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THE SPATIO-TEMPORAL DYNAMICS OF THE CIPRNIK COMPLEX LANDSLIDE, TAMAR VALLEY, JULIAN ALPS, SLOVENIA

Abstract. Mass movements represent important processes that shape relief in Alpine areas. In this article, we present the spatio-temporal dynamics of the Ciprnik landslide (Julian Alps, NW Slovenia) and interpret its triggering and evolution. In the study area, mass movement activity is characterised by two phases: normal deposition on the fluvial fans that dominated up to 2000, and a more active phase related to the triggering of the Ciprnik complex landslide and formation of an additional debris-flow fan. The Ciprnik landslide started as a translational movement over the discontinuity plane that was mobilised into a debris-flow. The triggering and slope failure resulted from a combination of tectonics (i.e. dip-slope position of the strata, and strong fracturing), lithology (alternation of thin beds of carbonates and fine-grained clastics), and accumulation of precipitation. The debris-flow fan remains active and interfingers with adjacent active fluvial fans.

Keywords: complex landslide, debris flow, debris-flow fan, fluvial fan, Tor Formation, Tamar Valley, Julian Alps

INTRODUCTION

Mass movements including debris flows are important processes that shape relief and landscape, and pose serious threat to human life and the environment (Iverson et al. 1997; Wieczorek, Glade 2005; Komac, Zorn 2007; Breien et al. 2008; Zorn, Komac 2008). They occur as a result of co-existence of several factors related to geological features, relief, climate, and human activity. The complexity of the environmental components and their succession often pose a challenge to fully understanding and reconstructing the development of mass movement. The area of Julian Alps (NW Slovenia) with high and steep relief, high precipitation and frequent intensive downpours (cf. Kajfež-Bogataj 1996; Fidej et al. 2015) represents an area with a potential high frequency of debris flow occurrence (Komac, Ribičič 2006; Komac, Zorn 2007; Zorn, Komac 2008; Komac et al. 2009). Despite this fact, large-scale debris flows are a relatively rare mass-wasting phenomenon in the Julian

Alps. This peculiarity is connected to the fact that the Julian Alps are mainly composed of pure carbonate rocks (Dachstein limestone for example), while formations of fine-grained clastic deposits are quite rare. Large debris flows in the Julian Alps are therefore mainly related to rare outcrops of the Upper Triassic Tor Formation (Stože, Ciprnik: Komac 2001; Majes 2001; Petkovšek 2001; Ribičič 2001; Zorn et al. 2006; Komac, Zorn 2007; Zorn, Komac 2008; Komac et al. 2009) and Cretaceous flysch deposits (Strug: Zorn 2007; Zorn, Komac 2008; Ribičič, Kočevar 2003; Mikoš et al. 2006a, b).

In this article we used the classification of R. Dikau et al. (1996) where mass-wasting events in which one form of failure develops into a second form of movement are called **complex landslides**.

Additionally, in this article we have subdivided the **alluvial fans** into two subgroups: **debris-flow fans** and **fluvial fans**. This division is following sedimentological classification of alluvial fans of H.G. Reading (1996), and G. Nichols (2009) in which the alluvial fans are classified according to the main sedimentary processes that dominate on the fan. **Debris-flow fans** are those where the main transport mechanism is debris-flows (viz. a dense mixture of coarse-grained, fine-grained material and water that behaves as cohesive viscous slurry of material (cf. De Blasio 2011). The debris-flow fans can be fed by feeder canyons containing a dense mixture of water, gravel and fines, or they can form at the toe of the debris-flow dominated slopes. The deposits on this fan have clay and silt matrix-supported fabrics and anomalously large 'floating' clasts, some of which

Fig. 1. The study site on W slope of Ciprnik Mt. 1747 m a.s.l., Tamar Valley, Julian Alps

may protrude from the top surface (Reading 1996). In contrast, on the **fluvial fans,** none or a very little fine-grained fraction is present. Coarse-grained debris is therefore transported by streams and sheetfloods as a bedload and suspension flows (Reading 1996; Nichols 2009; De Blasio 2011). Fluvial fans are fed by channels and/or gullies collecting water and debris from the catchment area of the fan. The resulting deposits are non-cohesive, have an open framework, formed of clast-supported breccias and conglomerates.

We present a complex landslide Ciprnik from the Tamar Valley, Julian Alps, NW Slovenia. In the night November 18–19 2000 (Jurkovšek 2001), after an exceptionally wet period, a landslide from the lower and middle slopes of the Ciprnik Mountain was triggered (Fig. 1). It flowed into the Tamar Valley as a debris flow, destroyed the road that leads to the Tamar cottage and, after 1 km of travelling towards the lower reaches of the valley, it stopped. Although this event has been reported, detailed research is absent. The Ciprnik landslide (debris flow) is briefly mentioned only in B. Komac and M. Zorn (2007) and B. Komac et al. (2009) where a general description and surface area of the landslide were approximated. In this article we try to fill this gap and present the spatio-temporal dynamics of the complex Ciprnik landslide and interpret its triggering conditions.

MATERIALS AND METHODS

The cartographic material consisted of contemporary satellite imagery and historical aerial photographs from 1954, 1975, 1989, 2001, 2006 and 2009. Since they were taken employing various technologies they differ in scale, colour and accuracy. Therefore, only basic spatial analyses were performed using the tools available in the ArcMap 10.2.2 software. The active parts of mass movements (i.e. landslides, debris flows and fluvial flows) were detected using the difference between the freshly exposed or/and transported rock and vegetation. This included visual analyses of the photo tone and colour of the black and white and colour pictures.

The analyses of rainfall were carried out using the daily data from the nearest-located (3.7 km away) meteostation Rateče (864 m a.s.l.) covering the period 1961–2015. Although the meteostation location is approximately 800 m below the studied slope (the main scare of the landslide) the short distance and location in the Tamar Valley's mouth make the data a reliable representation of the actual climate, including precipitation at the Ciprnik fan (Fig. 2). The rainfall sums for various periods (24, 72, 168, 336 hours) were calculated and used in two models that deliver the precipitation thresholds triggering the mass movements. The most classical and conservative worldwide threshold established in 1980 by N. Caine, and the more recent one provided by F. Guzzetti et al. (2007), were both employed.

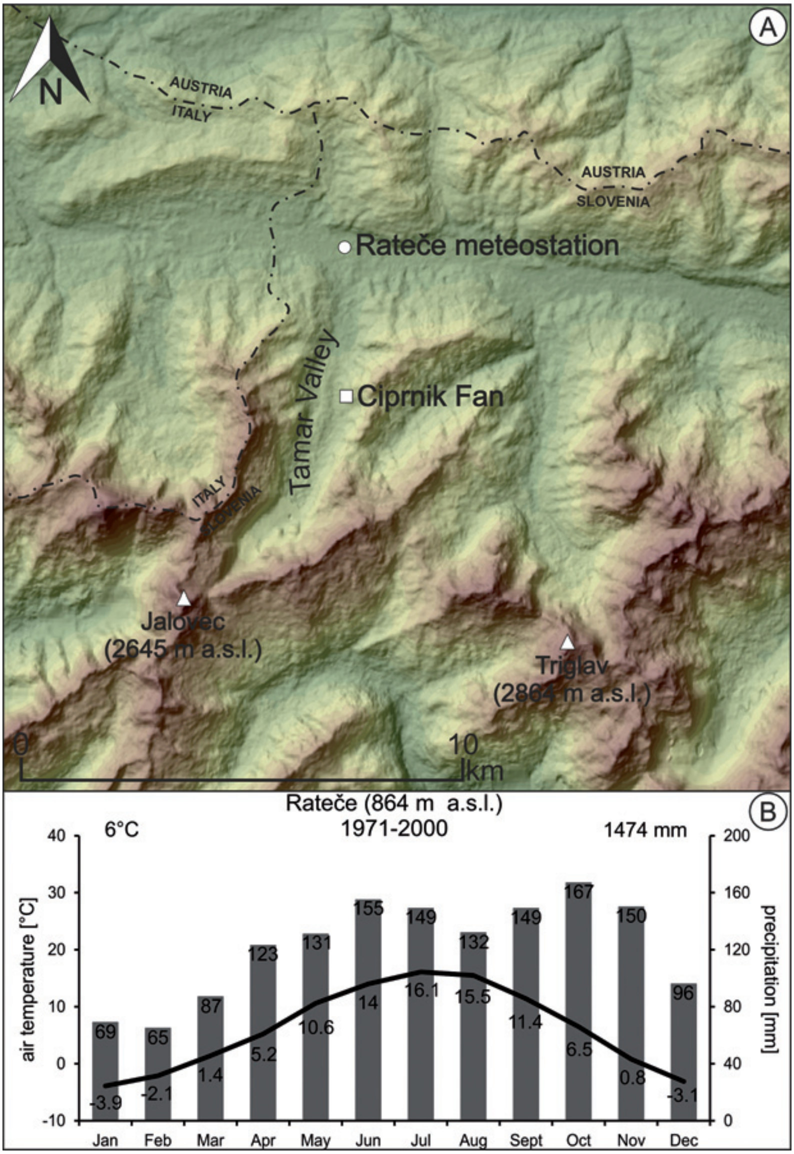

Fig. 2. The climate analyses were performed using the data retrieved from Rateče meteostation located in the mouth of the Tamar Valley (A). This meteostation is the closest located to the Ciprnik Mt. and the records well represents the climate of the lower part of the valley (B)

Sedimentological analysis involved grain size and lithological analysis. For the assessment of the grain sizes we used visual assessment and image analysis. For the particle size classification of sediments we used the classification of S. J. Blott and K. Pye (2012). The lithology of the clasts was determined macroscopically.

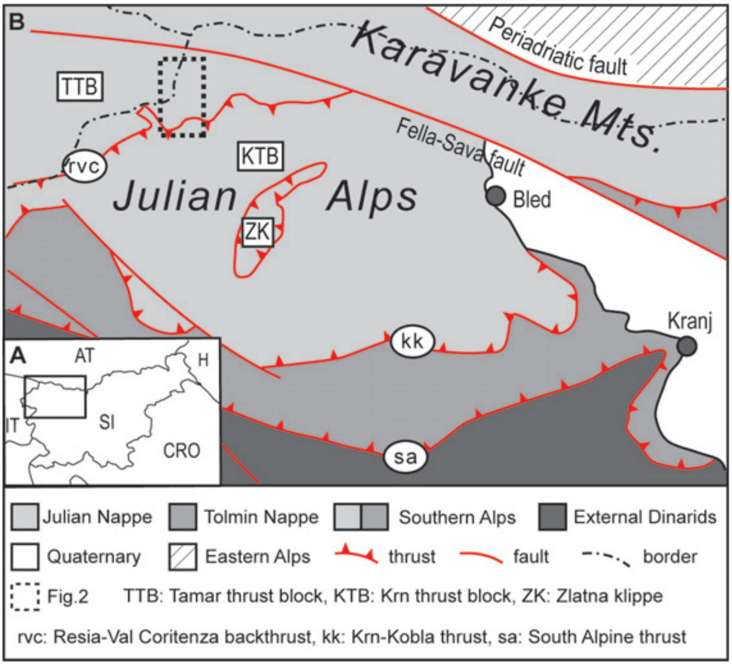

Fig. 3. The geographical and structural position of the study area and the Julian Alps (modified after L. Placer (2008) and L. Gale et al. (2015))

STUDY SITE CHARACTERISTICS

The Tamar valley is one of the most picturesque deep mountain valleys located in the Julian Alps in the NW part of Slovenia (Fig. 2A), perhaps most famous for the Planica ski jumping facility. The valley represents a typical, approximately 8 km long, glacial valley that continues into the Planica valley. It has a relatively flat bottom (with some glacial deposits still preserved (Triglav Čekada et al. 2016) bounded by steep cliffs. The valley is currently filled with numerous post-glacial rock falls, landslides, mass-gravity flows and fluvial deposits forming interfingering talus slopes and alluvial fans (Novak, Šmuc 2015). According to L. Placer (2008), the valley structurally belongs to the Julian Nappe (Southern Alps), or more exactly to the Tamar tectonic block overlain by the backthrusted Krn tectonic block (Celarc et al. 2013; Gale et al. 2015). The base-rocks of the valley are composed mainly of Upper Triassic shallow and deep-water carbonates (Ramovš 1981; Ogorelec 1984; Jurkovšek 1987; Celarc 2004; Celarc et al. 2013; Gale et al. 2015), with the exception of the Tor Formation, which is composed of an alternation of marls, mudstones and limestones, and crops out exactly at the Ciprnik Mountain 1746 m a.s.l. (Fig. 4). Quaternary deposits represent the youngest sediments of the valley. In the middle part of the valley, fluvial deposits and moraines composed of tills and erratic

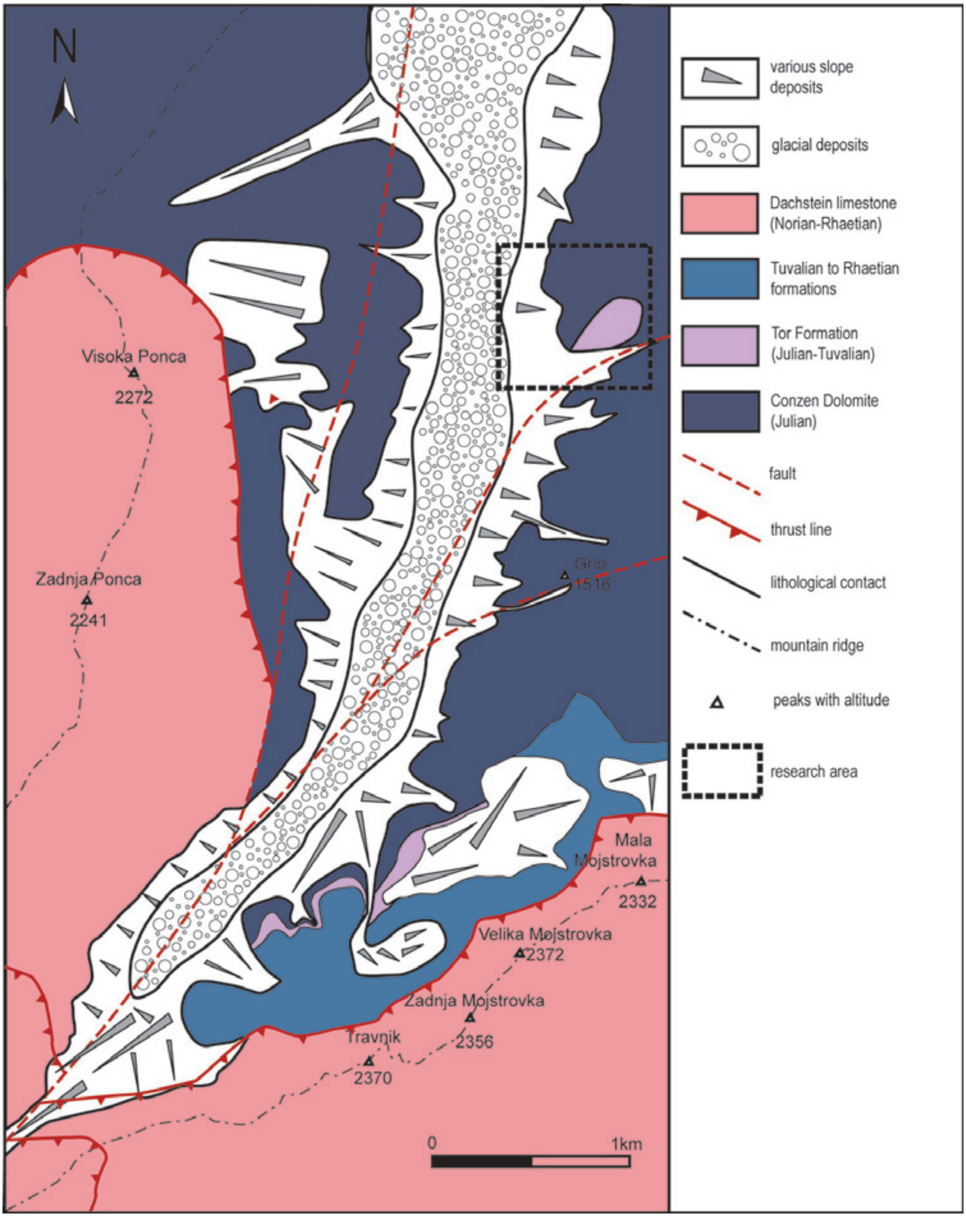

Fig. 4. The geological map of the Tamar Valley (modified after L. Gale et al. 2015)

blocks are present (Jurkovšek, 1987; Novak, Šmuc 2015), while the majority of the Quaternary deposits are represented by talus slopes and by active or abandoned alluvial fans (Novak, Šmuc 2015). The large majority of alluvial fans is represented by fluvial fans on which solely coarse-grained carbonate material is transported during high precipitation events by suspension flows. Their deposits are characterised by open framework relatively well sorted carbonate gravels. On a contrary, the debris-flow fans are unique, and are present only under the Ciprnik Mt. in the eastern part of the Tamar Valley. Beside carbonate clasts they also contain large amount of fine grained clastic particles (silt and clay). Their deposits are extremely poorly sorted matrix supported gravels with present also outsize megaclasts. The reason scarce presence of debris-flow fans in the valley is related to the base-rock geology of the valley. The only formation containing the fine-grained clastics necessary for development of the debris flow is Tor Formation that outcrops in large quantities only on the western slopes of the Ciprnik mountain.

The slopes of the Tamar valley are covered by a mosaic of different kinds of vegetation that depend on the elevation and stage of the succession: mixed forest predominated by European beech *Fagus sylvatica* L., subalpine Norway spruce *Picea abies* (L.) Karst forest, Dwarf mountain pine *Pinus mugo* L., and various shrub communities.

RESULTS AND DISCUSSION

HISTORY OF THE CIPRNIK COMPLEX LANDSLIDE SINCE 1954 BASED ON AERIAL PHOTOS

The succession of the spatial development of the mass wasting processes Ciprnik Fan during 1954–2009 can be divided into two phases (Fig. 5). There is no significant development during the period 1954–1989. At that time, mass wasting processes were related to the suspension flows, distributing coarse-grained dolomite debris and forming fluvial fan. The main sources of material are gullies located near the main ridge composed of Cozen dolomites at an elevation of up to 1520 m a.s.l. The secondary source is located lower (1200 m a.s.l.) on the slope composed already of loose dolomite material. The dolomite debris is transported almost directly downslope reaching the road at an elevation of 1052 m a.s.l. In the central part of the cone the material is stored rather sooner, around 1060 m a.s.l. In the 1954 the area of active processes of erosion, transport and accumulationn was 1.3 km^2. During the following 20 years the activity of the fluvial fan decreased. The toe fell to the road; the southern part of the source zone is partly covered by vegetation. The area of the active part was reduced only by 0.04 km^2.

The ortophotos taken in 1989 show few changes of the active surface. This concludes the first, relatively stable phase when the slow weathering of the rock surface and fluvial-suspension flows were the main processes shaping that part of the Tamar valley. The second phase started with the massive failure of the slope visible on the picture from 2001. The area and complexity of spatial pattern of the active slope increased radically. The creation of the completely new part on the northern slope (0.15 km^2) was the main development. The rocky slope

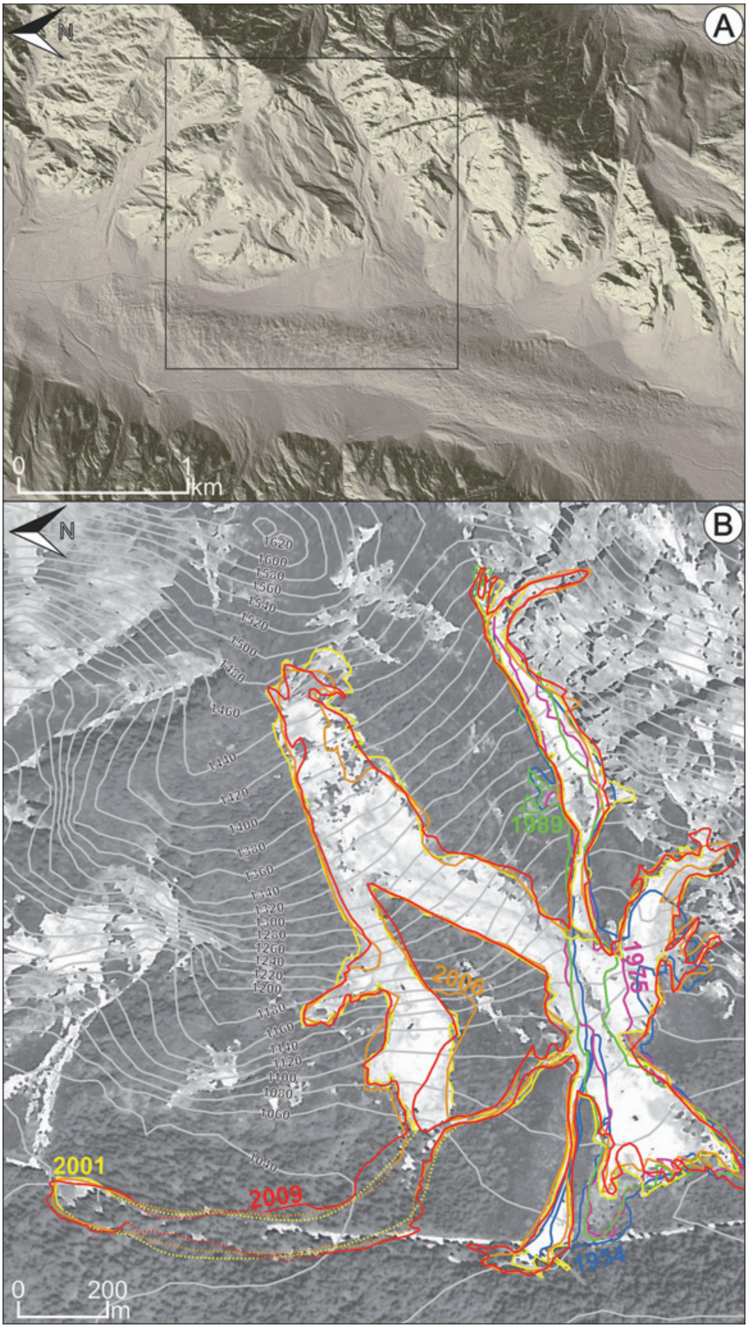

Fig. 5. The relief of NW part of the Tamar Valley is predominated by rocky ridges, and alluvial fans reaching down to the moraine hill occupying the bottom of the valley. The area of investigation is indicated by black rectangle line (A). The reconstruction of the spatio-temporal evolution of the Ciprnik fan based on the ortophotomaps (B): 1954 (blue), 1975 (pink), 1989 (green), 2001 (yellow), 2006 (brown), 2009 (red)

located up to 1500 m a.s.l. previously completely covered by forest was mobilised and turned into a complex landslide that went down in two directions: i) turning south and joining the existing fluvial fan in centre of the fan, ii) going directly downslope up to 1080 m a.s.l. Among other changes, the most important were extending the channel in the centre of fan by crossing and blocking the road, and the appearance of the new channel, oblique to the axis of the fan. The pictures from 2006 reveal further evolution of the forms existing in 2001.

Also, due to the quality of the picture, further details are valuable. The source of the dolomite debris (scare in the SE couloir) increased the surface stretching up to 1515 m a.s.l. In the lowest part, the previously described channel blocking the road also grew and stareted to feed the small cone at the end. The main change is related to the development of the forms in the northern part of the studied area. The channel oblique to the main direction of the flow joined the northern arm of the complex landslide. The flow of the debris changed direction, blocked by the moraine hill located in the bottom of the valley. The flow in the northern direction covered 700 m^2. As a result of all these changes, the area of the analysed form increased to 0.37 km^2. Between 2006 and 2009, only the shape and size of the northern arm of the complex landslide have changed. The cone built up under the failed slope, but some material was still transported downslope and along the road, widening the flow path.

CLIMATIC ANALYSES OF POTENTIAL EVENTS TRIGGERING THE CIPRNIK COMPLEX LANDSLIDE

According to the reports provided by B. Komac and M. Zorn (2007) and B. Komac et al. (2009), the main events took place during the night of November 18–19th 2000. Although the period before that date was exceptionally wet (sum of 7 day precipitation = 228.3 mm and two weeks precipitation = 356.7 mm), the daily precipitation for November 18th was only 14.1 mm (Fig. 6). The highest daily precipitation occurred 11 days before (November 7th = 98.7 mm). This was the maximum daily precipitation during 2000; nevertheless the recurrence period of 3.5 years suggests that events of such magnitude are not rare in the region. The key factor for triggering the landslide that evolved into the debris flow was the period of accumulation before the event. The daily precipitation did not meet the threshold proposed by F. Guzzetti et al. (2007) for highlands of the Central European Adriatic Danubian South-Eastern Space. Longer-periods (72 and 168 hours) totals are slightly higher than the limits of the rainfall threshold (85.2 mm and 228.3 mm, respectively). Applying the more conservative model developed by N. Caine (1980), identification of either the daily or a longer period of precipitation, as a triggering factor, is impossible. The incongruity of real event with two empirical models suggests that precipitation was not the sole factor responsible for the timing of the slope failure.

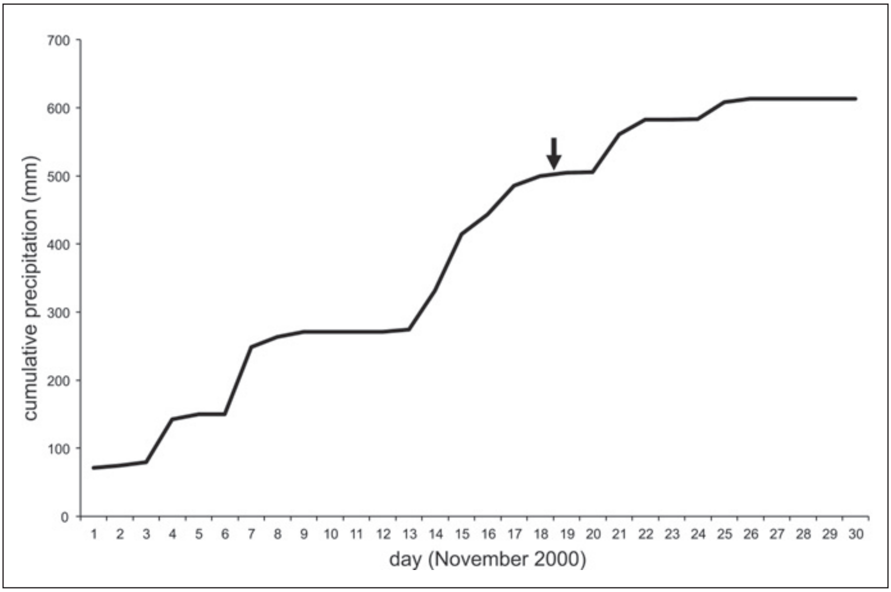

Fig. 6. Rainfall event triggered complex landslide in November 2000. The arrow indicates the reported (Komac, Zorn 2007; Komac et. al. 2009) time of the slope failure

During the period of 1954–1989, characterised as a stable phase, several events of high and intensive precipitation took place, among which eight were above 100 mm (1963, 1964, 1966, 1969, 1970, 1975, 1980, 1986) with maximum in 1969 (143.2 mm). Also between 1989 and 2000, two more such events occurred (1994 and 1999). None triggered any additional mass movements beside the usual deposition of dolomite debris on a fluvial fan. The landslide in 2000 changed the slope stability and, in the following years, a series of movements were observed. These can be linked to the daily precipitation events: i) in 2003 when the rainfall reached the value of 146.5 mm; the results of mass movements can be observed in the aerial photo from 2006, ii) in 2008 when total precipitation was 149.7 mm. The intensive development of the lower part of the complex landslide is probably due to this. Further evolution of the Ciprnik fan under the influence of heavy and intense precipitation events continued in the following years – the maximum daily rainfall in 2009 (179.5 mm) exceeded all previous records; in 2011 (138.4 mm), the next major event happened.

ARCHITECTURE AND SEDIMENT CHARACTERISTICS OF THE CIPRNIK COMPLEX LANDSLIDE

On the basis of the sedimentological and transport processes characteristics, the Ciprnik landslide represents a complex landslide (cf. Dikau et al. 1996), which we divided into four major units (Fig. 7). Unit 1 represents the catchment

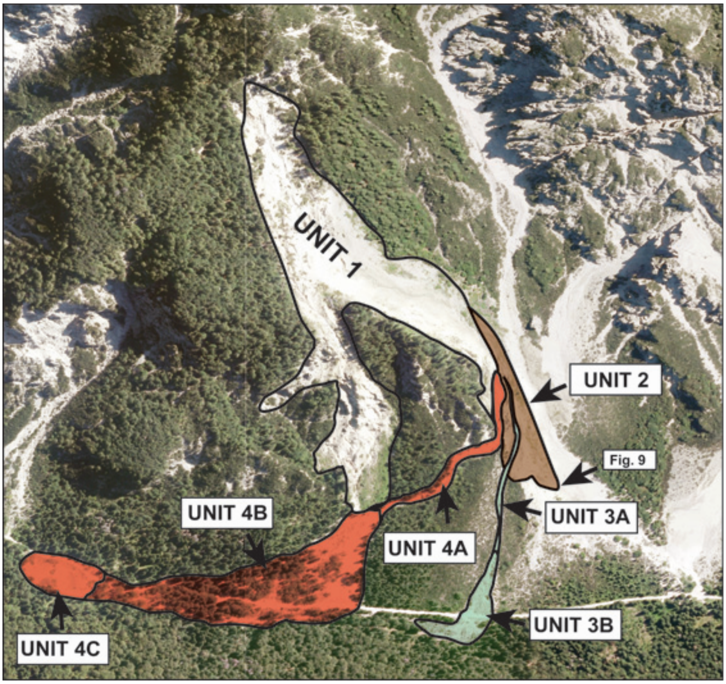

Fig. 7. The Ciprnik complex landslide with marked all of the recognised units

area of the landslide, while Units 2–4 represent three discrete fan bodies. Based on cross-cutting relationships, Unit 2 is the oldest while Unit 4 is the youngest.

Unit 1 represents the catchment area for the landslide and extends from approximately 1500 m to 1130 m a.s.l., covering an area of around 80,000 m^2 (Fig. 8). The area is composed of the strongly faulted Tor Formation underlain by faulted Conzen dolomites (G a l e et al. 2015). Cozen dolomites are poorly bedded to massive dolomites (bed thickness ranges from decimetre to metre scale) characterised by alternating lime mudstones, fenestral dolomites and stromatolitic and oncoidal dolomites (G a l e et al. 2015). The Tor Formation consists of thin to medium-bedded (bed thickness ranges from a few cm to a few 10s cm) alternation of carbonate beds (i.e. limestones, dolomites, marly limestones) and fine-grained clastics (siltstone, claystone and marlstone: G a l e et al. 2015). The dip of the beds ranges from 25–40° generally towards the south. The slip plane of landslide is clearly visible in Unit 1 (Figs. 7 and 8). In Unit 1, some loose "left over" debris of very poorly sorted, muddy sandy gravels is also present. Gravel clasts belong to the Tor Formation exclusively.

Unit 2 is represented by a small (230 m long and 68 m wide) fan-shaped body composed of poorly sorted coarse-grained sediments (Figs. 7 and 9). The clasts are composed of Cozen dolomites and clastic-carbonate rocks of the Tor Formation. The lowermost front of the fan is located at 1996 m a.s.l. on the gentle slope where it covers older fluvial fan deposits composed solely of the Coz-

Fig. 8. Catchment area of the Ciprnik complex landslide (Unit 1 of Fig. 7)

en dolomites. The characteristic feature of this fan is mega-boulders located at the front and sides of the fan and are genetically related to the debris flow forming the fan.

Unit 3 is eroded into deposits of Unit 2 (Figs. 7 and 10). The upper part (Unit 3A) is represented by a partly filled up (to a few metres deep and wide) erosional channel that extends from approximately 1150 m to 1073 m in altitude. The lower part of Unit 3 (Unit 3B) is represented by a fan-shaped body composed of a depositional sequence of poorly sorted muddy gravels in the upper reaches of the fan, while the clasts are finer at the fan end. The clasts are composed of Cozen dolomites and lithologies of the Tor Formation.

Unit 4 is most probably the youngest sedimentological feature of the Ciprnik landslide. Additional interpretation is that formed simultaneously to the

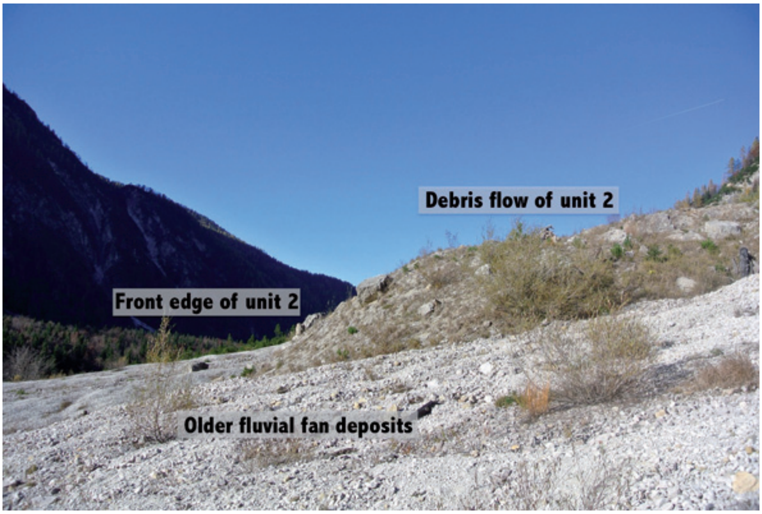

Fig. 9. The oldest debris-flow fan (Unit 2 of Fig. 7)

Fig. 10. Erosional channel eroded into older debris of Unit 2 (left on the picture) and fluvial fan deposits (Unit 3A of Fig. 7). View downwards

Unit 3. Unit 4 is further divided into three distinct units (Unit 4 A–C: Fig. 7). Unit 4A is a mainly erosional feature characterised by up to a few 10s of metres wide and around 270 m long erosional channel extending from 1130 m to 1060 m in altitude (Fig. 11). The channel is cut into bedrock or into older deposits (i.e. alluvial fan deposits and older debris flow deposits of Units 2 and 3) and is partly filled by poorly sorted muddy gravels, ranging from cm-sized pebbles to

Fig. 11. Erosional channel cut into contact of bedrock (left on the picture) and older mass deposits (Unit 4A of Fig. 7)

Fig. 12. Upper part of the fan-shaped body (Unit 4B of Fig. 7)

mega boulders reaching diameters of over a few metres. In the lower reaches of the channel, some spill-over deposits composed of medium-sorted, medium to coarse gravels are also present. The clasts are composed of Cozen dolomites and lithologies of the Tor Formation. Unit 4B is characterised by a depositional

Fig. 13. “Mud lake” at the end of the Unit 4 of the Ciprnik complex landslide (Unit 4C of Fig. 7)

sequence of poorly-sorted coarse-grained sediments forming a 470 m long and up to 140 m wide fan-like shaped sedimentary body (Figs. 7 and 12). Unit 4B extends from 1060 m to 1013 m a.s.l.. Down the fan is progressively wider; similarly the slope of the fan decreases from 20° in the upper part to the 5° in the lower reaches of middle part. The grain size of the sediments ranges from poorly to very poorly sorted muddy sandy gravels. The transition from middle to lower part of the fan is gradual and characterised by an increase in finer-grained components. The clasts belong to Cozen dolomites and Tor Formation lithologies. Unit 4C represents the terminal part of the flow fan and is characterised only by a sand to mud fraction forming so-called “mud lake”, located at 1013 m altitude (Figs. 7 and 13).

EVOLUTION OF THE CIPRNIK COMPLEX LANDSLIDE

On the night of November 18–19th 2000, a translational slide plane formed in the middle and lower reaches of the Ciprnik Mountain and caused movement and mobilisation of the complex Ciprnik landslide. What is important to stress is that, according to the data of the Seismological Office of Environmental Agency of the Republic of Slovenia (Cecić et al. 2001), no earthquakes were recorded at the time of the triggering of the Ciprnik landslide. Additionally, the Tamar valley is part of the Triglav National park and represents one of the most protected areas with a minimum of human intervention. Considering this, we believe that human activity and earthquakes were not responsible for triggering the Ciprnik landslide. In our interpretation, the initiation of this slide plane was caused by following interrelated factors. The first is lithology of the base-rock represented by the Tor Formation. Namely, this formation consists of interbedded, thin to medium-bedded carbonates and fine-grained clastites (i.e. claystones, siltstones, marlstones). The thickness of the clastic beds can reach up to 20 cm.

These beds represent laterally continuous mechanically weak discontinuity surfaces and also serve as hydrological barriers, forming local confined aquifers with increased pore-fluid pressure. Additionally, the clays have a high porosity and can swell after being wet, thus causing a decrease of effective normal stress (cf. Iverson et al. 1997). The second factor was tectonics. The previously mentioned beds have approximately the same dip as the slope of the Ciprnik Mountain, which is the most unfavourable structural condition for the formation of landslides. Additionally, the rocks of Ciprnik Mountain are located in the proximity of a large fault (see Fig. 4). Because of tectonic stresses, the initially highly bedded rocks of the Tor Formation were additionally fractured. This feature caused increase in effective porosity and decrease in the strength of material. The final factor that caused the initiation of the slip plane was the high precipitation in October and November 2000. The abundant rain saturated the highly fractured rocks of the Tor Formation, causing an increase of pore-fluid pressure, wetting the clay layers and causing the interlocking contacts between adjunct beds to become less tight, and the friction on contact planes to decrease. The slide plane parallel to the slope most probably formed first at its upper part, and then prolonged to the lower reaches of the landslide. Soon after the initiation of the slide plane and movement downslope, complete disintegration of already highly thin-bedded and strongly fractured rock mass and mobilisation of landslide into the debris-flow occured. This part of the Ciprnik complex landslide is represented by Unit 1.

From the crosscutting relationship of the depositional units (Units 2–4), the following evolution of the complex landslide can be interpreted. At first, only part of Ciprnik slope moved and was mobilised into debris-flow. It flowed from the toe of Ciprnik slope on the older alluvial fan, decelerated on the fan surface, ran out of momentum and "froze" forming an elongated debris lobe (Unit 2 in Fig. 7). The loss of momentum was most probably related to the gradient decrease and also to the loss of water content through highly porous underlying fluvial fan deposits. Following this, the entire Ciprnik slope was mobilised into a debris flow. One part of the flow travelled directly west towards the bottom of the valley, eroding previous debris flows (Unit 3A in Fig. 7) and older fluvial fan deposits, finally depositing the material in the shape of small debris-flow fan (Unit 3B in Fig. 7). Another part of the flow travelled downward, eroding a few metres deep channel, which mainly followed contact of base-rock with older mass movement sediments. This caused the flow to turn sharply in a NW direction (Unit 4A in Fig. 7). In this part, the underlying bed material was also mobilised and entrained into the flow. After the change of the slope to lower angles, the debris flow entered into the accumulation phase (Unit 4B in Fig. 7). As the flow continued downward, the additional change of slope to lower values, loss of water content, change of direction of the flow and mitigation of protective forest caused the progressive loss of the coarser fraction from the flow. At its final point, the debris flow evolved into a mud flow that stopped in the terminal part of the fan. This part of the debris flow is represented by Unit 4C in Fig. 7.

From the aerial photos it is clear that after the main mass-movement in 2000, the Ciprnik fan remained active. Its activity is related to the re-transportation of already loose debris and to the adjustment of the Ciprnik slopes to the new stress conditions.

COMPARISON OF THE CIPRNIK COMPLEX LANDSLIDE TO OTHER SIMILAR EVENTS IN THE JULIAN ALPS

In the last several years, few large landslides associated with debris flow events have been initiated in the Julian Alps. These are the Ciprnik landslide, Stože landslide and Strug landslide (Komac 2001; Majes 2001; Petkovšek 2001; Ribičič 2001; Ribičič, Kočevar 2003; Mikoš et al., 2006a, 2006b; Komac, Zorn 2007; Zorn, Komac 2008; Komac et al., 2009). All these landslides are complex landslides (cf. Dikau et al., 1996).

The Ciprnik and Stože landslides were triggered almost at the same time (Ciprnik on November 19th and Stože on November 15th 2000) after a period of intense rain, when the area received four times more precipitation than the November average (Cegnar 2000; Dolinar 2001). No earthquakes were recorded at that time. Additionally, both landslides are related to the outcrops of the Upper Triassic Tor Formation. However, there are important differences. In the case of the Stože landslide, the landslide was activated in non-lithified loose tills and slope debris covering the Tor Formation (Komac 2000; Majes 2001; Petkovšek 2001; Ribičič 2001). In this case, the Tor Formation mainly served as an impermeable layer, causing saturation of the overlying loose debris. Moreover, the Stože landslide represents two phase events. The first (November 15th 2000) is represented by sliding of the material that stopped in the lower reaches of the slope. Here it dammed up the Mangartski potok torrent. The second event (November 17th 2000) is marked by sliding of additional material that also caused mobilisation of material from the first landslide, resulting in a huge debris flow that flooded the village of Log pod Mangartom some 4 km downstream (Komac 2001; Majes 2001; Petkovšek 2001; Ribičič 2001).

The Strug landslide perhaps represents the most complex landslide. It was triggered in December 2001 as a rockslide, followed by rock fall within the rockslide (Ribičič, Kočevar 2003; Mikoš et al. 2006a, 2006b). The kinetic push of rock fall caused movement of a translational soil landslide that, after the first fast movement, came to a practical standstill in 2003. However, after heavy precipitation in 2002, part of this mass was mobilised as numerous (more than 20) small debris flows (Ribičič, Kočevar 2003; Mikoš et al. 2006a). The Strug landslide differs from the Ciprnik landslide in that it is related to the tectonic contact of the highly permeable calcareous Cretaceous Scaglia Formation overthrusted on impermeable clastic Cretaceous flysch deposits. Prior to the landslide, the rocks were intensively weathered down to 20 m into bedrock, so older loose slope material was also mobilised during sliding. Additionally, the strong earthquake in 1998 with a magnitude of 5.7 and an epicentre located less than 7 km from the Strug landslide (Ribičič, Vidrih 1998) is believed to have opened vertical fractures that increased water infiltration into the rockslide body (Mikoš et al. 2006a).

CONCLUSIONS

1. Spatio-temporal analyses of the Ciprnik area lead to the conclusion that the mass movement activity can be characterised by at least two phases. The first phase was relatively stable, marked by the usual Tamar valley mass movements, related to the activity of fluvial fans. These remained within similar boundaries for several decades. The second, more active phase began with the occurrence of a complex landslide on the Ciprnik slope in 2000, followed by the formation of the debris-flow fan that is still being reshaped. The debris-flow fan remains active and interfingers with adjacent active fluvial fans.
2. The mass movement event in 2000 represents a complex landslide in which one form of failure developed into a second. It started as a translational movement over the discontinuity plane, which was soon after mobilised into a debris-flow with complex run-out forms.
3. The triggering mechanism of the Ciprnik complex landslide can be traced back to the precipitation, but the event was not linked to the highest amount of daily precipitation at that time. This strongly suggests that slope failure resulted from more complex processes/factors. These factors include tectonics (dip-slope position of beds and strong fracturing), lithology (alternation of thin beds of carbonates and fine-grained clastics), and the accumulation of precipitation.
4. Compared to other mass movements, debris flows like Ciprnik are not a common feature in the Julian Alps. This is because they are related to the formations containing fine-grained clastic rocks that rarely crop out in the Julian Alps.
5. Although the aerial photos proved to be a useful source of information, a method providing more detailed dating (e.g. tree-ring dating, geophysics) is needed for better understanding the evolution of the Ciprnik debris flow fan.

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