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Research paper

Surface exposure dating of the Veliki vrh rock avalanche in Slovenia associated with the 1348 earthquake

Silke Merchel [a,b,*], Irena Mrak [c], Régis Braucher [a], Lucilla Benedetti [a], Blaž Repe [c], Didier L. Bourlès [a], Jürgen M. Reitner [d]

[a] Aix-Marseille Université, CEREGE, CNRS UM 34, F-13545 Aix-en-Provence, France
[b] Helmholtz-Zentrum Dresden-Rossendorf (HZDR), D-01314 Dresden, Germany
[c] University of Ljubljana, Department of Geography, 1000 Ljubljana, Slovenia
[d] Geologische Bundesanstalt, A-1030 Wien, Austria

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ABSTRACT

Over 30 samples from bedrock and boulders from the Veliki vrh rock avalanche have been collected for surface exposure dating. The limestone rocks have been radiochemically treated to isolate and determine long-lived ^{36}Cl by accelerator mass spectrometry. It could be shown that the Veliki vrh rock avalanche from the Košuta Mountain (Slovenia) event can be very likely linked to one of the major historical earthquakes in Europe happening on the 25th of January 1348. Taken into account independently determined denudation rates, inherited ^{36}Cl originating from pre-exposure at shallow depths (20–55 m) could be calculated. The high amount of inherited ^{36}Cl, i.e. 17–46% of the total ^{36}Cl, makes this site not suitable for a precise determination of the ^{36}Cl production rate as it was originally anticipated. Veliki vrh is a "classic" rock avalanche of high velocity. The slope failed in the upper part with a translational slide predominantly along the bedding planes, whereas dynamic fragmentation is the cause for further crushing of the material and the long runout.

1. Introduction

Understanding the causes of catastrophic rock avalanches is one of the biggest challenges in geosciences and a pre-requisite for future reduction of disasters. Several different processes can lead to catastrophic rock avalanches (e.g. Korup et al., 2007). Examples are climatic changes resulting in glacial melting (Le Roux et al., 2009; Darnault et al., 2012), intense precipitation events (Gabet et al., 2004) or strong earthquakes (e.g. Hammerl, 1991; Rohr, 2003; Stock and Uhrhammer, 2010).

The Veliki vrh rock avalanche is one of the largest mass movements' events in Slovenia (Fig. 1). Located on the southern slopes of the Košuta ridge in the Karawanke mountain it has been estimated to have a volume between 20 and $100 \cdot 10^6$ m^3 (Zorn, 2001). The impressive remnants of the event are evident in the mountain face as well as in the valley Pod Košuto. The rock avalanche may be associated with an earthquake that happened on the 25th of January 1348 (Hammerl, 1991).

This 1348 earthquake, also named the big Carinthian earthquake, is one of the major seismic events in Europe, with more than 20.000–40.000 casualties (Vidrih, 2009) in the territory that is nowadays divided between the three countries – Austria, Italy and Slovenia. The Eastern Alps and the Dinarides are the sources of the most important earthquakes in eastern Mediterranean with magnitude up to 7.2 that occurred in Montenegro in 1979 and several magnitudes over 6 in the last century (1996, 1927, 1976, 1962, 1942, 1898) (Karnik, 1979; Kuk et al., 2000). In historical catalogues, the most two damaging earthquakes within this area occurred in 1348 and 1511 both of intensity X (Baratta, 1901; Gruppo di Lavoro, 2004). The 1348 earthquake was also estimated to be of 9–10 on the Mercalli-Sieberg scale, (Rohr, 2003).

Two major rock avalanche events were historically associated with the 1348 earthquake, the first one in Austria and the second one, 50 km east of it, in Slovenia. The volume of the collapsed material of each rock avalanche is far over a million m^3. Both events occurred along south facing mountain ridges of the WNW-ESE striking Gailtaler and Karavanke mountains, respectively. Various written sources indicate that the multiple Dobratsch rock avalanches in Austria were triggered by the 1348 earthquake (i.e. Sieberg, 1940; Ambraseys, 1976; Postpischl, 1985; Gentile et al.,

* Corresponding author. Helmholtz-Zentrum Dresden-Rossendorf (HZDR), D-01314 Dresden, Germany. Tel.: +49 351 260 2802; fax: +49 351 260 12802.
E-mail address: s.merchel@hzdr.de (S. Merchel).

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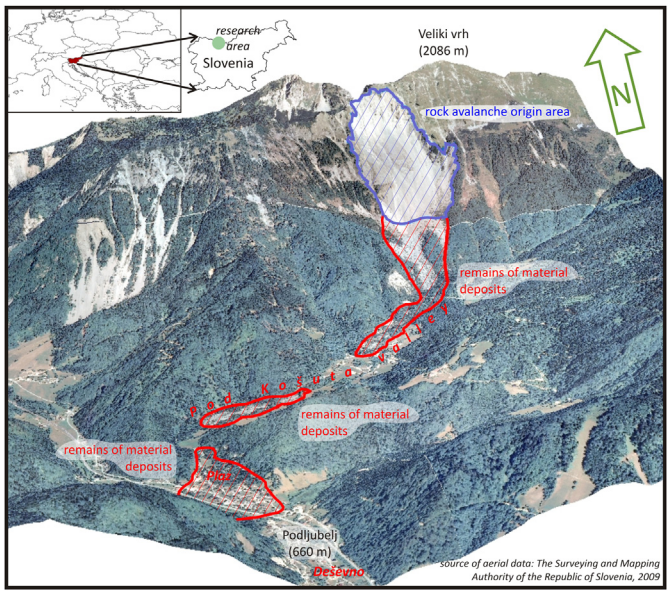

Fig. 1. Aerial pictures draped on a digital elevation model of the studied area. The scar area of the Veliki vrh rock avalanche is delimited by the blue contour and the remains of material deposits by the red contour lines. Source of aerial data: The Surveying and Mapping, Authority of the Republic of Slovenia, 2009.

1985; Lenhardt, 2007). On the other hand, the relation of the Veliki vrh rock avalanche and the 1348 earthquake is a subject of discussion. The Veliki vrh rock avalanche was first attributed to the 1348 earthquake by Koblar (1895) and Sedl (1895), and later on by Gruden (1910) and Badjura (1953). Historical reports suggest the rock avalanche buried the former Tržič settlement, which could have been located at the place where the settlement Plaz is situated today. Note that Plaz in Slovene language means "landslide" or "avalanche".

Surface exposure dating using cosmogenic nuclides could help to validate if there is an actual relation between the 1348 earthquake and the rock avalanche. Thus, the determination of in-situ produced ^{36}Cl by accelerator mass spectrometry (AMS) isolated from samples taken from the fresh bedrock and big boulders had been aimed here.

1.1. Regional setting

Previous research studies in the Veliki vrh rock avalanche area focussed on the geomorphic characteristics of the wider area but they mostly did not recognize the rock avalanche as the event that highly impacted the valley Pod Košuto. Melik (1954) claims that the valley Pod Košuto was glaciated. The terminal moraine was defined at the Plaz settlement and the ground moraine and boulders were defined to the south of the settlement Deševno. Big boulders were recognized as remnants from the Riss glaciation. The name of the settlement Plaz (see above) derives probably from the large amounts of rock particles and blocks that belong to the moraine. Šifrer (1969) writes about large amounts of rock material in the valley Pod Košuto that look like ablation moraine. The retreating glacier was covered with ablation moraine and was, therefore, slowed down in its retreat. The amounts of rock material were coming down as mass movements from the SW face of Košuta, preventing the melting of the ice. Buser (1980) determines moraine material in the valley Pod Košuto and defines the big boulders at the settlement of Plaz as erratics. However, Mrak (2004) explains the large amount of loose rock material in the valley to the debris with a relatively young rock avalanche and supports this hypothesis by measurements of the small corrosion forms on the barren rock surfaces.

Those observations, thus, suggest that the actual morphology of the area of the valley Pod Košuto is in fact caused by a rock avalanche – the so-called Veliki vrh rock avalanche. It is located on the south slope of the Košuta ridge that culminates at 2086 m a.s.l. just above the rock avalanche source area. The highest point of the rock avalanche source area is 1908 m and is easily identified by the large scar on the mountain slope also absent of vegetation (Fig. 2). The width of the source area is about 500 m and it extends beyond the talus slope with a concave shape dipping from 55° to 22° down slope southward. In the area of Podljubelj (Deševno) the bedrock is today covered by the Quaternary sediments (glacial and fluvial as well as with the rock avalanche blocks). During the event prominent escarpments of about 50 m high on both sides of the source area were created. The rock debris extends from 1300 m a.s.l. to the settlement Plaz at 650 m a.s.l. over a runout distance of almost 5 km along the valley Pod Košuto that most probably guided the debris and delimited the extent of the deposit. The resulting travel angel (fahrböschung according to Heim (1932)) is 15° (Fig. 3). The deposit area has a surface of 3 km^2 with a clast-supported surface cover of large angular boulders of metric to decametric diameter. Occasional outcrops show below this uppermost layer a matrix supported sediments with very angular clasts of gravel size in a sandy to silty matrix.

The rock avalanche source area as well as the majority of the debris material is barren although pine trees are already sparsely growing on some larger rock blocks. The forest line in the area it at 1700 m a.s.l. Above it there is the zone of alpine dwarf pine and up to the Košuta ridge the zone of alpine grassland.

1.2. Historical setting

According to various ancient written records, cited by Hammerl (1991), Vidrih (2009) and Rohr (2003), the 1348 earthquake caused between 20.000 and 40.000 casualties and severe damages in the town of Villach as well as in other settlements in Carinthia (Austria) and Carniola (Slovenia). The earthquake was felt in the radius of approx. 750 km (Vidrih, 2009). Located about 10 km west of Villach, along the Gail River, an important part of Mt. Dobratsch collapsed on the 25th January 1348 as the result of the earthquake large

Fig. 2. Mountain slope with scar area of Veliki vrh rock avalanche. Picture taken from boulder position VV12.