

INFLUENCE OF THE GEOLOGICAL STRUCTURE ON A ROCKSLIDE IN NORTHEASTERN ITALY

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ABSTRACT

In the Astico Valley (Venetian Pre Alps, north east Italy) a rockslide of approximately $10 \times 10^6 \text{ m}^3$ occurred in conjunction with the Verona earthquake (03.01.1117, I_0 IX MCS, M 7.0). The rockslide seems to have been favoured by the downhill dip of the carbonate beds and the deposit dammed the narrow valley originating a lake, later emptied by the river incision of the landslide deposit. Upwards of the crown more than $10 \times 10^6 \text{ m}^3$ of rocks are still hanging on the valley.

Here we present the results of a preliminary geological analysis of the slope, showing that the failure surface corresponds to a thrust surface with a stair case trajectory only partially coinciding with the beds, which has been reactivated by the rockslide.

Moreover, the kinematic analysis shows that the scarp of the landslide could be involved in a quite huge new landslide.

Along the Astico valley a motorway has been designed, with a viaduct and service areas just at the foot of this potential landslide. The field investigations suggest this potential landslide could have a high impact on such infrastructures and that a careful stability analysis is needed for an appropriate risk assessment.

KEY WORDS: rockslide, thrust, ramp-flat system

INTRODUCTION

Valleys in mountainous regions have recently experienced a strong demand for expansion of transporta-

tion and communication facilities. In such environment large landslides are infrequent events. In comparison with the length of human lifetimes, their occurrence is low and this can produce a false sense of security that may pervade even the local administrations. Existing studies (e.g. EISBACHER & CLAGUE, 1984) have demonstrated that major landslide disasters can be avoided if historical experience is evaluated. The Alps of Europe are a good example of region with a large body of documented evidence of landslide events.

Geological field investigations are essential in studying landslides. The lack of appropriate geological knowledge can lead to failure of the investigation process (OSTERBERG, 1979). In recent years, risk assessment has become an important factor in landslide hazard reduction. In particular, reliable landslide hazard maps are of paramount importance since they should indicate where landslides have occurred in the past, the locations of landslide-susceptible areas and the probability of future occurrences.

We document the example of the La Marogna rockslide in the Astico valley (Venetian Pre-Alps, Southern Alps), which has not been reported on existing maps of landslide hazard zonation (AUTORITÀ DI BACINO, 2012). This absence should be considered critical, because the design of a motorway running along the narrow valley doesn't take into account the vulnerability, elements at risk and specific risk associated with such potential instability.

GEOLOGICAL SETTING

The Venetian Pre-Alps are part of the Eastern Southern Alps, a SSE-vergent retro-belt of the Alps shortened and uplifted in Neogene times. The Southern Alps represent one of the best-preserved passive continental margins exposed in a mountain belt. The rifting begun in the Late Triassic and ended in the Middle Jurassic, when the drifting phase begun (BERTOTTI *et alii*, 1993). Extension was controlled by a set of c. N-S trending normal faults, which are now exposed and well recognizable in the field. During the development of the fold- and thrust-belt these normal faults were reactivated as strike-slip faults and acted as lateral or oblique ramps of the thrust sheets (ZAMPIERI & MASSIRONI, 2007).

The Neogene uplift of the Pre-Alps has widely exposed the 800 metres-thick unit of the “Dolomia Principale” (Hauptdolomit). This Late Triassic shallow water deposit is composed of a lower unit of peritidal well-bedded carbonates and an upper unit of thicker subtidal beds (BOSELLINI & HARDIE, 1988). Given its thickness, the Dolomia Principale constitutes the frame of the Pre-Alps plateaus, which are separated by deep valley incisions with steep slopes.

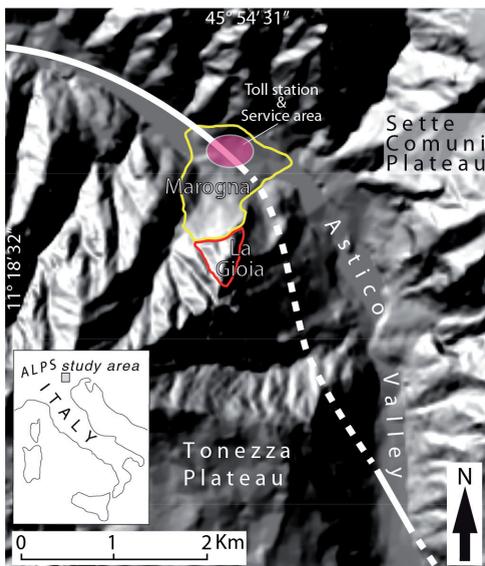


Fig. 1 - Location of the study area. The yellow line outlines of the La Marogna accumulation; the red line is the contour of the rock mass upstream of the crown (La Gioia) potentially involved by a future landslide. The white line is the designed motorway trace (continuous: surficial; dashed: underground)

THE MAROGNA ROCKSLIDE IN THE ASTICO VALLEY

The Astico valley is a fluvial incision separating the Sette Comuni (Asiago) Plateau to the east from the Tonzessa Plateau to the west (Fig. 1). The valley cuts orthogonally the core of the ENE-trending Spitz-Campolongo anticline (BARBIERI *et alii*, 2007) related to the Neogene uplift of the plateaus. The northern limb of the anticline dips towards the valley, since in its upper part the valley runs WNW changing its direction from a N-S trend across the fold.

The inclined attitude of the Dolomia Principale beds represents a structural element favouring sliding of rock masses along bed discontinuities. Indeed, a rockslide of c. 10×10^6 m³ occurred in recent historical times, since the valley floor was completely filled by rocks and debris (La Marogna). The triggering of the rockslide is related to the Verona earthquake, which has been the strongest seismic event of the northern Italy (I_0 IX MCS, M 7.0), occurred on 1117.01.03 (GUIDOBONI *et alii*, 2005). Two C¹⁴ dating of timbers collected at the base of the landslide deposit and one dating of peat buried beneath alluvial gravels upstream of the deposit gave ages consistent with that of the Verona earthquake (BARBIERI *et alii*, 2007).

The La Marogna deposit is composed of a main body due to a rockslide coupled with falls and a fan-shaped body due to a later process, probably a rock/debris avalanche. In the High Middle Age the tract of the Astico valley affected by the rockslide was prob-

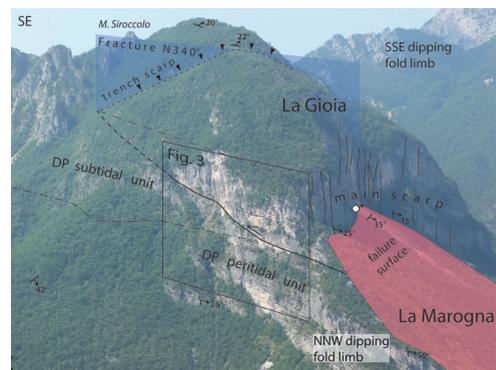


Fig. 2 - Oblique view of the La Gioia upper slope and the upper part of the La Marogna accumulation. The rockslide occurred on the northern limb of an anticline fold, of which the southern limb is visible in the background (upper right corner of the picture). DP: Dolomia Principale. The white circle is a temporary water spring

ably free from permanent settlements. The accumulation dammed the valley and a lake originated upstream. In 1278 the natural dam collapsed and an alluvial event damaged the road, a church and a spinning-mill just downstream (PERIN, 1899); eventual casualties are not reported. The emptying of the lake allowed the re-establishment of a road along the valley floor, which remained the only artifact until the end of the 20th century.

GEOLOGICAL STRUCTURE

LA GIOIA EAST FACE

The structure of the slope where the Marogna rockslide occurred is the northern limb of an anticline fold where beds, dipping towards NNW, increase their dip angle towards the valley floor. Upstream of the main scarp (elevation from 750 m to 1169 m), the beds dip less than 20°. At the base of the La Gioia main scarp (elevation from 750 m to 850 m) the beds dip 20° to 25°, while downstream the dip angle progressively increases up to 50° (elevation 550 m) (Fig. 2).

The N10° trending face delimiting to the east the La Gioia slope is a c. 150 metres-high wall, on which the Dolomia Principale formation is well exposed. A careful investigation of the wall face shows that a thrust with typical “stair case” trajectory (RICH, 1934) affects the fold limb (Fig. 3). The geometry of this type of thrust sheets is the product of rigid-body translation with minor internal bending strains as the sheet moves over the ramp-flat structure of the fault surface (e.g. SUPPE, 1983). In a contractional context ramps are steeper reverse fault tracts connecting flats (fault tracts subparallel to the bedding) at different stratigraphic levels. Ramps may also give rise to thrusts with opposite sense of displacement (backthrusts). Typically, ramps tend to form in stiff layers, while flats or detachments in weak ones.

This is what one can observe on the east-facing wall of the La Gioia slope (Figs. 2 and 3). More in detail, the lower exposed flat is located at the transition between the well bedded lower peritidal unit of the Dolomia Principale and the upper subtidal unit, which is characterized by much thicker bedding (Fig. 2). The NNW dipping ramp above this flat cuts through the thick and relatively stiff beds of the dolomite rock, giving rise also to minor SSE dipping ramps (backthrusts) (Fig. 3).

The origin of the thrust can be referred to flexural slip, i.e. slip along bedding interfaces during folding. In the same area, ramp-flat geometries at a fold core in bed-

ded carbonate rocks have been described by ZAMPIERI & MASSIRONI (2007) only few kilometres to the SW.

LA GIOIA NORTH FACE

La Marogna crown, called La Gioia, is a very steep rock wall ENE trending and reaching 100 metres in elevation. The wall is affected by some set of inclined and sub-vertical faults and fractures parallel and at high angle to the wall face. In particular, the scarp and the upstream slope are dissected by a main subvertical fracture trending N340° recognizable also on the east-facing slope (Fig. 2). Therefore, La Gioia scarp is divided into two parts: an eastern part, which represents a recess, and a western part corresponding to a salient (Fig. 4). The eastern part of the wall shows an inclined fault zone dipping 70° towards ENE. The geometry of the fault, which is characterized upwards by splay faults, typically points to a normal fault according also to the kinematic indicators collected on the fault plane.

In the Venetian Pre-Alps such faults affecting Mesozoic rocks are generally of Jurassic age, but normal faults of Palaeogene age has been also reported (ZAMPIERI, 1995; ZAMPIERI & MASSIRONI, 2007).

The main sets of sub-vertical fractures affecting the La Gioia wall trend N50° (K2), N70° (K3), N310° (K4), N340°-360° (K5), the most persistent being the K5 set, which controls the development of straight and deep incisions affecting the slope above the landslide crown (Fig. 4). The slope is segmented into two main blocks separated by a prominent fracture along which a 15 metres wide trench has developed. Minor sub parallel trenches have also found on the eastern ridge (Fig. 4).

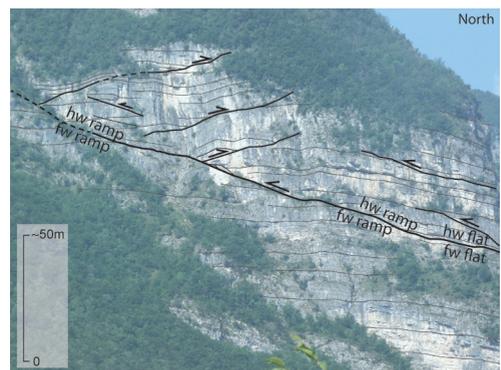


Fig. 3 - N-trending face of the eastern slope of the La Gioia showing the staircase geometry of a main SSE-vergent thrust with flats and ramps. HW: hanging wall, FW: footwall

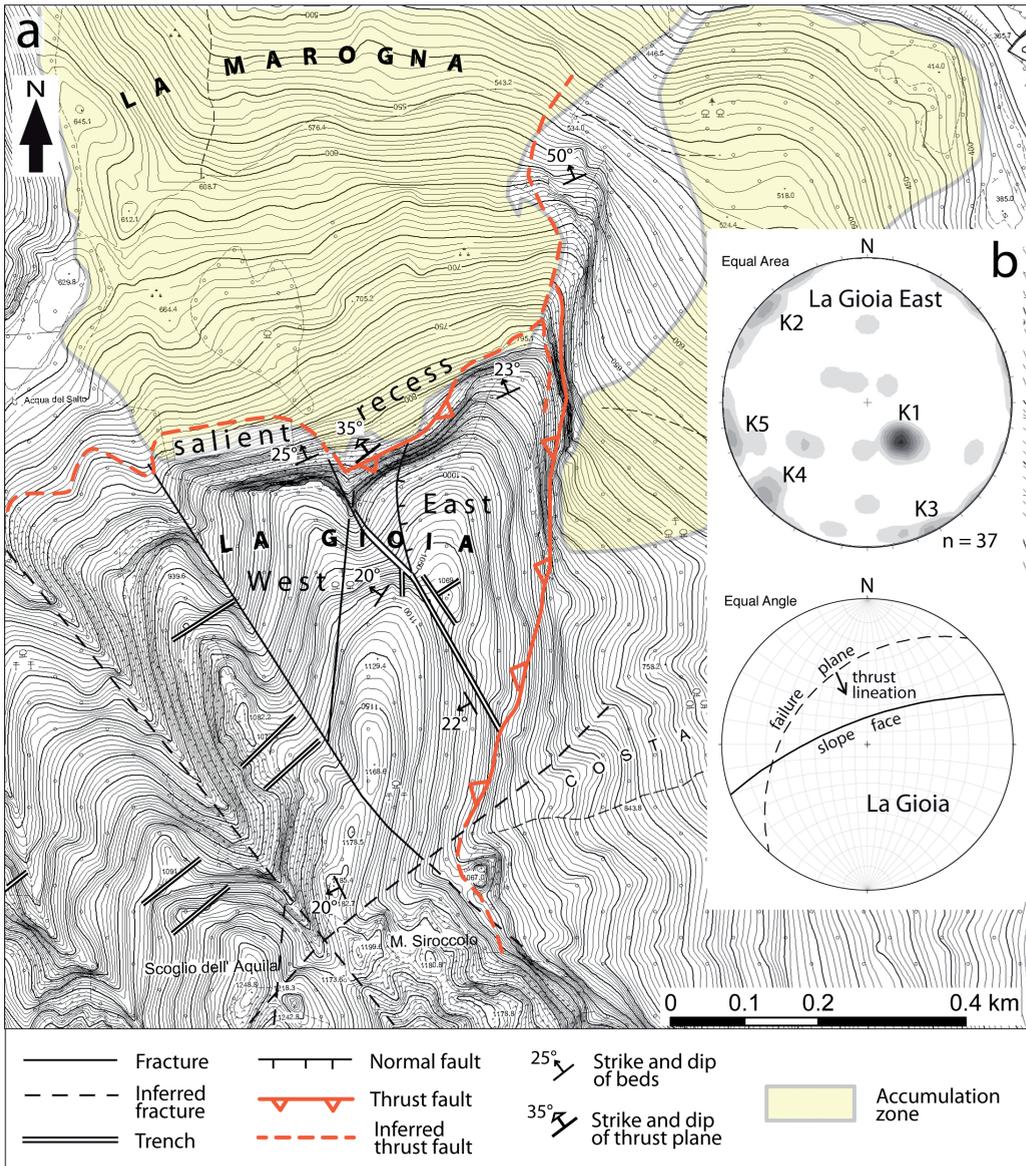


Fig. 4 - a) Structural sketch of the La Gioia upper slope of the La Marogna rockslide. b) Plots (lower hemisphere) of the main fracture/fault sets recognized on the eastern sector of the La Gioia upper slope and of the slope face with the failure plane

Several trenches at low angle to the trend of the main scarp affect the upper slope, confirming the pervasiveness of the K2 set.

At the base of the main scarp, where the beds dip 20°- 25° towards NNW, the sliding surface is well exposed and cuts the beds since it has a dip angle of 37° towards N310° (K1 in Fig. 4). This plane has a striated surface locally coated by a few cm-thick breccia and shows lineations plunging 35° towards N337°. The rock of the

wall lying above the slickenside shows a 1-meter thick damage zone with very poor strength. The striae are also recognizable looking inside the cavities below and laterally to the wall, not only in the depletion zone. This latest observation, along with the other features of the sliding surface, suggests that on the upper part of the surface of rupture sliding has occurred on a pre-existing fault surface cutting the beds, i.e. on a thrust ramp surface.

Water circulation along the upstream prolongation

of the sliding surface is shown by the occurrence of a temporary water outflow, which locally cleans up the debris accumulated on the slip surface at the base of the main scarp (Fig. 2).

DISCUSSION AND CONCLUSIONS

The analysis of the natural cross section exposed on the N10° trending face of the La Gioia (Figs. 2 and 3) shows that in its lowermost part the La Marogna failure surface is localized along a folded dolomite bed, while in the middle and upper parts it cuts through the beds (Fig. 5). Therefore, the failure surface was not controlled by the downhill dip of the bedding surfaces, as an inaccurate analysis could suggest.

The recognition of slickenlines inside cavities located along the surface of rupture uphill and laterally to the depletion zone suggests that the slip surface originated along a pre-existing thrust fault, i.e. along a plane of weakness.

The sliding surface corresponds to different tracts of a thrust plane, parallel to the beds (flat) in the lower slope, while truncating them (ramp) in the upper part. The flat and the ramp corresponding to the failure surface are part of a thrust structure affecting all La Gioia-La Marogna slope, i.e. the entire northern limb of the Spitz-Campolongo anticline. Other secondary discontinuities such as inclined faults and subvertical fractures contribute to the structural fabric of the slope.

In recent years the La Marogna slide deposit was quarried on the left bank of the Astico creek, while the mining of the right slope of the valley is ongoing. This activity has produced a flat area on valley floor, which is now suitable for development, since the Basin Authority (public agency charged to define the zone of respect for geologic and hydrogeologic hazards) didn't include La Marogna rockslide in the regulated areas, because its age > 300 y led to classifying it as a naturally stabilized "paleo-slide".

In the meantime, a plan for construction of an inter-regional motorway (A 31 Nord) along the valley has been proposed. More in detail, in the flat area produced

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Fig. 5 - Natural cross section of the La Marogna rockslide showing the relationship between bedding and sliding surface

by the quarrying of the landslide accumulation the preliminary project has designed a viaduct, a toll station, a maintenance centre, a service centre and a car park.

The lack of knowledge about the geological setting of the slope generating the rockslide has probably led to underestimate the risk. Given the effects of the 1117 rockslide, a new event with comparable volume of rocks could produce similar effects, i.e. sudden complete infill of the valley bottom with destruction of any development structure.

The results of the geological investigations of the La Marogna rockslide provide the basis for the stability analysis of the La Gioia slope. The structural setting of the slope presented here suggests that an accurate site characterization including identification of the geometry of relatively homogeneous zones and the constitutive properties of the material within the zones (with laboratory testing) is needed.

In addition, accurate investigations and modelling are needed in order to perform the risk assessment before to plan the development of the La Marogna area.

ACKNOWLEDGEMENTS

This research was executed within the research project GEORISK (n. STPD08RWBY_001) of the University of Padova. We thank R. Genevois, M. Masironi and an anonymous reviewer for their constructive criticism.

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