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Angelo Doglioni · Nicola Casagli · Massimiliano Nocentini · Francesco Sdao · Vincenzo Simeone

The landslide of Pomarico, South Italy, occurred on January 29th 2019

Abstract Pomarico is a very small town in Basilicata, South Italy, historically landslide prone. The latest main landslide started on 25th of January 2019, on the northern east side of the hill, rapidly evolving and causing, on January 29th, the collapse of the main road of the town as well as of the overlooked buildings and serious damages of several buildings of the town. This work introduces the main features of this landslide and the earlier results of the studies on this phenomenon. The main geological characteristics of the site and the morphological features of the landslide are presented. Moreover, the interpretation of the complex failure mechanism as well as an analysis of the singularity of the triggering rainfall event are shown. Finally, this work focuses on the terrestrial radar monitoring system, installed after the event, and its preliminary outcomes.

Keywords Earth slide · Earth flow · Failure mechanism · Triggering factors · Monitoring

Introduction

Pomarico is a very small town, located in Basilicata, South Italy, see Fig. 1. It is in the south-eastern part of the Bradanic Trough, a Pleistocene basin filled by typical foredeep sequences ranging between the lower-mid Pliocene and the mid Pleistocene (Guerricchio and Melidoro 1979; Galeandro et al. 2017). The town is at the top of a narrow long hilly ridge where regressive deposits outcrop: clays, clayey sands, and conglomerates. The ridge sides are quite steep and historically subject to manifold severe landslides, mainly roto-translation slides evolving in earth flows. Some are dormant others are active usually showing very slow movements. However, these landslides sometimes generated sudden movements, causing widespread damages to the town. The main events during the latest half century were in November 1959, March 1973, 1986, and 1997 (Palumbo 2019), all after prolonged and abundant precipitations.

The latest landslide, see Fig. 1, activated on January 25th 2019, after a sequence of prolonged low-intensity rainfalls. The earlier failure was a large rotational slide evolving into a channelized earth-flow along the southern west side of Pomarico ridge. Initially a bulkhead, built up at the end of the twentieth century, blocked the retrogressive evolution of the slide. However, on January 29th, the retaining structure failed and the landslide evolved causing the collapse of the main road of the town: Corso Vittorio Emanuele II, see Figs. 1 and 2, together with 20 buildings. Moreover, 12 buildings were damaged and 25 were evacuated. The area involved by the 2019 landslide is the same as the landslides occurred on January 1959 and 1960, which caused the collapse of several houses and about 100 people were evacuated.

This work presents a preliminary analysis of January 2019 landslide, based on geological surveys, aerial photos and very early

results of ground-based radar interferometry. The outcome of this analysis is the delineation of the geological and geomorphological features of the landslide as well as the early interpretations of data of the surveys and ground-based radar interferometry.

Geological and geomorphological description of the site

The hill ridge where the town of Pomarico is located is characterized by a regressive sequence (Genevois et al. 1984; Bozzano et al. 2002), see Fig. 3. Starting from the bottom, the sequence is made up of sup-Apennine gray-blue clays, lower Pleistocene, Monte Marano sands, and Irsina conglomerates at the top of the hill, both of mid Pleistocene. Sub-Apennine gray-blue clays are silty-marly blue clays laminated and fissured, with sandy and silty interlayers. The upper levels of the clays show a yellowish color due to weathering and an increase of sandy layers. The transition to the upper layer of sands is gradual, whereas the sand fraction progressively increases, until it becomes prevalent. The thickness of the sand layer ranges between 50 m in the urban area of Pomarico and 14 m along the slope downstream the urbanized area. In the urban area, there are several grottoes dug by locals in the sands level for several purpose. Along the slopes, there is a blanket of loamy clayey detrital slab, sometimes including arenaceous sandy yellowish blocks, through which a certain amount of water flows, likely fed by percolation of precipitations (Simeone and Graziadei 2019) or sometimes by leakages of the water networks. In the slope of the landslide, this blanket has a thickness ranging between few meters and 10–15 m.

Pomarico hill is asymmetric and with irregular profiles, typical of complex gravitative morphodynamics. These are related to large mass displacements, which occur as roto-translative retrogressive and composite slides (Cruden and Varnes 1996), sometimes evolving as longitudinal earth flows. Gray-blue clays, outcropping in the NE area of the landslide, are eroded as badlands, characterized by a tight stream network, made by narrow ditches.

The landslide of January 2019: Triggering and evolution

Pomarico landslide started and evolved between January 25th and 29th, due to a long rainfall event, occurred during the night between January 24th and 25th and after a particularly rainy autumn and winter (Sdao and Simeone 2019). It is a complex landslide constituted by an upstream roto-translational slide evolving downstream into an active complex earth flow. The landslide triggering can be divided in two stages:

- a) Between January 24th and 25th, due to the precipitations, an earth slide probably activated by the softening of clay level at the passage from the regressive sands and the sub-Apennine clays that evolved in an earth flow. The effect, on the town, of the roto-translational slide was attenuated by the presence of a pile bulkhead built up at the end of the twentieth century to support the main road of the

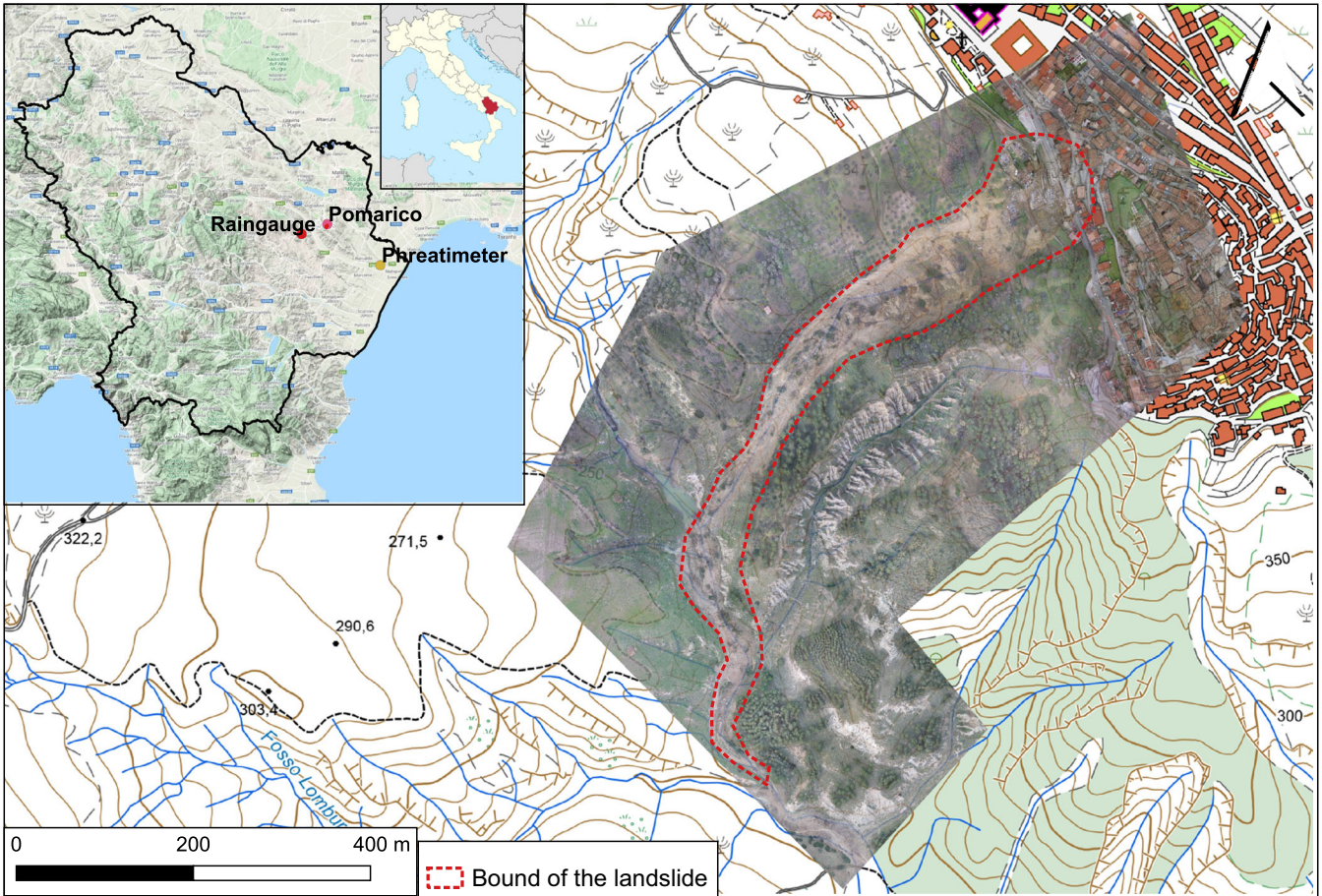


Fig. 1 Ubication of the landslide

town. The sliding soil gradually uncovered the piles letting them rotate downward, due to the likely not properly pre-stressed

anchors, see Fig. 2. The deformation of piles decompressed the retained soil, generating a subsidence behind the bulkhead.



Fig. 2 Upper scarp of the landslide and damages to structures and bulkhead

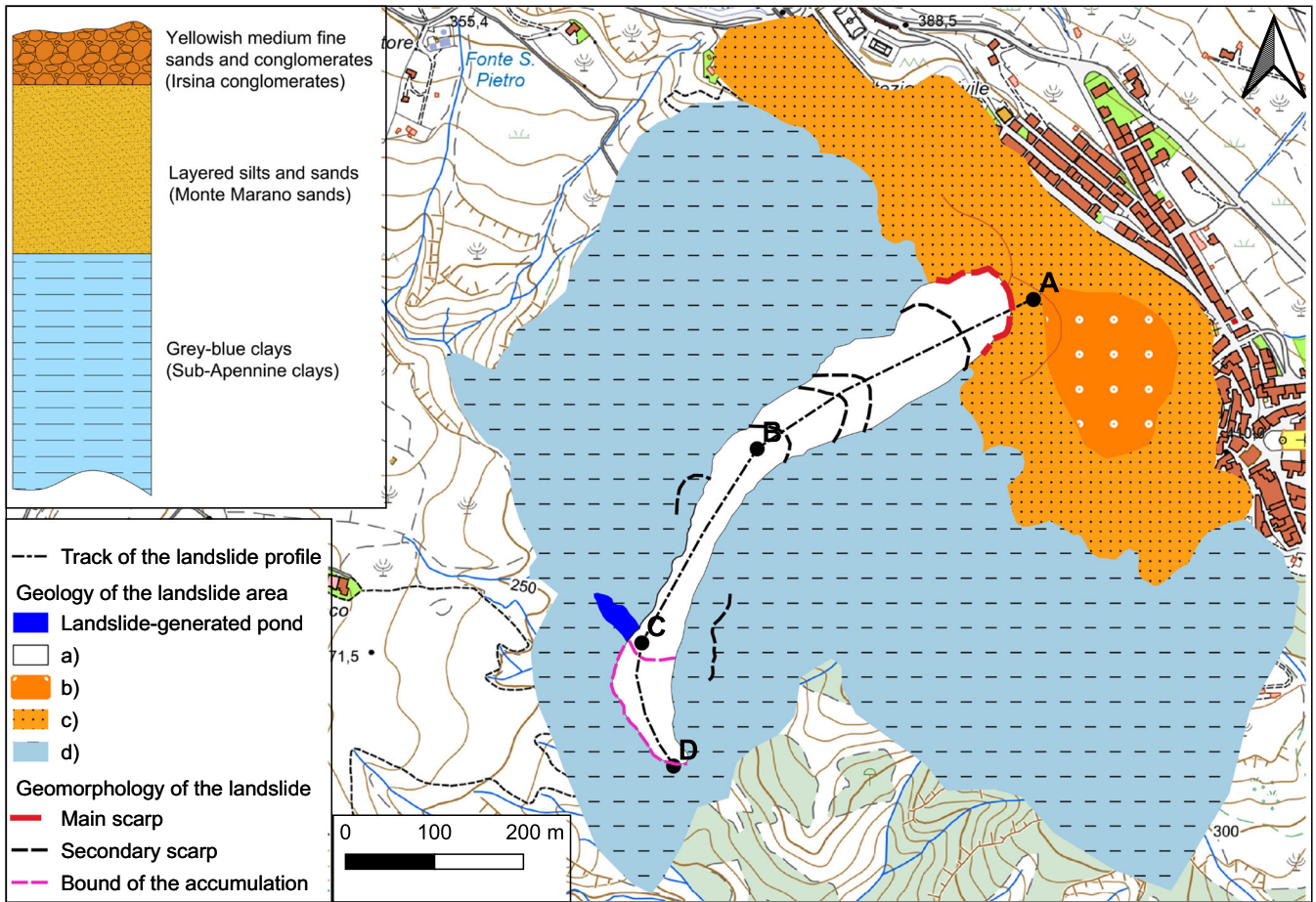


Fig. 3 Geological map of the landslide and stratigraphic sequence in the area of the landslide. The dotted line represents the track of the geological profile. Detail of the geological map. **a** Landslide detritus. **b** Yellowish medium-fine sands and conglomerates (Conglomerato di Irsina). **c** Layered silts and sands (Monte Marano sands). **d** Gray-blue clays (sub-Apennine clays)

b) The pile rotation increased until a sort of newborn trench originated. The buildings overlooking on the road sustained by the retaining structure collapsed into this trench, breaking the piles. Therefore, the pile failure fostered the retrogression of the landslide toward the town of Pomarico, see Fig. 2.

It is noteworthy that both the zone downstream and upstream; the bulkhead were already involved by past landslides; thus, these were partially remolded and destructured.

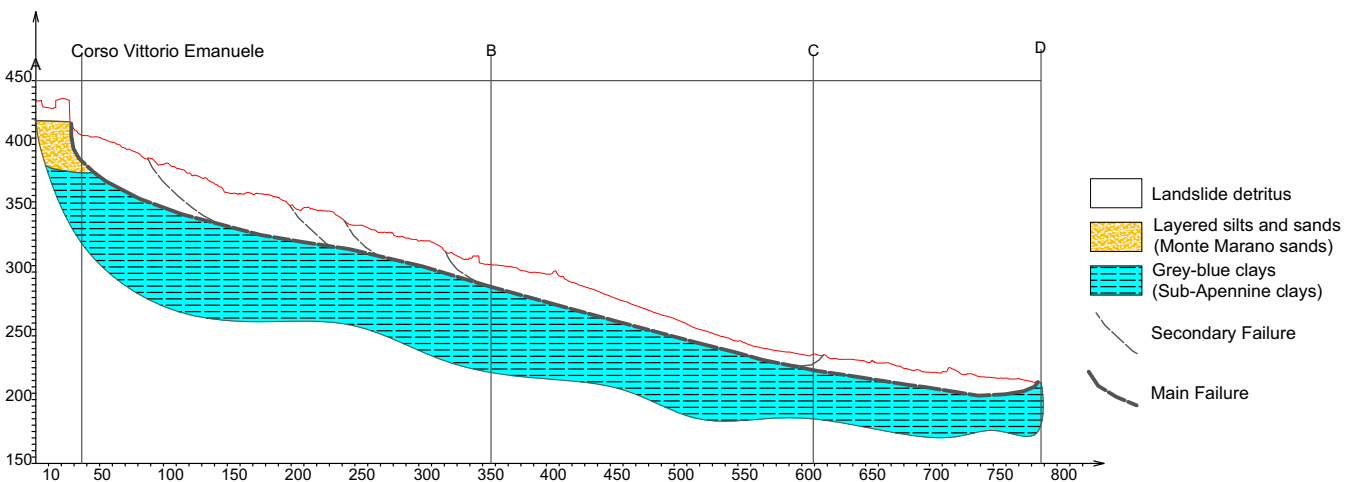


Fig. 4 Geological profile of the landslide

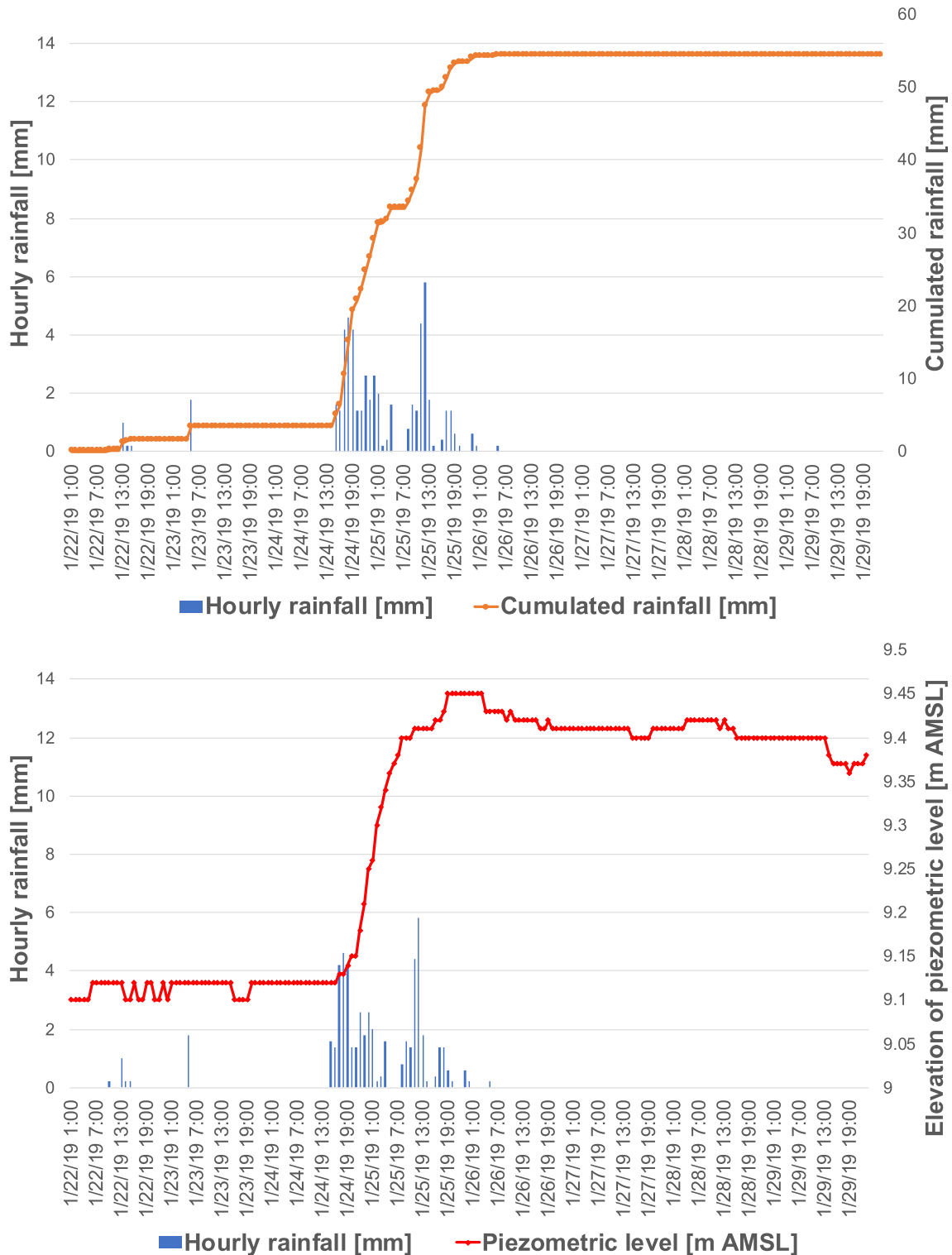


Fig. 5 Cumulated and hourly rain precipitations in Ferrandina raingauge station (a) and groundwater levels measured at Masseria Cardillo (b)

Main features of the landslide

The whole landslide is about 760 m long, while its width ranges between 80 and 100 m in the area of the translational slide and 60–70 in the channel, expanding to 150 m at the toe. The central body of the roto-translational slide is about 20 m deep, decreasing to

16 m at its end. Downstream, the channel of the earth flow is 10 m deep; the depth increases up to 15 m in the accumulation zone, see Figs. 3 and 4.

The roto-translational slide has a 10 m deep scarp and is arc shaped; it involves poorly cemented sands. The slope is about 21°

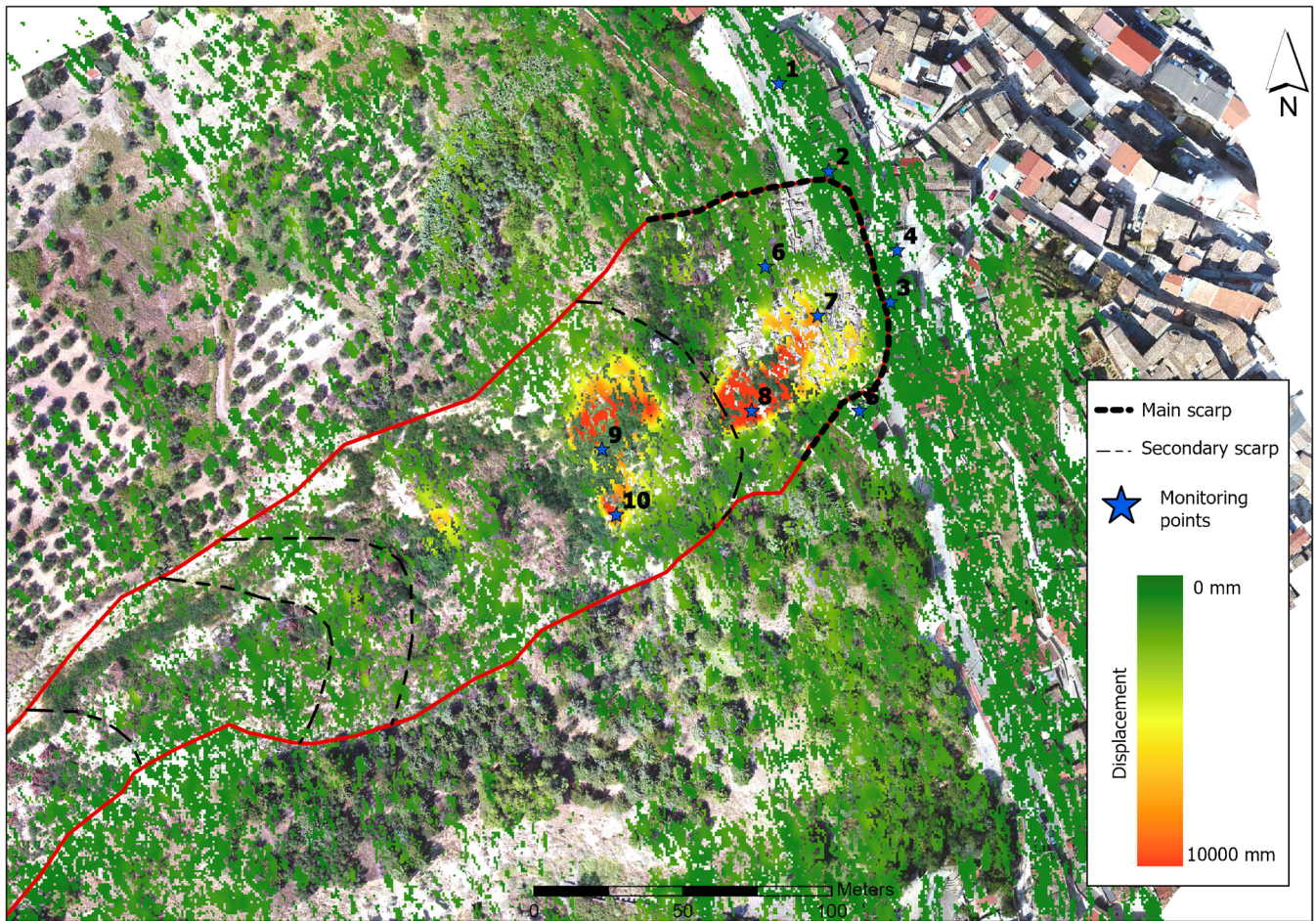


Fig. 6 Cumulated displacements from 28/02/2018 to 24/02/2020 on Pomarico landslides. The detailed cumulative displacement maps are represented with a color scale visualization: (i) stable areas are shown in light green (displacements from 500 mm); (ii) areas characterized by displacement toward the sensor L.O.S. feature colors from yellow to red (maximum cumulative displacement up to 10,000 mm); the red line delimited the landslide boundary. The localizations of the monitoring points are also visible

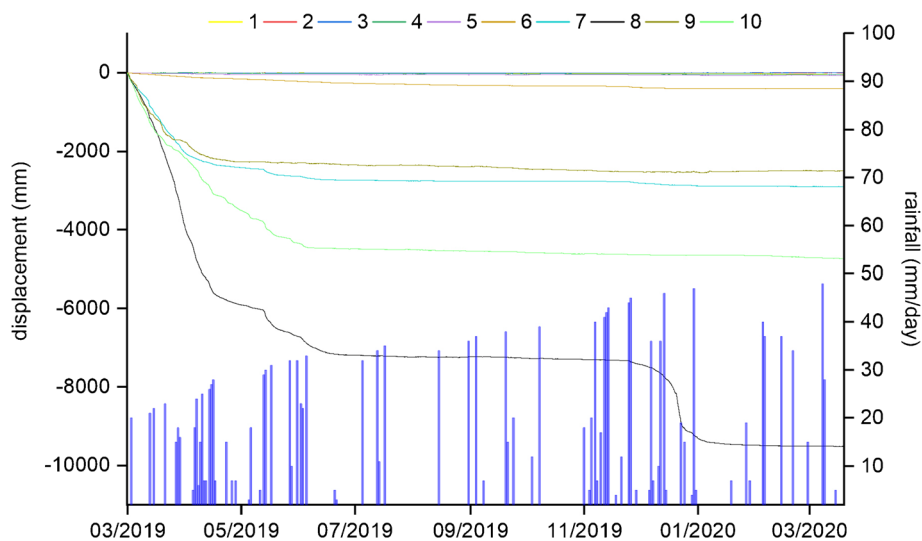


Fig. 7 Time series of GB-InSAR monitoring control points showing displacements of the main landslide's body from February 2019 to early March 2020. The displacements are showed with the daily precipitation values. The legend is referred to the monitoring point in Fig. 6

with a depth ranging between 20 m and 15 m. Here, the depth of the landslide does not account for the presence of the wreckages from the collapses of the buildings. The sliding surface is poorly curved and it mainly develops through the gray-blue clays and just marginally through the yellow sands. Downslope, the final part of the slide is characterized by a terrace, which shows a slope inversion. This generates a morphological depression, whereas some water ponds originates. At the bound between the slide and the earth flow, there are some springs.

The earth flow is fed by the upstream roto-translational slide as well as by remobilized old landslide bodies. The earth flow develops between 380 m AMSL and 215 m AMSL, being 660 m long. The landslide channel starts from the end of the roto-translational slide, continuing up to 240 m AMSL, where there is the accumulation area. The channel is 480 m long, its width ranges between 100 m upstream and 20–30 m downstream. The depth of the landslide is 10 m, with a decreasing trend going downslope. The average inclination of the channel is 16°. The channel shape is well defined by multiple lateral scarps and traction fissures. There are several modest springs, due to the presence of a shallow aquifer.

The accumulation is fan-shaped and asymmetrical, with a compression crest at 240 m AMSL; the accumulation continues downslope to 215 m AMSL. Here, the accumulated mass blocked a stream, thus generating a little lake. The accumulation area is 210 m long, its width ranges between 30 m upstream and 150 m downstream. Its inclination is between 5° and 6°; its depth ranges between 5 and 6 m upstream and 15 m downstream. The accumulation consists in two lobes; these are partly layered and retrogressive, with wide bulged areas and fractures. The end front of the accumulation is eroded.

Analysis of the rainfall as triggering factor

When the landslide occurred, no raingauge stations were available in Pomarico; therefore, in order to analyze the rainfall preceding the landslide event, Ferrandina raingauge station was selected. It is located about 8 km W the landslide, in the same hydrographic catchment, see Fig. 1. The cumulated rainfalls in the fall-winter period antecedent to the landslide were significantly higher than past years (Sdao and Simeone 2019). The whole rainfall volume of the event preceding January 25th landslide was 51.5 mm in Ferrandina, distributed between January 24th and 25th, which cannot be considered a particularly abundant event, see Fig. 5. Moreover, the precipitations were not intense, being regular and continuous, being the intensity normally lower than 3 mm/h, with a peak of 5.8 mm/h, on a timespan of about 37 h, corresponding to an average intensity of 2.1 mm/h. Even if not hydrologically exceptional, this kind of event can be considered “singular” for infiltration. In fact, prolonged low intensity precipitation produced a high infiltration volume, which contributed to landslide triggering.

The abundant and continuous precipitations of the rainfall event of January 24th and 25th, easily infiltrated and severely increased the water content of the landslide masses. Moreover, water infiltration increased the piezometric heads, thus lowering the consistence of clays at the contact with sands. These events presumably originated the retrogressive roto-translational slide and the earthflow.

Even if there are no phreatimetric wells close to Pomarico, an indirect evidence of the high infiltration generated by the rainfall

event occurred between January 24th and 25th was the sudden variation of the water level at the phreatimetric well in Masseria Cardillo, see Fig. 5b, 15 km SE far from Pomarico. In particular, the measured level of groundwater reached a peak value never measured since the start of the monitoring period in 2005.

Landslide monitoring

In the post-landslide event phase, on February 28th, 2018, a GB-InSAR (Ground-Based Interferometric Synthetic Aperture Radar) system was installed in front of the landslide’s toe, by the Centre for Civil Protection of the University of Florence. Aim of this monitoring is to produce 2D displacement maps (interferograms) of an area with high accuracy, i.e., sub-millimetric (Carlà et al. 2017; Leva et al. 2003). About 29 control points were placed on the obtained 3D mesh to achieve displacement time series; 10 of these points, shown in Fig. 6, are of particular interest. During the time range between February 2019 and March 2020, the major displacements were recorded in the main landslide body, with values up to 10 m, in good agreement with the prolonged rainfall events, in particular, the periods May to June 2019 and November to December 2019. Figure 7 shows the time plots of cumulated displacements of the 10 points in Fig. 6, and of the daily precipitations. These major displacements are likely due to the movements of shallow materials resting on the landslide body. The crown area of the roto-translational slide, corresponding to the collapsed urban portion, did not show particular movements, with maximum values of displacements limited to 14 mm. This is probably related to a poor correlation between the urban area where collapses occurred and the displacements of the main body of the landslide. Indeed, the very upper portion of the landslide moved due to the collapse of the retaining bulkhead, which caused a trench working like a sort of sinking ditch.

Conclusions

This work describes the complex landslide occurred in Pomarico between January 25th and 29th. This landslide was likely triggered by the abundant and continuous precipitations occurred before January 25th and by the singular rainfalls event occurred between January 24th and 25th. Moreover, the landslide involved an area where past and relatively recent landslides events occurred. Therefore, it is a remobilization of destructured landslide bodies. Finally, the monitoring activities, based on GB-InSAR, show that after the main event of January 29th, the central and upper bodies of the landslide kept on moving, in particular when rainfall events occurred. The up scarp, where the collapses of the building occurred, remained relatively stable, with movements of 14 mm at most.

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Availability of data and materials Data and materials are available for no profit purposes by directly asking to the corresponding author.

Code availability Not applicable

Author contributions All the Authors equally contributed to data processing and manuscript writing.

Conflicts of interest/competing interests All the authors declare no conflicts of interest.

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A. Doglioni (✉) · V. Simeone

Department of Civil, Environmental and Structural Engineering and Chemistry, Technical University of Bari, Via Orabona 4, 70125, Bari, Italy
Email: angelo.doglioni@poliba.it

N. Casagli · M. Nocentini

Department of Earth Sciences, University of Florence, Via La Pira 4, 50121, Florence, Italy

F. Sdao

School of Engineering, University of Basilicata, Potenza, Italy