Measurements of Various Erosion Processes in a Coastal Submediterranean Catchment (Southwest Slovenia)*

Matija ZORN

Key Words: geomorphology, soil erosion, rockwall retreat, gully erosion, chemical denudation, flysch, Istria, Slovenia

Abstract. Measurements of four different erosional-denudational processes were conducted between February 2005 and May 2006 in the Dragonja River Basin (Istrian Peninsula, southwest Slovenia): interrill soil erosion on three different land uses, rockwall retreat on steep flysch slopes, movements of debris in an erosion gully, and chemical denudation in the river basin.

Interrill soil erosion was measured on eight 1-m² erosion plots: on bare soil in a young olive grove (2 plots), in an overgrown meadow (2 plots) and in the forest (4 plots). The erosion plots in the forest were located on soil with two different slopes. The measurements (taken between May 2005 and April 2006) showed interrill soil erosion of 9,013 g/m^2 (90 t/ha; surface lowering of 8.54 mm) on bare soil in the olive grove with a slope of 5.5°; 168 g/m^2 (1.68 t/ha; surface lowering of 0.16 mm) in the overgrown meadow with a slope of 9.4°; 391 g/m^2 (3.91 t/ha; surface lowering of 0.37 mm) in the forest with a slope of 7.8°; and 415 g/m^2 (4.15 t/ha; surface lowering of 0.39 mm) in the forest with a slope of 21.4°.

The fastest erosion process was rockwall retreat in flysch badlands, with a specific erosion rate of 85 kg/m² per year, or almost 3.5 to 5 cm per year of rockwall retreat. Weekly measurements took place on four semi-open plots (open on the sides) ranging from 1.8 to 4.5 m^2 in size.

Movements of debris through an erosion gully were also measured in the same flysch badlands. A gully with a catchment area of approximately 1,000 m^2 and with an average slope of 46° was dammed. Almost 19 t of flysch material was accumulated behind the dam in twelve months.

A tipping bucket rain gauge was located next to the plots to monitor precipitation and intensity of erosive events.

Measurements of chemical denudation in the Dragonja River Basin were conducted monthly and showed a chemical denudation rate of 0.066 mm per year.

1. Introduction

In the river basins of the fluvial denudation relief (Gabrovec, Hrvatin, 2001), various erosion and denudation processes take place simultaneously; however, do we know at what speed they occur, and what the relationships between them are?

This is why we measured the speed of four erosion and denudation processes in the Dragonja River Basin (southwest Slovenia, the Slovenian part of the Istrian Peninsula; Fig. 1) in 2005 and 2006: interrill soil erosion on three different land uses, rockwall retreat on steep bare flysch slopes, movements of debris in an erosion gully, and chemical denudation in the river basin.

2. Measurements

Erosion and denudation processes are quantified either by means of measurements, or by various models (Stroosnijder, 2005). We decided to carry out measurements in the field. Advantages of research in the field are the possibility to conduct measurements at the proper scale, with realistic soil and plant characteristics and temporal changes in environmental variables (Stroosnijder, 2005), even though, at the same time, there is less control over dependent variables (such as weather conditions) than with measurements carried out in laboratories.

Measurement methods differ in scale, length of measurements, funding, and so on. Stroosnijder

---

*Paper presented at the "IAG Regional Conference on Geomorphology: Landslides, Floods and Global Environmental Change in Mountain Regions", September 15-25, 2008, Braşov, Romania.

(2005) differentiates between five size categories for the study of erosion processes: (1) the point (1 m^2) scale for interrill erosion, (2) the plot (< 100 m^2) for rill erosion, (3) the hillslope (< 500 m) for sediment deposition, (4) the field (< 1 ha) for channels, and (5) the small watershed (< 50 ha) for spatial interaction effects. Stroosnijder (2005) also differentiates between two time criteria: one rainfall event and a yearly average. With regard to the time criteria, Loughran (1989) differentiates the rainfall event criterion and any other suitable time interval.

For measuring interrill soil erosion we, according to Stroosnijder (2005), used a "point" scale. After the same author we used "plot" scale for rockwall retreat, as well as for the movement of debris in erosion gullies. After Poesen, Torri, and Bunte (1994) we used micro erosion plots for measuring interrill soil erosion, mezzo erosion plots for rockwall retreat, and macro erosion plots for debris movement in erosion gullies.

Measurements of soil erosion, rockwall retreat, and debris movement in erosion gullies were taken weekly, and water sampling for determining chemical denudation took place on a monthly basis. Especially for rockwall retreat, it is important that during the measuring period the average annual minimal air temperature in Koper, which is a few kilometers away, was 1.4 °C lower, and the average winter minimal temperature 2.4 °C lower than the long-term average (1961–1990; Klimatografija, 1995; Dnevne, 2006). For water erosion, it is important that during the measuring period the amount of precipitation at the nearby Portorož Airport was 85 mm or 8.2% higher than the long-term average (1991–1995) between May 2005 and April 2006 (Povzetki, 2007; Dnevne, 2007).

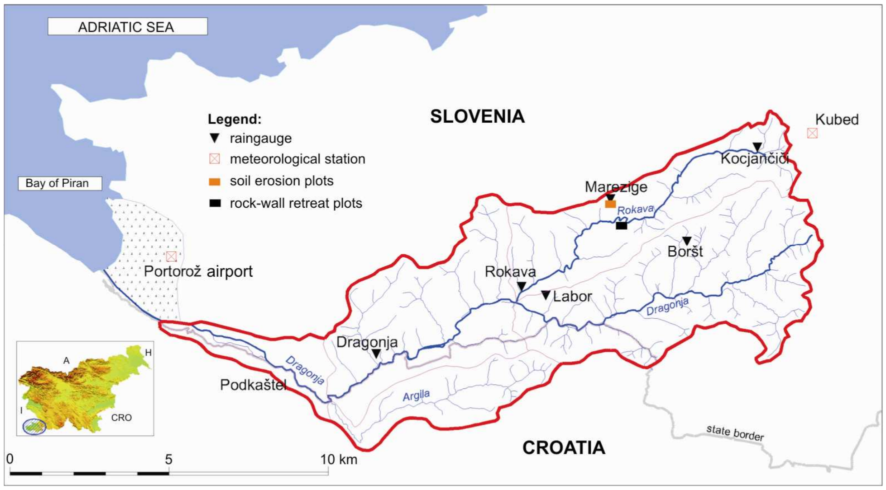

Fig. 1. **The study area in southwest Slovenia**

2.1. Interrill soil erosion

Soil erosion is the removal of soil particles and weathered debris by means of natural agents, in many cases accelerated by human activities (clear-cutting, overgrazing, and paths) and animals, and it is more intense than soil formation (Komac, Zorn, 2005; Zorn, Komac, 2005). It consists of interrill erosion (surface wash) and rill erosion. Our measurements were taken on closed erosion plots 1 m^2 in size that were used to measure interrill erosion (Fig. 2).

Measurements on erosion plots of similar size were, for example, taken in Spain (Dunjó, Pardini, Gispert, 2003; 2004; Usón, Ramos, 2001; Boix-Fayos et al., 2007).

The structure of erosion plots was found in a study by Vacca et al. (2000) and Ollesch and Vacca (2002). For the positioning of erosion plots in the landscape, works by Lal and Elliot (1994), and Dunjó, Pardini, and Gispert (2004) were used. Such small erosion plots are easily doubled and managed, but one must also keep in mind that such erosion plots usually overestimate actual erosion when extrapolated to larger spatial units because they do not take into account the sedimentation within larger spatial units (Collins, Walling, 2004).

The measurements took place in eight erosion plots. We placed two plots on bare soil in an olive grove with an average inclination of 5.5°, two in a meadow with an average inclination of 9.4°, and four in a forest (two on a slope with an average inclination of 7.8°, and two on a slope with an average inclination of 21.4°).

As a rule, measurements were performed weekly. First, the volume of the collected surface runoff was determined, and then samples of water and detached soil mixture from the reservoirs were taken. The samples were dried at 105 °C in the laboratory, where the concentration of undissolved particles was determined. A tipping bucket rain gauge equipped with a data logger was located next to the plots for monitoring precipitation and the intensity of erosive events (Zorn, 2008; Zorn, Petan, 2008).

Although our measurements are not long-term, it could still be seen that "larger" erosive events contribute a great portion to the total yearly soil loss. The biggest erosive rainfall event in the reference period occurred in the week from 5 August to 12 August 2005 (weekly erosivity was 1235.91 MJ·mm·ha^{-1}·h^{-1}; on 11 August the maximum 30-minute precipitation was 42.8 mm, and daily erosivity was 1110.5 MJ·mm·ha^{-1}·h^{-1}; the erosivity of precipitation was well above the August monthly average (507.8 MJ·mm·ha^{-1}·h^{-1}; Petkovšek, Mikoš, 2004) for the Dragonja River basin). During this week 30% of the total yearly soil loss was recorded on bare soil in an olive grove. In a meadow, 24% of the yearly soil loss was recorded. Because of the rainfall intercepted by treetops, the amount of soil loss in the forest was lower. In the forest with a lower inclination, 15% of the yearly soil loss was recorded during this week, and in the forest with a greater inclination the amount of soil loss did not stand out from other extremes. These data indicate that the vegetation period has considerable importance for soil erosion (Zorn, 2008; Zorn, Petan, 2008).

On a yearly basis, 9 kg of soil/m^2 is lost on bare soil, up to 170 g/m^2 in meadows, up to 390 g/m^2 in forests with a lower inclination, and 415 g/m^2 in forests with a greater inclination. In the measurement period, the surface level on bare soil was reduced by almost one centimeter; in the forest this did not even amount to half a millimeter, and in the meadow it was negligible, amounting to one-fifth of a millimeter (Table 1). Table 5 includes measured values extrapolated to longer time periods, under the presumption that the conditions remained the same as during the measurement period. Under such a presumption, one may expect surface lowering by up to 9 cm in ten years, and up to a little less than one meter in one hundred years. Considering such data, the question arises whether the difference in the speed of soil erosion (or surface lowering) on various land uses is evident in the morphology of a landscape after a few centuries. The fact is that relief changes on farmland occur (see Komac, Zorn, 2005; Zorn, Komac, 2005). In some places in Slovenia, land has been farmed in the same place for over 1,000 years. For example, Mason (1995) mentions that near Adlešiči (southeast Slovenia) a "four-meter wide deposit" was transported from the upper to the lower terrace during the historical period.

In addition to the presented data, one must not forget that, according to Govers and Poesen (1988), interrill erosion contributes to only approximately 20% of all soil erosion.

Table 1. **Interrill soil erosion and surface lowering under different land uses from 28 April 2005 to 26 April 2006** (Zorn, 2008)

	Bare soil			**Meadow**			**Forest: lower inclination**			**Forest: greater inclination**		
	Soil erosion		Surface lowering	Soil erosion		Surface lowering	Soil erosion		Surface lowering	Soil erosion		Surface lowering
	g/m^2	kg/ha	mm	g/m^2	kg/ha	mm	g/m^2	kg/ha	mm	g/m^2	kg/ha	mm
Avg. per week	173.34	1,733.35	0.16	3.23	32.34	0.003	7.52	75.22	0.01	7.98	79.78	0.01
Total (per year)	9,013.43	90,134.31	8.54	168.15	1,681.51	0.16	391.15	3,911.49	0.37	414.87	4,148.68	0.39

2.2. Sediment production in flysch rocks

Steep bare slopes (badlands; Fig. 4) are a morphogenetic peculiarity of the flysch part of the Istrian Peninsula. These include linear formations, such as erosion gullies or torrent river beds (section 2.3), and surface formations that may appear as steep rock faces or ribbed relief on gentler slopes (Jurak, Fabić, 2000).

We used semi-open erosion plots in our measurements. They were semi-open because they were limited by the edge of the slope at the top of the plot (so they were closed on the upper side), and they were open on the sides (Fig. 5). We set up four erosion plots. The sizes of the contributing areas were from 1.8 to 4.5 m^2.

Fig. 2. **Erosion plot on bare land in an olive grove with collected weekly runoff and eroded material** (7 April 2005–14 April 2005; photo: Matija Zorn)

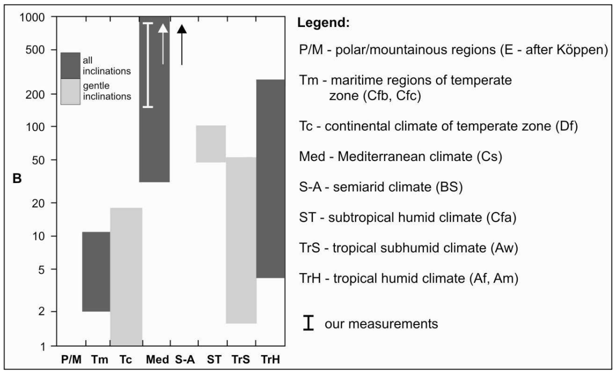

Fig. 3. **Placement of measurements in a Mediterranean climate, and comparison with other measurements in other types of climate** (1 B (Bubnoff) = 1 mm/1,000 years = 1 m^3/km^2·per year). **Erosion data for various climate types was gathered by Saunders and Young** (1983; Young & Saunders 1986)

Fig. 4. **The badlands where the measurements were taken** (photo: Matija Zorn)

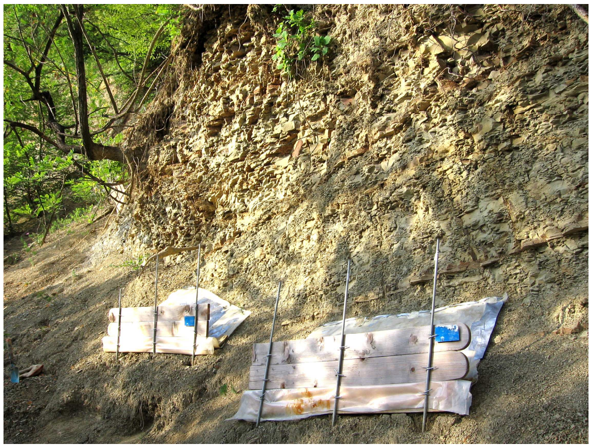

Fig. 5. **Semi-open erosion plots for flysch rockwall retreat measurements** (photo: Matija Zorn)

Sediment production amounted to approximately 85 kg/m^2 per year between 28 April 2005 and 26 April 2006 (Table 2, Fig. 6), which means that the slope is retreating from approximately 35 mm per year (taking into account the bulk density of flysch rocks: 2,300 kg/m^3 according to Miščević, Števanić, Štambuk-Cvitanović, 2008) to almost 50 mm per year (taking into account the bulk density of flysch rocks: 1,680–1,700 kg/m^3 according to Petkovšek, Klopčič, Majes, 2008). The extrapolation of these measurements to longer time periods indicates that slopes may retreat by approximately 0.35 to 0.50 m in ten years, or 35 to 50 m in one hundred years (Table 5; Zorn, Mikoš, 2008).

Considering these data as well as soil erosion, the issue of the role of badlands in recent morphodynamics raises. If we assume that badlands in Mediterranean landscapes were formed during the historical period (Poesen, Hooke, 1997), then the Dragonja River Valley has expanded by a few dozen meters in the badlands in the period of a few hundred years. Major transformations (mostly deforestation) in the Dragonja River Basin have been recorded since the middle of the fifteenth century. If we are to believe De Ploey (1992) that badlands in southern Europe are between 2,700 and 40,000 years old (Poesen, Hooke, 1997), then they appeared during even more extreme climate conditions and their role in the formation of valleys in Mediterranean landscapes is underrated in comparison to the combination of stream erosion and neotectonic activity.

Table 2. **Sediment production and rockwall retreat on steep flysch slopes from 28 April 2005 to 26 April 2006** (Zorn 2008)

	Sediment production		**Rockwall retreat**
	kg/m^2	kg/ha	mm
Average per week	1.62	16,203.47	0.70–0.95
Total (per year)	84.26	842,580.20	36.63–49.22

The speed of rockwall retreat clearly indicates the great erodibility of flysch rocks, which is also evident in Figure 6.

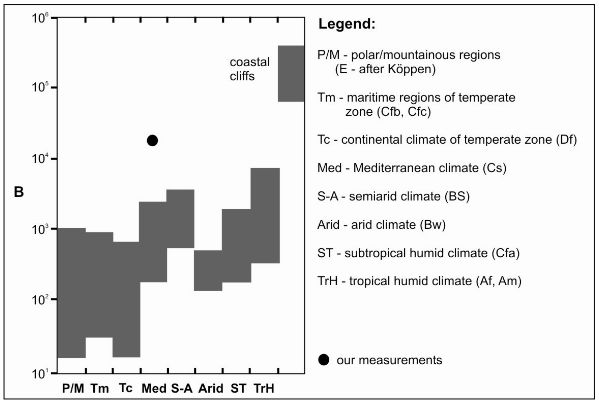

Fig. 6. **The placement of measurements in a Mediterranean climate and comparison with measurements in other climate types** (1 B (Bubnoff) = 1 mm/1,000 years = 1 m³/km^2 per year). **Erosion data for various climate types were gathered by Saunders and Young** (1983; Young, Saunders, 1986)

During the measurement period, we noticed three peaks in sediment production (Fig. 7). The primary peak is connected with the alternation of temperatures above and below freezing during the daytime in the colder part of the year. The secondary and tertiary peaks are connected with heavier precipitation in the spring and summer. The same conclusions were reached in the Pyrenees (Spain) (Regüés, Pardini, Gallart, 1995; Regüés, Guárdia, Gallart, 2000); namely, that heavy weathering is characteristic for the part of the year with below-freezing temperatures, and that, for the warmer part of the year rain (water) erosion is more characteristic. They claim that the amount of sediment produced depends on the speed of weathering (Regüés, Pardini, Gallart 1995). Regüés, Guárdia, and Gallart (2000) discovered that sediment production caused by intensive weathering in the winter is "about two orders of magnitude greater" than sediments produced due to rainwater erosion (Fig. 8).

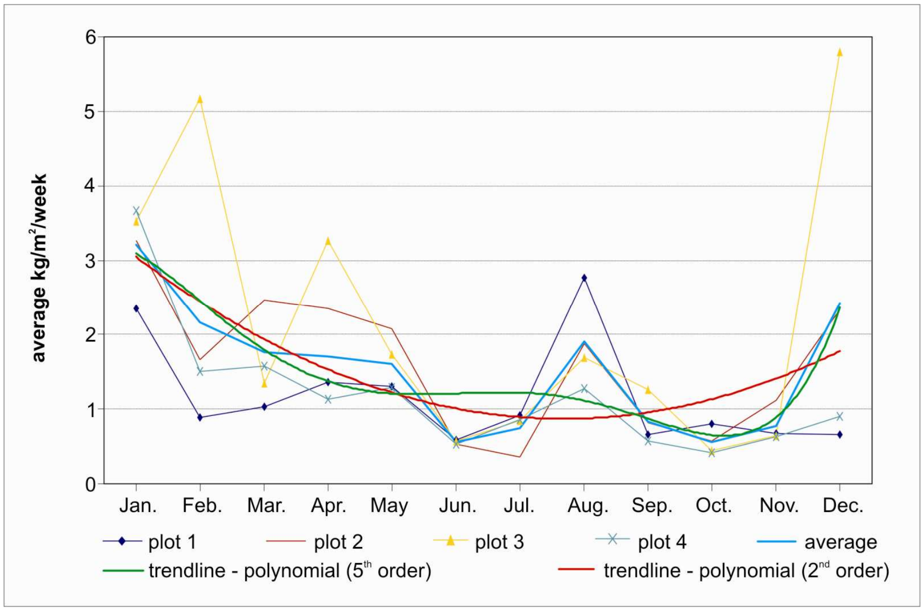

Fig. 7. **Sediment production in flysch rocks by month**

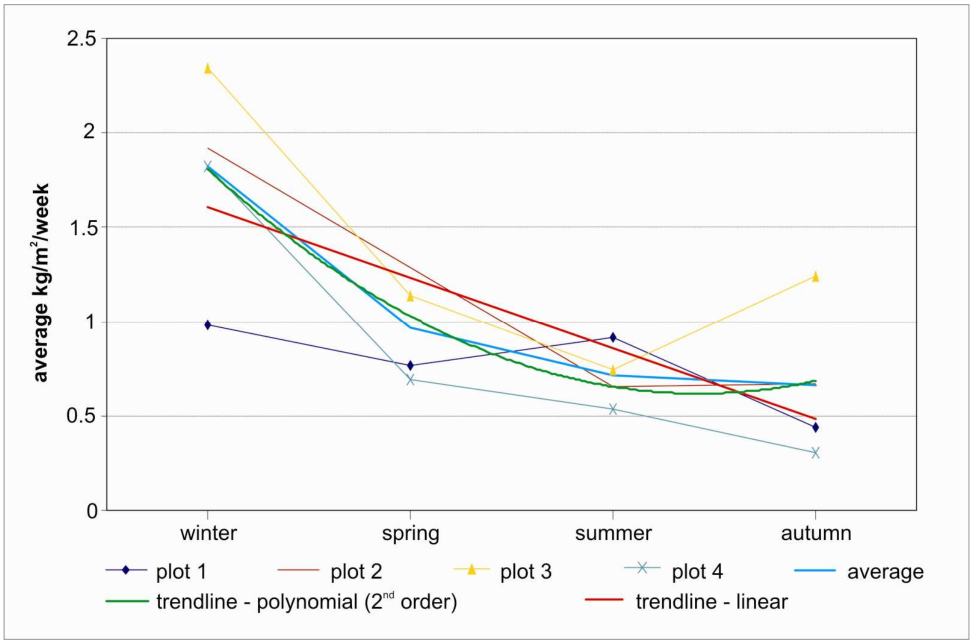

Fig. 8. **Sediment production in flysch rocks by season**

The data by season clearly show the trend (Fig. 8) of the decrease in sediment production from winter to fall. Sediment production is most intense in winter, followed by a nearly 50% decrease in spring, and then an almost even amount of sediment production in summer and fall. This indicates a close connection between sediment production and the cold part of the year. The lower degree of sediment production in summer and fall is mostly connected to the lower intensity of weathering, which causes less material to become unstable. Because there is less unstable material available, even heavy precipitation does not cause as much material to be released as frost weathering in winter.

2.3. Movement of debris in erosion gullies

Steep bare slopes include not only flysch rockwalls (with a 70–90° inclination; section 2.2) but also slopes affected by erosion rills and gullies. Erosion gullies are less steep than rockwalls (40–60° inclination) (Radinja, 1973).

Erosion gullies are formed by channelization of surface streams, mostly in places where there are already some natural outflow lines, as well as along various anthropogenic formations (such as excavations, furrows, plot boundaries, paths, and roads). In contrast to interrill and rill erosion, in which the material is for the most part deposited on the slope itself or at its bottom, gully erosion offers more chances for eroded material to reach streams in the valley bottom.

Fig. 9. **Dam in the erosion gully** (photo: Matija Zorn)

According to Poesen and Hooke (1997), there is neither a standardized methodology nor a universal model for measuring gully erosion. Problems already appear in determining the size of erosion gullies because they are “partly subjective,” say Wainwright and Thornes (2004), and most frequently their lower boundary is considered the surface of the gully’s cross-section > 900 cm² (30 × 30 cm).

We used a closed erosion plot to measure the movement of debris in the erosion gully because we used a dam to close off the entire catchment, which covered an area of 0.1 ha.

Between 28 April 2005 and 26 April 2006, almost 19 t of flysch debris accumulated behind the dam, which makes the sediment delivery almost 15 kg/m^2 per year (Table 3). This means that slopes in the gully retreated by approximately 6.3 to 8.5 mm in one year. Extrapolation to one hundred years indicates a slope retreat in the gully by just less than one meter (Table 5).

Table 3. **Movements of flysch debris in the erosion gully between 28 April 2005 and 26 April 2006** (Zorn, 2008)

	Sediment delivery		**Slope retreat**
	kg/m²	kg/ha	mm
Weekly average	0.28	2738.86	0.12–0.16
Total (in a year)	14.46	145,159.70	6.31–8.48

The effect of extreme events on erosion processes turned out to be the greatest in the movement of debris through erosion gullies. In the week between 19 January 2006 and 26 January 2006, as much as 52% of the year’s amount of debris was deposited behind the dam, and an additional 30% was deposited within seven weeks, with more than 3% of the yearly amount of debris caught. In the remaining 44 weeks, only 18% of debris was caught behind the dam. The peaks are a result of dry rock flows that are triggered in the gully if there is enough debris in the gully, and if there are strong winds that completely dry out the debris to a certain depth. Saturated flysch debris with many clay particles is not as mobile, and moves only in times of heavier precipitation.

The largest amount of debris was moved through the gully in the first three months of the year, and the secondary peak was in August (Fig. 10). August was the month with the highest erosivity of precipitation; however, it lags behind the first three months of the year regarding the amount of the aforementioned rock flows in the week prior to 26 January 2006. These flows also appeared in February and March, but there was not as much debris in the gully.

The effect of the amount of debris on the movement in the gully is shown by a comparison between the week prior to 23 March 2006 and the week prior to 12 August 2005. In the week of March, the erosivity of precipitation amounted to 100 MJ·mm·ha^{-1}·year^{-1}, and 3.34% of a yearly value of debris was moved. In the week of August, the erosivity of precipitation was no less than 1,235.91 MJ·mm·ha^{-1}·year^{-1}, and twice as much debris was moved. In the first case, there was much debris in the gully because many alternation between above-freezing and below-freezing temperatures caused significant sediment production on its slopes. Towards the summer, sediment production on the slopes decreased, and there was less debris in the gully from week to week. The lack of debris in the gully was even more evident in the fall months, when the least amount of debris was moved despite fall precipitation (especially in November; Fig. 11).

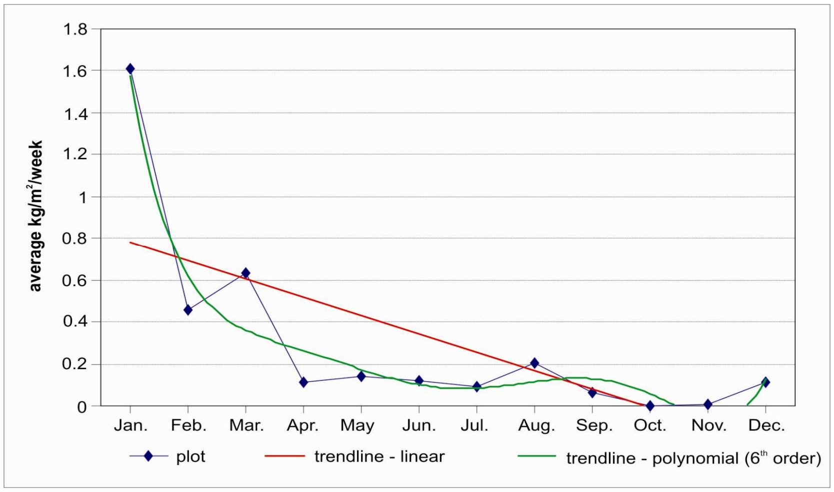

Fig. 10. **Monthly movements of flysch rocks in the erosion gully**

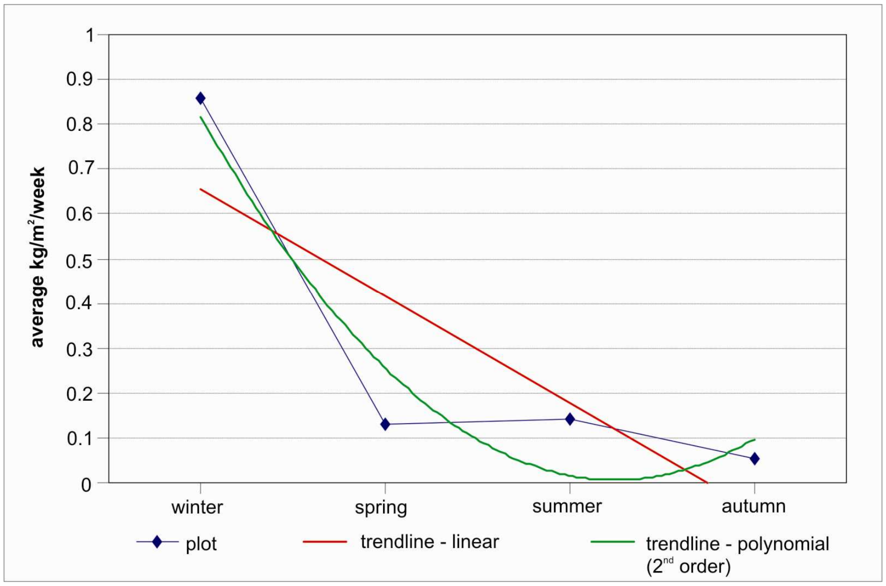

Fig. 11. **Seasonal movements of flysch rocks in the erosion gully**

Table 4. **The speed of various erosion and denudation processes and the ratio between them from 28 April 2005 to 26 April 2006** (Zorn, 2008)

	Rockwall retreat of bare steep flysch slope	**Movement of debris in erosion gully**	**Soil erosion on bare soil**	**Soil erosion in meadow**	**Soil erosion in forest** (lower inclination)	**Soil erosion in forest** (greater inclination)	**Chemical denudation**
Specific sediment production (g/m^2 per year)	84,258.02	14,455.27	9,013.43	168.15	391.15	414.8	113.32
Ratio to **bare steep flysch slope**	1.00	0.17	0.11	0.002	0.005	0.005	0.001
Ratio to **erosion gully** on bare steep flysch slope	5.83	1.00	0.62	0.01	0.03	0.03	0.008
Ratio to **soil erosion on bare soil**	9.35	1.60	1.00	0.02	0.04	0.046	0.013
Ratio to **soil erosion in meadow**	501.09	85.97	53.60	1.00	2.33	2.47	0.67
Ratio to **soil erosion in forest** (lower inclination)	215.41	36.96	23.04	0.43	1.00	1.06	0.29
Ratio to **soil erosion in forest** (greater inclination)	203.10	34.84	21.73	0.41	0.94	1.00	0.27
Ratio to **chemical denudation**	743.53	127.56	79.54	1.48	3.45	3.66	1.00

2.4. Chemical denudation

Most frequently, chemical denudation is measured in karst relief but can also be measured in other places if the rocks contain a high level of carbonates. The flysch rocks of Istria contain up to 75% carbonates (Magdalenić, 1972).

In determining chemical denudation in the Dragonja River Basin, we measured water hardness at the water gauging station below Kaštel once a month, a few kilometers from the river's outfall into the Adriatic Sea. We measured the amount of dissolved matter, especially calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions.

Some earlier authors (Gams, 1974; 2003) observed that the water hardness in rivers on flysch rocks in the Slovenian part of Istria is relatively high compared to the water hardness in karst areas. This is also true of flysch rocks in the Slovenian Julian Alps (northwest Slovenia) (Komac, 2001).

Our results indicate that chemical denudation in the Dragonja River Basin causes surface lowering at a rate of 66 mm per 1,000 years. This is slightly more than what Gams (1974; 2003) stated when he estimated 62 mm per 1,000 years.

2.5. Comparison of Measurements

Various erosion and denudation processes occur in basins simultaneously but their speed varies significantly. The measurements described enable us to compare the speeds of some of them.

The fastest are the processes on steep bare flysch slopes, followed by the movement of debris in erosion gullies, which is almost six times slower. Interrill erosion on bare flysch soil is almost nine times slower. Soil erosion in the forest is over 200 times slower and in the meadow over 500 times slower than sediment production in flysch rocks on steep slopes. The slowest is chemical denudation, which is 744 times slower than sediment production on steep flysch slopes (Table 4, Fig. 12).

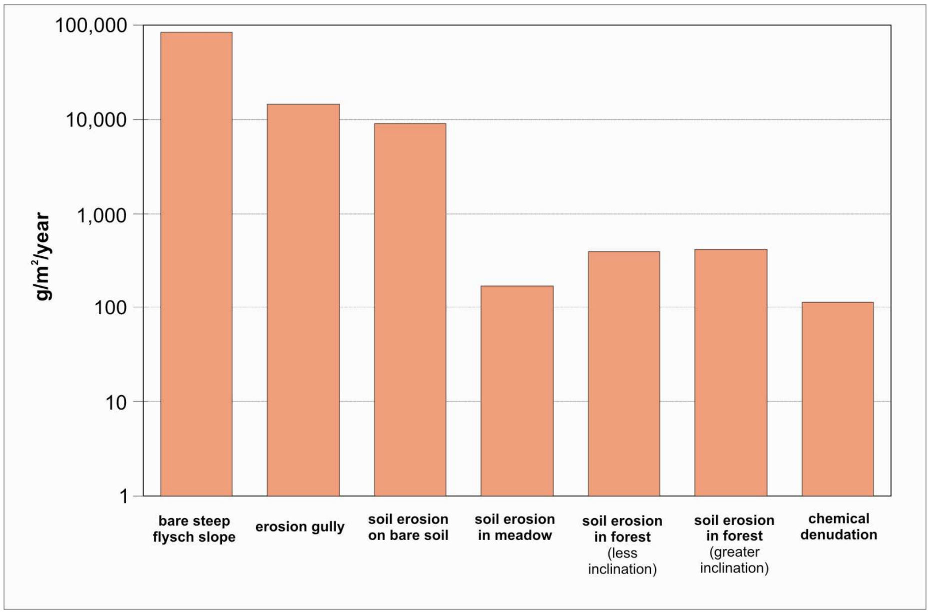

Fig. 12. **Speed of various erosion and denudation processes between 28 April 2005 and 26 April 2006** (Zorn, 2008)

Table 5. **Surface lowering/rockwall retreat in various time spans, assuming that the conditions are the same as at the time of the measurements** (28 April 2005–26 April 2006) (Zorn, 2008)

In ... years	Bare steep flysch slopes	Erosion gully	Bare soil	Meadow	Forest: lower inclination	Forest: greater inclination	Chemical denudation
	Slope retreat	Slope retreat	Surface lowering	Surface lowering	Surface lowering	Surface lowering	Surface lowering
	m	m	m	m	m	m	m
1	0.049	0.009	0.0085	0.0002	0.0004	0.0004	0.00007
10	0.49	0.09	0.085	0.002	0.004	0.004	0.0007
100	4.92	0.85	0.854	0.016	0.037	0.039	0.007
1000	49.22	8.48	8.54	0.16	0.37	0.39	0.066

3. Conclusion

The measurements presented were taken during a period that was above average concerning the amount of precipitation and low temperatures (and the transition from below-freezing to above-freezing temperatures). These measurements therefore indicate above-average sediment production. However, climate deviations were not great, and they are true for only the past few decades. Colder periods were already characteristic for previous centuries (e.g., the Little Ice Age). On the basis of the measurements presented, it is therefore easy to claim that denudation and erosion processes in Mediterranean flysch landscapes are rapid. The slopes of badlands are retreating by a few centimetres per year, and soil erosion is causing unprotected slopes to lower up to one centimeter a year. Due to this intensity, erosion and denudation processes are classified among significant morphogenetic factors in Mediterranean flysch regions.

REFERENCES

BOIX-FAYOS, C., MARTÍNEZ-MENA, M., CALVO-CASES, A., ARNAU-ROSALÉN, E., ALBALADEJO, J., CASTILLO, V., 2007: *Causes and underlying processes of measurement variability in field erosion plots in Mediterranean conditions*. Earth Surface Processes and Landforms, **32**, **1**, 85-101.

COLLINS, A. L., WALLING, D. E., 2004: *Documenting catchment suspended sediment sources: problems, approaches and prospects*. Progress in Physical Geography, **28**, **2**, 159-196.

De PLOEY, J., 1992*: Gullying and age of badlands: an application of the erosional susceptibility model* E_s. Catena, Supplement, **23**, 31-45.

DNEVNE padavine: Portorož, 2007. Agencija Republike Slovenije za okolje, Ljubljana.

DNEVNE temperature: Koper, 2006. Agencija Republike Slovenije za okolje, Ljubljana.

DUNJÓ, G., PARDINI, G., GISPERT, M., 2003: *Land use change effects on abandoned terraced soils in a Mediterranean catchment, NE Spain*. Catena, **52**, **1**, 23-37.

DUNJÓ, G., PARDINI, G., GISPERT, M., 2004: *The role of land use-land cover on ronoff generation and sediment yield at microplot scale, in a small Mediterranean catchment.* Journal of Arid Environments, **57**, **2**, 239-256.

GABROVEC, M., HRVATIN, M., 1998: *Morphological units and landforms*. In: National atlas of Slovenia. Rokus, Ljubljana, 80-83.

GAMS, I., 1974: *Kras: zgodovinski, naravoslovni in geografski oris*. Slovenska matica, Ljubljana, 358 p.

GAMS, I., 2003: *Kras v Sloveniji v prostoru in času*. ZRC Publishing, Ljubljana, 516 p.

GOVERS, G., POESEN, J., 1988: *Assessment of the interrill and rill contributions to total soil loss from an upland field plot*. Geomorphology, **1**, **4**, 343-354.

JURAK, V., FABIĆ, Z., 2000: *Erozija kišom u slivu bujičnog vodotoka u središnjoj Istri*. In: Zbornik radova: 2. hrvatski geološki kongres. Institut za geološka istraživanja, Zagreb, 603-612.

KLIMATOGRAFIJA Slovenije 1961–1990: Temperature zraka. 1995. Hidrometeorološki zavod republike Slovenije, Ljubljana.

KOMAC, B., 2001: *The karst springs of the Kanin massif.* Geografski zbornik, **41**, 7-43.

KOMAC, B., ZORN, M., 2005: *Soil erosion on agricultural land in Slovenia – measurements of rill erosion in the Besnica valley.* Acta geographica Slovenica, **45**, **1**, 53-86.

LAL, R., ELLIOT, W., 1994: *Erodibility and erosivity*. In: Soil Erosion Research Methods. St. Lucie Press, Delray Beach, 181-208.

LOUGHRAN, R. J. 1989: *The measurement of soil erosion*. Progress in Physical Geography, **13**, **2**, 216-233.

MAGDALENIĆ, Z., 1972: *Sedimentologija fliških naslaga srednje Istre.* Acta geologica, **7**, **2**, 71-100.

MASON, P. F. J., 1995: *Neolitska in eneolitska naselja v Beli krajini: naselja v Gradcu in izraba prostora v času od 5. do 3. tisočletja BC.* Poročilo o raziskovanju paleolitika, neolitika in eneolitika v Sloveniji, **22**, 183-199.

MIŠČEVIĆ, P., ŠTEVANIĆ, D., ŠTAMBUK-CVITANOVIĆ, N., 2008: Slope *instability mechanisms in dipping conglomerates over weathered marls: Bol landslide, Croatia.* Environmental Geology, **56**, **7**, 1417-1426.

OGRIN, D., 1992: *Dendrogeomorphological analysis of erosion processes – two case studies from Koprsko primorje (Slovenia).* In: Proceedings of the International Symposium 'Geomorphology and Sea' and the Meeting of the Geomorphological Commission of the Carpatho-Balkan Countries. Prirodoslovno-matematički fakultet, Zagreb, 115–118.

OLLESCH, G., VACCA, A., 2002*: Influence of time on measurement results of erosion plot studies.* Soil and Tillage Research, **67**, **1**, 23-39.

PETKOVŠEK, A., KLOPČIČ, J,. MAJES, B., 2008: *Terraced landscapes and their influence on the slope stability*. In: Living terraced landscapes: perspectives and strategies to revitalise the abandoned regions: international conference. Ljubljana.

PETKOVŠEK, G., 2002: *Kvantifikacija in modeliranje erozije tal z aplikacijo na povodju Dragonje*. Fakulteta za gradbeništvo in geodezijo. Ljubljana, 205 p.

PETKOVŠEK, G., MIKOŠ, M. 2004: *Estimating the R factor from daily rainfall data in the sub-Mediterranean climate of southwest Slovenia*. Hydrological Sciences Journal, **49**, **5**, 869-877.

POESEN, J., HOOKE, J. M., 1997: *Erosion, flooding and channel management in Mediterranean environments of southern Europe.* Progress in Physical Geography, **21**, **2**, 157-199.

POESEN, J., TORRI, D., BUNTE, K., 1994: *Effects of rock fragments on soil erosion by water at different spatial scales: a review.* Catena, **23**, **1-2**, 141-166.

POVZETKI klimatoloških analiz; letne in mesečne vrednosti za nekatere postaje v obdobju 1991–2005: Portorož, 2007. Agencija Republike Slovenije za okolje, Ljubljana.

RADINJA, D., 1973: *Prispevek k spoznavanju recentnega abrazijskega reliefa na primeru Strunjanske obale.* In: Mednarodni mladinski raziskovalni tabori 1971-1972. Republiški koordinacijski odbor gibanja 'Znanost mladini', Ljubljana, 72-94.

REGÜÉS, D., GUÁRDIA, R., GALLART, F., 2000: *Geomorphic agents versus vegetation spreading as causes of badland occurrence in a Mediterranean subhumid mountainous area.* Catena, **40**, **2**, 173-187.

REGÜÉS, D., PARDINI, G., GALLART, F., 1995: *Regolith behaviour and physical weathering of clayey mudrock as dependent on seasonal weather conditions in a badland area at Vallcebre, Eastern Pyrenees.* Catena, **25**, **1-4**, 199-212.

SAUNDERS, I., YOUNG, A., 1983: *Rate of surface processes on slope, slope retreat and denudation*. Earth Surface Processes and Landforms, **8**, **5**, 473-501.

STROOSNIJDER, L., 2005: *Measurement of erosion: Is it possible*. Catena, **64**, **2-3**, 162-173.

USÓN, A., RAMOS, M. C., 2001: *An improved rainfall erosivity index obtained from experimental interrill soil losses in soils with a Mediterranean climate.* Catena, **43**, **4**, 393-305.

VACCA, A., LODDO, S., OLLESCH, G., PUDDU, R., SERRA, G., TOMASI, D., ARU, A., 2000: *Measurement of runoff and soil erosion in tree areas under different land use in Sardinia (Italy)*. Catena, **40**, **1**, 69-92.

WAINWRIGHT, J., THORNES, J. B., 2004: *Environmental Issues in the Mediterranean: Processes and perspectives from the past and present*. Routledge, London, 479 p.

YOUNG, A., SAUNDERS, I., 1986: *Surface processes and denudation.* In: Hillslope Processes. Alleen & Unwin, Boston, 3-27.

ZORN, M., 2008: *Erozijski procesi v slovenski Istri.* ZRC Publishing, Ljubljana, 423 p.

ZORN, M., KOMAC, B., 2005: *Erozija prsti na kmetijskih zemljiščih v Sloveniji.* Ujma, **19**, 163-174.

ZORN, M., MIKOŠ, M., 2008: *Umikanje skalnih pobočij na erozijskih žariščih v slovenski Istri.* Geologija, **51**, **1**, 107-118.

ZORN, M., PETAN, S., 2008: *Interrill soil erosion on flysch soil under different types of land use in Slovenian Istria.* IOP Conference Series: Earth and Environmental Science, **4**.

Anton Melik Geographical Institute
Scientific Research Centre of the Slovenian Academy of Sciences and Arts
Gosposka ulica 13
SI-1000 Ljubljana, Slovenia
E-mail: matija.zorn@zrc-sazu.si