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Research paper

Lavini di Marco (Trentino, Italy): ^{36}Cl exposure dating of a polyphase rock avalanche

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ABSTRACT

The Lavini di Marco rock avalanche deposit ("Marocca di Marco") is located along the left side of the middle Adige Valley, south of the town of Rovereto (NE Italy). The deposit is estimated to have a volume of ~2 × 10^8 m^3 and cover an area of ~6.8 km^2. It comprises Jurassic Calcari Grigi limestones that detached from the western slope of Mt. Zugna Torta. The Lavini di Marco is composed of at least two different rock avalanche bodies, the main deposit known as Lavini di Marco (the principal) and the much smaller Costa Stenda deposit. Costa Stenda deposits overlie Lavini di Marco deposits. Samples for ^{36}Cl exposure dating were collected from boulders within the deposits, from sliding plane bedrock and from the bedrock wall at the head scarp. Exposure ages range from 800 ± 210 to 21310 ± 1000 years. The latter age stands as a notable outlier suggesting that that Costa Stenda boulder was exposed for a considerable amount of time in the pre-slide bedrock. Lavini di Marco and Costa Stenda boulder ages are 2600 ± 200, 2700 ± 200, 3100 ± 300, 3300 ± 300, 3400 ± 300, 4400 ± 290, 5300 ± 300, and 5400 ± 300 years. The latter three are Costa Stenda boulders which we also interpret to contain inherited nuclide concentrations. The five remaining boulder ages cluster around 3000 years. We calculate a mean age for the Lavini di Marco and Costa Stenda rockslides of 3000 ± 400 years. Within the uncertainties of our data the two slides were simultaneous. For the bedrock sliding plane we obtained significantly younger ages, 1600 ± 100 and 1400 ± 100 years, and for the head scarp 800 ± 200 years. The sliding plane ages record small-scale reactivation which seems to overlap in time with a catastrophic flood event of the Adige River in Verona, as reported in the Fulda Annales, in 883 AD. Only the single age of 800 ± 210 years suggests activity at Lavini di Marco coincident with the well-known Verona earthquake (1117 AD).

1. Introduction

Valley slopes in the Alps are in the stage of re-equilibration toward the present fluvial regime following the extensive reshaping by Pleistocene glaciers. The dominant response is numerous slope instabilities in both bedrock and cover sediments of varying size and type; such as rockfall, rockslide, and rock avalanche (Heim, 1932; Abele, 1974; Mantovani, 1997; Panizza et al., 1997; Pellegrini et al., 2005; Prager et al., 2008; Borgatti and Soldati, 2010). In the Trentino Province along the southern side of the Eastern Alps many rockslides are documented (see Fig. 1 for some of the larger deposits). About 40% of the 660 landslides that have affected the province are rock avalanches (Cocco, 1990), including, the Lavini di Marco, Molveno, Marocche di Dro, Marocche di Pietra Murata, Marocche di Lasino, Monte Palon, Castelpietra (Fuganti, 1969; Mantovani, 1997). The name "Marocca" derives from "Mar" which means "stone". Perna and Sauro (1978) point out that initially the term "Marocca" referred to a landslide onto a glacier, with the debris then being transported and deposited by the glacier. Landslides in Trentino are focused along faults (Cocco, 1990), mostly belonging to the main tectonic systems, such as the NNE-trending (Giudicarie), the NW-trending (Schio-Vicenza) and the N-trending (Trento-Cles) fault systems (Fig. 1a) (Castellarin and Cantelli, 2000; Castellarin et al., 2005). Active tectonism along

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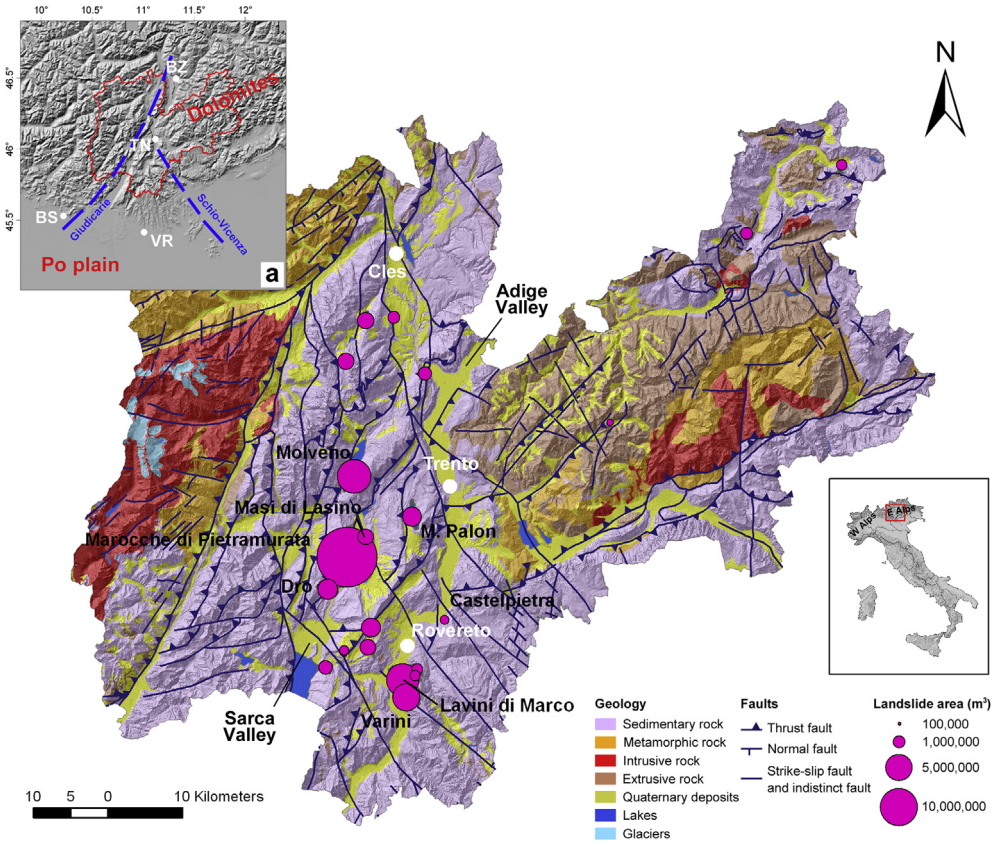

Fig. 1. Geological and structural map of the Trento Province (from Bosellini et al., 1999 and authors own work) with location of the Lavini di Marco and other landslides of the area. In sketch "a" the Giudicarie and Schio-Vicenza regional fault patterns are shown (Castellarin et al., 2005). TN Trento, BZ Bolzano, VR Verona, BS Brescia.

fault-controlled valleys in combination with stress redistribution related to slope over steepening due to undercutting by glaciers and rivers predisposes many of the slopes to instability. Large-scale landslides present in the densely inhabited valleys of the Alps, such as the Adige Valley, represent a threat for the local population and infrastructure. For this reason numerous slides have been studied in detail, dated, and the release and deposition processes have been modeled (Sørensen and Bauer, 2003; Cuman, 2007; Sosio et al., 2008; Crosta et al., 2004; Alonso and Pinyol, 2010; Ostermann et al., 2012).

The Lavini di Marco rock avalanche (or "Marocca di Marco", Perna and Sauro, 1978), located along the western slope of Mt. Zugna Torta (Fig. 2), is one of the largest rock avalanches of the southern flank of the Eastern Alps. The deposit has a volume of $\sim 2 \times 10^8$ m^3 and covers an area of about 6.8 km^2 (Fuganti, 1969; Eisbacher and Clague, 1984; Orombelli and Sauro, 1988). The Lavini di Marco comprises carbonate rocks of the Calcari Grigi Group that slid along a dip slope out onto the plain of the Adige River south of Rovereto. The Marco slides or "Slavini" were mentioned by Dante Alighieri, the Italian Poet who interpreted the Lavini di Marco deposits as the result of a slope instability ("*sostegno manco*") perhaps related to an earthquake ("*tremuoto*") (Alighieri, 1314).

The age and origin of the Lavini di Marco deposits have been the focus of controversy for centuries, with age estimates ranging from during the Last Interglacial to historic times. Some authors propose that the landslide occurred at 883 AD (Penck, 1886) in agreement with the Annales Fuldenses, 1891 (written in the late 9th century) which reads:

> "In the Italian territory, a mountain moving from its side fell down into the Adige River, halting the flow of the river. People living in Verona and surrounding areas were affected by the interruption of the flow (*tamdiu utilitate illius carebant*) until the river, breaching new caves (*cavernulas*), returned to its bed"

This was thought to be related to one or more local earthquakes (cf. Mariani, 1673; Giovanelli, 1834; Gorfer, 1977). For others, the Lavini di Marco deposits were overridden and re-shaped by the Adige Glacier, suggesting it occurred either before or during the Last Glacial Maximum (De Mortillet, 1861; Paglia, 1875; Fuganti, 1969; Abele, 1974). As the deposits are interpreted to overlie deposits of the Adige Glacier, most authors assigned a post-deglaciation age (Noriller, 1871; Goiran, 1879; Taramelli, 1881; Penck, 1886; Penk and Brückner, 1909; Heim, 1932; Eisbacher and Clague, 1984). Recently, a Medieval age, possibly related to the Verona earthquake (1117 AD), has gained acceptance (Orombelli and Sauro, 1988; Galadini et al., 2001; Stucchi et al., 2008).

As with numerous deep-seated gravitational events in the Alps, activity at Lavini di Marco may have occurred close to the Pleistocene/Holocene boundary (Poschinger and Haas, 1997; Ivy-Ochs et al., 1998, 2009; Tinner et al., 2005; Prager et al., 2008). Similarly, large-scale slope instabilities in the southern chains of the Eastern Alps (such as the Dolomites) that occurred at the Pleistocene/Holocene transition have been discussed (Mantovani, 1997; Panizza et al., 1996, 1997; Soldati et al., 2004; Pellegrini et al., 2005; Borgatti and Soldati, 2010). In addition, Prager et al. (2007, 2008) identified a focus of slope instabilities in Tyrol and surrounding areas around 4200–3000 years ago.

To determine the age as an aid for assessing the factors contributing to failure at Lavini di Marco, we dated 12 carbonate bedrock and boulder surfaces using cosmogenic ^{36}Cl. We compare exposure ages with radiocarbon dates from material found under nearby landslides at Mt. Zugna Torta (Orombelli and Sauro, 1988),