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THE SELO LANDSLIDE: A LONG RUNOUT ROCK AVALANCHE?

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The northern slopes of the Vipava Valley represent one of the areas in Slovenia with the highest landslide susceptibility (Komac & Ribičič 2006). Geomorphology of the area is primarily determined by a fold-and-thrust structure, composed of a series of nappes of Mesozoic carbonates thrust over Palaeogene flysch domains. This structural and lithological setting poses primary control on slope morphology, generally characterised by escarpment profiles with steep upper slopes in stronger, although highly fractured carbonate rocks, underlain by weaker shales, marls and sandstones, forming gentle lower slopes. Lower parts and foot zones of the escarpments in the Vipava Valley are covered by coarse grained carbonate colluvial (talus) deposits, generally in a form of relatively steep and short fans of scree coalesced into aprons, and locally as discrete fan- and tongue-shaped bodies, mostly deposited by debris-flow reworking of carbonate scree and weathered flysch material (Popit et al., 2014).

The Selo landslide (Popit & Košir, 2003) is a large Pleistocene landslide complex, predominantly composed of coarse carbonate material that differs from slope deposits and active landslides in the area in its exceptional size and a considerable runout length. Stratigraphy and clast fabric studied in natural outcrops and in well exposed road-cuts during the motorway construction works near the village of Selo lead Popit & Košir (2003) to invoke a single or multiple debris-flow events as a major depositional mechanism for the Selo landslide. However, even a conservative estimate of the landslide's immense volume and its spatial extent raises fundamental questions about the possible source of the debris, the magnitude of event(s), and the transport mechanisms compatible with the extreme runout length and a large lateral (radial) spread of the landslide.

The runout distance of a landslide depends primarily on the volume (Legros, 2002). Therefore, we re-examined the volume and geometry of the Selo landslide and its potential source area by the integration of geological mapping, ground penetrating radar (GPR), and GIS techniques (Verbovšek et al., 2015). The estimated material balance, sediment volume and geometry indicate that the main landslide deposit most probably corresponds to a large-scale slope collapse and development of a rock avalanche.

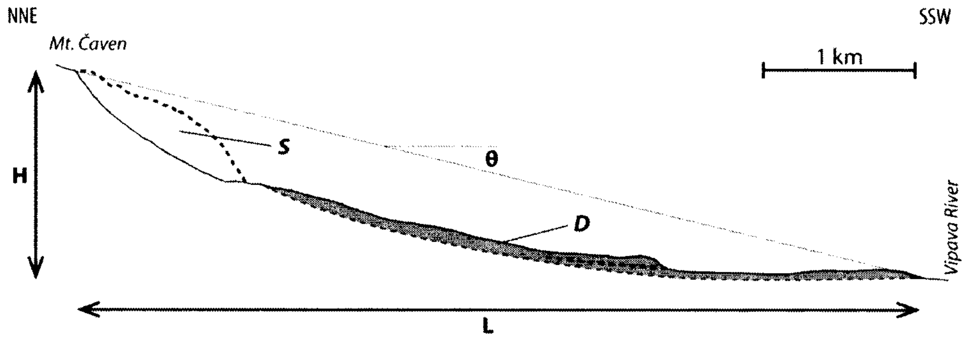

Fig. 1. Simplified longitudinal section of the Selo lanslide area showing potential failing mass - source of material (S), landslide deposit (D), and the definition of parameters H, L and θ.

Figure 1 shows a longitudinal section through the Selo landslide and its potential source mass represented by a large scallop on the edge of the Čaven Mountain (Veliki rob). The carbonate debris of the landslide (shaded area marked with *D* in Fig. 1) spreads over a maximum distance of ~4.5 km, covering an area of more than 10 km^2. The total landslide volume calculated from the bounding surfaces obtained by field measurements, GPR data and GIS techniques (Verbovšek et al., 2015) has been estimated 100 to 190×10^6 m^3, depending on different interpolation methods and taking into account significant volume loss due to erosion. The volume of the supposed source mass (*S* in Fig. 1), calculated from the present topography and a virtual surface, extrapolated over the scar (scallop) from its margins, is approximately 128×10^6 m^3. Considering a substantial increase in total volume between initial failure and deposit ("bulking", Davies & McSaveney, 2012), possible entrainment of the older slope deposits, and interpolation uncertainties, volume estimates of the source mass (*S*) and deposited material (*D*) show a fairly good match.

Parameters describing geometrical relations of a landslide (Fig. 1) are: H - the elevation difference between the crest of the source area and the toe of the deposit, and L - the length of the horizontal projection of the streamline connecting these two points. The ratio H/L corresponds to an apparent coefficient of friction, whereas the angle θ (*Fahrböschung* of Heim (1932), also known as the angle of reach) is defined as the inclination of the line connecting the extreme points of the landslide source and deposit, as measured along the approximate centreline of motion ($\tan\theta = H/L$). The values of the Selo landslide are: H = 1.000 m; L = 5.800 m; H/L = 0.17; θ = 10°.

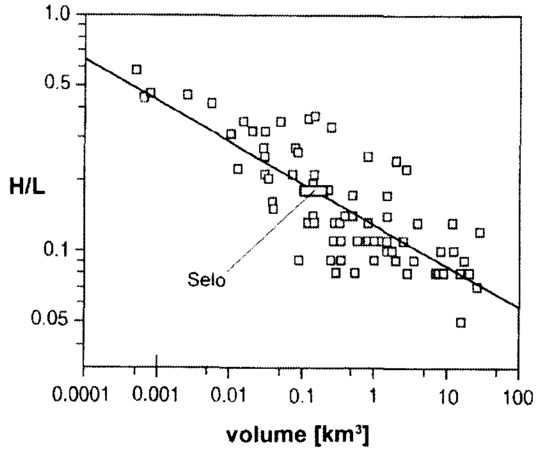

Fig. 2. Plot of H/L ratio related to landslide volume based on a global database of large landslides (adapted from Straub, 1997). Width of the grey rectangle illustrates the range of volume estimates for the Selo landslide (0.1–0.19 km^3) at H/L = 0.17.

There is a clear negative correlation between the apparent coefficient of friction (H/L) and the landslide volume (Fig. 2; Straub, 1997; Legros, 2002). The volume and H/L values of the Selo landslide are in accordance with the data for the landslides of comparable size (Hsü, 1975; Legros, 2002), including some classical examples of the subaerial non-volcanic landslides, e.g., Elm, Switzerland (V = 0.01 km^3, H/L = 0.31), Frank, Canada (V = 0.03, H/L = 0.25), Blackhawk, U.S.A. (V = 0.28 km^3, H/L = 0.125) etc. Numerous landslides of comparable size and from similar geological settings have formed as rock avalanches - extremely rapid, massive flows of fragmented rocks generated by large rock falls or slides. Hence, a slope collapse involving breakdown of the rock mass and development of an avalanche of high mobility appears to be the most plausible explanation for the origin of the Selo landslide complex.

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