International Conference
Analysis and Management of Changing Risks for Natural Hazards
18-19 November 2014 l Padua, Italy

ISBN: 9788867873074

Geomorphological analysis of the historic landslide of Sottrù (Badia Valley, Italy) reactivated on December 13, 2012

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Keywords
[Landslide, geomorphological mapping, Dolomites, Italy]

INTRODUCTION

The Sottrù landslide, located in the Upper Badia Valley (Dolomites, Italy), is a historic landslide that reactivated in December 2012, destroying a few houses, cutting two roads and almost damming the Gadera torrent. The previous known event dates back to June 1821, which took place after persistent rainfall and snow melting. What strikes the most is that the 2012 event occurred during an unusual season for landslides in the study area, while its spatial extent appears to be quite similar to that of the 1821 event. During summer 2014, a detailed geomorphological survey has been performed, aiming at identifying the instability causes, mapping the landslide in detail and investigating the hydrological and hydrogeological characteristics of the slope, within a wider geomorphological framework, comprehensive of the surrounding slopes. The survey, integrated with the analysis and comparison of pre- and post-2012-event morphological features and with the analysis of local meteorological time series, has led to a preliminary interpretation of the movement type and style of activity and to define the role of sub-surface drainage in the sliding process. Possible triggering mechanisms have been investigated.

THE 1821 LANDSLIDE EVENT

From historic documents[1], the 1821 landslide event that affected a wide portion of the south-western slope of the Sas dla Crusc (Kreuzkofel) mountain peak in the vicinity of the village of La Villa (Figure 1), was triggered by long-lasting rain and by snow melting, at the onset of the summer season.

While at present it is quite unusual to have relevant snow melting in early June, it should be noted that the year 1821 was still within the Little Ice Age period (although at its final stage), therefore making it plausible to have snow cover lasting longer than nowadays.

The landslide started on 11 June with small superficial slides, opening of fissures in the ground and soil displacements. Only on 19 June the landslide morphology was similar to the one depicted in historic documents[2] (Figure 2).

[1] "Il Messagiere Tirolese", volume 7, Venerdì 29 Giugno 1821.
[2] Kreisingenieurs-Adjunct Blitzburg: Situationsplan des Bergrutsches bei Abtei und des dadurch entstandenen Sees, 1821. Tiroler Landesarchiv Innsbruck: Bestand: Karten und Pläne, Nr. 299.

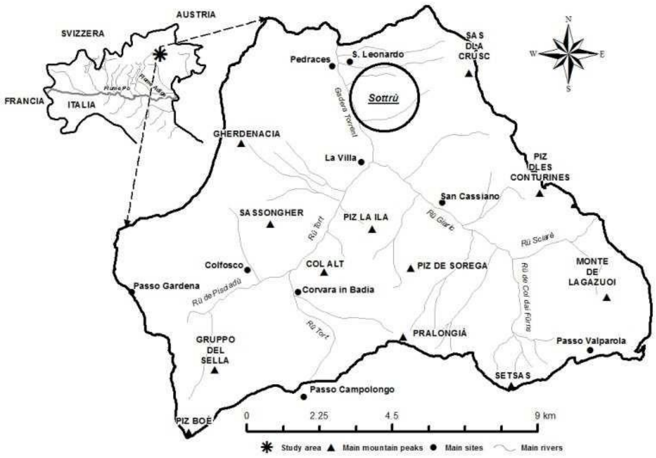

Figure 1. Geographic sketch map of the Upper Badia valley (Dolomites); the black circle locates the study area, near the village of Sottrù.

Figure 2. Shape of the 1821 Sottrù landslide and of the lake that formed after the damming of the Gadera torrent. Tiroler Landesarchiv Innsbruck. The red circle identifies the village of Sottrù.

The movement seems to have originated from the slope sector above the village of Sottrù, within cultivated and grazing meadows; it propagated downslope passing close to the village and damming the Gadera torrent. Among the effects, the destruction of the hamlet “La Muda” (possibly a station for goods trade along the Gadera torrent) and damages to 17 private houses are cited. Moreover, the damming of the river created a lake, afterwards called "Lèc de Sompunt" in Ladinian language, with an estimated maximum depth of 35 m, width of 160 m and length of more than 1 km. According to one bibliographic source (Röhrs, 2012), in order to prevent the sudden collapse of the natural earth dam, starting from 1822 the lake was slowly drained and in 1833 it was completely dried up. According to another source (Tetamo, 1998), after rapid snow melting in June 1827 (to be noted once again the occurrence of snow melting at the onset of summer), the natural dam collapsed and the water and debris wave hit meadows and villages valley-ward.

GEOMORPHOLOGICAL SURVEY AND FIELD EVIDENCE

The geomorphological survey of the Sottrù landslide occurred on 13 December 2012 (Figure 3), performed during the summer of 2014, was aided by the use of a GPS track logger, allowing the precise mapping of geomorphological, hydrographic and hydrogeological details. Important reference maps of the area were the "Carta Geomorfologica dell'Alta Val Badia" and its reference notes (Panizza et al., 2011), and the "Carta Geologica delle Dolomiti Occidentali 1:25.000" (Brandner et al., 2007).

Figure 3. Front view of the 2012 landslide event taken some days after its occurrence. The village of Sottrù is identified by the yellow ellipse. Photograph by M. Soldati.

The survey has revealed the presence of a superficial, highly incoherent deposit of glacial origin (probably ablation till). The deposit is present all around the upper and middle parts of the landslide and has been recognised also within the landslide accumulation. The fresh slope cutting that occurred during the 2012 landslide event allowed to detect an average thickness of the deposit of around 2 metres. Under the till, weathered bedrock is present, formed by alternating marls, sandstones and shales belonging to the Wengen Formation; in the upper part of the landslide and uphill, the deposit lies upon the weathered marls and marly limestones of the San Cassiano Formation. The permeability contrast existing between the till and the bedrock is thought to extend to larger portions of the slopes of the Gadera valley, at least within the limits of the Municipality of Badia. This contrast could be reasonably considered as one of the main predisposing factors for the many landslide events that characterise the present morphology of the area (cf. Soldati et al., 2004; Borgatti and Soldati, 2010), among which also the Sottrù landslide. From the base of the dolomitic wall named

Sas dla Crusc (Kreuzkofel) to the upper scar of the Sottrù landslide, a wide and gently sloping surface is present, characterised by an extremely irregular topography resulting from the deposition of the ablation till after the last glacial retreat. This favours the presence of an extremely unordered drainage network, with discontinuous drainage lines, indicative of sub-surface infiltration prevailing on runoff.

When comparing the current landslide morphology to the pre-2012 one, it is possible to identify which sectors of the historic landslide body were reactivated during the last event. It should be noted that the upper scar, probably related to the earlier events occurred during the Late-glacial or the Holocene (not yet dated) was not reactivated during the 2012 event (Figure 4), while relevant mobilisation occurred at the two side parts that join together below the foot of the current fresh, middle scarp.

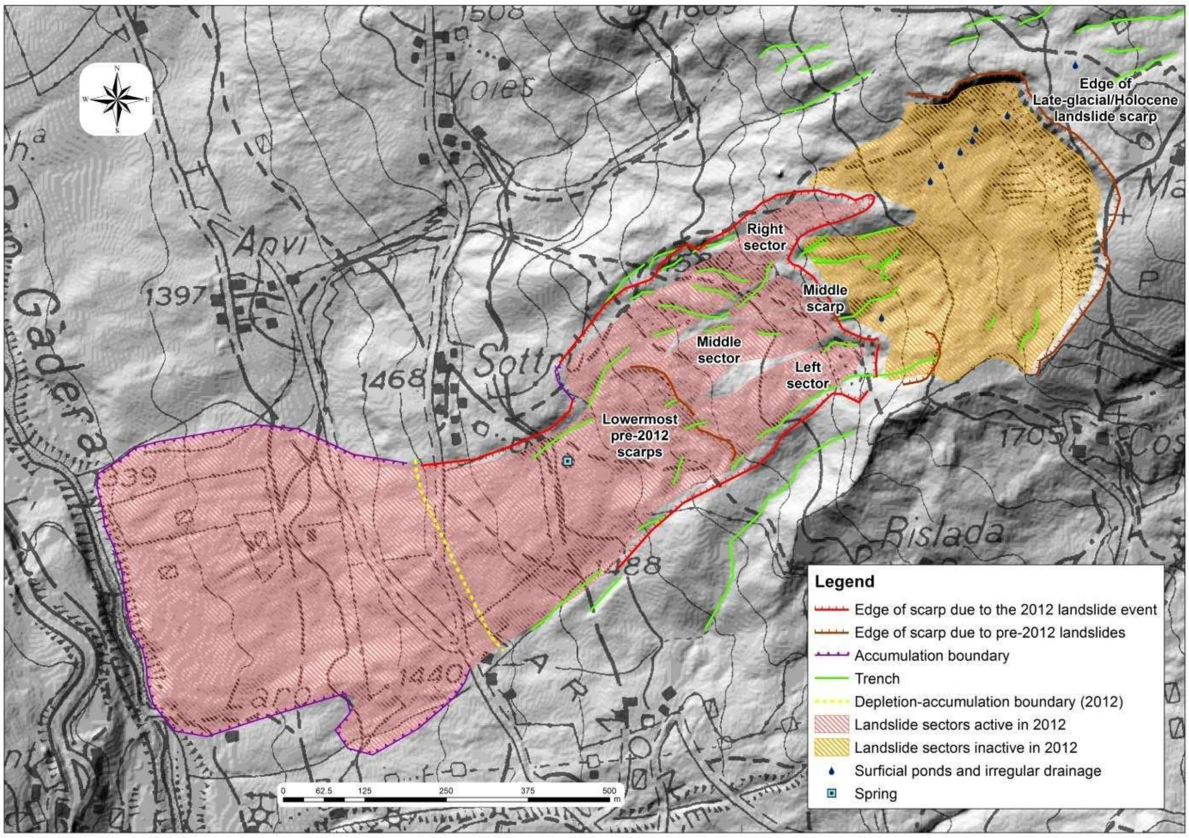

Figure 4. Simplified geomorphological sketch of the Sottrù landslide.

The latter, during the last event, experienced a retreat of some metres uphill and the generation of a fresh new scarp, with more or less the same height of the previous one; the thickness of the collapsed material seems to be relatively thin here, up to 5 m. A translational slide can be hypothesised along the scarp, followed by a rotational slide and partly flow at the slope break (Figure 5). The almost uniform and unbroken snow cover (the last snowy precipitation was on the 8 December, 5 days before the landslide occurrence) reveals a certain degree of compaction of the slid material, probably due to the frozen top-soil layer.

The same evolution seems to have characterised also the left part of the middle scarp, where the sliding uncovered an outcrop of the Wengen Formation layers. Field evidence in the days just after the event, when maximum daily temperatures were still around 0°C, shows water discharges starting from the base of the detrital cover and reaching the base of the scarp, testifying the presence of unfrozen subsurface water.

Figure 5. Middle scarp of the 2012 event and related landslide accumulations. Photograph by M. Soldati.

The most striking feature can anyhow be found along the right side of the landslide area, where a less surficial and elongated depression developed, completely transforming the superficial morphology. Comparing it to the morphology depicted in the map of Panizza et al. (2011), the head scarp retreated some 200 m uphill, reaching far above the altitude of the middle fresh scarp; the left lateral scarp is almost sub-vertical while the right lateral scarp is less steeply inclined towards south-east. Part of the slid material reached a ridge some 100 m uphill the village of Sottrù, accumulating and stopping on top of it, while most of the earth mass was mobilized along a track bending towards south, joining with the mass mobilized by the left-sector slide and with the earth mass coming from the middle scarp.

Until a few metres below the village of Sottrù, the lateral scarps are well visible although thinning up. Below Sottrù the accumulation zone starts, reaching the Gadera torrent. From Figure 3 the hummocky morphology characterising the whole toe area can be appreciated.

During summer 2014, above the upper scarp of the right landslide sector, the ground was completely saturated, giving origin to ponds and running water rills conveying the whole discharge in the landslide depletion area, thus maintaining this sector highly susceptible to future movements.

The 2012 event completely cancelled the lowermost former scarp sector, visible in Figure 4 between the fresh middle scarp and the village of Sottrù. In this sector, sub-parallel tension cracks could be seen in the ground surface two days after the last activation, indicating extension stresses affecting that slope sector.

ANALYSIS OF METEOROLOGICAL TIME SERIES AND HYPOTHESES ON THE TRIGGERING MECHANISMS

In order to understand what could be the principal triggering causes and the mechanism of movement of the landslide, given the fact that the period of the year in which it reactivated is unusual for landslides in the study area, meteorological time series have been analysed, namely of daily minimum and maximum air temperatures and precipitation height. The data were taken from two local meteorological stations: one placed in the village of La Villa, at 1390 m a.s.l., and one on top of the mountain peak “Piz la Ila”, at 2050 m a.s.l. As it can be appreciated from the plots in Figure 6, a high precipitation event, with a total of 50 mm in La Villa and 60 mm at Piz la Ila, occurred on the 28 and 29 November. The day after a sudden drop of both minimum and maximum air temperatures took place and both remained below 0° until 24 December; in some days, inversions of m inimum temperatures were recorded between La Villa and Piz la Ila, but since all values were well below 0°C, a contemporary snow thawing at higher elevations and water freezing at lower ones can be excluded.

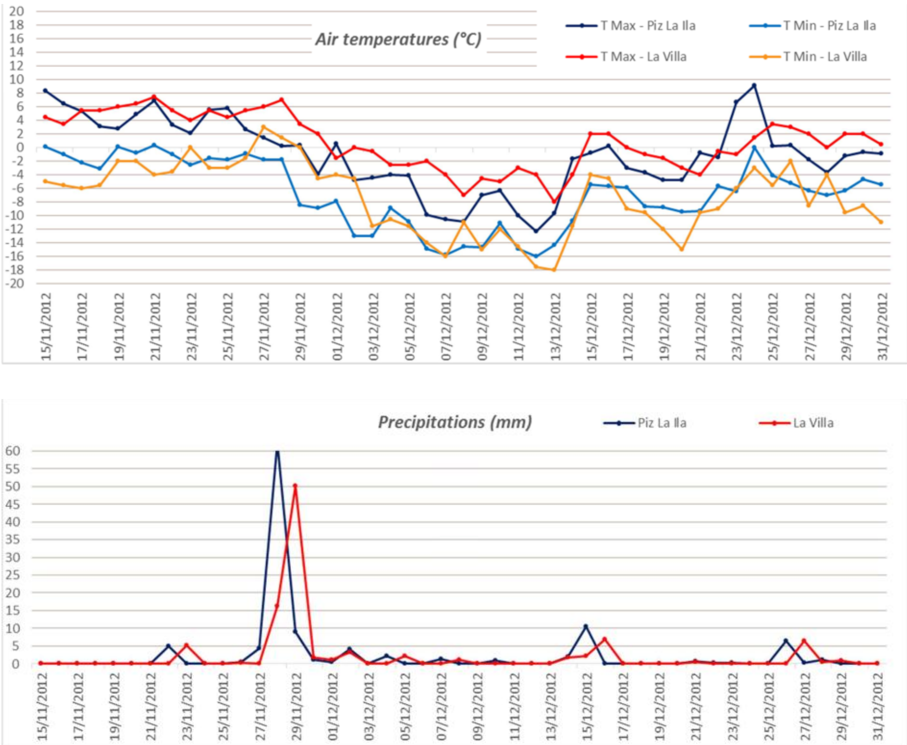

Figure 6. Meteorological time series, recorded at two local stations from 15 November to 31 December 2012.

This peculiar combination of high precipitations, shortly followed by a drastic lowering of air temperatures, may have almost completely saturated the thin and highly permeable till, generating a confined aquifer in it, with no possibility of discharge, thus rapidly increasing the saturated weight of the debris on the underlying weathered visco-plastic material. Low temperatures may have frozen up also the spring depicted by topographic maps near the village of Sottrù, within the landslide area. This may have led to the destabilization of the landslide sector between the spring itself and the lowermost pre-2012 scarps. A similar hypothesis has been made also for landslide events occurred in the Dolomites (e.g., in Zoldo Valley in 1991) (Govi et al., 1993).

In a retrogressive manner, this may have led to the destabilization of the other three upper sectors – the left and right side slides and the toe of the mid scarp. Newly formed scarps developed, shifted uphill with respect to the pre-2012 ones. Since December 2012, those newly formed scarps have been affected by soil slips and gully erosion.

CONCLUSIONS

The landslide activated on 13 December 2012 near Sottrù, characterized by considerable length and width (1300-1400 m and 500 m respectively), can be identified as a complex

(earth slide - earth flow) landslide from the geomorphological observations described beforehand. It was triggered during winter, a quite unusual period for landslides in the study area nowadays. Therefore it was of prior importance to identify which was the most likely triggering factor. This was found to correspond to a rather peculiar combination of high precipitations (50-60 mm of rain), suddenly followed by a drop of minimum and maximum air temperatures below 0°C, starting from 29 November. During the 14-day period between the precipitation event and the occurrence of the landslide, a confined aquifer is likely to have been built up within the superficial debris (of glacial origin) that covered a wide extent of the pre-2012 landslide and its surrounding slopes. The freezing of the water within the first centimetres of soil and of a spring near the village of Sottrù, probably led to the rapid increase of pore water pressures and to the initiation of earth slides from the lowermost pre-2102 landslide scarps. The retrogression of the earth slides favoured the instability of the upper sectors of the landslide, generating three main landslide sub-units with coalescent deposition areas. From the village of Sottrù down to the Gadera torrent, the landslide movement switched from sliding to flowing, generating a wide deposition area that almost blocked the course of the torrent. Thanks to the quick response of the local institutions and Civil Protection, the damming of the torrent was avoided.
The hypotheses mentioned above, regarding triggering causes and mechanisms of the 2012 event, which are mainly supported by geological and geomorphological investigations, should be taken as preliminary. In future, they should be compared with geophysical and geomechanical data in order to validate them and to achieve a more comprehensive framework of the 2012 landslide event which would also be crucial in term of landslide hazard evaluation (Soldati et al., 2014). Besides the validity of the hypotheses, we think that one of the most critical points, for the future evolution of the landslide, is represented by the sub-surface drainage within the debris cover, whose spatial distribution should be precisely assessed and modelled, extending its analysis also far uphill the upper crown of the landslide, where surficial and subsurface flows have to be further investigated.

ACKNOWLEDGMENTS

The present paper is published in the framework of the PRIN 2010-11 MIUR Project "*Response of morphoclimatic system dynamics to global changes and related geomorphological hazards*" (Project Coordinator: Carlo Baroni; scientific responsible UNIMORE: Mauro Soldati).

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