south by an up to 115 m high WNW-ESE-trending subvertical lateral release surface (Figure

2a). A detailed structural analysis will be performed to improve our understanding of the rockslide failure mechanism and the role of active faults in the location and development of large rockslides.

ROCK AVALANCHE PROPAGATION

The rock avalanche caused significant erosion of the 1.5 km long valley down to the Aysén fjord with a maximum run-up height of 150 m on the opposite valley flank (Figures 2b, 4). The rock avalanche impacted the fjord and caused a tsunami [Sepúlveda and Serey, 2009]. Based on the pre-earthquake topography obtained by photogrammetry and the post-earthquake HR-DEM acquired in this study, detailed volume computations and run-out analyses will be made. Based on the present morphology of deposits it is likely that the rock avalanche occurred in several pulses, but more detailed investigations are necessary to assert this hypothesis.

Entrainment of surface material into the rock avalanche is likely substantial. Preliminary estimates of entrainment of soil and vegetation into the Punta Cola rock avalanche indicate that those materials contributed a 15-20% to the entire rock avalanche volume. Close to the shoreline rock avalanche deposits where more than 35 m thick and display a typical steep front (Figure 2c). The composition of the deposits varies between the two valley sides with more blocky material on the left valley side and more soil rich material on the right side. This higher soil content seems to be related to higher entrainment of soil and vegetation cover along the right valley flank compared to the left flank, where the rock avalanche run-up height was also lower.

SECONDARY ROCKSLIDES

Five major secondary rockslides occurred within the valley of the Punta Cola rock avalanche (Figures 2b, 3 and 4). The detailed HR-DEM obtained by TLS also allows understanding the sequence of sliding with the secondary slides having occurred after the main rock avalanche. Lobate landslide deposits with high soil content overlying fresh blocky rockslide debris suggests that these secondary landslides were caused by scouring of valley flanks by the main Punta Cola rock avalanche or by earthquake aftershocks (Figures 2b, 3 and 4).

CONCLUSIONS

The study of the 2007 Punta Cola rock avalanche highlights the complex structures and mechanisms involved earthquake-triggered landslides and the complex propagation of the rock avalanche in the valley with intense scouring along the valley flanks and the triggering of several secondary rockslides.

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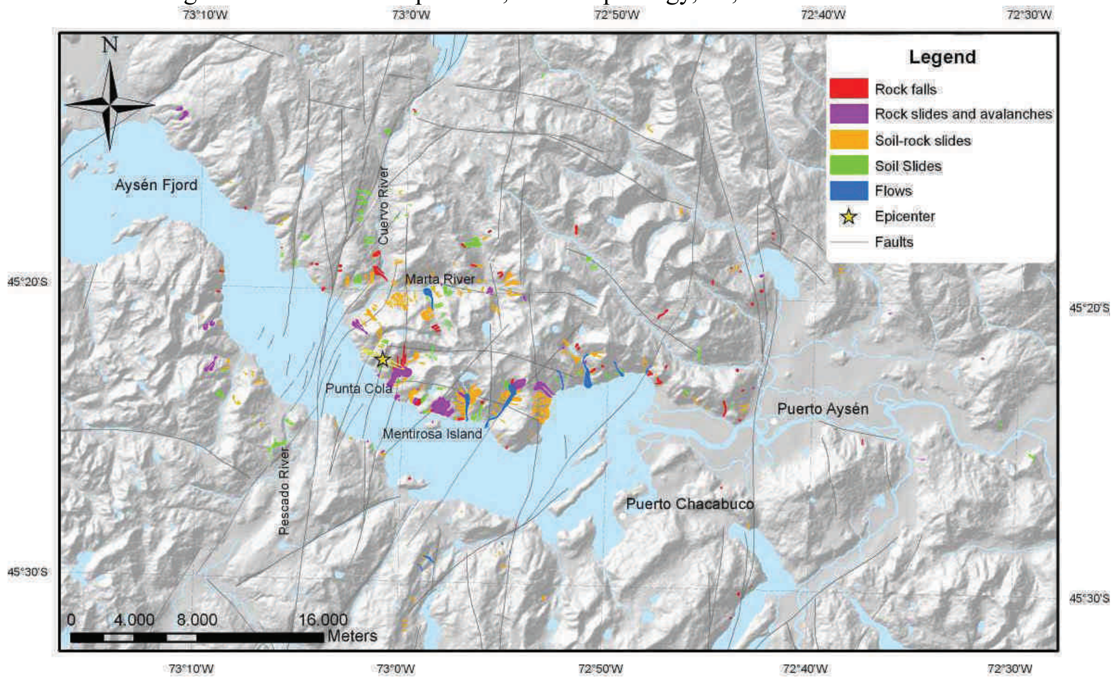

Figure 1. Distribution of landslides triggered by the 21 April 2007 Aysén earthquake [Sepúlveda et al., 2010]. The Punta Cola rock avalanche occurred in immediate vicinity to the epicentre.

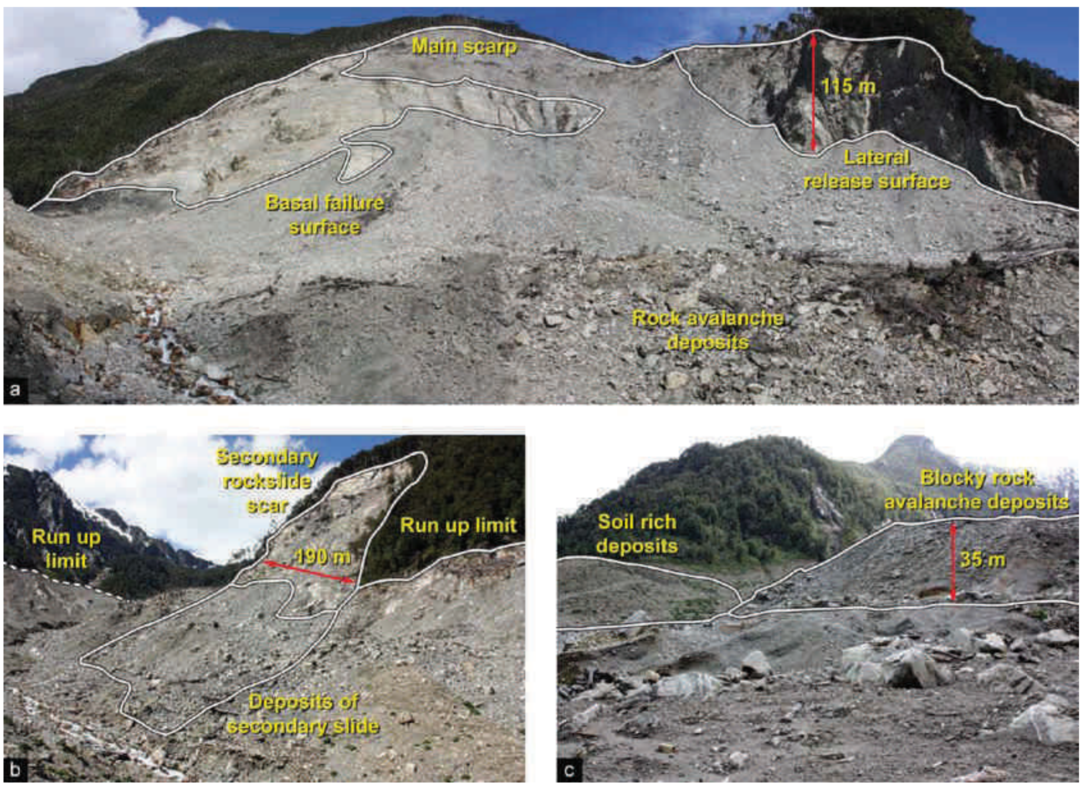

Figure 2: Photographs of the Punta Cola rock avalanche: a) panorama of the rockslide scar displaying the outcropping basal failure surface and the 115 m high lateral release surface. A branch of the LOFZ passes across the lateral release surface and the head scarp; b) secondary rockslide scar, associated deposits and run up limits of the main rock avalanche on the right valley side; c) steep rock avalanche deposits with different compositions (blocky vs. soil rich).

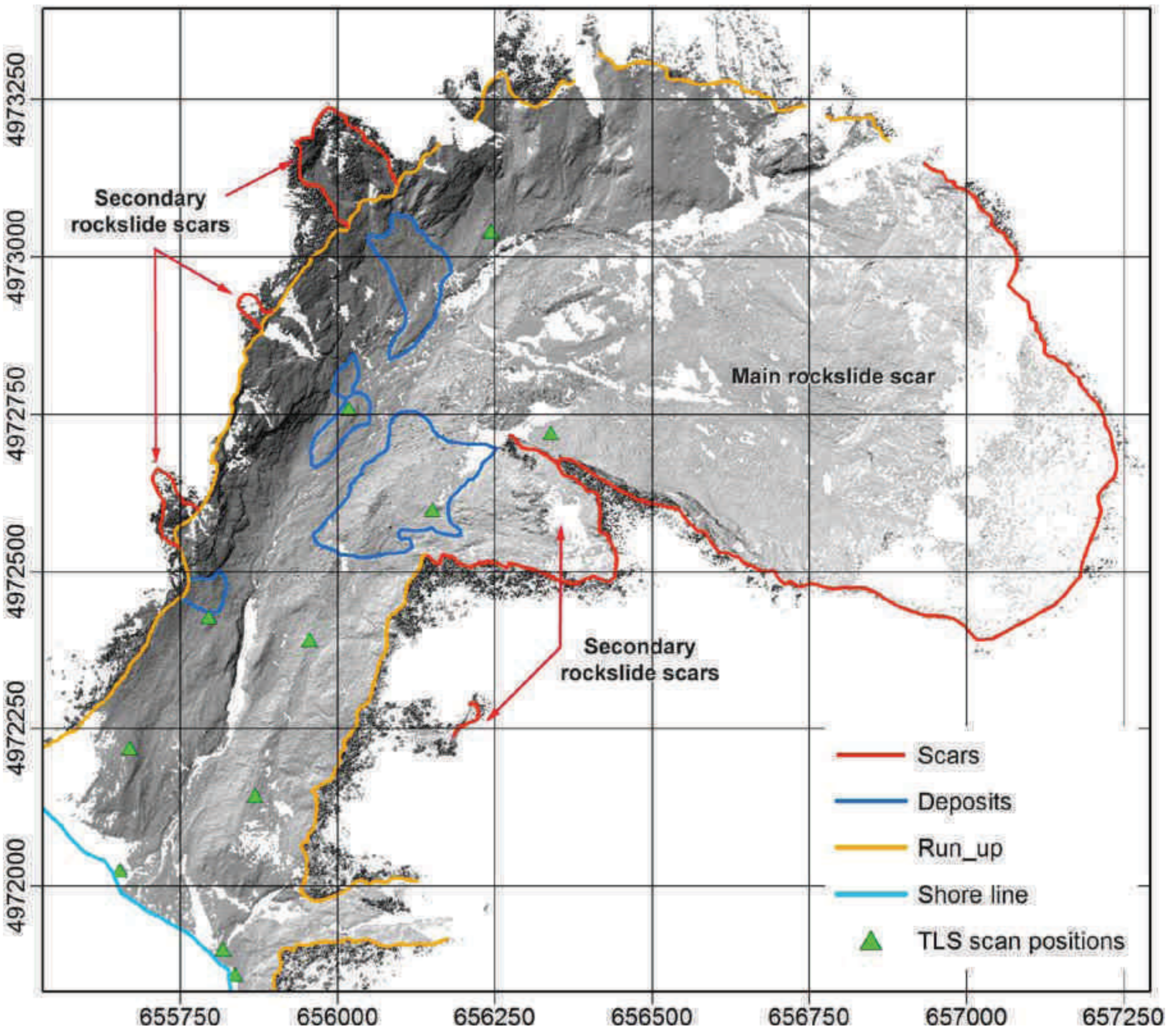

Figure 3. Hillshade of the HR-DEM created from the TLS point clouds of the Punta Cola rockslide scar and the rock avalanche deposits. The main morphological features of the rock avalanche and the TLS scan positions are shown (coordinates in UTM 18S).

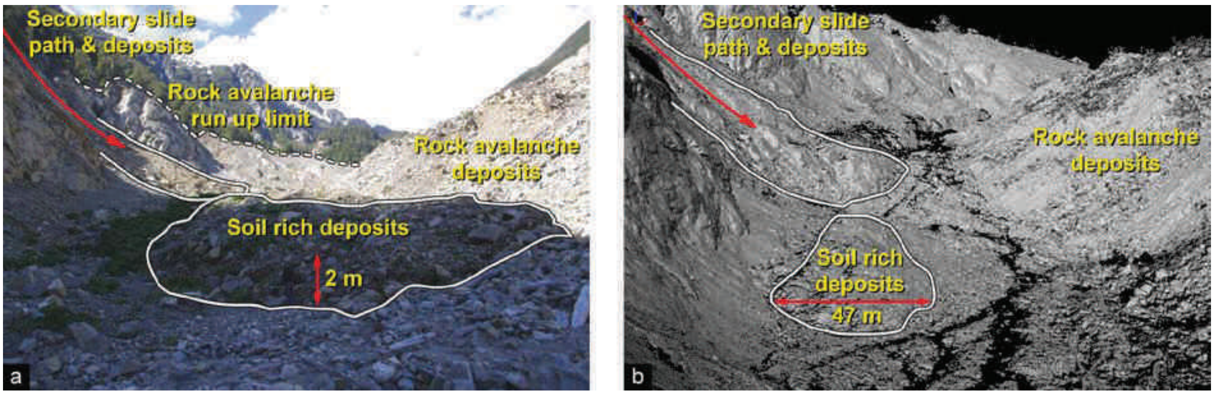

Figure 4. a) Lobate soil rich landslide deposits in the run out area of the Punta Cola rock avalanche attest that scouring by the rock avalanche along valley flanks caused secondary landslides contributing significantly to the total landslide volume; b) terrestrial laser scanner point cloud with similar view as the photograph reveals the morphology of the different deposits, including the soil rich lobe deposited onto the main rock avalanche deposits.