

Recent landslides on the Istrian Peninsula, Croatia

Sanja Dugonjić Jovančević · Željko Arbanas

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Abstract This study presents a review of recently recorded instability phenomena on the flysch slopes of Istria, Croatia. The northeastern part of the Istrian Peninsula, the so-called Gray Istria, is built of Paleogene flysch deposits, where instability phenomena are frequent and where a large number of landslides, with significant consequences, have been recorded over the past 35 years. Based on field investigations conducted for the purpose of remedial study design, a database of these landslides was created. An investigation of the documented landslides and their elements found some common features that enabled general conclusions about the conditions and causes of landslide occurrence. In total, 19 documented landslides have been analyzed as individual phenomena, and from the results of these analyses, general conclusions were drawn about sliding conditions and the main triggering factors. Geological conditions and processes on slopes where landslides occurred are shown in detail, and geotechnical properties have been systematically represented. The sliding conditions and dimensions of four recent landslide occurrences, specifically by type, have been described in detail and analyzed.

Keywords Landslide · Flysch · Triggering factor · Rainfall · Cumulative precipitation

1 Introduction

This paper presents a review of the research results on recent landslides that occurred in the central and northern parts of the Istrian Peninsula over the past 35 years. The area of investigation is in the Pazin Paleogene Flysch Basin in the northeastern part of the peninsula. This area is formed of flysch units and, because of their gray color, is called Gray Istria. In this area, landslide types, mechanisms and conditions of occurrence have several analogies. Local roads and, rarely, other structures and facilities suffer major damage as a consequence of landslides (Arbanas et al. 1999). The studied area covers 550 km², and the estimated volume of landslides included in the dataset is approximately 500,000 m³.

S. Dugonjić Jovančević · Ž. Arbanas (✉)
Faculty of Civil Engineering, University of Rijeka, Radmile Matejčić 3, 51000 Rijeka, Croatia
e-mail: zeljko.arbanas@gradri.hr

The majority of studied landslides occurred during winter or spring. Generally, they are rotational and translational type landslides, as well as rock falls and debris flow (recorded at one single location). The identification of the factors that caused the existing landslides in the area is the first step in determining the presence of landslide hazard on slopes with similar geological, hydrological and geotechnical conditions.

2 Geology of the Istrian Peninsula

The Istrian Peninsula is located in the northwestern part of the Adriatic Sea, and most of it is in the Croatian territory. Geologically, the Istrian Peninsula is a foreland of the Adriatic microplate (Brückl 2011). The western part of the peninsula is formed of Jurassic limestones, sporadically covered by the so-called *terra rossa* (eng. *red Mediterranean soil*), mostly derived from weathering of the limestone bedrock (Velić and Vlahović 2009). The Pazin Paleogene Flysch Basin or Gray Istria area stretches from Trieste Bay in the west to Učka Mountain in the east (Fig. 1).

The geological fabric of Istria today is a result of repeated tectonic deformations from the Cretaceous in addition to the intensive processes of erosion and accumulation.

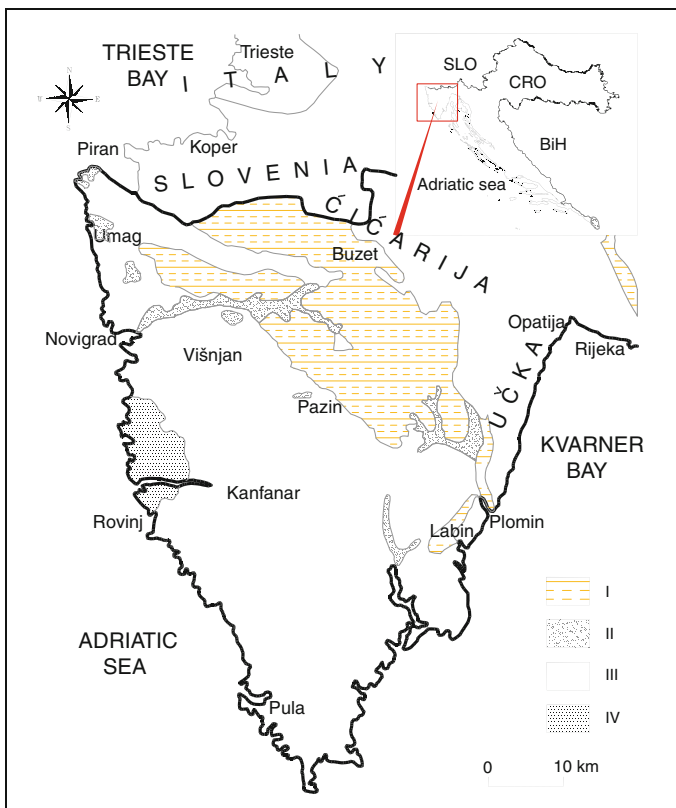


Fig. 1 Simplified geological map of Istria. *I* Paleogene flysch, *II* Alluvium, *III* Cretaceous Limestone, *IV* Jurassic Limestone (after Velić et al. 1995)

Sediments have nearly subhorizontal layers, except for the contacts with the Čićarija Mountain range in the northeast and Učka Mountain in the east, where the flysch rock mass was significantly deformed during tectonic activities. In the process of morphogenesis during the Pleistocene and Holocene, differential erosion processes took place on flysch terrains. Hills were formed where resistant sandstones and breccia conglomerates are significantly present, and the depressions were filled with eroded clayey and silty sediments (Mihljević 1996, 1998). In the bottoms of river valleys, and especially in the large river estuaries (Mirna, Raša and Dragonja river), significant alluvial deposits composed of thick layers of clay and clayey silt are present.

2.1 Paleogene flysch of the Istrian Peninsula

The lithology of the lowest part of the flysch series is usually homogeneous and marly, while the upper part is more heterogeneous, showing vertical and lateral alternations of claystones and siltstones with calcitic sandstones and breccia conglomerate interbeds.

The flysch rock mass that has been exposed to water and air is strongly affected by chemical weathering and decomposition, with leaching of CaCO_3 components, oxidation and swelling. These processes cause changes in the physical and mechanical properties, as shown in Fig. 2. Mechanical weathering also influences the chemical weathering of flysch components (Attewell and Farmer 1979). Fine-grained fractions, such as siltstones, are the most affected by chemical weathering. As a result of these processes, the flysch rock mass increases its volume over time, disintegrates and becomes silt or clay, as shown in Fig. 2. Through this gradual degradation, the physical and mechanical properties of clayey silt materials become more like engineering soil. A consequence of these types of geomorphological processes is a sporadic accumulation of eroded Quaternary deposits on the slopes that can be susceptible to sliding (Arbanas et al. 2007; Benac et al. 2005).

In a typical situation, the flysch bedrock is covered by these Quaternary deposits, except the isolated areas where the erosion is more expressed. This is particularly evident on the southwestern margin of the Čićarija Mountain, at the foot of the cliffs, where the coarse-grained fragments have mixed with the silty clay materials from the flysch-weathering zone (Benac 1994; Arbanas et al. 2006). Two zones of different hydraulic conductivity can be recognized in the geological profile: the clayey and silty cover with low hydraulic conductivity and the unfractured fresh rock mass in the flysch bedrock, which can be considered to be completely impermeable. Systems of vertical fissures and joints in marls



Fig. 2 Weathering and decomposition of flysch rock mass exposed to water and atmospheric conditions

and sandstones allow easy infiltration and flow of groundwater from the upper part of the slope. Deeper, slightly weathered and fresh unfractured siltstone layers act as watertight zones, causing the draining of groundwater along the fissure-joint system running down the slope. After long rainy periods, the joint system cannot completely drain the infiltrated water, resulting in the rise of the groundwater level in the vertical joints and a subsequent increase in pore pressures (Arbanas et al. 2010).

3 General features of recent landslides

The creation of the landslide database for the Gray Istria area began in 2008 at the Department of Hydrotechnics and Geotechnics, Faculty of Civil Engineering, University of Rijeka, using documentation collected from the department's archives and the archives of the Istrian County Roads Office and the Civil Engineering Institute of Croatia. These documents include geological and geotechnical data from geotechnical field studies for remediation works on landslides that overtook roads and railways in Istria. Field investigations were performed according to specific site conditions and consisted of geodetical surveying, borehole drilling, geological mapping, geophysical surveying using seismic refraction, geoelectrical tomography techniques and soil/rock laboratory testing. Data from approximately 19 landslides that occurred from 1979 through 2010 were gathered and systematized (Fig. 3; Table 1). Other instability phenomena occurred during the time period of the study, but because of the lack of landslide inventories in the area of Istria and Croatia, the precise number of landslides cannot be determined. Although it is well known that more than 10 landslides, in addition to those included in the study, were investigated during this period, documentation of these landslides is not available.

The collected data for the studied landslides contain basic information about the location, type, dimensions and time of occurrence, as well as other data from geological and geotechnical studies, laboratory test reports, remediation designs, etc., as shown in Table 1. It was observed that landslides on flysch slopes have multiple styles and retrogressive distribution (Cruden and Varnes 1996). In most cases, the rotational mechanism occurs, whereas other types of instability are rare (Arbanas et al. 2010; Mihalić et al. 2011). It was also noticed that these instabilities were, in some ways, anticipated by deformation

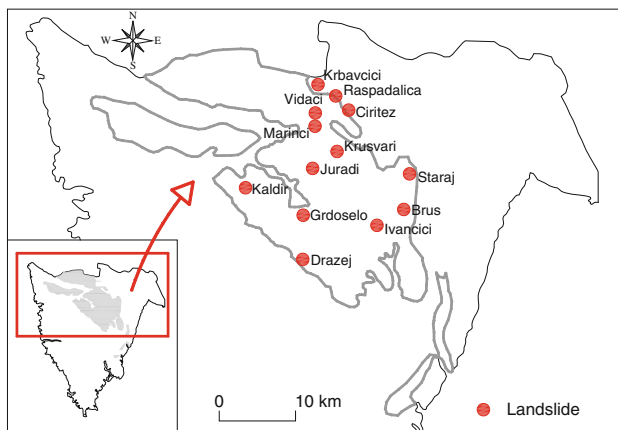


Fig. 3 Recent landslides in Gray Istria

Table 1 Basic data related to the recent landslides in Gray Istria

Location	Time of occurrence	Type of instability	Estimated volume (m ³)	Slope angle (%)	Triggering factor
Krbavčiči	January 1979	Rotational landslide	59,000	Average 15–20	Rainfall
Krbavčiči 1	January 1979	Translational landslide	176,000	Average 15–20	Rainfall
Staraj	Spring 1993	Rotational landslide	1,900	Average 10–30	Rainfall
Krušvari	Spring 1993	Rotational landslide	68,500	Average 14; lower part 10; below road 30	Rainfall/human activity
Raspadalice 1	1992	Translational landslide	900	50–70; upper part vertical	Rainfall
Raspadalice 4	1994	Rotational landslide	4,100	50–70; upper part vertical	Rainfall
Čirtež	1995	Rotational landslide	37,000	Average 14	Rainfall
Raspadalice 2	1995	Rotational landslide	2,900	55–70; upper part vertical	Rainfall
Raspadalice 5	1995–1999	Rotational landslide	13,400	50–70; upper part vertical	Rainfall
Grdoselo 1	Winter 2002	Rotational landslide	1,800	Average 25; lower part 15; upper 35	Rainfall/human activity
Grdoselo 2	Winter 2002	Rotational landslide	2,300	Average 25; lower part 15; upper 35	Rainfall/human activity
Krbavčiči—reactivated	January 2003	Debris/earth flow	35,000	Average 15–30	Rainfall/human activity
Ivančiči	Spring 2004	Fall	1,500	Upper part 45; lower part 15–30	Rainfall
Vidaci	Winter 2004	Fall	1,400	Upper part 54; lower part 35	Rainfall
Dražej	January 2005	Rotational landslide	9,800	Average 30; lower part 15	Rainfall/human activity
Brus	Spring 2005	Translational landslide	35,000	Average 15; lower part 35	Rainfall
Marinci	Spring 2006	Rotational landslide	1,800	Average 30; lower part 55	Rainfall/human activity
Juradi	November 2010	Translational landslide	47,000	Upper part 5–7; below road 10–25	Rainfall/human activity
Kaldir	Winter 2010	Rotational landslide	2,000	Average 22–30	Rainfall

in the slope caused by long-term creeping (Arbanas et al. 2007). The sliding surface is usually formed inside the layer of the weathered flysch rock mass, between the cover and the fresh bedrock. Instability is caused directly by the weathering of superficial flysch deposits exposed to atmospheric activity and unfavorable hydrological conditions (water infiltration and groundwater table rising) that causes the shear stresses to exceed the soil strength and initiates the sliding.

The assessment of the strength properties of the flysch bedrock was made impossible by the disarrangements of the flysch rock mass during the sampling, while the tested samples presented here were collected from different parts of the landslide body, although rarely from the surface of rupture. Different test methods were employed, using different direct shear apparatus, ring shear apparatus and triaxial apparatus. The strength parameters showed considerable variations in value, and it is impossible to determine the acceptable range of values that can be generally adopted as characteristic of all materials in slope stability analyses (Table 2).

The main test consisted of a point load test (PLT) in which samples, obtained by boring, were used without further processing and almost immediately after sampling (ISRM 1985). Obtaining undisturbed samples in completely-to-moderately weathered siltstones was not always possible. A significant difficulty is also caused by the sudden degradation and disintegration of slightly weathered-to-fresh siltstones after removal of geostatic loads and exposure to air and water during boring. The test results of the PLT on fresh siltstone samples showed that the corresponding uniaxial strength of these materials ranges from 10 to 15 MPa and, in extreme cases, to 20 MPa. The corresponding uniaxial strength of moderately-to-slightly weathered samples showed values <2 MPa. However, these values obtained from the PLT are unreliable and unacceptable for engineering analyses without taking adequate precautions (Arbanas et al. 2008).

In slope stability analyses, the gravitational/colluvial cover and the residual soil can be considered as materials with similar properties (Figs. 4, 5). The cover is, as a rule, formed of clay of intermediate- (CI) to-high (CH) plasticity and is semisolid to plastic in consistency, depending on the water content. In cases where the cover was brought from the higher slope areas, it can contain an even larger portion of rocky fragments, mostly

Table 2 Geotechnical properties of soils in the landslide body

Location	Liquid limit— w_l (%)	Plastic limit— w_p (%)	Plasticity Index— I_p (%)	Cohesion (kN/m ²)	Internal friction angle (°)
Raspadalica 2	38.48–54.53	21.24–26.68	17.24–33.01	1	10.2–18.6 ^a
Raspadalica 3	49.26–62.57	18.81–26.46	29.98–37.54	21	9.7–22.3 ^a
Raspadalica 4, 5	36.12–60.42	16.7–28.0	19.29–32.42	5–29 ^a	20.7–30.28 ^a
Grdoselo 1	44.65–66.56	19.12–23.94	24.45–42.63	28–100 ^b	21.9–32 ^b
Ivančići	36.42–79.94	17.92–27.25	18.50–52.70	0–30 ^b	30–35 ^b
Čiritež	38.46–80.11	16.29–29.52	22.17–54.60	213	18–19 ^c
Staraj	38.97	18.37	20.6	10–100 ^b	25–28 ^b
Krbavčići	42.1–57.6	19.3–24.5	21.2–33.1	2.5–63.7 ^{a,b}	12–27 ^{a,b}
Drazej	37.34–77.60	16.57–26.81	20.78–50.80	10.0–20.0 ²	22–36 ²
Krušvari	35.13–55.03	17.81–24.37	21.91–30.66	10.7 ^{a,b}	25 ^{a,b}
Kaldir	41.76–64.41	19.21–24.1	22.55–40.31	6–30 ^b	27–32 ^b
Juradi	29.07–71.46	16.94–28.40	12.13–46.35	35–76.7 ^b	5.1–13.9 ^b

^a Ring shear apparatus (residual values); ^b Direct shear apparatus; ^c Triaxial apparatus

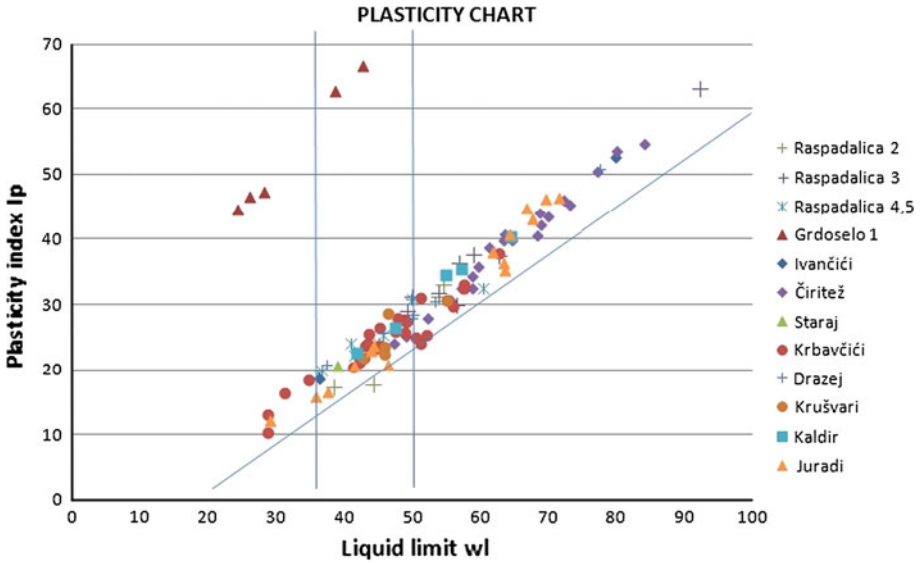


Fig. 4 Plasticity chart with the distribution of soils from landslide locations

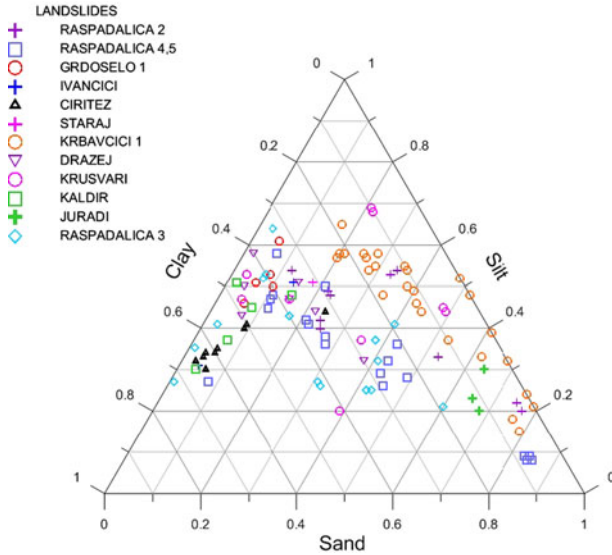


Fig. 5 Granulometrical composition of soils from landslide locations

sandstones and siltstones originating in the bedrock. Residual soils are the products of flysch rock mass weathering and consist of silty clay of low- (CL) to-high (CH) plasticity without rocky fragments.

The mean annual precipitation distribution (mm), based on the measured precipitation values at weather stations in Istria, is shown in Fig. 6. To determine the direct triggering

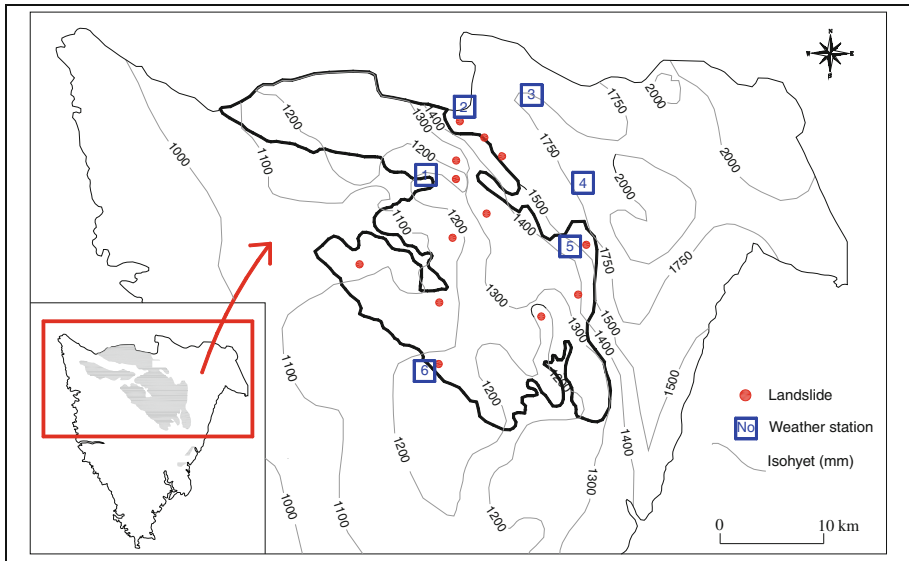


Fig. 6 Weather station positions (1 Abrami, 2 Rakitovec, 3 Vodice, 4 Lanišće, 5 Lupoglav, 6 Pazin) and mean annual precipitation distribution (mm)

factors of sliding, recorded precipitation in the area of Gray Istria was analyzed. For analyzing the influence of the rainfall amount on anticipated sliding, data on daily, monthly and annual precipitations from the four closest weather stations in the investigation area were used (Fig. 6).

4 Types and mechanisms of recent landslides

In this paper, the Krbavčiči (1979 and 2003 events), Brus and Juradi landslides are described in detail (see also Table 3).

4.1 The Krbavčiči landslide (1979 and 2003 events)

The first signs of sliding on the slope in the Krbavčiči village area, near the city of Buzet, appeared in 1961, but the most important movements occurred during the night between January 30 and 31 of 1979, when multiple retrogressive sliding occurred after a prolonged rainy period from October 1978 through January 1979 (Fig. 7a). The landslide involved the clayey superficial deposit of colluvium and residual soil that was 10 m thick, together with the road embankment, bringing material down the slope for 200 m and burying a vineyard in the landslide toe. Field investigations were performed in the spring of 1979 and consisted of geological mapping, borehole drilling and laboratory testing. The investigation indicated the surface of rupture between the superficial deposits and the siltstone bedrock. The landslide was naturally suspended, the damaged road was repaired, and the landslide body was overbridged. A new reactivation of the Krbavčiči landslide occurred in the winter of 2003, resulting in movements in the upper part of the slope above the viaduct (Figs. 7b, 8a). The first movements occurred in December 2002, and the widening progressed until the initiation of debris/earth flow in early January 2003 (Arbanas et al. 2006). To clearly

Table 3 Landslide dimensions

Dimension (m)	Krbavčiči (1979)	Krbavčiči (2003)	Brus	Juradi
Total length from crow to toe (L)	242	140	208	63
Length of displaced mass (L_d)	240	137	142	55
Maximum length of sliding surface (L_r)	220	130	142	60
Maximum width of displaced mass (W_d)	55	40	37	150
Maximum width of slide surface (W_r)	45	50	37	145
Thickness of displaced mass (D_d)	10	6	8–10	8
Maximum depth of sliding surface (D_r)	12.5	10	10	11

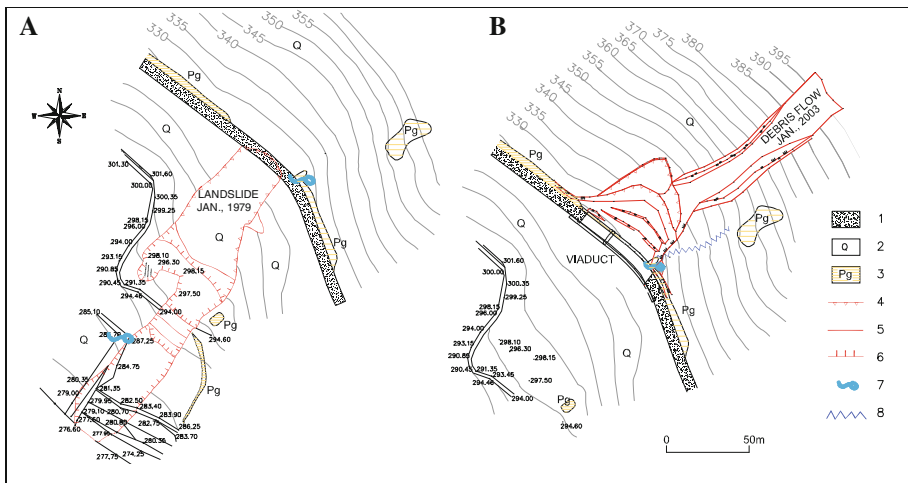


Fig. 7 Geological map of the Krbavčiči landslide in 1979 (a) and debris flow in 2003 (b). 1 road embankment fill, 2 Quaternary deposits, 3 marl and siltstone outcrops, 4 main scarp, 5 shear cracks, 6 compression cracks, 7 temporary spring, 8 ravine

ascertain the dimensions of the new appearance, a geodetical survey and geological mapping were conducted. It was found that approximately 35,000 m³ of colluvium material, mostly silt with 25–55 % limestone, was sliding down the slope.

4.2 The Brus landslide

The Brus landslide is located near the Brus village in the central part of the Istrian Peninsula. The sliding occurred on April 9, 2005, at 3.15 pm, but the open cracks positioned on the main scarp occurred in December 2004 (Fig. 9). The movement was a typical translational block sliding (Skempton and Hutchinson 1969; Antoine and Giraud 1995) with a landslide body consisting of one almost-undisturbed flysch rock mass block. The sliding was prepared by the unfavorable orientation of the layers: parallel to the slope and dipping out of it in the lower part due to river erosion, while intensive rainfalls were the triggers. The general orientation of rock mass bedding planes varies from 220/13 to 225/19, with an average value of 223/14 (Arbanas et al. 2010). The rock mass block was



Fig. 8 Photographs taken after sliding. **a** Krbavčiči landslide (photo taken in January 2003), **b** Juradi landslide (photo taken in January 2011)

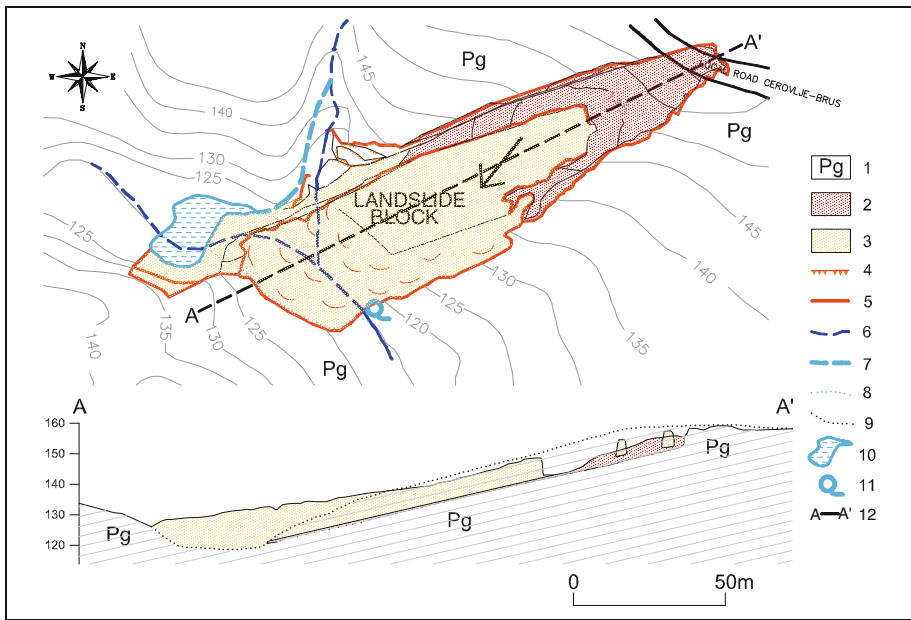


Fig. 9 Geological map and cross section of the Brus landslide. 1 flysch bedrock, 2 depletion zone, 3 block translated by sliding, 4 main and flank scarps, 5 toe of the landslide, 6 old permanent and temporary streams, 7 part of the stream covered by the landslide foot, 8 overflow of the accumulated water, 9 original ground surface before sliding, 10 lake formed as result of sliding, 11 drainage water through the landslide body mass, 12 cross section through the landslide body (after Arbanas et al. 2010)

150 m long, 30 m wide and moved 33 m downslope along a single, planar bedding plane. A local road running close to the main scarp was damaged.

Field investigations were carried out in the spring of 2004 and consisted of a geodetical survey and geological mapping. Because of the clearly visible geological outcrop on the flank scarp, it was not necessary to perform borehole drilling. The involved rock mass consists of alternating tabular layers of sandstone and marl (Fig. 10), covered by a thin,

clayey superficial deposit of colluvium and residual soil. The slip surface was identified inside the weathered zone, on the contact between the slightly weathered and fresh siltstone. The landslide foot formed a small temporary lake (Fig. 9).

4.3 The Juradi landslide

The main scarp of this landslide divides Juradi, a small village located in the central part of the Istrian Peninsula (Fig. 8b). The last reactivation of this landslide occurred on December 1, 2010, but according to village inhabitants, movements have been repeatedly occurring for the last 80 years. The landslide was temporarily suspended by the construction of surface drainage trenches and by the end of the heavy rainfall season. In spring 2011, field investigations were performed, and it was established that the Juradi slope is made up of flysch bedrock (tabular layers of prevailing siltstone and marl with sporadic sandstone interbeds, Fig. 11), covered by a 5- to 14-m-thick clayey cover (colluvium deposits and residual soil). The surface of rupture was positioned on the contact between the cover deposit and the siltstone bedrock layers, whose orientation (340/08) is similar to and dipping out from the slope. The dimensions of the landslide cannot be precisely measured because only the main scarp in the head of the landslide is clearly visible (Figs. 8b, 11). Despite this, it was estimated that the volume of the landslide body is approximately 47,000 m³. During the study, it was concluded that, due to the low permeability of the soil, only a small fraction of precipitation (<15 %) was infiltrating the subsoil.

5 Causes and triggering factors

Landslides in Istria are usually caused by heavy rainfall and/or human activity that significantly changes the slope geometry and/or assists in leading and retaining surface water in the sliding zone (Arbanas et al. 2007) (Table 1). Others factors, such as snow melting and earthquakes, cannot be considered significant because of climate conditions and a lack of sufficient seismicity in this area.

In respect to risk rising, rainfall analyses based on historical data from 1961 to 2010, in association with landslide events, represent empirical estimates that can be used as important information for the local authorities and companies that maintain the local roads.



Fig. 10 The Brus landslide-view on the old road remains (photo taken in August 2005) (a) and the flank scarp of the landslide (photo taken in January 2010) (b)

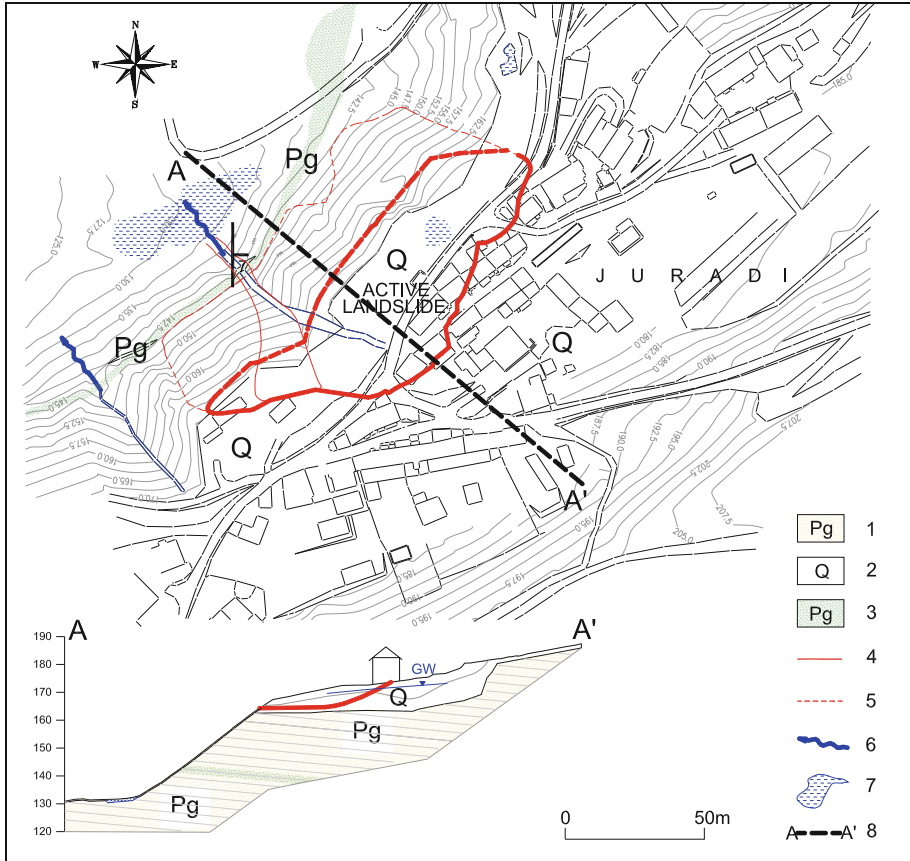


Fig. 11 Geological map and profile of the Juradi landslide. 1 flysch bedrock (in the cross section), 2 cover deposit—colluvial and eluvial deposits, 3 sandstone outcrops, 4 landslide main scarp, 5 accumulation zone, 6 surface outflows, 7 marshy zone, 8 cross section

Using a summation of daily precipitation during the period from 1 week to 6 months, the cumulative precipitation values for different time periods were obtained. On 4 of the studied landslides, cumulative monthly precipitation values were compared with total precipitation values for an equal time period using historical rainfall data (Fig. 12).

It appears that precipitation from the 3 months prior to landslide initiation, with relatively high monthly totals, probably has the primary influence on rising infiltration and water levels. This period varies from 70 to 100 days, depending on local morphological, geological and hydrogeological conditions, vegetation and land use, and cumulative precipitation values. As confirmation of this statement, in the period before sliding, many shorter periods with higher cumulative precipitation were recorded, although sliding did not occur. It was also determined that the analyzed landslides are activated primarily during the late autumn and early winter period, when the number of rainy days during a 3-month period was large and the evapotranspiration values were low.

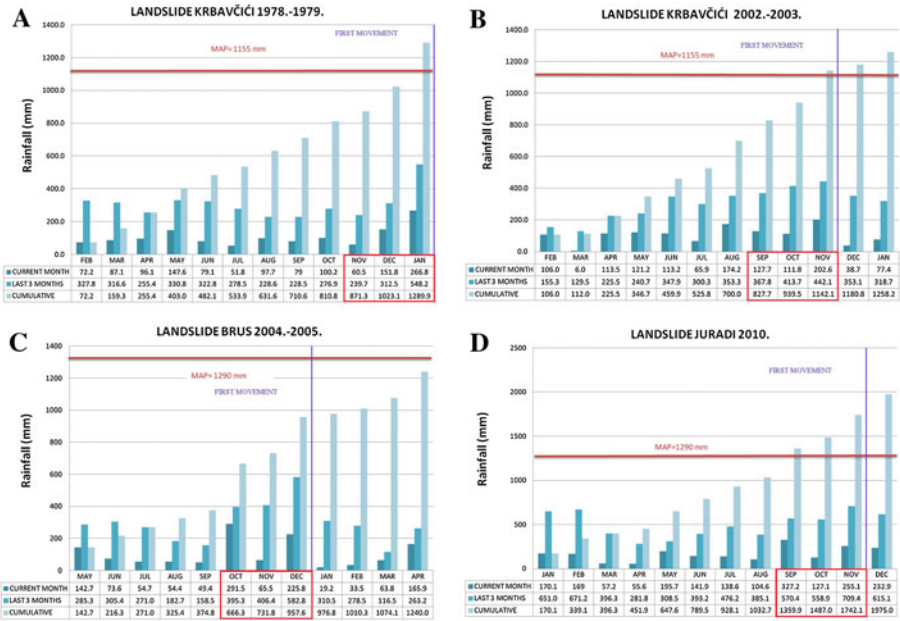


Fig. 12 Rainfall diagram showing the precipitation for the current month and cumulative precipitation for 3 and 12 months before sliding. **a** Krbavčiči landslide, 1978–1979 (Abrami weather station). **b** Krbavčiči debris flow, 2002–2003 (Abrami weather station). **c** Brus landslide, 2004–2005 (Lupoglav weather station). **d** Juradi landslide, 2010 (Lupoglav weather station). Red lines show the mean annual precipitation, and red squares are the 3-month period before the first movement occurred

6 Discussion and conclusions

Data from 19 documented landslides recorded as singular phenomena were analyzed, and general conclusions about sliding conditions and triggering factors have been drawn. The analysis of the gathered data established that the appearance of relatively small landslides, related to the sliding of clayey talus cover on the contact with flysch bedrock, is typical for the Gray Istria area (Arbanas et al. 1999). The results in the case of the Krbavčiči debris/earth flow and the Brus translational sliding differ somewhat from the general conclusions. Landslides, as a rule, are caused by unfavorable geological settings (e.g., the dip and direction of the layers) and hydrological conditions, very often in combination with human activities on the slope (e.g., the construction of roads and infrastructure) (Arbanas et al. 2007).

Geological profiles of the studied landslides consist mainly of flysch bedrock (of Paleogene age) covered by a clayey colluvium and/or residual soil. On most of the analyzed slopes, there was no evidence of historical sliding. It appears that nearly all of the studied landslides were caused by a longer rainy period and water infiltration, which caused a rise in the groundwater level, a pore water pressure increase and a decrease in strength on the slip surface from total to effective values.

In determining the landslide causes and direct triggering factors, precipitation in the wider landslide area was analyzed, using the impact of rainfall amount on sliding and including the use of data on daily, monthly and annual precipitation from 6 weather

stations in the study area (Fig. 6). It is clear that landslides occurred in years with precipitation totals near the mean value and, in some cases, years with extremely high precipitation, but rainfall totals are not the determining factor in landslide activation. The infiltration measurements were not performed continuously, resulting in minimal data for confirmation of the analysis, but it seems that the infiltration into the unsaturated part, the increase in water level and the increase in pore pressures are slow processes. Therefore, it can be concluded that long rainy periods are crucial for the initiation of landslides, whereas short rainfalls have a significant influence on erosion and less influence on landslide appearance. The total cumulative values for the last 12 months before sliding, as well as the maximum monthly, weekly or daily precipitation, do not have a significant influence on landslide initiation.

From the cumulative precipitation analyses within 90 days that preceded first movements on the landslide, it can be observed that landslides occurred when the cumulative precipitation values ranged from 400 to 700 mm (Fig. 12). These could be compared to experience in the Polish Flysch Carpathians, where Gil and Dlugosz (2006) defined 250–300 mm of cumulative precipitation values as a threshold between 25 and 45 days. Due to the insufficient infiltration data and the measurements of groundwater level changes, it is difficult to define a rainfall-duration threshold for the possible initiation of landslides in the flysch area of Gray Istria. However, it is important information that first movements on the landslides occurred after a 3-month rainy period with approximately 50 % rainy days without longer dry interruptions. Maximum daily precipitations within these periods were from 48.5 mm/day (the Brus landslide) to 114.1 mm/day (the Juradi landslide). This period suggests conditions in which the risk of landslide reactivation increases and that requires initiation of enhanced monitoring. It would be possible to determine the threshold value expressed as cumulative precipitation of rainfall by further analysis of the long-term ground water level measurements associated with the precipitation levels during the monitoring.

Analysis of the processes of sliding phenomena in similar flysch deposits in Europe indicated that the main types of instability phenomena in flysch slopes occurred as debris flows and shallow landslides (<3 m) in superficial deposits and deep-seated landslides with a surface of rupture through the flysch bedrock. The main triggering factors were rainfall and snow melting, and earthquakes (only in Italy, Tosatti et al. 2008). The period of 3-month cumulative precipitation that caused landslide initiation on the flysch slopes in Gray Istria is longer than the periods in other countries that have similar flysch geological settings (25–45 days in the Polish Flysch Carpathians, according to Gil and Dlugosz (2006); 15–60 days in the Northern Apennines in Italy, according to Tosatti et al. (2008); 30–60 days in the Southern Apennines in Italy, according to Polemio (1997); 25 days in the Slano Blato Landslide in Slovenia, according to Logar et al. (2005); and, broadly, “several months” in the Outer Western Carpathians in the Czech Republic, according to Klimeš et al. (2009). A longer period ranging between 180 and 360 days of accumulated precipitation was associated with major landslide reactivations in the Southern Apennines, according to Polemio (1997). The variability of these findings depends on different regional and local conditions, but the most important condition associated with the time until the landslide activation is the rate of infiltration.

According to the well-known and widely applied principle “The past and the present are keys to the future” (Varnes 1984; Carrara et al. 1995), it is assumed that new landslide occurrences on the flysch slopes of Istria will appear in morphological, geological, hydrogeological and geotechnical conditions that are similar to the conditions of recent landslide occurrences (Dugonjić et al. 2008). From the previous conclusion, conditions that

predispose future landslides on flysch slopes are as follows: (1) geological conditions in which the clayey superficial deposit is present over the flysch bedrock on a slope with suitable inclination and kinematic conditions for sliding; (2) conditions that allow the admission of a corresponding amount of water from higher parts of the slope; (3) conditions in which the inclination of the almost-impermeable flysch bedrock retaining the groundwater at the location or in the direction of the groundwater flows is close to the slope inclination; and (4) conditions in which the slope is exposed to a sufficiently long, continuous period of rainfall with corresponding infiltration. The fourth condition is the main triggering factor for the activation of landslides on the flysch slopes of Gray Istria, and it is important to landslide susceptibility and hazards assessment as well as mitigation measures and risk management.

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