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Fotografija na naslovnici: Kamniti most čez reko Rak na obrobju kraškega polja Rakov Škocjan, ki je sicer bolj znano po čudovitih naravnih mostovih (fotografija: Matej Lipar).

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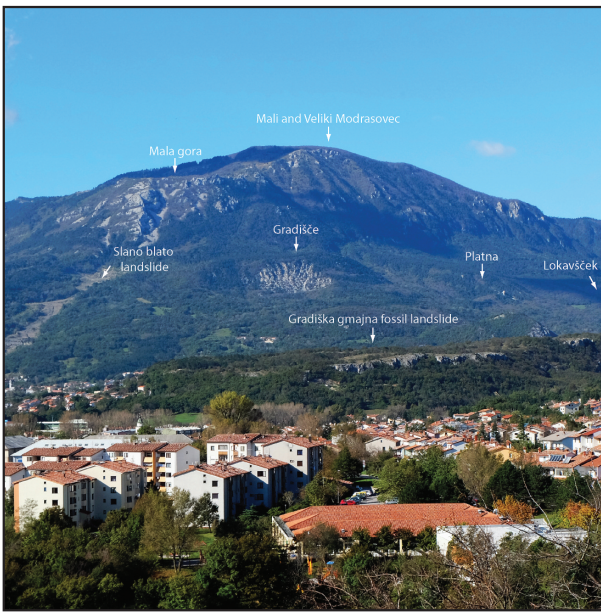
GRAVITATIONAL SLIDING OF THE CARBONATE MEGABLOCKS IN THE VIPAVA VALLEY, SW SLOVENIA

Maja Kocjančič, Tomislav Popit, Timotej Verbovšek



Photograph of carbonate gravitational blocks, Slano blato landslide and Gradiška gmajna fossil landslide on the southern slopes of the Trnovo Plateau from Ajdovščina, Vipava Valley (view towards NW).

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Gravitational sliding of the carbonate megablocks in the Vipava Valley, SW Slovenia

ABSTRACT: The area of Lokavec in the Vipava Valley, SW Slovenia, consists of Mesozoic carbonates thrust over Paleogene siliciclastic flysch. Overthrusting and tectonic damage of carbonates accelerated their mechanical disintegration. As a result, accumulations of slope gravel and large carbonate gravitational blocks are deposited on the slopes. Based on previous research, basic geological mapping and analysis of the DEM, ten carbonate blocks were identified. The aim of our research was to map lithology, measure and analyse the dip of carbonate strata and to determine transport mechanisms for individual blocks. The displacement of blocks from the source area ranged from 80 m to 1950 m. With the displacement of gravitational blocks, changes in dip direction and dip angle were also observed. The differences between the strata dip of carbonate source area and gravitational megablocks are from 4° to 59°.

KEY WORDS: mass movement, slope deposits, gravitational carbonate blocks, lidar, Vipava Valley, Slovenia

Gravitacijski karbonatni megabloki v Vipavski dolini

POVZETEK: Širše območje naselja Lokavec v Vipavski dolini gradijo mezozojski karbonati narinjeni preko paleogenskega siliciklastičnega fliša. Zaradi narivne zgradbe in tektonske pretrtosti, ki pospešuje mehansko razpadanje karbonatov, se na pobočjih med Trnovskim gozdom in Vipavsko dolino odlagajo večje količine pobočnih gruščev med katerimi izstopajo tudi veliki karbonatni bloki. Na podlagi predhodnih raziskav, osnovnega geološkega kartiranja in analize digitalnega modela višin, ki je bil pridobljen z lidarsko tehnologijo, je bilo identificiranih 10 blokov. Namen raziskovalnega dela je bil določitev litologije blokov, meritve in analize vpada karbonatnih plasti ter določitev mehanizmov transporta posameznega karbonatnega bloka. Rezultati meritev so pokazali, da so razdalje premikov blokov po pobočju znašali od 80 m do 1950 m. Vpadi plastnatih karbonatnih blokov so pri premiku, glede na karbonatne plasti izvornega območja, spremenili smer in naklon. Razlike pri vpadu karbonatnih plasti izvornega območja in karbonatnih blokov so od 4° do 59°.

KLJUČNE BESEDE: masni transport, pobočni sediment, gravitacijski karbonatni blok, lidar, Vipavska dolina, Slovenija

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1 Introduction

The Vipava Valley is a SE-NW oriented valley in SW Slovenia, bordering Italy, and named after the 49 km long river Vipava. The valley is geomorphologically very diverse, with elevations from 60 m to almost 1500 m. a. s. l. Large differences in elevation occur due to overthrusting of Mesozoic carbonates over flysch. Fractured carbonates easily disintegrate and, in addition to the large amount of sediment (scree deposits), form huge detached translational or rotational carbonate slide blocks. Such large carbonate blocks are mostly known in submarine mass movements (Alves 2015; Alves and Lourenço 2010; Jo, Eberli and Grasmueck 2015; Reijmer, Mulder and Borgomano 2015) and less in terrestrial settings (Benac et al. 2005; Davis and Friedmann 2005; Huntley, Duk-Rodnik and Sidwell 2006; Di Maggio, Madonia and Vattano 2014). Movement of large individual blocks is a known phenomenon and has been documented early for the Alps region (Moser 2002). The purpose of our research was to investigate the position and spatial distribution of these gravitational blocks, their outline and lithology, to investigate their mass transport mechanisms.

1.1 Geological and geomorphological setting

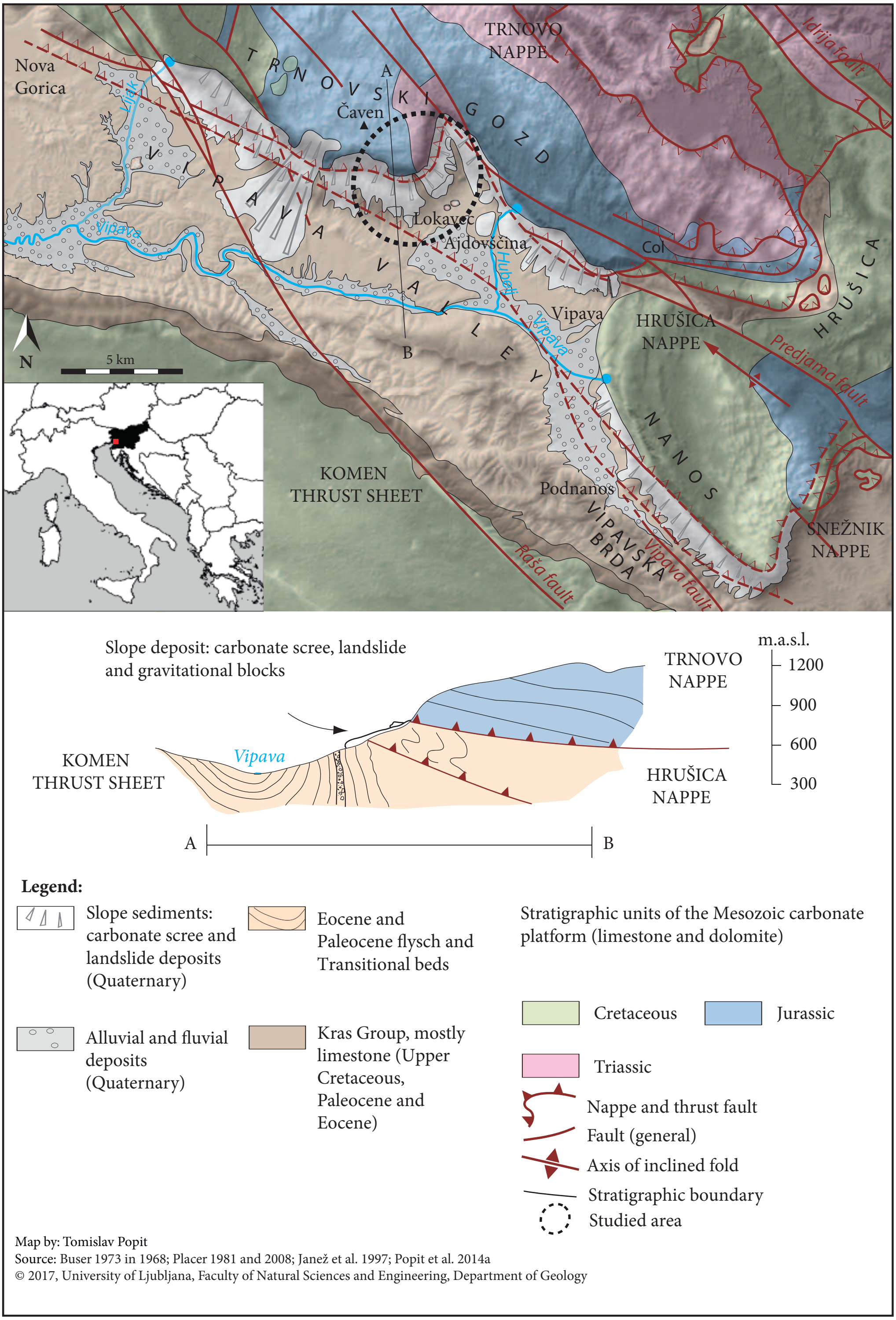
The study area covers approximately 18 km^2 (4.0 × 4.5 km) on the southern slopes of the high Trnovo plateau (*Trnovski gozd*; with elevations of major peaks: Kucelj – 1237 m, Mala gora – 1032 m and Mali Modrasovec – 1306 m), overlooking the Vipava Valley. High relief differences in the northeastern part of the Vipava Valley occur due to overthrusting of the Trnovo Nappe composed mostly of stratified Mesozoic carbonate platform limestone and dolomite, over Paleogene flysch composed of an alternation of sandstone, shale, and marl of the Hrušica Nappe (Figure 1). Both nappes belong structurally to the External Dinarides (Placer 1981; Placer 2008), with carbonates belonging to former Adriatic Carbonate Platform (Vlahović et al. 2005).

The Trnovo plateau is in this region composed of Upper Triassic (Norian-Rhetian) Main Dolomite (appearing on the eastern side of the study area) and Lower and Upper Jurassic limestones (on the western side). Besides the tectonic thrust contact, the major SE-NW oriented Predjama fault passes through the eastern part of the area (Figure 1), also responsible for mechanical disintegration of carbonates (Buser 1968).

Overthrusting and consequent erosion of carbonates has produced very steep slopes in carbonates compared to low-lying flysch with more gentle slopes. As a result, large deposits of limestone and dolomite scree have accumulated on the slopes in the transition zone between steep carbonates and low-relief flysch, and they cover the carbonate-flysch thrust contact. In some places, unconsolidated carbonate scree has consolidated into a slope breccia (Leban 1950; Melik 1960; Habič 1968; Jež 2007; Popit and Košir 2010). Such mechanical weathering of carbonates was probably more pronounced during Pleistocene, but the process is still active now (Melik 1959; Habič 1968; Komac and Ribičič 2006; Zorn and Komac 2008; Komac 2009; Kodelja, Žebre and Stepišnik 2013; Žebre, Stepišnik and Kodelja 2013; Ribičič 2014).

Average yearly precipitation is very high in the broader area of the Vipava Valley, from 1500 mm/year in the valley to more than 3000 mm/year on the higher Trnovo plateau (Janež et al. 1997; Agencija Republike Slovenije … 2016). Extremes can reach over 300 mm/day. Although the movement of the carbonate blocks cannot be regarded as classical landsliding, the movements are usually related not only to the total amount of precipitation, but to the intensity of precipitation during some time period (Komac 2005; Zorn and Komac 2009). Such a large amount of rainfall in combination with earthquakes and the geological and geomorphological setting has also triggered several active and fossil mass movements in the valley. These movements are of different types and have already been recorded (Habič 1968; Buser 1968; Zorn and Komac 2009; Popit and Košir 2010; Popit and Jež 2015; Popit 2016). Among the most studied is the large Slano blato landslide on the northern edge of the Vipava Valley (Kočevar and Ribičič 2002; Logar et al. 2005; Placer, Jež and Atanackov 2008; Fifer Bizjak and Zupančič 2009; Mikoš et al. 2014), and nearby the landslide Stogovce (Petkovšek et al. 2011). Other fossil complex landslides (Popit and Košir 2003; Popit et al. 2014b) and other mass movements (rockfall, creep, rotational landslide, debris flow and avalanche) also occur in the broader area, but are still not well studied (Jež 2007; Ribičič 2014). Several of these landslides have caused major damage in the Nova Gorica statistical region (Zorn and Komac 2011), comprising the Vipava Valley and studied area, and still pose a problem to the infrastructure and residential objects.

Figure 1: Geological map of broader area of the Vipava Valley, location of study area and cross-section through Trnovo plateau and the Vipava Valley (Buser 1968; Janež et al. 1997; Placer 1981; Placer 2008; Popit et al. 2014a). ➤ p. 10


Nova Gorica
TRNOVO NAPPE
TRNOVSKI GOZD
Čaven
A
B
Lokavec
Ajdovščina
Col
Vipava
Hubelj
Vipava
Vipava
Vipava
Idrija fault
HRUŠICA
HRUŠICA NAPPE
Predjama fault
NANOS
VIPAVA VALLEY
N
5 km
KOMEN THRUST SHEET
Podnanos
VIPAVSKA BRDA
Raša fault
Vipava fault
SNEŽNIK NAPPE
Slope deposit: carbonate scree, landslide and gravitational blocks
TRNOVO NAPPE
m.a.s.l.
1200
900
600
300
KOMEN THRUST SHEET
Vipava
HRUŠICA NAPPE
A
B
Legend:
Slope sediments: carbonate scree and landslide deposits (Quaternary)
Eocene and Paleocene flysch and Transitional beds
Stratigraphic units of the Mesozoic carbonate platform (limestone and dolomite)
Cretaceous
Jurassic
Triassic
Alluvial and fluvial deposits (Quaternary)
Kras Group, mostly limestone (Upper Cretaceous, Paleocene and Eocene)
Nappe and thrust fault
Fault (general)
Axis of inclined fold
Stratigraphic boundary
Studied area
Map by: Tomislav Popit
Source: Buser 1973 in 1968; Placer 1981 and 2008; Janež et al. 1997; Popit et al. 2014a
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Among these, huge carbonate gravitational blocks appear on the gentle flysch slopes. They are observed above the village of Lokavec, near the Slano blato landslide, and clearly visible as positive relief structures on a Lidar-derived 1 m digital elevation model (DEM) map (Figure 2). It has already been interpreted by Placer, Jež and Atanackov (2008) that these carbonate blocks have been transported by gravitational movement. They identified 12 carbonate blocks. Five carbonate blocks (Mala gora, Gola gorica, Visoko, Križec and Gradišče) were named by the nearest topographical name in their vicinity, while other blocks were named by consecutive alphabetic letters from A to F (the Slovenian alphabet, including the letter Č between C and D). However, we use different names than proposed (topographical instead of consecutive), as (described in the Results section) their proposed blocks A and C are not carbonate blocks at all, but only local accumulations of carbonate scree. Therefore, these two blocks were excluded from further analysis and results, and other carbonate blocks were named according to topographic names (with the former names of Placer, Jež and Atanackov (2008) in parentheses): Kovači (B), Platna (Č), Lokavšček (D), Skuk (E) and Lozica (F). Placer, Jež and Atanackov (2008) noted that the major carbonate block of Mala gora was detached from the source area, due to its structural setting in a south-trending wedge-shaped carbonate plateau, which combined with a nearby E-W fault caused the Mala gora carbonate block to rotate slightly and settle compared to the Čaven source area. This geological setting was later used mostly for the explanation of groundwater related to the Slano blato landslide; however, no further discussion was provided for the individual blocks (i.e. no measurements of the block movement or mapping of the individual blocks were performed).

2 Methods

Our methods can be briefly divided into field mapping and in relief analysis as follows. Field mapping formed the basis for the identification of the carbonate gravitational blocks. It was performed at a scale of 1:10,000, on topographic maps (layers with settlements and infrastructure) of Slovenia, produced by The Surveying and Mapping Authority of the Republic of Slovenia (Internet 1). In addition, a shaded digital elevation model (DEM) was used in combination with these maps. The DEM (Figure 2) was produced from Airborne Lidar Scanning (ALS) data, widely used for the analysis of landslide movements (Baldo et al. 2009; Geist et al. 2009; Jaboyedoff et al. 2012; Popit and Verbovšek 2013; Popit et al. 2014b) and used as a topographic base map for the field mapping. It turned out to be very helpful in the determination of carbonate block locations, as the bare-earth DEM at a 1 × 1 m grid resolution was used to eliminate the vegetation cover. Also, a Lidar-derived DEM map was useful for delineation of some problematic parts of the carbonate blocks on several inaccessible points, as the slopes of some carbonate blocks were too steep and dangerous to measure directly.

The main objective of field mapping was to outline the carbonate blocks, to determine their lithological composition, and to measure the dip direction and dip angle of the carbonate strata. The results were then compared to a source area in the hinterland, which we assume to be the reference carbonate mass with no movement. The type of movement was therefore determined on the DEM layer by a horizontal distance of the carbonate block from this stable source area (Figure 1) and by the difference between the dip direction and dip angle of the strata of the carbonate block and source area. In this way, both changes in dip direction and dip angle could be defined. Change in dip direction (azimuth) was defined with rotation of a carbonate block around its vertical axis. A positive value was assigned to clockwise rotation (greater value of azimuth) and negative value to anticlockwise rotation (lower value of azimuth). Similarly, change in dip angle was defined with rotation of a carbonate block around its horizontal axis, with a positive value for a downward rotation from the horizontal plane with increase in dip angle and vice versa. With measured dip direction and dip angle, we were able to calculated the differences between the angles of carbonates of the source area and of individual blocks. In such way, we were able to determine the individual block movement.

The lithological composition of individual carbonate blocks was also compared to the source area, to check for changes in measured angles. The accurance of Triassic dolomite and Jurassic limestone in the source area and of individual block was mapped. Research points were taken on carbonate blocks and the source area. Points were assigned a unique ID, block name/source area, WGS84 point coordinates (latitude, longitude) and lithological and directional measurements. To determine the position, a handheld GPS receiver with horizontal precision of about ±5 meters was used.

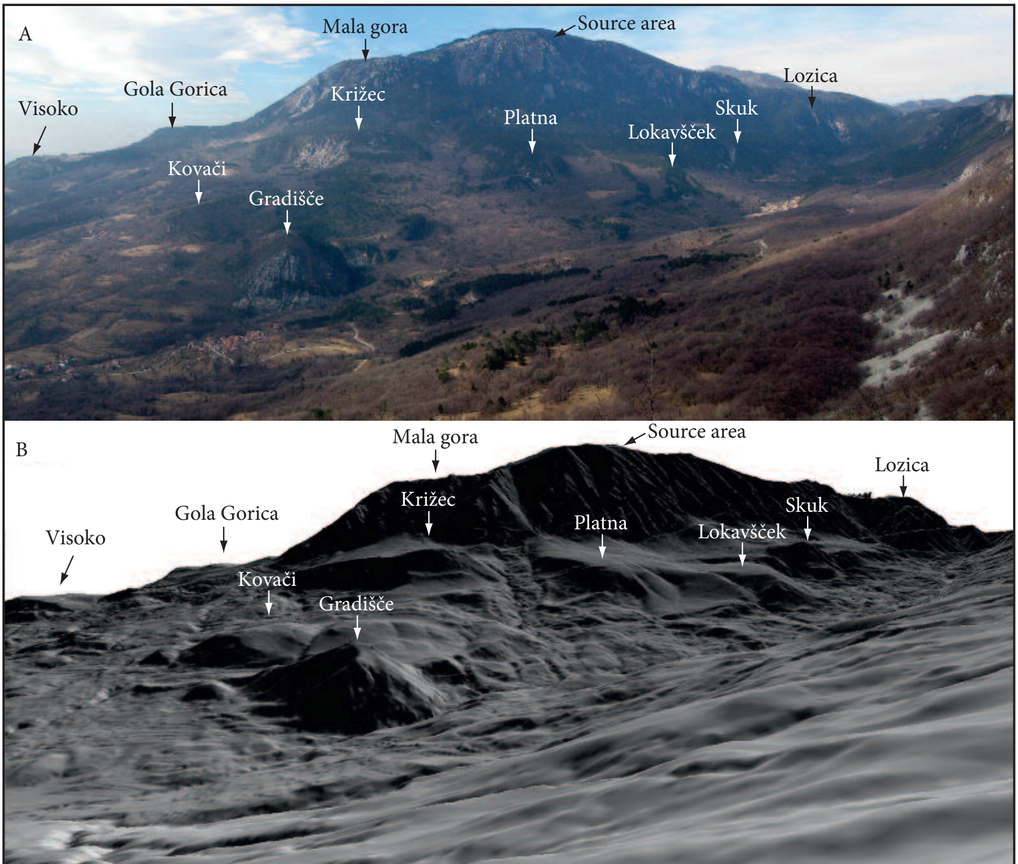

Figure A by: Tomislav Popit
Figure B by: Maja Kocjančič, Timotej Vrbovšek

Figure 2: A: Photograph of carbonate gravitational blocks from Navrše hill (view towards W). B: DEM of studied area (same viewpoint).

These field data were transferred to *ESRI ArcGIS v. 10.0* (ESRI 2012). The GIS environment served to produce a map, to measure the transport distance from the source area, to produce the longitudinal profiles for each carbonate block and to visualize the blocks in 3D on the Lidar DEM surface. The distance of transport was defined from the upper margin of each carbonate block to the supposed scarp of the carbonate source area.

Finally, the mean value of dip direction and dip angle for individual carbonate blocks and the source area were obtained in the stereographic program *Stereo32* (Röller and Trepmann 2013) by directional (circular) statistics. Consequently, differences of mean dip direction and mean dip angle between a gravitational carbonate block and the source area could be obtained in stereological program *Stereonet 9* (Allmendinger 2014). Values have been rounded to 5° for dip directions and dip angles, distances to 10 m, and areas to 100 m^2.

3 Results

The calculated dip angles of carbonate strata are presented for the source area, followed by results for each carbonate block. The blocks are clearly visible in the field from the valley and on the DEM (Figure 2), as they stand out as positive topographic anomalies of carbonate mass on the flysch slope. At the source area, 15 measurements were performed along the carbonate escarpment in the stable, undisturbed area (Table 1). The eastern part of the source area belongs to Upper Triassic dolomite (measurement points T02–T08), and western part to Jurassic limestones (points T01, T09–T15).

Table 1: Results for source area. Average dip direction and dip angle are 225/25.

Point	Latitude (°, WGS84)	Longitude (°, WGS84)	Dip direction (°)	Dip angle (°)	Lithology
T01	45.92703	13.85022	235	25	limestone
T02	45.92858	13.85583	220	20	dolomite
T03	45.93103	13.85858	220	20	dolomite
T04	45.92994	13.85878	220	20	dolomite
T05	45.93767	13.86292	220	20	dolomite
T06	45.93828	13.86064	230	30	dolomite
T07	45.94111	13.86250	230	25	dolomite
T08	45.94225	13.86683	230	25	dolomite
T09	45.92853	13.85178	220	30	limestone
T10	45.92467	13.83242	220	15	limestone
T11	45.92828	13.83236	240	35	limestone
T12	45.92839	13.82897	230	35	limestone
T13	45.92881	13.82689	230	30	limestone
T14	45.92878	13.82608	230	20	limestone
T15	45.92869	13.82503	220	20	limestone

Carbonate blocks are briefly described below, as Table 2 summarizes most of the results that are discussed in the next section. The largest carbonate block of Mala gora (Figure 3), lying between 650–1040 m a. s. l., has been transported about 100 m southwards from the source area. It covers an area of about 174.7 ha (Table 2). The eastern part of the block is composed of Triassic dolomite and the western part of Jurassic limestone, similar to the composition of the source area. In the most western part of the block, strata are not visible, and block is mostly disintegrated into carbonate gravel. The average dip direction and dip angle are 215/25, giving the angular difference from the source area of only 4º.

The carbonate block Gola gorica is composed of Jurassic limestone and has been displaced much more than the Mala gora block from the source area, about 850 m. Due to inaccessible steep parts of the block, six measurements were performed, but their variation is minimal. Apart from limestone, some breccia appears on the western side of the carbonate block Visoko. Carbonate strata are visible only in the south-eastern side, where the measurements were made. Weathered flysch was observed at the base of the block. Carbonate blocks Križec, Kovači, Platna, Lokavšček and Skuk are composed of dolomite and some carbonate breccia; weathered flysch also appears at the base of these blocks. On the carbonate block Gradišče, measurements were performed only on the accessible southwestern part. This block is composed only of dolomite. Dolomite layers and the contact of dolomitic block Lozica with the underlying flysch are well exposed in two road cuts; otherwise the block is mostly difficult to access.

The smallest difference between the strata dip was obtained for the carbonate block Mala gora (4°), which lies very close to the source area and has been among those with the smallest displacement. In contrast, the largest change between source area dip angle and block dip angle was observed for carbonate block Visoko, about 59°. This block has also one of the largest displacements, so it rotated greatly during the transport (Figure 4). This can be straightforwardly explained by the fact that blocks can change their rotation from clockwise to counter-clockwise during the transport and vice versa.

4 Discussion

Our observations confirm that block lithology corresponds to the lithology of the source area. Blocks lying below the eastern dolomitic part (blocks Mala gora, Križec, Gradišče, Kovači, Platna, Lokavšček, Skuk and Lozica) are also composed of dolomite, and those on the southern limestone side (blocks Mala gora, Gola gorica in Visoko) are composed of limestone. Some breccia was also mapped on blocks Visoko, Križec, Kovači, Platna, Lokavšček and Skuk (see Figure 3). This indicates a former scree that was consolidated behind the blocks (Figure 5), and was in some cases moved with the blocks to be present now in different positions. Flysch and carbonate scree appear in all areas around the blocks. The length of the transport was quite different: the minimum travel distance was about 80 m for carbonate block Lozica, with high elevations and close to source area, and maximum about 2050 m for carbonate block Gradišče, with the lowest elevation near the levelled bottom of the valley. Such a runout distance is quite long, but not unusual,

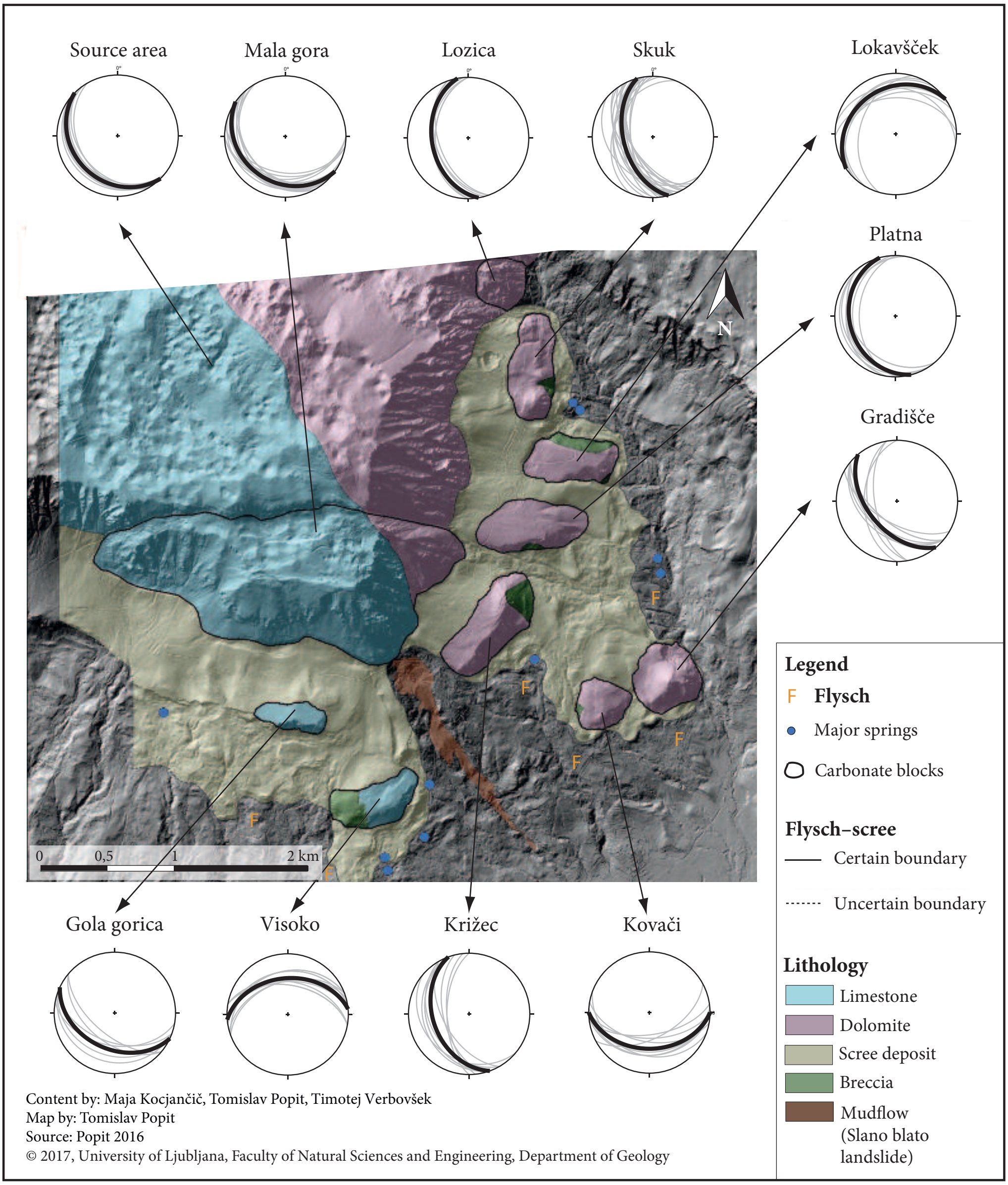

Figure 3: Lithology of the wider source area and studied carbonate blocks, locations of dip directions and dip angle measurements, springs on DEM Lidar surface stereographic plots of strata in individual carbonate blocks and in source area. Area without symbology (colours) belongs to flysch.

Table 2: Results of measurements for individual carbonate blocks and source area.

Block	Elevation [m a. s. l.]	Lithology	Area [ha]	Horizontal travel distance [m]	Number of measurements [–]	Average dip direction and dip angle [°/°]	Change of dip direction [°]	Change of dip angle [°]	Difference between source area dip and block dip [°]
Source area	/	dolomite & limestone	/	/	15	225/25	/	/	/
Mala gora	650–1040	dolomite & limestone	174.7	100	23	215/25	−10	0	4
Gola gorica	580–650	limestone	7.5	950	6	205/40	−20	+15	18
Visoko	440–510	limestone	15.2	1460	10	355/40	+130	+15	59
Križec	540–660	dolomite	23.5	850	10	250/40	+25	+15	20
Gradišče	260–380	dolomite	16.8	2050	10	230/50	+5	+25	25
Kovači	330–400	dolomite	9.9	1720	10	180/40	−45	+15	28
Platna	480–660	dolomite	20.9	750	10	255/25	+30	0	13
Lokavšček	470–620	dolomite	16.7	1000	10	325/25	+100	0	38
Skuk	580–700	dolomite	18.7	800	27	255/50	+30	+25	30
Lozica	700–930	dolomite	10.0	80	10	260/40	+35	+15	24

as the transport distances have been observed from some km to more than 15 km elsewhere in similar geomorphological and geological settings

(Davis and Friedmann 2005). In the nearby geologically similar area in Croatia (Dugonjić Jovančević and Arbanas 2012), several mass movements occur on the contact between steeper Paleogene and Cretaceous carbonates and flysch (Đomlija et al. 2014; Jovančević, Vivoda and Arbanas 2015), but such carbonate blocks have not been documented.

We assume that the transport mechanism is a combination of translational and rotational block-type slope movements, driven only by gravity, so the transport direction is downslope (mostly towards the south or southeast) with rotation of blocks around the horizontal and vertical axes. Some possible deviations from this direction could appear due to irregularities of the flysch slopes, which served as sliding surfaces

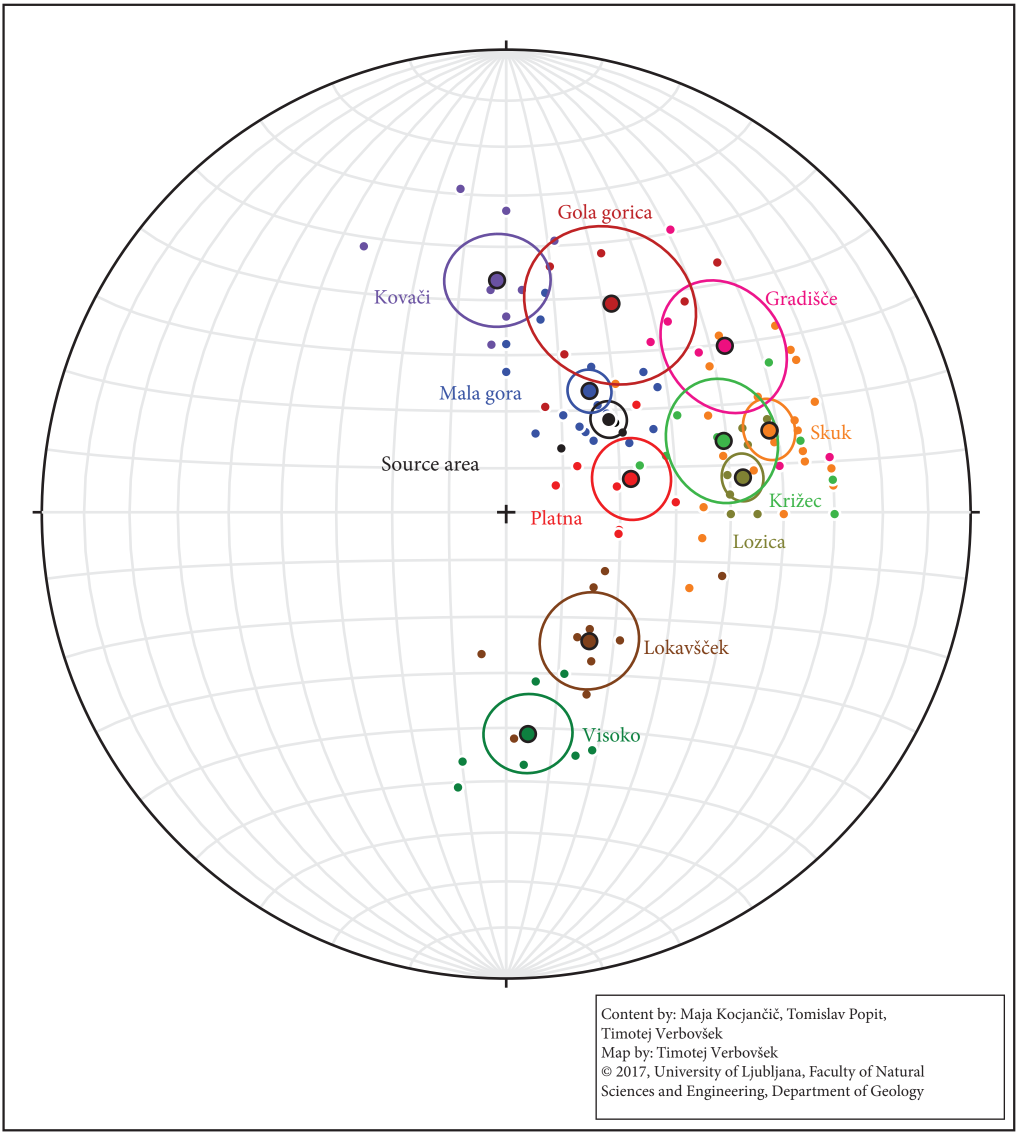

Figure 4: Plots of all strata poles on stereographic projection plot (small dots), with Fisher mean vectors (larger dots) and one circular standard deviation (ellipses).

for the blocks. The slope of the flysch terrain, measured below the blocks Visoko, Gola gorica and Mala gora, is on average 10° (9.5–12.6°). The movement of blocks can be related to tectonic and structural parameters in bedrock formation and some major triggering events (e.g. earthquakes). The wider region is seismically still active, as earthquakes with magnitudes above 5.5 have been recorded in 10s km radius around the studied area (obtained from the earthquake catalogue of Slovenian Environment Agency (Internet 2 and 3) and comprising earthquakes younger than 1348). Such large events are known to be a major cause for major landsliding (Benac et al. 2005; Shroder et al. 2011; Esper Angillieri and Perucca 2013). The study area lies in an active seismic zone (Poljak, Živičič and Zupančič 2000; Placer, Vrabec and Celarc 2010), very close to the Predjama fault, between the Raša and Idrija faults (Vrabec and Fodor 2006). These are active faults, as it was recently found that the Raša fault has slip-rates of about 1.3–2.8 mm/year and the Predjama fault has a mean slip-rate of about 1.4±0.1 mm/year (Moulin 2014). The Idrija fault has been active since Miocene (reactivated from oblique-normal to dextral strike slip from Miocene to Pliocene time) (Bavec et al. 2012; Moulin et al. 2014), with a major earthquake in 1511 (magnitude 6.8; (Bavec et al. 2013). Before this event, several earthquakes of similar magnitude most probably occurred (one of the major landslide events in the Vipava Valley probably related to earthquakes (Popit and Košir 2003) was dated to at least 40,000 years BP). Also, tectonic uplift of the Trnovo Nappe area is believed to be still active and is estimated to be about 2.0 mm/year (Rižnar, Koler and Bavec 2007). Maps for the seismic acceleration with a 1000-year return period (Internet 4) show about 0.225 g for the study area, and for the 10,000-year return period about 0.45 g. The latter acceleration is very close to the value of 0.5 g, being the lower limit for the sliding of large blocks (Davis and Friedmann 2005). Therefore, in such a time span, it is possible that the block movements were triggered due to ground shaking and consequent movement(s) due to seismic activity. The minimal earthquake magnitude to cause the movement is estimated as $M_L \approx 4.0$ (Keefer 1984) and magnitudes of this order and larger have been documented historically in broader area (Poljak, Živičič and Zupančič 2000). Another important factor is the river incision of the flysch bedrock (Huntley, Duk-Rodnik and Sidwell 2006), which could have easily been eroded by the Vipava River). Even apart from the river incision, erosion in flysch of the SW Slovenia is high and exceeds the European average for the Mediterranean part of Europe (Zorn 2009). On a micro level, erosion depends also on the steepness of the flysch slopes, with steeper relief allowing better drainage due to water-retaining clay minerals washed into lower parts (Jamšek Rupnik, Čuš and Šmuc 2016). Also, water can accumulate as groundwater in the carbonate blocks, as they are strongly fractured, karstified and permeable (Verbovšek 2008; Verbovšek and Veselič 2008), and some water can also be accumulated in carbonate scree, depositing above the blocks. In both cases, the presence of water can intensify the weathering of flysch below the blocks and deteriorate its mechanical properties. The presence of water accumulation is documented as the existence of several springs below the blocks (Figure 3) on the less permeable flysch. Only major springs are listed in the table: those that do not dry up during the year, with an average outflow of each spring around 3–5 l/s (Janež et al. 1997). Some unknown quantity of groundwater also flows to the more permeable flysch underground and does not emerge in springs, as was documented for the Slano blato landslide (Placer, Jež and Atanackov 2008). The infiltrated surface water and groundwater contributes to the weathering of the flysch, acting as a sliding base layer for the carbonate blocks. During the Pleistocene, especially in climatic conditions prevailing in the last glacial maximum (Monegato et al. 2015), climatic and hydrologic setting was very different from the present, and mechanical weathering, sediment accumulation and also carbonate block movements may have been greatly accelerated compared to recent mass movement processes. However, there is no proof for such influence in the research area. Finally, the weight of accumulated scree can act as an additional force on the blocks.

During some extreme rainfall and earthquake events, transport of gravitational carbonate blocks is possible, so they would require monitoring. By observing the movement of a block, the velocity could be determined. Velocities of blocks are presently unknown, as no measurements have been performed, but can lie over a very large value range (Davis and Friedman 2005). Most importantly, it would be possible to assess whether the movement is more or less slow and constant during the year, or only occasional and related to extreme catastrophic events (tectonically or climatically conditioned). Regardless if the movements are mostly controlled by climatic factors and/or the seismic events, transport of carbonate blocks could continue in the future, as neither of these factors can be neglected in the future. The region is seismically active with earthquakes of magnitudes above 6, and due to probable vertical uplift of the Trnovo Nappe (Rižnar, Koler and Bavec 2007).

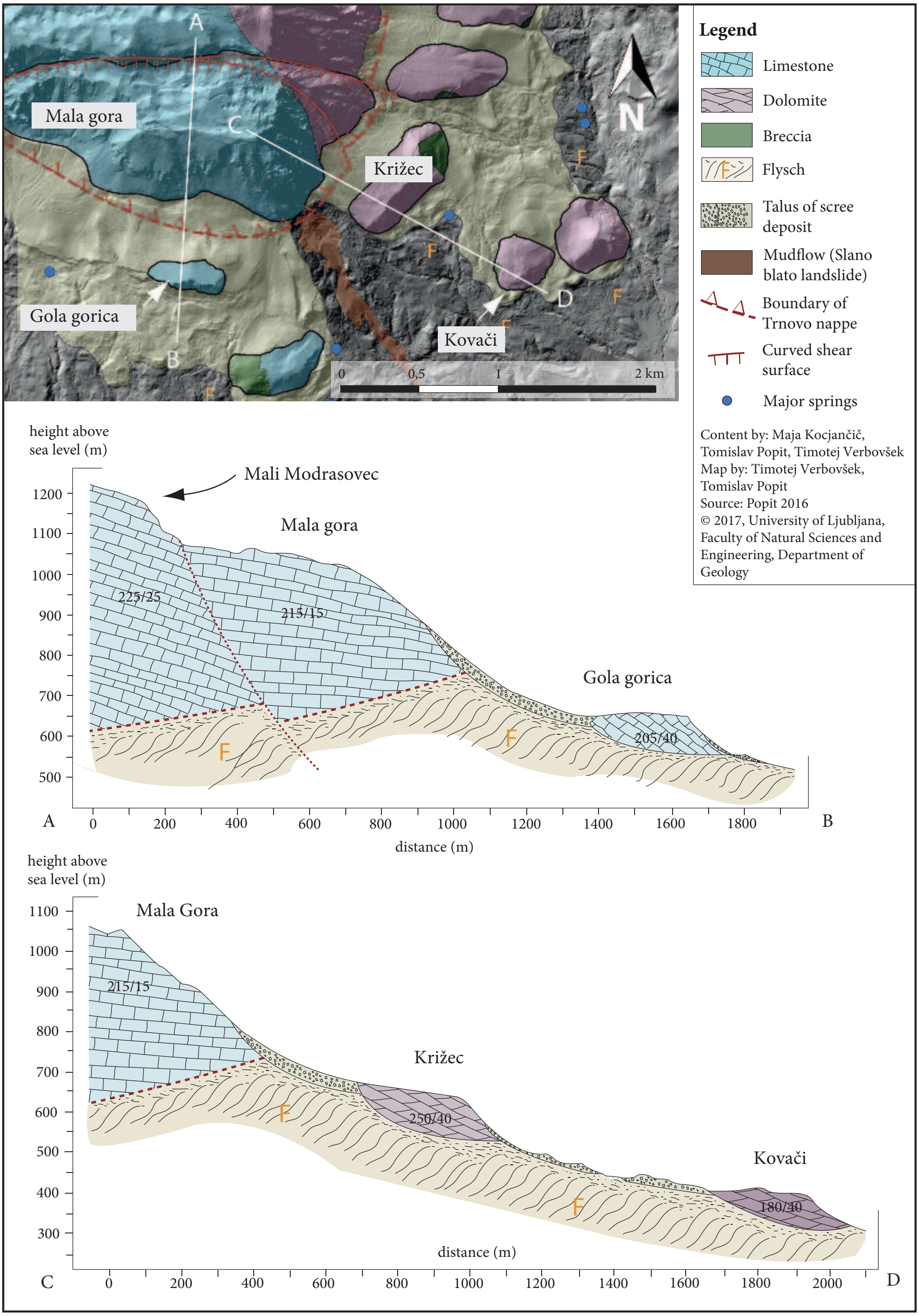

Figure 5: Two selected longitudinal profiles through the source area and Mala gora, Gola gorica, Križec and Kovači carbonate blocks.

5 Conclusion

The main conclusions can be summarized in the following statements:

- In the study area, ten separate carbonate gravitational blocks have been detached from the steep carbonate edge of the Trnovo plateau. Movement was both translational and rotational, proved by correlating lithology between the blocks and the source area and significant change in elevation of the blocks compared to flysch in the longitudinal profiles.
- The distance of the transport ranges from 80 m to about 2 km, and block areas range from 7.5–175 ha. The smallest difference between the strata dip was obtained for carbonate block Mala gora, 4° and the largest change in strata dip was for carbonate block Visoko, about 59°. There is no direct correlation of travel distance with the rotation/tilt angles.
- As seen from the earthquake magnitudes records and seismic acceleration maps the area is seismically still active, with the active nearby Predjama, Raša and Idrija faults, and the blocks can be transported at the major earthquakes events.
- The blocks and carbonate scree, accumulating behind the blocks, act as (ground) water accumulations, and several small springs appear below the blocks and on the contact between the permeable carbonate scree and the less permeable flysch.
- The velocity of the movement is unknown and it should be monitored, as several buildings lie below some of the blocks. Transport of blocks could continue in the future, due to vertical uplift and increasing potential energy of the blocks, and in the scenario of changed climatic conditions, which will change the quantity and intensity of precipitation.

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