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LANDFORM EVOLUTION IN MOUNTAIN AREAS
Recent geomorphological hazards in Carpatho-Balcan-Dinaric region

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# MASS MOVEMENTS AND FLASH-FLOODS IN SLOVENE ALPS AND SURROUNDING MOUNTAINS

**Abstract.** The dissected relief of Slovene mountains with steep slopes above narrow valley bottoms is the result of very active geomorphic past and the playing-ground of vigorous recent geomorphic processes such as rockfalls, landslides, flash-floods etc. These occasional events are the main constituent part of recent geomorphic activity in the mountains, and at the same time, a real threat to the local population and infrastructure which is mainly concentrated in narrow valley bottoms along rivers and smaller streams. The situation in the Dinaric mountains is completely different — there, karst is a predominant feature, corrosion of carbonate rocks is a main geomorphic process and mass movements are exceptional.

In the paper, a selection of large-scale geomorphic events is studied from two perspectives: as natural hazards and as principal components of recent landform evolution. The main focus is on three largest geomorphic events in last twenty years: the debris flow of Log pod Mangartom on November 17, 2000, and catastrophic flash-floods in the Savinja river drainage basin on November 1, 1990 and in the villages of Rateče and Ugovizza (Italy) on August 31, 2003. During the first event, man was only a powerless observer of raging nature, while for the second event the contribution of man to the extent of the disaster was rather obvious, especially due to inappropriate location of settlements and economic activities in narrow floodplains and on alluvial fans.

**Key words:** mass movements, natural hazards, debris flows, flash-floods, landslides, slope processes, Slovenia

## INTRODUCTION

Geographic position of Slovenia on the contact of four large European geographic regions (the Alps, the Dinaric mountains, the Pannonian plain, the Mediterranean) is reflected in high diversity of rocks and relief features as well as in large differences between recent geomorphic processes in different regions. While karst is a predominant feature almost everywhere in the Dinaric mountains and corrosion is a distinctly predominant geomorphic process, denudation processes (including numerous landslides and rockfalls) and flash-floods are the most efficient landscape-shaping forces in Alpine and Prealpine areas. Landform transformation in karst is relatively intensive, especially due to high solubility of the most frequent limestones and dolomites (Upper Triassic, Jurassic, Cretaceous), considerable soil and vegetation coverage and high specific runoff due to abundant precipitation (over 70 $l \cdot s \cdot km^{-2}$ in the high mountainous part of the Soča catchment area, 30–40 $l \cdot s^{-1} \cdot km^{-2}$ on the Kras plateau, 26–40 $l \cdot s^{-1} \cdot km^{-2}$ in the Krka river basin (Kolbezen and Pristov 1998), however it is practically never demonstrated as fast mass movement.

According to I. Gams' calculations (Gams 2003), corrosion induced surface lowering in the Ljubljanica catchment area is approximately 60 mm per 1000 years, while in Julian Alps it is 80–100 mm per 1000 years due to higher precipitation. Intensive lowering of karst surface was also confirmed by the discovery of the so called unroofed caves (Mihevc et al. 1998; Mihevc 2001). The effect of corrosion on shaping the slopes in karst areas is a hardly known phenomenon, but as Tables 2 and 3 show, slope gradients in Dinaric karst are considerably smaller than in Alpine areas, reducing the possibility of the occurrence of larger mass movements.

Collapse dolines which develop when cave roofs collapse are typical in the Dinaric karst (e.g. around Divača and Škocjan caves in Slovenia or around Imotsko polje in Croatia), however there are no reports of such events in historical sources. All known sudden collapses in karst areas were caused by human activity (building of houses, construction of the Ljubljana–Postojna motorway; Habič 1984). It is also known that strong earthquakes near Makarska in Croatia (January 11, 1962; magnitude 6.1) and near Budva in Montenegro (April 15, 1979; magnitude 7.2) induced numerous rockfalls on steep slopes in the close hinterland of the Adriatic coast, however when compared to the Alpine ares, contribution of these processes to landform transformation in Dinaric karst is of minor importance (Table 1).

## A COMPARISON BETWEEN THE ALPS AND THE DINARIC MOUNTAINS

In recent years, we witnessed several large mass movements in Slovenia which were induced by extreme precipitation (landslides, debris flows) and earthquakes (rockfalls) (Fig. 1).

According to estimates, 7,000–10,000 active landslides exist in Slovenia (Fajfar et al. 2005) which means 0.35–0.5 landslides per $km^2$; among them, one fourth represents a threat to infrastructure and buildings.

The largest identified mass movement in Slovenia is the prehistorical rockfall Kuntri on the southern slope of Polovnik in the Julian Alps, with a volume of about 200 million $m^3$ (Zorn 2002b).

Table 1

Areas prone to landslides and rockfalls (Zorn and Komac 2004)

| | Slovenia [km$^2$] | Share of Slovenia's land area [%] | In the Alps [km$^2$] | Share of Slovenia's land area [%] | In the Dinaric mountains [km$^2$] | Share of Slovenia's land area [%] | Alpine share of mass movement-prone areas [%] | Dinaric share of mass movement-prone areas [%] |
|---|---|---|---|---|---|---|---|---|
| Areas prone to landslides | 1214.2 | 6.0 | 530.3 | 2.6 | 110.8 | 0.6 | 43.7 | 9.1 |
| Areas prone to rockfalls | 699.9 | 3.5 | 619.8 | 3.1 | 73.7 | 0.4 | 88.6 | 10.5 |

Table 2

Comparison of some physical geographic features between the Alpine and the Dinaric areas in Slovenia (Perko and Orožen Adamič 1998)

| | Area [km$^2$] | Share of the total land area [%] | Average slope gradient [°] | Average altitude [m] |
|---|---|---|---|---|
| Alpine areas | 8541 | 42.13 | 18.4 | 731.6 |
| Dinaric areas | 5706 | 28.15 | 11.4 | 579.8 |
| Slovenia | 20,272 | 100 | 13.1 | 556.8 |

Table 3

Land area in the Alps and the Dinaric mountains by gradient categories and prevailing geomorphic processes (adapted from Demek 1972; Natek 1983; Komac 2005)

| Gradient categories [°] | Alpine areas [%] | Dinaric areas [%] | Predominant geomorphic processes |
|---|---|---|---|
| < 2 | 8.8 | 11.6 | Relatively weak erosion, predominant sheet erosion with frequent occurrence of stagnant water; corrosion |
| 2–6 | 7.2 | 17.4 | Moderate erosion with soil erosion on cultivated fields and soil creep in forests; corrosion |
| 6–12 | 13.0 | 26.7 | Strong erosion with soil erosion on cultivated fields and meadows, smaller landslides; corrosion |
| 12–20 | 23.8 | 25.5 | Very strong sheet erosion that develops into linear erosion, frequent landslides |
| 20–32 | 30.9 | 15.1 | Heavy erosion with predominant linear erosion and frequent landslides |
| 32–55 | 15.7 | 3.7 | In our conditions, 32° is a natural angle of repose, therefore no continuous soil cover is present, frequent rockfalls |
| > 55 | 0.6 | 0.005 | Rock walls from which every rock fragment falls downwards under the influence of gravity |

## SOME RECENT LARGE-SCALE MASS MOVEMENTS IN SLOVENIA AND ITS NEIGHBOURHOOD

### ROCKFALLS

We tend to attribute the responsibility for rockfalls to earthquakes. A. Heim (1932, p. 177) writes that in many historical sources from the period 1600–1850 it is stated that a rockfall "was a consequence of an earthquake". In recent years, a notion that earthquakes are the main cause of rockfalls appeared on two occasions in Slovenia. The first occasion was on April 12, 1998 when the "Easter earthquake" shook the Upper Soča area (NW Slovenia) (magnitude 5.6; EMS intensity VII–VIII). The earthquake in 1998 (Natek et al. 2003) caused over a hundred sizeable geomorphic changes in nature. Out of 52 rockfalls, two were of a larger scale (on Mt Krn and Mt Osojnica) with a volume of over a million $m^3$ of material (Photo 1). In case of the 2004 earthquake, 44 rockfalls were registered in approximately the same area, however they were smaller correspondingly to the intensity of the earthquake (Mikoš et al. 2005).

In the past, the area was affected by at least three earthquakes stronger than the above mentioned couple. According to sources and literature, they also triggered numerous landslides and rockfalls (Lapajne 1988; Lapajne 1989; Zorn 2002a): the Villach earthquake in nearby Austria on January 25, 1348 (esti-

Photo 1. Rockfalls triggered by the Easter earthquake 1998 on the south-western slope of Mt Krn (Photo by K. Natek)

mated magnitude 6.4–6.6; EMS intensity X), the Idrija earthquake on March 26, 1511 (estimated magnitude 6–7; EMS intensity IX–X), and the earthquake in the Friuli province, Italy, on May 6, 1976 (magnitude 6.5; EMS intensity X).

Rockfalls induced by the Villach earthquake were especially devastating. From Dobratsch mountain in the Carinthia province, Austria, about 148 million m$^3$ of material was triggered, covering an area of 6.11 km$^2$ in the lower Gail valley (Zorn 2002a). Interestingly, despite several centuries that have passed since the Villach earthquake, its effects, especially the Dobratsch rockfalls, are still alive in Slovenian historical memory.

Such unique events displace huge quantities of material that can match or even exceed average annual quantities of sediment production. For example, in case of a relatively weak earthquake in 1998, several million m$^3$ of material was displaced (Zorn 2002b).

Average annual sediment production in Slovenia is estimated to 3,924,000–5,723,000 m$^3$. Specific annual sediment production amounts to 3.7–4.52 t/ha/year which corresponds to surface lowering of 0.23–0.28 mm/year (Komac and Zorn 2005). In the Alps, sediment production is more intensive, i.e. in the Upper Soča area sediment production is 44.8 t · ha · year which corresponds to 1.6 million m$^3$ of produced sediment per year (Zemljič 1972). This means that the quantity of displaced material in case of the 1998 earthquake exceeded the average annual sediment production.

According to the quantity of sediments produced in Slovenian Alps by rockfalls we can join the opinion of D. J. Sauchyn et al. (1998) that rockfalls are a predominant geomorphic process on rocky slopes.

## LANDSLIDES AND DEBRIS FLOWS

### Stovžje landslide and debris flow in log Pod Mangartom

To the west of Mt Mangart (2,679 m), a landslide was triggered on November 15, 2000 at the altitude between 1,340–1,580 m. At first, a mass of several hundred thousand cubic meters stopped at the confluence of Mangartski potok and Predelica streams. Due to massive water inflow into the material, the mass became waterlogged and on November 17, several minutes past midnight, a debris flow was triggered. In the Log pod Mangartom village, more than 700,000 m$^3$ of material was deposited on the area of 15 hectares. The disaster claimed seven lives, 18 houses and 8 other buildings were destroyed or damaged. Total damage on buildings was estimated at € 2 million, on road infrastructure € 5 million, on other infrastructure € 3.5 million and on farmland half a million €. The survived were evacuated for almost three months (Komac 2001; *Report...* 2001).

In the sliding area which is 900 m long and 300–400 m wide, about 1,500,000 m$^3$ of material was displaced. Of this, 1,000,000 m$^3$ slided down to the valley while 500,000 m$^3$ of material remained in the sliding area (Majes et al. 2000). Above the landslide, cracks appeared reaching upwards all the way to the watershed ridge. The average thickness of the landslide was 10 m, while in some places it exceeded 40 m.

Main cause for land sliding at the Stovžje location was geological structure, especially 100–200 m thick Raibl beds (Buser 1987) of limestone, marly limestone, marlstone and shale (Upper Triassic), deposited on Carnian grainy dolomite. Clay minerals absorb water, swelling in the process, while clay shale decomposes into clay when in contact with water. Above them, there is up to 700 m thick sequence of tectonically disrupted main dolomite, while at the contact between dolomite and marlstone there are water springs. All mentioned rock layers are inclined by 30° towards the south or south-west. Concordant slopes and springs were an important sliding factors.

However, the trigger of the debris flow was abundant precipitation. In November 2000, Log pod Mangartom received as much as 1,234 mm of precipitation which is about half of average annual precipitation and four times the long-term November average (Cegnar 2000). October precipitation also exceeded long-term average by 50%. Bovec received 411 mm of precipitation between November 14 and 16, while the amount in Log pod Mangartom was 396 mm in the same period. Sliding was also caused by water flowing into a temporarily stopped sliding mass.

The 1998 earthquake did not directly induce the process, however the influence of cracks that could have been formed at that occasion and through which water could have entered deeper layers cannot be completely eliminated. It is known that in the area of the Koseč landslide several cracks were formed during the 1998 earthquake, two years before sliding occurred (Zorn and Komac 2002; Natek et al. 2003).

A small change in water content is enough for the sediment material in Stovžje to become liquid. In the process, properties of seemingly dry material can completely change instantly. Material slides down and runs off as a debris flow. A minimum gradient is sufficient to allow the process to develop, while below Mangartska planina, the gradient of the Mangartski potok is more than 10%. Other mechanisms enabling mixing of sediments and water are also important for the development of debris flows — in most cases, these are landslides. Lack of vegetation coverage also increases proneness to erosion and sliding.

Despite their rarity, debris flows are a relatively important landscape shaping factor in Alpine areas. Since these are usually a large-scale phenomena, large quantities of material were transported to lower areas in this way (Photo 2; Fig. 2). In the Koritnica valley similar larger-scale phenomena occur approximately once in a hundred years (Zorn and Komac 2002) while in many other mountainous, arid and volcanic areas they are even more frequent. In Japan, as much as a quarter of natural disaster deaths are caused by debris flows. The occurrence of debris flows is also a sensitive indicator of climate change. In the canyons of Californian desert, debris flows occur approximately once in every 30–100 years (Ritter et al. 1995).

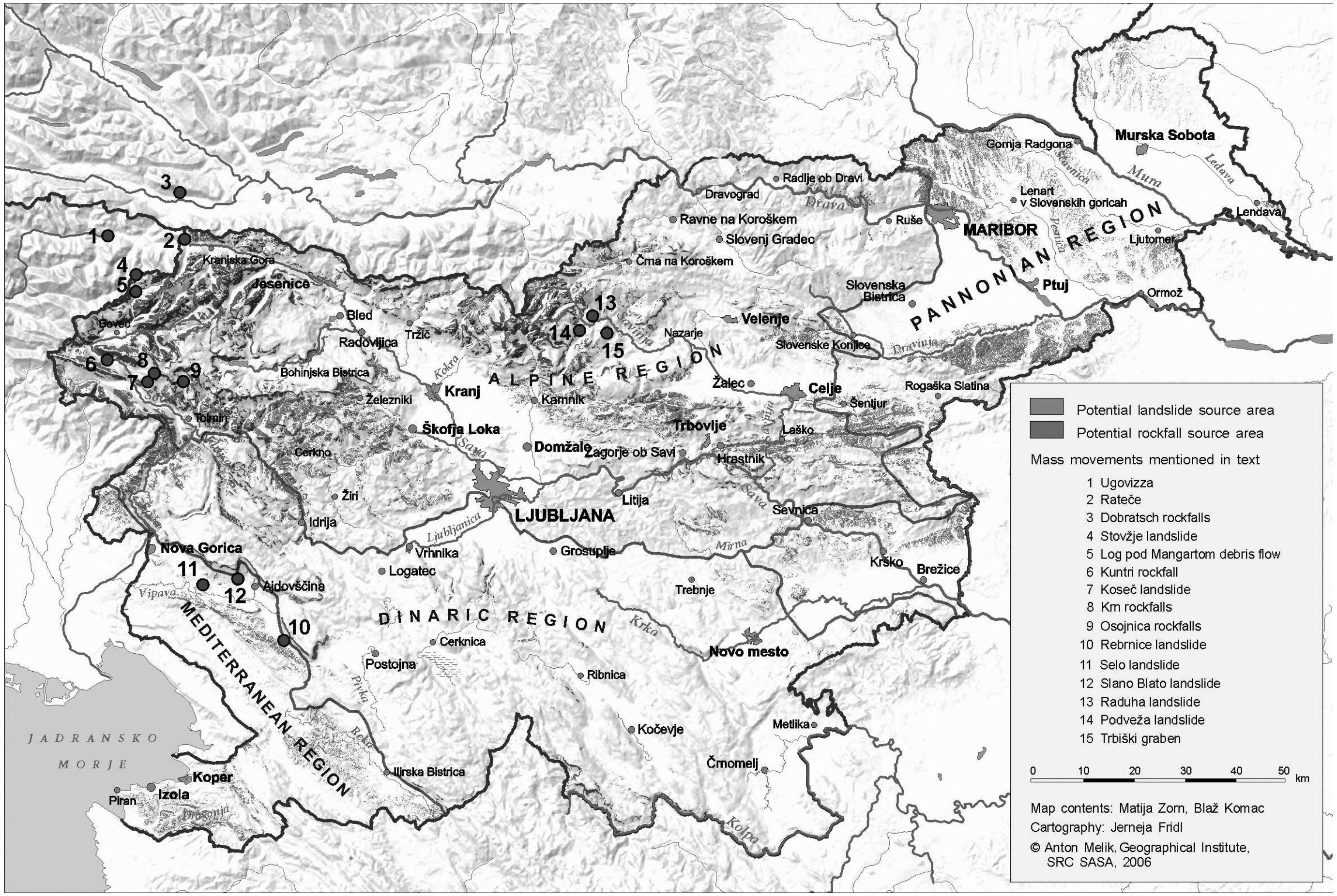


Fig. 1. Areas prone to landslides and rockfalls in Slovenia

Photo 2. Debris flow in Log pod Mangartom (Photo by B. Komac, November 19, 2000)

According to the most recent research, large debris flows occurred in Julian Alps also in the geological past. In last 150,000 years, there seems to be at least two generations of such flows, the first one 150,000–120,000 years B.P. and the second one at the end of the last glacial (20,000–10,000 years B.P.). It seems that both generations of flows were related to climate change in transition from colder to warmer periods of upper Quaternary (B a v e c 2002). Is recent climate change indicating we are entering such a period again?

### Landslides and rockfalls on the edge of the Dinaric mountains in the Vipava valley

Although landslides and rockfalls are not typical phenomena in the Dinaric areas of Slovenia, they are quite frequent on their south-western edge above the Vipava valley where the Dinaric mountains meet the Mediterranean. Here, Mesozoic carbonate rocks of the Dinaric high plateaus are thrusted onto younger Eocene flysch of the Vipava valley. Along the thrust they are intensively tectonically disrupted and subjected to weathering. Tens-of-meters thick layers of scree, mostly of Pleistocene age, accumulated on the slopes; numerous abundant springs on the thrust contact contribute to their mobility. Instability of the south-western edge of the Dinaric high plateaus is also indicated by numerous boulders of several hundred cubic meters in size, scattered over the long slopes all the way to the valley bottom, however no large rockfalls have been recorded in historical sources.

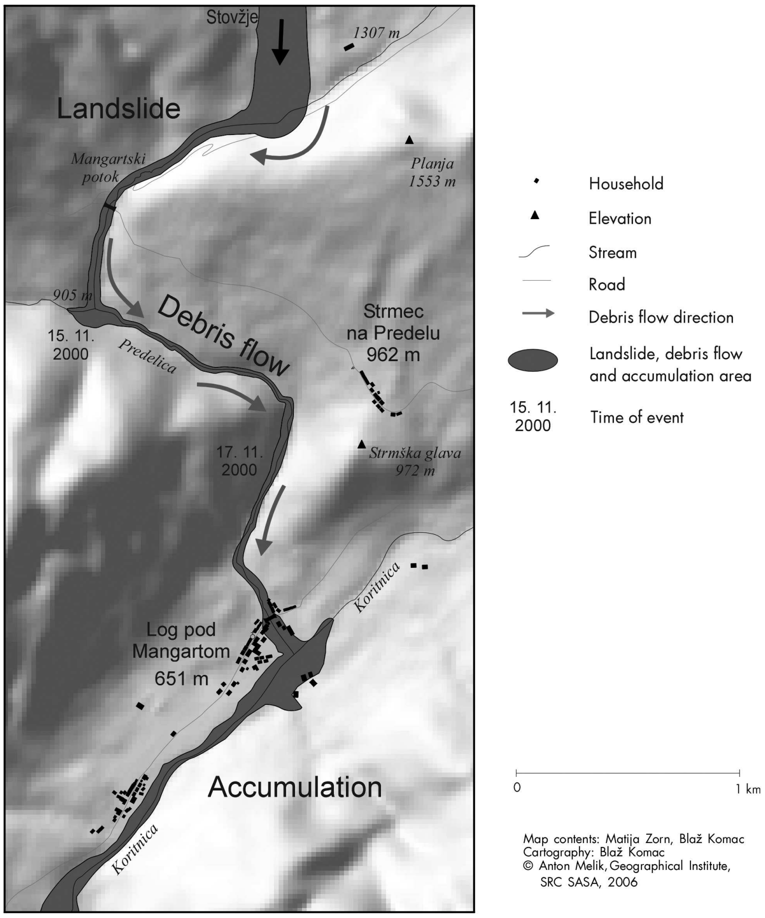


Fig. 2. Stovžje landslide and debris flow in Log pod Mangartom

Near the village of Selo, a huge Pleistocene landslide with a volume of about 100 million m$^3$ is known (Popit and Košir 2003). After abundant precipitation, the relatively large Slano blato landslide was triggered above the village of Lokavec near Ajdovščina on November 18, 2000. A 1 km-long and 280 m-wide landslide of flysch and slope scree material slided at the altitude of 330–630 m, the maximum sliding velocity was 90 m/day. The Lokavec village at the slope base was threatened by the landslide, however extensive remediation works reduced the risk to a certain degree. Interestingly, a landslide was already triggered in the same location about 200 and 100 years ago (Kovač and Kočevar 2001).

In recent years, construction of a motorway towards Italy is under way on these unstable slopes. During the construction, several landslides were triggered — among the largest was the Rebrnice landslide near the Lozice village which was activated in spring of 2001. Above the motorway cutting, 400,000 m$^3$ of slope material started sliding. The slope gradient is 15–20°, while the depth of a sliding plane was 10–20 m. The landslide occurred on the location of a larger fossil landslide (Jež 2005).

## FLASH-FLOODS

In highly dissected mountainous areas of Slovenia, torrents are among the most important landscape shaping forces, while every few years they also cause a lot of damage with extremely turbulent debris transport and its accumulation in downstream areas. Among the worst disasters of this kind were the floods in the Sora and the Gradaščica river basins to the west of Ljubljana (September 27, 1926), in the Savinja river basin and in the city of Celje (June 4 and 5, 1954), in Haloze hills on the western edge of the Pannonian plain to the south of Ptuj (July 3 and 4, 1989) and again in the Savinja river basin and Celje (November 1, 1990), not to mention local flash-floods that occur almost annually. Experts from different fields have been involved in studying these phenomena for many years, however their precise geomorphic impacts have not been estimated so far. Environmental Agency of the Ministry of the Environment and Physical Planning measures load transport in Slovenian rivers at about 20 gauging stations, however large local differences within more than 26,000 km of rivers and streams in Slovenia with extremely variable landscapes are impossible to be covered by these measurements (of these, approximately 1,700 km are distinctly torrential streams which transport over 2 million $m^3$ of sediments annually from about 4,000 $km^2$ of erosion prone areas, the vast majority during short storms).

### Flash-floods in Rateče and Ugovizza

In August 2003, extreme precipitation occurred in the extreme north-west of Slovenia in the Upper Sava valley and in the extreme north-east of Italy in the Val Canale valley, causing severe local floods and landslides. Extreme three-day precipitation on August 29–31, 2003 amounted to 287 mm in Rateče (August 2003 total was 313 mm), which is highly above the long-term August average of 158 mm (1961–1990; Zupančič 1995) or the August average of 129 mm for the period 1991–2000 (Internet 1). Recurring period for such hourly precipitation was 44 years but, for a recorded 6-hour precipitation intensity was as much as 250 years. The recurring period for the registered amount of precipitation between August 29 and 31, 2003 was 75 years (Dolinar 2004).

In Rateče, several houses were threatened by load carried by the Trebiža stream, while a bridge had to be removed in order to enable uninterrupted flow of the stream. Below the village, large quantities of debris and mud were deposited, similar to 1885 when as much as 12 ha of fields and meadows were covered by debris and mud. A regulation plan for the Trebiža is preserved from 1888 which is the oldest preserved plan for any torrent in Slovenia. The regulation was carried out between 1888 and 1890 (Jesenovec et al. 1995; Zorn and Komac 2004).

The Trebiža catchment area covers 4.8 km$^2$, the length of all tributaries within the catchment area is 17.8 km. Average altitude difference of the area is 304 m, while average slope gradient is 45%. Average riverbed gradient is 14%, calculated average discharge is 0.213 m$^3$ · s$^{-1}$, while expected discharge with a 100-year recurring period is 40 m$^3$ · s$^{-1}$. Calculated average sediment production in the catchment area is 174 m$^3$ · km$^{-2}$ · year, while average sediment yield is 88 m$^3$/km$^2$/year. It was a lucky coincidence that the majority of precipitation fell on this catchment area because the sediment yield in the nearby Suhelj stream with a catchment area of 1.8 km$^2$ is considerably higher and the consequences would have been accordingly more severe. Calculated average sediment production in the Suhelj catchment area is as much as 2,960 m$^3$ · km$^{-2}$ · year, while average sediment yield is 2,523 m$^3$ · km$^{-2}$ · year (Mikoš 1995).

More severe were the consequences of a storm several kilometers to the west in the village of Ugovizza (Val Canale, Italy). The area received more than 400 mm of precipitation at the end of August 2003 (long-term 1961–1990 August average for nearby Tarvisio is 147.7 mm; Gunde 2004). Road was destroyed by waters in 13 places and the railway link between Udine (Italy) and Villach (Austria) was disconnected. The Ugovizza stream with a catchment area of 28 km$^2$ buried the western part of the village of Ugovizza with debris. More than 300 people had to abandon their homes and 2 people were killed. The debris flow destroyed the village only 14 days before the 100th anniversary of a similar event that

Photo 3. Debris filled the “Via 13. Settembre 1903 alluvione” Street in Ugovizza up to the second floor (Photo by M. Zorn, September 1, 2003)

struck Ugovizza in September 13, 1903. The street named Via 13. Settembre 1903 alluvione (September 13 flood Street) is a reminder of the event when debris reached the second floor of houses in this street (Photo 3). Below the village, a large alluvial fan composed of debris was formed. In the past, people were aware of the hazard — decades ago they built wooden bridges across the stream in Ugovizza to allow the floods or debris flows to carry them away. However, the new concrete bridge withstood the disaster and caused deposition of material in the village (Palmieri et al. 2003; Zorn and Komac 2004). Lower part of the village was also buried by debris up to the windows in October 14, 1923 when the bridge was also carried away, while according to the newspapers, fields and meadows were "covered with sand and stones in a large area".

The authors of Joseph II military maps already warned about the hazards posed by the Ugovizza and other nearby streams in 18th century. According to them, the stream is "very swift in the rainy weather and damages various buildings in the Ugovizza village" (Rajšp and Serše 1998).

### Flash-floods in the Savinja catchment area

The source of the Savinja river is located in the heart of the Kamnik–Savinja Alps. It flows through heavily dissected Prealpine mountains towards the Celje basin and then cuts through the Sava Mountains in a narrow valley, finally reaching the Sava river (total length 102 km, catchment area 1,848 $km^2$). As its tributaries, the main river is a distinctive torrent with highly fluctuating discharge (typical 1961–1990 discharges in the upper stream at Nazarje gauging station: minimum discharge 2.2 $m^3 \cdot s^{-1}$, maximum discharge recorded 635 $m^3 \cdot s^{-1}$ and mean discharge 17.0 $m^3 \cdot s^{-1}$; Kolbezen and Pristov 1998) along with the abundant load transport.

Between October 26 and November 4, 1990, Slovenia was on the eastern edge of a large low-pressure system centered above Great Britain. Prevailing south-western winds carried abundant precipitation, especially to the Alpine–Dinaric mountain barrier. On October 31 and November 1, the upper part of the Savinja catchment area received over 220 mm of rainfall in 48 hours, most of it during the night of October 31. This amount of precipitation is not particularly exceptional for Slovenia (in Julian Alps, maximum 24-hour precipitation exceeds 400 mm). However, due to heavy rains in previous days, all water retention capacity was already used — as a result, the aforementioned night peak precipitation was fed directly into the streams as sheet runoff, causing rapid increase of water levels. At the same time, huge quantities of load were transported down the slopes to riverbeds (Pristov 1991). The Savinja reached its peak discharge in Nazarje already on Nov. 1 at 10:00 a.m. 635 $m^3/s$ or water level 3.7 m above the average water level, considerably exceeding the highest recorded value of 480 $m^3 \cdot s^{-1}$ in 1926 (Kolbezen 1991). Travelling downstream very quickly, the flood wave reached the gauging station in Laško 45 km downstream at 4:30 p.m. (maximum discharge 1,406 $m^3 \cdot s^{-1}$; highest recorded value until that date was 1,200 $m^3 \cdot s^{-1}$ in 1933).

The disaster caused enormous damage in the upper Savinja drainage basin (Kladnik 1991; Meze 1991; Natek 1993), while in the lower part it also flooded a large part of Celje (population 40,000). Together with its tributaries, the Savinja river destroyed the main road in the valley in many places as well as most of local roads. It also carried away many bridges and destroyed many residential and other buildings. From a wider geographic and spatial planning perspective, the most important conclusion was that the disaster directly affected almost exclusively newer parts of the settlements which were inappropriately located on recent alluvial fans or flood plains along water courses, while older central parts of villages and numerous mountain farms remained virtually unaffected despite their unfavorable natural conditions (very steep slopes, high relief amplitudes). This is a very illustrative indicator of considering the principle of sustainable spatial management in traditional agrarian society which, however, remains largely ignored by local communities and planners despite the disastrous experience in 1990.

From a geomorphologic perspective, the most interesting in the 1990 disaster was relief transformation on recent alluvial fans and triggering of large landslides. In this part of Prealpine mountains, there are distinctive differences between large periglacial alluvial fans from the last Ice age where the streams have carved their valleys more than 20 m deep (Meze 1966) due to reduced supply of slope material after the forest line raised from 600 to today's 1,700 m, and recent

Photo 4. Material deposited by the Trbiški graben stream at its confluence with the Savinja river upstream from Ljubno (Photo by K. Natek, November 3, 1990)

alluvial fans where strong erosion and accumulation processes occur during flash-floods. Accordingly, settlements on older alluvial fans are completely flood-safe (mountain farms or small villages are almost exclusively located there), while recent alluvial fans are extremely flood-prone areas. A combination of high precipitation and landslides on steep slopes in narrow mountain valleys presents a special hazard — in these cases, devastating debris flows develop, depositing huge quantities of load in very short periods of time at the contact of alluvial fans with valley bottoms (Photo 4).

Apart from several hundred smaller landslides, the wild force of geomorphic processes related to flash-floods was convincingly proved by two large landslides in the villages of Raduha and Podveža (Natek 1991, 1992, 1993; Meze 1991). The first landslide (Fig. 3) was triggered two days after the peak floods on a relatively steep slope at the altitude 750–790 m (approximately 300 m above the Savinja river), settling after 900 m of sliding in the bottom of the valley where it destroyed a family house. In its upper part, the landslide was 100–150 m wide, while lower on the slope it narrowed to 30–40 m and at the same time the sliding speed increased. About 200,000 m$^3$ of bedrock (Oligocene andesite tuff, periglacial scree and regolith) was displaced, however only its smaller part reached the valley bottom — the majority of the mass stopped after several tens-of-meters of sliding.

Detailed studies revealed that the landslide was triggered on the same location as the even larger landslide several hundred years ago from which a wide landslide scar remained, limited with distinctive landslide ruptures. The old landslide also reached the valley bottom — the hardly passable landslide area filled with boulders was named Pekel ("the Hell") by local residents. In the immediate

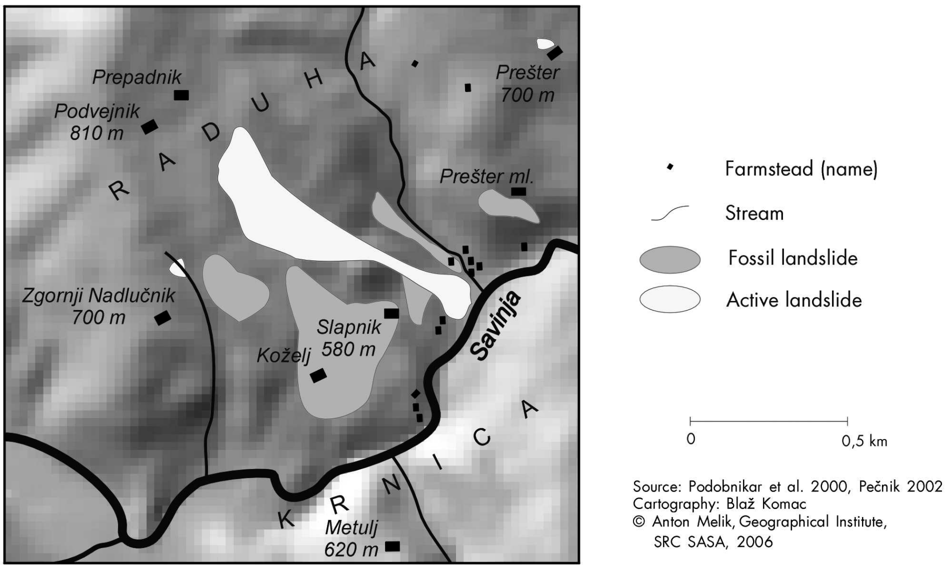


Fig. 3. Landslides in the Raduha village in the Upper Savinja valley

vicinity of this landslide, an even larger landslide was triggered in the past. In was 400 m wide in its upper part, also limited by a distinctive, steep landslide scar which is a clear indicator of unstable slopes in the Prealpine areas after the end of Würm glaciation.

More severe were the effects of a landslide in the Podveža village in the Lučnica valley several km upstream from the Luče village. The landslide was triggered on November 1, 1990 around 10:00 p.m. It destroyed a family home and blocked the swelled Lučnica stream. A 20-m deep lake with a volume of 1 million $m^3$ formed behind the dam and several houses were completely flooded until the water broke through the dam at 5:20 a.m. the next morning, developing into a 2-m high flood wave which devastated the Luče village downstream. An elderly woman died in the lake, while the disaster in Luče was prevented by a high level of awareness of local people and their self-organization skills.

## CONCLUSION

Frequent occurrence of large mass movements in the Alps is in extreme contrast with recent morphodynamics of the Dinaric mountains where the corrosion is a distinctly predominant geomorphic process. Pointing out the differences between the two mountain systems similar in geologic development and rock composition makes even more sense when these recent events are studied from the perspective of natural disasters since exposure to natural hazards is much higher in the Alps than in the Dinaric mountains. Concentration of population and infrastructure in narrow mountain valleys is a large risk factor which is not taken into consideration adequately when development activities are carried out in the Alpine environment. The examples presented above also clearly show that we are completely helpless when faced with these events, however, many risks could be avoided through more thoughtful selection of locations and consideration of traditional experience.

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STRESZCZENIE

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RUCHY MASOWE I GWAŁTOWNE POWODZIE W ALPACH SŁOWEŃSKICH ORAZ SĄSIEDNICH GÓRACH

Rzeźba gór Słowenii charakteryzuje się znacznym rozczłonkowaniem przez doliny o stromych stokach i wąskich dnach. Jest to rezultat bardzo aktywnych procesów morfogenetycznych w przeszłości i współcześnie. Dominujacymi zjawiskami geomorfologicznymi są obrywy skalne, osuwanie i gwałtowne powodzie. Zdarzenia te mimo, że występują w sposób nieciągły, są bardzo istotnymi przejawami współczesnej aktywności procesów geomorfologicznych, a równocześnie stanowią zagrożenie dla mieszkańców gór i infrastruktury istniejącej w dnach dolin głównych rzek i ich dopływów. W górach należących do systemu dynaryjskiego istnieje odmienna sytuacja. Tam dominuje rzeźba krasowa, a głównym procesem morfogenetycznym jest denudacja chemiczna skał węglanowych. Ruchy masowe występują tylko sporadycznie.

W artykule przedstawiono wielkoskalowe zdarzenia geomorfologiczne rozpatrywane z punktu widzenia zagrożeń dla człowieka oraz jako składników współczesnej ewolucji rzeźby. Opisano trzy największe zdarzenia geomorfologiczne, które wystąpiły w ostatnich 20 latach; spływ gruzowy na obszarze Log pod Mangarton powstały 17 listopada 2000 roku, katastrofalną powódź w dorzeczu rzeki Savinja w dniu 1 listopada 1990 roku oraz w włoskich wioskach Rateče i Ugovizza w dniu 31 sierpnia 2003 roku. W pierwszym zdarzeniu człowiek był tylko biernym obserwatorem powstania wielkich osuwisk i przekształceń rzeźby stożków napływowych, natomiast w pozostałych człowiek przyczynił się do powiększenia katastrofalnych skutków procesów naturalnych poprzez niewłaściwe zlokalizowanie osiedli i działalności gospodarczej na równinach zalewowych oraz na stożkach napływowych w wąskich odcinkach dolin.