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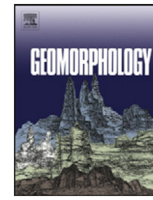

Analysis of past and future dam formation and failure in the Santa Cruz River (San Juan province, Argentina)

Ivanna M. Penna [a,b,c,*], Marc-Henri Derron [a], Michele Volpi [a], Michel Jaboyedoff [a]

[a] *Research Centre for Terrestrial Environment — CRET, University of Lausanne, Geopolis 3156, CH-1015 Lausanne, Switzerland*
[b] *Departamento de Ciencias Geológicas, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Ciudad Universitaria, Pabellón II, 1427, Buenos Aires, Argentina*
[c] *Consejo Nacional de Investigaciones Científicas y Técnicas-CONICET, Buenos Aires, Argentina*

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ABSTRACT

Around $11.5*10^6$ m^3 of rock detached from the eastern slope of the Santa Cruz valley (San Juan province, Argentina) in the first fortnight of January 2005. The rockslide–debris avalanche blocked the course, resulting in the development of a lake with maximum length of around 3.5 km. The increase in the inflow rate from 47,000–74,000 m^3/d between April and October to 304,000 m^3/d between late October and the first fortnight of November, accelerated the growing rate of the lake. On 12 November 2005 the dam failed, releasing $24.6*10^6$ m^3 of water. The resulting outburst flood caused damages mainly on infrastructure, and affected the facilities of a hydropower dam which was under construction 250 km downstream from the source area. In this work we describe causes and consequences of the natural dam formation and failure, and we dynamically model the 2005 rockslide–debris avalanche with DAN3D. Additionally, as a volume ~$24*10^6$ $m^3$of rocks still remain unstable in the slope, we use the results of the back analysis to forecast the formation of a future natural dam. We analyzed two potential scenarios: a partial slope failure of $6.5*10^6$ m^3 and a worst case where all the unstable volume remaining in the slope fails. The spreading of those potential events shows that a new blockage of the Santa Cruz River is likely to occur. According to their modeled morphometry and the contributing watershed upstream the blockage area, as the one of 2005, the dams would also be unstable. This study shows the importance of back and forward analysis that can be carried out to obtain critical information for land use planning, hazards mitigation, and emergency management.

1. Introduction

Landslides constitute a major direct hazard in most mountainous regions. Also, catastrophic failure of landslide-dammed lakes causes large magnitude outburst floods that can affect population and critical infrastructure (lifelines, hydropower dams, etc.), even in areas located a thousand kilometers far from the dam (Hewitt, 1982, 1985; Costa and Schuster, 1988; Clague and Evans, 1994; Hewitt, 1998; González Díaz et al., 2001; Dai et al., 2005; Evans et al., 2011). In Argentina, because of its demographic distribution, the direct impact of landslide is lower than in other countries of the Andean Cordillera. However, historical events have shown that many populations in the foreland area are exposed to sudden floods triggered by natural dams breaching in the mountain area. Recently, Hermanns et al. (2011a), based on an inventory of 61 cases of landslide dams, showed that in the eastern side of the central Andes around 11% of the dams failed catastrophically, though the amount could be greater because ~50% of causes of breach are not known. The largest disaster caused by a dam failure occurred in the northern part of the Neuquén province, where a landslide-dammed lake 22 km long collapsed during the summer of 1914. The sudden release of around 1.55 km^3 of water caused 155 fatalities and affected infrastructures along ~1000 km from the Main Cordillera to the Atlantic Ocean (González Díaz et al., 2001; Evans et al., 2011). The degree of primary and secondary hazard posed by this kind of events derives from a combination of geomorphologic and environmental conditions. The complete damming of a river depends mainly on the relationship between the morphometry of the valley floor and the volume and dynamics of the rockslide (Costa and Schuster, 1988; Hermanns et al., 2011b). The time that a dam can last until its collapse will depend on water inflow (related to catchment area upstream of the dam and climatic conditions), its morphometry (shape, thickness, and width), and rate of seepage through the dam (Costa and Schuster, 1988; Ermini and Casagli, 2003; Korup, 2004; Hermanns et al., 2011b). A catastrophic dam failure can also be triggered by a rock mass falling into a lake (Hermanns et al., 2004). As all those factors determine the maximum capacity of the water reservoir, they also relate to the magnitude of the outburst flood in case of catastrophic dam breach. Therefore, forecasting the direction of propagation of the landslide and its depositional geometry is essential in assessing hazards related to dam formation and

* Corresponding author at: Departamento de Ciencias Geológicas, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, Ciudad Universitaria, Pabellón II, 1427, Buenos Aires, Argentina. Tel.: +41 21 692 35 42; fax: +41 21 692 35 35.
E-mail address: ivanna.penna@unil.ch (I.M. Penna).

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failure, mitigation, and emergency management. In the last years, back analyses of past events carried out with DAN3D (McDougall and Hungr, 2005) allowed to calibrate the dynamic behavior of landslides, showing their utility to rapidly forecast and with few input data primary hazards (Sosio et al., 2008; Hungr and McDougall, 2009; Hungr, 2011).

In January 2005, a slope collapse built a natural dam in the upper part of the Santa Cruz River tributary of the San Juan River, one of largest rivers in the San Juan province (D'Odorico et al., 2009; Fig. 1). The 12 November 2005 the dam failed catastrophically, producing a flood over 250 km downstream (Perucca and Esper Angillieri, 2009). The aim of this work is to model the dynamics of the rock mass that produced the natural dam in 2005 (back analysis), and to document the changes in the valley morphology (erosion, sedimentation and changes of stream path) caused by the outburst flood. The final goal is, based on the results of the back analysis, to evaluate the likelihood and magnitude of future landslides occurrence as a volume of unstable rock still remains on the slope (forward analysis). The study shows that it is possible to extract critical information about the likelihood of landslide dam formation in almost inaccessible areas and using publically available data sets.

2. Regional setting

The Santa Cruz range (Fig. 1) is located on the eastern slope of the central Andes, in a sector where the subduction of the Nazca plate is subhorizontal, referred as Pampean flat slab (Baranzagi and Isacks, 1976). Tectonically, this sector of the Andes corresponds to the northern segment of the La Ramada fault and thrust belt, where compressive structures are the result of the Cenozoic tectonic inversion of Triassic normal faults (Ramos et al., 1993; Cristallini, 1996; Alvarez and Ramos, 1999). Although this sector is one of the most seismically active of Argentina, seismicity distribution shows considerably less shallow earthquakes (hypocenter < 100 km deep) than in the trench area (located ~ 200 km west) or in the Precordillera (120 km east; Pardo et al., 2002).

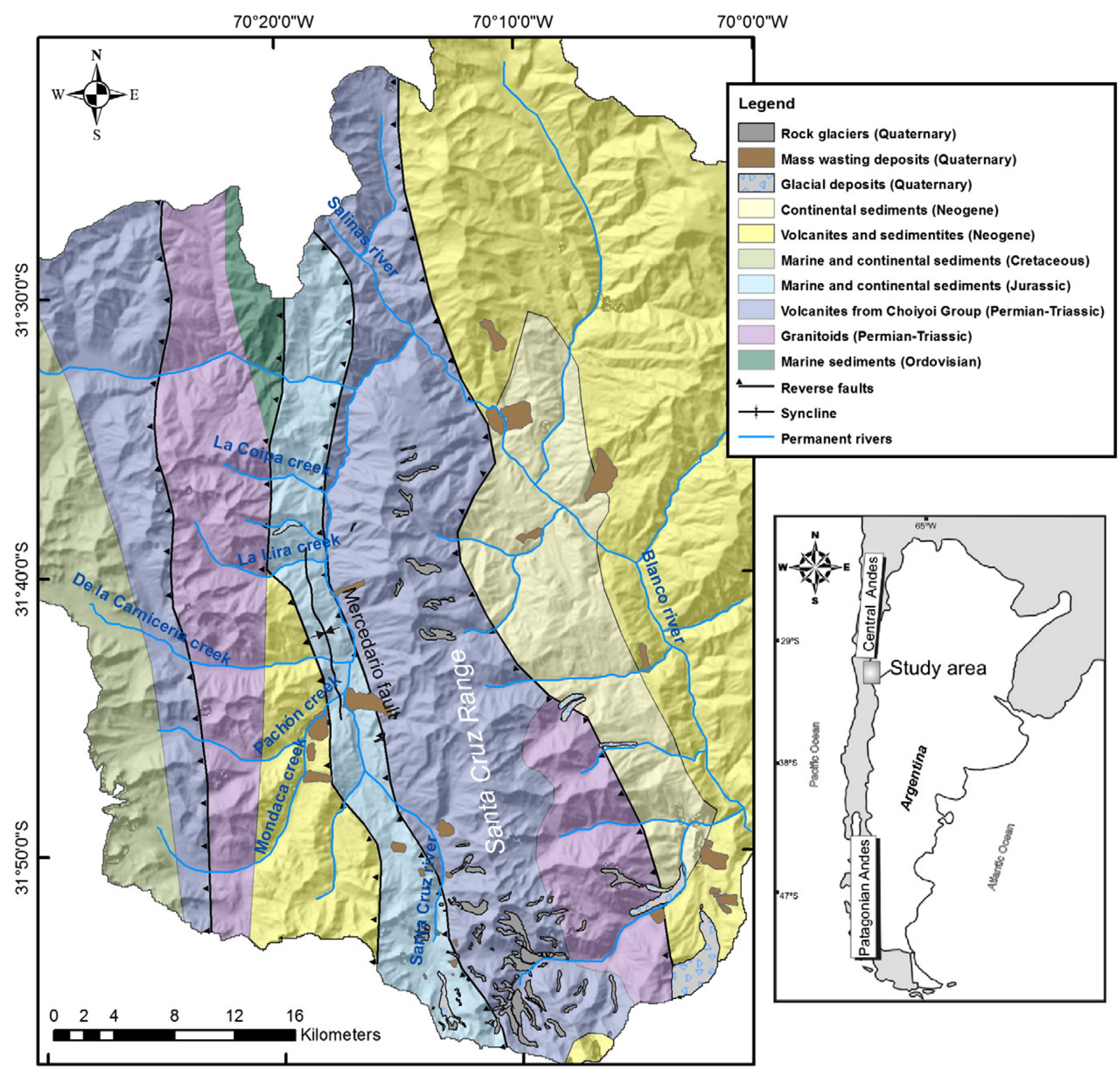

Fig. 1. Geologic-shaded relief map of the study area and main fluvial courses. (Modified from SEGEMAR, 1997).