
Geomorphological Characterization, Monitoring and Modeling of the Monte Rotolon Complex Landslide (Recoaro Terme, Italy)

230

Francesco Fidolini, Veronica Pazzi, William Frodella, Stefano Morelli,
and Riccardo Fanti

Abstract

The Rotolon landslide, located in the upper Agno River valley (Vicenza, Italy), has threatened the valley for centuries. During November 2010, after 637 mm of rainfall in 12 days, a debris mass of about 225,000 m³ collapsed from the lowermost portion of the landslide and evolved into a debris flow that channeled in the Rotolon Creek riverbed, damaging the villages of Maltaure and Parlati in the Recoaro Terme municipality. On December 8th, 2010 the Department of Earth Sciences of the University of Firenze started a real-time monitoring using a GB-InSAR radar interferometer. The radar data are elaborated to obtain weekly, monthly and total cumulated 3D displacement maps and displacement time series of ten control points selected on the landslide mass. Accurate field surveys were carried out to analyze the landslide physiographic features and to validate the ground deformation retrieved from the radar data. The geomorphological features, supported by the radar data, led to an interpretation of the complex Rotolon landslide as a Deep Seated Gravitational Slope Deformation, whose detrital cover is often affected by detachments triggering debris flows. The November 2010 detachment area was modeled in order to: (i) calculate the main geotechnical properties of the collapsed material by means of a back analysis; (ii) define the residual risk; (iii) simulate new critical scenarios for the new topographic slope surface.

Keywords

Rotolon landslide • DGSD • GB-InSAR monitoring • Geomorphological map

230.1 Introduction

Deep-seated gravitational slope deformations (DGSD) are gravity-induced processes affecting large portions of slopes evolving over very long periods of time. DGSDs are normally not considered hazardous phenomena because their evolution is typically very slow. Nevertheless, despite their slow deformation rates, DGSDs may cause damage to surface and underground structures and, under certain conditions, movements can accelerate or lead to catastrophic slope failures that may also evolve into faster mass movements or favor

collateral landslide processes (Crosta and Agliardi 2003). DGSDs may involve a variety of lithologies, including metamorphic, sedimentary, and plutonic rocks, and are particularly common in over-deepened glaciated valleys. Moreover they are strongly constrained by structural and sedimentary anisotropies, such as joints, faults or bedding (Agliardi et al. 2009). DGSDs can be triggered by different and potentially coexisting mechanisms, including postglacial debuttrressing (Ballantyne 2002) and topographic or regional tectonic stresses (Miller and Dunne 1996). According to this, a multidisciplinary approach is fundamental to understand the complex nature of such phenomena and assess the right mitigation procedures to protect the communities potentially threatened by this kind of landslides.

This paper deals with a large complex landslide (Rotolon landslide) located in the uppermost Agno River course (Vicentine Prealps, Veneto, Italy). Damages due to failures

F. Fidolini · V. Pazzi (✉) · W. Frodella · S. Morelli · R. Fanti
Department of Earth Sciences, University of Firenze, Via G. La
Pira 4, 50121 Firenze, Italy
e-mail: veronica.pazzi@unifi.it

and flooding connected with the landslide activity are reported starting from the 16th century (Altieri et al. 1994). The 4th of November 2010 a debris mass of about 225,000 m³ detached from the lowermost part of the landslide and reached the Rotolon Creek riverbed, mixing with water and evolving into a destructive debris flow. Such a flow, with a more than 3 km run-out distance, put at high risk the population of three villages placed along the creek banks (Maltaure, Turcati, Parlati) and damaged many infrastructures directly facing the watercourse. After this event the Department of Earth Sciences of the Firenze University, on behalf of the National Department of Civil Protection, started several activities to evaluate the Rotolon landslide kinematics. A ground based radar interferometer (GB-InSAR) was implemented to monitor the landslide displacements, which are daily reported to the National Department of Civil Protection. Accurate field surveys were also carried out to analyze the landslide geomorphological features and improve the interpretation of radar-derived data.

230.2 Geographic and Geological Setting

The Rotolon landslide affects the southeastern flank of the Little Dolomites chain, within the Vicentine Prealps. The landslide develops in the Upper Agno Valley and involves the uppermost portion of a sub-horizontally bedded, mainly dolomitic succession (Fig. 230.1) from middle Triassic to lower Giurassic in age (De Zanche and Mietto 1981). The landslide has a triangular areal extent and appears to be constrained by the local tectonic lineaments, which are mainly NE-SW, NNW-SSE and E-W oriented (De Zanche and Mietto 1981). It is delimited to the northwest by the Mount Obante Group ridge and it develops between 1,700 and 1,100 m a.s.l. (Fig. 230.1).

230.3 GB-InSar Monitoring

The real-time monitoring activity of the Rotolon landslide kinematics by means of a GB-InSAR (Gigli et al. 2011; Del Ventisette et al. 2012) started on December 2010. The system was installed near the Maltaure Village, at an average distance from the target area of about 1,700 m, pointing upwards to NW (Fig. 230.1). It consists of a continuous-wave step-frequency (CW-SF, central frequency of 17.375 GHz) radar that realizes a synthetic aperture by moving the antennas along a 2.7 m long horizontal straight rail. The radar images are produced every 10 min and are elaborated to generate the 2D displacement maps. Based on the landslide physiography, 10 control points (8 inside and 2 outside the landslide area) were selected to draw the displacements and velocities time series that are uploaded on a

web platform. During the whole monitoring period a weekly bulletin reporting the landslide displacements was sent to the local civil protection authorities: four significant displacement acceleration events were recorded. All these events were located in the area monitored by control points 7, 8 and 9 (Fig. 230.2). This area, according to our geomorphological interpretation, corresponds exactly to the apex of the detrital accumulation located at the main spring of Rotolon Creek. Fortunately the acceleration here observed did not generate significant slope failures although, in the meantime, precipitations comparable to that of November 2010 have hit the area.

230.4 Geomorphological Characterization

The Rotolon landslide is a gravitational mass movement characterized by a complex activity (Cruden and Varnes 1996) that leads to a very irregular physiography. The whole area can be mainly subdivided in two distinct portions basing on the dominant processes (Frodella et al. in press): (i) an upper “Detachment sector”, followed immediately downstream by a (ii) “Dismantling sector” (Fig. 230.2). The Detachment sector develops downstream of the main landslide crown with a mean slope of 30°. It is dominated by extensional deformations that induce the occurrence of extensive tensional fractures, resulting in trenches and crests, doubled ridges, scarps and counterslopes, creating a very rough and stepped topographic surface. Gravitational and erosional processes lead to the accumulation of various depositional elements (colluvial fans and aprons, rock fall and debris avalanche deposits). The Dismantling sector (mean slope of 34°) is characterized by a compressional stress field resulting in a remarkable toe bulging with common against-dip fractures in its uppermost part. Nonetheless this area is apparently dominated by surficial processes, such as soil erosion, slope waste deposition and detrital cover failures that widely cover the evidences of deeper deformations. This sector supplies material for debris flows, which channelize downstream within the Rotolon Creek.

230.5 Slope Stability Modeling

The 2010 detachment area is partly hidden from the radar view beyond some mountainous crests, making difficult to assess any further eventual slope deformation. The large amount of debris that is still present on the steep slopes of this sector reveal that this area is still critical, thus we tried to assess the residual risk by means of a stability analysis using the Slope/W software (Krahn 2004) along 5 longitudinal sections crossing the 2010 detachment area. Basing on pre- and post-event Lidar images, a back analysis was performed

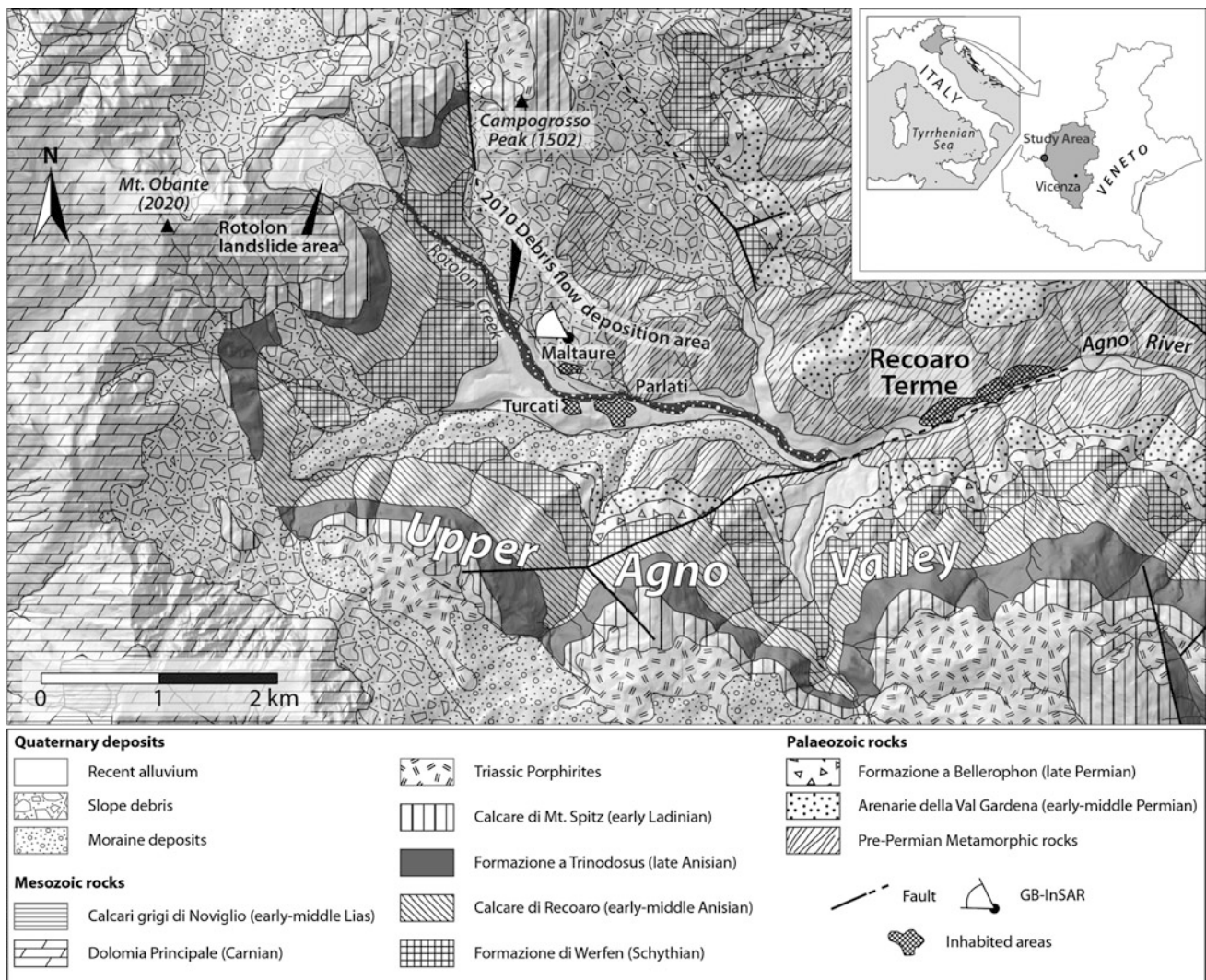


Fig. 230.1 Geological sketch map of the study area and location of the Rotonlon landslide

to establish the conditions at the time of the failure, considering three possible options for soil moisture: (i) completely dry soil; (ii) ground-water level emerging at the center of the area (as mapped by Altieri et al. 1994) (iii) ground-water level emerging almost at the top of the area. The GLE (general limit equilibrium; Fredlund 1977) analysis method was used in such simulation. Relying on the obtained average parameters of the residual strength ($\phi = 31.6^\circ$ and $c = 0$) for the most plausible ground-water level (point ii), new analyses were run considering the current morphology in the three mentioned soil moisture conditions. Along all the sections, with the exception of number 4 that centrally crosses the area, significant failures can occur starting from the unsaturated condition, including a slope portion extending from upstream of the landslide scar up to the central part of 2010 detachment. In each case, with the

rise of the water table, failures can become relatively deeper and larger towards higher altitudes, with an increase rate that however, is not constant by one section to another. Sections 230.1 and 230.5 show the larger failures. The most critical situation, is along Sect. 230.5 (under saturated soil conditions), which, according to the radar estimate, is very close to the area with the greater displacement.

230.6 Discussion and Conclusion

The performed geomorphological surveys reveal morphological features that are typically associated to deep-seated gravitational slope deformations, while debris production and detachment are accessory phenomena that involve the surficial detrital cover. The displacement radar map for the

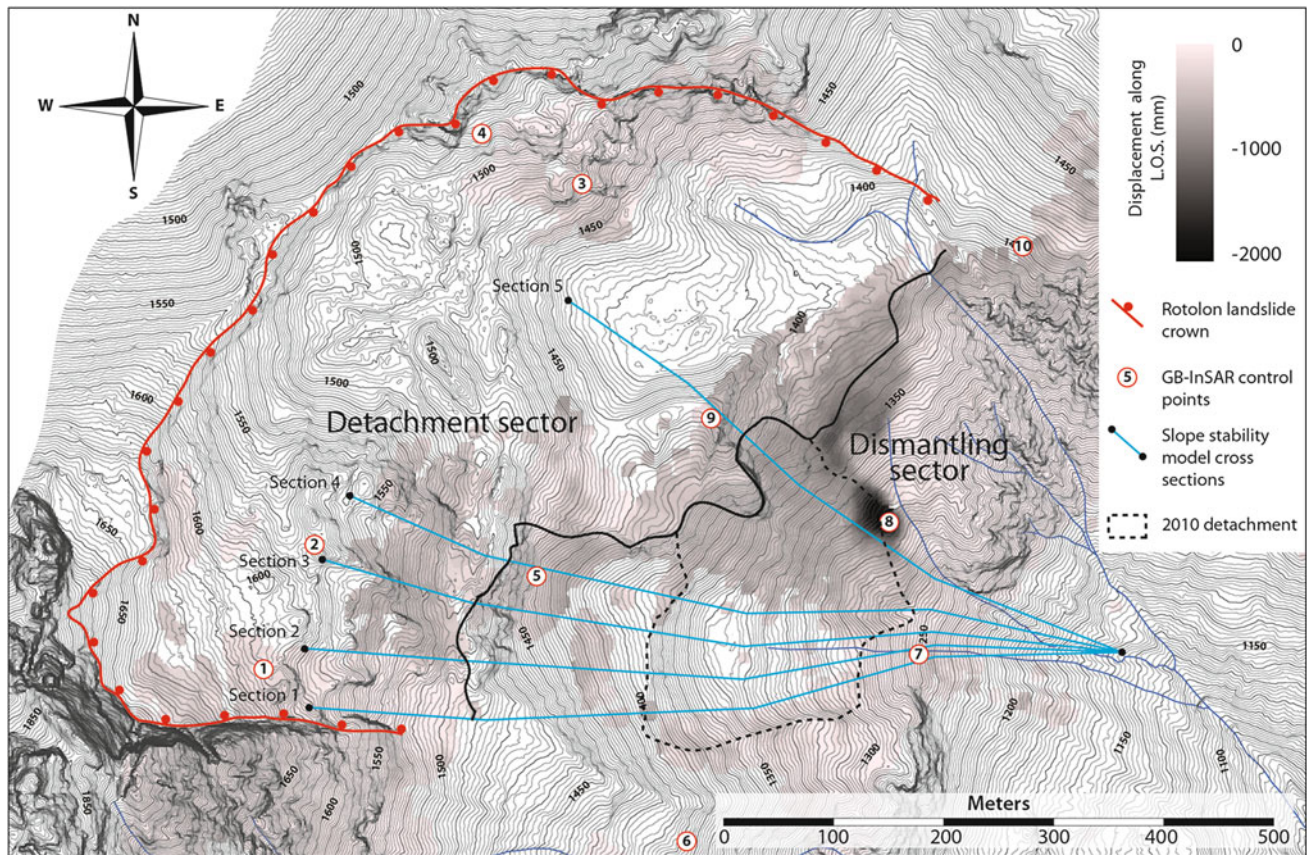


Fig. 203.2 Image showing the Rotonon landslide area with the radar displacement map, the geomorphological sectors and the slope stability analysis cross-sections

whole monitoring period clearly shows the different kinematics of the Detachment and Dismantling sectors. The former shows displacement values of few mm/year for the rock outcrops, which are comparable with those typical of deep-seated deformations, while the latter is characterized by the highest displacements (1,900 mm), referable to the rearrangement of the detrital cover. The slope stability analysis suggests the presence of residual criticalities regarding the detrital cover not mobilized by the 2010 event, whose failure could be triggered even under non-saturated conditions. In particular the major susceptibility is concentrated on the suspended debris placed along the two flanks of the 2010 scar. In conclusion, according to geomorphological and radar data, the Rotonon landslide appear to be characterized by long-term deep seated processes, above which a wide spectrum of short-term secondary phenomena (minor slope failures, rock falls, rock avalanches, debris accumulation and debris flow triggering) were recognized. Presently debris flows represent the most hazardous phenomena for the inhabited areas located along the Rotonon Creek valley.

References

- Agliardi F, Crosta G, Zanchi A, Ravazzi C (2009) Onset and timing of deep-seated gravitational slope deformations in the eastern Alps, Italy. *Geomorphology* 103:113–129
- Altieri V, Colombo P, Dal Prà A (1994) Studio per la valutazione delle condizioni di stabilità dei versanti e del fondovalle del bacino idrografico del Torrente Rotonon nell'Alta Valle dell'Agno in Comune di Recoaro Terme (Vicenza). *Relazione Geologico-Geotecnica*. Reg del Veneto, Segr Reg per il Territorio, Dip Lavori Pubblici, Venezia, pp 97
- Ballantyne CK (2002) Paraglacial geomorphology. *Quatern Sci Rev* 21:1935–2017
- Cruden DM, Varnes DJ (1996) Landslide types and processes. In: Turner AK, Shuster RL (eds) *Landslides: investigation and mitigation* (Special Report 247, pp 36–75). Transportation Research Board, National Academy of Science, Washington, DC
- Crosta GB, Agliardi F (2003) Failure forecast for large rock slides by surface displacement measurements. *Can Geotech J* 40(1):176–191
- Del Ventisette C, Casagli N, Fortuny-Guasch J, Tarchi D (2012) Ruinon landslide (Valfurva, Italy) activity in relation to rainfall by means of GBInSAR monitoring. *Landslides* 9(4):497–509
- De Zanche V, Mietto P (1981) Review of the triassic sequence of Recoaro (Italy) and related problems. *Rend Soc Geol It* 4:25–28

- Fredlund FK, Krahn J (1977) Comparison of slope stability methods of analysis. *Can Geotech J* 14:429–439
- Frodella W, Morelli S, Fidolini F, Pazzi V, Fanti R (in press) Geomorphology of the Rotolon landslide (Veneto Region, Italy). *J Maps* doi:[10.1080/17445647.2013.869666](https://doi.org/10.1080/17445647.2013.869666)
- Gigli G, Fanti R, Canuti P, Casagli N (2011) Integration of advanced monitoring and numerical modeling techniques for the complete risk scenario analysis of rockslides: the case of Mt. Beni (Florence, Italy). *Eng Geol* 18:48–59
- Krahn J (2004) Stability modeling with SLOPE/W. An engineering methodology, 1st edn. Revision 1, GEO-SLOPE/W International Ltd. <http://www.geoslope.com>
- Miller DJ, Dunne T (1996) Topographic perturbations of regional stresses and consequent bedrock fracturing. *J Geophys Res* 101:25523–25536