Large rock avalanches in northern Chile, an integrated analysis towards regional hazard assessment.

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Abstract. This contribution presents the results of an ongoing research project that tries to assess the effects of a future high magnitude earthquake on the stability of natural rock slopes, and their impact on people, infrastructure and emergency management in an area nearby the city of Iquique, Chile, a seismically active region with an overdue recurrent M>8 earthquake/100 yr. Ten large rock avalanche deposits have been identified along the coastal plain to the south of the city. The deposits are concentrated in two sectors to the north and center of the study area. ^{14}C dating shows that deposits related to older events are >40 kyr. Results from numerical run out simulations (performed with DAN 3D) show that recent events can be categorized as typical rock avalanches, but older events apparently correspond to more complex processes. No large current instabilities have been detected using satellite based InSAR techniques. Preliminary results show that there is no clear correlation between the occurrence of past large rock slope failures and the return period of large earthquakes. Older events were controlled by complex mechanisms and probably occurred on conditions different that the current conditions in the area. However, additional work must still be done.

Keywords: Rock avalanches, Iquique, hazard, earthquakes

1 Introduction

Iquique (Figure 1) is a city of about 215,000 inhabitants (Chilean national census 2002) settled on one of the seismic gaps in the South American subduction zone (Bilek, 2010; Comte and Pardo, 1991), where a M >8 earthquake with overdue return periods of ca. 100 yr is expected in the near future. The city has only two access roads coming from the east and south. The road to the east comes down along the escarpment that connects the Coastal Cordillera to the Coastal Plain. The road has been blocked by small magnitude earthquake-triggered landslides at least once in recent years. The second road, coming from the south, crosses along the Coastal Plain and connects the city to the airport where at least ten ancient debris deposits related to rock avalanches are found. These facts show the importance of determining the effects of a future high magnitude earthquake on the stability of the slopes in the area, and the impact of possible slope failures on people, infrastructure and emergency management.

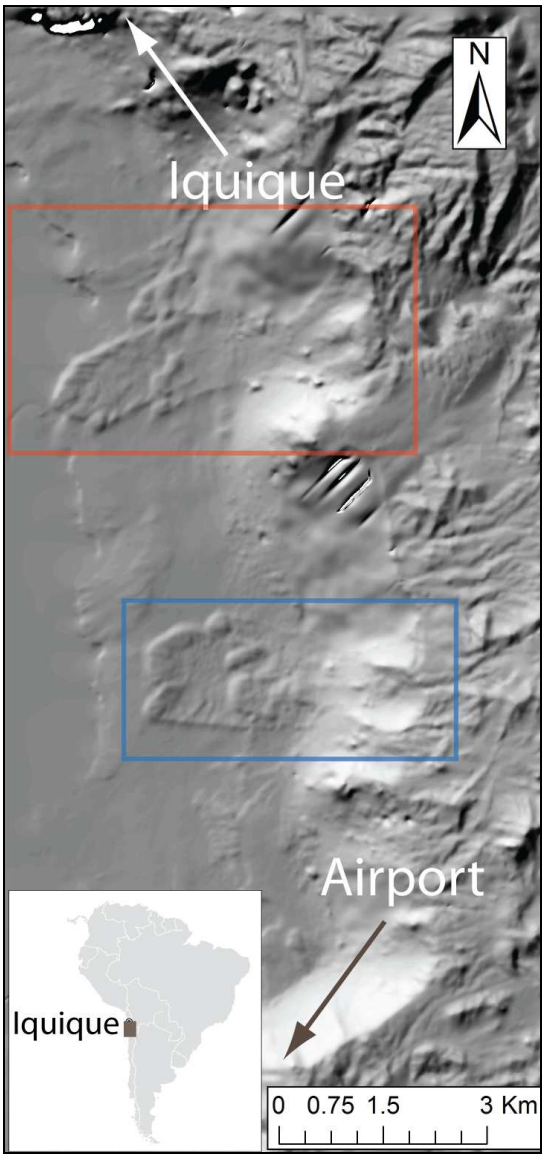

Figure 1. Location of the study area. Red and blue rectangles enclose the two clusters of rock avalanche related deposits.

The present work covers an area of approximately 130 km^2 parallel to the coastline to the south of Iquique, divided into the two main morphological units briefly mentioned above. The eastern part corresponds to the Coastal Cordillera, a set of smoothed hills and shallow valleys that reaches up to 1200 m asl. This sector is limited to the west by a steep escarpment followed by the Coastal Plain and a narrow emerged marine plateau (1-3 km wide) locally overlaid by deposits of recent rock avalanches. Rock avalanche events have recurrently occurred at two sites to the north and center of the study area on the Coastal Cordillera escarpment. Another major single event has been mapped to the south. Marls, red and black shales, and shallow marine glauconitic deposits from Jurassic constitute the source rock for the rock avalanches in all sites. Clusters of deposits are found in the first two sites (retrogressive advance) with younger events running shorter distances and partially overlaying the older ones. Multiple lobes have been mapped characterized by well defined lateral levees and clear internal morphological features (ridges and furrows, hummocks).

Digital photogrammetry, sampling collection and dating, numerical modelling of run out trajectories, and satellite based InSAR have been used to assess the potential of new rock slopes failures in the area connected to large earthquakes.

2 Methods and results

Rock avalanche run out simulations have been carried out to back analyze the sites using DAN 3D (Hungr and McDougall, 2009) and a 3 m pixel resolution digital elevation model (DEM) obtained from stereoscopic Geoeye-1 images. Models were performed for frictional and Voellmy basal reologies using typical values for rock avalanches (Sosio et al., 2008). The results present a good fit to the morphological characteristics of the mapped deposits for the cases of the most recent events (an example shown on Figure 2), which in general present shorter run out distances than older ones and have not reached areas close to the main transportation corridor, the connecting road to the airport. Older deposits, which have larger run out distances and lower travel angle values could not be simulated using such parameter values. New simulations are going to be performed using values characteristic of other type of phenomena (e.g.: rockslide-debris avalanche) to evaluate the possibility that more complex mechanisms controlled their run outs

The older lobes mapped on the area were dated by radiocarbon methods. Results indicate ages higher than 40,000 yr BP for the northern site (Figure 3). The second site could only be dated relatively with an underlying terrace that resulted older than the age limit of radiocarbon dating (43.5 kyr BP). All the deposits are positioned well above (40-70 m) the present sea level rise and at the reported uplift rates for the area they could be associated to events older than some hundreds of thousand years. A more complete record of the failure history of the sites will be obtained when results of cosmogenic nuclides (CN) and luminescence dating will become available later this year.

Satellite-based radar interferometry (InSAR) was performed using 22 ERS-1 and ERS-2 scenes from 1995-2000 as well as 37 ENVISAT ASAR scenes from 2004-2010. Both datasets show only small deformation in the area. This deformation includes sliding of small superficial slope deposits and subsidence apparently due to local groundwater withdrawal. No deformation of bedrock along the escarpment edge is apparent.

3 Conclusions

Results show that only major older, probably more complex rock avalanches could reach the main access roads to Iquique and currently no large slope segments show signs of large displacement rates. There is no strong correlation between M > 8 earthquakes return periods and age of the dated deposits, which implies that large rock avalanches could have been triggered by other factors. From a hazard and risk perspective, it is unlikely that large rock avalanches, that could block the access roads to the city, would occur in the near future. Results from CN and luminescence dating and new run out models of the larger deposits taking in account more complex mechanisms will help to get a better understanding of the conditioning and triggering of past events.

References

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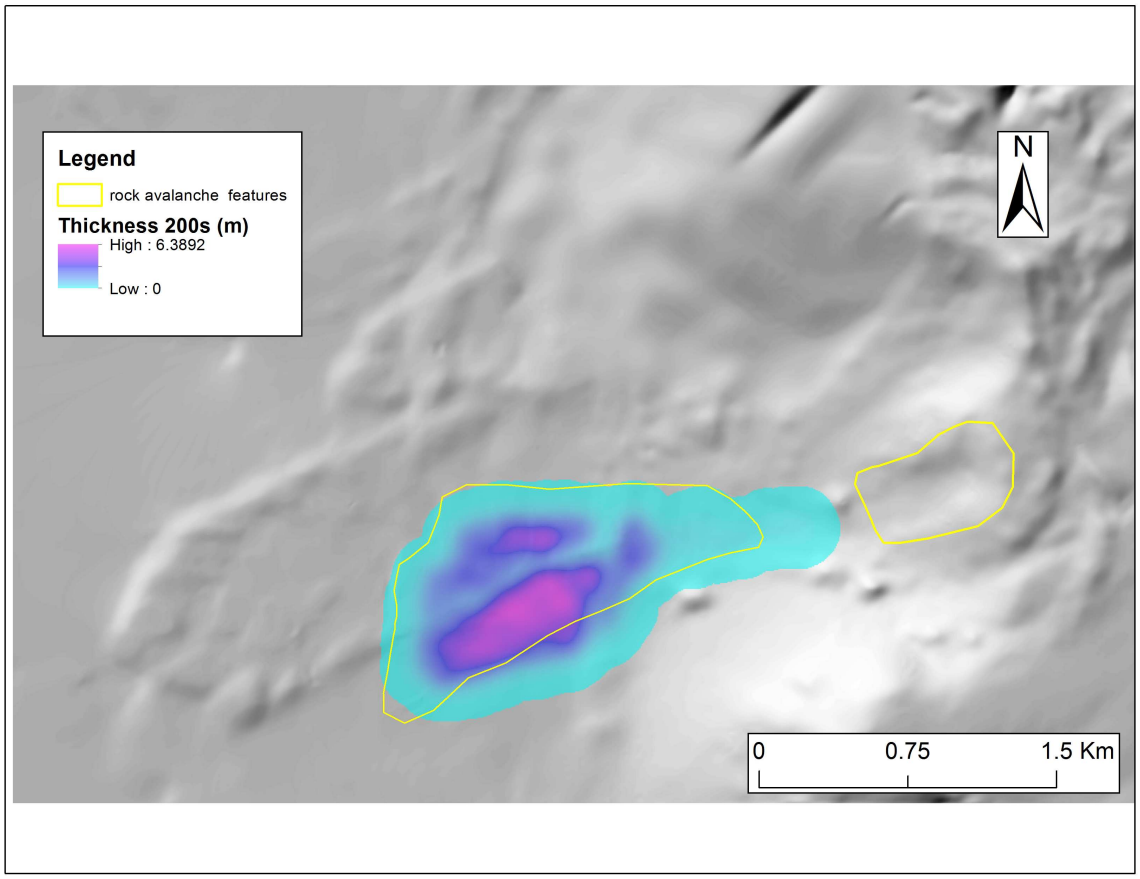

Figure 2. An example of the results obtained for run out modelling using DAN 3D. The yellow polygons represent mapped source area and run out deposit of one of the recent events in the northern cluster of the study area. Color coded legend shows the final thickness of the deposits produced by the model after 200 seconds.

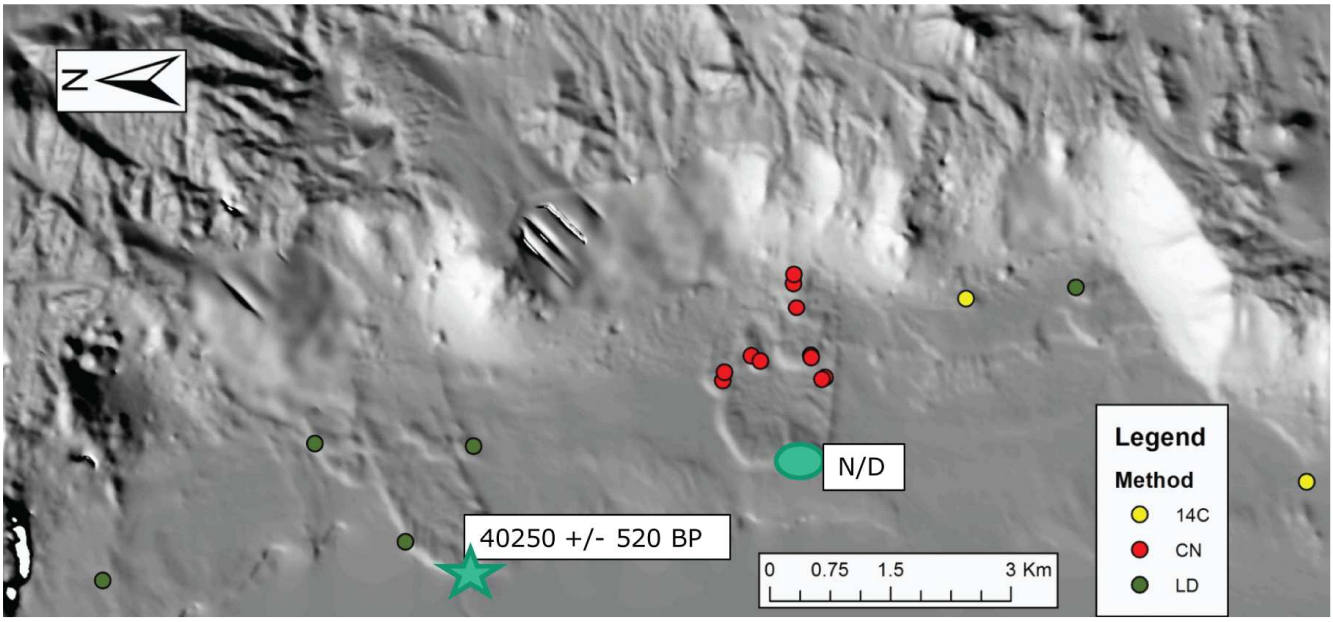

Figure 3. Location of the samples collected for the study area for dating. Red dots correspond to ^{14}C samples, red dots to Cosmogenic nuclide samples, and green dots to luminescence dating samples. Green star shows the location of the only currently dated sample with an age of 40,25 kyr. Green ellipse show the location of other two samples which could not be dated by ^{14}C methods (sampled material older than the range of the method).